INVESTIGATING THE ROLE OF OPEN SPACES AND PUBLIC BUILDINGS FOR EARTHQUAKE VULNERABILITY REDUCTION IN OLD DHAKA

by

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Dedication

To my parents,

Md. Younus and NasimAkhter.

Abstract

No one can prevent nor accurately predict earthquakes early on and that actually cause sudden death and destruction at a large scale. This certainly makes such an extreme event a part of urban agenda and more crucial for an unplanned city like Dhaka. This sort of extreme urban event should be taken as a prime consideration while designing in densely populated areas, particularly in old Dhaka in order to explore and arrive at coherent urban design solutions. Old Dhaka, the historic part of Dhaka city, is more vulnerable to any imminent earthquake due to its high population density, unplanned development, non-engineered buildings, contiguous building pattern, narrow streets withlow level of accessibility, lack of open spaces coupled with least response and recovery capabilities. In order to reduce the earthquake vulnerability, the first and foremost task is vulnerability assessment before designing any guidelines for rescue and recovery. Therefore, this research attempts to identify the scenario of vulnerability of sample area of old Dhaka by assessing its built environment.

After a major earthquake, the open space network becomes a kind of ‘second city’, providing multiple complex functions such as gathering and shelter, the distribution of goods and services, temporary inhabitation etc. Therefore, a designed network of open spaces and public buildings not only significantly contribute to the quality of everyday urban life, but also has the latent capacity to act as essential life support and an agent of recovery in the event of an earthquake. Therefore, the aim of this thesis is to examine the role of open spaces and public buildings for earthquake rescue and recovery process in old Dhakathrough a theoretical framework and spatial analytical procedure. The main concept within the framework is to develop an accessibility model regarding rescue and recovery for old part of Dhaka city.

This study revealed that open spaces and public buildings in old Dhaka are useful elements of rescue and recovery for an earthquake post management process and planning. But, detail planning guidelines incorporating the open spaces and public buildings (emergency shelters) in an existing urban setting is stillless intervened research arena. Therefore, space syntax technique, geographic information system and field survey were used as triangulation methods for analysing the accessibility network in a prevailing urban setting in old Dhaka. A sample area of old Dhaka was used as a macro level case study for applying the suggested methods. Furthermore, this research analysed the study area at micro level in order to design the guidelines for safest evacuation model at neighbourhood scale. The results showed that the accessibility network model incorporating open spaces and public buildings could be a starting point for effective rescue and recovery in existing urban settings and can be applicable at both city and neighbourhood scale. Besides, the proposed ideas may further impart awareness among the future design professionals.

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CHAPTER 1: INTRODUCTION

1.1. Background

Bangladesh is a beautiful and prosperous country yet suffering from millions of problems like any other developing one. Natural disaster is one of them. It is vulnerable to wide variety of natural hazards, like flood, cyclone and storm surge, drought, earthquake and riverbank erosion, etc.(Ali and Choudhury, 2001) Earthquake has been the cause of many devastating natural catastrophes in the twentieth century. Unlike some other natural disasters, in earthquake there is no warning, the impact is often widespread, and the effects multifarious (Olafsson and Akanson, 2006). Most part of Bangladesh lies in very seismically active zone making the occurrence of major earthquakes a realistic possibility (Ali and Chowdhury, 2001).Bangladesh is susceptible to earthquakes due to its close location to the plate margins of the Indian and Eurasian plates(Mathin et al., 1983,). Moreover, the Professor Roger Bilham of Colorado State University came up with his recent research findings that major earthquakes might take place in the sub-Himalayan region, including Bangladesh(Bilham et al., 2001). Besides that, the historical seismicity and recent seismic tremors occurred in Bangladesh and adjoining areas indicate that the country is at high seismic risk. As a result the country is always under a potential threat of earthquake of any magnitude at any time, which might cause catastrophic devastation in less than a minute. Ansary (2005) argues that a strong earthquake affecting major urban centres like Dhaka, Chittagong, and Sylhet may result in damage and destruction of massive properties and may have disastrous consequence for the entire country(Ansary and Ali, 2004). In addition, Bangladesh has the seventh highest population density in the world and currently the population is approximately 156 million(The World Factbook, 2011). As per recent UN world urbanization urban prospects data, about 35 million people, or approximately 25 percent (%) of Bangladesh's population, currently live in urban areas, compared to only 8 percent (%) at the time of independence: the number is projected to cross 80 million by the year 2030.

However, with a rapid population growth over the past 40 years and recent repeated seismic activity during this period, the unplanned developments of the built environment in Bangladesh resulted in little resilience to earthquakes. Dhaka, the capital city of Bangladesh, acts as the focal point of all social, political, and economic activities of the country and is facing a huge pressure of urbanization.In view of earthquake disaster risk index, Dhaka city is placed among the twenty most vulnerable cities of the world. In addition, micro seismicity data also supports the existence of at least four earthquake source points in and around Dhaka (Ansary et al 1999, 2001; Ansary, 2005; Hussain et al., 2010; Islam et al., 2010; Islam and Ahmad, 2010). Dhaka's highest relative earthquake disaster risk is primarily due to its exposure, its vulnerability And emergency response and recovery factors (Cardona et al., 1999). In Dhaka an overwhelming demand for build able land continues to surpass needs for urban open space. Such a pattern of development resulted in a dense urban fabric. However, most vulnerable to earthquake remain particularly in the old part of Dhaka city due to its unplanned settlements, high population and building density (CDMP Unpublished report, 2009);(Kamal, 2010); (Jahan et al., 2011), vulnerable structures due to age of buildings, non-engineered building structures (Ansary, 2005)(Jahan et al., 2011), contiguous building pattern, lack of open spaces and shelters(Jahan et al., 2008), poor accessibility and mostly least response and recovery capabilitiesare increasing the risk of earthquake vulnerability to a greater extent.It is believed to be waiting for a devastating earthquake at any time now.

Disaster management needs to be considered as prime issue for overall development of the country. With this in mind, disaster management is defined as a cycle of activities including mitigation, preparedness, response and recovery(Hosseinin and jafari, 2007). Mitigation efforts refer to those activities whichreduce the vulnerability of society to the impacts of disasters. Preparedness efforts refer to those activities which make the government and disaster responders prepare for responding to a disaster, if it occurs. Response refers to the activities necessary to address the immediate and short-term effects of a disaster, which focus primarily on the actions necessary to save lives, to protect property and to meet basic human needs. Relief, rescue, search, fire fighting, medical service, permit control, sheltering, evacuation, law enforcement and many others are samples of disaster response activities. Recovery efforts refer to those activities that bring communities back to normal (such as reconstruction) and they should be towards meeting mitigation and preparedness needs.Allthese activities are essential for a community as well as a country for capacity building. In our country, generally, the practice of capacity development to become resilient gets lesspriority. But, proper capacity development, which may lead to sustainable development, can be proved to be the best mean of disaster management. These sustainable attitudes can reduce the risk of potential disasters, prevent the incident and prepare the community to respond according to the needs.

If a great earthquake hit the city, Dhaka may suffer immense loss of life and property due to the unplanned city development and vulnerable settlements(Ansary and Ali, 2004). This will have long term consequences for the entire country. Before taking any decision in order to reduce vulnerability, earthquake vulnerability assessment of urban areas put a remarkable importance in proposing an accessibility network model for rescue and recovery considering the prevailing local condition. Moreover, in any mitigation measures and preparedness such model is of utmost importance in reducing loss to a great extent. The accessibility network (open space network) model can make a locality self-dependent in coping with disaster and minimize the risk in time. This research hasinvestigated the present scenario of a sample area of old Dhaka, assessed the earthquake vulnerability and proposed an accessibility network model for the community.

1.2. Present State of the Problem

With increasing population and urbanization in earthquake-prone countries, the losses from earthquakes have been increasing significantly over the last decade. But it is the urban area, which is more susceptible to natural hazard. Large scale catastrophes from urban disasters have been graphically demonstrated in the recent years. In 1995, an earthquake in Kobe, Japan caused more than 6000 fatalities and over $US120 billion in economic losses. In 1999, an earthquake in Izmir, Turkey caused 20,000 fatalities and an estimated $US20 billion in economic loss. In 2001, an earthquake in Bhuj, India caused more than 16,000 casualties and in 2005, the Kashmir earthquake caused more than 80,000 casualties (Ansary and Alam, 2007). Since the cities are the main growth centre in terms of population and economy, it is quite apparent that the losses will also be higher in cities than rural areas (ADPC, 2006). According to the World Urbanization Prospects: The 2011 Revision, the population of Dhaka is 15.4 million (2011) and projected population is 22.9 million (2025). Failure to plan development in the poor and disaster prone country like Bangladesh will result in greater exposure to natural and manmade hazards for large number of people. In addition, unplanned and rapid growths of Dhaka city, made it most vulnerable to potential earthquake.

The most effective actions to reduce the impact of earthquake are those that reduce the vulnerabilities of cities. In order to reduce the earthquake vulnerabilities, a comprehensive earthquake risk management plan is essential for Dhaka, as well as other cities of Bangladesh. This plan requires long-term plan of action and involves multidisciplinary contribution. One of the important part of this plan will be redesigning the existing one.

Old Dhakaexperienced earthquake vulnerability due to its high population density and low preparedness of people, etc. At present, the density of population in Lalbaghthana (2.2 km2) is 1, 68,151.4 inhabitants per square kilometre and in Sutrapurthana (2.6 km2), it is 81,234.6 inhabitants per square kilometre (BBS, 2001).Besides, the densely built urban fabric consisting of non-engineered buildings and poor accessibility make the locality more prone to earthquake disaster. In order to mitigate the risk of life and property, an enormous amount of researches is lacking on the effectiveness of community preparedness, planning and designing guidelines for rescue and recovery, and planning and performance of lifeline services. An extensive amount of research (Sadat et al., 2007);(Rahman et al., 2007)has been undertaken on the structural stability of individual buildings in Dhaka for earthquake vulnerability reduction. But one of the goals of this type of research is to promote effective evacuation, rescue and recovery for many part of the Dhaka city, especially in case of old Dhaka. Yet the role of city's landscape its network of open space (accessibility network), and effectively the place where rescue and recovery happens, is still new in our country.Moreover, planners, urban designers and architects are rarely involved in earthquake vulnerability reduction planning in Dhaka.

To look at the problem holistically it is of utmost importance to aim for an effective rescue and recovery plan by accessibility networking for different areas in old Dhaka considering any earthquake mitigation measure with existing and specific site situations - to reduce an unthinkable amount of loss of life and wealth. Such accessible emergency route design, being a key component of the built environment along with accessible green open spaces (McGregor, 1998);(Ibrahim al., 2007) and public buildings (shelters), is needed to be identified for its contribution to the problem and as a potential solution.

1.3. Objective of the Study

The research focuses on investigating the role of open spaces and public buildings (shelters) in earthquake vulnerability reduction, to ensure safe rescue and recovery, during and after earthquake, with reference to old Dhaka. The main objectives of this thesis are:

1. To investigate how open spaces and public buildings can influence evacuation, rescue and recovery process in terms of their location and accessibility networking, scale and density of surrounding urban fabric, size and capacity (to accommodate people as shelters) and distribution to reduce losses from an earthquake for a specific (the study area) earthquake vulnerable area in Old Dhaka.

2. To identify a safest and shortest evacuation route through a micro level analysis within the study area to take people towards the identified and designed shelter spaces (green open spaces and community facilitate buildings) as part of a post-earthquake management criteria.

1.4. Research Methodology

Over the past few decades, the vulnerability framework of disasters research has gained a strong foothold. More and more, vulnerability research and hazards research are being used to complement one another. “Vulnerability involves, perhaps above all, the general and active capacities of people—what enables them to avoid, resist or recover from harm. Whereas a hazards perspective tends to explain risk and disaster in terms of external agents and their impacts, vulnerability looks to the internal state of a society” (Hewitt, 1997, pp27-28). Essentially, the vulnerability framework does not ignore the importance of the physical hazards, but it emphasizes the human dimensions of vulnerability to reduce risk (Blaikie et al., 1994; McEntire, 2001). A premise of the vulnerability framework is that without a human component, a natural hazard would not cause a disaster. The vulnerability framework evaluates risk as a product of hazard and vulnerability (Risk = Hazard x Vulnerability), in which vulnerability represents the human component. This approach is also referred to as comprehensive vulnerability management, a framework that seeks to expand the “research agenda of disaster studies because there are numerous factors from both the physical and social environments that interact to determine the degree of vulnerability” (McEntire et al., 2002, p. 11). Comprehensive vulnerability management includes investigation of the “factors that produce risk and susceptibility, as well as the characteristics that promote resistance and resilience, and the complex interactions of liabilities and capabilities" (McEntire et al., 2002, p.11).Planning and designing for disaster mitigation is a complex field and can be approached from many different angles. In essence, the field seeks to analyse, understand and reduce aspects of risk, which is, in the broadest sense, continuously and socially constructed. It promotes an active and adaptive view of the responsibilities of human societies (Hewitt, 1997, p.22). Such dynamic phenomena as risk and disaster require a multi-faceted approach.

In present research, main goal is investigating the role of open spaces and public buildings for earthquake vulnerability reduction in an existing urban setting. The methodology presented in this study derived on the basis of vulnerability framework in disaster planning research. The research has been designed in two parts: a theoretical part based on the literature review of relevant theories and researches on impact of the open spaces and public buildings for earthquake vulnerability reduction in urban areas, and an investigative empirical part based on field survey, secondary sources (GIS layout of Dhaka, 2006 and Google earth, 2011) and syntactic analysis for accessibility network.

It is not possible to complete any study in a systematic way without setting objectives which provides some guidelines and makes it easier to complete the study. In this study, the research problem is divided into two research objectives. These objectives will be attained through methods as described in two phases below.

Phase 01: Macro level study

Objective:Phase 01 will establish the significance of accessibility and networking of open spaces and shelters for rescue and recovery to reduce earthquake vulnerability.

Method:

a) Literature Review: Related current literature were reviewed and summarized to support the relevance of analysing the impact of accessible open spaces and public buildings for earthquake vulnerability reduction and also to identify key variables which have significant causal relationship with safe evacuation process, rescue and recovery.

b) Field Survey: To accomplish the objective in Dhaka city's perspective, field survey will be conducted in the following steps:

i) Selection of the study area: In order to assess the vulnerability, a sample area of old Dhaka was selected based on the population density and building density, becausedensity is one of the important factors to address vulnerability. Moreover, population, as the main driver is added to the model framework to achieve better understanding the proportion of the actual risk as it is directly related with the casualties.

ii) Vulnerability assessment of the study area based on the field survey data, and data from GIS map (2006) and Google earth map (2011) of old Dhaka.

iii) Identification and analysis of existing open spaces (parks, play fields, green tracts and streets, etc.) and public buildings: surrounding land use pattern, built form (scale, physical condition etc.), density of built form, size, scale, street pattern and their width, proximity, landmark, etc.,the data will be collected from the findings of the empirical research "Earthquake Vulnerability Reduction Strategies for unplanned urban areas--- in the context of old Dhaka" by Dept. of Architecture, BUET funded by MOSICT.

c) Accessibility network analysis (Triangulation analysis):

i) Verifying space syntax results: Space syntax analysis of the existing urban grid to understand the spatial properties of street configuration and accessibility pattern in the study area. It demonstrates different metric radii analysis to demonstrate time/distance factors. Based on the syntactic analyses, it generated an optimum route network for the studied area.

ii) Data gathering for movement densities and locations: Evaluation of natural movement in the high dense settlements becomes a crucial issue in terms of disaster management. In order to assist further decisions in emergency route network, this step analysed the pedestrian movement density along with the road width hierarchies in case study area by gate system method. The gathered data then, compared with the simulated evacuee's potential movements to verify the degree of correlation between the real data and syntactic simulation model's results.

iii) Weighting by existing morphological characteristics: The third step of accessibility network analysis is weighting all the gathered data by existing morphological features, such as land use pattern, building density and heights, and location of community facilities (green open spaces, play fields, parks, community buildings, etc.) for improving the proposed route network.

Phase 02: Micro level study

Objective:Phase 02 will investigate the detail micro level study for safe evacuation model

Method:

a) A model area (size of the model area was set based on proposed route network analysis) analysis:

i) Field survey analysis: street elevation, section, building density, building height, population density, road width, road length and distance, depth, location and capacity of existing green open space and community buildings, etc. were analysed forproposal of emergency response centre (shelter).

ii) Finally, an approach was established for neighbourhood level evacuation through designing open spaces and public buildings network.

1.5. Scope of the Study

This study is unique in its approach. The research will investigate correlations between the concepts of resilience and urban design. To reinforce the potential for the alignment of urban design strategies and earthquake protection planning in rescue-recovery so that incremental everyday changes to urban structure can improve urban life of Bangladesh.

This research can contribute greatly to sustainable urban development of Bangladesh by exploring the different urban design strategies for future development of vulnerable cities. This will not only reduce the earthquake risk but also contribute significantly to the quality of everyday urban life in a developing city’s context.Findings of this research, therefore, will add new perspective to design philosophies of planners, urban designers and architects.

1.6. Limitations of the study

The study tried best to cover all the relevant aspects rather it is not beyond limitation.

The rapid urbanization of Dhaka is pushing its inhabitants into a vulnerable situation. Thispressure is not only the consequence of socio-economic condition of the country, but also the result of globalization and open market economy. A city cannot be judged without considering its regional links. Cities are the result of economic need and this depends on the regional policiesof economic development. At the same time intensive socio-economic study is required to understand the cause of the inhabitants' risky behaviour and the issue of sustainability also incorporates social and economic dimensions. Without analysing the socio-economic condition and capacity, any study on resiliency is incomplete. But, here because of academic and time constrains the regional and global issues, as well as socio-economic factors are ignored consciously. The consideration of regional economic link can provide more effective recommendations tosave city from its unsustainable development. Not incorporating this issue can be considered as a limitation of this study.

To assess the risk of an earthquake in old Dhaka, a sufficient GIS-based up-to-date map is necessary.But, this study is hampered by the unavailability of those kinds of data, which is nationally accepted.There is hardly very little research in this line, so adequate information is lessto make a background study to get into the problem.

1.7. Organization of the study

The research is organized in several chapters to attain set objectives. The overall structures are stated below:

Chapter 1: Introduction

This is the introductory part of the thesis. It mainly rationalizes the background of this research and attempts to state the current research problem with relevant published data and research findings. This chapter also includes objectives of the research, research methodology and significance of this earthquake vulnerability reduction study.

Chapter 2: literature Review

This chapter develops the theoretical background to support the relevance of analysing the impact of accessible open spaces and public buildings for earthquake vulnerability reduction and also to identify the key components of rescue and recovery planning.

Chapter 3: Old Dhaka and its Earthquake Risk

This chapter elaborates the urban pattern and physical condition of old Dhaka. Besides, historical and earthquake scenario of Bangladesh is discussed for understanding the background. Review on urbanization and its association with earthquake risk are discussed based on previous research findings and published data from secondary sources.

Chapter 4: Case Study area of old Dhaka and its earthquake Vulnerability Assessment

It deals with the characteristics of the study area with its present status. It incorporates morphological features, and socio –economic characteristics of the study area of old Dhaka. This chapter also puts light on the vulnerability assessment of the target area with respect to earthquake hazard. Data collected from the field survey, GIS map (2006) and Google earth map (2011) of old Dhaka, is analysed here to plot the existing vulnerable situation of study area.

Chapter 5: Analysis and Findings

It mainly contains both macro and micro level analysis of the study area. Both macro and micro level analyse the entire collected data and syntactic measures to obtain a meaningful result and findings related to this research objectives.

Chapter 6: Recommendation and Conclusion

This chapter summarizes the overall findings of the research based on analyses from chapter 5 and reveal the limitations along with necessary quality considerations of this research. Finally some specific and general recommendations along with some directions for future research guideline in earthquake vulnerability reduction conclude the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 Earthquake Hazard and Its Effects

An earthquake (also known as a quake, tremor or temblor) is the result of a sudden release of energy in the Earth's crust that createsseismic waves (fig: 1)(Wikipedia, 2011). Seismologists explain this complex mosaic of earthquake activity in terms of plate tectonics. The continents on the earth's surface consist of large areas of relatively cohesive plates, forming the earth's structure, floating on top of the mantle, the hotter and more fluid layer beneath them. Convection currents in the mantle cause adjoining plates to move in different directions, resulting in relative movement where the two plates meet. This relative movement at the plate boundaries is the cause of earthquakes (Coburn & Spence, Earthquake Protection, 2002, pp. 14-15). According to the direction of the tectonic movements at the plate boundary the fault plane may be vertical or inclined to the vertical, this is measured by the angle of dip, and the direction of fault rupture may be largely horizontal, largely vertical, or a combination of horizontal and vertical. These three main types of fault, namely normal, reverse (thrust) and strike-slip faults cause an earthquake.

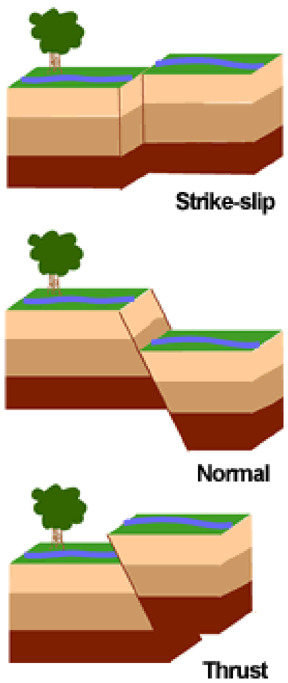

Figure 1: Different fault- type (Wikipedia, 2011)

Violent shaking of an earthquake can result Shaking and ground rupture, Landslides and avalanches, fires, soil liquefaction, tsunami, floods, and many human impacts.

Earthquake can be devastating to people as individuals, to families, to social organizations at every level, and to economic life (fig: 2). Unquestionably the most terrible consequence of earthquakes is the massive loss of human life which they are able to cause (Coburn & Spence, Earthquake Protection, 2002). The first task of earthquake protection is universally agreed to be reducing the loss of human life.

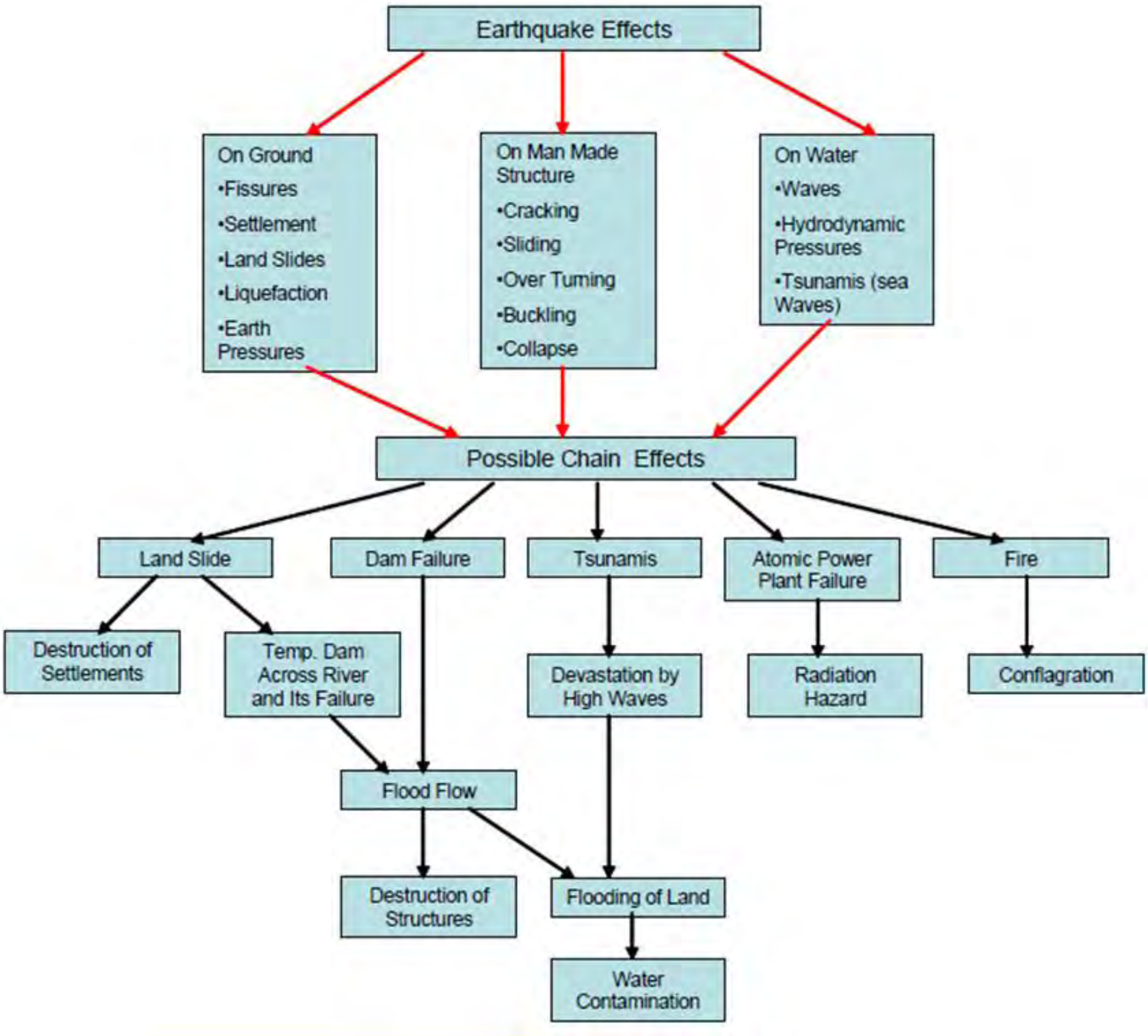

Figure 2: Risk Chain and Earthquake Effects(Arya, 2001)

2.2 Earthquake Vulnerability

Vulnerability is widely used in scientific social and economic languages and understood differently. There is little consensus among researchers, designers, planners and disaster managers regarding the meaning of and approaches in undertaking vulnerability assessment analysis(Wisner, 1993). Vulnerability assessment thus depends on how we define it and on what criteria we are interested in(Bhandari & Okada, 2008). Numerous definitions of vulnerability exist. Weichselgartner(2001) points out three distinct themes in vulnerability studies; First vulnerability as the degree of loss (exposure) associated with the occurrence of a hazard, Second Vulnerability as socio-cultural and economic process and the ability to cope with disaster. The third is vulnerability as both biophysical and social response within a specific geographic area. Cutter (2000)mentions about the hazard of place model where vulnerability is dependent both on geographic context and social fabric (community ability to cope, economic and demographic characteristics). Turner (2003)mentions that the components of vulnerability as exposure, sensitivity and resilience (coping) are interactive and scale dependent (place, region and globe). Such that analysis is affected by the way in which the system is conceptualized.

Vulnerability is the conditionsdetermined by physical, social, economic and environmental factors or processes, which increase the susceptibility of community to the impact of hazards (UN/ISDR, 2004).

The impact of disaster is influenced to some extent by the degree of community's vulnerability to hazard. Vulnerability is the human dimensions of disasters related to the capacity of a person, a group or a society to anticipate hazard, cope with hazard, resist hazard and recover from its impact. It is the constituent of whole range of economic, social, cultural, institutional, political and psychological factors that shape people's lives and create the environment that they live in (Twigg, 2004).Therefore, the question of society's resilience and vulnerability is very important for understanding the impacts of disaster and making appropriate choices to intervene.

Within minutes of shaking, the earthquake reveals the vulnerabilitiesof buildings, households, communities, and of a country. Theconsequences expose flaws in governance, planning, sitting of physical structure, design, construction, and use of the builtenvironment in country with seismic hazard. It reveals the influenceof prevailing culture and way of life, on the capacity of thecommunity to be preparedness for an earthquake hazard. The scaleof physical damage and social disruption inflicted upon a communityor a nation by an earthquake event is the measure of how vulnerablethe community or the nation is.

As a whole, vulnerability is a set of prevailing or consequential conditions, which adversely affect an individual, a household or a community's ability to mitigate, prepare for or respond to the earthquake hazard.

Earthquake vulnerability is thus a function of the potential lossesfrom earthquakes (death and injury to people, damage and otherphysical structures) and the level of preparedness (the extent towhich a society has been able to translate mitigation measures intopractice). It reflects the unattended weakness in the builtenvironment of a community and the constraints in the society thataffects ability (or inability) to absorb losses after an earthquake andto recover from the damage.

2.2.1 Vulnerability Categories

A range of factorsdetermines vulnerability:

- The population density
- Level and nature of physical assets
- Economic activities located in the earthquake risk zones.

Human action and hazard risks continually interact to altervulnerability, both at the household and macroeconomic level.

Anderson & Woodrow (1998)(Dwyer et al., 2004)grouped vulnerabilities into threecategories:

Physical/material vulnerability: inherent weakness of the builtenvironment and lack of access to resources, especially of poorsection of the population

Social/organizational vulnerability: inherent weakness in thecoping mechanism, lack of resiliency, lack of commitment

Attitudinal/motivational vulnerability: fatalism, ignorance, andlow level of awareness

2.2.2 Vulnerable elements in the physical environment

The likelihood of an earthquake disaster increases when the community's built environment (i.e., buildings and lifeline systems—or community infrastructure) is comprised of the following vulnerable elements (Hays et al., 1998); (ADPC, 2002);(Bhattarai & Conway, 2010):

- Older residential and commercial buildings and infrastructure constructed of unreinforced masonry (i.e., URM's) or any other construction materials having inadequate resistance to lateral forces of ground shaking, or if they were built to seismic codes and standards that are now considered by engineers to be out dated and inadequate
- Older non-engineered residential and commercial buildings that have no lateral resistance and are vulnerable to fire following an earthquake.
- New buildings and infrastructure that have not been sited, designed, and constructed with adequate enforcement of modern, state-of-the-art building regulations, lifeline standards, and land use ordinances.
- Buildings and lifeline systems sited in close proximity to an active fault system, or on poor soils that either enhance ground shaking or fail through permanent displacements (e.g., liquefaction and landslides), or in low-lying or coastal areas subject to either seiches or tsunami flood waves.
- Modern buildings of poor design and construction (examples are buildings that were damaged seriously even in low intensity of shaking in Ahmedabad and Bhuj in the January 2001earthquake).
- Lack of open spaces (play fields, parks, green lots, etc.) in urban area and their unplanned distribution
- Schools and other buildings that have been built to low construction standards.
- Communication and control centres that is concentrated in one area.
- Narrow alleys and streets in urban areas and poor accessibility into the urban areas.

- Hospital facilities that is insufficient for large number of casualties and injuries.

- Bridges, overhead crossings and viaducts that have not been built to withstand lateral forces of earthquakes and are likely to collapse or be rendered unusable by ground shaking.

- Electrical, gas, and water supply lines that are likely to be knocked out of service by ground failure (i.e., liquefaction, lateral spreads, and landslides).

2.2.3 Factors contributing to earthquake vulnerability of built environment in developing countries

Earthquake vulnerability is rapidly increasing worldwide, especially in developing countries. The rapid urbanization, lack of proper planning, constraint of resources to response, absence of vulnerability reduction measures, poor enforcement of existing measures, and most importantly lack of awareness of the community are the main reasons for increasing this vulnerability. The need to combat the resultant colossal destruction of earthquake has been at the forefront concern of vulnerable nations.

An earthquake is a natural event and its risk cannot be completely eliminated. However, the destruction of earthquake can be minimized largely by comprehensive earthquake preparedness and mitigation strategies. The earthquakes in Haiti and Chile provide a good comparative example. Given the fact that both countries sit over of large active faults, in the first quarter of 2010, Haiti faced a major earthquake of 7.0 magnitudes which resulted to about 230,000 deaths, while Chile which was hit with even more severe quake of 8.8 magnitudes had only 486 deaths. This incomparable difference between the two countries' causalities comes from the implementation of comprehensive earthquake preparedness and mitigation strategies.

The member city project under the RADIUS compared the vulnerability of over 60 cities in the developing countries. Bilham et al. (2001) indicated that over 50 million people in the urban settlements at the foot of the Himalayan Range are vulnerable to earthquake. Unfortunately, most of the people subject to such high level of vulnerability are unaware of the earthquake threat they face.

2.2.4 Social and Economic Vulnerability

2.2.4.1 Vulnerability at Household level

Earthquakes affect the full range of social classes – from royalties to the homeless. Apparently, earthquake treats everyone equally. Actually, the poor and socially disadvantaged groups of the society are the most vulnerable to, and affected by, earthquakes and other natural hazards,reflecting their social, cultural, economic and political environment.

Usually, communities in seismic countries are subject to a multitude of natural hazards and environmental problems. The natural hazards themselves are the source of transient hardship and distress, and a factor contributing to persistent poverty. Disasters exacerbate poverty by inflicting physical damage, loss of income-generating opportunities, and the resulting indebtedness.

Thus at the household level, poverty is the single most important factor determining vulnerability to natural hazards including earthquake. The poor are the vulnerable. The vulnerability is reflective of

- The location of housing (poor and marginal lands)
- Poor quality building (non-engineered, using poor quality materials)
- Primary types of occupation, level of access to capital (low)
- Degree (low) of concentration of assets (Benson, 2003)

2.2.4.2 Vulnerability at Community level

Vulnerability of the individual households, naturally, contributes to the communities' overall vulnerability to earthquakes. However, existing social and cultural structures within the community determines, to a great extent, the resilience of the community to the disaster. The socio-cultural networks – extended family, neighbours, community organizations (e.g., community and religious trusts), and the interdependence within communities, provide the strength during disasters. Destruction of such network, for example by relocation during the reconstruction phase of an earthquake, causes the community to be more vulnerable.

Such community networks, the interdependence and also the traditional values are also disturbed during urbanization andeconomic advancement. It is seen that the traditional coping mechanism no longer is capable to continue the in-built resiliency to disasters. Individual and collective preparedness towards earthquake is necessary. Earthquakes are a difficult societal problem because they have low annual probability of occurrence, but a high probability of causing adverse societal consequences. Continued preparedness, making it a culture of community life makes communities resilient towards earthquake. Lack of it makes communities vulnerable.

2.2.4.3 Vulnerability at National Level

A nation, or its government, in a seismic country is vulnerable to earthquakes and disaster risks unless it actively realizes the inevitability of earthquakes and the treat they represent to the nation, and invests in mitigation, the most cost-effective long-term strategy for loss reduction. Nation's declared policies to protect people, property, and community resources, provide the legal mandate for implementing mitigation, preparedness, emergency response, and recovery and reconstruction and regulation. Countries without such policies, or those not implementing such policies (if they exist), in line with their developmental policies are vulnerable to disasters including earthquake disasters.

Lack of effective communication and dialogue between government and the people makes a country vulnerable. Strict and centralized governance with top-down approach makes nations vulnerable at every phases of a disaster.

To manage its earthquake risk effectively, a community must have the capability to adopt, adjust, and change its public policy on the basis of scientific, technical, political, and legal consensus that is evolving with time as the community, lives with and learns fromearthquakes, both in its country and in other countries having similar hazard and built environments.

The following are the vulnerabilities that were revealed by earthquake to surprise people-

- Discovering after the earthquake disaster that the active fault system was located directly beneath the affected community or very close to the community.
- Experiencing unanticipated damage and loss of function to essential buildings (e.g., hospitals, schools, government buildings) and lifelines (e.g., elevated highway

systems, ports), especially when the scientific and technical consensus before the earthquake is that these structures are earthquake resistant.

- Discovering that portions of the community are susceptible to fire following the earthquake.
- Experiencing thousands, to tens of thousands, of deaths and injuries, and thousands, to hundreds of thousands, of persons left without homes and jobs.
- Sustaining unexpected loss of community revenue, economic loss, and insured payments in the billions of dollars.
- Discovering that the country lacks the capability for speedy emergency response and effective recovery and reconstruction, and evacuation planning in urban areas.
- Discovering after the earthquake disaster that the causes of the surprises were within the power of the country's policymakers and stakeholders (earth scientists, engineers, planners and urban designers, insurers, businesses, and others) to correct before the disaster occurred.

2.3 Earthquake Vulnerability for Urban areas in Hazard Research

Throughout the world, urban areas are becoming environmentally complex; home to over half of the world's population, these urban areas provide employment and commerce opportunities as well as administrative services to residents. Even in smaller urban areas many complex infrastructures have been developed to provide essential amenities to their overcrowded urban populations. At the same time, unplanned developments in urban areas often lead to increased vulnerability, and in many cases a variety of urban vulnerabilities, that taken together, make public solutions difficult if not impossible to anticipate, ameliorate or address adequately(Bhattarai & Conway, 2010).

Research has identified a mix of urban vulnerabilities (Alexander, 1993);(Kaplan, 1996);(Richardson, 1994);(Shaluf, 2007).As a spatial science, geography concerns itself with the behaviour and distribution of: 1) urban objects, such as residential and commercial buildings, pedestrians, and vehicles; 2) urban features, such as land parcels, shops, roads, sidewalks; and 3) natural features, such as green/ open spaces, rivers, and the seismic vulnerability of places. Spatial science considers these dynamic factors as "urban ensembles," which vary at different locations and scales (Benenson & Torrens, 2004).Urban ensembles such as buildings, streets, bridges, public and industrial areas, roofs, facades, open and green spaces, are obviously highly interrelated, but they can be visualized using design plans, drawings, and video data records (Pissinou et al.2001).The World Vulnerability Report (2003) presented 50 different indicators of urban vulnerabilities by analysing "urban ensembles" at various scales.

Urban vulnerability to natural hazards such as earthquakes is a function of human behaviour (Rashed & Weeks, 2003). They argue that urban vulnerability describes the degree to which socioeconomic systems and physical assets in urban areas are either susceptible or resilient to the impact of natural hazards. Over the past two decades, it has come to represent an essential concept in hazards research and in the development of mitigation strategies at the local, national, and international levels (White & Haas, 1975);(Hewitt, 1997);(Mileti, 1999);(Alexander, 2000). Several models of vulnerability have been proposed to address the various ways by which society becomes subject to hazard impacts (Burton et al. 1978)(Mitchell et al. 1989)(Cutter, 1996)(Menoni and Pergalani, 1996)(Menoni, 2001). The concept of human/nature interaction is firmly entrenched at the heart of these models representing natural hazards as dynamic phenomena that involve people not only as victims but also as contributors and modifiers (Kates, 1996). Because this interaction exhibits strong spatial components, vulnerability is an inherently spatial problem since it almost always deals with communities within a defined urban space.

Once composite layer of all hazards is created, 'vulnerability assessment' of various elements of urban areas (built environment) can be conducted simply by overlaying the composite layer of hazards with layers that represent the spatial distribution of each element. Elements located in multi- or higher-intensity-hazard zones will be considered more vulnerable than those located in single- or low-intensity-hazard zones, also elements with high density zones in urban areas will be considered more vulnerable than low density zones (White and Haas 1975).

2.3.1 Tools used to Identify Urban Vulnerability in Hazard Research

Researchers often apply spatial, multi-criteria approaches using spatial objects to examine the quality of life, urban conditions and physical structures, because these "urban ensembles" represent dynamic phenomena involving people not only as users but also as victims, contributors, and modifiers (Burton et al. 1978); (Hewitt, 1997); (Koeninger & Bartel, 1998); (Mileti, 1999); (Alexander, 2000); (Menoni, 2001). Remote sensing and GIS technologies have proved to be especially-helpful tools to identify vulnerable and/or non-vulnerable urban ensembles across urban landscapes.

Alexander (1993) used GIS to locate areas within seismic zones and analysed the degrees of urban vulnerability they posed.Cutter (2003) used GIS to develop weighted social and biophysical indicators associated with urban vulnerability.Madhavan et al. (2001) used remote sensing to explain how land use and land cover changes are associated with urban vulnerabilities in the Metropolitan area of Bangkok, Thailand. Rashed and Weeks (2002) explained how a society might be subjected to various hazards because of its own actions, such as construction of congested structures or substandard buildings and narrow roads. Li et al. (2006) used quantitative models using GIS and remote sensing and analysed urban vulnerabilities associated with environment conditions in the upper reaches of the Minjiang River, China.

Researchers have found the 3D visualization technique useful in examining the effects of adjacency (what is next to what), containment (what is enclosed by what), proximity (how close one geographic object is to another), accessibility (how an object can be reached from a certain road), and visibility (how far certain objects are visible from certain locations)(Pullar & Egenhofer, 1998). However, as in simple two-dimensional features, it is essential in 3D features to either associate the distance and direction with the object as an attribute to the housing unit, or to compute the distance and direction between the roads and houses along with the height or depth of individual objects. In earlier times, 3D visualizations were possible only in computer aided design (CAD) (Lee, 2007)and cadastral mapping (Bilien & Zlatanova, 2003). Today, ArcGIS 9.4 beta version incorporates 3D functions in its Network Analyst, making it accessible and functionally more useful to planners, urban designers and researchers alike in the accessibility analyses (Kwan, 2002).

Urban vulnerability analysts have found 3D models very efficient for correlating societal and biophysical factors while working in unfamiliar locations (Rashed & Weeks, 2003)(Whiteman & Lagorio, 1998, 2001).

Findingsfrom the various researches (Pullar & Egenhofer, 1998); (Bhattarai & Conway, 2010)revealed the usefulness and value of 3D visualization techniques by examining adjacency, proximity, accessibility, and environmental conditions within the uncontrolled and unevenly patterned conurbation of Nepal's Kathmandu Valley.

2.4 Earthquake VulnerabilityReduction for Cities (EVRC)

Earthquake Vulnerability Reduction for cities (EVRC) is a concept of action has developed to ensure Safety of human lives and reduce losses from earthquakes that may occur tomorrow (ADPC).

Earthquake and Mega Cities Initiative (EMI) focuses on addressing specific earthquake risk management issues of concern in mega cities. Global Earthquake Safety Initiative (GESI) was developed by Geo Hazards International(GHI) and the United Nations Centre for Regional Development (UNCRD) to build the capacity of city managers to assess risk from natural disasters, predict future risk patterns, and track the long-term success of efforts undertaken. Along with these, Tokyo Metropolitan Area Urban Revival Manual (1997) was initiated Urban Disaster Prevention Project to reduce urban vulnerabilities and prepare metropolis more resistant to big earthquakes and other natural disasters. This initiated lots of Countermeasures to reduce the earthquake vulnerability for urban areas. Among many Countermeasures, there are some important measures:

- Promotion of urban redevelopment
- Development of disaster-proof living zone
- **Securing open spaces for refuge bases and shelters**
- **Securing safety and refuge and shelter (Public Buildings) for victims & recovery**
- Earthquake resistance building diagnosis (public buildings)
- Measurement of the vulnerability of Districts
- Promotional plan for a disaster resistant city
- Retrofitting the vulnerable structures
- Urban Revival Manual

In order for a community's risk management measures and regulations to be effective, the community must integrate risk assessment with risk management, choosing specific measures or regulations having a benefit/cost of at least one to eliminate or reduce perceived vulnerabilities in the built environment.

Every community at risk from earthquakes has many proven and cost-effective options available to it to reduce its perceived unacceptable risk. Each option carries cost and an expected benefit. Because risk is not static-changing over time as the level of understanding of earthquakes and their consequences increases risk management requires a long-term investment of resources to realize the greatest benefit/ cost. The options and benefits of vulnerability reduction are based on experiences in developed countries. A refinement of approaches is necessary for selecting and implementing these options in developing countries. Acceptability of the options by the local communities depending upon the acceptable level of risks and the community's capacity to understand and implement technical measures should be considered and the options should be selected on a consensus basis. Grafting high-tech solutions may not prove sustainable in many developing countries (ADPC).

In any urban setting, open spaces and community buildings should be designed accordingly not only for reducing earthquake vulnerability but also for a better urban life for city dwellers. In next section, it has been discussed how open spaces and community buildings are important in earthquake vulnerability reduction.

2.5 Open Spaces and public buildings (Shelters) in Earthquake vulnerability reduction planning

Rogers (1999) defined urban open spaces as an important part of the urban integration required to achieve a liveable environment. He says, "A clear articulation of public space connects neighbourhoods to connect to each other and link people within localities to their social institutions. They do not only provide outdoor areas to relax and enjoy the urban experience, venues for activities and places for walking and sitting out, but they also establish a balance between people and their environment."

Researches on responses to earthquakes from around the world suggest that ample and adaptable amounts of open space surrounding buildings are of enormous value both during and after an earthquake event (Godschalk, 2003). Many researches (TMURM, 1997) (Ibrahim et al. 2007) of earthquake vulnerability reduction had shown that Open Spaces in urban areas, such as parks, play fields, green tracts and roads, and have important functions in disaster prevention (Table 1). Open space becomes a refuge for, and a temporary home to thousands of people who need to quickly adapt to their new environment for days, months or even years. After a major earthquake, the open space network becomes a kind of 'second city', providing multiple complex functions such as gathering and shelter, the distribution of goods and services, the re-establishment of commerce, temporary inhabitation, commemoration, and the storage of contaminated or hazardous materials (McGregor, 1998); (Miidleton, 2007). A recent research (Ibrahim et al. 2007) shows that, roads and steps were connected into a network. The network becomes charged with new meaning; its spaces and their components are re-assessed for their capacity to support survival and recovery.

Anything relatedto the urban environment as a place for response and recovery is either quantitative and extremely specific or too general to be of much use(Moehle, 2009). For example, a recent study(Geis, 2000)suggests how much open space is required for egress or refuge, but there is very little discussion about the particular qualities or arrangement of urban open space that might encourage adaptation by communities and governments to facilitate rescue and recovery in order to reduce earthquake vulnerability.

The diversity of the city's open space structure isimportant because it created a range of options during the emergency period immediately following the earthquake that allowed people of the community to come together, support each other and re-establish the pattern of their daily lives before a formal and co-ordinated relief strategy will be available (Allan & Bryant, 2010). The legibility created by permeability of the gridded access network linked the divergences of type. Efforts to secure open spaces should give top priority to areas where they are lacking.

Table 1: Uses of Open Spaces in Disaster prevention (Tokyo metropolitan Earthquake Disaster Prevention Plan, 1997)

Type of Open Spaces	Roles in Disaster Prevention	Direction of Improvement
Large Scale Parks (Metropolitan, etc.)	Refuge base, Disaster recovery bases	Improvement and construction of Metropolitan parks.
Smaller Parks, play fields (ward. city. town. etc.)	Disaster shelter, Disaster resistant activity bases. Rendezvous sites	Secure a park for every town block.
Roads (city planning roads)	Firebreaks. Refuge roads	Improvement of roads in high-risk areas.

Besides the role of open spaces, public buildings (community buildings) play vital role during disaster to support rescue and recovery. According to the Urban Disaster Prevention by Bureau of City Planning Tokyo Metropolitan Government, Public Buildings in urban areas like schools, hospitals, community centre, religious buildings, police stations, fire stations, etc. can be used as evacuation shelter or emergency rescue centre. Other studies (Rajib et al,2001); (Ibrahim et al., 2007)had shown that different types of public buildings (like-Schools, fire stations etc.) of a community plays an important role during disaster like earthquake and illustrated a relation with urban vulnerability due to earthquake hazards.

2.5.1 Evidence of Rescue and Recovery in Historical Earthquake: Contribution of Open Spaces

On April 18th, 1906 San Francisco was a city of about 500,000 people. Within hours of the earthquake the key concern was for security and shelter. Many people refused to go back inside their houses for fear of another earthquake. Some people fled the city. However a large proportion, some 250,000, gathered in parks and open spaces (streets)(Allan & Bryant, 2010). The local park was an important source of information and a form of solace and community support.

San Francisco's network of open spaces contributed to its quick recovery (fig: 3). In a report to the authorities at the end of July that year, Major General Greely (1906) suggested that the question of providing temporary shelter for the 200,000 homeless people who remained in San Francisco was facilitated by the mildness of the climate, the abundance of canvas, and the considerable numbers of convenient squares and public grounds. This degree of spatial redundancy ensured that recovery in place, now recognized as an important component of community survival and recovery, (Mitchell , 2004) was possible.

The city streets were another important locus of recovery(Allan & Bryant, 2010). Their width and gridded layout encourageda range of unimagined adaptive responses.The streets became an important community space, where families cooked together.

Figure 3: San Francisco's hilltop parks provided a vantage point allowing local communities to quickly respond to the advance of the fires (Allan and Bryant, 2010)

Sometimes the whole street was invited for dinner. Streets were wide and uncluttered enough to allow for a strip of 'gutter kitchens' on either side of the road and still allow for emergency vehicular passage down the centre and pedestrian passage on either side of the street. The width of streets facilitated access. People walked to open space, sometimes taking multiple trips to collect all their belongings Immediately following the earthquake, when many streets were filled 'with fallen brick, mortar and iron, and were lined and crossed with a tangled net-work of electric wires and poles' and impassable, the grid and networking of open spaces provided alternative options(Allan & Bryant, 2010).

2.6 Urban Morphology

Urban morphology is a good featurefor looking at resilience (capacity of a city to adapt): it operates on a number of scales and embraces human habitat, built form and open space in an inter-relational landscape (Moudon, 1997). This multi scalar contextual application is also a hallmark of resilience (Walker and Salt, 2006).

What do we mean by the open space network and how do we analyse it? According to Lefebvre, cities are conglomerations of processes (social, economic, political, and ecological) and forms (buildings, streets, infrastructure, parks, monuments etc.)(Lefebvre, 2003). The two co-exist and are mutually interdependent. Urban form is a product of relationships and in particular, the relationship between built form and open space. Morphological analysis is the examination of that relationship and the way it changes over time, in response to a wide range of influences. It is sometimes used to highlight the capacity of a city to adapt and is typically conducted at a range of scales; the scale of the city, the neighbourhood and the lot (Moudon, 1983); (Lipsky, 1999). It is a useful way to quickly analyse the open space/built form relationship of a city in terms of the amount, distribution and configuration (at the scale of the city) and in terms of structure and function at more detailed scales. In the literature of urban design and landscape architecture, open space has a range of meanings, from 'green space' (parks, greenways, reserves etc.) to all public open space (including streets and squares) to private open space (gardens, courtyards) (Swanick et al. 2003).

2.6.1 Methodology for Investigating the Morphological Transformation in Urban areas: Space Syntax Method

The development of space syntax techniques of analysis of urban and built space, coupled to theories of society in which the spatial morphology of the built environment plays an active rather than a passive role (Hillier and Hanson, 1984)(Hanson, 1989)(Hillier, 1996). Their methods represent and quantify the pattern properties of built space in order to control for morphological variations in studies of other aspects of urban function. Research using these techniques has found that spatial configuration has a pervasive effect on many aspects of social function (Penn and Turner, 2003).It adopts a configuration approach to study to whatextent and in which conditions the social and spatial attributes are correlated (Kubat, 1999).

Space syntax provides a unique, evidence-based approach to the planning and design of built forms and urban areas. It has been considered an important theory and analytical tool to investigate the morphological transformation in urban areas. It is a computer-based analysis technique to describe the spatial pattern of urban space.Space Syntax describes the unique spatial characteristics of urban movement network in terms of vehicular and pedestrian spatial distribution of land use attractions. The tool provides precise, diagnostic descriptions of places that can be set against prevailing policy and development objectives. In prognostic mode, the tools are used to forecast how places will develop as a result of physical and spatial change. Outputs include forecasts of movement, space use, safety and land value. Core attributes of this tool are:

- Baseline studies
- Undertaking studies to understand the existing form and functioning of cities and buildings
- Strategic design solutions in disaster
- Forming sustainable visions to deliver social and economic objectives
- Planning support
- Supporting design proposals with evidence of efficacy

The aim behind the technique is to describe different aspects of relationships between the morphological structure of man-made environments and social structures and events. The main theoretical argument is that settlement patterns originate in the social life of the user. Accordingly, the analysis of the spatial patterns of settlements can lead to knowledge about the social norms of societies. The analytical method is based on the transformation of plans into graphs and the quantifying of the spatial qualities of nodes using mathematical formulae (Hillier, 1996). Such a method offers a simple objective procedure for describing, comparing and interpreting settlements.

A number of characteristics make this method a powerful research tool(Kubat, 1999). First, it provides a simple, analysable, and realistic spatial model of settlement. Secondly, it entails analysis of the elements of a city as related parts of system. Thirdly, it gives quantitative values to elements and provides statistical and graphical comparisons within the system.

Space syntax describes the logic of society through its manifestation in spatial systems: howspaces are put together – or the configuration of space – relates directly with how people perceive, move through and use spatial systems of all kind, ranging from small domestic spaces to large-scale urban settlements (Hillier, 1996; Hillier and Hanson, 1984; Hanson and Hillier, 1987). Generally speaking, space syntax is an overarching concept – or a paradigm – and a set of specific theories, such as the theory of order and structure (Hanson, 1989), natural movement (Hillier et al, 1993),centrality as a process (Hillier, 2001), movement economy (Hillier, 1996) and movement generated land-use agglomeration (Penn and Turner, 2004). Furthermore, there are analytical models and tools, such as axial analysis (Hillier and Hanson, 1984), visual graph analysis (Turner, 2003) and segment-angular analysis (Hillier and Iida, 2005), which are direct products of the main theoretical paradigm and its theoretical propositions.

The research has shown that there is a strong relationship between spatial configuration and how people move through the city (Hillier et al, 1993; Hillier and Penn, 1996). The spatial configuration is also associated closely with other important issues in the city, such as: the patterns of vehicular movement (Penn et al, 1998), cognition and wayfinding (Conroy-Dalton, 2003), location of prominent urban elements (Hanson, 1989a, 1989b; Karimi, 1998), land uses (Kim and Sohn, 2002; Penn and Turner, 2004), social segregation (Vaughan, 1997; Vaughan, 2007; Vaughan and Arbaci, 2011) and crime (Hillier, 2002; Hillier and Shu, 2000).

The generative association between space and society, as well as the inherent congruence between spatial configuration and human activities or urban functions, make the use of space syntax in design a strong proposition. As there is a direct relationship between spatial configuration and urban functions, analysis of the spatial configuration provides a powerful tool for designing, shaping, maintaining and altering urban functions. On the basis of this assumption, a series of representation and modelling techniques has been developed for analysing spatial configuration. These techniques are primarily based on fundamental concepts, such as movement, visual perception and human occupation, which link physical space with people directly (fig: 4).

The models use simple geometrical attributes, such as lines of sight and movement or visual fields, to create a network. This network is then turned into a pattern of relationships, or a graph representation, which can be analysed quantitatively to determine the relative role that each space plays in the configuration of the system, as a whole, or in its parts (fig: 6).

The output of the analysis is usually shown by a range of colours from dark red (most connected/integrated) to dark blue (least connected/integrated) (fig: 4).

A very important type of syntactic analysis for urban studies is the description of the network of public spaces by a series of 'axial' lines that represent the longest lines of sight and movement (fig: 6). This is an efficient representation of the spatial network described by a network of lines that can be analysed more easily. The advantage of this model is that it creates an uncomplicated model of the spatial network that corresponds directly with how the network is perceived (visibility) and navigated through (movement) by people. The direct association between how space is configured and how it is used by people creates an analysis that could be used and interpreted directly in the urban design process.

The lines in the spatial network could be treated as continuous entities, or they can be de-composed into segments. The relationship between each segment and all other segments is calculated by an analytical computer software,2 using various methods, such as metric distances (how far to travel), topological distances (how many changes of direction) and angular distances (what degree of angular shift). The second type of analysis is called an 'axial analysis' and the third, which has been developed more recently, is called 'segmental angular analysis' (Hillier and Iida, 2005).

By translating the network of lines into a graph that represents the topological relationships between lines, a quantitative analysis of the system is performed by calculating how each space is connected with the other spaces in the system. The analysis can be based on the relative depth (or shallowness) of spaces from each other, which is a measure of 'proximity' or '**to-movement'**, or based on the possibility of being used in journeys throughout the system, which is a measure of 'between-ness' or '**through movement'**. The former measure of analysis in space syntax terminology is called integration and the latter is called Choice (Hillier and Iida, 2005). Each of these measures explains certain aspects of the urban structure and is used in connection with specific questions that have to be answered in an urban study.

The analysis can also be performed for the entire system (the global network), or parts of it (the local network). In the global scale of analysis (fig: 4), we take into account every possible relationship in the system (from anywhere to anywhere), whereas in the local scale of analysis (fig: 4) the analysis is restricted to a certain local catchment, which could be topological (up to a certain number of changes of direction from each line), or angular (up to a certain degree of angular change from each segment), or metric (up to a defined metric distance from each segment). The local and global analyses are very useful methods of looking at different scales of a spatial system, but they could also be used to define how an entire system is understood by the perception of its parts. The congruence between local and global spatial configuration determines how intelligible the system is to the people who navigate through it (Hanson, 1989, 1989; Hillier and Penn, 1996). The intelligibility of the network is another set of analytical metrics that could be used in the process of urban design.

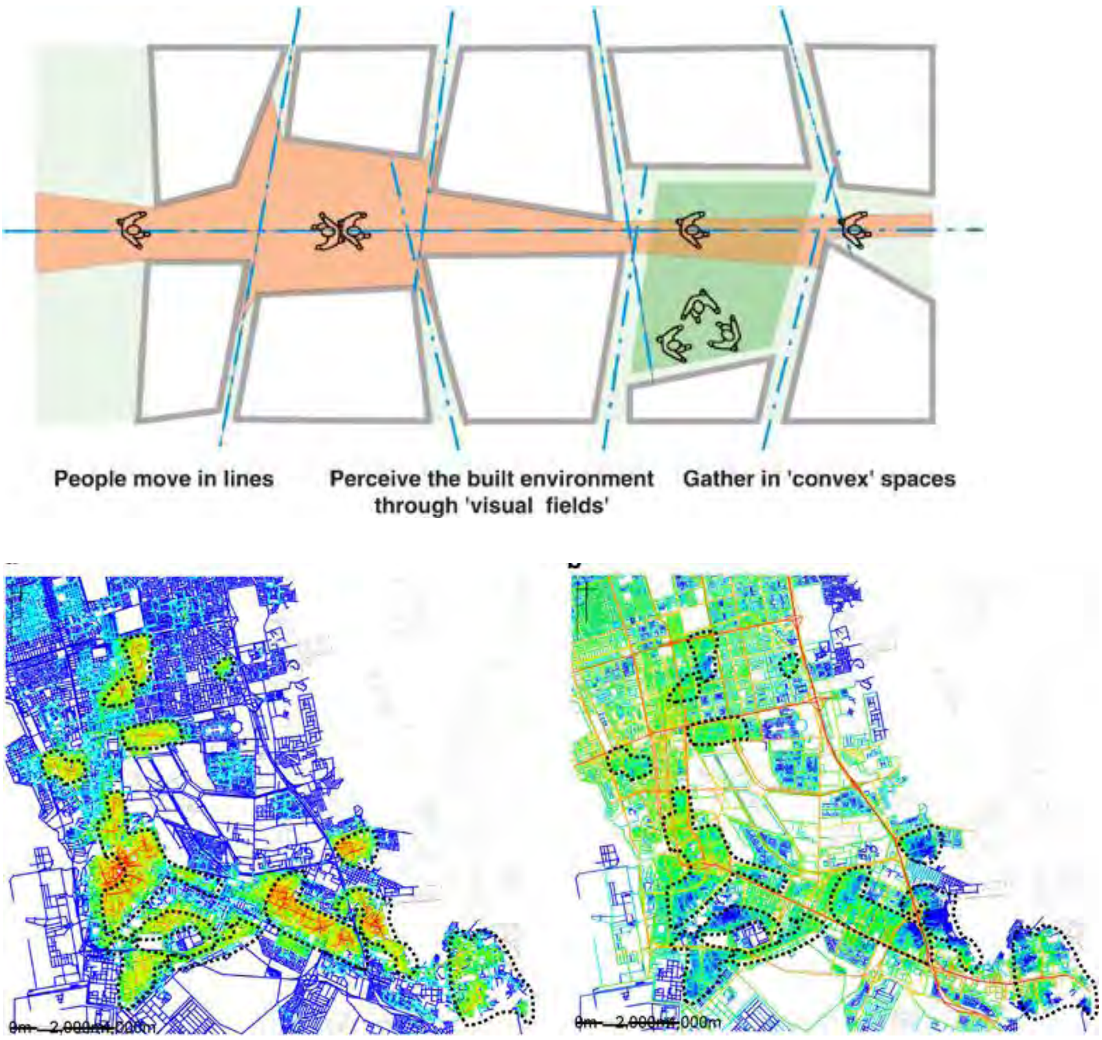

Figure 4: A space syntax model (above) and asegmental angular analysis of the city of Jeddah, Saudi Arabia. Analysis of the urban grid at the local level (below left) and at global level (city-wide analysis) (below right)

2.6.1.1 Diagnosis: Understand spatial accessibility

Measure the accessibility of the movement network, to understand the hierarchy of routes of the cities (fig: 5).

Figure 5: Spatial accessibility using the colour scheme, the most connected (dark red) to least connected (dark blue)

2.6.1.2 Diagnosis: Urban block size

Measure the size of urban blocks to describe the "permeability character" of the network (fig: 6).

Figure 6: Permeability character of the urban structure

2.6.1.3 Diagnosis: Land Use pattern

As cities evolve, land uses exploit spatial accessibility. Movement-sensitive land uses locate on movement-rich streets (fig: 7). Less movement-sensitive uses locate around the corner. In this way, historic cities organise themselves, mixing land uses in a natural way that people understand intuitively.

Figure 7: Movement-sensitive land uses

2.6.2 Why Space Syntax method for rescue, evacuation and recovery in urban areas?

Predicative evaluation on space usage patterns of potential users is a critical and essential factor in the planning and design stage of urban areas. In particular, the speediness and ease of the evacuation and a safe rescue operation for the users in the cases of disasters, such as fires, earthquakes, etc.is an extremely significant element in the planning and design stage since the matter is directly related to the disaster prevention planning of urban areas.

The earthquakes bring on two types of casualties. Initial casualties are generally due to the collapsed buildings, shaking of the ground and damage on the urban land. Secondary casualties, on the other hand, are generally related with the physical conditions of durability of the urban structure. These also can reach to huge numbers especially for the poor settlements with vulnerable physical conditions. People, who survive from the incident, may get trapped in the disaster core because of fires, collapsed buildings, fallen bridges, broken lifelines etc. Then, accessibility between the disaster site and outside world gets on a poor level. Roads to dispatch rescue personnel from outside to disaster area and to transfer victims from disaster area to outside cannot be accessed due to debris obstacles.

Space syntax theories and methods have a long history of informing designers to predict the socio-economic impact of their schemes (Hillier, 1996), which could be used as a basis to assess the effects of intervention-led improvement schemes. Space syntax theory is built on two main ideas: the objective of space configuration, which is the interrelation between the spaces that form the spatial layout of the city, and our intuitive engagement with it. Dalton and Holscher argued that the spatial configuration is the society's artefact. They added that the relationship between the spatial and the social interaction is a two-way process, although society creates the spatial system that its members use; they are affected and influenced by the spaces they inhabit (Dalton and Holscher, 2006). As a result, a fundamental link between the structures and functioning of cities is established, as the configuration of network is the primary shaper of the pattern of movement. Penn et al. explained that the configuration of the street's grid causes a pattern of movement for the pedestrian population as a whole, which is reflected in a correlation between spatial integration and pedestrian flow rates (Penn et al., 1998). Streets with higher spatial integration values attract more pedestrian flows. Integration in space syntax refers to accessibility. It describes the average depth of a space to all other spaces in the systems, which indicates the preferable potential places to move to as a movement destination 'to-movement' (Hillier et al., 2007). The space of the system can be ranked from the most integrated values to the most segregated values (Hillier and Iida, 2005). These values are illustrated as a graph: integrated routes are shown as thick, red lines while segregated routes are shown as thin blue lines (fig: 30). Space syntax provides choice analysis, which is the degree of choice that each space represents, or how likely it is to be passed through on all shortest routes from all spaces to all other spaces in the system (Hillier and Hanson, 1997). It is the potential of 'through-movement' (Hillier and Iida, 2005).

The model is based on the shortest number of turns in escaping (movement) which is related to accessibility analysis in space syntax and the visual cognition ability of people for selecting the appropriate routes to evacuate and rescue to the surrounding context.

It has been interpreted that a sufficient risk assessment and natural movement studies such as Space Syntax approaches can produce a guideline for disaster intervention process (Kubat, 1999) (IMM,2005) (Mohareb, 2009) .Using Space Syntax tools, which would help definition of the routes that people prefer to use, will help the interventions being put in an order(Sari and Kubat, 2012). In other words, this would provide a guideline to local authorities wiping the vulnerable buildings which are located on the major segments embody the major framework of the roads. This will eventually allow the post-earthquake services to be provided more easily, and allow much more people to be evacuated from the danger zone(Mohareb, 2009).

2.7 Urban Resilience

Resilience (the capacity of a city to absorb and adapt to disturbance) and sustainability are related concepts, but the activities and processes associated withthem, the rules we make for them and the way we design for them are often quite different. Theoverwhelming goal for sustainability is the mitigation of impacts. The concept of resilience, stronglyinfluenced by systems thinking and defined here as the capacity of a system to respond to disturbancewhile still maintaining structure and function(Holling, 1973), is useful because it shifts the focusaway from controlling impacts or threats towards developing a system's capacity to respond to them. "Resiliency should be understood comprising the following elements: having the capacity to absorb stress or destructive forces through resistance or adaptation; capacity to manage, or maintain certain basic functions and structures, during disastrous events; and, capacity to recover or 'bounce back' after an event (Udugama, 2007)." When the community becomes fully resilient, then there is no scope for disasters to take place. It may be helpful to think of a disaster-resilient or disaster-resistant community as 'the safest possible community that we have the knowledge to design and build in a natural hazard context' (Geis, 2000) throughminimizing its vulnerability.Ecologists Holling and Walker have developed a resilience model that suggests that a thoroughunderstanding of a system's existing structure and function and its history of disturbance allows us todesign for and manage resilience (Walkeret al. 2004).

Cities are complex systems and communities, as an integral part of those systems, play an importantpart in the adaptive response. While recovery planners are concerned with encouraging communitiesto adapt, urban designers are beginning to be interested in howthe design of cities might encouragethat to happen. Both disciplines are making tentative moves, albeit unconsciously, towards the other.

Because an earthquake may never happen there is likely to be a reluctance to retrofit a city toaccommodate the needs of recovery, particularly if there are cost implications. But if urban designstrategies and earthquake recovery planning strategies are aligned, through a focus on urban resilience,then the on-going and incremental retrofitting of a city for day to day purposes will automaticallycreate opportunities to facilitate effective rescue and recovery should an earthquake occur. The commondenominator for urban design and recovery planning is a city's open space network: the streets andparks and left over spaces that are part of the everyday city, and that come to life as the 'second city' during recovery(Allan and Bryant, 2010).

2.8 Vulnerability Studies in Bangladesh

In Bangladesh, extensive amount of researches have been undertaken on the structural stability of individual buildings in cities for earthquake vulnerability reduction(Rahman, 2004) (Ansary and Noor, 2006) (Sadat et al., 2007)(Rahman et al.,2007) (Kamal, 2009). But one of the goals of this type of research is to promote effective evacuation, rescue and recovery for many parts of our cities. But, very few detail researches on earthquake evacuation and rescue in our country (Reja, 2008)(Jahan et al., 2008) (Jahan, 2010)(Ansary, 2010)(Jahan et al., 2011). Moreover, earthquake awarness related seminars, mock drills, etc. are conducting by different organizations but that are not enough to cover the whole country. Bangladesh Army has divided Dhaka city in eight zones to ensure sector wise emergency help during disaster but no more detail planning was done in this issue. CDMP did few researches and prepared contingency plan for earthquake in Dhaka, Chittagong and Sylhet city (Kamal, 2009). But it is a large scale planning and there is no implementation of this plan (Jahan, 2010). In addition to the earthquake vulnerability study, there are other researches focuses on Tsunami/Storm vulnerability (Kamal, 2009), (MoFDM , 2009a)(MoFDM,2009b); Geo-climatic and cyclone disaster Vulnerability in coastal araes of Bangladesh (Kabir, 2012)(Chodhury et al., 2005).

2.9 Summary of Literature Review

A summary of literature in the field of earthquake vulnerability reduction and their association with built environment has identified the pattern of relationship with the accessibility of open spaces and public buildings, distance to wide emergency shelter, road pattern, connectivity of roads with main emergency routes etc. (fig: 8). The role of the city's landscape and its network of open space, and effectively the place where rescue, recovery happens, is discussed where planners, urban designers and landscape architects are rarely involved in earthquake recovery planning. However while there is a little information regarding the approximate quantities of open spaces per capita required for egress or refuge (Wang), information about the quality is almost non-existent.

Several studies and researches have notably identified the role of open spaces and public buildings as post disaster shelter. But there is fewguidelines for evacuation plan relating these spaces. Very few researches have been conducted on evacuation plan for post-earthquake hazard, but in the realm of earthquake disaster (during and after), detail rescue and recovery planning guidelines and earthquake vulnerability reduction incorporating postdisaster shelter (open spaces and public buildings) for urban areas remain unaccomplished.

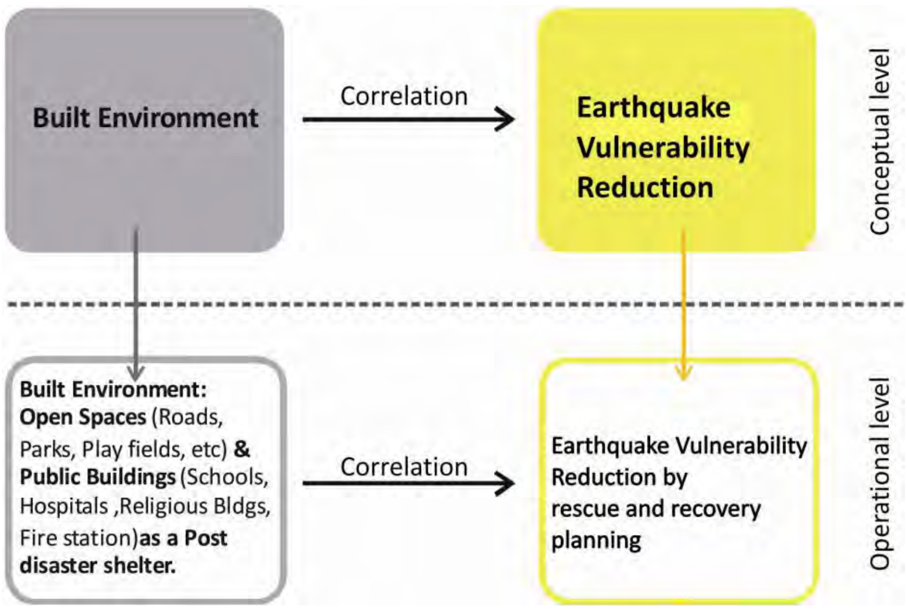

Figure 8: Chart showing framework for the study

Chapter 3: OLD DHAKA AND ITS EARTHQUAKE RISK

3.1 Physical Growth and Present Physical Condition of Dhaka

Rapid urbanization is now becoming a threat to the environment and sustainable development on a global level. Two centuries ago there were only two cities with a million inhabitants, London and Beijing (Desai & Potter, 2002). But now it reached to 293 cities where most of the million cities are within the developing world. The growth rate of these cities counted tenfold between 1950 and 1990. Some of these cities, such as Abidjan, Amman, Dhaka, and Harare are now defined as mega cities with 10 million inhabitants (Desai and Potter 2002: 244). Environmental degradation and booming populations in these cities are the burning issues of the present world in case of urbanization.

Over the last 400 years, the city has experienced a number of dramatic historic events. Political changes and shifts in power have also brought about changes in demography and structural development. Over the last few centuries, Dhaka has expanded to approximately 40 kilometres from north to south and 14 kilometres from east to west. In 1951, it covered 85 square kilometres and had 0.4 million inhabitants. It experienced a very rapid expansion in area and population after independence in 1971. Since then, the rapid development of human settlements, the growth of national and international business, the opening of new trades and the expansion of private and public establishments, industry and infrastructure have made Dhaka one of the most unplanned urban centres.

Dhaka, the capital of Bangladesh, has grown from a small trading town to a metropolitan city because of rapid urban growth and physical expansion.Today's mega city Dhaka was established on the bank of Buriganga River. During the first few decades the city was expanding along the Burignga River. Until 1950, development of the city took place on the higher terrain and the surrounding rivers, networks of canals and the lakes were harmoniously used for transportation, defense, fishing or agricultural purposes. Planned development of Dhaka city started after 1947 when the city gained regional and political importance (Sultana, 2007). Its rapid urbanization started just after 1971, when it became the capital city of an independent country. Dhaka City has undergone radical changes in its physical form, not only in its vast territorial expansion, but also through internal physical transformations over the last decades. These have created entirely new kinds of fabric. With these changes in urban form, the elements of urban form have changed. Plots and open spaces have been transformed into building areas, open squares into car parks, low land and water bodies into reclaimed built-up lands etc. (Ahmed et al. 2009). In the figure 9, historical growth of Dhaka, and in figure10,Dhaka's gradual physical changing pattern with population from 1600 to 2003, are shown.

"Urban growth in Bangladesh is associated with rapid land use change. High population growth creates extra pressure on the land and forces conversion of agricultural lands into housing developments and roads. Rapid population growth and extra pressure on land have triggered unplanned development; for example, filling up lakes and canals and development in flood plain zones. Unplanned development means more development without considering the consequences of environmental degradation and thus Dhaka is becoming more vulnerable to natural hazards, like urban flooding and earthquake (Sultana, 2007)."

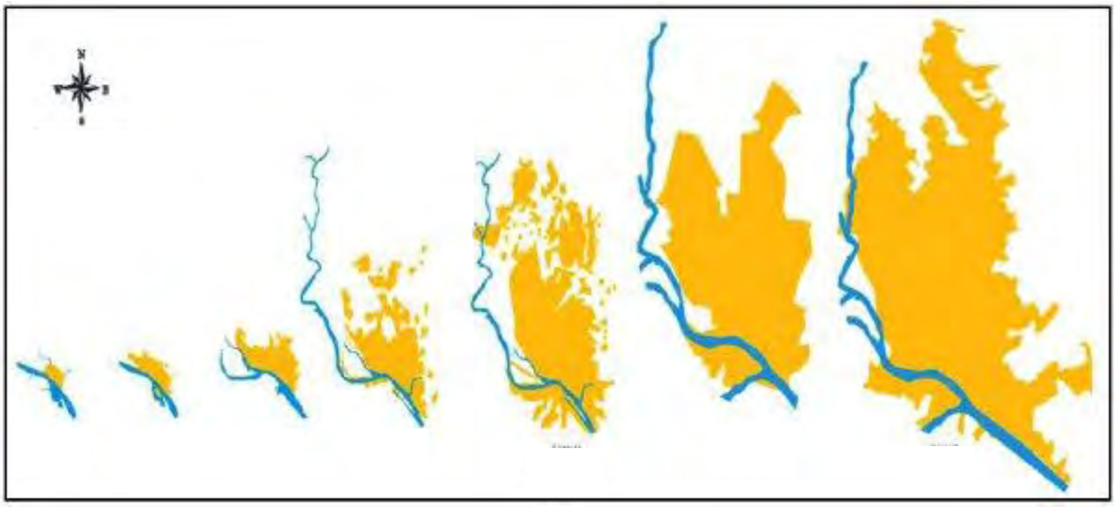

Figure 9: Historical growth of Dhaka (Not to Scale) (Source: Urban Planning Department, Dhaka City Corporation, 2004)

3.1.1 An Understanding of Urban patterns of old Dhaka

An understanding of the social and spatial aspects remains equally important to plan for post disaster management in urban areas, because the rescue and recovery process after earthquake is influence by its geomorphology and urbanstructure.Rescue and recovery clearly has a spatial dimension, and resilience theory suggests how we might design form and space as well as process in order to influence rescue and recovery, during and after earthquake(Allan & Bryant, 2010).

Within the successive stages of growth, two dominant urban patterns are conspicuous in Dhaka; they are the historical core or “old Dhaka” and the later development towards the north, known as “new Dhaka”. Human settlement and the development of infrastructure started in the sixteenth century in the southern part of the present city corporation that is known as “old Dhaka”. The historic kernel of old Dhaka retains the traditional features it has inherited from the past. The natural endowment of its organic morphology is valued for its ‘indigenous’ urban pattern. The residential neighbourhoods of old Dhaka, locally known as ‘Mohallas’, are considered by many to be a morphological archetype of this historic city(Nilufar, 2010).

The organic character of the old part of Dhaka is particularly distinctive because of thedensity of its built-up areas in comparison to the looseness of the later organic developments(Khan & Nilufar, 2009).The oldest, original settlement of old Dhaka that grew along the river Buriganga characterised by its mixed-use buildings jostling against each other in a rambunctious way, its narrow, winding streets, and its traditionally organised neighbourhoods (mohollas). Even within the old city there is now much diversity, but above all, the old city is coming apart at the seams. It is no longer able to sustain its morphological matrix in the onslaught of overwhelming commercialisation and further densification, and adoption of alien "development" strategies(Ashraf, 2003).

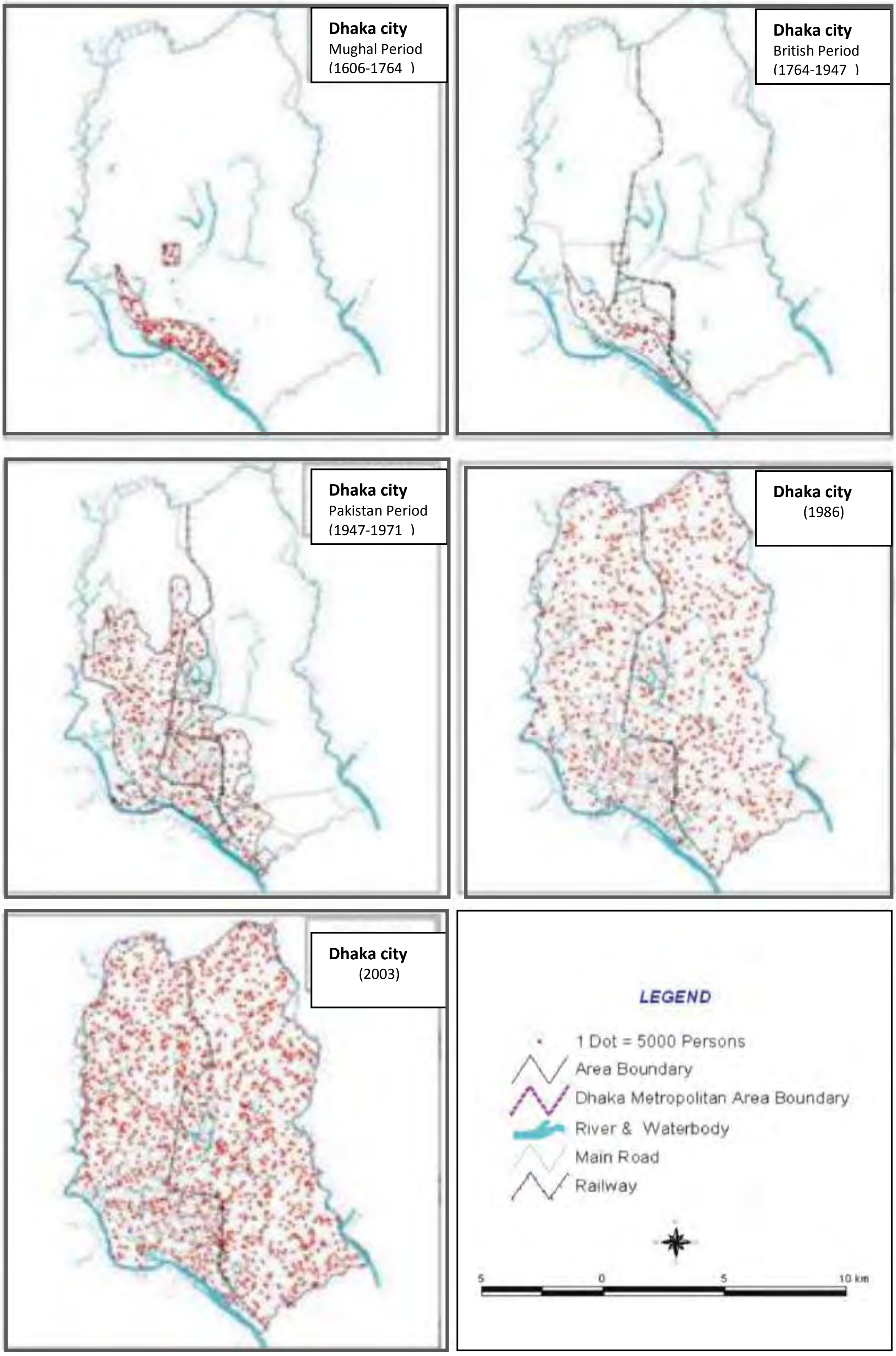

Figure 10: Changing pattern of Dhaka city and its population (source: GIS Division, Bangladesh Centre for Urban Studies)

"The pattern that exists in the old city is the winding and intricate street network and the walls defining the houses. The streets in the historic part are narrow and continuously twisted in and out - tortuous to an extreme degree in some places. The dead-end passages sometimes cut deep inside the urban block presenting a series of sharp turns. These were found indiscriminately along both the thoroughfares and the alleys. In some areas, a few long lines passed through the residential areas, which gave rise to another type of urban pattern e.g. Shankhari Bazaar Road, Tanti Bazaar Road. These were mainly the commercial interfaces of the city; and such areas have no lanes and by lanes as the access are from single bazaar streets. These streets are defined by closely spaced buildings in contrast to the former pattern (Nilufar, 2010)."In the event of an earthquake, when rescue and recovery will be a big concern to reduce the earthquake vulnerability then the accessibility to these areas remains questionable either in terms of evacuation of the inhabitants or any help from outside of the city.

There has been a mix of uses and building types in old Dhaka. According to Mowla(2008), permanent, semi-permanent, temporary structures and shades stand side by side in old part of Dhaka city. Generally, structures along main thoroughfares have a predominance of commercial use and being permanent (Mowla, 2008). It is estimated that 80% of residential houses in old Dhaka have some kind of factory or warehouse on the ground floors and residential flats on other floors. Most of these warehouses or factories are either of chemicals or plastic materials. Both are dangerously toxic and inflammable(Imam, 2010). What will happen if a big earthquake hit the city? Because in many historic earthquake disasters, it is evident that fire is the most common hazard following earthquakes. In old Dhaka, these toxic and inflammable chemical factories increase the threat of earthquake disaster to many more folds.

3.2 Consequences of Urbanization

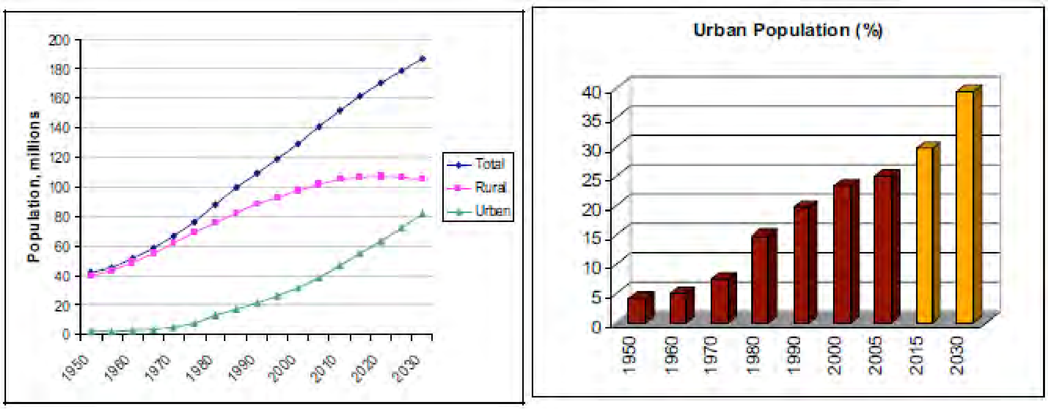

Figure 11: Urban population in Bangladesh (Source: UN World urbanisation prospect, 2007)

According to World Bank Bangladesh Development series 2007, urbanization in Bangladesh has been running at a significant pace. After independence in 1971, the country's national population growth was 2.2% but the urban population growth was 7% yearly. According to UN population division, around 35 million, on 25% of country's total population, is living in urban areas. This 35 million is expected to exceed 80 million by 2030 which is shown vertically in above figure 8. In the left side of the figure, it shows total population with both rural and urban. Total and urban population is clearly rising upward indicated by blue and green line in the figure. Dhaka city is the largest among four big cities. The other three large cities of Bangladesh are Chittagong, Rajshahi and Khulna. Dhaka city estimated more than 13.1 million inhabitants that are around eightfold increase since 1971. It is estimated by UN population division that by 2015 the urban population would reach 22 million which will make the city the sixth largest city in the world and third largest in Asia.

Dhaka city is one of the most densely populated cities in the world as well as Bangladesh as a country. Urban population growth has been outstanding since its independence in 1971. Bangladesh counted urban population 13.5 million in 1981, 22.9 million in 1990, in 2000 the urban population was 37.3 million and in 2005 it was 46.4 million(Chowdhury & Amin, 2006). There are some elements like lack of equal development and resources distribution, natural hazards, limited job opportunities in rural areas that accelerates urban growth in Dhaka (Rana, 2010). According to Islam, three factors mostly work behind rapid urbanization. These are "(1) A high natural increase in native urban population (2) the territorial extension of existing urban areas and a change in definition of urban areas, and (3) rural to urban migration" (Islam, 2001, quoted Rana, 2010). As per government statistical organization BBS (Bangladesh Bureau of Statistics) push and pull factors work intensively on growth rate of urban inhabitants during 1974-1981, they indicated pull factors are better life status, educational opportunities, transport facilities, comparatively better social security, employment opportunities etc. On the other side push factors such as natural calamities like river erosion, cyclone and floods as well as poverty, lack of job and availability of higher education force people to migrate to the cities (BBS, 2001). According to the World Bank, 300,000 to 400,000 new people migrate to capital city Dhaka each year (World Bank, 2007). Therefore, migration plays an important role to Dhaka's rapid urbanization.The table2, shows total population of Dhaka Divisionwith its size of living area and density per $km^2$and table 3 shows same components for Dhaka City Corporation.

Table 2: Increasing trend of total population, area and density of Dhaka Division (Source: BBS, 1991; BBS, 2001 and Dhaka city state of environment, 2005)

Year	Area (Km^2)	Population	% Increase of Population	Density (Km^2)
1951	85.45	411,279	--	4813.09
1961	124.45	718,766	74.76	5775.54
1974	335.79	2,068,353	187.76	6159.66
1981	509.62	3,440,147	66.32	6750.41
1991	1352.82	6,844,131	98.95	5059.16
2001	135282	10,712,206	56.51	7918.43

Table 3: Increasing trend of total population, area and density of Dhaka City Corporation (Source: BBS, 1991 and Dhaka city state of environment, 2005)

Year	Area (Km^2)	Population	% Increase of Population	Density (Km^2)
1981	208	2,816,805	--	13,542.33
1991	276	4,486,421	59.27	16,255.15
2001	276	5,378,023	19.87	19,485.59

On the other hand, the population density of old Dhaka is much higher than any other part of our country. In old Dhaka, the population density is apparently 150,000 per Km^2(Hillary, 2006).Where, the maximum desirable population density in urban areas is apparently 40,000 per Km^2.These trends of rapid urbanization in old Dhaka have exposed high percentage of the population to vulnerable situation in the event of earthquake.

Another important consequence of this rapid urbanization is unplanned development through filling the flood flow zones or marshy lands across the city. Dhaka is gradually expanding towards all directions through rapid development of housing estates. The Master Plan for the city that was prepared under the name of Dhaka Metropolitan Development Plan (DMDP) has two parts: Dhaka Structure Plan is valid for 1995-2015, whereas the Urban Area Plan was valid during 1995-2005. This plan indicates keeping at least eight flood flow zones undisturbed (Dhaka West, DND Triangle, Eastern Fringe polders, Kamrangir Char, Jinjira, Narayanganj West, Dhaka NW, Narayanganj East). Unfortunately, this is not happening. Already two flood flow zones are being filled up by unscrupulous developers, something that RAJUK (a prime Planning Authority of Bangladesh) has failed to prevent (Ferdousi, 2006).In order to cope with the continuous pressure of urban growth the city kept filling up the wetlands both within and beyond the city areas and converting highly alluvial agricultural land into urban land and these low terraces, depressions, back swamps are usually of elevation 2-5 meter AMSL. Most of the high flood plain and gully fill areas have been filled and raised above the normal flood level by sand filling.Thus, Dhaka is expanding gradually towards different directions on marshylands. This phenomenon is common for eastern fringe, western areas and southern periphery.

These cases represent the circumstances of housing estates developmenton marshy lands during last one and half decade that is ultimately leading to a large development which not only bringing an impending environmental disaster but also consistently choking the capital with constant water logging and upsetting the sewer system and making vulnerable for the liquefaction effect of an earthquake event.

3.3 Earthquake scenario of Bangladesh

Bangladesh is susceptible to earthquakes due to its close location to the plate margins of the Indian and Eurasian plates. Moreover, the Professor Roger Bilham of Colorado State University came up with his recent research findings that major earthquakes might take place in the sub-Himalayan region, including Bangladesh (Bilham et al. 2001).Although in the recent past no large scale earthquake has occurred in this region but in past few hundred years it have seen several catastrophic earthquakes. The earthquake record suggests that since 1900 more than 100 moderate to large earthquakes occurred in Bangladesh, out of which more than 65 events occurred after 1960. This brings to light an increased frequency of earthquakes in the last 30 years. This increase in earthquake activity is an indication of fresh tectonic activity or propagation of fractures from the adjacent seismic zones (Banglapedia,2004). The Bengal earthquake of 1885 and the 1897 Great Indian earthquake are more significant among the devastating earthquakes that had severe impact on Bangladesh. There was no seismographic record available for the Bengal earthquake of 1885. Only the felt reports and observed damage to buildings, boundary walls, factory chimney, tomb and cemetery, tower like octagonal mandirs with conical apex, earth fissures and vents were described in the report on the Bengal earthquake by Middlemiss (1885). According to the report, this earthquake was felt with violence throughout the Bengal province. The extent of felt areas extended west-ward into Chota Nagpur and Bihar, northwards into Sikkim and Bhutan, and eastward into Assam, Manipur and Burma. The area over which it was sensibly felt may be roughly 6,00,000 sq. km.

The 1897 Great Indian earthquake with a magnitude of 8.7, considered being one of the strongest earthquakes in the world, originated at an epicentral distance of only 230 Km from Dhaka. While the earthquake affected almost whole of Bangladesh, damages were very severe particularly in Sylhet, Rangpur and Mymensingh(Sharfuddin, 2001).It occurred on June 12 at 5.15 pm, caused serious damage to masonry buildings in Sylhet town where the death toll rose to 545. This was due to the collapse of the masonry buildings. The tremor was felt throughout Bengal, from the south Lushai Hills on the east to Shahbad on the west. In Mymensingh, many public buildings of the district town, including the Justice House, were wrecked and very few of the two-storied brick-built houses belonging to *zamindars* (land-lords) survived. Heavy damages were done to the bridges on the Dhaka-Mymensingh railway and traffic was suspended for about a fortnight.

During the last 150 years, 7 major earthquakes (with M_7) have affected Bangladesh (Table4).

Table 4: List of Major Earthquakes Affecting Bangladesh (Ali and Choudhury, 2001; Banglapedia, 2006)

Date	Name of Earthquake	Magnitude (Richter)	Location of Epicentre	Epicentre Distance from Dhaka (km)	Effects
Jan 10, 1869	Cachar Earthquake	7.5	Northern Border of Jaintia Hills of Assam (India)	250	It caused great damage in Monipur and Cachar District of Assam (India) and eastern part of sylhet (Bangladesh). The tremor was felt all over Bangladesh.
July 14, 1885	Bengal Earthquake	7.0	Bogra (Bangladesh) fault (24.80^0N, 89.50^0E) Source: Bolt, 1987	170	Northern to central parts of Bangladesh (Sirajganj, Bogra, Jamalpur, Sherpur and Mymensing district) faced considerable amount of damages for this earthquake
June 12, 1987	Great India Earthquake	8.7	Central part of the Shillong Plateau (India)	230	It is epicentral area was in the central part of the Shillong Plateau. It was one of the greatest earthquakes in the world and in Bangladesh it perhaps caused the most

					widespread damages.
July 08, 1918	Srimongol Earthquake	7.6	Balisera valley near Srimongol, Bangladesh	150	Intense damages occurred in Srimongol; but due to shallow focal depth, the intensity rapidly decreased and in Dhaka only minor damage occurred particularly throughout the country
July 02, 1930	Dhubri Earthquake	7.1	Dhubri town in Assam (India)	250	It caused major damaes in the eastern parts of Rangpur district (northern part of Bangladesh)
Jan 15, 1934	Bihar-Nepal Earthquake	8.3	North of Darvanga (India)	510	It caused great damages in Bihar (India) but did not affect any part of Bangladesh with any degree of severity.
Aug 15, 1950	Assam Earthquake	8.5	Arunachal Pradesh, northeast of Assam (India)	780	The tremor was felt throughout Bangladesh.

The earthquakes of recent days are grouped below:

1997: Occurred on May inSylhet earthquake with a magnitude of 5.6 and its epicentre was in north-east Sylhet, near Jaintiapur cracking of a number of buildings in and around Sylhet (e.g. Sylhet airport building, College near Jaintiapur, Grameen Bank building in Barlekha).

1997: Occurred on November 22 in Chittagong with a magnitude of 6.0. It caused minor damage around Chittagong town.

1999: Occurred on July 22 at Maheshkhali Island with the epicentre in the same place, a magnitude of 5.2. Severely felt around Maheshkhali Island and the adjoining sea-houses cracked and in some cases those were collapsed.

2001: in December, 2001, an earthquake with a magnitude of 4.8 Mb occurred around 40 km west of Dhaka which caused leaning in a four story building constructed on fills in city area.

2003: Occurred on July 27 atKolabunia union of Barkalupazila, Rangamati district with magnitude 5.1(Banglapedia, 2006).

2007 to 2008: The meteorological department detected at least 90 earthquakes taking place in the country between May 2007 and July 2008, nine of them above five (5) magnitude on the Richter scale and epicentres of 95 percent being within a 600 Km radius of Dhaka city.

2011: According to the Bangladesh Meteorological Department, In2011 Dhaka's roughly 13 million people were rocked by three earthquakes each registering at least 6 (six) on the Richter scale, but without any damage or casualties.

2012:A mild 5.3 magnitude earthquake hit Assam, India and its surrounding zones in India and Bangladesh on 6:11pm IST, 6:41pm BDT (12:41 GMT), Friday, May 11, 2012. No damages reported so far. The main jolt felt in Assam, India, where a 5.3 magnitude shakes the state.

The historical seismicity data of Bangladesh and Adjoining area, recent repeated earthquakes in many region of Bangladesh indicates that Bangladesh is waiting for a big earthquake near future. That's why, it is essential to develop an effective earthquake risk management plan, which requires long-term plan of action and involves multidisciplinary contribution to safe our country for 21st century.

3.4 Earthquake Riskfor Dhaka

The earthquake disaster risk index has placed Dhaka among the 20 most vulnerable cities in the world. Dhaka with its population of around 14 million and enormous poorly constructed and dilapidated structures signifies extremely vulnerable conditions for massive loss of lives and property in the event of moderately large earthquake.According to a report published by United Nations IDNDR-RADIUS Initiative, Dhaka and Tehran are the cities with the highest relative earthquake disaster risk (Cardona et al., 1999). Highlighted in this report, Dhaka's highest relative earthquake disaster risk is primarily due to its exposure, its vulnerability and emergency response and recovery factors.

When the historical devastating earthquakes hit Dhaka and other urban areas, those were not densely populated and had very few buildings, at that time. But, the urban scenario has drastically changed now. The 1993 Killari and 2001 Gujarat earthquakes in India have clearly demonstrated that inappropriate construction technology can lead to high casualty levels even for moderate earthquakes (Sinha & Goyal, 1994). A peak ground acceleration of0.11g (g is the acceleration due to gravity) caused the collapse/serious damage of numerous mid to high-rise buildings in Ahmedabad, a city around 240 km away from the epicenter of M=7.7 Bhuj earthquake. Note that according to the Bangladesh Building Code, the major cities of Dhaka and Chittagong can be subjected to ground motion reaching higher values (0.15g) (fig: 9) (Al-Hussaini, 2005). The metropolis Dhaka is an integral part in the southern tip of Madhupur Tract encircled by some very active tectonic units viz. the Sylhet through on the North, the JamalpurGraben on the West, the Dhaka Depression on the south and NE-SW tending Meghna fault zone in the East (Ansary & Noor, 2006).

So, the present urban trends of Dhaka city, unplanned development and high population density with its higher values of ground motion make the city a potential threat for the city dwellers. The table 5 shows evidence of historical damaging earthquakes at frequent intervals.

Figure 12: Seismic Zoning Map for Bangladesh (BNBC, 2006)

Table 5: Magnitude, EMS Intensity and Distance of Epicentres from Dhaka of some Major Earthquakes

Name of the Earthquake	Magnitude	Intensity[3] at Dhaka	Distance (Km) from Dhaka
1869 Kachhar	7.5	V-	250
1885 Bengal	7.0	VII	170
1897 Great Indian	8.7	VIII+	230
1918 Srimangal	7.6	VI	150
1930 Dhubri	7.1	V+	250

3.4.1 Earthquake threats for Old Dhaka

Old Dhaka is relatively more vulnerable due to its high density of population. Besides, the spontaneous and organic growth of old Dhaka has increased the vulnerability of human lives, economy and infrastructures. In the event of an earthquake, this part of the city will suffer immense losses of life and property due to the developments without maintaining any rules and regulations.

Along with the informal settlements and high dense built fabric, the presence of old dilapidated unreinforced masonry buildings, narrow road pattern and contiguous building pattern, irregular building shapes and lack of open spaces made the locality more prone to earthquake disaster(fig: 13). According to a study conducted by Bangladesh University of Engineering and Technology (BUET) in 2003, about 60 percent structures in old Dhaka are non-engineered. Of those, 50 percent are made of flammable materials. It is also reported that 50 thousand houses of old Dhaka are risky for living. Among them, 22 thousand are at high risk. Nearly three (3) million people living in old Dhaka face the risk of death(Imam, 2010). Moreover, most of the houses in old Dhaka grew in clusters. In most cases, the roads and alleys are so narrow that the ambulances or fire fighting vehicles find it extremely difficult to approach the place of occurrence for any rescue operation. That is what happened in the Nimtoli fire incident on the night of June 3, 2010 (fig: 14).

Figure 13: High building density of old Dhaka

Figure 14: Nimtoli fire hazard in old Dhaka, June 3, 2010 (Source: The Daily Star)

For earthquakes of much higher intensity (than the design level), engineered structures are expected to collapse in such a manner as to minimize the injury to the occupants. Since Dhaka is a city of over 400 years, its old structures have already exceeded their useful service life and several of them have deteriorated badly(fig: 15), mostly in the older part of the Dhaka.

Unreinforced brick masonry buildings have been observed to behave poorly during earthquakes and they can be more dangerous if they are 4or more stories high, or built on 5 inch walls, which is not uncommon in Dhaka. Reinforced Concrete construction can also pose equivalent danger if earthquake resistant design provisions are not followed; this has been amply demonstrated in recent earthquakes of Bhuj[1] and Izmir[2]. Economic reasons,

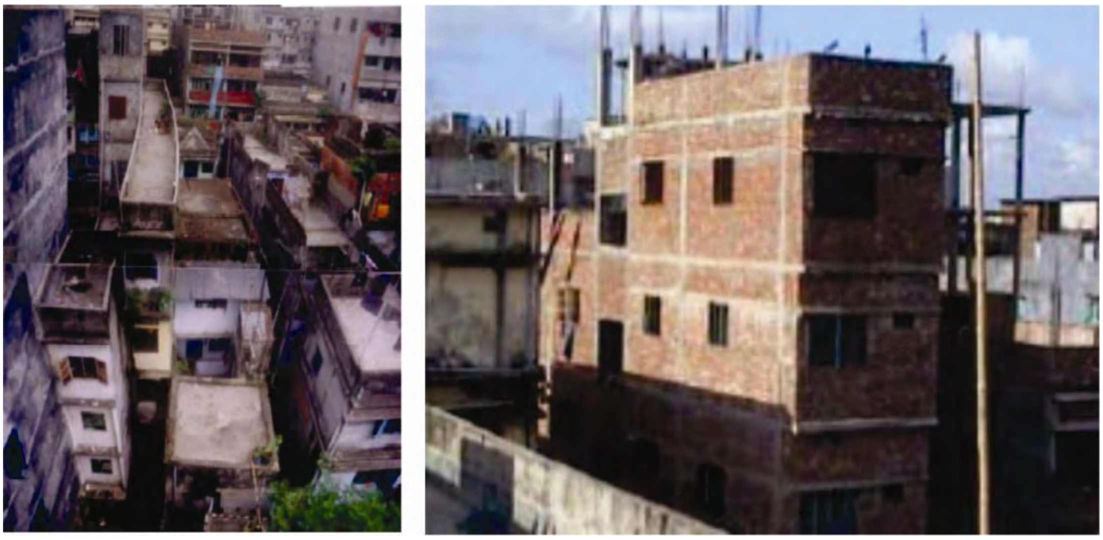

Figure 15: Poor condition of old Dhaka

lack of quality control in construction and use of poor quality of materials all contribute to the high vulnerability of buildings. A recent building survey, funded by Bangladesh Ministry of Science and Technology research grant, in parts of Sutrapur, Lalbagharea of Old Dhaka reveals concentration of multi-storied un-reinforced brick masonry buildings in the older part of the city. While the percentage of un-reinforced brick masonry buildings in Sutrapurarea of the old city was found to be around 65%, the same in the relatively new West Dhanmondiwas found to be around 42% (Al-Hussaini, 2005).

The Old Dhaka was once considered a centre of education, culture and trade and commerce, and a place enriched with tradition, history and memories of good old days. But it is now crippled with manifold problems like nasty traffic congestion, erratic supply of power and water and mismanagement of sewerage system. The waste disposal system in this neglected part of the city spreading over 25-sq. km area and covering three thanas namely Lalbag, Kotwali and Sutrapur, is so unplanned and vulnerable that living there is a

[1]On January 26, 2001an earthquake hit Gujarat, India. Its epicenter was in Bhuj of Gujarat. With a magnitude of between 7.6 and 8.1 on the Richter scale, the quake killed around 20,000 people (USGS, 2001).
[2]The city Izmir of Turkey was very badly damaged because of an earthquake with 7.6 Magnitude on August 17, 1999.The event killed around 40 to 45 thousand people (USGS, 1999)

struggle against all odds. Garbage either gathers on streets or overflows misplaced dustbins, distressing both residents and commuters. The growing population has compounded the problems, putting pressure on utility services. According to the News Network, It has now grown by 10 times. Life was easy in those days because narrow lanes were not really causing any problem. Traffic was thin and population low. Rickshaws or carts were the main vehicles of the commuters.

But population of the old city has reached two (02) millions, according to a recent study by City Survey Centre. On the other hand, facilities like development and widening of roads and smooth supply of water and power are not enhanced accordingly. As a result, lakhs of inhabitants of old Dhaka (especiallyLaxmibazar, Narinda, Dholaikhal, Tipu Sultan Road and adjoining areas) have been suffering a lot. Besides, continuous digging of roads due to uncoordinated plans of the city planners for development works adds to the miseries of the people of the old Dhaka. To meet the demand of the heavily crowded people, electricity lines have been dangerously drawn like nets. So, accidents like electrocution take place frequently.If an earthquake hit the city, it may cause heavy damage to its infrastructures and consequently the whole country may suffer.

3.5 Assessment of Earthquake Risk for Dhaka

The impact of a seismic wave will not be same for all over Dhaka. It will depend on the specific location's ground quality, individual structure's condition, and cumulative three dimensional formation of the area(Chowdhooree, 2011). From a study, Ansary (2005) identified that, an earthquake (EMS Intensity VIII) in Dhaka may lead to massive losses of life and damage to buildings. Depending on the time of the day, between 45,000 to 86,000 people may perish due to collapse and damageof structures. The numbers of serious injuries may range between 11, 0000 to 21, 0000, possibly placing a very severe strain on the emergency relief and healthcare infrastructure. Similarly, a very large number of buildings may be damaged (Ansary, 2005). The rate of vulnerability is increasing day by day because of the rise of population, expansion of urban areas and increase of the number of buildings in vulnerable locations. In another study, conducted by Comprehensive Disaster Management Programme (CDMP) under the food and disaster management ministry (from 2008 to 2009, it estimates that there will be an economic loss of about US $1,112 million for only structural damage in case of 7.5 magnitude earthquake from the Madhupur Fault.

This study also mentioned, “The Economic loss due to damage of structures will be US $ 650 million and US $ 1,075 million respectively in case of an 8-magnitude earthquake from the plate boundary-2 and in case of a 6-magnitude earthquake from under Dhaka city.”

In terms of debris collection after earthquake, this study claimed that some 30 million tonnes of debris, equal to 2, 88,000 truckloads (25 tonnes for per truck), will be generated if a 6-magnitide earthquake jolts the city from beneath of it.According to the study, at least 10 major hospitals, 90 schools in the capital will be destroyed completely and another 241 hospitals and clinics, 30 police stations and four fire stations destroyed partially in case of a 7.5 magnitude quake.

Recalling the recent earthquake that hit Haiti, it is evident that some 2,00,000 people were killed in Haiti for delayed rescue operation, which was hampered due to lack of sufficient open space. According to Prof Shamim (project manager of the Earthquake and Tsunami Preparedness Programme in Bangladesh, for Dhaka, Chittagong and Sylhet city), “A mega city needs at least 25 percent (%) open space for carrying out rescue operation with heavy equipment after any earthquake havoc. But, Dhaka city has only eight percent open space due to rapid urbanisation”. About road condition of old Dhaka, he said six to eight metre wide road is required to move heavy equipment in carrying out rescue operation. “Rescue operation will be hampered for the lack of wide road in the city,” he added (Unb, 2010).

In a workshop (held on July, 2009) on “Disaster Risk Reduction and Media”, arranged by Comprehensive Disaster Management Program (CDMP) of Bangladesh Government, the experts mentioned that, more than 200,000 buildings out of the total 350,000 in the capital city are vulnerable to earthquake. Dr. Maksud Kamal, Director of CDMP also mentioned that, the rate of engineered buildings that can withstand an earthquake of middle magnitude is 60% and only 150,000 structures out of 350,000 in the city are engineered (B.S.S., 2009).

3.6 Summary

In this chapter, it is understood that Dhaka is facing tremendous pressure of urbanization and as a result experiencing huge environmental alternation. Along with other hazard, earthquake is a potential threat for Dhaka and it has experienced historical earthquake damages. When the historical devastating earthquakes hit Dhaka, it was not densely populated and had very few buildings, at that time. But, the urban scenario has drastically changed now.

However, with rapid population growth over the past 40 years and recent repeated seismic activity during this period, the unplanned developments of the built environment in Bangladesh resulted in little resilience to earthquakes. Dhaka, the capital city of Bangladesh, acts as the focal point of all social, political, and economic activities of the country and is facing a huge pressure of urbanization. Overcrowded neighbourhood with narrow alleys, poorly constructed buildings, insufficient infrastructures, unauthorized development, insensible environmental transformation, absence of open spaces, and lack of awareness, etc. are the general characteristics of most parts of Dhaka and especially in old Part of the city. Besides, it is predicted to be waiting for a devastating earthquake at any time now.

Moreover, in our country, the practice of capacity development to become resilient gets less priority. This capacity building includes three components: risk reduction, prevention and preparedness. Risk reduction and preventive measures are the foremost task and this study focuses on these two components of capacity building regarding the issue of earthquake planning in built environment. The resilience approaches align with urban design strategies can create a model for the adaptability of the cities like Dhaka especially in old Dhaka, where it represents physical earthquake vulnerability like high population density, informal or unplanned settlements, non-engineered buildings and shelters, large number of poorly built buildings, contiguous building pattern and lack of open spaces add up to the problem. The following chapter will be discussed the morphological features and socio-economic condition of the case studied area, and assess its vulnerability for analysis.

CHAPTER 4:CASE STUDY AREA OF OLD DHAKA AND ITS EARTHQUAKE VULNERABILITY ASSESSMENT

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4.1. Selection of the case study area

According to earthquake vulnerability, the most risky zone of an urban area is that, which have organic (haphazard/ unplanned) development and high density (both population and dwelling density)(Coburn and Spence, 2002). At present, Dhaka City Corporation (DCC) has 90 wards in its jurisdiction. Among those wards, Old Dhaka and it'senclosed wards arecharacterized by high population density and high building density. In addition to that, thispart of Dhaka city is characterized by older and more vulnerable buildings and narrow road width. It will be very difficult for any mandated agency to carry out rescueoperationafter any disaster.

According to the objective, thecase study area was selected on the basis of population and building density of old Dhaka. According to the CDMP-2009 unpublished report on Structural Vulnerability of Dhaka-Chittagong city, the population density [no. /km^2] (day time and night time) and building density [no. /km^2] of different wards of old Dhaka are presented below (fig:13).

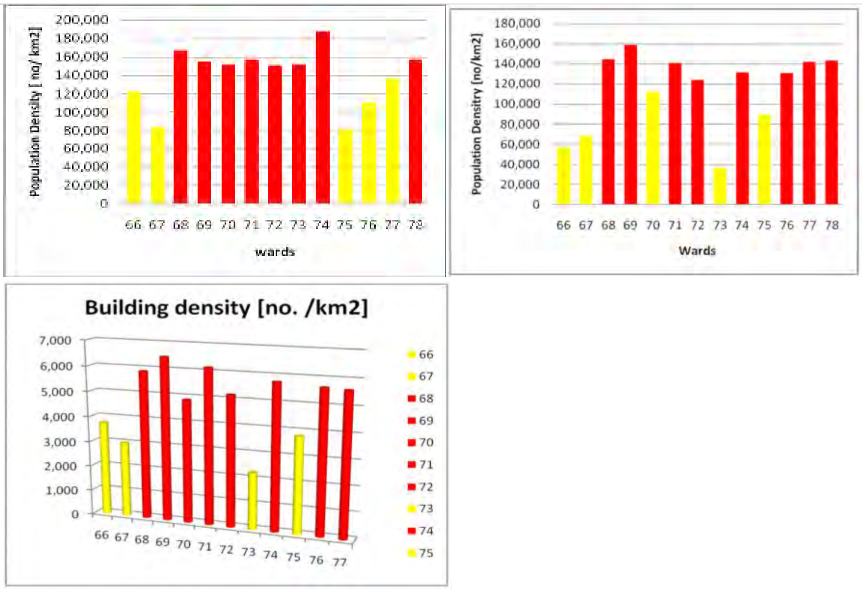


Figure 16: Population and Building density of old Dhaka (source:CDMP-2009 unpublished report on Structural Vulnerability of Dhaka-Chittagong)

Case study area has been selected from old Dhaka firstly based on administrative boundary of ward by Dhaka City Corporation, along with the highest value of population density and building density.It is evident from the figure 16 that ward number of 68, 69, 71, 72, 74 and 78 have both high value of population and building density. Among these, ward number 71 and 74 has been selected as case study area.As, this research aims in preparing accessibility network for earthquake vulnerability, so to incorporate the complete peripheral road for analysis, it was necessary to incorporate Wari, the only planned area of Old Dhaka.

This study area covers a major portion of old Dhaka. Moreover, this site is characterized by a high density of population living in a very small land area with close proximity of buildings along a very narrow local street. In most cases, it is difficult to differentiate the buildings and boundary lines from each other. This situation is very risky and vulnerable for any disaster and any small scale earthquake may worsen this situation.

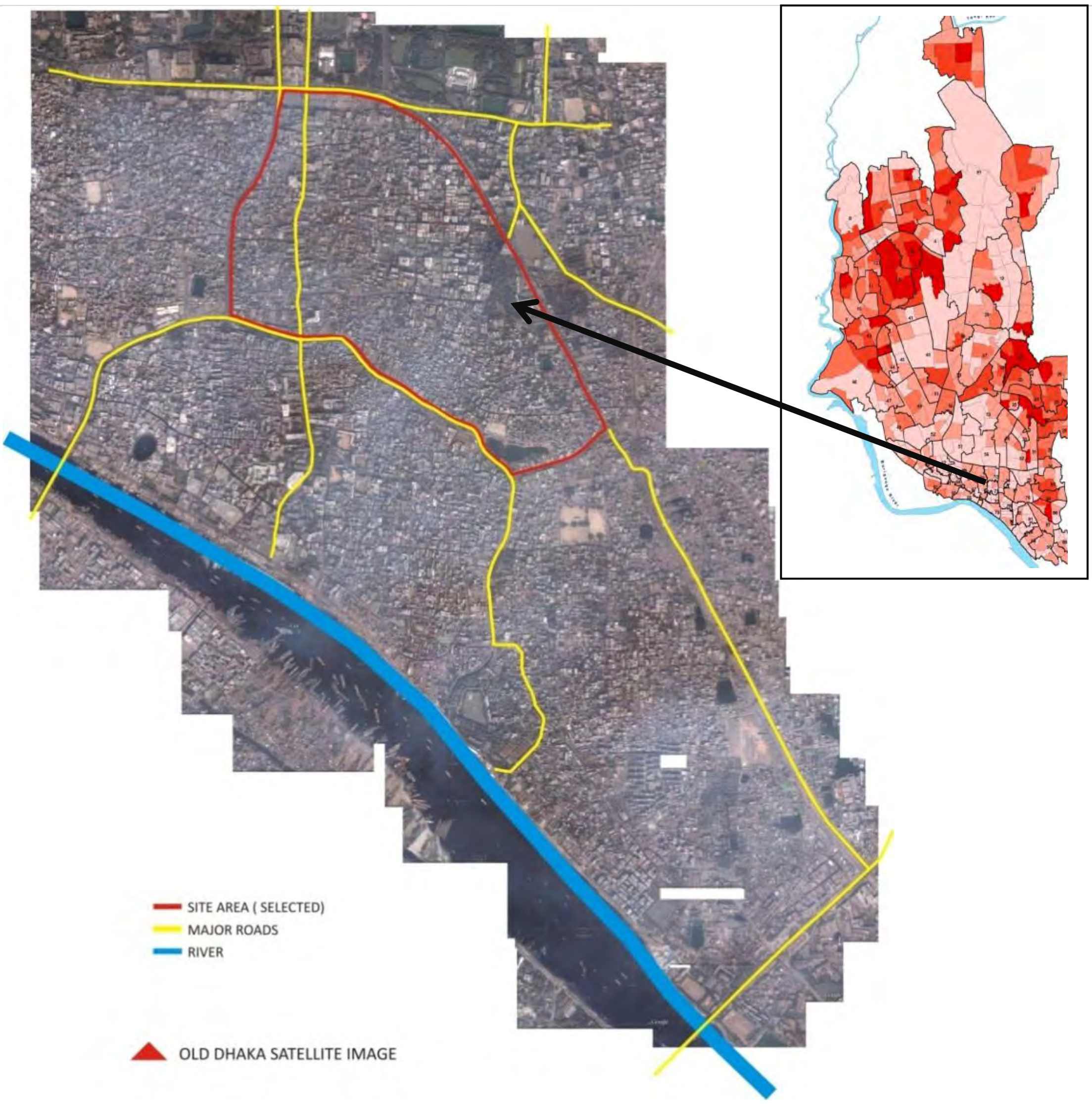


Figure 17: Case study area of Old Dhaka (source: Google Earth image)

4.2. Morphological features of the case study area

From the findings of recent study by Allan and Bryant (2010), it is clear that urban morphology is a good featurefor looking at resilience (capacity of a city to adapt): it operates on a number of scales and embraces human habitat, built form and open space in an interrelational landscape and this multiscalar contextual application is useful in earthquake response and recovery planning.

It is evident from the various writings on Dhaka thatthe areas to the east, northeast, and southeast of Babur Bazar up to the Dulairiver on the left bank (northern bank) of the Buriganga formed the old part of Dhaka city. The city of Dhaka expanded in different historical stages and experienced indigenous, formal and informal development. Outside the boundary of densely developed indigenous old city, the rest of the development is known as New Dhaka(Siddiqui, 1991). Within the spatial pattern, both Old and New Dhaka have experienced two different phases of development. Hence, among the spatial structures within this it has been observed that there are two distinct phases, Old Dhaka and New Dhaka exists side by side – one in the historic core and the other in the extemporaneous settlements of recent years – the former is commonly called the 'indigenous' and the latter is labelled as 'informal' development(Siddiqui, 1991). In old Dhaka, from the pre-Mughal period the city grew in a natural way as at that time no comprehensive attempt was undertaken to develop the city in a planned way. As a consequence, the city grew in an innate manner and the resultant form is irregular, non-geometric, organic above all indigenous with an incidence of crooked and curved streets and randomly defined open spaces. Such a process of growth in city form is generally spoken of as 'instinctive growth'. Later some planned scheme was developed but beyond the edge of old Dhaka.

4.2.1 Existing Land Use Pattern

The land use distribution pattern of the study area is evaluated based on the field survey data from the completed empirical research "Earthquake vulnerability reduction strategies for unplanned urban areas –in the context of old Dhaka" funded by Ministry of Science & Information and Communication Technology (MOSICT), Government of the People's Republic of Bangladesh. Different kind of land uses exists in the study area as residential, commercial, industrial, educational, religious, community services, service activity and mixed uses are available in this case study area. In most of the cases, two or more different types of activities are accommodated in the same floor with each activity using significant portion of the floor space. In many buildings of the old Dhaka, particularly in this study area, it is evident that there is a small market comprising eight to nine shops in the building front adjacent to a road, while in the inner part of the plot there are residential units. There are various types of light industries developed here like printing and packaging workshop, mechanical workshop, recycling industry, bakery, bottle factory, and some chemical factory, etc.

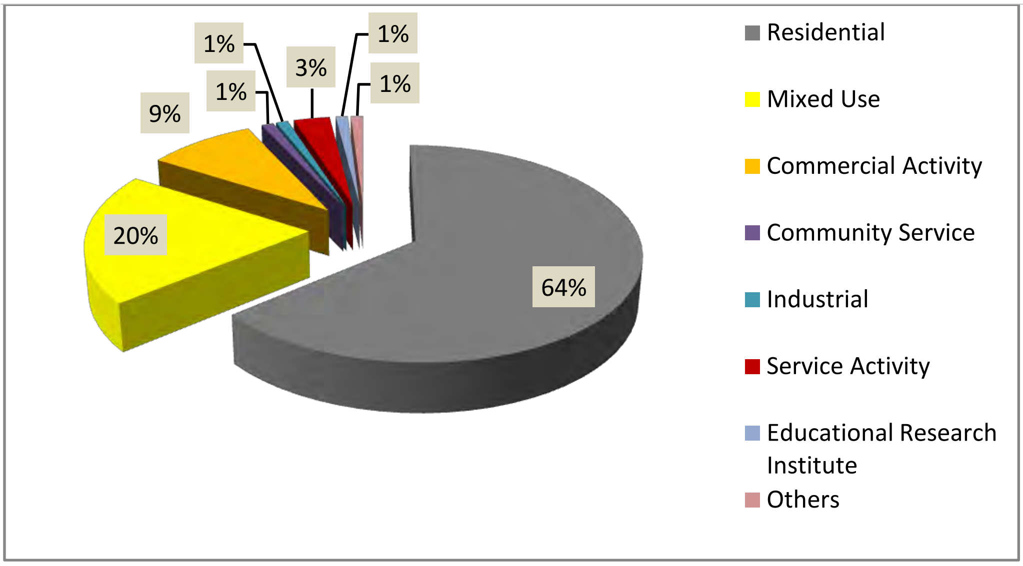


Figure 18: Land Use distribution of case study area (source: field survey and GIS map of Dhaka 2006)

It is found that residential use and mixed type land use are dominant here. Mixed use includes residential use and office; residential, market and retail shop; mosque and retail shop, etc. Service activity includes water pump house, hospital or health facility buildings, financial institution like bank and insurance office, hotel or restaurant, etc. Figure 18 shows the land use distribution in the case study area.

Scarcity of green open spaces is evident in this part of the city. From the field survey, there are forty six green spaces (different sizes) and two graveyards were found in the study area. Almost every green spaceis accumulated in one side of the case study area. The land use map and location of green open spaces (play field, park, grave yard, etc.) of the case study area has shown the distribution of these spaces (fig: 19)

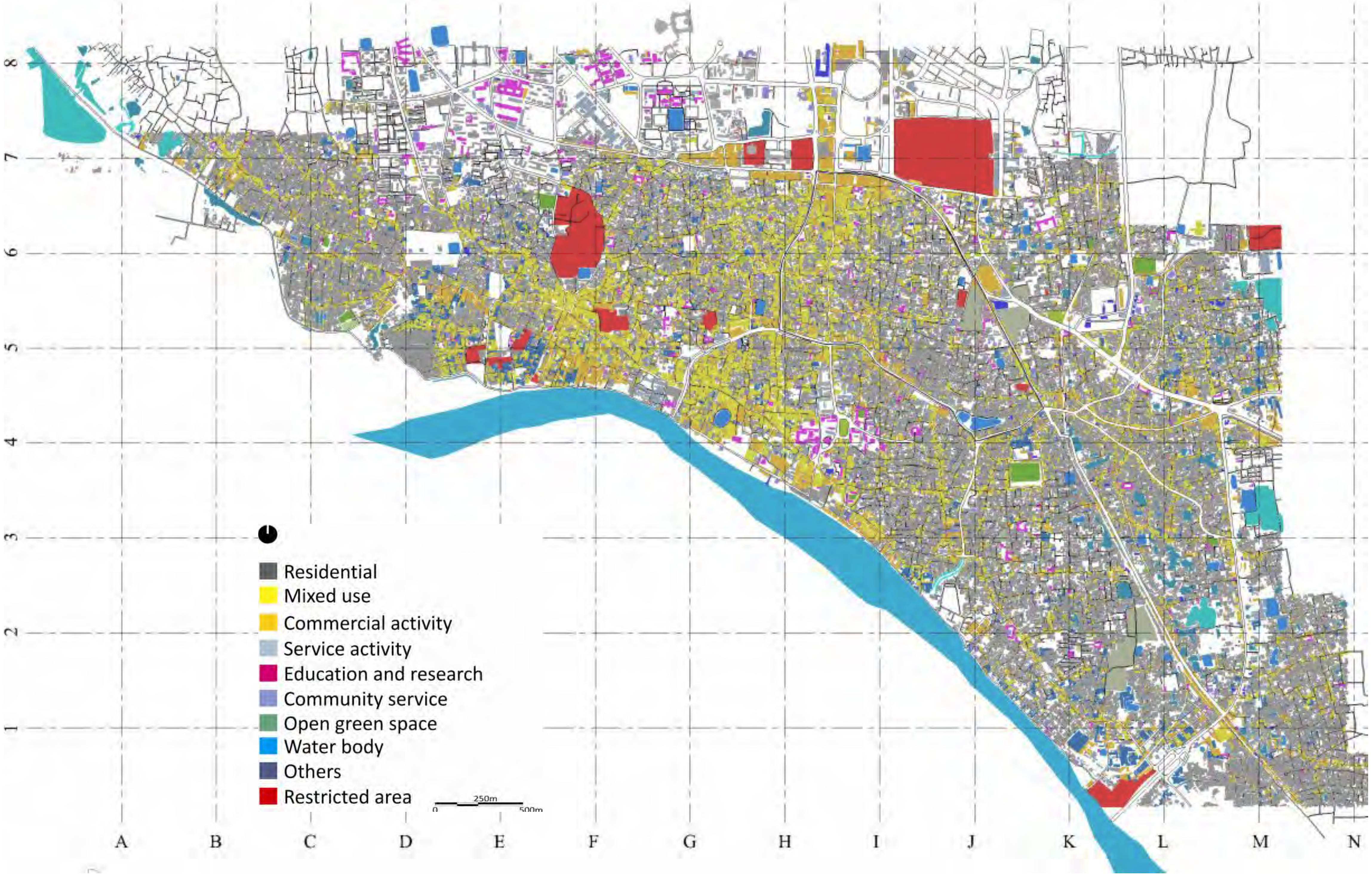


Figure 19: Land Use map of the study area and Old Dhaka (source: field survey and GIS map of Dhaka 2006)

4.2.2 Building Pattern

In old Dhaka, buildings stand only a foot away from each other, engulfing the narrow streets. These irregular shape buildings have weakened with ages and without any renovation efforts. According to field survey (MOSICT, 2010) in the case study area there are approximately 7,828 buildings and more than five hundreds of the buildings are old. Most of the buildings in this area did not follow the building construction act. Thus congested and unplanned situation is prevalent (fig: 20).Majority of them are approached by narrow alleys from its local road and the vertical circulation of the building is narrow in its size and shape. Besides this, the contiguous arrangement deprives residents from fresh air and adequate light.

Figure 20: High dense building pattern in study area

4.2.3 Buildings by Height

It is interesting to note that one storied buildings are more in number (49%) followed by two storied buildings (20%) in the study area. But in the study area six to fourteen storied buildings are also found in small percentages. Due to construction period, the number of Unreinforced Masonry (URM) structure is significant and they are most commonly one to two storied structures. Figure 21 shows the distribution of buildings according to their height.

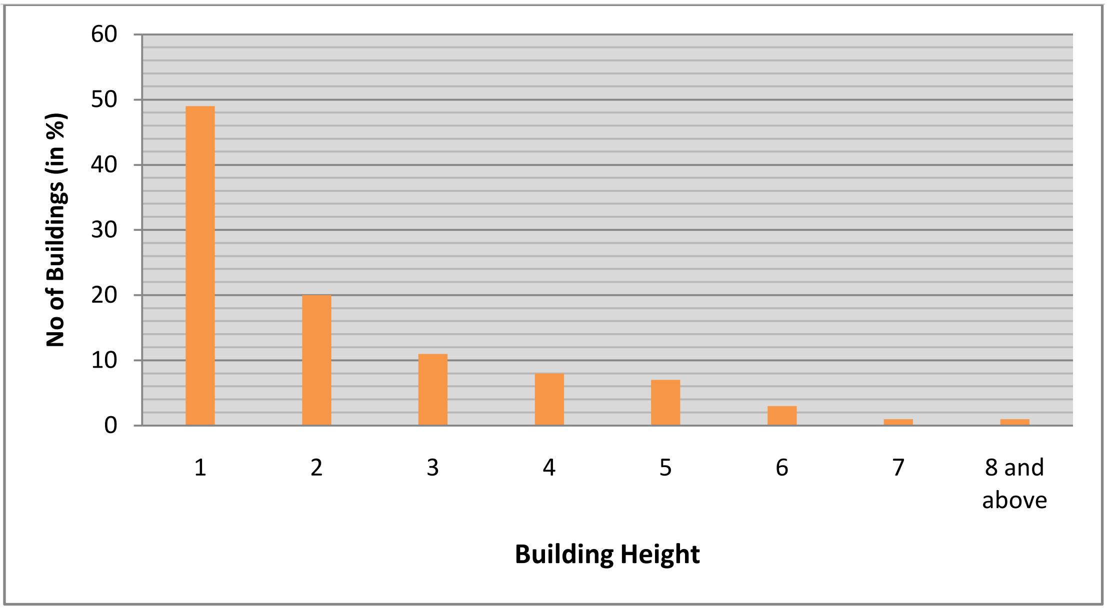


Figure 21: Distribution of Buildings according to their height

4.2.4 Street Pattern

City streets are important locus of recovery (Allan & Bryant, 2010), as their width and network layout encouraged a range of unimagined adaptive responses in historical earthquake. The streets become an important community space during and after earthquake and the width of streets can facilitate access in the event of rescue and recovery.

The historical core of the present Dhaka city, "old Dhaka" grew in an innate manner and the resultant form is irregular, non-geometric, organic above all indigenous with an incidence of crooked and curved streets and randomly defined open spaces. In Old Dhaka, streets also have turned into chawk or nodes. There was another important element in this part which is called 'Bazaar Street'. Over and above mahalla is a spatial archetype that existed in old city. In the old city of Dhaka, historically, a mahalla was created out of a few houses, which were mostly arranged linearly along the urban spaces of Bazaar Street. Morphologically in Old Dhaka, the access street was the centre of mahalla as well as the axis of urban spaces that could never be used to demarcate boundaries.

The streets and alleys are winding, narrow and connect each other in such a way that give the road network of the case study area (major part) an organic and intricate form, and small part are grid pattern especially the Wari part (fig: 22 and fig: 23). It has been found that there are a number of dark lanes (Gully) and streets with varying width at different places throughout their length. Though a considerable amount of ground space was used for the road network, still the whole road system was developed without proper plan and design (fig: 23). So, Dhaka's old part, best recognized for its antiquated buildings, time-honoured cuisine and ever-friendly residents, is also notorious for its gallingly narrow streets and slapdash traffic congestions.

Figure 22: Some of the internal alleys and streets of studied area

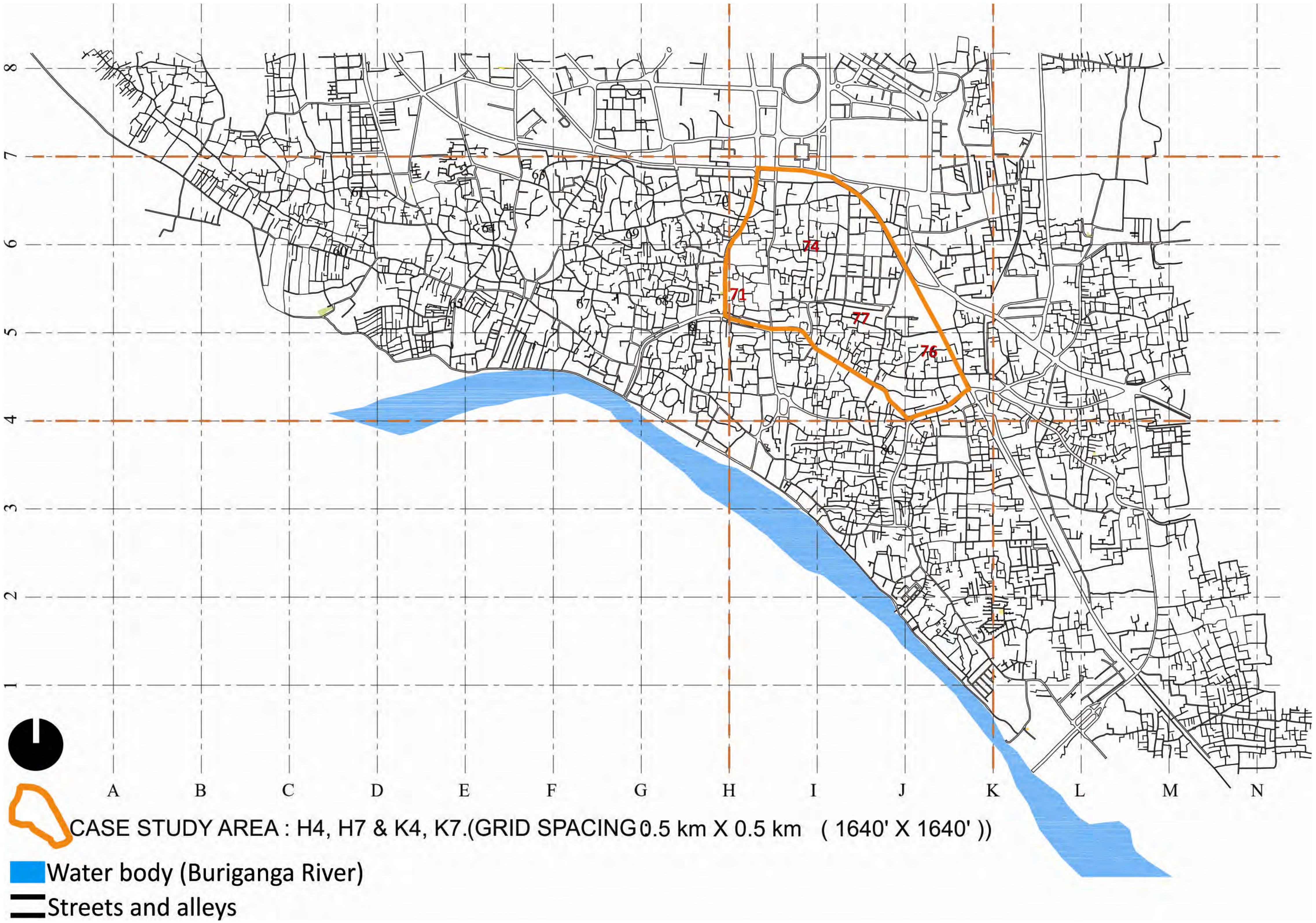


Figure 23: Street pattern of study area and Old Dhaka (source: field survey and GIS image of Dhaka 2006)

4.2.5 Open spaces (Green) pattern

Old Dhaka is being mercilessly transformed into an uninhabitable place as population increases. Lack of following building construction rules and regulation is leading to haphazard construction of buildings; which in turns is filling up all green open spaces. In last few decades, parks, playgrounds and open spaces of old Dhaka fell prey to land grabbers, illegal occupants and non-compatible development.

In case studied area, there are around 45-50 small scale green open spaces, one big park (Balda Garden) and one big graveyard (Christian cemetery)is available. But these are very few in terms of population density and unevenly distributed (fig: 24).Even many vacant spaces are encroaching by local influential people illegally.

4.3. Socio-economic Characteristics

The area evolved mainly as a business district and hence the principal occupation of most of its people is business and commerce. People, who have business there, tend to live within Old Dhaka, at or near their business place. For example, one may run his business in the ground floors of the building and live in the upper floor which is eventually his own property. The second important occupation in terms of number of people engaged is

service. Low income people in the Jhupris (slums and squatters) and middle income people in the buildings coexist here side by side. The low income people are engaged in various professions ranging from day labourer to rickshaw puller, hawkers, industrial workers etc.

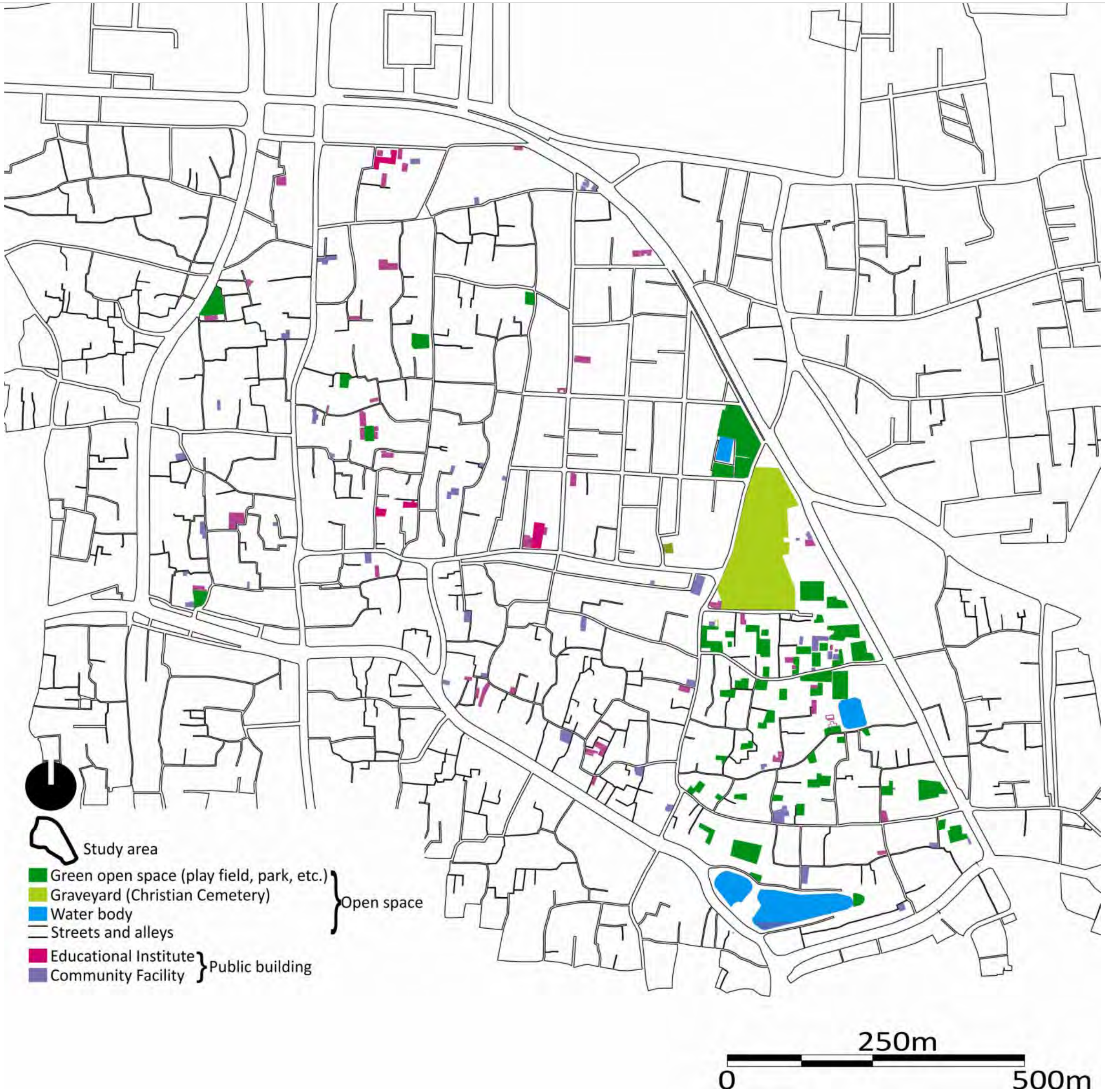


Figure 24: open spaces and Public buildings in study area (source: field survey)

4.4. Community Facilities

In the study area there are various types of community facilities. The adjoining wards are inseparably correlated and inter-dependent on each other for functional purpose. The study area has health facilities like clinics; diagnostic centers; community centers; training institutes; religious structures; and primary and high schools (fig:24). People from other adjoining wards use these community facilities also. The business and commercial activities of different wards are interrelated in terms of availability of raw materials, supply of goods, labor and other supplementary facilities. In this way, the wards of Old Dhaka are inter-related and inter-dependent entities rather than self-contained units in the city. Fire service facility is not available in the study area.

4.5. Earthquake Vulnerability Assessment

For earthquake vulnerability assessment data collection is very important. In this research, GIS image of Dhaka (2006), Google Earth archive, field survey data, secondary source, and 3D visualization technique was used to develop weighted social and biophysical indicators associated with urban vulnerability at this area (fig: 25). Urban earthquake vulnerabilities are assessed using: 1) population growth and urban density-intensification; 2) building density and contiguous character; 3) available open spaces; 4) emergency vehicle accessibility to residential houses; and 5) poor lifeline facilities

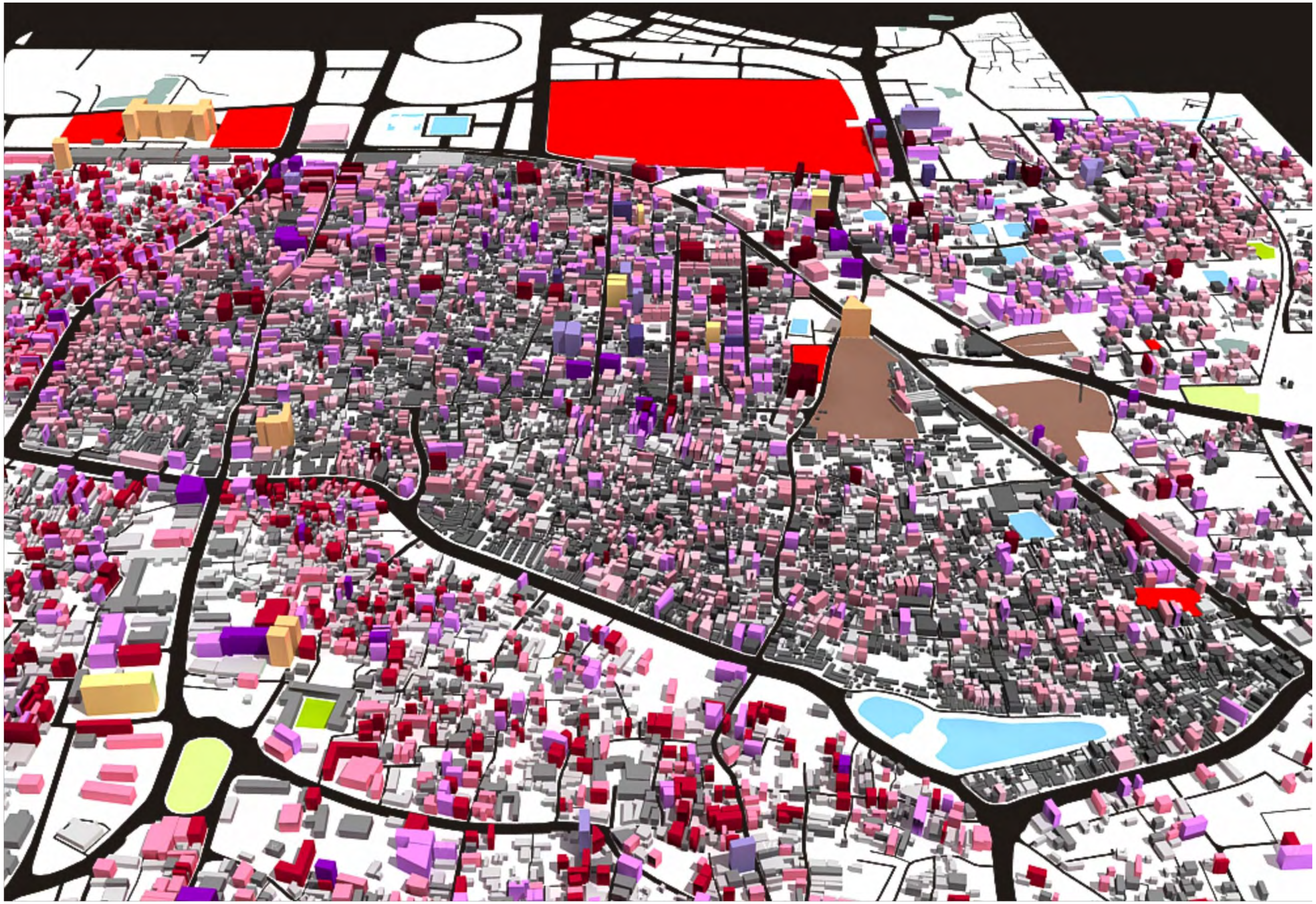


Figure 25: 3D Visualization of study area for vulnerability assessment

4.5.1 Population Growth and Urban Density-Intensification

The population of Old Dhaka has increased manifold. The population density of old Dhaka is much higher than any other part of our country. In old Dhaka, the population density is apparently 150,000 per Km^2(Hillary, 2006). Where, according to UN report the maximum desirable population density in urban areas is apparently 40,000 per Km^2. These trends of rapid urbanization in old Dhaka have exposed high percentage of the population to vulnerable situation in the event of an earthquake. At the moment, a guesstimate is that one third of the population there is constituted by people coming from other districts.This increase in population has in-filled many open areas in the already-emerging “concrete jungle” of the Old Dhaka increasing the vulnerabilities of many urban areas of Dhaka city. To make matters worse, new houses are continued to be built on any available space. Like other parts of Old Dhaka, the study area is highly dense and congested locality. The population number varies with respect to day time and night time, which is evident in the section 4.1.

4.5.2 Building Density and Contiguous Character

In Old Dhaka, large number of population is living in a very compact land area with close proximity of buildings along very narrow local street. As a result, people live in overcrowded and often dangerous situation. In many cases congested buildings are sharing the side walls even though they are in different heights. The differences in the building (the floor) heights, materials and construction technology in new constructions, are likely to produce a “pounding effect” vis-à-vis adjacent houses in the event of an earthquake. It is evident from the Google image, GIS map and 3d visualization image of the case study area that building density is very high and most of the cases, it is almost difficult to differentiate blocks from each other (fig: 26 and fig: 27).

Figure 26: contiguous character of buildings in studied area

Figure 27: Contiguous building pattern in study area (source: Google Earth)

4.5.3 Availability of Open Spaces and shelters (Public buildings)

Each household needs some open space for a healthy environment and an escape-route for safety in the event of a disaster. An open space is defined as the ratio of circulation area divided by the total area that is specific to cultures and places.Caminos and Goehert(Gomez, 2001)recommended an open area of 150 m^2 per 10,000 m^2 of built-up area, while the World Bank housing project recommends 20 to 25% open space for a built-up area. For the safety of an individual, a 2 m^2 space is needed. In general, 5-10% open space is needed for housing purposes; however, the unplanned housing schemes in the Kathmandu urban areas leave few open spaces producing conditions far below any Western standards(Bhattarai & Conway, 2010). Even in Manhattan, New York, an average of 19.2 m^2 of natural area is available for each skyscraper; in London, the number is 30.4 $m^2$for each building accounting for the city's surrounding Green-belt spaces; in Paris, it is 12.2 m^2; and in Tokyo, it is 2.1 m^2 (Ojima, 1996).

These aforementioned numerical values of "open space", however, may not be the best measures when evaluating "accessibility" and its efficiency and cost- effectiveness as it pertains to a metropolitan area's housing growth and development. For example, only 12-16% open spaces are maintained in Singapore, but all houses are accessible by emergency vehicles. Nonetheless, for cities like Dhaka especially Old Dhaka to serve 2- to 4-story spontaneous and congested housing growth, sufficient open spaces are needed to rescue people from possible seismic vulnerabilities.A detailed analysis of the case study area of old Dhaka from the Googleand GIS images of 2006, and field survey data reveal that it is difficult to meet this goal given the diminishing number of open spaces resulting from the infilling of housing in small open spaces(Fig: 28). Study area has 13.87% (34.006 acres) open space.

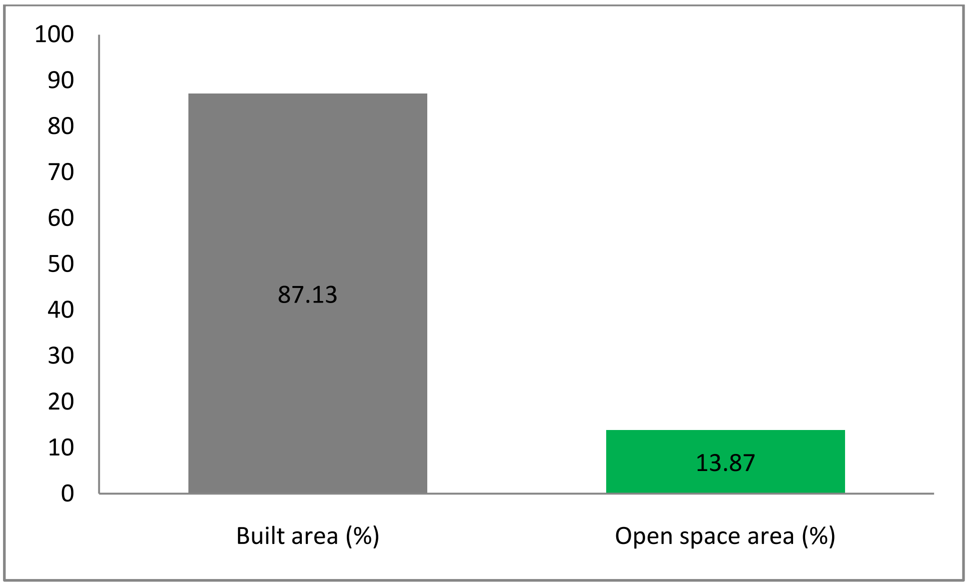


Figure 28: Built form and open space ratio in study area (source: GIS image of Dhaka 2006 and field survey)

Additionally, the loss of open spaces and vegetation due to conversions into sub-standard buildings, has not only hindered vehicular accessibility to houses of this area, but also has made the living standards very low. In addition, existing open spaces of study area are not well connected (network) in terms of a big disaster like earthquake or fire hazard, where rescue and recovery is important. Before filling up the rest of open spaces, it should be preserved and planed for the betterment of the locality through a proper networking. In addition, during disaster public buildings (educational institutes, religious buildings, community centres, fire stations, hospitals and clinics, etc.) may be used as emergency shelters. Study area has more open space than Singapore, Hong Kong or Tokyo but it is not strategically located and well connected. That's why, they should be structurally sound for the earthquake and they must be connected with the emergency open space network.

4.5.4 Road Accessibilities

For good connectivity and the movement of people and goods, both within urban areas and between urban centres and hinterlands, effective transportation networks are essential. However, narrow streets and cul-de-sacs limit vehicular accessibility to individual houses.

From road width analysis (fig: 29 and fig: 30) of the study area by field survey, the narrow streets (<2.5 metres) and sturdy boundary walls erected for security reasons are posing problems of accessibility. Also, many of streets are so narrow that ambulances or fire fighting vehicles find it extremely difficult to approach the place of occurrence for any rescue operation. That is what happened in the Nimtoli fire incident in old Dhaka on the night of June 3, 2010. Another important feature about the street pattern of the area is that there is no segregation of pedestrian and vehicular traffic within the area and most other places of the Old Dhaka as well by providing footpaths and over bridges. One more thing to bring into light is that the area accommodates quite a sizeable amount of wholesale and retail business activities and heavy traffic must be able to pass through the area and park for loading and unloading goods. There is only few provision of space for loading and unloading facilities. Trucks and lorries use the road space during the day for movement and parking for loading and unloading adding to the problem of traffic congestion. No public transport is serving the area at present and neither it is possible to allow such public transport within the area to meet the need of movement of local people.

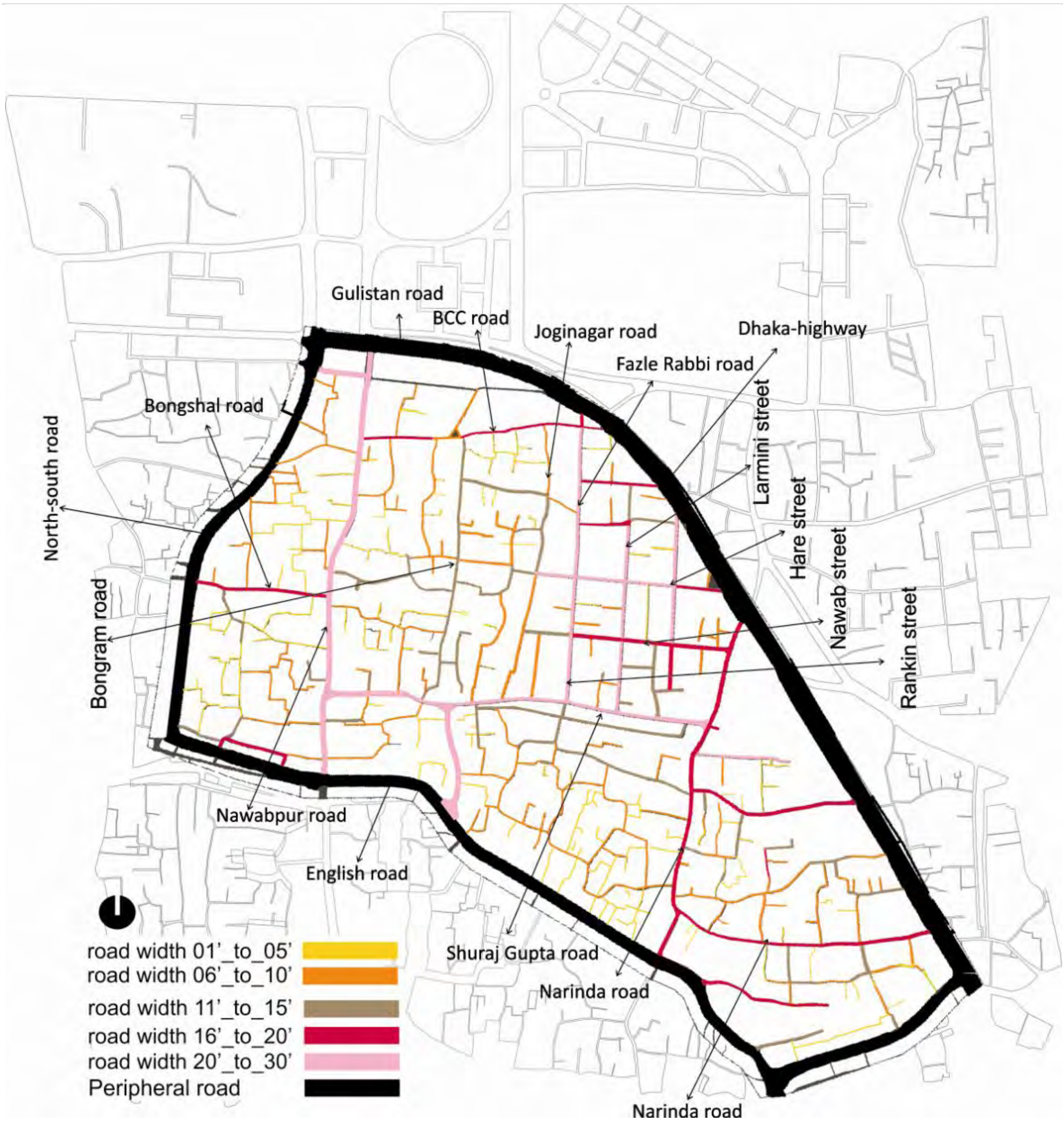
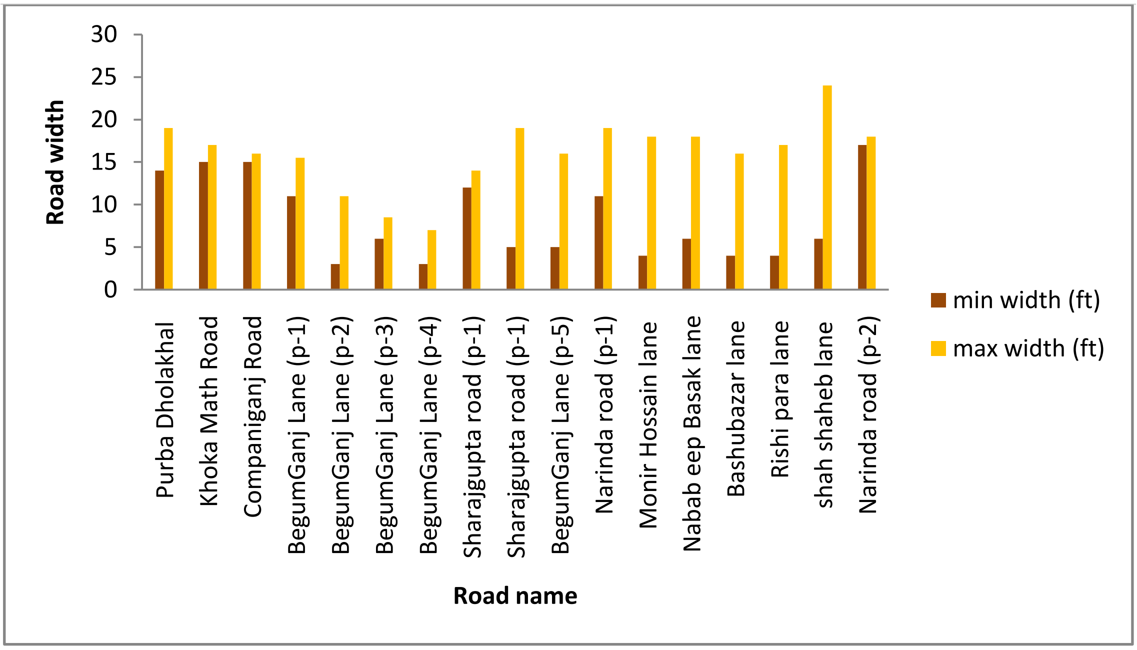
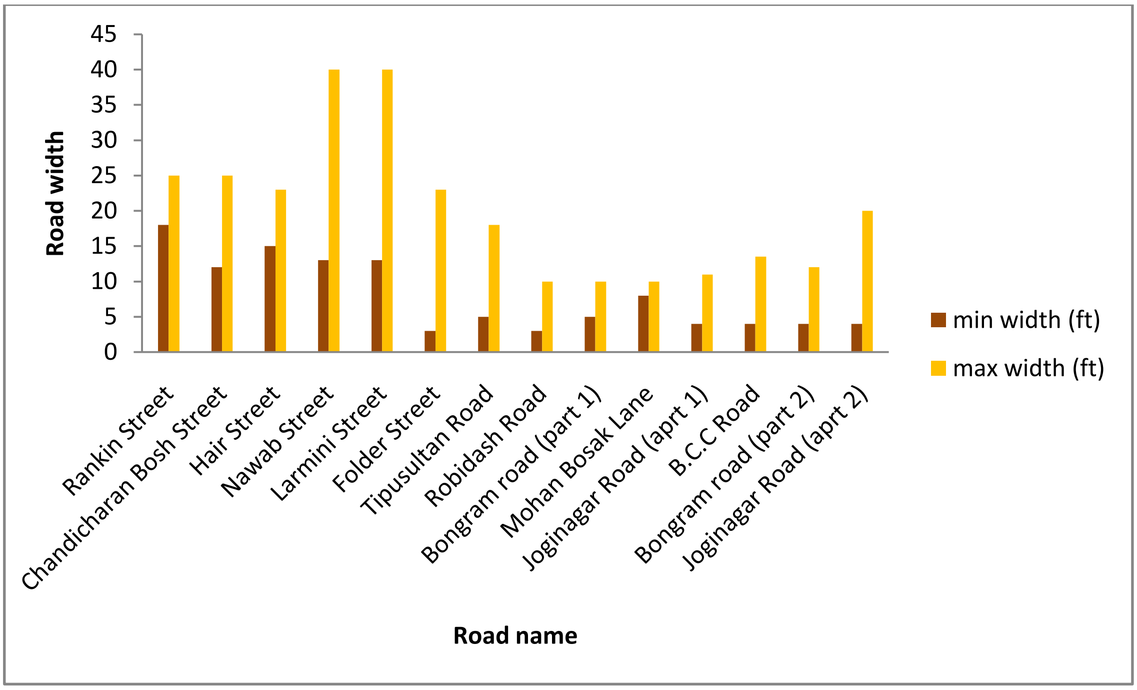


Figure 29: Road width analysis of case study area (source: GIS image of Dhaka 2006 and field survey)


Road width
30
25
20
15
10
5
0
Purba Dholakhal
Khoka Math Road
Companiganj Road
BegumGanj Lane (p-1)
BegumGanj Lane (p-2)
BegumGanj Lane (p-3)
BegumGanj Lane (p-4)
Sharajgupta road (p-1)
Sharajgupta road (p-1)
BegumGanj Lane (p-5)
Narinda road (p-1)
Monir Hossain lane
Nabab eep Basak lane
Bashubazar lane
Rishi para lane
shah shaheb lane
Narinda road (p-2)
Road name
min width (ft)
max width (ft)


Road width
45
40
35
30
25
20
15
10
5
0
Rankin Street
Chandicharan Bosh Street
Hair Street
Nawab Street
Larmini Street
Folder Street
Tipusultan Road
Robidash Road
Bongram road (part 1)
Mohan Bosak Lane
Joginagar Road (aprt 1)
B.C.C Road
Bongram road (part 2)
Joginagar Road (aprt 2)
Road name
min width (ft)
max width (ft)

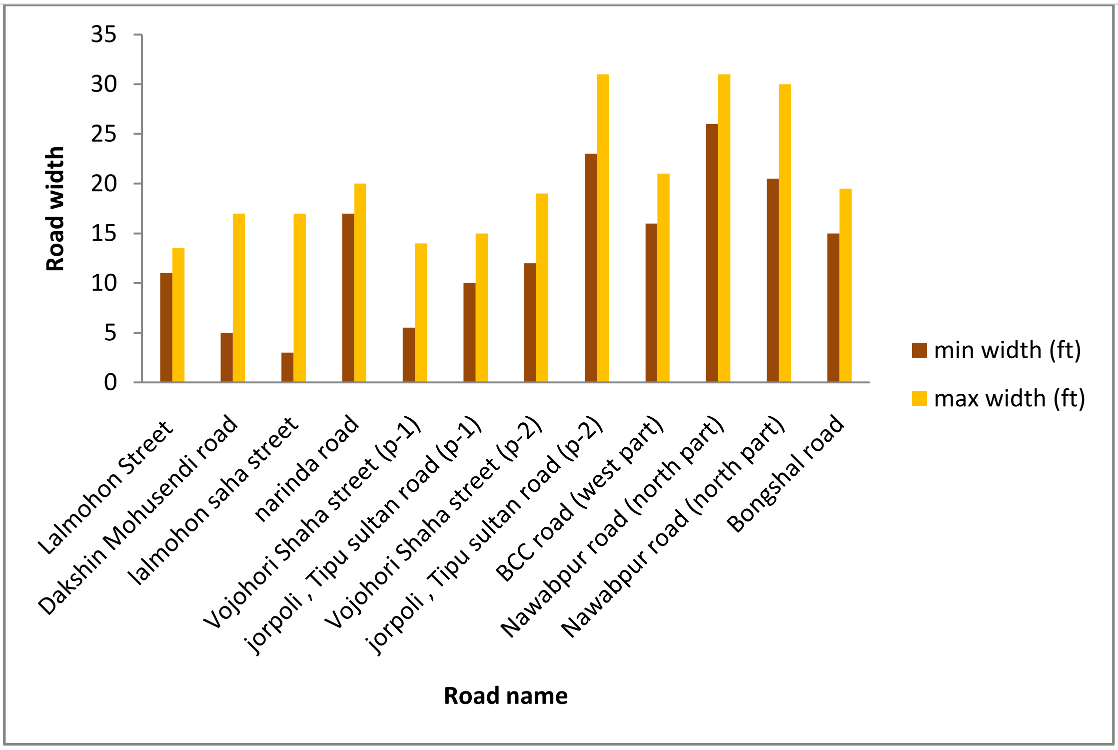


Figure 30: Charts showing that maximum and minimum road width of important road of study area (source: field survey)

4.5.5 Condition of Lifeline Facilities

Infrastructure and utility services are key sectors that are vulnerable to earthquake and its impacts. The limited performance of these sectors during and after earthquake increases the vulnerability of city dwellers, and this vulnerability varies according to economic and social status, and it is evident from the previous historical earthquakes. Water supply, sanitation, solid waste management, sewage management, electricity and gas supplies, and telecommunications all suffer damage as a result of earthquake.

The old part of Dhaka City is sinking under weight of its problems. The growing population has compounded the problems, putting pressure on utility services. The utility services and facilities were installed long ago in this study area. The capacity of the utility services is short by far than required by the existing population. These service facilities face age related deterioration and require replacement and repair. The electricity lines and telephone lines hanging overhead create jumble of wires and pilferage is a common problem. Many areas of the study area are home to very unhygienic conditions due to broken and damaged sewerage lines(fig: 31).

Figure 31: poor quality utility services of study area

Road transportation and communication become slow and risky due to broken manholes or sewerage lines. Due to very high density of buildings, and very irregular pattern of roads, it is very difficult to design and lay down utility lines properly. Moreover, lack of vacant space in between building and road space, the coverage of underground utility network cannot be extended to all buildings. As the building density is very high, the risk of electrification and fire hazards is very high in case of any accident. So, this study area of Old Dhaka becomes more vulnerable to any disaster because of its weak structures and poor service utility.

4.6. Summary

In this chapter, the earthquake urban vulnerability in the Old Dhaka due to physical events (seismic hazards) and societal conditions (substandard dwelling and unplanned layouts) has been identified and addressed accordingly. Moreover, a general picture of the study area with its physical and socio-economic condition related to urban earthquake vulnerabilities, and the vulnerabilities in the study area resulting from unplanned developments with irregular, substandard, and inaccessible (by emergency vehicles) building patterns, and poor quality utility services has drawn. This chapter also assessed the character of open spaces and their availabity in the study area, because a vast amount of open spaces and their networking characters not only enhance the quality of everyday urban life, but also contribute to the community resilience and facilitate rescue and recovery in the event of earthquake. After these vulnerability assessments, the following chapter will discussed the analysis and findings for the studied area.

CHAPTER 5: ANALYSIS AND FINDINGS

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5.1. Introduction

Evaluation of natural movement in the high dense informal settlements becomes a crucial issue in terms of disaster management. Safe evacuation for less casualties, and access for sound rescue and recovery, now reveal as the two major aspects of the security of people in a disaster core.As well, definition of cognitive properties of the urban spaces may help the casualty reduction after any disaster(Sari and kubat, 2012). According to the Johnson (2005), these urban spaces are a critical issue and a dominant factor in simulating outdoor evacuation and accessibility network for recovery planning. That's why; this analysis presents an approach to the improvement of informal settlements of urban areas through limited physical interventions. The main argument in this research is that successful integration of recovery and evacuation planning, and urban design; which illustrates city's open spaces as a 'second city': a network of open spaces, that designed not only to contribute significantly to the quality of everyday urban life, but with the latent capacity to act as essential life support and an agent of recovery in the event of an earthquake or any other disaster. Besides open space network evaluation, this study also evaluated the location of public buildings (Emergency shelters) into the network.

The chapter is divided in two parts. The first part proposed a macro level analysis of study area of old Dhaka, which illustrates the methodology for open space network. This part of the study will discuss the triangulation analysis. And, the second part discusses the micro level analysis of case study area. This part of the study is to demonstrate what the spatial solution look like; how the micro scale space type is designed in further detail.

5.2. Macro level analysis of case study area

5.2.1 Proposed triangulation analysis

Spatial configuration in urban spaces affects pedestrian's andvehicle's mobility movement (Hillier et al., 2007). Understanding their potential location is an advantage for open space network analysis. Instead of starting from a virtual or random distribution of people during evacuation and rescue that leads to less reliable results; the triangulation of space syntax, field survey and GIS (Geographic Information System) gives an adequate starting pointwhich can be used as a weighting factor for each part in urban spaces in the simulation model (fig: 29). The first method examines the spatial configuration of the selected urban space using a space syntax method. It applies different metric radii analysis to demonstrate time/distance factors. The second method analyses the current situation using a field survey and movement density pattern. This system depends on monitoring all potential exits in the selected urban spaces through various times. Basically, this systemcounts people and vehicles to select the peak movement data. But, due to the narrow street pattern, this study counted only people movements of the case study area. The gathered data are compared with the simulated evacuee'spotential movements to verify the degree of correlation between the real data and the model's results. From the field survey road width data will be layered with the syntactic layer. The third process aggregates all the gathered data into GIS datasets for exploring different networking scenarios under various conditions. This triangulation analysis is a part of the proposed model framework; see fig: 32, which includes social, physical and environmental aspects.

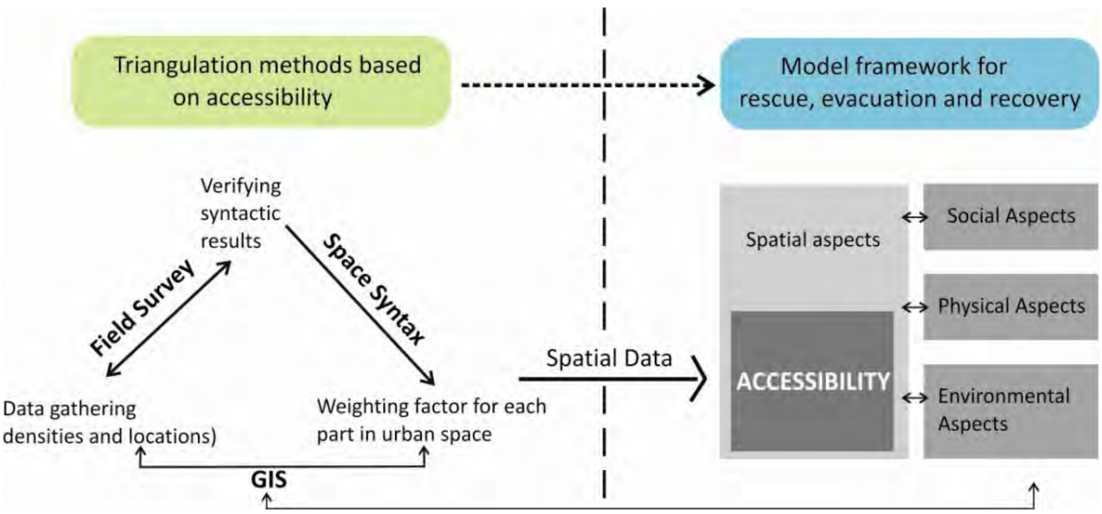


Figure 32: Triangulation methods based on accessibility as a starting point for any evacuation, rescue and recovery model (on the left), and a suggestion to be used in the suggested model framework (source: After Mohareb, 2009a)

5.2.2 Strategic Planning Framework

The process begins with a series of spatial analyses. This initial phase of analyses and modification is repeated over several rounds to generate an optimum route structure of case study area of old Dhaka. After that, analyses of the evacuee's pedestrian movement density and route width hierarchies with spatial analysis, toassist further guidelines in the final open space network or route design network. The spatial design is further continued by specific planning for land use and building density, building height, location of shelters (public buildings and open green spaces)and other planning issues. Giving each layer (sub-aspect) a weighting factor in the GIS data sets, the proposed comprehensive framework determines how the new spatial structure of case study area will function, during and after disaster. This process links design and analysis through a reiterative process that can be applied not only to the unplanned areas of old Dhaka, but any other similar cases in other cities of Bangladesh. There are four aspects framing the model framework:

- Spatial aspects, which include the accessibility factor;
- Social aspects; e.g. type of movement (walking/running and riding), Degree of familiarity (local user and global user), Cultural background, etc.
- Physical aspects; e.g. urban morphology (space envelope, building blocks, building's height, building's condition, block size, buildings frontages, route's width, etc.) and type of spaces (enclosed and open spaces)
- Environmental aspects; season, wind direction, day-time/ night-time, fog, etc.

The spatial aspects are analysed using space syntax software (Depthmap8) and the data is layered with GIS layer of case study area and its surrounding buffer zone. While the other aspects, their data are gathered and analysed by the GIS layer map. In this study, type of movement (walking) and degree of familiarity (both local and global users) are used as social aspects; urban morphological features (building blocks, building's height, block size, route's width, and topography) and type of spaces (open space and enclosed space) are used as physical aspects.Finally, daytime and night time is used as environmental aspects. These factors are stimuli factors, adding as a weighting measurement to select the appropriate open space network and create a base for design intervention at selected vulnerable area. Due to time limitation, other factors are not weighted in this research.

5.2.3 Route Selection Strategy: Space Syntax Analysis

The first step of triangulation approach is verifying the space syntax analyses, which illustrates the strategies for open space networking. To secure human safety during disaster, emergency road network ensure an initialstep for the city dwellers. From the

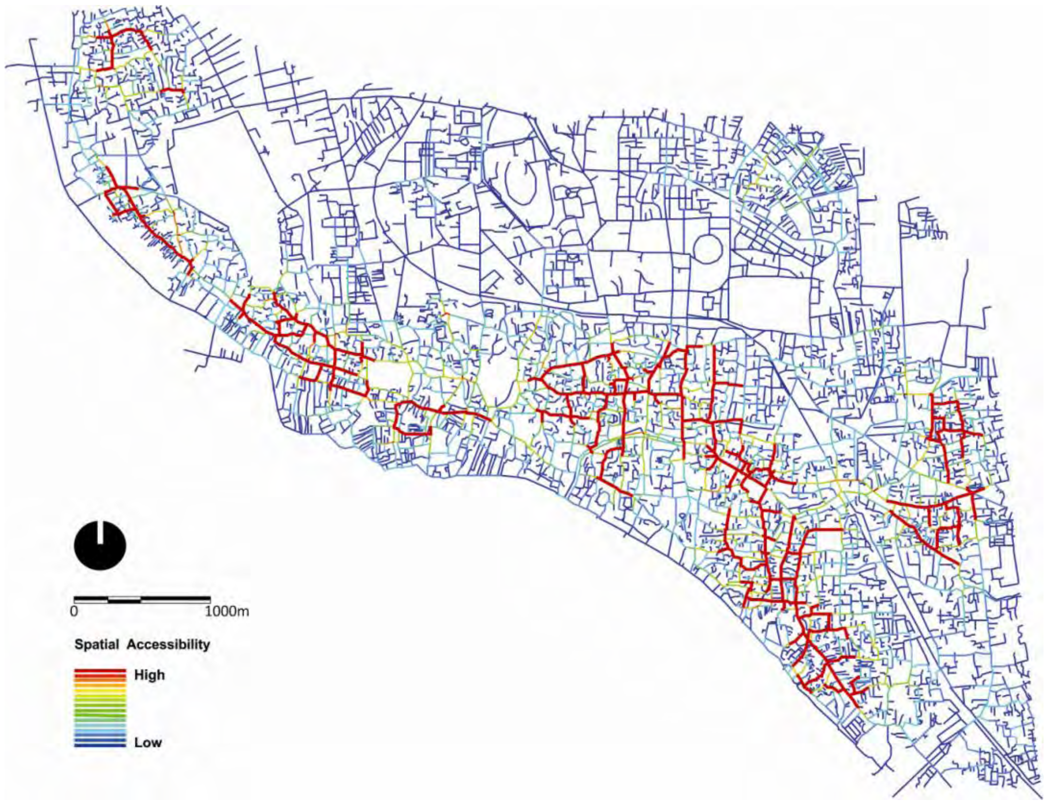


Figure 33: Segment choice analysis of Old Dhaka, local choice (above) and global choice (below)

spatial diagnosis of the study of informal settlements of old Dhaka, there seems to be a break in the hierarchy when moving from the global to the intermediary, and finally to the local scales of the urban network. This gap is clear from the analysis of the segment angular choice of old Dhaka in space syntax technique, where the cores of informal settlements are highlighted as highly accessible at the local scales, but not at the global scale as illustrated in figure 33.The suggested methodology, therefore, attempts to identify the inconsistent points of a network. The basic requirement is to define a criterion that selects street segments with high angular choice value in different metric radii (i.e. global, intermediary and local scales). The output will be used as a base for identifying the potential open space or street network and its weak points, and solutions to fix them (e.g. road widening, intervention building removal or just improving the quality of the existing road). A statistical method was utilized to filter the routes that have the highest values in angular choice at each level of metric radii (i.e. from local to global). In effect, five levels of analysis are used from the local to the global including the following radii: 500 and 1,000 meters (the local level) (fig: 34), 1,500 meters (intermediate level) (fig: 35), and infinity and 2,500 meters (the global level) (fig: 36). The aim here is to use the extracted routes at each level of radii to get a clear picture of the inconsistencies of the street network(fig: 37).

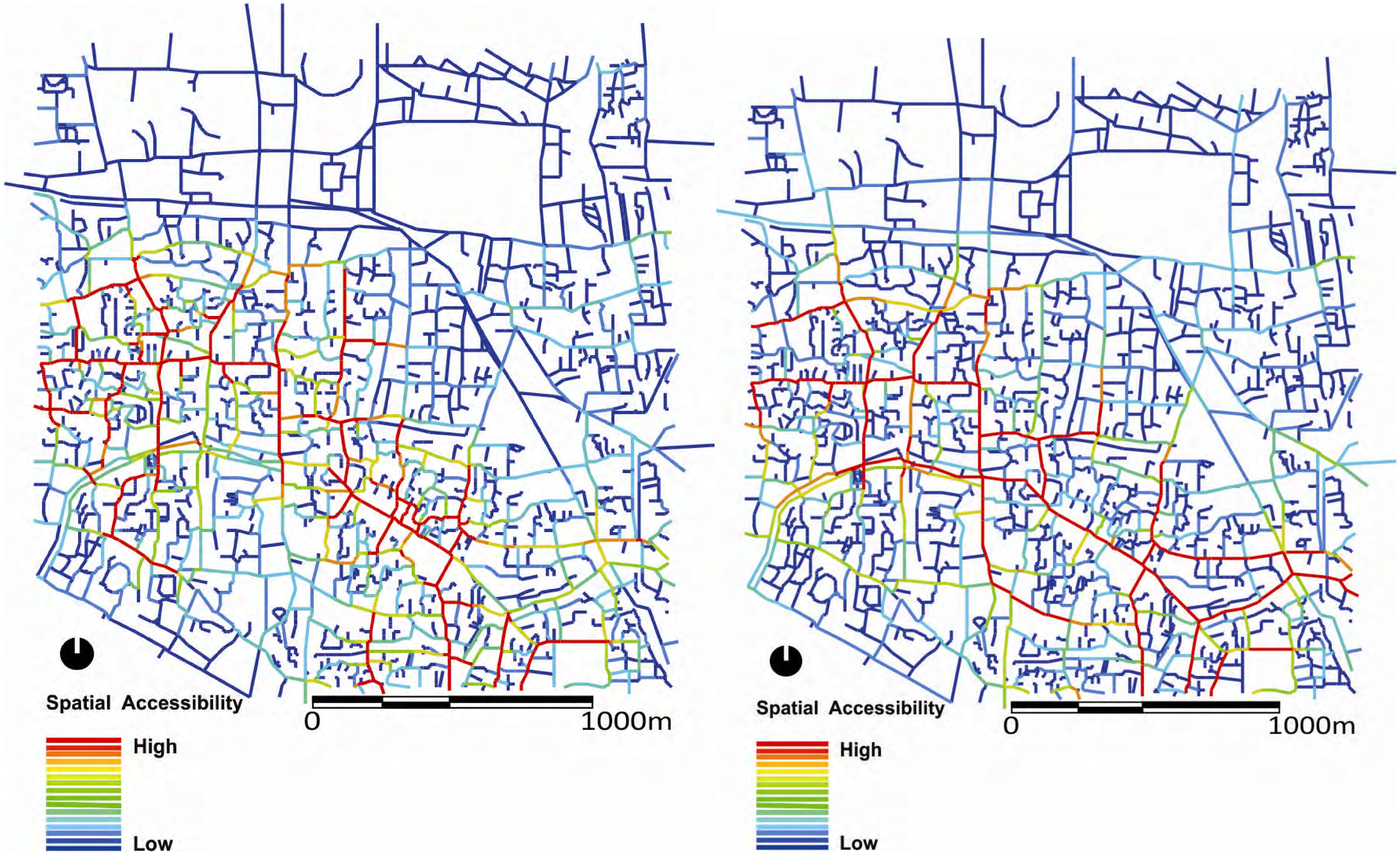


Figure 34: Choice analysis at local level (500 and 1,000 meters)

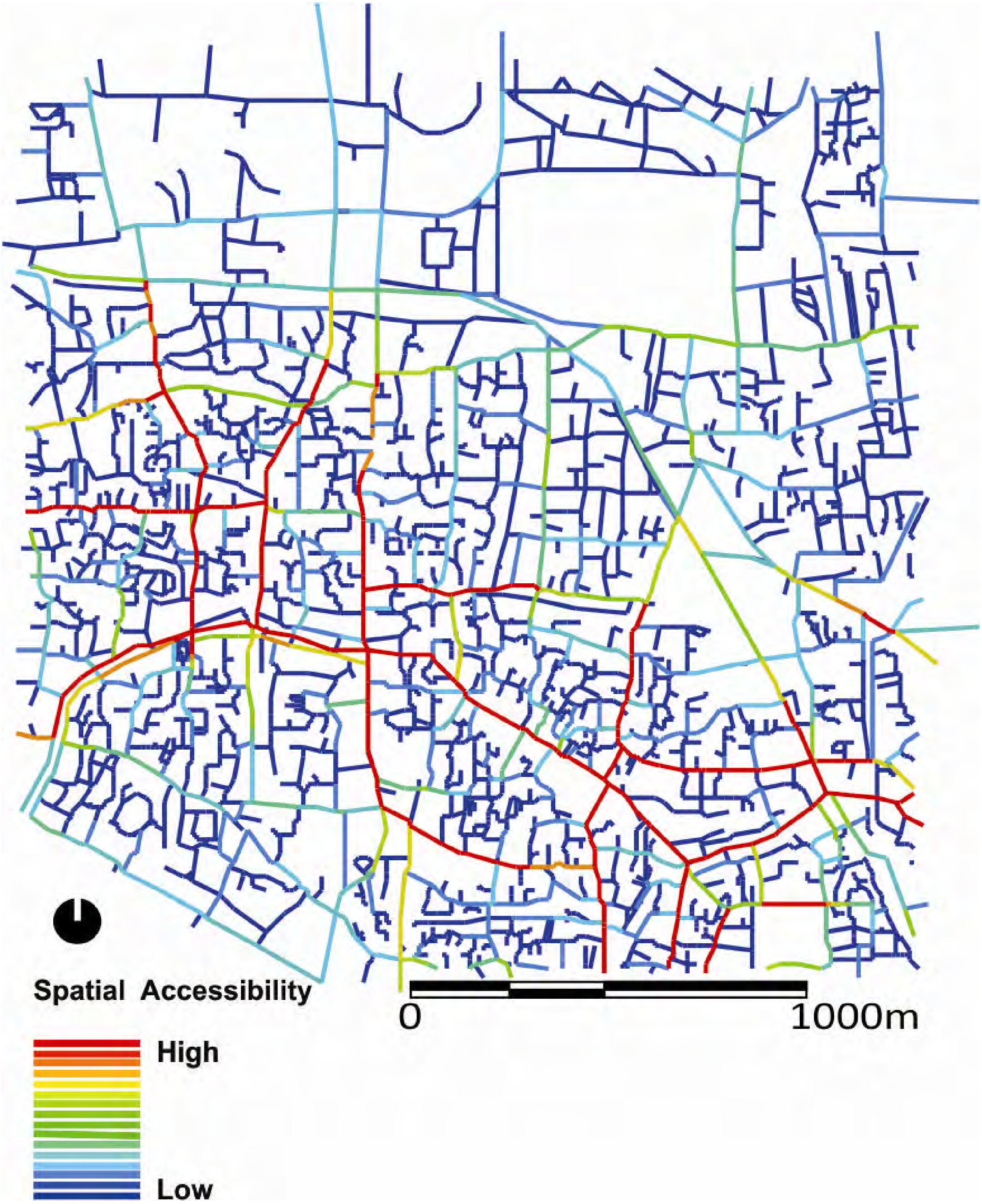


Figure 35: Choice analysis at intermediate level (1,500 meters)

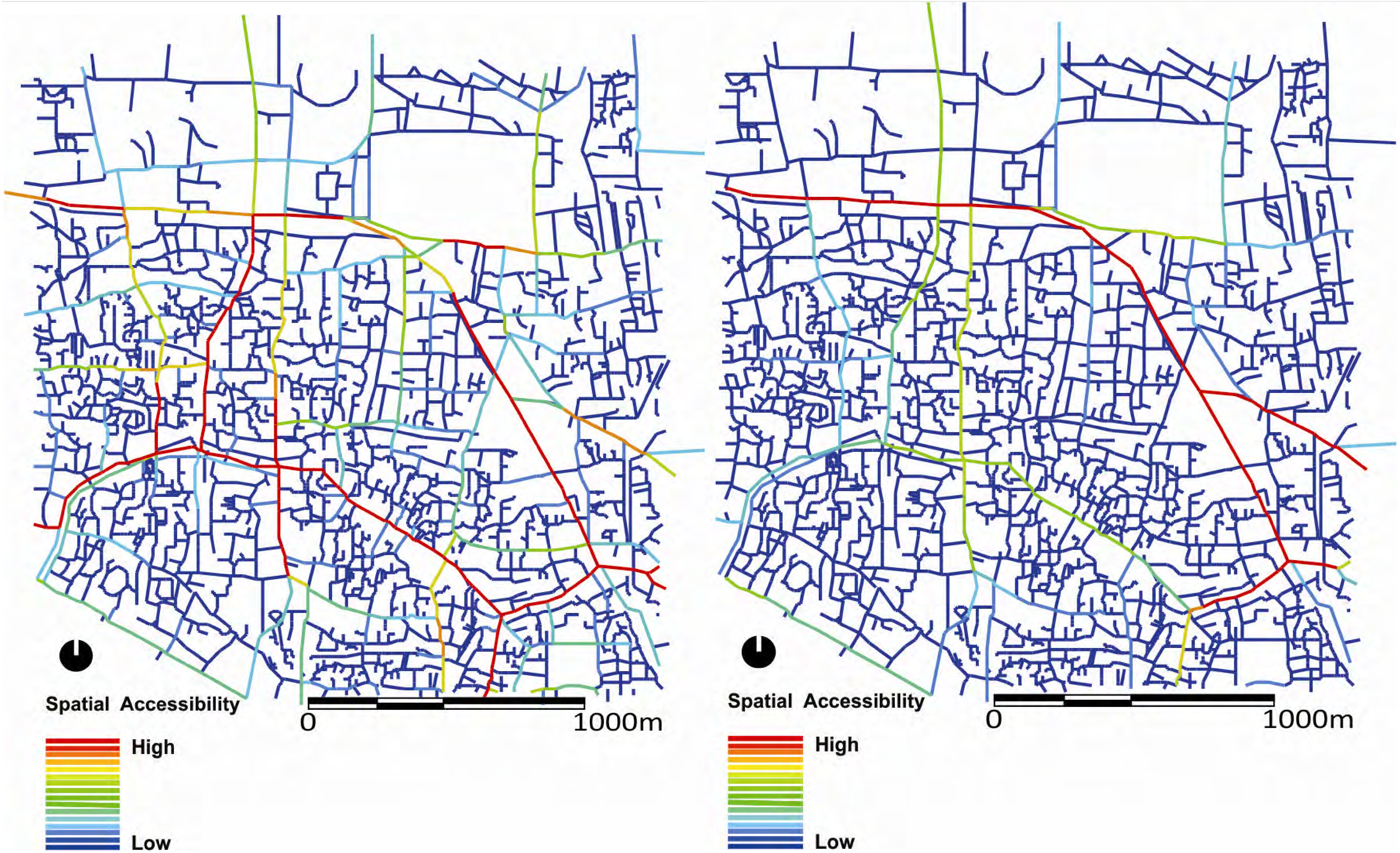


Figure 36: Choice analysis at global level (2,500 meters and infinity)

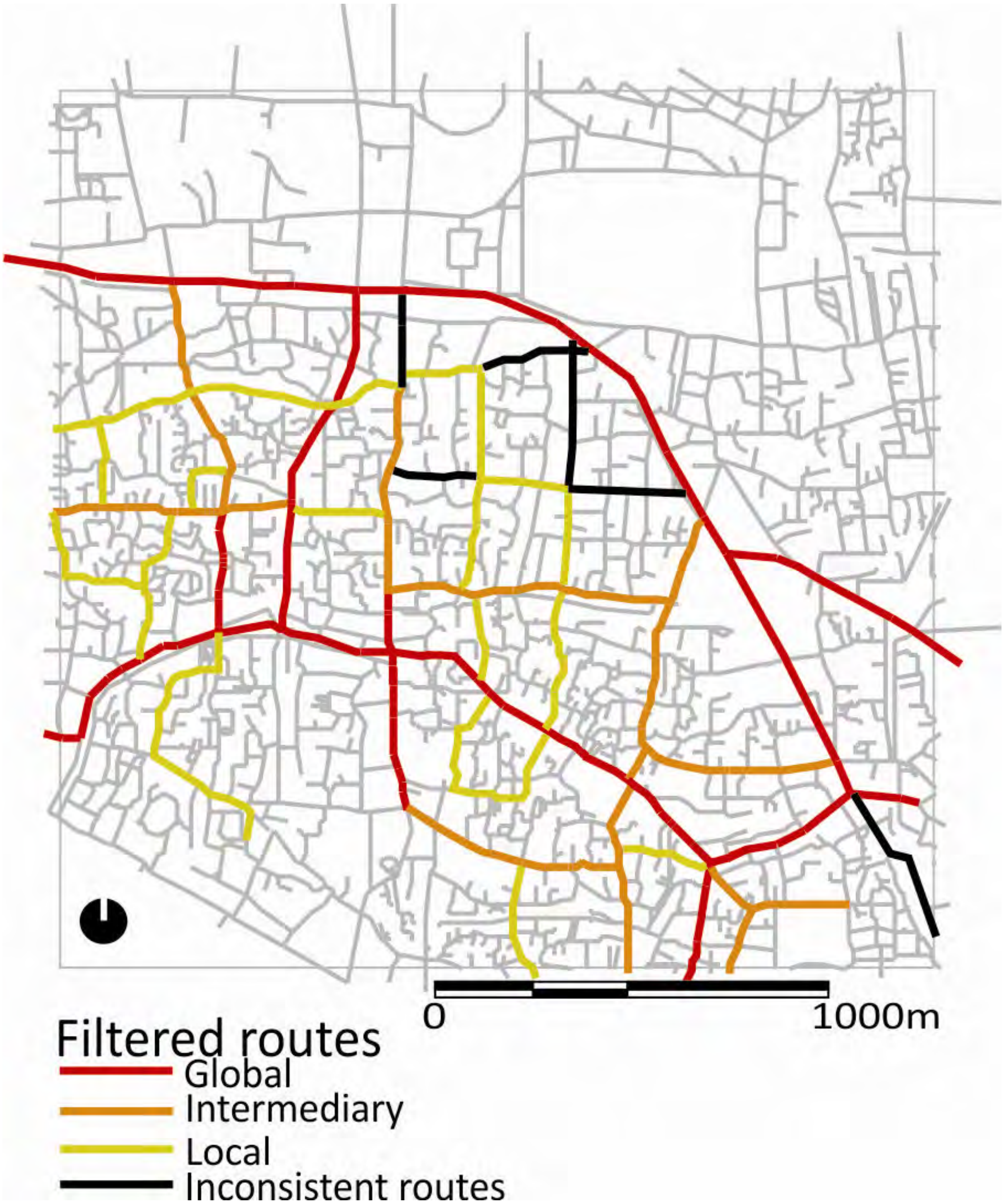


Figure 37: Extracted routes at each level (local, intermediate, and global) of radii for future proposal

The question is what percentage of the street segments with higher choice value should be picked to inform the design stage. After experimenting with different thresholds it was concluded that the optimum threshold was 15% of the routes that have the highest values at each level. A measure of distance from the overall mean, expressed as multiplications of standard deviation (SD), was used to control the percentage of selected records. Assuming that 85% of records were below the 2.0 SD of the mean in a normal distribution, the remaining 15% of routes were selected at different levels of spatial angular choice. After the statistical filtering of routes, a first 'raw' spatial network with different levels of spatial choice is derived from the segment model. The 'raw' spatial network in this context refers to the route network established by the first round of filtering at all scales (fig:37).

After getting the first raw spatial network, and identifying their inconsistencies into the network, a proposed network is suggested for future analysis (fig: 38). Based on this analysis, the proposed network of routes can be designed through different levels of physical intervention. The result of this design intervention can be subject to the same filtering methodology in order to test its validity. Based on the new results the design proposal can be refined and retested. The methodology can be applied as many times as is necessary toreach the optimum result. This filtering method ultimately aims to ensure that the proposed street network scheme will target the segregated areas of the informal settlements and result in a tangible improvement of the spatial and, therefore, socio-economic integration of these areas in the city.Based on the five metric networks, a route network was chosen from the spatial analysis; three street type categories were introduced: primary streets, secondary streets and locally important streets (fig: 38).

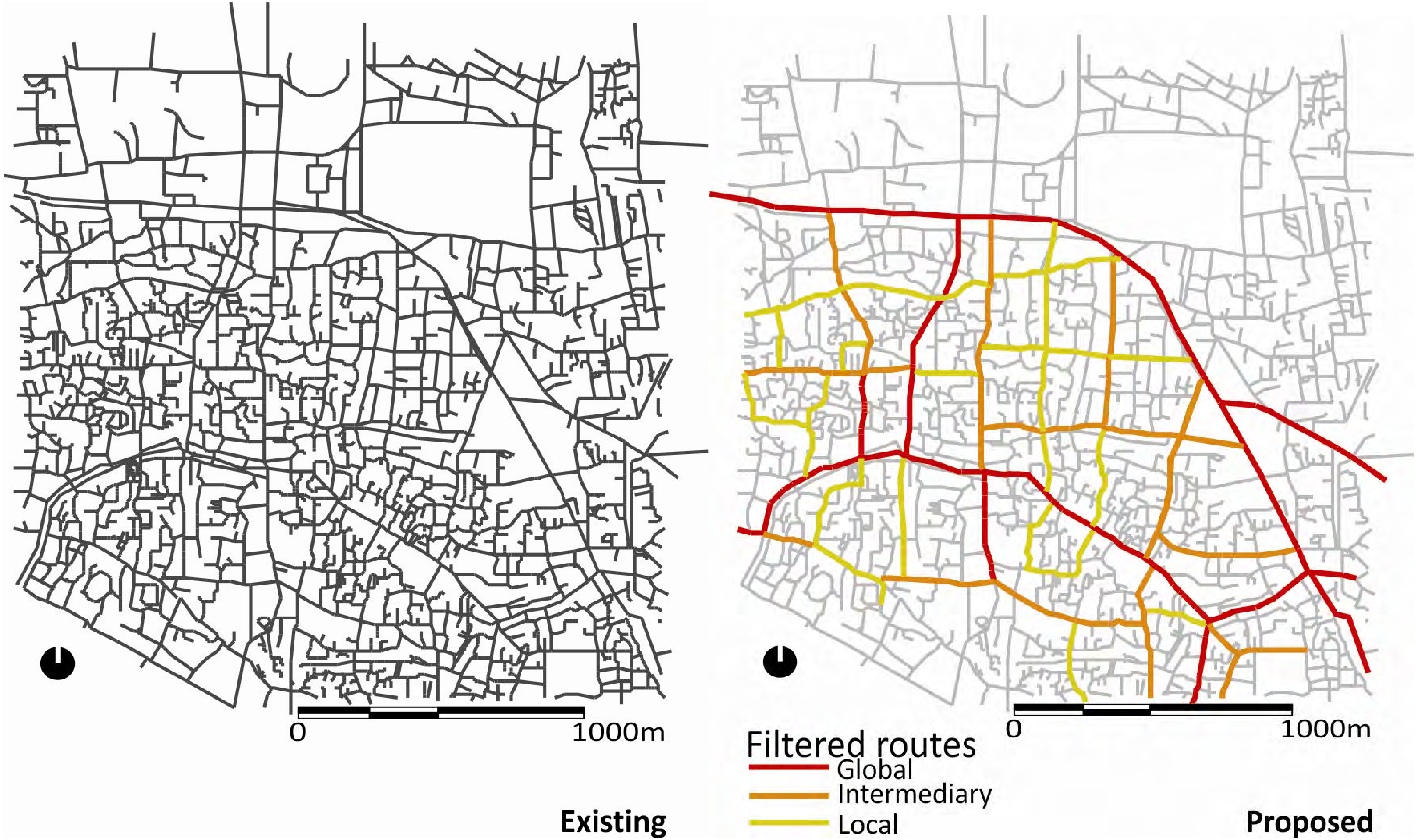


Figure 38: Existing route structure (left), and proposed 'accessibility network' (right) of case study area of old Dhaka

5.2.4 Field Data Analysis for Route Selection: Road width and Movement Density

To build a safe route network or open space network in old city, analyses of existing road pattern and their width, and pedestrian movement density is inevitable. Because, an emergency road network with road width (a minimum width of fire fighting vehicle and a car, 12'+8'= 20') (TMUDP, 1997) (IFC, 2012) and equal distribution of movement density throughout the network, can ensure the safe evacuation, rescue and recovery at a constant rate. However, from the previous literature review, we can get the real picture of it.

For movement density analysis, 22 gates of the case study area are selected for pedestrian movement observations based on the proposed route network. The data are gathered by using the 22 gates. They represent all the routes from/to case study area (fig: 39).

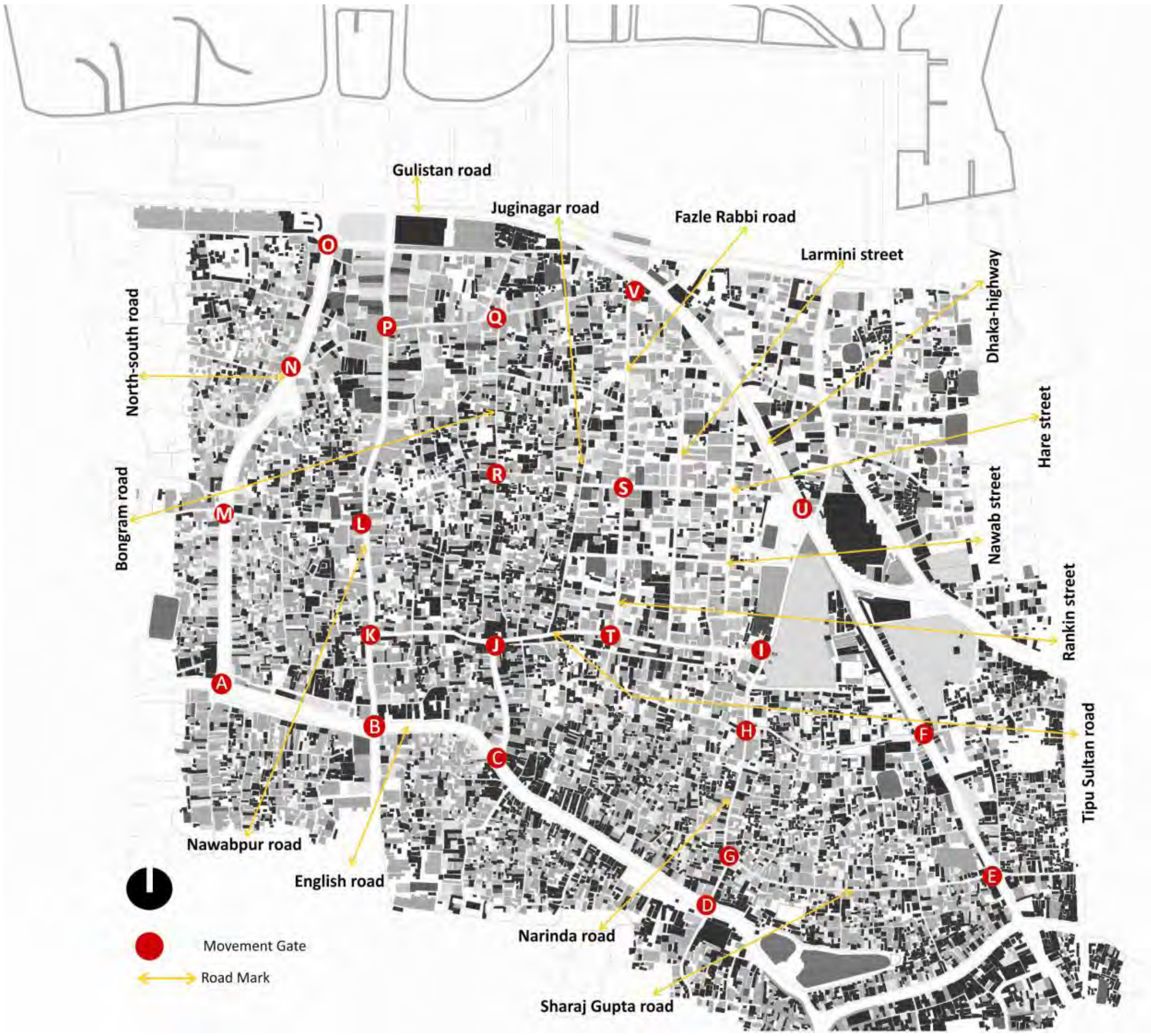


Figure 39: Gate location for 22 selected gates surrounding the case study area of Old Dhaka

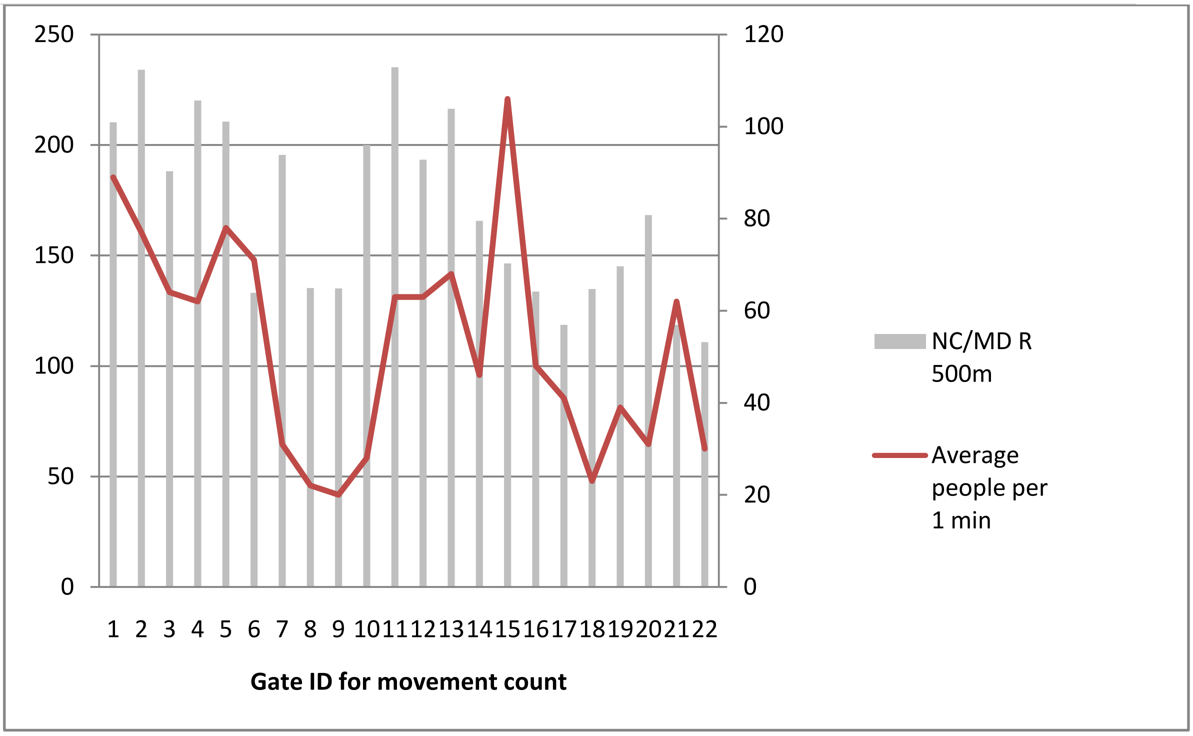
Each gate is a counting unit for five minutes (all gates at the same time) and this is repeated six different day times on the same day for three working days in a week. The results in table 6 are the average of the peak one minute as they represent base case for evacuation.

Table 6: Data from 22 gates (from A to V) of average pedestrian movement and their relationship with different metric radii of accessibility (see fig: 39 for their location). NC/MD represents the nodes count divided by mean depth to obtain accessibility (integration or to movement) in space syntax method.

ID	Gates	Connectivity	NC/MD R 500m	NC/MD R 1500m	NC/MD R 2500m	Average people per 1 min
1	A	4	210.28	1119.7	2017.76	89
2	B	5	234.04	1189.14	1939.64	77
3	C	4	188.09	954.95	1724.97	64
4	D	4	220.15	1033.82	1892.47	62
5	E	5	210.62	1115.44	1677.03	78
6	F	5	133.06	928.35	1949.89	71
7	G	4	195.57	992.67	1686.43	31
8	H	3	135.29	813.88	1647.01	22
9	I	4	135.2	686.56	1687.63	20
10	J	4	200.07	897.07	1530.5	28
11	K	6	235.18	1042.13	1924.75	63
12	L	4	193.34	990.49	1809.9	63
13	M	4	216.4	932.96	1596.26	68
14	N	4	165.74	815.15	1611.66	46
15	O	6	146.43	1013.5	2235.85	106
16	P	4	133.65	925.18	1728.9	48
17	Q	3	118.65	775.84	1800.08	41
18	R	4	134.79	532.63	1081.37	23
19	S	5	145.14	722.16	1455.1	39
20	T	4	168.34	726.89	1518.51	31
21	U	4	118.64	933.42	2110.57	62
22	V	5	110.74	819.11	1870.16	30

Gate O represents the highest density of movements on entry point of the north-south road. It is the one of main connector between the new city centre and the old part of the city. Gate I, H, R represents the lowest observed movement. Here, I denote the connecting point between Narinda road and Tipu Sultan road; H denotes the connecting point between Narinda road and Babushaheb lane; and R denotes a point on Bongram road. The vehicle movement value does not represent the real densities inside the case study area, becausemany of them are narrow in terms of their width. Consequently, vehicle counting were excluded as they represent a low pattern (most of the parts are mainly loading, unloading and rickshaw [local mode of transport] movement) movement, while the pedestrian mobility has higher movement densities. Therefore, the pedestrian movements are examined in relation to space syntax results alone in this particular case study (Table 1).Three different catchment areas are selected for analysing accessibility (integration); they are radii 500m (fig: 40), 1500m (fig: 41) and 2500m (fig: 42).

Radius 500m analyses the local accessibility, radius 1500m analyses the intermediate level and radius 2500m analyses the global level of accessibility. From fig: 40, 41, 42 and table 6, there is a 76.5% correlation between observed pedestrian movements with radius 1500m, 69% correlation with 2500m and only 42% correlation with 500m. These results represent a correlation scenario between real movements and the spatial configuration analysis usingspace syntax. Based on these analyses, it is clear that in particular this study area, the accessibility at 500m radius level must be improved for better network. However, while the old Dhaka is modelled independently, the analysis leads to a general conclusion that this part has high correlational structure, like 500m radius with 1500m, and 1500m with 2500m. Figure 43 shows the different level integration (NC/MD) analysis for old Dhaka and figure 44 shows the same analysis focusing only study area.



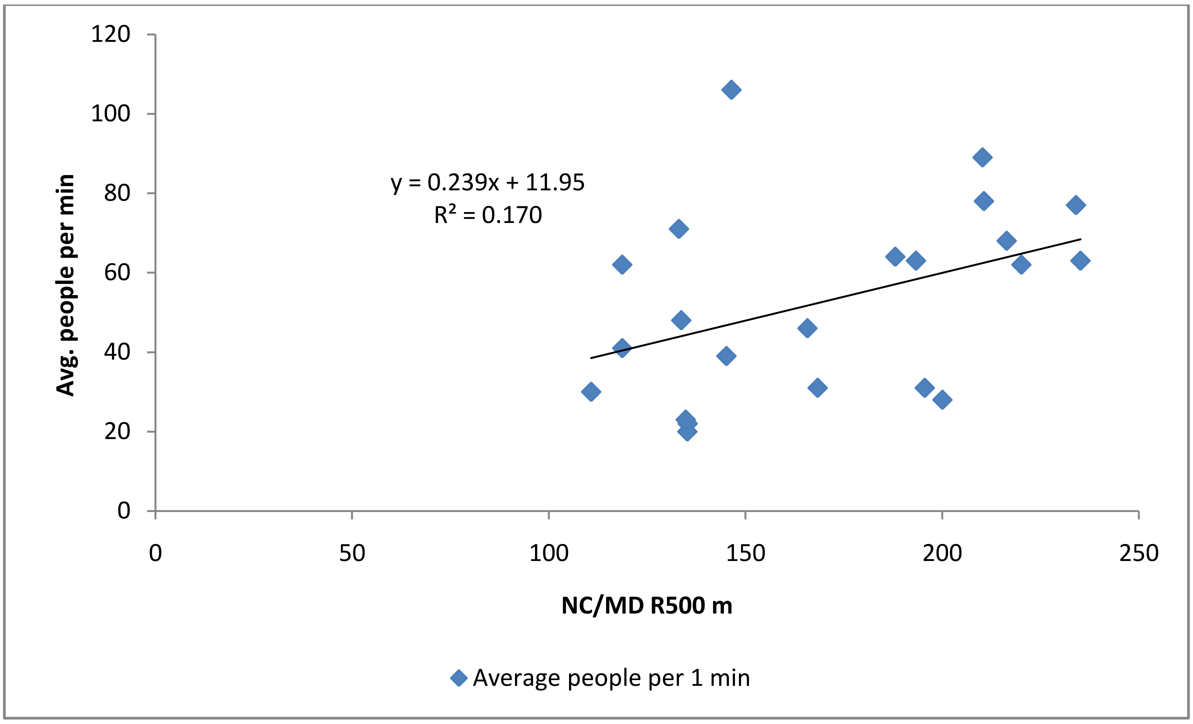
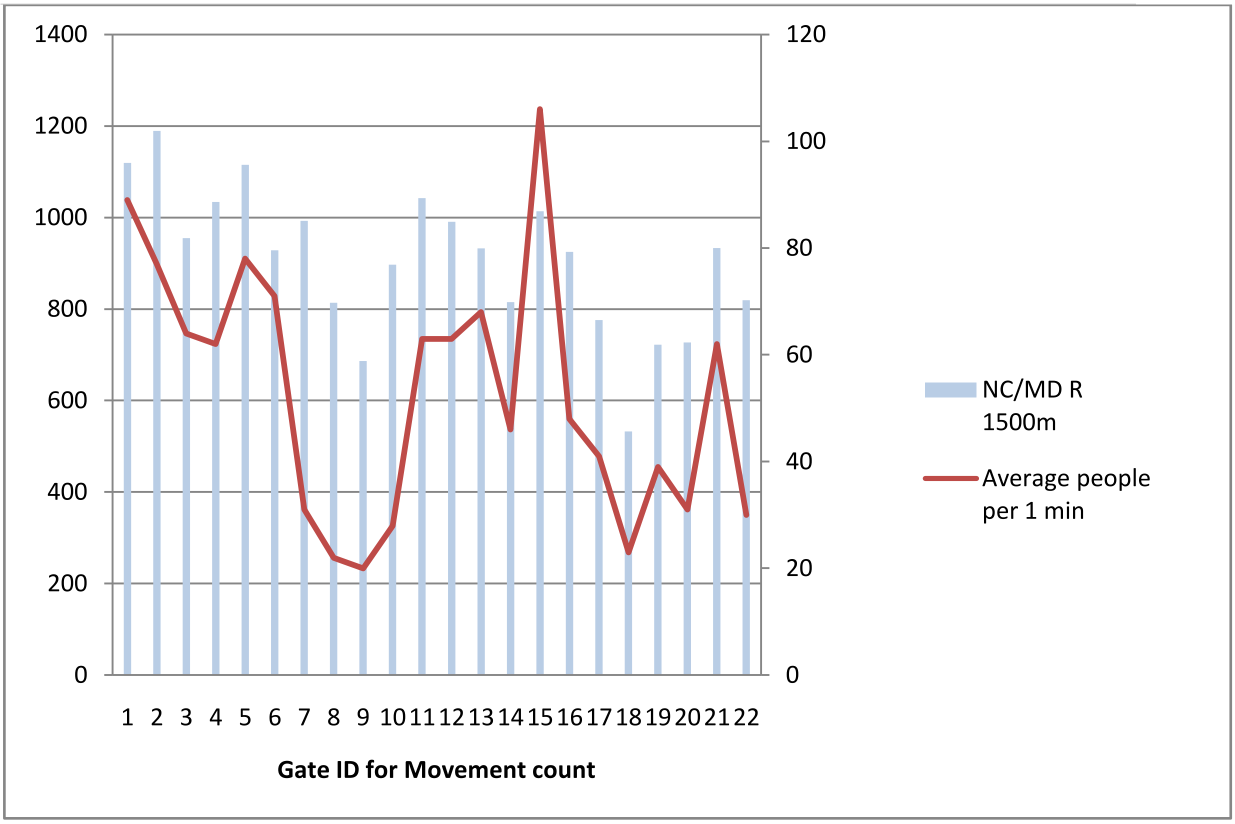


Figure 40: Accessibility (integration) analysis at 500m catchment area with observed pedestrian movement at every gate



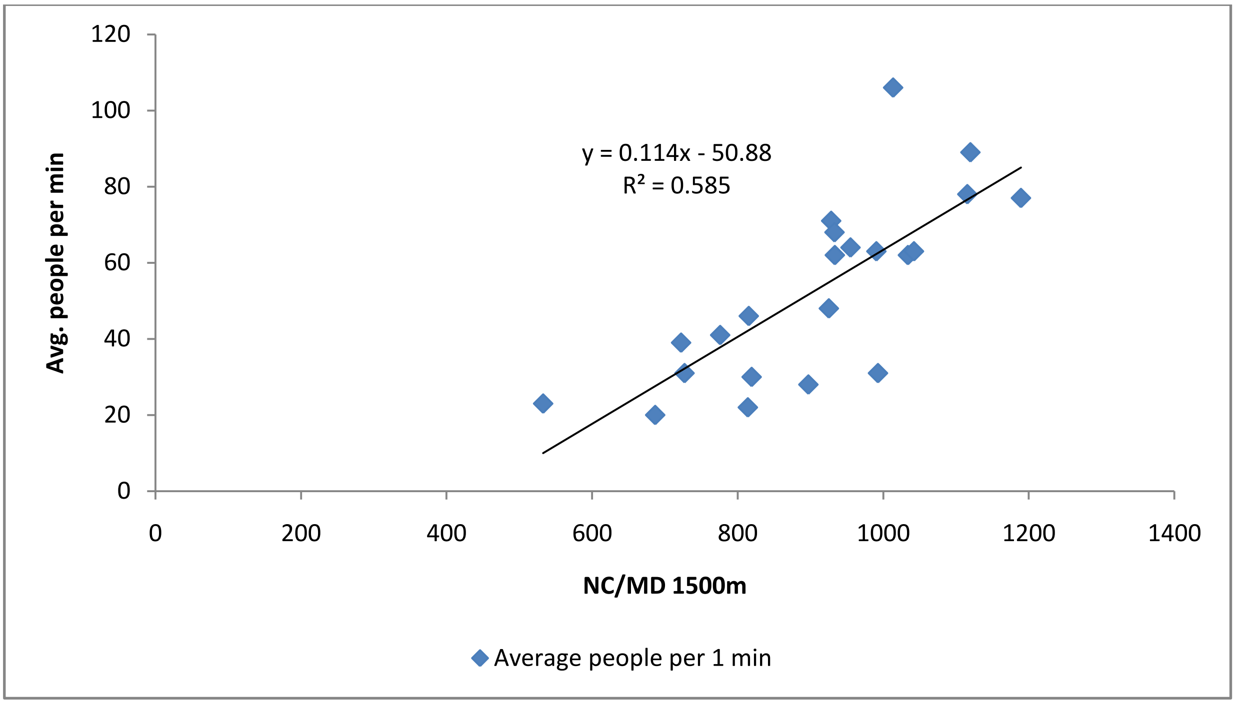
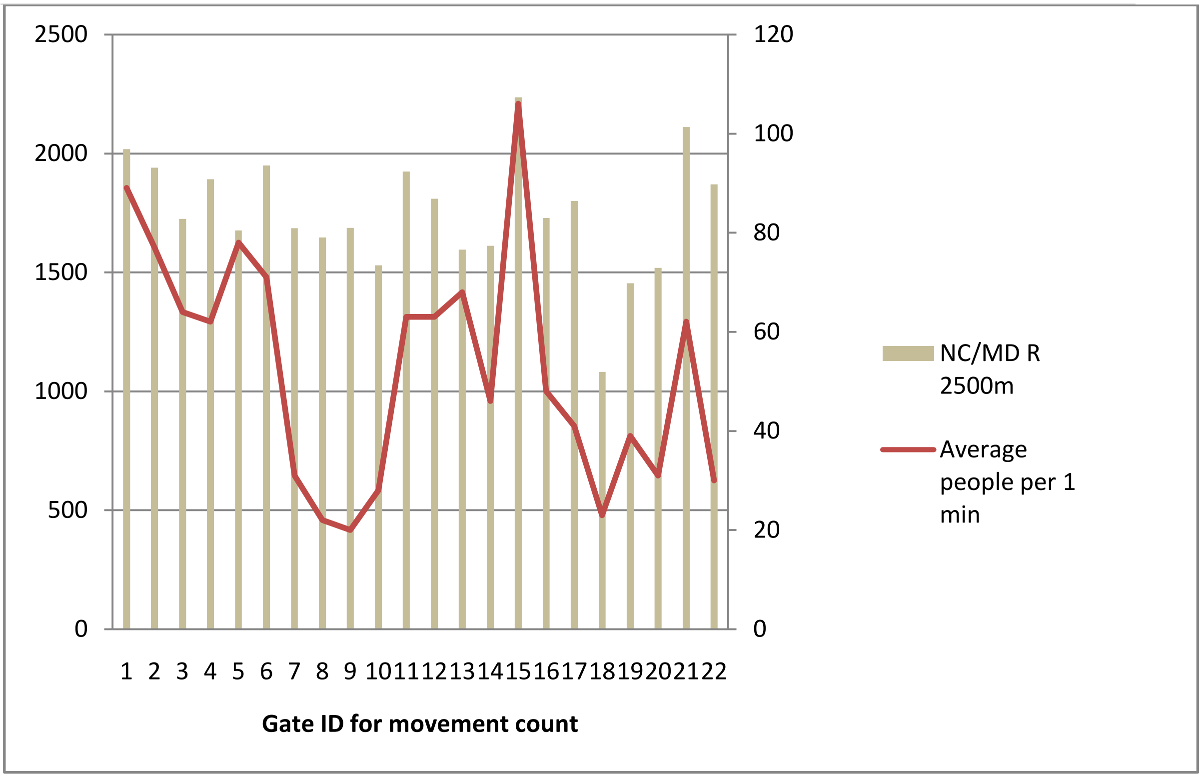


Figure 41: Accessibility (integration) analysis at 1500m catchment area with observed pedestrian movement at every gate



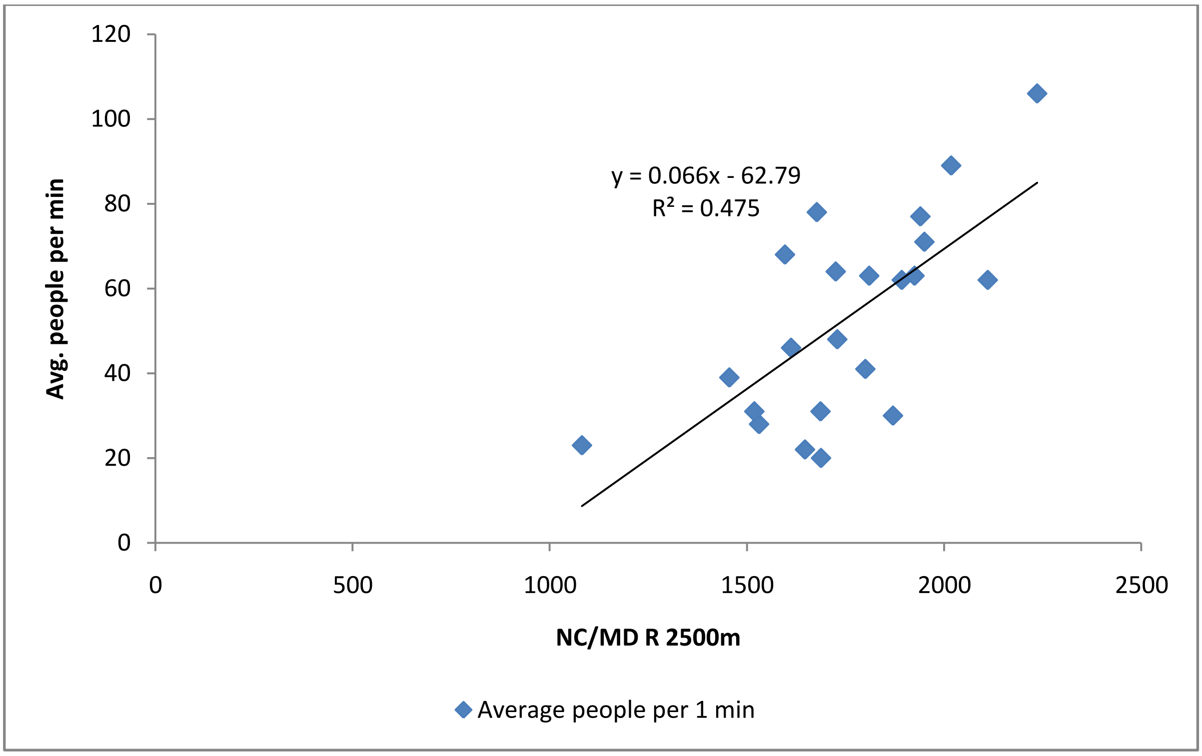
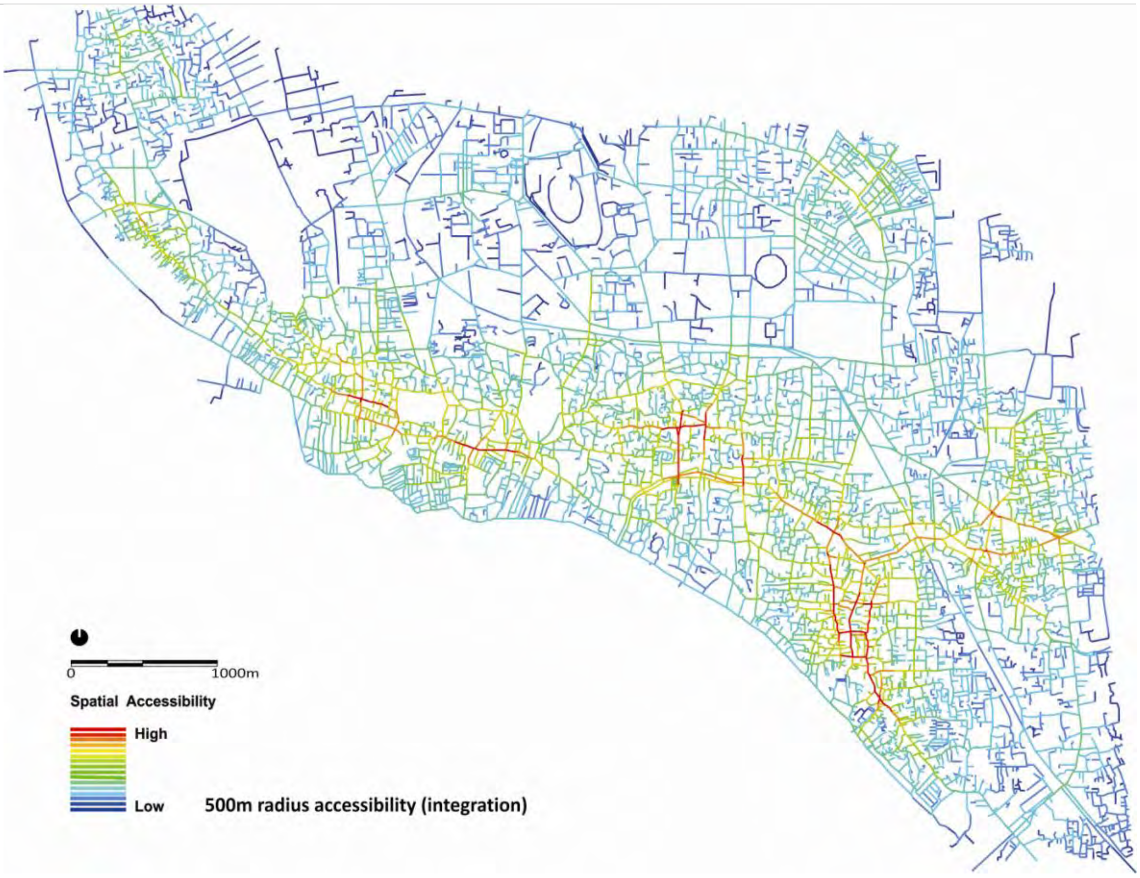
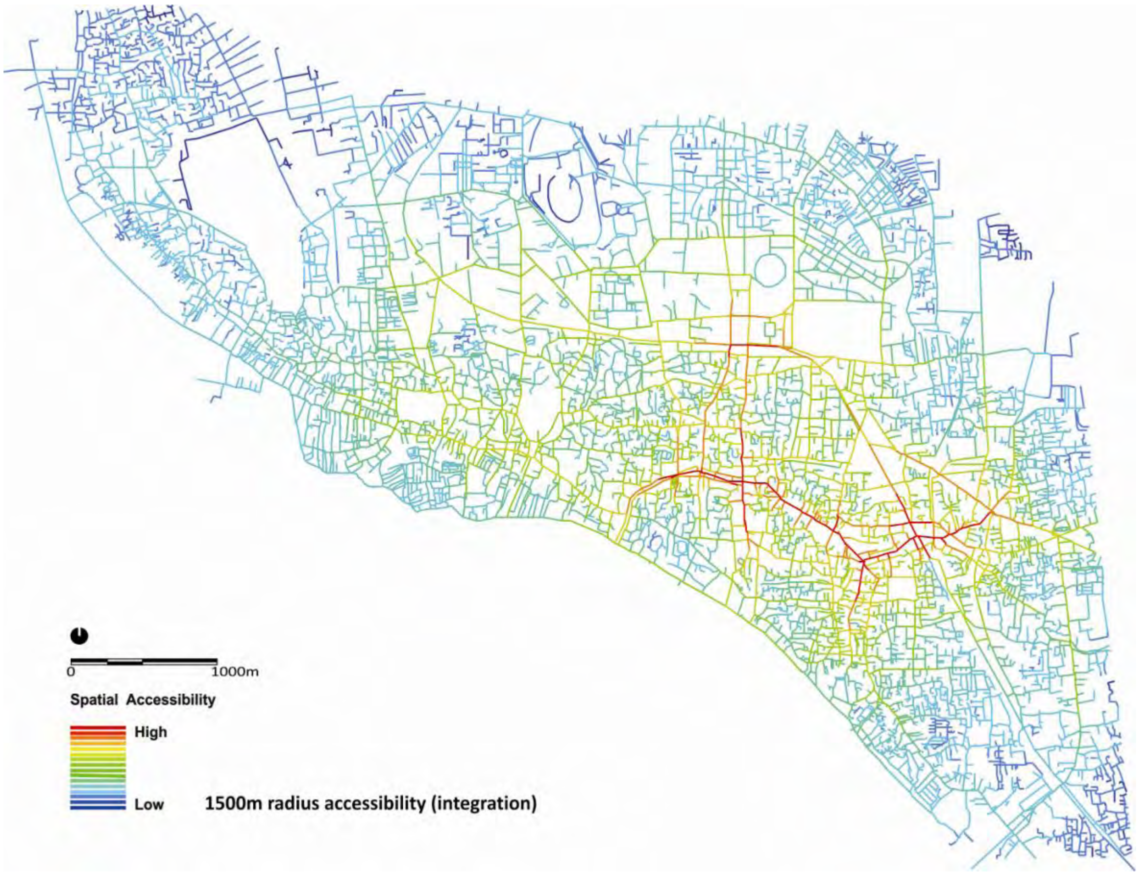


Figure 42: Accessibility (integration) analysis at 2500m catchment area with observed pedestrian movement at every gate


0
1000m
Spatial Accessibility
High
Low
500m radius accessibility (integration)


0
1000m
Spatial Accessibility
High
Low
1500m radius accessibility (integration)

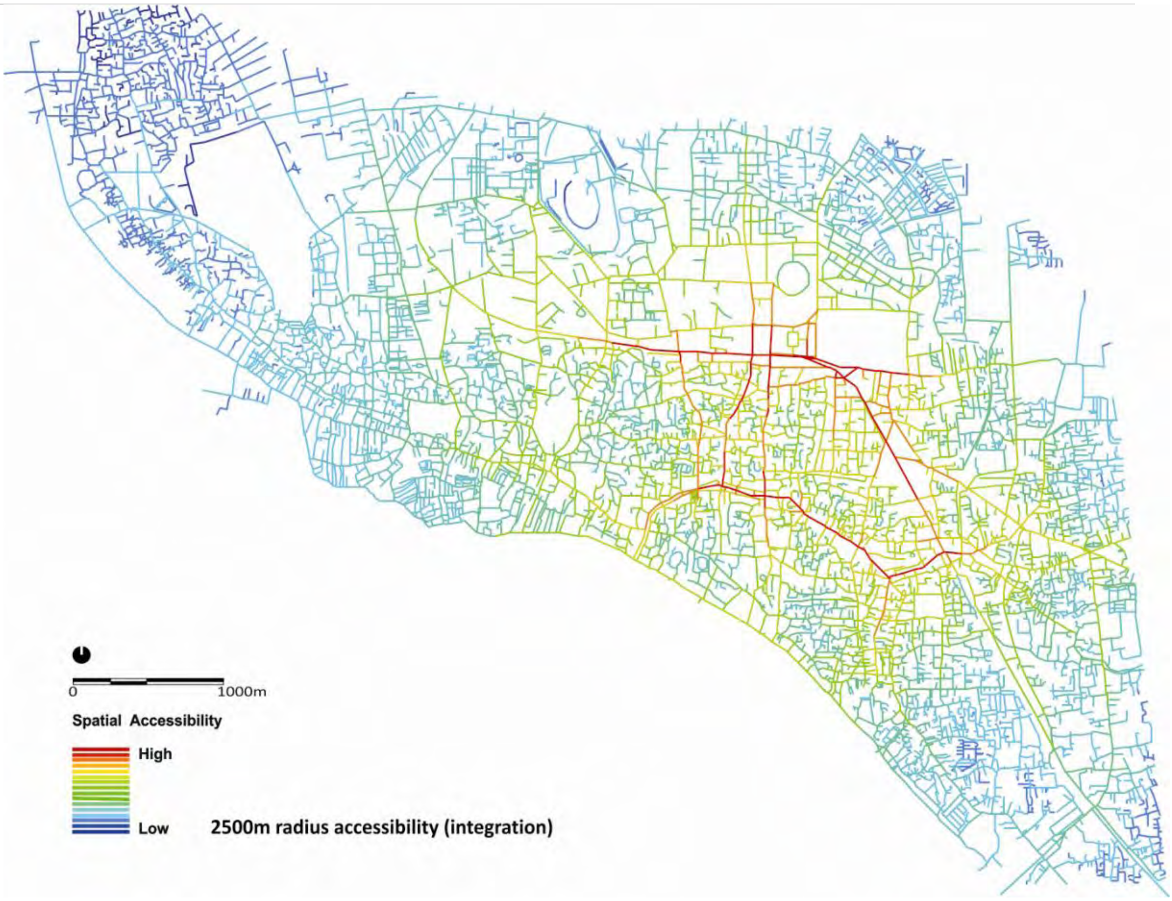


Figure 43: Different level integration (NC/MD) for old Dhaka [500m radius (above), 1500m radius (middle) and 2500m radius (below) integration]

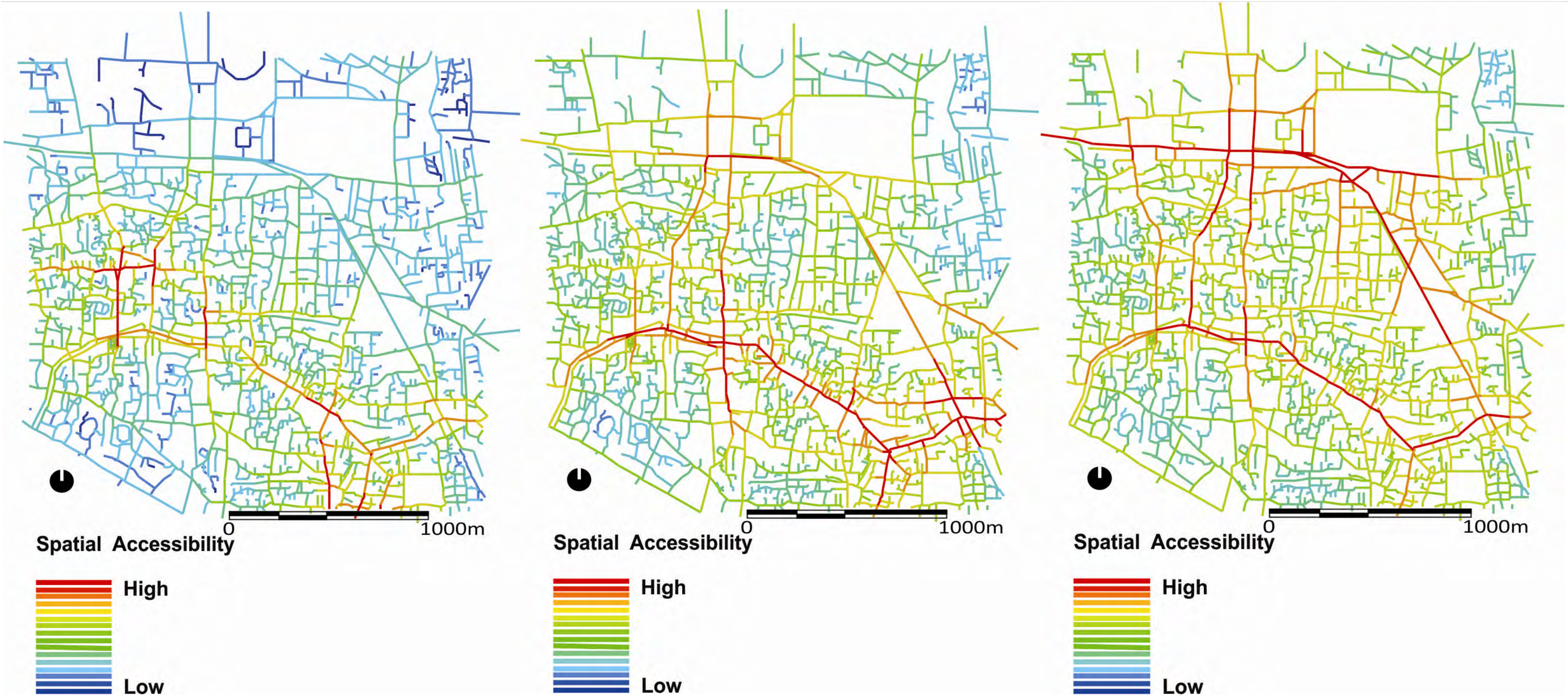


Figure 44: Different level integration (NC/MD) for case study area, 500m radius (left), 1500m radius (middle) and 2500m radius (right)

In above figures, the red lines indicate higher accessibility routes, while the gradation from light blue to dark blue lines shows lower accessibility routes. The spatial analysis from figure 44 shows that at both 2500m and 1500m radius, the case study area is highly integrated with surrounding area. But at 500m radius structure, the study area not highly integrated. These results has match with the findings from movement density versus spatial analysis (fig: 40,41 and 42).

The physical interventions in the unplanned areas are not complete until the urban blocks are fixed and the widths of roads are determined. From the previous chapter, we can see that many of the roads of study area are very narrow in terms of their width. As a consequence, these narrow road patterns prolong the rescue and recovery, during and after disaster. And, also hamper the evacuation process. In this study, the intention is to create a safe route network which can maximize the evacuation, rescue and recovery facilities during and after disaster. Thus this open space or route network can reduce the vulnerabilities. In order to have a more informed response to this design stage, a study of road width is conducted to determine at what level we have to intervene. After that the existing road width survey also layered with the proposed road network (form choice analysis) to select the routes for further modification. The result is a helpful guide for designing streets in case study area. For that the approach is combining accessibility and existing route width hierarchies (fig: 45). From this analysis, the Bongram road, Narinda road, connecting road from Rankin street to English road, BCC road to North-south road, and Sharaj Gupta road have to be widening up within the macro level route network in terms of case study area.

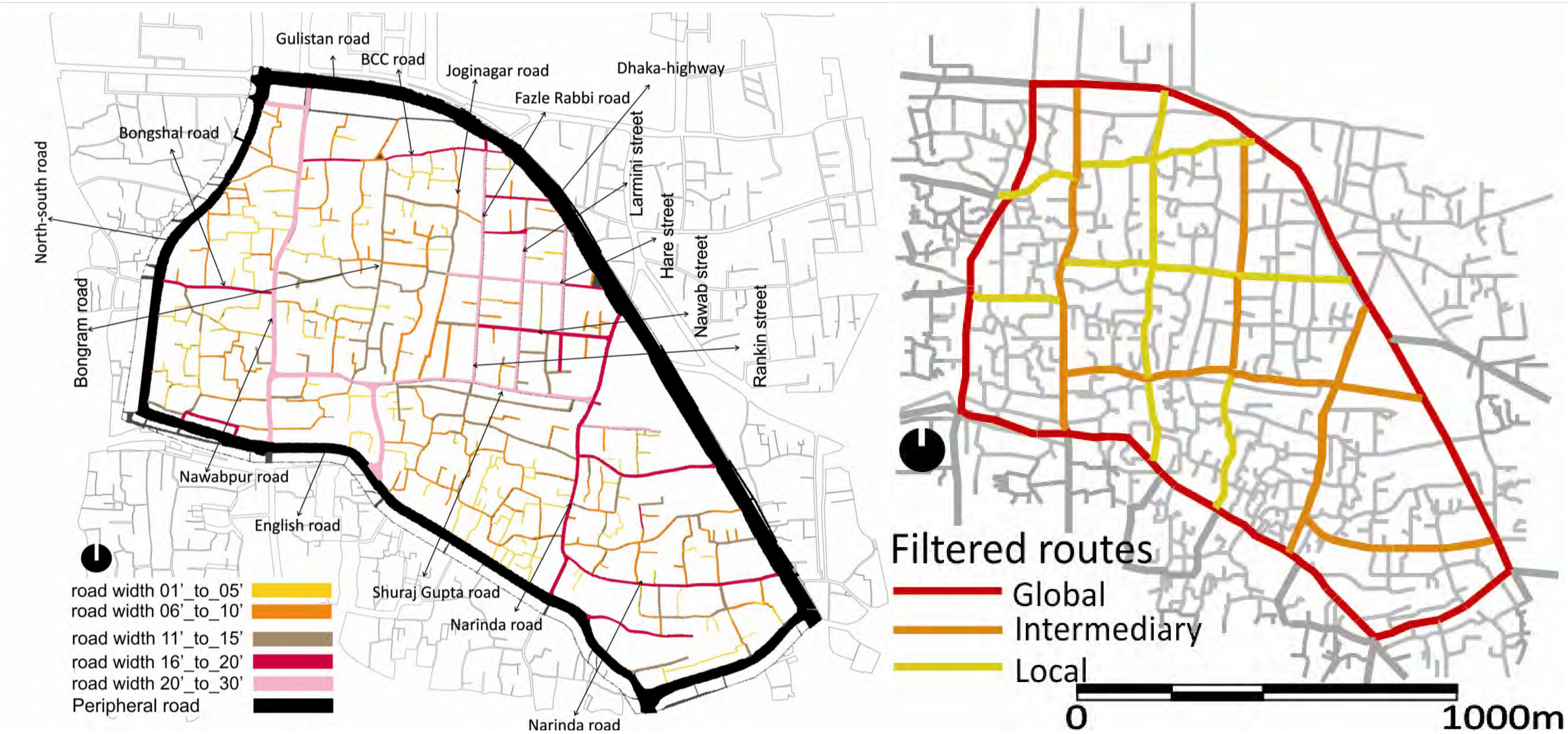


Figure 45: Existing road width (above) and proposed road network (below) of case study area

5.2.5 Other Weighting Factors Analysis by GIS

To search out for an emergency open space network, any decision concerning street widening or aligning should take into account the existing condition of the buildings along the street. In many cases, widening a street involves the removal of buildings which subsequently affects the life of people living in those areas and the future of the city as a whole. As part of the network identification and design intervention process, the comparing method (the result from spatial analysis versus weighting morphological characteristics) has been developed, taking into account for any recommendation. That's why; the analyses of weighting the existing factors play a vital role for future redevelopment of vulnerable settlements. The results based on this analysis used as a guideline for decisions related to open space network design and the degree of physical intervention in each sector. In this study, the categories: land use distribution; size of building blocks and building heights; community facilities (play fields, grave yards, water bodies, community centres, hospitals) and public buildings (institutions, religious buildings, etc.) were the main weighting factors for analyses, see fig: 46, 47, and 48. It should be mentioned that depending on the available data and the nature of a project, the weighting presented here could be further improved by additional data, such as land value and land ownership.

At first, by weighting the existing land use with proposed route network, we can see that Nawabpur road; BCC road; Bongshal road; Tipu Sultan road and part of the Bongram road go through with mainly commercial and mixed use buildings. Except Bongram road, others road's width fit into their land use pattern. On the other hand, rest of the roads pass through mainly residential and mixed use buildings. According to the road width hierarchies, Part of BCC road have 6'-10' width; Bongram road have 11'-15' width; and connecting road between English road and Tipu Sultan road have also 6'-10' width. So, each of the roads should be widen up to appropriate standards for maintaining their existing land use type and also for rescue and recovery.

Secondly, by weighting the existing building height with proposed route network, it is clear that along with the whole network of the study area the buildings are mainly three (03) to six (06) storied heights, except the Bongram road of this network, which have one (01) to three (03) storied building heights. But, with reference to road width hierarchies, maximum road width of this study area is 20'-30' and most of the buildings are very adjacent to the roads,

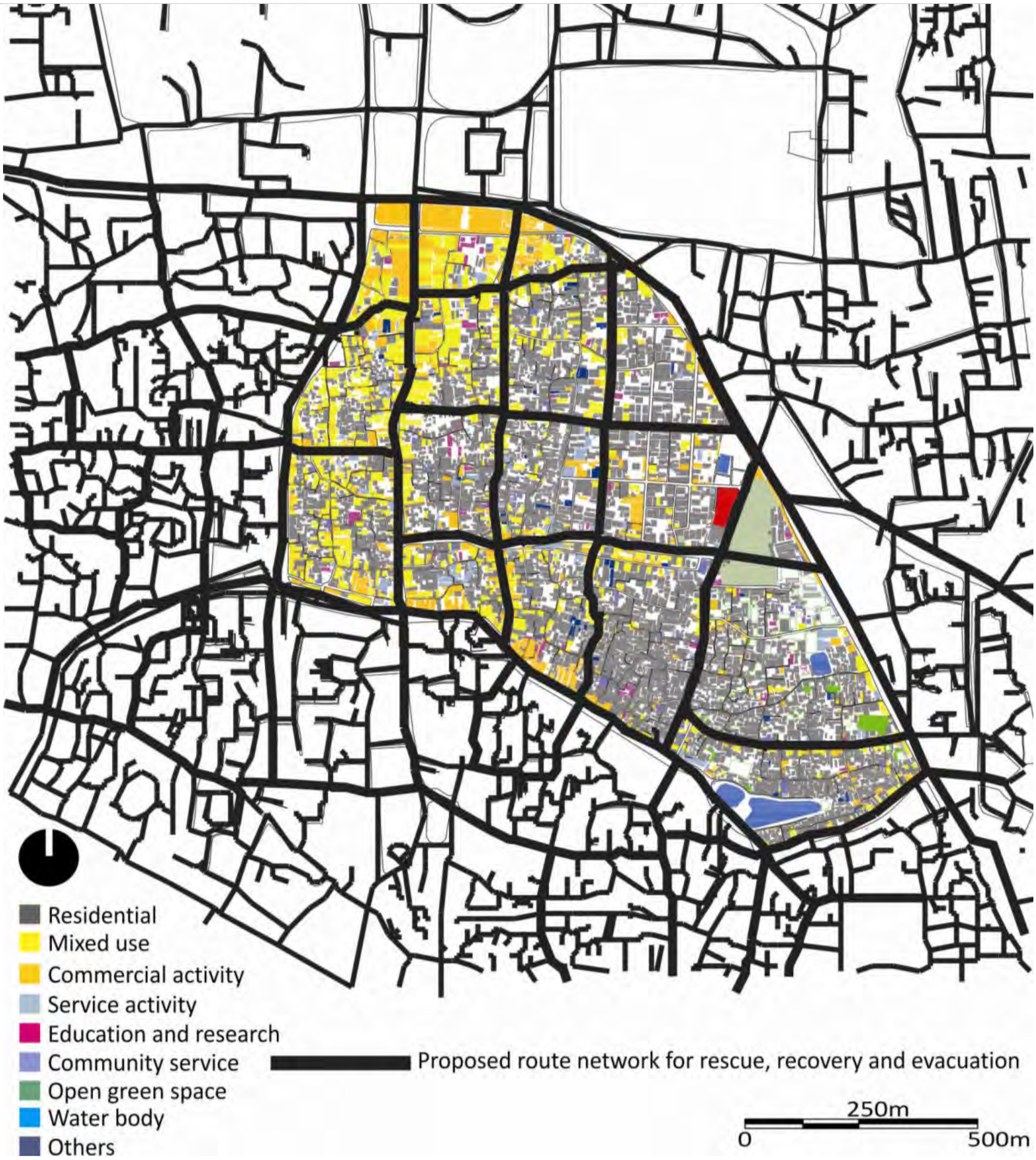


Figure 46: Proposed route network (after spatial analysis) versus existing land use map (from GIS map of Dhaka, 2006), as a guiding tool for designing a safe urban grid for old Dhaka. The selected routes for widening or re-aligning are compared against the land use of the study area.

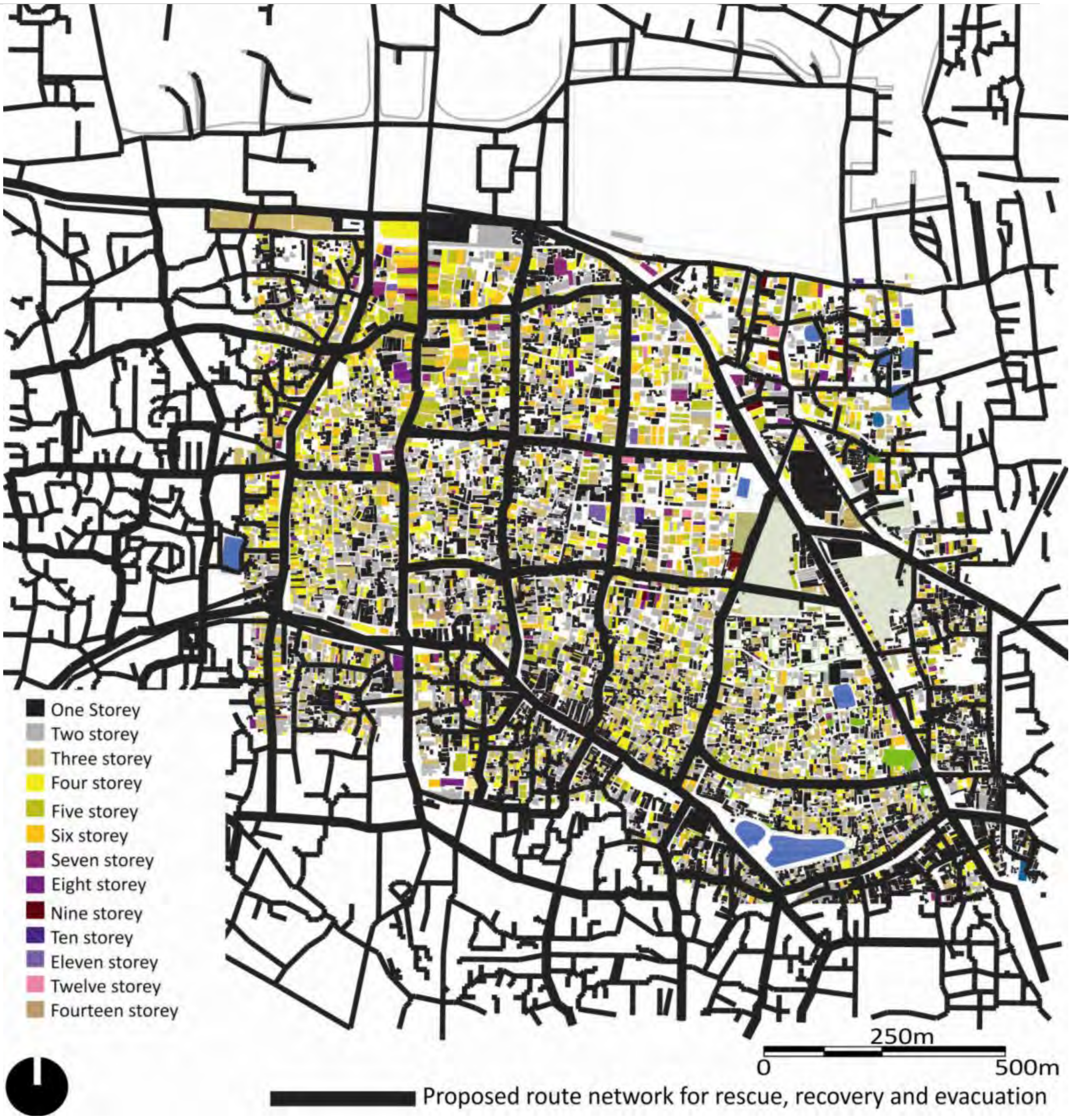


Figure 47: Proposed route network (after spatial analysis) versus existing building height and density map (from GIS map of Dhaka, 2006), as a guiding tool for designing a safe urban grid for old Dhaka. The selected routes for widening or re-aligning are compared against the building height of the study area.

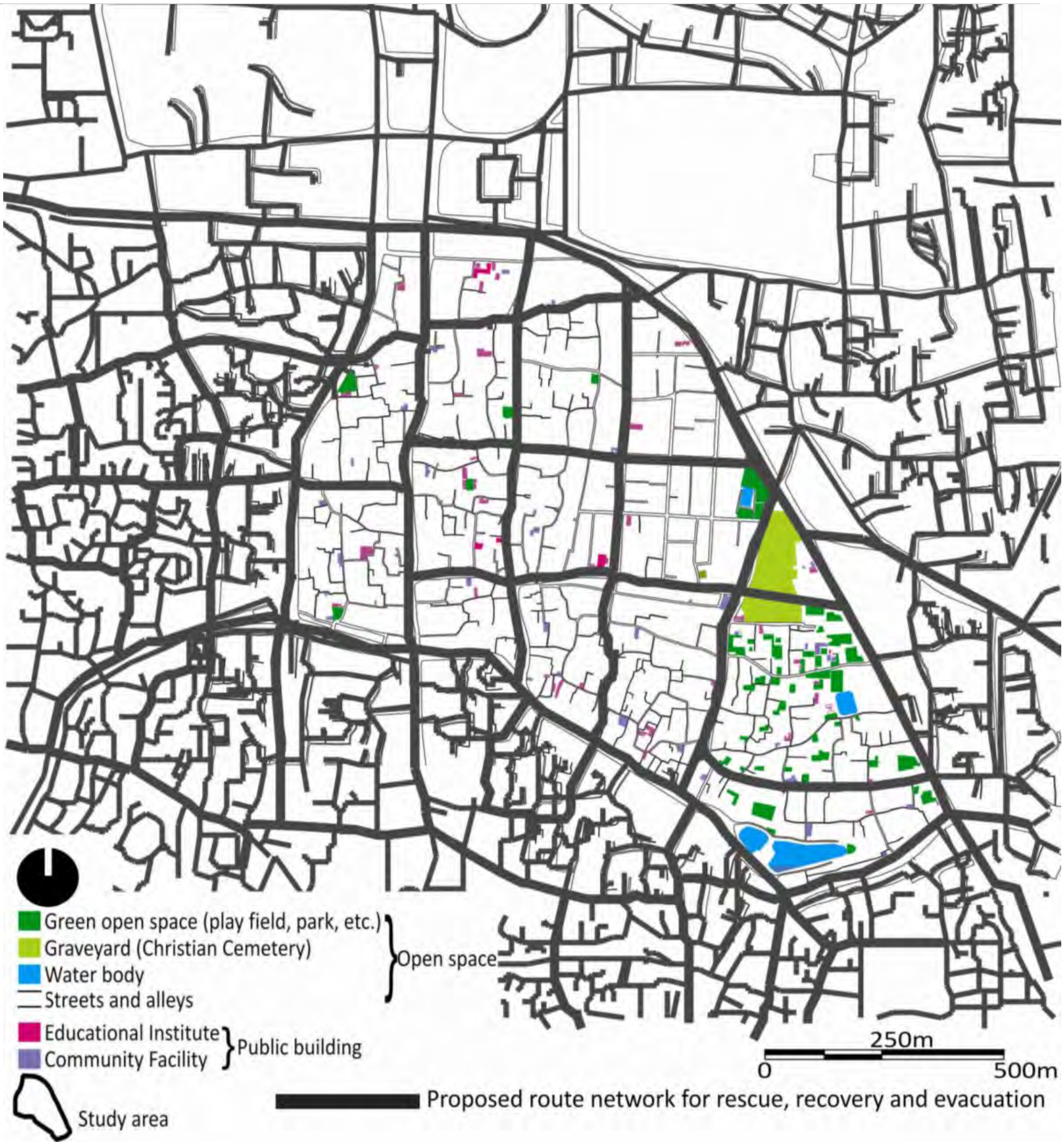


Figure 48: Proposed route network (after spatial analysis) versus existing community facilities locational map (from GIS map of Dhaka, 2006), as a guiding tool for designing a safe urban grid for old Dhaka.

the city, then existing road network will be covered with building debris and it may hamper therescue and recovery processes. So, buildings alongside the network will be evaluated for retrofitting.Finally, by weighting the locational map of existing community facilities (green open spaces and community buildings) with proposed route network, it is evident that all facilities which can be a part of the network as emergency shelters are not distributed evenly. Most of them are Shuraj Gupta road and Narinda road. This approach can contribute to design all means there is no set back between roads and buildings. As a consequence, if any big earthquake hitcommunity facilities align with route network in equal distribution of them. Thus people can use these spaces as safe shelters in evacuation, rescue and recovery process.

5.3. Micro Level analysis for case study area

After setting the emergency route network at macro level of the study area, the next important task is to do micro level analysis for better empirical result. According to the proposed street network, the whole study area is divided into number of individual units, and among them one single unit I, is selected for further detail analysis (fig: 49).

In order to reduce earthquake vulnerabilities; ensure safe rescue, recovery and evacuation, emergency response centres are needed. Distribution, placement and characteristics of these emergency centres, their size and capacity based on population density and emergency condition, vulnerability, etc. are some of the main items that should be considered for any development in earthquake vulnerable settlements of urban areas, especially in the old part of Dhaka.

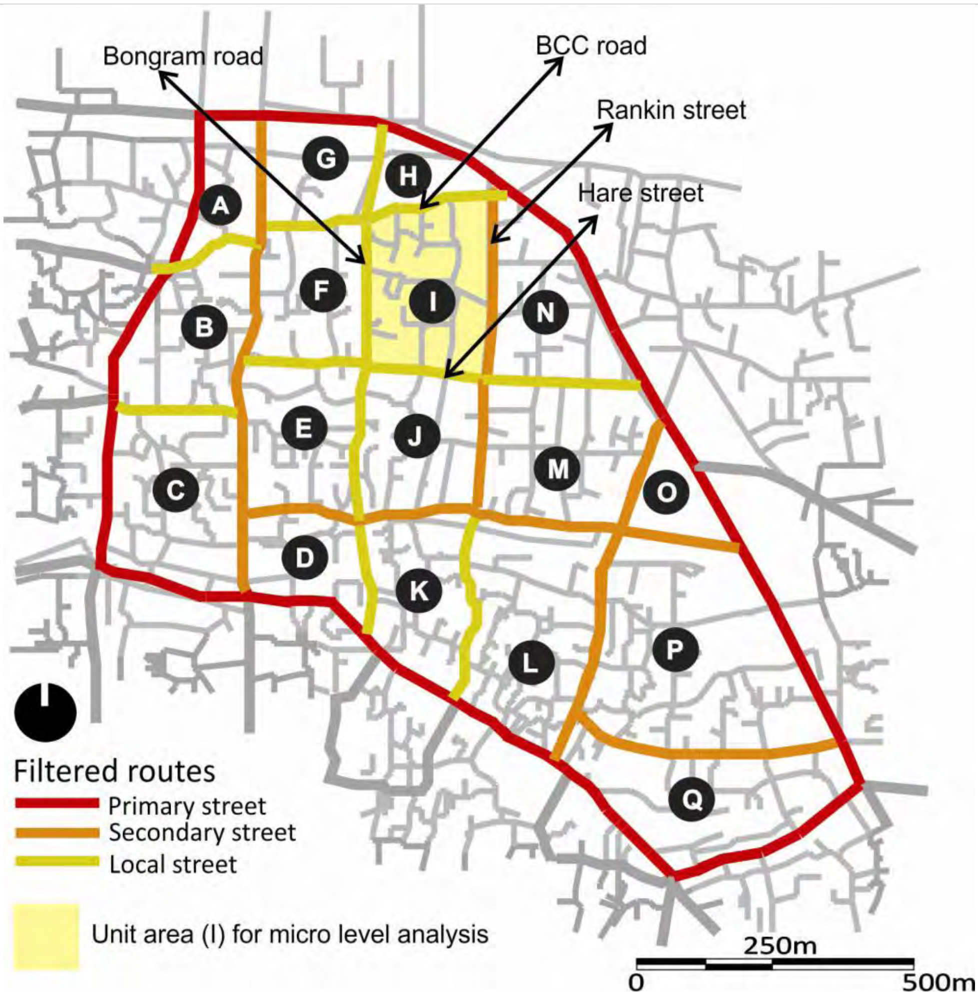


Figure 49: Individual unit layout of study area after route network and selected unit (I) for micro level analysis

5.3.1 Present physical situation of the unit area

The unit is surrounded by three local streets (BCC road; Bongarm road; and hare street)and one secondary street (Rankin street) from the proposed network (fig: 49). Among four roads, Bongram road is ten (10) feet width, BCC road is sixteen (16) feet width road and part of Hare street (MohonBoshok lane) is six(6) to ten(10) feet width (fig: 50).Each of the roads have been lacking the standard road width, which is mention in the section 5.2.6. Regarding that there is no problem with other two roads. According to field survey (2011) and building density from GIS map 2006, present population is 14,100 (approx.) (day time) and area of this unit is 8,17,500sft (75,900 sqm). Majority of the buildings are one (1) to four (4) storied and major type is residentialbuilding (fig: 52). At present, one school building and one play field is located in unit I, which can be used as emergency centre during earthquake (fig: 50).

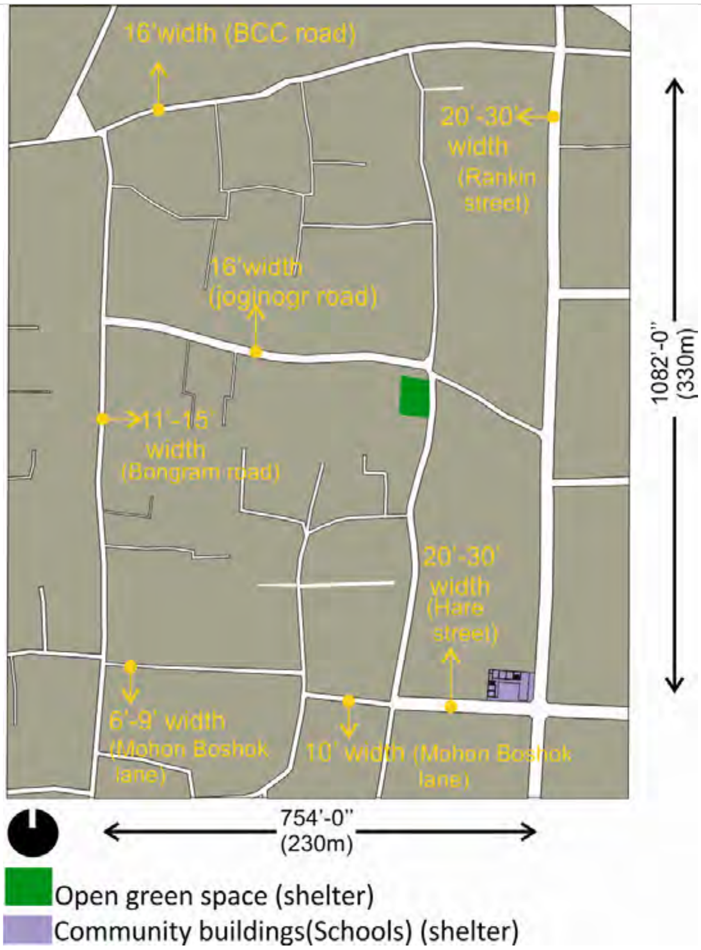


Figure 50: Road layout of unit I and showing their width. Location of two community space (school building + Play field)

5.3.2 Road widening proposal

In emergency route network, all streets should have a minimum width all the way through. Minimum width for these roads should be considered to ensure free movement of fire fighting vehicle and an ambulance, side by side. According to Tokyo metropolitan disaster prevention plan, usually it is considered twelve (12) feet as a standard for maximum width of fire truck and eight (08) feet width for an ambulance. So, minimum width of the roads should maintain the (12+8=20) twenty feet (IFC, 2012). In case of road widening the adjacent plot size and building condition should be studied and analysed in detail. When maximum portion of the of the plot falls under the areas needed for road widening, the whole plot should be acquired by the government and used for that purpose. In case when some portion, such as first bay of the building along the road side falls under widened area, then this part can be demolished by strengthening the other part of the building.

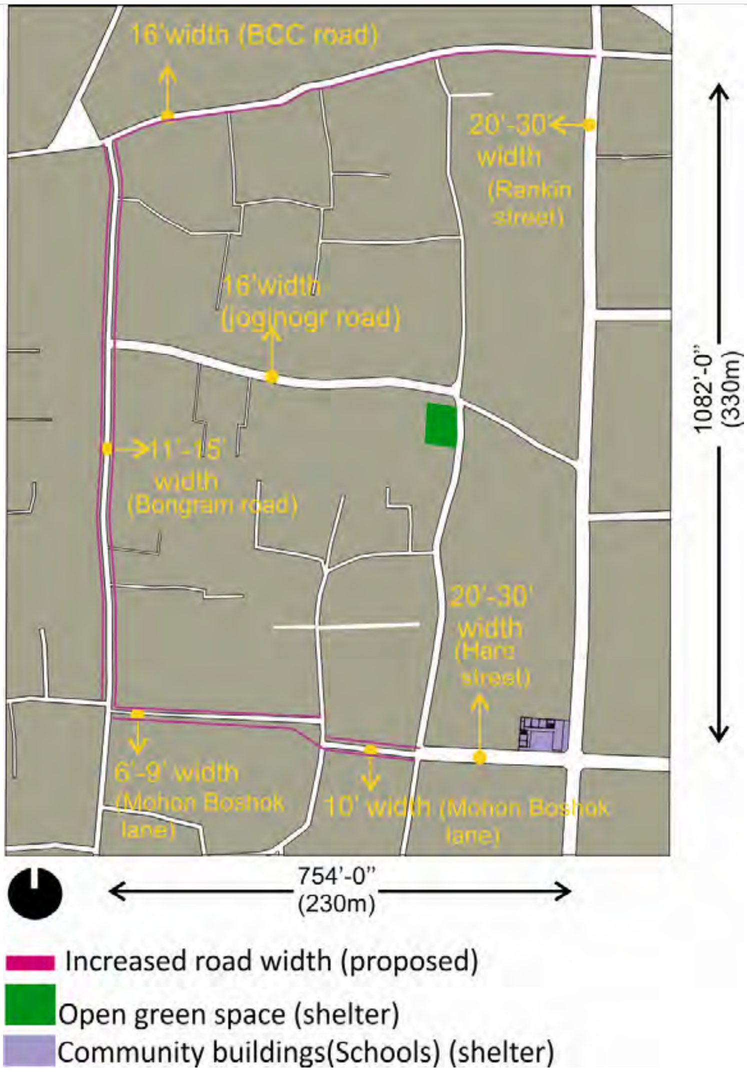


Figure 51: Road widening proposal for unit area I (showing only road layout)

In many times free space can be found also by removing the boundary wall. Based on existing road width hierarchies (see section 4.6.4), Bongram road shouldbe widened up to five(5) to nine (9) feet; BCC road up to four (4) feet and MohonBoshok lane up to ten (10) to fourteen (14) feet (fig: 51 and 52). Satisfactory results could be obtained through demolishing the boundary walls of individual plot or building (fig: 54). Besides, twenty nine (29) buildings have to be demolished partially (fig: 55 and fig: 56) and Four (4) buildings should be demolished fully (fig: 52 and fig: 53). Among them fourteen (14) fourteen are one storied, ten (10) are two storied, Four (4) are four storied, four (4) are five storied and one (1) is six storied.

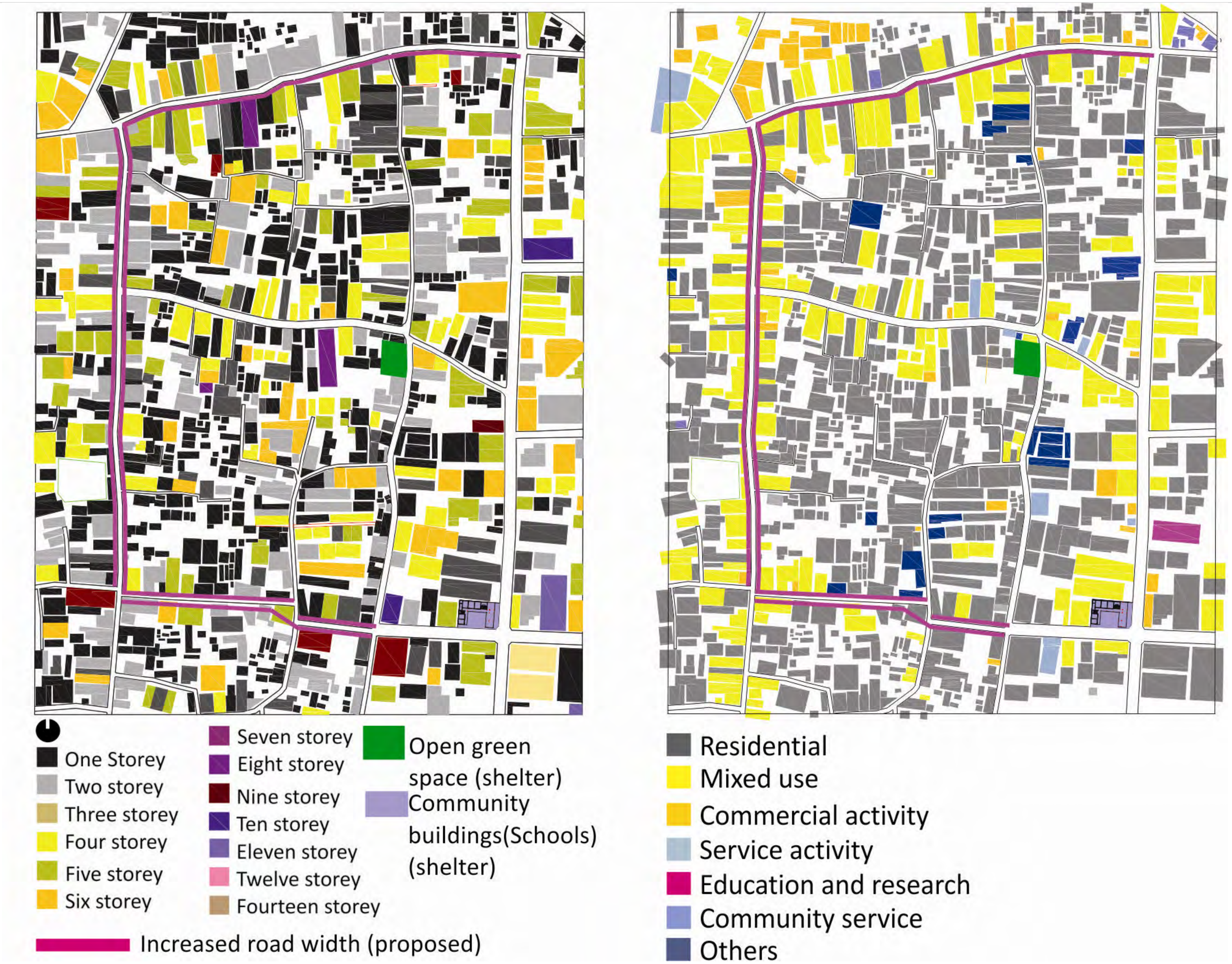
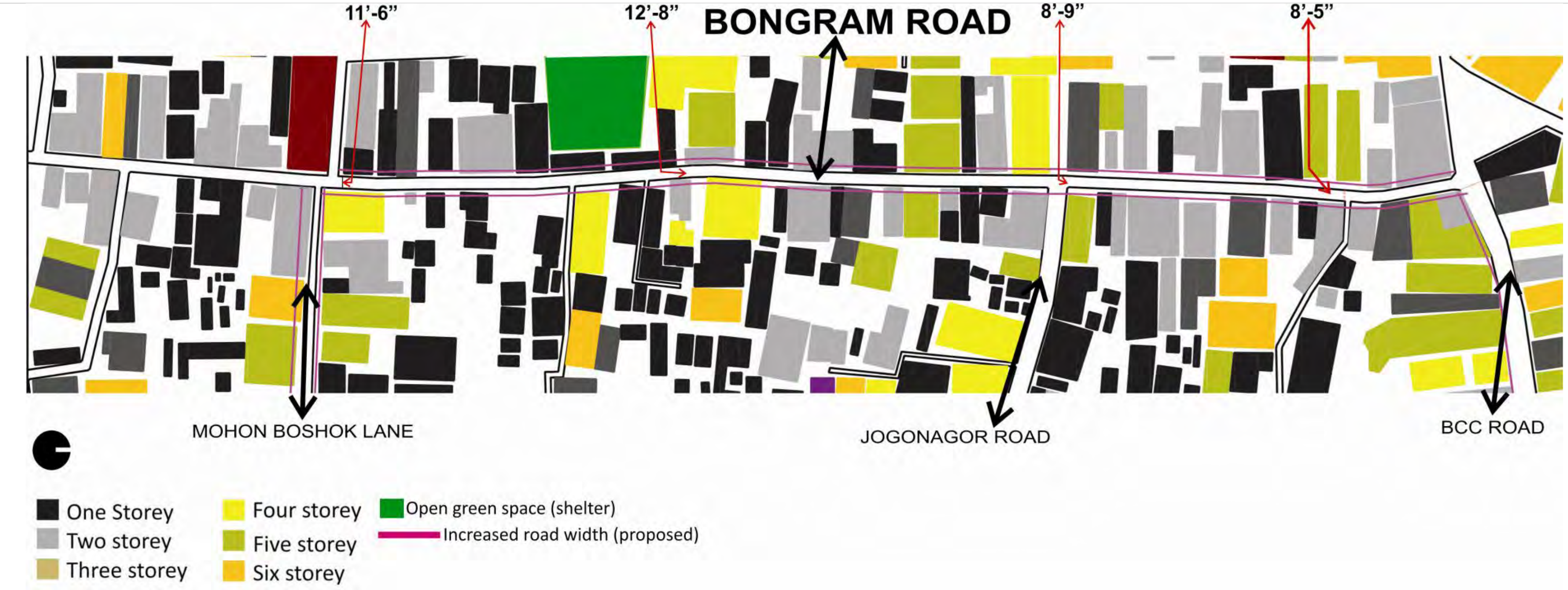


Figure 52: Road widening proposal for unit area I (showing building height and land use)



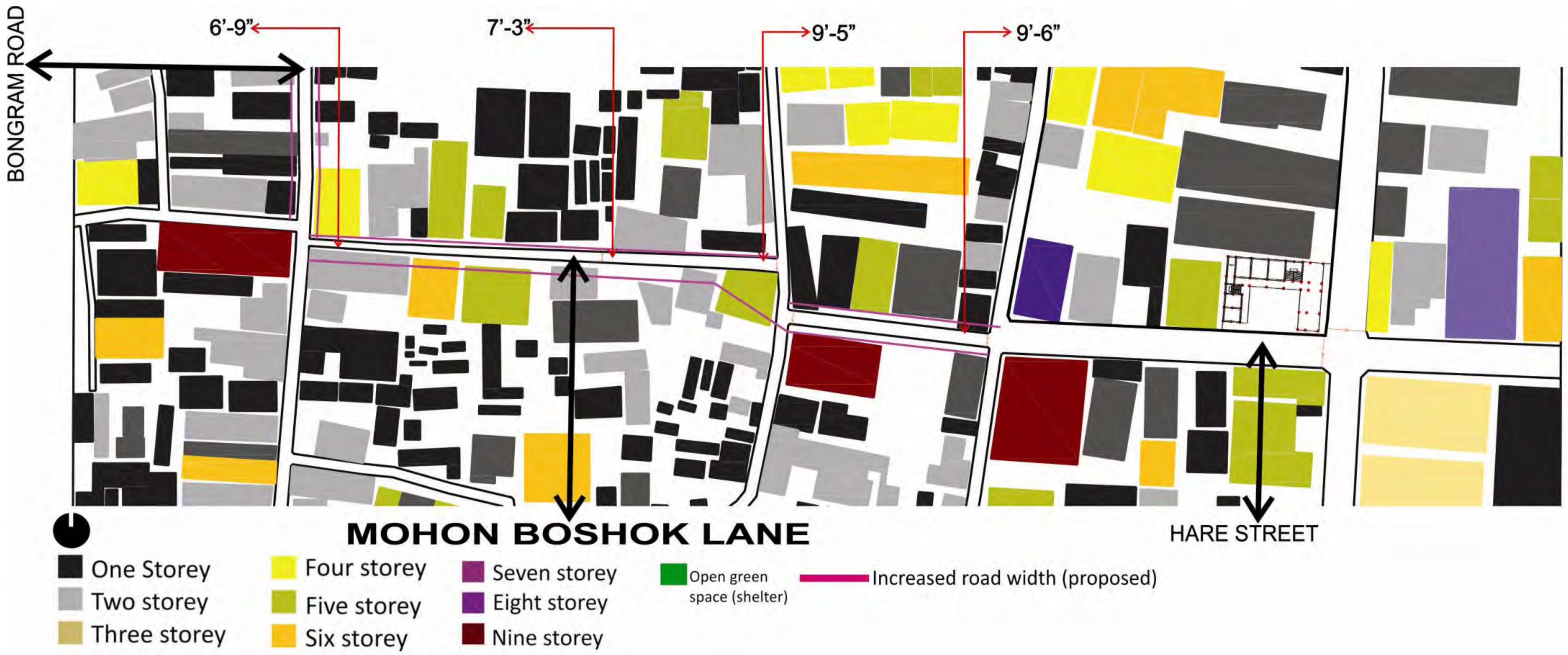


Figure 53: Detail layout of Bongram road and MohonBoshok lane for road widening proposal

Figure 54: proposal for boundary wall demolition for road widening (Bongram road)

Figure 55: proposal for partial one storied building demolition for road widening (Bongram road)

Figure 56: proposal for partial two or three storied building demolition for road widening (Bongram road)

5.3.3 Proposal for emergency centre with their capacity and distribution

Emergency shelters (both open fields and buildings) are the designated place designed as post disaster shelter for earthquake. These places are the safe confined or open areas prepared for protecting the human lives. The open fields (parks, playgrounds, etc.) and public buildings (educational institutions i.e. schools, colleges, etc., community centres, religious buildings, and medical centres, etc.) are considered for emergency centres. This is already explained in literature review (chapter 2). It is an imperative task to make the centres itself safe during and after the occurrence of disaster ensuring the safety of its residing people. Proper implementation of rescue, evacuation and recovery activities is dependent on size, capacity and capability of these centres at the time of earthquakes. In fact basic physical characteristics of these centres should be selected based on the vulnerability of the areas, potential hazards and population density.

Though there are two big green open spaces located in macro level study area, which can serve as efficient shelter during earthquake due to their size. But their location is off centred and they are very close to each other. That's why, individual shelters for each unit area of the study sample is required for better functioning of rescue and evacuation process.

The size of the emergency centres for each unit area has been determined by the population density. Following the Tokyo metropolitan earthquake disaster prevention plan one (1) sqm or ten (10.76) sft area per person has been considered for each evacuee in post-earthquake shelter. Population number for this unit has been calculated from CDMP-2009 report (the population density [no. /km^2] (day time and night time) and building density [no. /km^2])along with existing building footprint and their height information from GIS data analysis. After that size of the centre can be calculated as follows:

Size of the centre= No. of people X area required for each person (10 sft [approx.])

= 14,100 person (approx.) X 10 sft = 1,41,000sft (approx.)

At present, the area of the existing two centres is 17,590 sft. It has been observed that there is a big gap between the existing and the required space. In order to fulfil the requirements, two new centres are proposed and one is extended based on the consideration of low density, low building height (especially one storied), building condition, and the location (fig: 57 and fig: 58). So, for the entire unit area four emergency centres (green open spaces and community buildings) has been suggested (fig: 58). For proposing the new centres nine (09) one storied buildings,eleven (11) one storied semi-permanent structures and three (3) two storied buildings should be acquired by the government for this purpose with proper policy making and planning (fig: 57). The calculation of the four centres has been shown in the figure 60. From that the number of people to be accommodated in proposed centres is found 13,400. Due to the space limitation against high density of vulnerable population, the roof space of the community buildings (shelters) is considered to be used effectively during the disaster period.

In addition to the capacity, proper distribution of these centres around the area is quite important to facilitate rescue and evacuation activities after an earthquake. As shown in this figure 57, the new proposed centres are at the two opposite corners.

Figure 57: Proposed emergency centres after widening the road for unit area I

5.3.4 Placement of shelters and access to emergency route network

It is appropriate if these evacuation places be adjacent to emergency street network to secure the supply of necessary material after earthquake. During and after earthquake, at the time of evacuation process, people first move to the route network according to their choice and then go to the shelters. So, to make a safe evacuation to the shelters, it is necessary that the centres should be

Proposal for emergency centre- expanding the existing one (beside Joginogor road)

Proposal for emergency centre- the existing high school (beside Rankin street)

Proposal for new emergency centre (beside BCC road and Rankin Street)

Proposal for new emergency centre (beside Bongram road)

Figure 58: Four emergency centres in unit area I

alongside with the route network. After any disaster, when people gather in the shelters, they need food; medicine; water; etc. to survive. In order to communicate with them, the accessibility along the route network is important. Also, if community building is medical centre, it is essential that the hospitals located along the emergency roads to assure that their functions would not be affected by blockage of the streets after an earthquake. To keep in mind that in unit area (I), the placement of the proposed shelters suggested adjacent to the route network (fig: 57).

5.3.5 Buildings alongside the emergency route network and centres

The proposed route for emergency use has to be designed in a way that it is free from all kind of damages and debris during earthquake. Consequently building alongside the street network should be earthquake resistant or retrofitted, so that the network remains uninterrupted during and after earthquake. Also, emergency support from outside can safely reach the selected shelters serving the affected locality. Detailed vulnerability assessment (structural) must be conducted for the buildings on both sides of the route network and also adjacent to the centres. Proper investigation and measures should be taken to retrofit the vulnerable or risky buildings.

5.3.6 Evacuation scenario

Accessibility is the main starting point in evacuation model scenarios. In a hazard situation, the initial available data for the decision makers are the available spaces and routes surrounding the hazard site that the evacuees might choose to escape to, in addition to the general knowledge of the evacuee's behaviour and their potential reaction to the hazard situation. According to the capacity of the emergency shelters, each centre serves for a target group of people. Based on the capacity of the each shelter the number of evacuee is calculated (fig: 60). To make a safe evacuation, internal roads are connected with the integrated route network (fig: 59). Evacuee from every building can use these internal roads after the earthquake and before any after earthquake shock or fore-shock. The placement of the shelters can be designed for other unit area based on adjacent unit area character. Thus this may help to create a safe accessible area (macro level) for rescue, evacuation and recovery. During fire hazard, this network will be supportive also for sound fire fighting action.

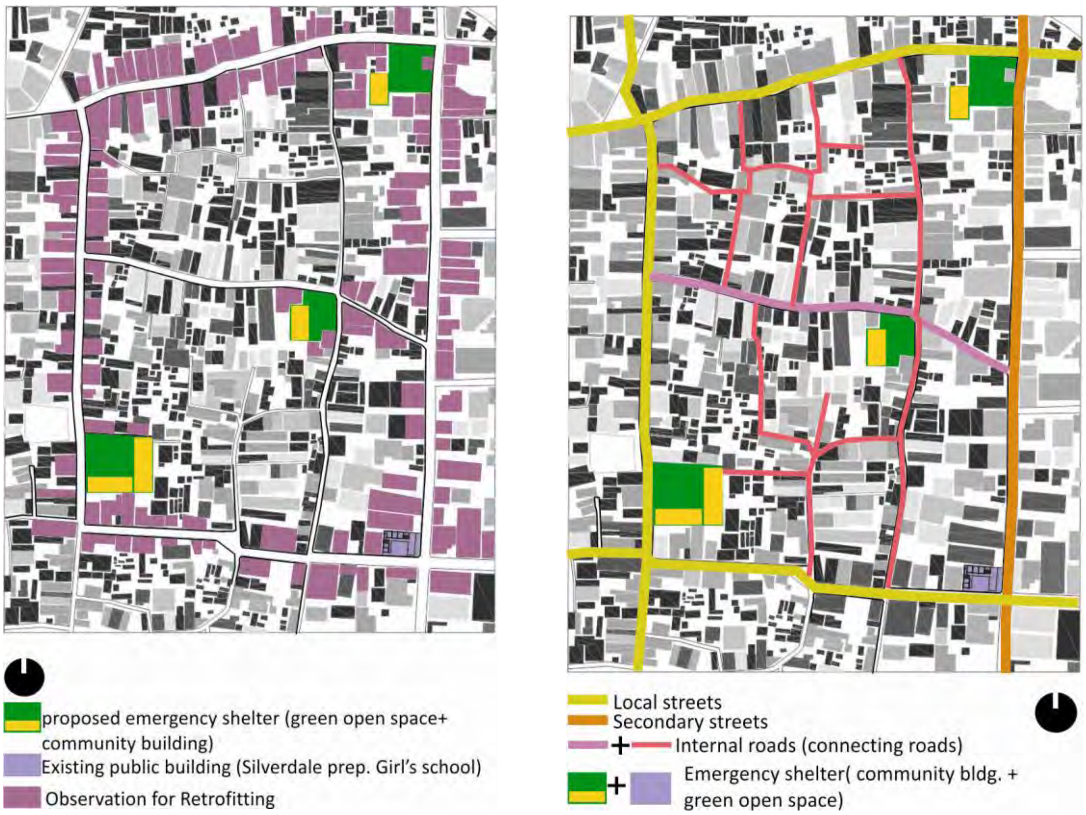


Figure 59: Buildings adjacent to the route network and emergency centres (left), and accessibility network with emergency centres (right) for unit area I

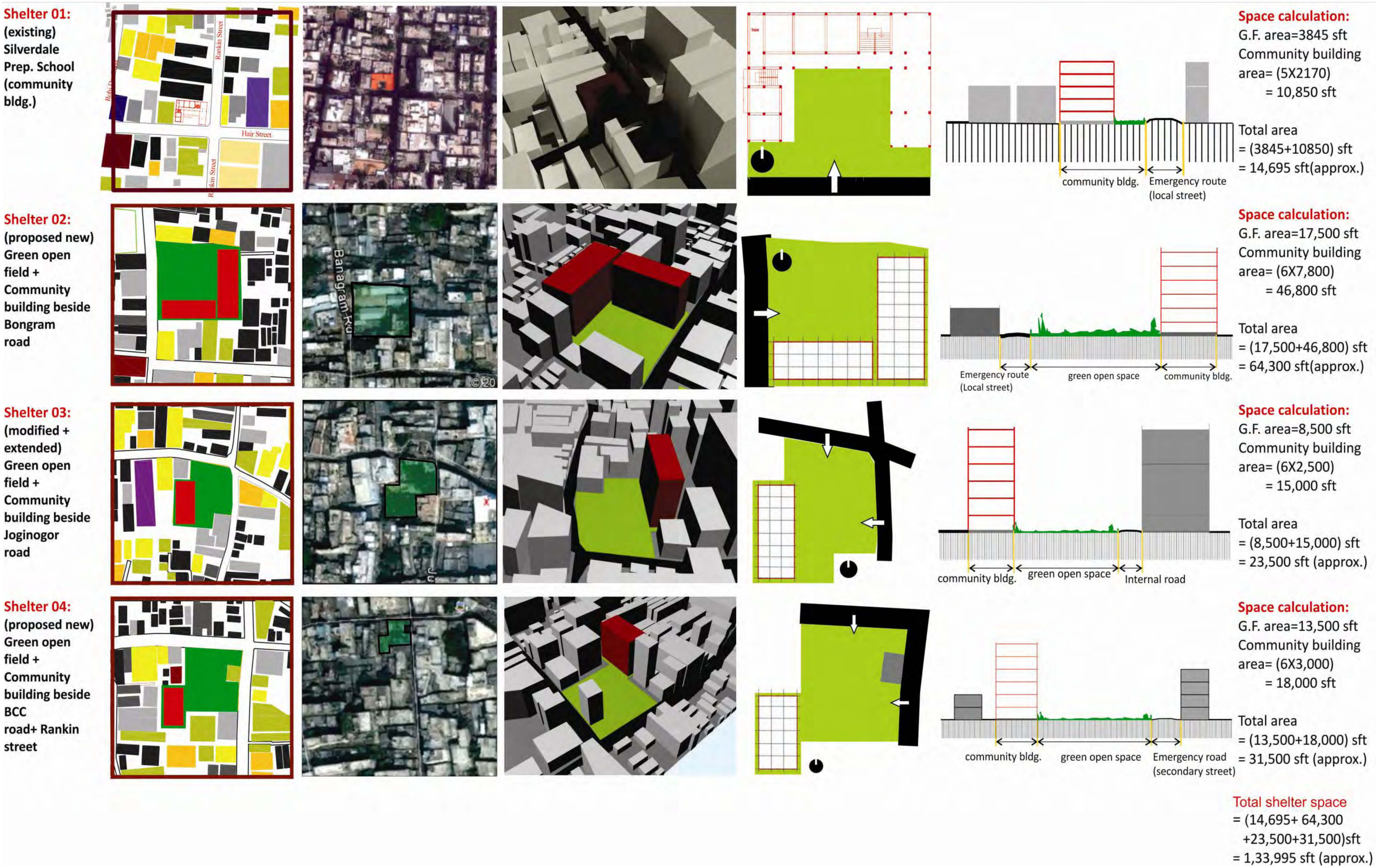


Figure 60: proposed four emergency centres for unit I

5.4. Findings of the Research

This research has analysed the existing case studied area in both macro and micro level, which have authenticated the practicality and objectivity. Findings from both macro and micro level analysis are discussed below:

5.4.1 Findings of Macro level Analysis

Each of the routes selected through the route selection process belong to different metric networks (local, intermediate and global) and were categorized according to their corresponding network. The categorization of routes was reflected in their morphological characteristics, such as road width and building height; land use development strategy for the surrounding areas; movement densities; and distribution of shelter locations. Based on the five metric networks, a route network was chosen from the spatial analysis; three street type categories were introduced: primary streets, secondary streets and locally important streets (fig: 38).

Primary streets are routes with global importance in the old Dhaka, connecting the study area with the surrounding areas. The routes are prominent in the global and 2500 meter network analysis (fig: 38). These primary roads will be developed as an effective model for multiple forms of movements during rescue, recovery and evacuation. In case study area, the North-south road, English road, Gulistan road, Dhaka highway; all peripheral roads will serve as primary streets during earthquake and other disaster. Their road width also allows them to do that. These primary streets will connect the sample area with its immediate surroundings and finally with the whole city network. If this module will be followed and replicated for the entire Dhaka city, then these primary roads will act as central streams for the rescue and recovery purposes during and after the disaster.

Secondary streets share almost similar characteristics to primary streets and they are the connectors between the local street network and primary street network. These streets are more connected within the respective study area than to the global or city network. These secondary streetshave been identified through the 1500 meter network analysis (fig: 38), and are effective for lighter traffic volumes and high pedestrian movements. Nawabpur

road, Tipu Sultan road, Narinda road, Sharaj Gupta road, Fazle Rabbi road and Rankin street; all these roads will be denoted as secondary roads in the event of an earthquake.

Locally important routes appear at the neighbourhood level, and identified through the 500 and 1000 meter network analysis (fig: 38).A low traffic flow is expected along these streets, but they are predominantly used as pedestrian movements. Bongram road, BCC road, Bongshal road, Hare street, connecting road between Tipu Sultan road and English road; will be used as local streets during an earthquake. Moreover, these are the initial step for fast evacuation during and after disaster.

For proper function of rescue and recovery process in any location, the minimum width of the road should ensure free access of fire fighting vehicle and an ambulance, side by side. Based on this standard, in case studied area, mentioned local streets need to be redesigned and widened accordingly. According to section 5.2.3, minimum width of the roads should maintain the (12+8=20) twenty feet. It has been observed that most of local roads are not fulfilling the minimum requirement of width (fig: 48), that's why the buildings on either sides or one side of the road will have to be demolished fully or up to certain portions to increase the width of road (fig: 52, 53, 54 and 55). Based on the movement density analysis, it has been detected that local streets are not integrated into the area. In order to improve this situation, some roads of the network can be straightened up by relocating or removing the building blocks. Finally, it would enhance the accessibility and permeability of that road.

It is evident from the correlation percentage in regression analysis between different metric radius integration (to movement) and number of average people from gate count method in field survey, that the correlation percentage is very much dependent on the land use pattern. For example, the highest (76.5%) correlation is in intermediate level (fig: 41) where commercial land uses are predominant and the lowest value (42%) is at local level (fig: 40) where land use are mostly residential (fig: 46). But during or after earthquake for safe evacuation, the density of pedestrian movement should be higher in local streets.

For land use distribution in the study area (fig: 46), the three types of street network were the basis for the relocation and redevelopment of land use pattern in an existing urban setting. This layer analysis helped to take decisions will ease the job of policy makers. Since all the attributes follow the spatial structure, they produce a high degree of coherence and consistency. It means where there is higher spatial accessibility, and consequently more movement, there will be the land uses that are linked with high degrees of movement.

Building height analysis with route network play a vital role in order to identify a safe route network, during and after earthquake. According to road width versus building height analysis, it will help to prepare a guideline for retrofitting. Building condition and construction technique are also important for retrofitting. In study area, it has been observed that majority of buildings along the route network are thirty to sixty feet height and have 20'-30' road in front of them, then it will obvious that all buildings should be retrofitted partially or fully depend upon evaluating their condition (fig: 47).

Finally, based on this triangulation analysis, it proposed an emergency route network for the study area of old Dhaka. These networks are important infrastructures, which interruption in their functions will greatly affect emergency and recovery activities after an earthquake.

5.4.2 Findings of Micro level Analysis

The main objective of rescue and recovery operations is to save lives of vulnerable people after a disaster. Due to importance of the first hours after an earthquake to save lives, the quick search and rescue activities could play an important role for reducing causalities. Therefore, the placement of emergency centres or shelters should be selected along emergency route network.

From the micro level study of the sample area, it can be summarized that proper planning and designing should be needed for improvement of the existing infrastructures. Increasing the road width, emergency centre design based on population density (capacity), proper distribution and placement of those emergency centres, detail investigation (structural) for adjacent buildings of emergency routes, evacuation network at neighbourhood level, connection between shelters and route network, accessibility, etc. are the key categories to design an existing urban area (old Dhaka) for setting a sustainable rescue, evacuation and recovery network. It should be mentioned that depending on the available data the analysis presented here could be further improved by additional data, such as land value and land ownership. In order to land acquisition by government for designing the shelter space, value and ownership of the land will be an important factor.

In existing dense urban location, several renovation, relocation, and demolition works need to be carried out for making a successful accessibility network model considering earthquake vulnerabilities. In this research, through micro level analysis, an emergency evacuation model has been suggested for a unit area of old Dhaka. Findings from this analysis have stated below:

Road widening was one of the major undertakings for the selected unit area. In most of the cases, satisfactory results could be obtained through demolishing the boundary walls of individual plot or building (fig: 54). And, partial demolitions of few buildings with necessary retrofitting were necessary to achieve desirable minimum standard(fig: 55 and 56).

Emergency response centre (evacuation centre) is the integral part of an emergency route network model. Thus, in the unit part of case studied area, four evacuation shelters were proposed based on population density (fig: 58). Except one rest of the three shelters were proposed and sited by the researcher, based on the findings from field investigation and syntactic analysis. Moreover, the suitable location for these shelters were chosen based on distance, building height, building condition, density and most importantly availability of lands on that existing unit area (fig: 57 and 58).

Placement of these evacuation shelter is an important decision making process as it has immense impact on vulnerability during disaster period. For this unit area of old Dhaka, required shelters were located beside the accessibility route network which has been identified in macro level analysis (fig: 59).

5.5. Summary

This chapter has specifically focused on analysing data, obtained from space syntax analysis, field survey and GIS system investigation, through a systemic analysis. Based on the analysis of the study area of old Dhaka, it has been observed that to make an empirical solution for rescue, recovery and evacuation; both macro and micro level study is inevitable. All objectives (stated in 1.3) of this research have been fulfilled by findings of the chapter. These analyses and findingsfacilitated to come up with potential recommendations and future directions, in the field of earthquake vulnerability reduction considering the open space and public buildings network, which will be discussed in the next chapter.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

In this research, the role of open spaces and public buildings (shelters) were studied in order to reduce earthquake vulnerability in old part of the Dhaka city of Bangladesh. The analyses of findings have been presented in the previous chapter. Both macro and micro level study of the sample area of old Dhaka were analysed to investigate how open space network and public (community) buildings can play an important role during and after an earthquake or any other earthquake related disasters (fire hazards, after shock or foreshocks, etc.). This concluding chapter will discuss the significant findings of this research and will recommend some guidelines for the improvement of earthquake vulnerable settlements in old Dhaka. Finally, the contribution of this research and some directions for future scope of work will be discussed.

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6.1 Conclusions

This study revealed that open spaces and public buildings in old Dhaka are useful elements of rescue and recovery for an earthquake post management process and planning. But, detail planning guidelines incorporating the open spaces and public buildings (emergency shelters) in an existing urban setting is still less intervened research arena. Therefore, space syntax technique, geographic information system and field survey were used as triangulation methods for analysing the accessibility network in a prevailing urban setting in old Dhaka. A sample area of old Dhaka was used as a macro level case study for applying the suggested methods. Furthermore, this research analysed the study area at micro level in order to design the guidelines for safest evacuation model at neighbourhood scale.

From macro level study, a route network was chosen from the spatial analysis; three street type categories were introduced: primary streets (city scale), secondary streets (between city and neighborhood scale) and locally important streets (neighborhood scale).

Primary streets are routes with global importance in the old Dhaka, connecting the study area with the surrounding areas. The routes are prominent in the global and 2500 meter network analysis. These primary roads will be developed as an effective model for multiple forms of movements during rescue, recovery and evacuation. In case study area, the North-south road, English road, Gulistan road, Dhaka highway; all peripheral roads will serve as primary streets during earthquake and other disaster.

Secondary streets are more connected within the respective study area than to the global or city network. These secondary streetshave been identified through the 1500 meter network analysis, and are effective for lighter traffic volumes and high pedestrian movements. Nawabpur road, Tipu Sultan road, Narinda road, Sharaj Gupta road, Fazle Rabbi road and Rankin street; all these roads will be denoted as secondary roads in the event of an earthquake.

Locally important routes appear at the neighbourhood level, and identified through the 500 and 1000 meter network analysis.Bongram road, BCC road, Bongshal road, Hare street, connecting road between Tipu Sultan road and English road; will be used as local streets during an earthquake.

For proper function of rescue and recovery process in any location, the minimum width (width of fire fighting vehicle and an ambulance) of the road should ensure free access of fire fighting vehicle and an ambulance, side by side.

It is evident from the correlation percentage in regression analysis between different metric radius integration (to movement) and number of average people from gate count method in field survey, that the correlation percentage is very much dependent on the land use pattern. From the study, it is evident that the highest (76.5%) correlation is in intermediate level where commercial land uses are predominant and the lowest value (42%) is at local level where land use are mostly residential . For land use distribution in the study area, the three types of street network were the basis for the relocation and redevelopment of land use pattern in an existing urban setting.

In study area, it has been observed that majority of buildings along the route network are thirty to sixty feet height and have 20’-30’ road in front of them, then it will obvious that all buildings should be retrofitted partially or fully depend upon evaluating their condition.

From the micro level study of the sample area, it can be summarized that proper planning and designing should be needed for improvement of the existing infrastructures. Increasing the road width, emergency centre design based on population density (capacity), proper distribution and placement of those emergency centres, detail investigation (structural) for adjacent buildings of emergency routes, evacuation network at neighbourhood level, connection between shelters and route network, accessibility, etc. are the key categories to design an existing urban area (old Dhaka) for setting a sustainable rescue, evacuation and recovery network

In this research, through micro level analysis, an emergency evacuation model has been suggested for a unit area of old Dhaka. Road widening was one of the major undertakings for the selected unit area. In most of the cases, satisfactory results could be obtained through demolishing the boundary walls of individual plot or building. And, partial demolitions of few buildings with necessary retrofitting were necessary to achieve desirable minimum standard.

Emergency response centre (evacuation centre) is the integral part of an emergency route network model. Thus, in the unit part of case studied area, four evacuation shelters were proposed based on population density.Moreover, the suitable location for these shelters were chosen based on distance, building height, building condition, density and most importantly availability of lands on that existing unit area.For this unit area of old Dhaka, required shelters were located beside the accessibility route network which has been identified in macro level analysis.

6.2 Recommendation

Each city should have its own urban-scale emergency route network model that depends on an appropriate starting point of analysis, as demonstrated in this research. All the aspect’s data from the suggested framework should be aggregated into a GIS system to analyse and perform different scenarios for rescue and recovery across different scales, starting from micro to macro scale of the city. The findings of this study clearly depict that open spaces and public buildings can play an important role for reducing the earthquake vulnerability in dense urban areas. The following recommendations can be made from this research in consideration of earthquake vulnerability reduction in an unplanned and densely populated urban area in old Dhaka.

- Based on the method presented in this study an emergency route network for the entire old Dhaka can be prepared.
- The method presented here is not only applicable forold Dhaka but it also can be applied to any other similar vulnerable settlements of an unplanned and organic cities.
- The accessibility network analysis through space syntax method identified hierarchy of street network such as local (neighbourhood), intermediate (between neighbourhood and city scale) and globally (city scale) important routes for rescue and recovery, based on different metric networks like distance, connectivity, road width, land use and building density along them, etc.
- Land use planning is important for hazard mitigation and it can be strictly controlled on the basis of accessibility route network. Besides, it can be redesigned along the main emergency evacuation route, which is identified and designed from the syntactic analysis.
- Varying road width throughout the locality, hierarchy of road width can be maintained for safe rescue and recovery of a community.
- The streets should have a minimum width all the way towards the emergency shelters and open spaces. Minimum road width should be to ensure free movement of a fire fighting vehicle and an ambulance side by side.
- In general, the required size of an emergency shelter is directly related and should be based on the population density of the catchment area. It is advisable to maintain a minimum space requirement of one (01)square meter per person while designing these emergency shelters.
- Due to lower space availability per person than the required square meter area per person, this study suggests that for efficient utilization of the roof spaces of

earthquake resistant public buildings (community buildings) as part of the evacuation shelters in old Dhaka.

- To ensure road widening policy, plot size and building height could be controlled by controlling FAR (Floor Area Ratio) by RAJUK. The road width should be higher in proportion with the population density and building height.
- To make a successful evacuation model for existing dense urban areas, a self-sustained policy is necessary addressing all demolition, renovation, relocation, and retrofitting of buildings and infrastructures. (see Appendix B)
- In order to improve the quality of urban life and for safe rescue, it is recommended that for high dense urban areas like old Dhaka there should be 20-25% open spaces of total built-up areas for each locality
- Moreover, a multi-disciplinary involvement is inevitable to make the recovery plan efficient, where necessary care should be given on every necessary details of retrofitting of existing buildings, life line facilities development, and so on.
- To implement such method, extensive mass awareness program for earthquake vulnerability reduction should be launched. This awareness will enhance the capacity development, which in turn will make the community more resilient. This awareness includes all the concern body of our country. It includes city dwellers, government agencies, design professionals, public authorities, etc.
- To reduce losses from any disaster, community involvement is indispensible to implement the plans, strategies and policies. So, appropriate training program should be developed for the community development along with many design professionals.
- Finally, more academic and empirical researches are needed to understand the issue of earthquake vulnerability reduction in our country.

6.2 Directions for Future Work

Works in this research topic may be expanded in a number of different ways. Some suggestions for further research works emerge from this thesis are as follow:

- There is a great necessity to make respective urban-scale rescue and recovery model for each and every locality of all metropolitan cities in Bangladesh.
- These earthquake vulnerability reduction guidelines can also be identified for the planned urban areas of Bangladesh.
- Moreover, a comprehensive guideline for any newly developed community or locality could be suggested based on further researches.
- Finally, common attributes could be identified from both urban design strategies and urban resilience, which in turn will make not only a liveable city for the dwellers but also reduce the vulnerabilities caused by any disaster.

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Appendices

Appendix A: Movement data for 22 Gates

Saturday

ROAD	NODE	TIME	TALI	NO.
English road (N-S road)	A	09:00-09:05		389
		10:00-10:05		470
		12:00-12:05		453
		02:00-02:05		396
		04:00-04:05		475
		05:00-05:05		499
			total	2682

Monday

ROAD	NODE	TIME	TALI	NO.
English road (N-S road)	A	09:00-09:05		400
		10:00-10:05		438
		12:00-12:05		441
		02:00-02:05		436
		04:00-04:05		492
		05:00-05:05		508
			total	2715

Wednesday

ROAD	NODE	TIME	TALI	NO.
English road (N-S road)	A	09:00-09:05		362
		10:00-10:05		428
		12:00-12:05		422
		02:00-02:05		412
		04:00-04:05		490
		05:00-05:05		476
			total	2590

Saturday

ROAD	NODE	TIME	TALI	NO.
English road (Nawabpur road)	B	09:00-09:05		308
		10:00-10:05		405
		12:00-12:05		375
		02:00-02:05		334
		04:00-04:05		453
		05:00-05:05		422
			total	2297

Monday

ROAD	NODE	TIME	TALI	NO.
English road (Nawabpur road)	B	09:00-09:05		341
		10:00-10:05		420
		12:00-12:05		364
		02:00-02:05		330
		04:00-04:05		469
		05:00-05:05		422
			total	2346

Wednesday

ROAD	NODE	TIME	TALI	NO.
English road (Nawabpur road)	B	09:00-09:05		297
		10:00-10:05		398
		12:00-12:05		373
		02:00-02:05		288
		04:00-04:05		425
		05:00-05:05		469
			total	2250

Saturday

ROAD	NODE	TIME	TALI	NO.
English road (Dholai Khal road)	C	09:00-09:05		267
		10:00-10:05		349
		12:00-12:05		344
		02:00-02:05		256
		04:00-04:05		380
		05:00-05:05		372
			total	1968

Monday

ROAD	NODE	TIME	TALI	NO.
English road (Dholai Khal road)	C	09:00-09:05		243
		10:00-10:05		325
		12:00-12:05		345
		02:00-02:05		301
		04:00-04:05		351
		05:00-05:05		367
			total	1932

Wednesday

ROAD	NODE	TIME	TALI	NO.
English road (Dholai Khal road)	C	09:00-09:05		255
		10:00-10:05		308
		12:00-12:05		365
		02:00-02:05		262
		04:00-04:05		308
		05:00-05:05		326
			total	1824

Saturday

ROAD	NODE	TIME	TALI	NO.
English road (Narinda road)	D	09:00-09:05		278
		10:00-10:05		362
		12:00-12:05		302
		02:00-02:05		268
		04:00-04:05		342
		05:00-05:05		333
			total	1885

Monday

ROAD	NODE	TIME	TALI	NO.
English road (Narinda road)	D	09:00-09:05		241
		10:00-10:05		318
		12:00-12:05		331
		02:00-02:05		304
		04:00-04:05		309
		05:00-05:05		338
			total	1841

Wednesday

ROAD	NODE	TIME	TALI	NO.
English road (Narinda road)	D	09:00-09:05		260
		10:00-10:05		310
		12:00-12:05		319
		02:00-02:05		346
		04:00-04:05		308
		05:00-05:05		296
			total	1839

Saturday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Sharaj Gupta rd)	E	09:00-09:05		368
		10:00-10:05		431
		12:00-12:05		418
		02:00-02:05		343
		04:00-04:05		422
		05:00-05:05		392
			total	2374

Monday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Sharaj Gupta rd)	E	09:00-09:05		349
		10:00-10:05		378
		12:00-12:05		382
		02:00-02:05		327
		04:00-04:05		444
		05:00-05:05		445
			total	2325

Wednesday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Sharaj Gupta rd)	E	09:00-09:05		335
		10:00-10:05		398
		12:00-12:05		365
		02:00-02:05		328
		04:00-04:05		468
		05:00-05:05		420
			total	2314

Saturday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway	F	09:00-09:05		298
		10:00-10:05		365
		12:00-12:05		378
		02:00-02:05		324
		04:00-04:05		380
		05:00-05:05		391
			total	2136

Monday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway	F	09:00-09:05		278
		10:00-10:05		326
		12:00-12:05		369
		02:00-02:05		355
		04:00-04:05		412
		05:00-05:05		390
			total	2130

Wednesday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway	F	09:00-09:05		291
		10:00-10:05		345
		12:00-12:05		351
		02:00-02:05		316
		04:00-04:05		388
		05:00-05:05		395
			total	2086

Saturday

ROAD	NODE	TIME	TALI	NO.
Narinda road (sharaj Gupta road)	G	09:00-09:05		112
		10:00-10:05		161
		12:00-12:05		178
		02:00-02:05		132
		04:00-04:05		168
		05:00-05:05		180
				931

Monday

ROAD	NODE	TIME	TALI	NO.
Narinda road (sharaj Gupta road)	G	09:00-09:05		145
		10:00-10:05		165
		12:00-12:05		161
		02:00-02:05		129
		04:00-04:05		191
		05:00-05:05		180
				971

Wednesday

ROAD	NODE	TIME	TALI	NO.
Narinda road (sharaj Gupta road)	G	09:00-09:05		110
		10:00-10:05		123
		12:00-12:05		146
		02:00-02:05		115
		04:00-04:05		163
		05:00-05:05		171
				828

Saturday

ROAD	NODE	TIME	TALI	NO.
Narinda road	H	09:00-09:05		75
		10:00-10:05		90
		12:00-12:05		136
		02:00-02:05		109
		04:00-04:05		116
		05:00-05:05		110
				636

Monday

ROAD	NODE	TIME	TALI	NO.
Narinda road	H	09:00-09:05		78
		10:00-10:05		123
		12:00-12:05		110
		02:00-02:05		98
		04:00-04:05		134
		05:00-05:05		132
				675

Wednesday

ROAD	NODE	TIME	TALI	NO.
Narinda road	H	09:00-09:05		98
		10:00-10:05		99
		12:00-12:05		145
		02:00-02:05		89
		04:00-04:05		141
		05:00-05:05		134
				706

Saturday

ROAD	NODE	TIME	TALI	NO.
Narinda road (Tipu Sultan road)	I	09:00-09:05		69
		10:00-10:05		93
		12:00-12:05		108
		02:00-02:05		82
		04:00-04:05		108
		05:00-05:05		125
				585

Monday

ROAD	NODE	TIME	TALI	NO.
Narinda road (Tipu Sultan road)	I	09:00-09:05		84
		10:00-10:05		100
		12:00-12:05		106
		02:00-02:05		78
		04:00-04:05		127
		05:00-05:05		135
				630

Wednesday

ROAD	NODE	TIME	TALI	NO.
Narinda road (Tipu Sultan road)	I	09:00-09:05		79
		10:00-10:05		94
		12:00-12:05		97
		02:00-02:05		82
		04:00-04:05		102
		05:00-05:05		105
				559

Saturday

ROAD	NODE	TIME	TALI	NO.
Tipu Sultan road (Dholai khal rd)	J	09:00-09:05		109
		10:00-10:05		147
		12:00-12:05		148
		02:00-02:05		165
		04:00-04:05		152
		05:00-05:05		173
				894

Monday

ROAD	NODE	TIME	TALI	NO.
Tipu Sultan road (Dholai khal rd)	J	09:00-09:05		98
		10:00-10:05		124
		12:00-12:05		168
		02:00-02:05		162
		04:00-04:05		145
		05:00-05:05		132
				829

Wednesday

ROAD	NODE	TIME	TALI	NO.
Tipu Sultan road (Dholai khal rd)	J	09:00-09:05		82
		10:00-10:05		146
		12:00-12:05		151
		02:00-02:05		180
		04:00-04:05		145
		05:00-05:05		142
				846

Saturday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road(Tipu Sultan rd)	k	09:00-09:05		256
		10:00-10:05		378
		12:00-12:05		365
		02:00-02:05		278
		04:00-04:05		318
		05:00-05:05		355
				1950

Monday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road(Tipu Sultan rd)	k	09:00-09:05		234
		10:00-10:05		369
		12:00-12:05		380
		02:00-02:05		219
		04:00-04:05		330
		05:00-05:05		402
				1934

Wednesday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road(Tipu Sultan rd)	k	09:00-09:05		215
		10:00-10:05		360
		12:00-12:05		341
		02:00-02:05		280
		04:00-04:05		305
		05:00-05:05		325
				1826

Sunday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road(Bongshal road)	L	09:00-09:05		285
		10:00-10:05		358
		12:00-12:05		321
		02:00-02:05		367
		04:00-04:05		330
		05:00-05:05		357
				2018

Tuesday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road(Bongshal road)	L	09:00-09:05		245
		10:00-10:05		342
		12:00-12:05		372
		02:00-02:05		290
		04:00-04:05		310
		05:00-05:05		318
				1877

Thursday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road(Bongshal road)	L	09:00-09:05		212
		10:00-10:05		321
		12:00-12:05		330
		02:00-02:05		278
		04:00-04:05		311
		05:00-05:05		310
				1762

Sunday

ROAD	NODE	TIME	TALI	NO.
North-south road(Bongshal road)	M	09:00-09:05		285
		10:00-10:05		340
		12:00-12:05		342
		02:00-02:05		312
		04:00-04:05		356
		05:00-05:05		362
				1997

Tuesday

ROAD	NODE	TIME	TALI	NO.
North-south road(Bongshal road)	M	09:00-09:05		291
		10:00-10:05		298
		12:00-12:05		350
		02:00-02:05		332
		04:00-04:05		369
		05:00-05:05		390
				2030

Thursday

ROAD	NODE	TIME	TALI	NO.
North-south road(Bongshal road)	M	09:00-09:05		303
		10:00-10:05		322
		12:00-12:05		315
		02:00-02:05		356
		04:00-04:05		346
		05:00-05:05		370
				2012

Sunday

ROAD	NODE	TIME	TALI	NO.
North-south road	N	09:00-09:05		118
		10:00-10:05		198
		12:00-12:05		248
		02:00-02:05		223
		04:00-04:05		284
		05:00-05:05		289
				1360

Tuesday

ROAD	NODE	TIME	TALI	NO.
North-south road	N	09:00-09:05		98
		10:00-10:05		201
		12:00-12:05		259
		02:00-02:05		245
		04:00-04:05		291
		05:00-05:05		276
				1370

Thursday

ROAD	NODE	TIME	TALI	NO.
North-south road	N	09:00-09:05		103
		10:00-10:05		167
		12:00-12:05		253
		02:00-02:05		289
		04:00-04:05		311
		05:00-05:05		289
				1412

Sunday

ROAD	NODE	TIME	TALI	NO.
North-south road	O	09:00-09:05		419
		10:00-10:05		476
		12:00-12:05		564
		02:00-02:05		489
		04:00-04:05		591
		05:00-05:05		601
				3140

Tuesday

ROAD	NODE	TIME	TALI	NO.
North-south road	O	09:00-09:05		431
		10:00-10:05		532
		12:00-12:05		456
		02:00-02:05		532
		04:00-04:05		640
		05:00-05:05		619
				3210

Thursday

ROAD	NODE	TIME	TALI	NO.
North-south road	O	09:00-09:05		464
		10:00-10:05		498
		12:00-12:05		389
		02:00-02:05		476
		04:00-04:05		698
		05:00-05:05		675
				3200

Sunday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road (BCC road)	P	09:00-09:05		144
		10:00-10:05		232
		12:00-12:05		247
		02:00-02:05		198
		04:00-04:05		306
		05:00-05:05		327
				1454

Tuesday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road (BCC road)	P	09:00-09:05		138
		10:00-10:05		210
		12:00-12:05		239
		02:00-02:05		204
		04:00-04:05		301
		05:00-05:05		303
				1395

Thursday

ROAD	NODE	TIME	TALI	NO.
Nawabpur road (BCC road)	P	09:00-09:05		156
		10:00-10:05		198
		12:00-12:05		261
		02:00-02:05		237
		04:00-04:05		335
		05:00-05:05		319
				1506

Sunday

ROAD	NODE	TIME	TALI	NO.
BCCr road (Bongram road)	Q	09:00-09:05		134
		10:00-10:05		198
		12:00-12:05		178
		02:00-02:05		176
		04:00-04:05		206
		05:00-05:05		245
				1137

Tuesday

ROAD	NODE	TIME	TALI	NO.
BCCr road (Bongram road)	Q	09:00-09:05		109
		10:00-10:05		178
		12:00-12:05		197
		02:00-02:05		234
		04:00-04:05		249
		05:00-05:05		278
				1245

Thursday

ROAD	NODE	TIME	TALI	NO.
BCCr road (Bongram road)	Q	09:00-09:05		131
		10:00-10:05		189
		12:00-12:05		168
		02:00-02:05		235
		04:00-04:05		271
		05:00-05:05		288
				1282

Sunday

ROAD	NODE	TIME	TALI	NO.
Bongram road (Mohon B.)	R	09:00-09:05		107
		10:00-10:05		115
		12:00-12:05		104
		02:00-02:05		89
		04:00-04:05		111
		05:00-05:05		119
				645

Tuesday

ROAD	NODE	TIME	TALI	NO.
Bongram road (Mohon B.)	R	09:00-09:05		110
		10:00-10:05		103
		12:00-12:05		114
		02:00-02:05		99
		04:00-04:05		131
		05:00-05:05		124
				681

Thursday

ROAD	NODE	TIME	TALI	NO.
Bongram road (Mohon B.)	R	09:00-09:05		98
		10:00-10:05		121
		12:00-12:05		97
		02:00-02:05		115
		04:00-04:05		134
		05:00-05:05		145
				710

Sunday

ROAD	NODE	TIME	TALI	NO.
Hare Street (Fazle R. road)	S	09:00-09:05		156
		10:00-10:05		187
		12:00-12:05		134
		02:00-02:05		187
		04:00-04:05		234
		05:00-05:05		214
				1112

Tuesday

ROAD	NODE	TIME	TALI	NO.
Hare Street (Fazle R. road)	S	09:00-09:05		182
		10:00-10:05		178
		12:00-12:05		160
		02:00-02:05		148
		04:00-04:05		246
		05:00-05:05		259
				1173

Thursday

ROAD	NODE	TIME	TALI	NO.
Hare Street (Fazle R. road)	S	09:00-09:05		196
		10:00-10:05		193
		12:00-12:05		170
		02:00-02:05		132
		04:00-04:05		230
		05:00-05:05		267
				1188

Sunday

ROAD	NODE	TIME	TALI	NO.
Tipu Sultan road (rankin street)	T	09:00-09:05		125
		10:00-10:05		143
		12:00-12:05		156
		02:00-02:05		139
		04:00-04:05		187
		05:00-05:05		181
				931

Tuesday

ROAD	NODE	TIME	TALI	NO.
Tipu Sultan road (rankin street)	T	09:00-09:05		131
		10:00-10:05		158
		12:00-12:05		152
		02:00-02:05		126
		04:00-04:05		161
		05:00-05:05		198
				926

Thursday

ROAD	NODE	TIME	TALI	NO.
Tipu Sultan road (rankin street)	T	09:00-09:05		142
		10:00-10:05		138
		12:00-12:05		159
		02:00-02:05		142
		04:00-04:05		179
		05:00-05:05		172
				932

Sunday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Narinda road)	U	09:00-09:05		279
		10:00-10:05		347
		12:00-12:05		302
		02:00-02:05		268
		04:00-04:05		342
		05:00-05:05		333
				1871

Tuesday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Narinda road)	U	09:00-09:05		241
		10:00-10:05		318
		12:00-12:05		331
		02:00-02:05		304
		04:00-04:05		309
		05:00-05:05		338
				1841

Thursday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Narinda road)	U	09:00-09:05		260
		10:00-10:05		310
		12:00-12:05		319
		02:00-02:05		346
		04:00-04:05		308
		05:00-05:05		296
				1839

Sunday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Fazle Rabbi rd)	V	09:00-09:05		135
		10:00-10:05		181
		12:00-12:05		138
		02:00-02:05		119
		04:00-04:05		159
		05:00-05:05		192
				924

Tuesday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Fazle Rabbi rd)	V	09:00-09:05		118
		10:00-10:05		176
		12:00-12:05		162
		02:00-02:05		141
		04:00-04:05		164
		05:00-05:05		159
				920

Thursday

ROAD	NODE	TIME	TALI	NO.
Dhaka highway (Fazle Rabbi rd)	V	09:00-09:05		104
		10:00-10:05		192
		12:00-12:05		135
		02:00-02:05		126
		04:00-04:05		151
		05:00-05:05		175
				883

Appendix B: Brief Description of Selected Legislations and Policies

Playground, Open Space and Water body Preservation Act for Urban Area, 2000

The main objective of this act is to protect and preserve the playground, open space, park and natural water bodies within the boundary of mega cities, divisional towns and municipalities of district towns. These places should be properly designated in the master plan or demarked by the government. Rivers, channels, stream, wet land, flood plains, and retention pond are included in the scope of water bodies. These places should not be used other than their designated uses and should be preserved and protected in such a way so that those can have their designated functions. Even any change or alternation should not be allowed.

National Disaster Management Policy 2008 (Draft)

The National Disaster Management Policy (Draft) defines the national policy on disaster risk reduction and emergency response management, and describes the strategic policy framework, and national principles of disaster management in Bangladesh. The overall national objectives in this regard are:

To reduce the underlying risks by

• Integrating disaster risk reduction approaches and climate change adaptation in all ongoing and future development plans, programs and policies.

• Enhancing professional skills and knowledge of key personnel on risk reduction, preparedness, warning and forecasting system, climate change risk reduction and post disaster activities

• Strengthening mechanisms to build capacities for the Community and Institutions at all levels Community based Programming for risk reduction.

• Promote and facilitate the incorporation of longer term disaster risk reduction due to climate change into disaster management

• Promote livelihood strategies and options for poor that incorporates disaster management and risk reduction practices

• Strengthen capacities for risk assessment for flood, cyclone, drought, river bank erosion, pest attacks, earthquake, epidemics, including assessment of climate change risk.

To establish and strengthen the systems and procedures for effective response management through

• Creating a legal and institutional framework for effective response management

• Strengthening national capacity for response management with emphasis on preparedness and support to disaster management committees at district, upazila and union levels

• Improving the early warning and community alerting system

• Strengthening search and rescue capabilities of relevant agencies

• Introducing an effective response management coordination mechanism including a relief management logistic system to handle different levels of emergency response

• Establishing an electronic based information management system (DMB and MoFDM, 2008)

Disaster Management Act 2008 (Draft)

Still this act is not enacted, it is in draft format. Its main objective is to have an act to reduce the risk of people from the effects of natural, environmental and human induced hazards to a manageable and acceptable humanitarian level, and to have in place an efficient emergency response system capable of handling large scale disasters for the whole Bangladesh. It provides the legislative format for the administrative organization to help communities to mitigate the potential adverse effects of hazard events, prepare for managing the effects of a disaster event, effectively respond to and recover from a disaster or an emergency situation, and adapt to adverse effects of climate change. It is supposed to provide a national disaster management plan.

It defines the clause to Declare of the State of Disaster and Disaster Area. It also defines the Powers and Responsibilities of Various Authorities, Organizations and Individuals; Offences, Penalties and Procedure and financial arrangement for various steps of disaster management.

National Plan for Disaster Management 2008-2015 (Draft)

Still this plan is also in draft format. This plan has been developed on the basis of the vision of the Government of Bangladesh and the mission of Ministry of Food and Disaster Management with the following objectives:

To align the strategic direction of disaster management programs with national priorities and international commitments.

To articulate the vision and goals for disaster management and to outline the strategic direction and priorities to guide the design and implementation of disaster management policies and programs.

To create a cohesive and well-coordinated programming framework incorporating government, non-government and private sector.

To ensure that disaster management has a comprehensive program for all kind of hazards comprising disaster risk reduction and emergency responses.

To illustrate to other ministries, NGOs, civil society and the private sector how their workcan contribute to the achievements of the strategic goals and government vision on disaster management.

This is an umbrella plan which provides the overall guideline for the relevant sectors and the disaster management committees at all levels to prepare and implement their areas of roles specific plans. It has suggested preparing hazard specific management plans, such as Flood Management Plan, Cyclone and Storm Surge and Tsunami Management Plan, Earthquake Management Plan, Drought Management Plan, River Erosion Management Plan, etc. for each administrative areas.

The Acquisition and Requisition of Immovable Property Ordinance of 1982

It allows having compulsory acquisition of private land for public purpose, on payment of compensation at average market price of past one year. The main purpose of Land Acquisition department is to acquire land for different projects of RAJUK. When Land Acquisition get notice/request of acquisition from the planning department, Land acquisition department opens a land acquisition file for the project and takes necessary steps. This case information includes land requirement, nature of the land, detail description of project and structure etc. According to the site map from the Town planning department the land department makes detail index to estimate amount of land to be acquired and also identifies the exact location. After estimating of the compensation based on the area of acquisition and infrastructure of the affected plot, Total compensation against the estimate is paid by RAJUK. After getting possession certificate RAJUK handovers the project to project development department.