ANALYZING POPULATION DISTRIBUTION AND ITS EFFECT ON EARTHQUAKE LOSS ESTIMATION IN SYLHET, BANGLADESH

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March, 2013

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ABSTRACT

Bangladesh is vulnerable to earthquakes. The frequency of earthquake events is increasing and information from historical earthquake events suggests that Bangladesh may well be affected by a strong earthquake in the near future. Disaster risk assessment helps to estimate the probable loss of property and human life. During risk assessment it is necessary to consider and analyse the impact of the temporal distribution of the population living in an earthquake prone area. Buildings are always exposed to the threat of earthquake hazard while people and other moveable elements are not. The duration that people stay in their houses or work places needs to be calculated. The main objective of this study was to distribute the population and loss estimation for a possible earthquake event in the city of Sylhet. The population distribution modeling was done for four different temporal scenarios: a regular week day, a strike day, a weekly holiday and a Ramadan day, for every two hour interval in a day. To distribute the people in each building a relationship between the occupancy class and average space per person (person/ 100 m^2) was used and then the population loss was estimated for each of the temporal scenarios. For the distribution modeling only people inside buildings were considered. This study also analysed the uncertainty of population data per building occupancy type in an existing dataset, which was evaluated as very high. The analysis results show that the spatial distribution of the population in the different temporal scenarios varies due to their distinct characteristics. As a result also the population loss estimation varies. For loss estimation CAPRA vulnerability curves (for human) were used to get the mean death ratio. The relationship between building type and injury severity level was taken from the HAZUS approach. The result shows high population loss for different earthquake scenarios. This study has found that less people are present in buildings in a regular week day from 2PM to 4PM, with less potential population loss as a consequence. In a Ramadan day the periods from 6PM to 8PM and from 8PM to 10PM show less population loss than other time period. In this time period many people might be in the streets. From all the considered temporal scenarios, the weekly holiday shows both the lowest loss in day-time and night-time. The lowest loss at night-time was found for the strike day. The study also shows that the population loss estimation depends on other factors, such as the number of trapped people in different building types, and the earthquake intensity at the location of a particular building.

Key words: earthquake, population distribution, population modeling, loss estimation, temporal scenarios, day-time, night-time.

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LIST OF ABBREVIATION

BBS	Bangladesh Bureau of Statistics
CDMP	Comprehensive Disaster Management Program
CIESIN	Center for International Earth Science Information Network
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GIS	Geographic Information System
GPW	Gridded Population of the World
GRUMP	Global Rural Urban Mapping Project
HAZUS-MH	HAZUS Multi Hazard
MDR	Mean Death Ratio
NRC	National Research Council
PE	Exceedance of probability
PGA	Peak Ground Acceleration
RCC	Reinforced Cement Concrete
RS	Remote Sensing
UDD	Urban Development Directorate
UN	United Nations

1 INTRODUCTION

1.1 Background of the research

Earthquakes are one of the most devastating and unpredictable (in time) events that cause substantial loss of life and property damage. Earthquakes may cause economic losses in developing countries that form a larger percentage of their gross national products (GNP) than those that occur in developed countries (Tucker et al., 1993). The impact of an earthquake depends on the number of factors such as earthquake magnitude and depth, distance to the populated area, density of population, building types and the time of occurrence. An earthquake-prone area with high population density and non-earthquake resistant buildings has a high chance of having more loss of life and properties Risk assessment can help to understand the possible losses in such areas and forms the basis of risk reduction planning. Risk is a function of the probability of a hazardous event and the vulnerability of the exposed elements.

A risk assessment can be done either in a qualitative, semi-quantitative or quantitative manner. The suitability of an assessment approach depends on the available input data, required results and on the nature of the risk problem (Dai et al., 2002). However for decision-making regarding risk reduction measures, a quantitative analysis of the level of losses and the effects of risk reduction measure is very important. The extent of the risks and the effects of risk reduction measures can be quantified in a quantitative risk assessment (QRA), as a basis for Cost-Benefit Analysis. Therefore the quantitative approach can provide a basis for rational decision-making regarding risks (Jonkman et al., 2003). For risk evaluation and decision making process the risk to loss of life has an important role (Jonkman et al., 2010; Jonkman, et al., 2003). Different damage and loss estimation techniques are used to quantify the potential social and economic losses from an earthquake. These quantification processes are very complex but are a useful tool for developing an emergency preparedness plan and reducing seismic risk for future (Agrawal & Ajay, 2004). The loss estimation can be done by methods using GIS and remote sensing techniques (Chen et al., 1998), using GDP and population distribution data (Chen et al., 1997; Dunbar et al., 2003) and a specialized computer based modeling approach. These methodologies give the information about the physical loss, social loss and economic loss caused by an earthquake. By using high-resolution images and geographic information systems, it is possible to assess the building damage and associated population losses. It helps to determine where risk reduction measures should be taken to reduce the loss.

There are different earthquake loss estimation software tools available worldwide, based on the scale of the assessment that are developed for a local, regional and global scale. There are two basic components for loss estimation study. One is the earthquake hazard analysis which involves the identification and quantitative description of the earthquake that can be used for loss estimation. The second component is the vulnerability analysis, which includes the vulnerability of the building, population, lifelines and emergency facilities (NRC, 1989). The difference is in the scale of analysis, data requirement and designing in the modeling steps. These tools generally require sophisticated expert knowledge on earthquake ground motion, attenuation, seismicity, soil characteristics etc.

Researchers are giving emphasis on carrying out earthquake loss estimations for different time periods of a day as the population distribution is very different in a day-time and night-time situation. Alexander (1996) concluded that the risk of injury varies significantly between night and day when an earthquake occurs,

which leads to the recommendation that vulnerability and exposure should be assessed in this temporal cycle. Due to the human activity in the urban area, day-time and night-time distribution and density of the people varies considerably. For disaster management and planning it is required to consider the population distribution over time.

Bangladesh is vulnerable to earthquakes because of its geographical location, as it is surrounded by regions of high seismicity. There is a joining point of two plates: the Indian plate and the Eurasian plate in the north of Bangladesh, and another joining point of two plates: Barmiz plate and Indian plate in the east of Bangladesh. The Indian plate is moving in north-east direction and Barmiz plate is moving in north-west direction. Bilham et al.(2001) predicts that because of the movement of these plates, the possibility of higher magnitude earthquake might hit the Himalayan region in Nepal, India, Bangladesh etc. There are several fault zones active in this joint area, which are the sources of earthquakes. The historical earthquake record suggests that since 1900 more than 100 moderate to large earthquakes (Magnitude 6-8.5) have occurred in Bangladesh (Khan, et al., 2001) . Based on the severity of the probable seismic ground motion and damages, the country is divided into three seismic risk zones (see Figure 1-1). Among these, zone I is most active (HBRI-BSTI, 1993). The study by CDMP concludes that if a moderate to strong earthquake hits the major cities like Dhaka, Chittagong and Sylhet city, there will be disastrous consequence in the entire nations (CDMP, 2009b).

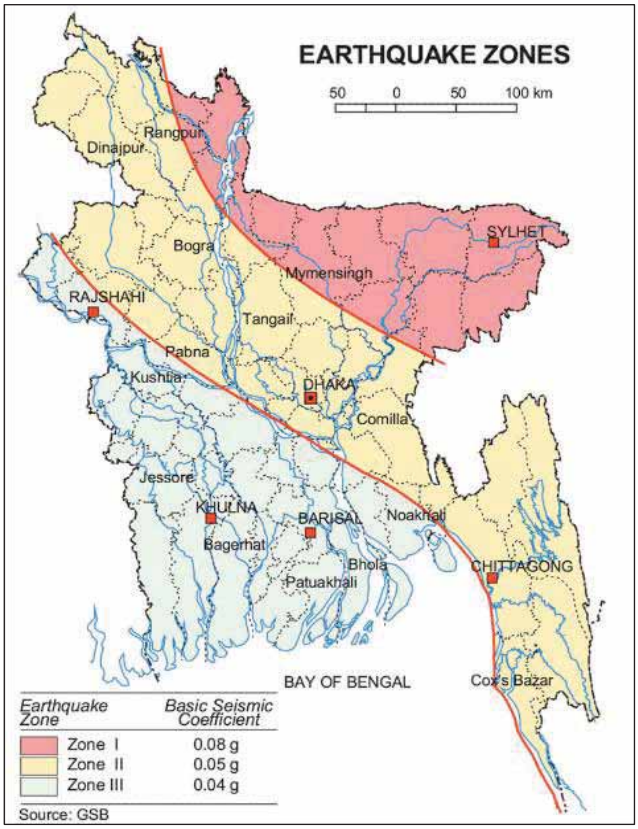


Figure 1-1: Earthquake zone map of Bangladesh
(Source:http://mapofbangladesh.blogspot.nl/2011/10/bangladesh-seismicearthquake-zones.html)

Loss estimation studies provide information to the authorities about the impact of the different possible scenarios, both in terms of earthquake sources and the time period that the earthquake may hit. Apart from a day-time and night-time scenario, also other scenarios should be evaluated which have very different population patterns, such as a strike day or a Ramadan day.

1.2 Problem statement

In this research, the effect of population distribution over different temporal scenarios on loss estimation will be carried out for Sylhet city in Northeastern Bangladesh. Sylhet is located in one of the most active seismic zones (zone I) of the country (see Figure 1-1), which is surrounded by plate boundary fault lines (PBF) and the Dauki fault lines (DF) (see Figure 1-2). During the last 150 years, three earthquakes (with magnitude larger than 7.5 on the Richter scale) have occurred in this area (Ansary, 2002). The municipality of Sylhet has been converted to a City Corporation in 2001 and became the center of the north-eastern part of Bangladesh. As a result, the urbanization rate is increasing without proper planning guidelines and regulation. Buildings are designed and constructed without proper enforcement, which may cause extensive damage in future earthquakes. Considering the existing situation of this city, a study on the

status of the buildings and detailed population analysis is required to estimate the expected damage for buildings and population loss due to an earthquake. For accurate population loss estimation, the spatiotemporal distribution of population is required to be modeled for different time periods. As an earthquake may hit anytime of the day and the population loss depends upon the spatial and temporal distribution, a population modeling approach can assist in the estimation. This information is also required to design the emergency response plan and risk reduction.

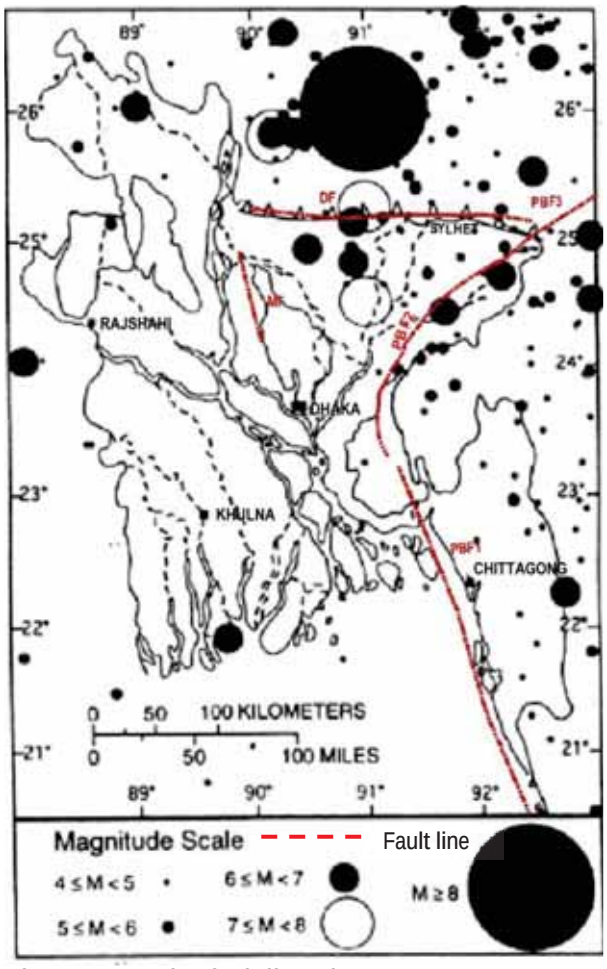


Figure 1-2: Active fault lines (PBF1, PBF2, PBF3, MF and DF) and historical earthquake location in Bangladesh
Source: (CDMP, 2009c; Khan et al., 2001)

A recent initiative (in 2009) of the Ministry of Food and Disaster Management of Bangladesh and UNDP, DFID and EC resulted in the Comprehensive Disaster Management Program (CDMP) phase I. The aim of this program was to strengthen the disaster management system in Bangladesh, to analyse the earthquake hazard, vulnerability of buildings, people and other elements at risk and then carry out a scenario-based risk assessment in three major cities in Bangladesh (CDMP, 2009a). In this study, the HAZUS software was used. For casualty estimation, day-time and night-time population data along with census data has been used. The population distribution analysis was done with a large degree of uncertainty, resulting in a relatively large range of casualty estimates. However loss estimation process is not only depends on the population exposure but also it depends on assessment of the hazard and vulnerability of the society. There is also uncertainty involves in ground motion intensity and failure and building damage. However more detailed population distribution and their variability over the space and time can provide reliable loss estimation source and the uncertainty can be minimized from this part. This gives the idea about the casualty; therefore it assists the planning authority to take decision about risk reduction measures, preparedness and response planning for the earthquake prone area.

This research will focus on modeling the population distribution within the city of Sylhet and will pay specific attention to special buildings (schools and mixed-use buildings) where at a daily basis the number of people can change considerably over time.

1.3 Objectives and research questions

The main objective of the research is to model the population distribution within an urban area for different temporal scenarios (the day and year) and apply it to the city of Sylhet in Bangladesh. To achieve this objective a series of specific objectives and related research questions were formulated (see table 1-1).

Table 1-1: Research objectives and corresponding research questions

Specific research objectives	Research questions
1. To model the day-time and night-time population using existing data sets and evaluate the level of uncertainty.	a) How large is the uncertainty in population distribution?
	b) What are the reasons for internal inconsistencies the population data?
2. To improve the population distribution modeling using newly collected data	a) To what extent can the population distribution be improved by incorporating more information on schools and mixed-use buildings?
	b) Is it possible to include the large variation in population density per occupancy class in the modeling and what is the overall effect?
3. To model the population distribution in the whole city for different temporal scenarios	a) Which temporal scenarios can be identified that have a very different population distribution throughout the year?
	b) What method can be used to evaluate the population distribution for different temporal scenarios?
	c) How many people are expected to leave the city or enter the city from outside in each of the temporal scenarios?
	d) How many people are expected to be in the streets and in the open in comparison with people in the buildings in the different scenarios?
4. To analyze the impact of changes in population distribution for the different scenarios on the population loss estimation	a) How the population loss estimation effected by changes in population?

1.4 Concept of the research

Many human beings are exposed to hazard, of which seismic hazards are especially dangerous in areas where buildings are not constructed in a proper anti-seismic manner. The risk assessment process it is not complete without taking into account the people (Freire & Aubrecht, 2012). The definition of risk assessment incorporates hazard probability, vulnerability of the elements at risk and the amount of exposed elements at risk, which is shown below:

$$\boldsymbol{Risk = Probability\ of\ a\ Hazard\ with\ certain\ intensity \times Degree\ of\ loss\ to\ elements\ at\ risk \times Amount\ of\ elements\ at\ risk}$$

If any of the component misestimates in this relationship the risk assessment result will be affected. This study will focus only on one component of above equation, the number of exposed people. If the amount of population varies temporaly and the hazard remains constant there will be significant changes in the risk. The vulnerability of the people is related to where people are: in which types of buildings, or in the open and therefore also changes together with the population distribution. People in open areas are less vulnerable. They become more vulnerable when they move into narrow streets surrounded by brick-buildings, and they become even more vulnerable when they enter these buildings and move to the third floor. In this study population in day-time and night-time will be estimated using average values for the number of persons per unit floor space area and then the total day and night population will be distributed to different time periods of the day (2 hours interval) and also to different scenarios in a year based on some assumptions. The variations in the population exposure maps for different scenarios of the year are expected to cause potentially large differences during an earthquake. Therefore such scenarios should be taken into account in designming risk reduction measures, e.g. awareness campaigns, and disaster response planning.

1.5 Methodology of the research

The research is mainly based on existing data which were used to calculate the day-time and night-time population. After that the data were evaluated and a field survey in the study area was made to collect additional data on schools and mixed-use buildings. Due to time limitations the data collection only focused on two occupancy classes. To get a better understanding of the population dynamics in different occupancy classes, two hour interval data were collected during the field survey. From the mixed-use occupancy, the dynamics of population in residential and commercial building were extracted. Expert judgement was applied to model the population in different temporal scenarios. In the final stage, the population loss was estimated and the effect of population changes in different time period was analysed on the loss. See Figure 1-3 for the main methodological steps in the research. The details are discussed in the respective chapters.

1.6 Structure of the research

Chapter 1 provides briefly the background of the research, and describes the research problem. After describing the problem, research objectives and questions were defined with the overview of the main methodological steps (or research framework).
Chapter 2 gives a literature review regarding population distribution modeling and loss estimation techniques from previous research.
Chapter 3 discusses about the study area, its location, demographic information, earthquake scenario of the area, and results from the CDMP study on risk assessment.
Chapter 4 details about the data collection process in the field, preparation and finally the analysis process to achieve the objectives of the research.
Chapter 5 discusses about evaluation of the existing data and validation; and comparison of the results from the existing data and improved data and population distribution in different occupancy classes based on the field work
Chapter 6 provides the population distribution modeling approaches for different scenarios. It tries to explain the factors which might affect the population distribution in different period of the day.
Chapter 7 discusses about the impact of the population distribution in loss estimation for different earthquake scenarios.
Chapter 8 states the conclusion, limitations and recommendations based on the analysis.

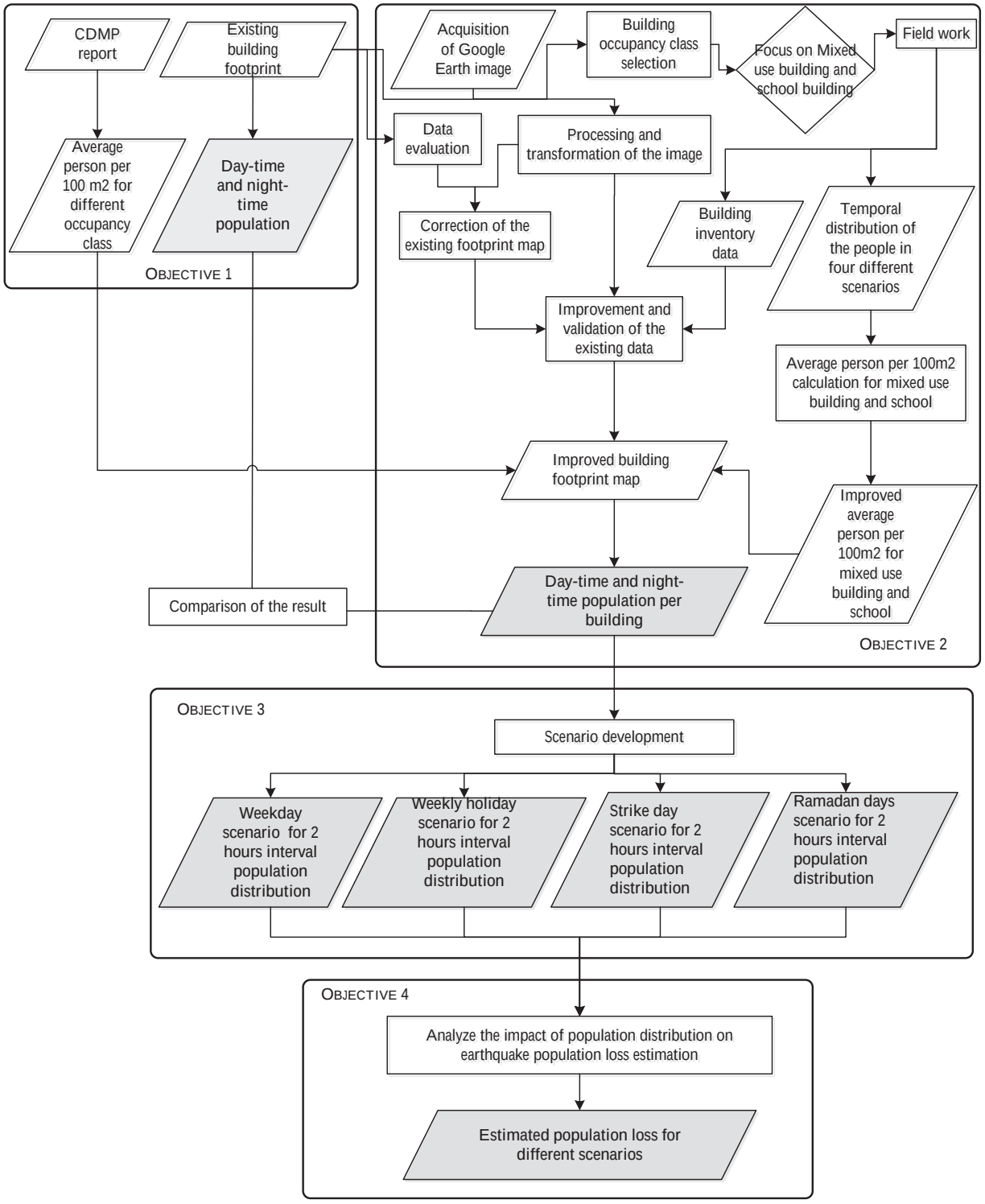


Figure 1-3: Flowchart of the main task in the research
(the dark box indicates the main results)

2 LITERATURE REVIEW

This chapter provides a short literature review on different approaches for population distribution modeling and the effect of the population dynamics on earthquake risk assessment. One section of the review focuses on process of census data collection in Bangladesh and its limitations.

2.1 Population distribution

Population distribution means the pattern of settlement and dispersal of a population (PRB, 2013). It is highly important to know the spatial location of people in order to understand the impact of any natural disaster. It is also important for different kinds of studies especially for sustainable planning, socio-economic development, disaster mitigation, preparedness, emergency rescue, risk reduction etc. For damage assessment (specifically for unpredictable and rapid types of hazard e.g. earthquake hazard), detailed building inventory databases with population data are very important (Freire, 2010).

2.1.1 Factors affecting population distribution in urban area

Population distribution is related to different socio-economic factors, physical factors, natural resources, cultural factors, political factors etc. The land use, land cover, elevation, distance to city centre, height of the buildings and many other factors have an impact on the population distribution. In urban areas the population distribution varies due to the activity pattern of the people. It also depends on the distribution of the demographic groups in the area. Du et al.(2006) analyses the causes and characteristics of population distribution in urban areas. The statistical analysis shows that the distribution of different public sector facilities (e.g. school, collage, hospital, market, government office etc.) and infrastructures have also an important effect on the population distribution.

2.1.2 Sources of population data

The main source of population data can be categorized in two classes: local or factual and global or proxy estimation. Local population data sources include national census of a country, death and birth registration or sample demographic survey by any organization and the use of mobile phone network. The global or proxy estimation population data sources are for instance GPW, LandScan, GRUMP etc. These datasets are big interest for different professionals like urban and rural planners, sociologist, and agriculturist (FAO, 2005). Figure 2-1 shows different types of population data sources.

Usually the census data is available at the administrative level or census tract level and sometimes census organization keeps the data as confidential. It is not possible to get the building by building population data from a census. Mainly census gives the population data in residence or dwelling basis and aggregates it as census tract and the data represents the night-time population of the tract. But it does not take into account the daily migrations or movements of people to workplaces, schools or shopping centres. The residential population databases are useful for the purposes of exposure assessment if it is assumed that the majority of the people are in their home. Since the census data represents the night-time population as residential people, therefore, the use of these population data in population casualty estimation will produce considerable error for day-time scenarios (Bhaduri, 2010; McPherson & Brown, 2004). This issue demands to acquire the data of non- residential population distribution as well. Another important aspect of census data is, for some countries the population data is not available at block level. Therefore the accurate assessment of the number of affected people and building became difficult by using the census data.

There is also a great possibility of overestimation or underestimation of the people and application of this data in disaster management and planning will be negatively influenced. Therefore it is required the up-to-date information which can help to take vital decision on disaster preparedness, relief, rehabilitation process etc. For example in Pakistan during the earthquake in October 2005, the census data were seven years old and out-dated. Usually the population census is made every ten years. So it didn't represent the proper population characteristics of the affected area (NRC, 2007) . However there are advantages of census data e.g. it collects demographic and socio-economic aspects which are useful for urban planning, environmental impact assessment, emergency preparedness and response etc.(Bhaduri, 2007).

Another source of population data is registration based statistics instead of census. There are few examples of registration based (administrative data) population data such as Belgium, Finland, the Netherlands, and Switzerland in Europe. In Netherlands all municipalities have a central population registration system. It has also a registration which covers the working group and another is social security administrations registration. After that all the informations are integrated or compiled and it is named as virtual census. This registry system helps to get the total number of population with varieties of information (demographic information, commuting people, working people, etc.) in each municipality even in each building (Statistics Netherlands, 2004; Surkyn, 2006). The advantage of this system is i) per building information ii) availability of the data iii) less cost.

Recently another source of the population data is from the mobile phone companies. Some researchers are working on this to estimate the population data in space and time of the day. The cell phone network and call detail records gives the real time population dynamics in the city (Becker et al., 2011; Pulselli et al., 2008).

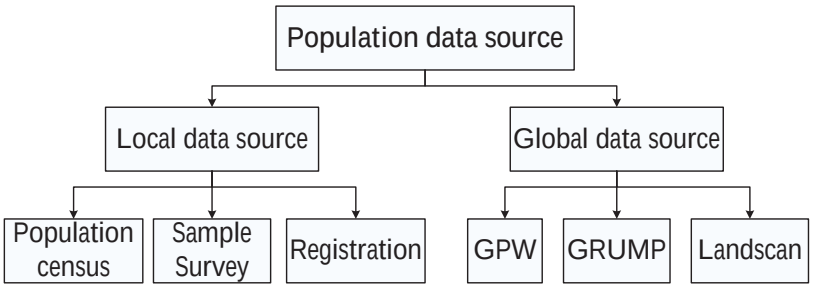


Figure 2-1: Existing population data sources

Source: (FAO, 2005)

Researchers and different international organization (e.g. UN, IPC) have been working to produce an international or global population database. The primary source of population data are UN and US census bureau (IPC). UNSD also provides data on the population of capital cities. There are also some well know geo-referenced population distribution data sources available like as GPW,GRUMP, LandScan global population database etc. Different types of global population datasets are described briefly:

The GPW is the first initiative to generate global population dataset in 1995 by National Centre for Geographic Information Analysis. It uniformly distributes the population to each grid cell of an administrative unit. It uses very simple area weighting method for distribution of the people by using the census data. The main limitation of this dataset is that its spatial resolution is very coarse (2.5 arc-minutes) (FAO, 2005).

The LandScan global data base is developed by the Oak Ridge National Laboratories (ORNL) in 1998 to overcome the limitations of the GPW database. The spatial resolution of this data set is 3 arc seconds (90 meters) which is one of the finest resolution dataset. This dataset uses the Night-time Lights and satellite imagery for land cover data. It distributes the population by land cover category. For each

category of land cover there is coefficient value for population but this coefficient value differs from country to country and even one region to another within the same country. One of the aims to develop this dataset is to assist in emergency management (FAO, 2005).

GRUMP is a recent initiative by the CIESIN and other partners organization such as the International Food Policy Research Institute (IPFRI), the World Bank and the Centro Internacional de Agricultura Tropical (CIAT). It gathers the data as points and each point has latitude and longitude and associated population. From this method the data is derived through simple dasymetric modeling. The main advantage of this dataset is that it uses the census data and city population from respective country. It does not use the Night-time Lights to identify the urban and rural areas instead of this it uses different GIS technology (FAO, 2005).

From the above discussion it is clear that there are several population data sources and each of them has strengths and limitations. In case of census data, sometimes it became out-dated or old with respect to the research period, which does not express the real scenario of that time. Again some other data sets cover large scale area, but for the small scale analysis these data sets are not suitable for accurate result. Based upon the requirement researchers are working to adapt or improve these source of dataset for relevant work. In the section 2.3 and 2.4 different population distribution modeling approaches are discussed which uses these population data as main source or input.

2.2 Role of population distribution in earthquake risk assessment

For any kind of disaster (natural or man-made), the impact on human beings is the most important component. It is necessary to protect the life of human beings from disasters. Since the risk assessment depends on the number of exposed people and their vulnerability, it is required to know the updated and detailed population exposure data of an area which assists to make decision for all phases of disaster management. The fine scale population data provides an accurate estimation of the affected population (Deichmann et al., 2011). The spatial and temporal distribution of the population data gives more advantage to disaster management planning (e.g. determination of how much, where and what kind of response is required, which socio-economic groups are mostly affected) (Freire, 2010; NRC, 2007; Sutton et al., 2003). Since earthquake is the most unpredictable natural event which occurs instantaneously but the impact lasts for long and causes lot of social losses (e.g. injury, casualty etc.). Some of the disasters (e.g. fires or explosions) have an impact area that is as small as neighbourhood or single building even. Thus it is essential to know the spatial and temporal distribution of the people in a fine resolution. The National Research Council (NRC) stated that the quality and level of population data have a direct effect on the quality of the response and the number of lives saved due to disaster (NRC, 2007)

2.3 Population distribution modeling in space

There are different approaches available from the literature and it reflects the complex nature of the population data. It is evident that there is no single best method for population distribution. Each method has its own strengths and purpose to use. The various types of methods are: choropleth method, areal interpolation method, dasymetric method, and statistical approach for population distribution in urban area (Bhaduri, et al., 2007; Holt et al., 2004; Langford et al., 2008; Wu et al., 2005).

a) Choroplethic mapping

Choroplethic approach is a cartographic approach for population distribution in a given area. This is one of the simplest approaches for distribution of population in space. When there is no other information

available, this model is a good choice (Langford, et al., 2008). However this method is widely used by the users to display the population distribution in space.

Advantages

- Easy to compute in GIS
- Easy to interpret for non- technical persons about the population density in an area

Disadvantage

- It does not take into account the potential variations in density due to scale and boundary effects
- It gives an impression of abrupt changes at the boundaries of administrative areas (such as wards or census tracts), while representing population as a continuous variable across the entire mapping unit.
- It overestimates population density in unpopulated and sparsely populated areas and underestimates population density in densely populated areas (Holt, et al., 2004).

b) Dasymetric mapping

This approach is also like choroplethic mapping but there is a difference in the boundaries of the administrative units. In the dasymetric mapping, the administrative areas are divided into smaller spatial units and then the socio-demographic variables (e.g. population) are averaged to obtain a rate e.g. population density. Both the choropleth and dasymetric mapping are good for cartographic representation. From the literature it was found that recently researchers are using this technique for the population distribution with the GIS and RS technology along with census data (e.g. (Bhaduri, et al., 2007; Chen et al., 2004; Mennis, 2003). Langford and his colleagues used this approach for generating the raster population surfaces (1 Km resolution) with census data and Landsat TM image (to extract land use) for Leicestershire in U.K in 1991 (Mennis, 2003).

The dasymetric method provides more precise population density data than the choroplethic method (Holt, et al., 2004). LandScan global database is also based on the dasymetric approach. In this database the census data is the main data and census blocks are subdivided into finer grid cells (30 meters) (Bhaduri, et al., 2007). Then the total population in a block is allocated in each cell proportionally. The relative weight (or coefficient) is distributed to the cell based on some indicators like road networks, slope, land cover, night-time light etc. and their availability (Dobson et al., 2000). The probable coefficient for each cell is calculated in following way:

- Roads: weighted by distance from cells to roads;
- Slope: weighted by favourability of slope categories;
- Land Cover: weighted by type with exclusions for certain types; and
- Night-time Lights of the World: weighted by frequency.

A multi- layer multi-class framework is a more specific dasymetric mapping approach, which is better to redistribute the census populations spatially and provides more realistic population distribution (Su et al., 2010). Some advantages and disadvantages of the dasymetric approach is given below:

Advantages

- Because of the smaller spatial units the abrupt changes in the zonal boundaries became less and gives better reflection of the true scenario
- It gives more precise estimation of the population in a given area

Disadvantages

- It is also slightly affected by the unit of the administrative area.

c) Areal Interpolation

Areal interpolation methods are primarily designed for the zone transformation problem that involves transforming data from one set of spatial unit to another unit. The issue of two spatial units arises because sometime spatial datasets are stored in two or more incompatible areal units. Goodchild et al (1993) termed these spatial areal units as source zone and target zone. This approach uses census population data as the input and applies interpolation or disaggregation techniques to obtain a refined population surface (Wu, et al., 2005). In the context of population interpolation, census data is the vector based source zone data and interpolated to finer-scale raster data by a certain interpolation method. This method is subject to errors from original areal aggregation. The quality of the interpolation estimates depends largely on how source zones and target zones are defined; the degree of generalization in the interpolation process, and the characteristics of the partitioned surface Areal interpolation methods can be further separated into two categories depending on whether ancillary information is used.

Areal interpolation can be done with or without ancillary data. In case of with ancillary data, the technique is basically same like the dasymetric mapping approach. It uses land use and transportation network data as ancillary data. On the other hand, without ancillary data the areal interpolation can be done in two ways: point based method and area based method. The techniques used by these two methods and other approaches are given in the Table 2-1.

Advantage

- It minimizes the effect of the lack of coordination and objectives between data collecting agency.
- It preserves the total number of population while it transforms from one unit to another unit.

Table 2-1: Summary of different population distribution modeling

Category	Methods			Data requirement	Techniques
Cartographic method	Choroplethic mapping			Population census data	Divides the total population to the total land area
	Dasymetric mapping			Population census data, land-use data	Divides the areas into smaller spatial units (using the ancillary land use data) where the population is averaged to obtain the density
Surface based model	Areal interpolation	Without ancillary data	Point based	Population census data	Simple areal weighting, population-weighted centroids with a distance decay function
			Area based		Pycnophylactic interpolation
		With ancillary data		Population census data, land-use data, transportation network data	Same as dasymetric mapping approach
Statistical model	Statistical modeling			Socio-economic variables, remote sensing image, population census data (indirectly)	Makes a relationship between urban areas; land use; dwelling unit; image pixel characteristics; physical and socio-economic characteristics.

Source: (Holt, et al., 2004; Wu, et al., 2005)

d) Statistical modeling

This approach infers a relationship between population and other socio-economic variables (e.g. land use, dwelling unit, size of the city etc.) for the purpose of estimating the total population for a given area. This approach does not directly use census data as input (Wu, et al., 2005). The main purpose of this approach is to estimate the total population for an area at a specific time. With the advancement and availability of the remotely sensed images, researchers are using this approach efficiently for population distribution. The accuracy of the estimation depends on how the land use is classified. Researchers are also using urban light as an indicator for population size (Wu, et al., 2005). This approach of population distribution modeling is mainly designed to estimate an overall population count rather than population density. There are five categories of statistical approach. A brief discussion is given below:

- Correlation with urban areas: A general approach based on functional relationship between urban areas and population size. Morton & Yuan (2009) used the statistical modeling approach for the population estimation in the urban area using the census data and remotely sensed image.
- Correlation with land use: This approach gives more precise result than the previous one. It correlates the population counts with different land use. Land cover classifications also have been used frequently to distribute the population. Linard et.al (2010) uses land cover weight factors were assigned for each respective class and then reallocation of the population was done for per pixel.
- Correlation with dwelling units: The total population of an area can be estimated by multiplying the total number of dwelling units with the number of persons normally living in a dwelling unit. The total number of dwelling units in an area may be estimated from remote sensing images. The improvement in high resolution image and LIDAR data makes it efficient to extract the dwelling unit information and use this in population estimation.
- Correlation with image pixel characteristics: There is a correlation between the population density and the spectral reflectance of the image. Researchers are working to find out new techniques like image texture analysis, homogeneity of the texture analysis to get accurate output of population estimation.
- Correlation with other physical and socioeconomic characteristics: Distribution of population is also related to the transportation network, demography, topography, city center etc. using this idea population count and distribution has been done. It was found that there is strong correlation between the distance of central business district and population in urban area.

2.4 Population distribution modeling in time

In most of the approaches the census data is the basic data source. As mentioned in the section 2.1.2, there are some limitations in census data with respect to the capturing of population dynamics in space and time. Landscan Global database is an innovative approach which considers both day and night-time population distribution with a very high resolution. The population distribution form this database can be beneficial to the emergency response planning and relief and it enables to estimate the amount of people at risk. Dobson et al.(2000) claimed that LandScan appears the most available and suitable global database for estimating population at risk. The main driving force of developing LandScan database is to develop a nationally to globally scalable population distribution model which represents the night-time and day-time population distributions at a very high spatial resolution. The population distribution varies in a day with respect to the time. According to Bhaduri et al.(2007) distribution of population during the day and night-time can be expressed conceptually as:

Day-time Population = Workers + School children + Tourists + Business travellers + Residual Night-time Residential Population + (Static Population)

and *Night-time Population = Night-time Residential Population + Night-time Workers+ Tourists +Business travellers + (Static Population)*

Figure 2-2 explains how the population distribution done in LandScan dataset and their components. In this modeling different human activities and their mobility from one place to another were considered.

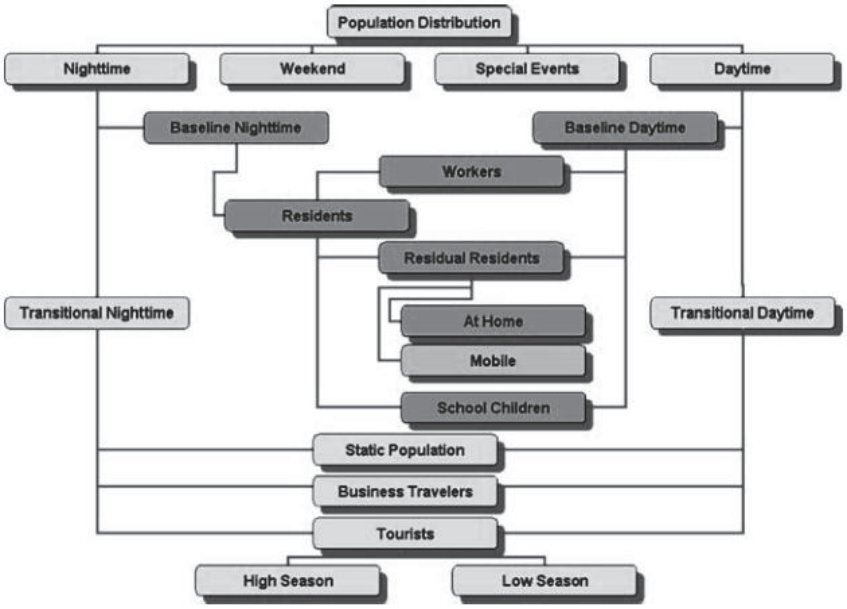


Figure 2-2: Population distribution model components used in LandScan USA

Source: (Bhaduri et al., 2007)

Besides these approaches few others are also found from the literature. Freire & Aubrecht (2012) used the intelligent dasymetric mapping approach to disaggregate the population census data for day-time and night-time for metropolitan area of Lisbon, Portugal. The street centre line was used as the reference unit to allocate the population (Freire, 2010). They produced four raster population distribution surfaces at 25 meters resolution: i) night-time (residential) population, ii) day-time residential population, iii) day-time worker and student population and iv) total day-time population. The night-time population distribution surface was obtained by allocating resident population from census zones to residential streets and the total day-time population distribution found from the summation of day-time residential, worker and student population. The commuting data was used to generate the worker group of people. They put emphasis to different temporal scenarios e.g. weekly and seasonal cycles which affects population distribution in urban areas.

The recently developed new approach from the cellular network data can also be used for population distribution modeling. The dispersion or distribution of the people in space is time dependent. It is possible to display this dispersion geographically in space and time (Becker, et al., 2011). It gives reliable data on the population distribution.

2.5 Population loss estimation for earthquake risk assessment

Loss estimation study is comprised of two components: hazard and vulnerability assessment. There are different components in population loss estimation such as estimation of deaths and injuries; homelessness or displaced people etc. (Dunbar, et al., 2003). Spence & So (2009) classified the available earthquake population loss estimation in three conventional approaches: empirical, semi empirical and

analytical approach. The empirical approach consists mainly of simple correlations of the exposed population to earthquake casualties and estimated ground shaking intensity. It only makes gross assumptions and eliminates many of the explanatory variables. A semi-empirical approach estimates damage rates for different building types in the study area and then sows a relationship between the casualty rates (death and injury) and each type of buildings. This approach takes into account the effect of the very different types of buildings (by climatic zone, urban/rural location, culture, income level etc.), and their mix, and also to factor in local characteristics of search and rescue and post-rescue treatment capability. The analytical approach predicts the behaviour of buildings in earthquakes and therefore finds the effects on the people who are inside the building. The limitation of this method is it does not take into account the behaviour of the non-engineered buildings in earthquake-prone parts of the world where the impacts on humans are extensive The output of all three approaches is quantitative and for this GIS and remote sensing techniques (Chen, et al., 1998; Chiroiu, 2005; Chiroiu & Andre, 2001) and specialized computer-based modeling approaches are widely used tools.

Among the computer based modeling approach GEM, CAPRA, HAZUS-MH, RADIUS, ELER, MAEviz, PAGER, NHEMATIS etc. (CAPRA, 2012; Elnashai & Hajjar, 2006; FEMA, 2003; GEM, 2012; Hancilar et al., 2010; IDNDR, 1999; Jaiswal et al., 2011) are well known and extensively used based on the requirements and zone of the study. These tools and methodologies have been developed by different organizations for specific countries with their requirements. Most of these tools are proprietary and can't be used by public. Only some of them are free and open for the user. There is a great need to develop tools that can be widely used all over the world for loss estimation. Most of the conventional approaches for loss estimation require the ground motion data, detailed building inventory data and population data. These methodologies for loss estimation help the urban planners, civil engineers, and policy makers to carry out the risk evaluation as a basis for the management and mitigation of the risk against natural disasters like earthquakes.

2.5.1 Computer based modeling approach

Global Earthquake Model (GEM) initiated one platform OpenQuake, which is a web based and open source risk assessment package. The stakeholder and professionals can use the tools for risk assessment to the local level. This platform is still under construction but it is a good initiative of GEM to make the society resilient from the earthquake disaster. There are different kinds of tools available in this package and user can use GEM's data resources and their own datasets as well (GEM, 2012).

CAPRA (Central American Probabilistic Risk Assessment) is another recent methodology which has been introduced for multi hazard (probabilistic and deterministic) risk assessment. It has different modules for different hazard: hazard mapping, risk analysis, vulnerability module. The vulnerability module is called ERN-vulnerability, which is composed of lot of vulnerability curves (building and human). This helps to calculate the population casualties directly by using human vulnerability curves for different building types. There are a lot of factors which have influence on the shape of curve and user can change the factors value. This approach estimates the population loss in one step. It does not take into account the building damage information but it requires the detail information about the building structure. In the risk module, CAPRA-GIS is used to calculate the potential losses for different return periods and specific earthquake scenarios. It gives the result in probable maximum loss (PML) curve for population in different return periods (CAPRA, 2012). In this current research, the vulnerability curves were taken from this package to estimate the loss of life.

Hazards United States (HAZUS) is one of the standard tools for risk assessment and loss estimation. It can be used by the local, federal and state government for the mitigation, emergency preparedness, response and recovery planning. This methodology was first developed by the Federal Emergency

Management Agency (FEMA) in 1997 for United States. After that some modification has been done in recent years and renamed as HAZUS-MH, which includes multi hazards for loss estimation. There are six modules in HAZUS-MH to estimate the consequences: potential earth science hazard (PESH), inventory, direct physical damage, induced physical damage, direct economic and social loss and indirect economic loss. This methodology helps to estimate a very detailed loss assessment based on enormous amount of information. It is a GIS based software to display the output of hazard and risk assessment and is applicable for small to large geographic extent with large number of population (FEMA, 2003).

The HAZUS method calculates the population loss (social loss) in a two-step approach. It assumes that there is a strong correlation between the building damage state and human injury level. The model estimates casualties directly caused by structural or non-structural damage. The census tract data is divided into six major land use groups (residential, commercial, industrial, educational, commuting and hotel). For the casualty estimation census tract data used and the number of casualties is divided in to four levels of injury class based on the severity. To estimate the human casualty, population distribution data is most important. The data requirement for the loss estimation is given below:

- Earthquake scenario time (day-time, night-time and commuting time)
- Population distribution data, building inventory data and damage state probabilities
- Casualty rate data

2.5.2 Other approaches for population loss estimation

Besides these open sources methodology, researchers are working on other approaches which can help to calculate the risk as well as loss of life. Jonkman et al. (2010) proposed a general framework for loss estimation. To make the general framework they considered the specific characteristics of the analysis of the number of people exposed and evacuation and the estimation of mortality. This method attempts to provide a basis for efficient and standardised loss estimation for different domains. Samardjieva & Badal (2002) proposed a quantitative model for a preliminary assessment of casualties which shows a correlation between the earthquake magnitude and number of casualties as a function of population density.

Chen et al. (2004) applied a dasymetric mapping approach to estimate loss only in the residential area using the post code and census collection district (CCD). They highlighted on incorporating the hazard information, recently updated elements at risk and local vulnerability curves which can improve the loss estimation. Population casualty estimation has been done for Sylhet city by Ansary (2002) and Alam et al. (2008). They used mortality prediction model to estimate the casualty and also considers the type of the building. Based on the building type different coefficients were assigned e.g. the trapped percentage, density rate, percentage of injured population etc.

There are few theses that have done ITC MSc studies for earthquake risk assessment and loss estimation. Among them Islam (2004) and Singh (2005) are remarkable. Islam (2004) tried to determine the vulnerability factors for population and the distribution of population over time and space. He used secondary population data in four different times for loss estimation. A community-based approach has been used in Singh (2005) research to determine the population vulnerability in a ward level and it also considers the activity pattern of the people and presence of people in the road network to estimate the loss. In both of these researches for loss calculation a relationship between the casualty rate and building type was used.

2.6 Census in Bangladesh

In 1872 the first census was conducted under British India in current Bangladesh. Usually the census takes place in February or March of the first year of a new decade. The first housing census in Bangladesh was

conducted in 1973 followed by the first population census in 1974. After that the second census conducted in 1981 and later on every ten year one census has been conducted by Bangladesh Bureau of Statistics under the Ministry of Planning. In March 2011, 5th population and housing census was conducted (ESCAP, 2011).

2.6.1 Population census procedure

Some features of the census in Bangladesh (BBS, 2012) are described below:

a) Period of the census: The whole census period is five days.
b) Phases of the census: There are three approaches involves in the population and housing census in Bangladesh: main census, post enumeration quality checking and sample census.
c) Methods of enumeration: In the main census the modified 'de facto' procedure is applied for enumeration. This procedure means that it reports all persons physically present in the area at the census date except the people who are on board or on duty, counted at their residence.
d) Post enumeration check: This survey usually conduct within the 15 days of the main census survey.
e) Sample census: After the main census, a sample census conducted which follows the 'de jure' procedure. In this process the citizens are counted at their place of residence. This survey conduct with the three months after the main census enumeration.
f) Data collection process: In the main census and sample census all the data are collected through a short questionnaire.
g) Types of data available from census: In the sample census through a questionnaire for each household the detailed data are collected. In the Table 2-2 the collected data and their possible applicability in loss estimation is given below:

Table 2-2: Census data and their applicability in population loss estimation

Sl. no	Data type	Use in loss estimation (Yes/No)
1.	Number of people in ward level	Yes
2.	Size of the household	Yes
3.	Age of the each household member	Yes
4.	Gender	Yes
5.	Number of disable people	Yes
6.	Marital status	No
7.	Religion	Yes
8.	Level of education	Yes
9.	Field of education	No
10.	Occupation	Yes
11.	Ethnic group	Yes
12.	Toilet facilities	No
13.	Utility information	No
14.	Sources of drinking water	No
15.	Access to media	No
16.	Land and property ownership	Yes
17.	Fertility and reproductive health	No
18.	Birth and death rates	Yes
19.	Migration	Yes
20.	Types of house/ structure	Yes

Source: Adapted from (BBS, 2012)

2.6.2 Problems in the census data in Bangladesh

Bangladesh is a densely populated country and the rate of urbanization and growth rate of people is very high. In this situation the enumeration of the whole country within five days is not sufficient. Therefore a million of people remain outside the enumeration process. Thus the census data becomes inaccurate and it doesn't represent the real scenario of the county's population and household. This issue makes problem in decision making and planning for urban area. There are reasons behind this inaccuracy of the data: lack of expert knowledge and resources, proper training and obsolete maps to accomplish the census. Again there is often great uncertainty about spatial distribution of residents within the census counting units. Another problem of the population data is not geo-referenced.

In summary, for any catastrophic risk assessment the specific information about the location of people is very important data in estimating the probable risk to human life. Uncertainty is the inevitable part of earthquake loss estimation. Population distribution also contributes wide range of uncertainty in loss estimation. Therefore new technology and concept has been adopted by the researcher to reduce the uncertainty of the population distribution in time and space. This would help the respective authority in taking risk reduction measures and for development of appropriate action plan to minimize human loss in any disaster. Another advantage is that it helps in to assess the location specific quantitative population estimation.

3 STUDY AREA

This chapter provides an overview of the study area in terms of geographical location, demographic information, earthquake scenario in Sylhet. It also briefly discusses the findings from recent study on earthquake risk assessment by CDMP.

3.1 General characteristics

Sylhet is one of the largest cities in north-eastern Bangladesh. The geographical location of the city is 24°32' 0" N, 91°52' 0" E, situated on the northern bank of the Surma River (see Figure 3-1). This city is distinctive from the other cities in the north-eastern region due to its geographical location. The total area of the Sylhet district is 3490 sq. km and the area of the city is 57.64 sq. km.

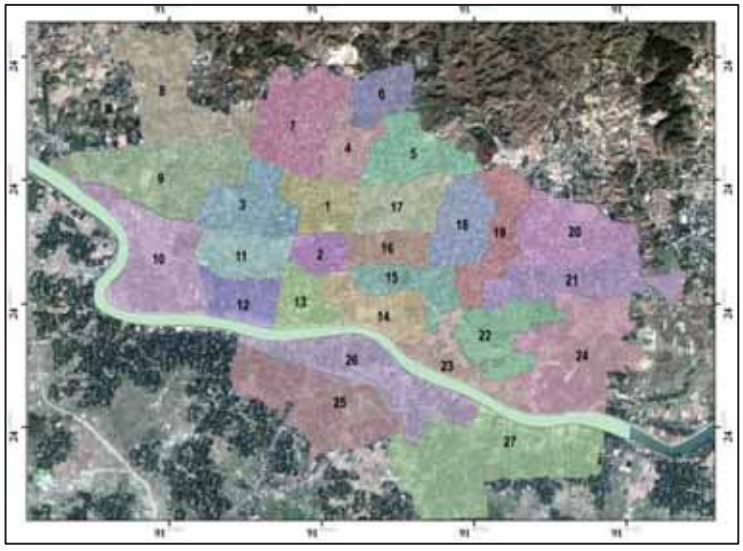


Figure 3-1: Sylhet city on the top of Google earth image with indication of the ward boundary

The city is located both on hills and plain areas. In the plane area of Sylhet, Holocene soil is distributed and it mainly consists of stiff soils and soft clayey soil with relatively complicated distribution (CDMP, 2009a). The geomorphology of this region is complex; high topography of Plio-Miocene age and small hillocks along the border (CDMP, 2009c).

3.1.1. Population and spatial growth of the city

There are 27 wards[1] in the city and according to the census of 2011 total population is 479837.The average household size is 4.8 in the city but in ward 12, 25 and 27 the house hold size is 5.3. The estimated number of buildings are almost 52,000 (CDMP, 2009b). According to the 2011 census, the percentage of Tribal people in Sylhet city is 0.54 (BBS, 2012). The census data and other statistical report illustrates that there is increasing trend of urban population growth in Sylhet city. In 2001 the total population was 262,899 which increase to 479,837 in 2011. The main reasons behind this high urban population growth are the high rate of remittance from expatriates and better economic opportunities. These factors accelerate people to live in the urban area with all kind of better services and facilities. Figure 3-2 (A) shows the spatial population distribution among the 27 wards in Sylhet city in 2011 and Figure 3-2 (B) shows the population growth trend of Sylhet from 2001 to 2011. This illustration indicates that maximum numbers of people are living in the North West part of the city which is mainly a residential area.

The trend of spatial growth in Sylhet city was influenced by many factors including road infrastructure, market and port facilities, economic improvement, etc. It is observed that spatial growth mostly took place on the north-east and the west. In the south originally Sylhet is edged by the Surma River but later the city expanded also on the southern bank of the river.

[1] Ward is the administrative unit for City Corporation area in Bangladesh

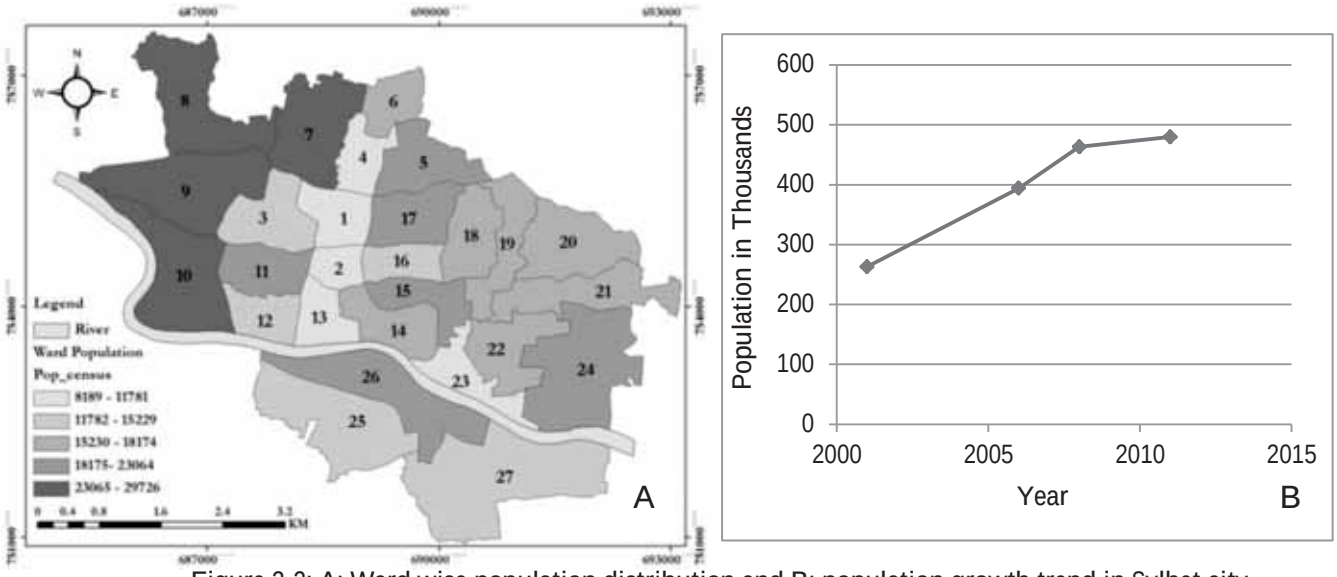


Figure 3-2: A: Ward wise population distribution and B: population growth trend in Sylhet city
Source: (BBS, 2012; CDMP, 2009b)

3.1.2. Earthquakes in Sylhet

Sylhet is located in one of the most earthquake prone zones in Bangladesh. From an analysis of historical earthquake data it was found that the devastating earthquakes (with larger magnitudes) in Bangladesh occurred mostly in the north-eastern region. They caused extensive damage in the area with brick masonry building (Ansary & Sharfuddin, 2000). In Table 3-1 important features of some historical devastating earthquakes are given.

Table 3-1: Some historical earthquake events around Sylhet

Name of the earthquake	Source Area	Fault	Magnitude	EMS intensity	Distance from Sylhet (Km)	Focal depth (Km)
1869, Cachar Earthquake	Cachar, India	Tripura	7.5	VIII	92	56
1885, Bengal Earthquake	Sirajgonj, Bangladesh	Bogura	7	V	234	72
1897, Great Indian Earthquake	Assam, India	Assam	8.1	IX	151	60
1918, Srimangal Earthquake	Srimangal, Bangladesh	Sub-Dauki	7.6	IX	71	14
1954, Manipur Earthquake	Manipur, India	-	7.4	VI	-	-

Source: (Ansary & Islam, 2005)

It can be perceived by analysing these historical data that this region might experience damaging earthquake with intensities up to IX (Ansary, 2002). Most of the buildings in Sylhet are constructed without engineering design. Basically four different kinds of house types found: a) buildings with RCC frame and brick wall, b) masonry building with RCC roof, c) masonry buildings with corrugated iron sheet roof and d) buildings constructed with mud, bamboo, wood, steel etc. (Alam, et al., 2008). The census from 2011 revealed that 47% of the total buildings are *Pucka* (which means that these buildings are

constructed with brick, cement, RCC frame, or steel) and 12% buildings are *Kutcha* (which means that buildings are made of wood and bamboo, mud etc.). *Pucka* buildings include both engineered and non-engineered buildings. The past experience of different historical earthquake events e.g. Bhuj earthquake in India shows that mainly the non-engineered and masonry buildings were destroyed (Humar et al., 2001). By analysing different information sources, during the last 10 years a number of quakes were felt in the Indian-Bangladesh (Assam, Meghalaya) border with a magnitude between 5.0 to 6.5 (in Richter scale).

3.2 Previous work on earthquake hazard and vulnerability assessment for Sylhet

Considering the susceptibility to earthquake situation, CDMP carried out the hazard and vulnerability assessment for the earthquake prone areas in Bangladesh. The results are described below:

3.2.1 Hazard assessment

- For hazard and risk assessment study the whole city was divided into 82 clusters to provide detail level of results.
- Earthquake hazard assessment can be done using a deterministic and probabilistic approach. In this study both of approachs were considered and eventually a deterministic approach was adopted and recommended to improve and refine the results of the probabilistic approach for future application.
- Five fault models were considered for earthquake hazard assessment. Relevant parameters for these faults were calculated to obtain the empirical attenuation relationship (see Appendix A for the fault parameters).
- Four relationship (between magnitude and distance) formula were used from NGS project for PGA-attenuation relationship. From the attenuation analysis it was found that the most important earthquake for Sylhet is Dauki Fault (DF) and Plate Boundary Fault-2 (PBF-2) and PGA is 270 to 420 gal and 230 to 420 gal respectively.
- In Figure 3-3, parameters of five earthquake scenarios and their shaking levels (in PGA) are shown at cluster level. For deterministic hazard study two earthquake scenarios (scenario 1 and 2) were selected and for probabilistic study another two earthquake scenarios (scenario 4 and 5 indicated as % of probability exceedance in 50 years) were selected and scenario 3 is the special one. Among the five scenarios, except scenario 2, the PGA value is very high.
- Finally they calculated the liquefaction susceptibility and slope failure susceptibility for Sylhet. For this analysis they used the soil properties data, ground water level, Mw, PGA value, DEM of the area.
- The analysis shows that Sylhet is susceptible for liquefaction and slope failure. About 6% of the total area in the south-east part of the Sylhet city is susceptible to very high liquefaction and 47% of the total area is susceptible to moderate liquefaction in north-west part of the city.

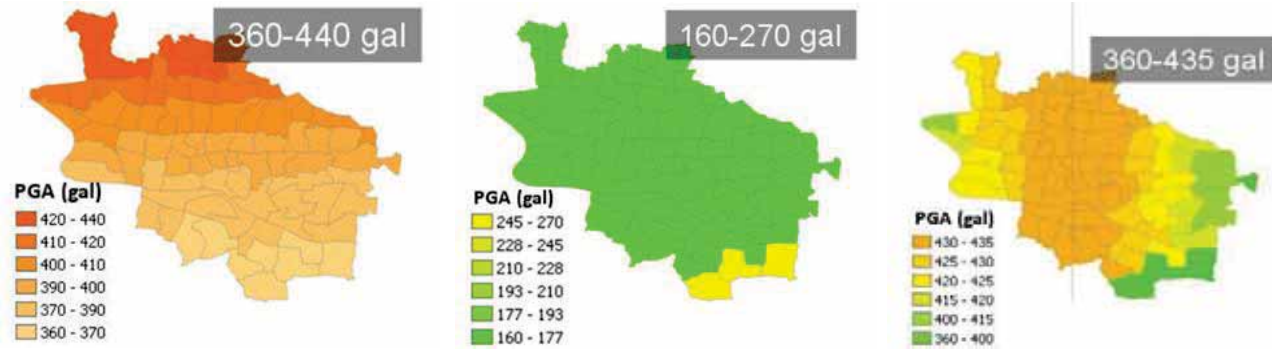
3.2.2 Vulnerability assessment

a) Building vulnerability

- The CDMP study used the Turkish vulnerability assessment method for the buildings.
- There are three levels of building survey based upon their complexity in data type and collection method. Level 1 building survey do the building evaluation by side walk and questionnaire survey; Level 2 survey is applied to the buildings which need more in-depth evaluation and Level 3 survey applies the linear or non-linear analysis of the specific building (Alam et al., 2012). Level 2 and Level 3 survey covers more engineering aspects of the building.

- Among the 52,000 buildings, in Level 1 survey total 3536 buildings, in Level 2 survey 353 buildings and in Level 3 survey 30 RCC buildings were surveyed in the city.
- The following factors were taken into consideration in Level 1 survey: no of stories, floor area, earthquake zone, presence of soft storey and heavy overhang, apparent building quality, short columns, pounding effect, and topography effect. Using these factors a performance score was calculated for each building and then a vulnerability value was derived from this performance score and earthquake zone. In Figure 3-5 higher value indicates low vulnerability.

Scenario 1	Scenario 2	Scenario 3
Mw: 8.0 Depth to top of fault: 3 Km Dip angle: 600 Fault name and type: Dauki Fault, Reverse Coordinate: Latitude 25.1, Longitude 91.2	Mw: 8.3 Depth to top of fault: 3 Km Dip angle: 300 Fault name and type: PBF-3, Reverse Coordinate: Latitude 25.7, Longitude 93.7	Mw: 6.0 Depth to top of fault: 7 Km Dip angle: 900 Fault name and type: Underneath the city, Reverse Coordinate: Latitude 24.9, Longitude 91.87



Scenario 4	Scenario 5
Mw: 8.0 Depth to top of fault : 3 Km Dip angle: 60^0 Fault name and type: Dauki Fault, Reverse Coordinate: Latitude 25.03, Longitude 91.2	Mw: 8.5 Depth to top of fault : 3 Km Dip angle: 600 Fault name and type: Dauki Fault, Reverse Coordinate: Latitude 24.91, Longitude 91.2

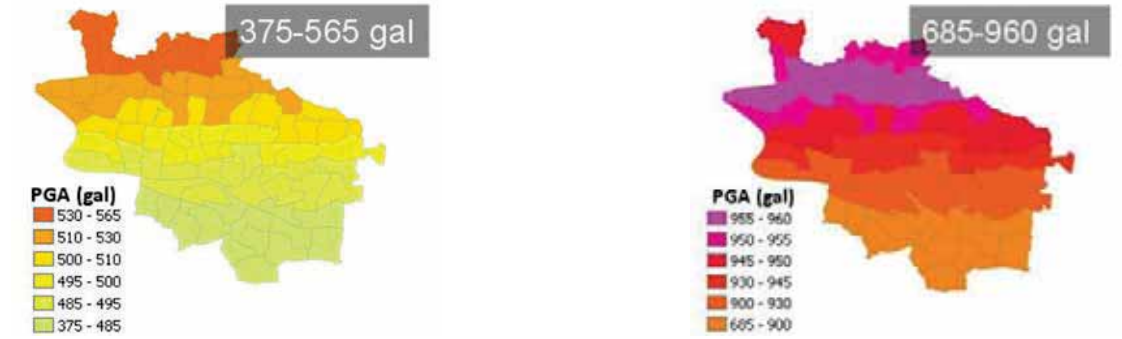


Figure 3-3: Parameters of different earthquake scenarios and PGA (gal) in Sylhet City (ward wise)
Source: CDMP (BBS, 2012; 2009a)

- Survey results shows that 55% of the buildings are non-engineered and 44% are engineered. Among these engineered buildings 82% are low rise with masonry infilled walls.
- 51% buildings are concrete and 43% are masonry building. A total of 41% buildings are less than 10 years old and 16% are more than 30 years old (from the CDMP's survey year). Figure 3-4 shows the building age distribution ward wise.
- In Sylhet city, 46% of the buildings have an overhanging part, which makes the buildings vulnerable to earthquake.

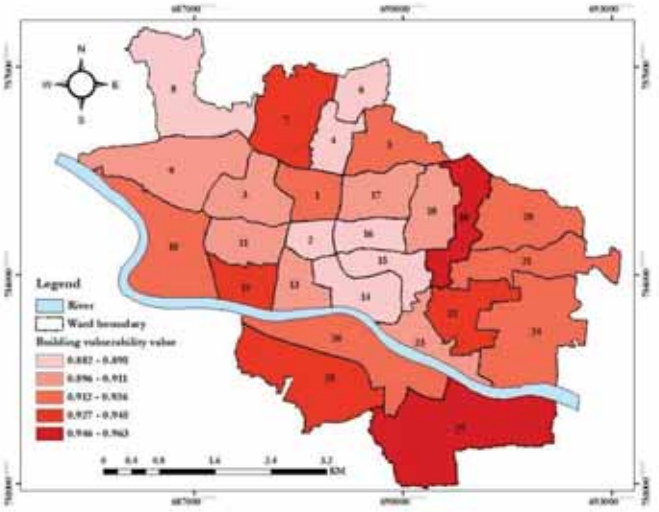


Figure 3-5: Building vulnerability value in ward level

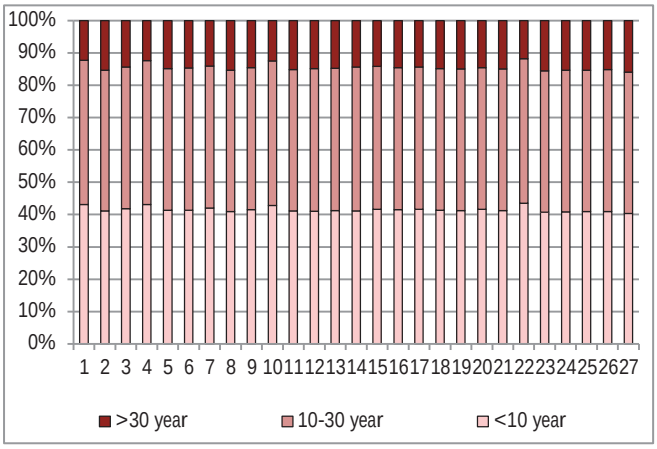


Figure 3-4: Building age of the city in ward wise
Source: (CDMP, 2009b)

b) Population vulnerability

- According to CDMP study, 85 % of the total buildings are used as residential houses and the average number of occupants per floor area in day-time is lower than night-time.
- Other than the residential uses, in the commercial, industrial, government and educational institutions have more people in day-time than night-time.
- The highest population density in both day-time and night-time was found in Ward no 5, 12, 21. However in day-time wards 3, 14 have a higher density than the night-time because most of the offices are located in these wards.

3.3 Previous work on earthquake loss estimation for Sylhet

The CDMP project carried out a risk assessment for the general building stock, different essential facilities (e.g. hospitals, schools, emergency operation centres etc.) and lifelines (e.g. transportation and utility system) of the city. This project used the HAZUS software tools and calculated the social losses (or human causalities) by combining the building damage information and population data. Building damage information was calculated from the direct damage module of HAZUS. The estimated population loss was for two times in a day (2:00 PM and 2:00 AM) according to the HAZUS methodology with four severity levels. The earthquake loss estimation was done for five above mentioned earthquake scenarios. The key findings from the risk assessment study are described below:

a) Building damage estimation

The Dauki fault line has significant impact on Sylhet than the other fault lines. The most devastating scenario is Dauki fault with magnitude 8.5. Using the HAZUS method it was estimated that in this worst

scenario more than 97% buildings will be damaged completely. Table 3-2 summarizes the damage results from the study for masonry and concrete buildings. Among these collapsed building, 44% are masonry building. This study also found minimum damage in the tin shed and bamboo made building. It is remarkable that the concrete buildings are more vulnerable than any other type of structure. But it is expected that the reinforced buildings are stronger than other structural types.

Table 3-2: Building damage status in different scenario earthquake

Scenario	M_w	Complete damage				Total collapse building	
		Masonry		Concrete building			
		Number	Percentage	Number	Percentage	Number	Percentage
1. Dauki fault	8.0	13015	52	11574	46	24945	48
2. Plate boundary Fault-3	8.3	393	20	1488	78	1919	3
3. M_w 6.0 beneath city	6.0	5237	44	6370	53	11891	22
4. Dauki fault	8.0	16810	50	15877	47	33858	65
5. Dauki fault	8.5	22218	44	26139	51	50880	97

Source: CDMP(2009a)

b) Population loss estimation

With the HAZUS method the population loss cannot be estimated directly without first analysing the building damage. After the building damage estimation the population losses are estimated using empirical relations between collapsed buildings and severity levels of injuries and causalities. Table 3-3 summarizes the casualty states for different scenario earthquakes. A maximum of 20,000 people will be killed in the worst case scenario earthquake with magnitude 8.5 at night-time (at 2:00 AM) and 14,000 people will be killed in day-time (at 2:00 PM). In this scenario at any time of the day maximum number of casualty will be expected.

Table 3-3: Population casualty level in different scenario earthquakes

Scenario	M_w	Injury severity level							
		Level 1		Level 2		Level 3		Level 4	
		Injuries with medical attention		Injuries with hospitalization		Injuries with emergency hospitalization and life threating		Victims killed	
		2 AM	2 PM	2 AM	2 PM	2 AM	2 PM	2 AM	2 PM
1. Dauki fault	8.0	14689	9665	2761	1910	958	608	9506	6151
2. Plate boundary Fault-3	8.3	1363	1041	212	177	51	42	892	667
3. M_w 6.0 beneath city	6.0	7508	5173	1329	966	417	282	4723	3242
4. Dauki fault	8.0	19455	13005	3701	2586	1275	817	13107	8724
5. Dauki fault	8.5	28226	19414	5370	3850	1814	1190	20708	14276

Source: CDMP (2009a)

4 DATA COLLECTION AND PREPARATION FOR ANALYSIS

This chapter provides an overview of data collection and preparation, improvement of the data, analysis procedure, and modeling approaches used in this study.

This study is based on both primary and secondary data sets. The main source of the secondary datasets is from the CDMP study. It was a multi-year project and lots of people were involved to collect the data. Since it is not possible to collect population information and building information together for the whole city within the framework of the MSc time period, therefore the existing data was used. Besides this, a field work was done to understand the population distribution of the city in two different occupancy classes.

4.1 Secondary data collection

It is already mentioned above that the main secondary data source is from the CDMP I project of Government of Bangladesh and also from census and different websites. Data from CDMP includes the building foot print map of Sylhet, a map of the surveyed buildings and the reports of the project. The reports are related to earthquake hazard, vulnerability and risk assessment in Sylhet city.

A high resolution satellite image from Google earth (resolution 31cm) was downloaded and then geo-referencing and transformation was done in Arc GIS10. The given GIS datasets are all in the local datum system (GCS_Everest 1830) and the projected coordinate system is Transverse Mercator. However the coordinate system of the satellite image was geographic coordinates (latitude and longitude) with WGS (World Geodetic System) 1984 datum. Therefore to match the shape files with the image it was required to transform the WGS 84 datum to the local datum system. The method used for geographic datum transformation is position vector with seven parameters in ArcGIS 10. The values used for the transformation are given in the Table 4-1:

Table 4-1: Parameters for WGS 1984 to Everest 1830 datum transformation

Parameter name	Value
X axis translation (meter)	283.729
Y axis translation (meter)	735.942
Z axis translation (meter)	261.143
X axis rotation (seconds)	0
Y axis rotation (seconds)	0
Z axis rotation (seconds)	0
Scale difference (ppm)	0

After the transformation of the image it was used as backdrop image for the building footprint map to complete the missing parts of the building footprints. After the field work it was used to identify the surveyed buildings properly and some corrections has also made when it requires.

4.2 Data evaluation and improvement

One of the objectives is to evaluate the existing data and validate with the field work. To do the evaluation of the existing spatial data, building occupancy class and structural class have been considered. The building use and land use for each building was carefully matched to get the correct building occupancy class. These two provides more detail description about a building's occupancy. To get the correct structural type for each building, the given structural type description and number of floors were compared and inconsistencies were corrected (see Appendix E). This correction was also done after the field work for the surveyed buildings. The result will be described in chapter 5.

4.3 Primary Data collection

The main target was to collect information about the population distribution in different building types specifically in the mixed-use buildings and schools. The existing population data has a very large uncertainty for these two types of buildings. Mixed-use buildings are buildings that have a combination of occupancy classes, such as residential and commercial; residential and office etc. The mixed-use buildings and schools was selected for field work because it is anticipated that there is a lot of variation in the mixed-use building throughout the day and in the school the concentration of the people is only in the specific hours in a day. Before starting the household and school survey, a reconnaissance survey was done and a questionnaire was tested to check whether it required any modification. During the reconnaissance survey, different occupancy classes within Sylhet city were analysed focusing on those that had the largest variation in persons per 100 m^2 in the existing database. It was observed that in wards 11, 12, 13, 14, 15, 16 most of the mixed-use buildings are located. Therefore most of the sampled buildings were mainly taken from those wards. The geographic location of the sampled buildings was recorded by GPS and photographs of the buildings were taken during the field work. The survey was done by the researcher with one volunteer surveyor.

4.3.1 Sampling strategy

A stratified random sampling technique was applied for selecting the samples from mixed-use buildings and school. The sample size from these two occupancy classes was decided based on the number of buildings in the study area. From each of the occupancy classes 5% samples were taken to do the questionnaire survey. Mixed-use buildings were selected which have the combination of shop, office or other commercial activities together with residential use. See Figure 4-1 which indicates the sampled buildings in the field work. The sample buildings were selected based on the willingness to share the information from the respondent.

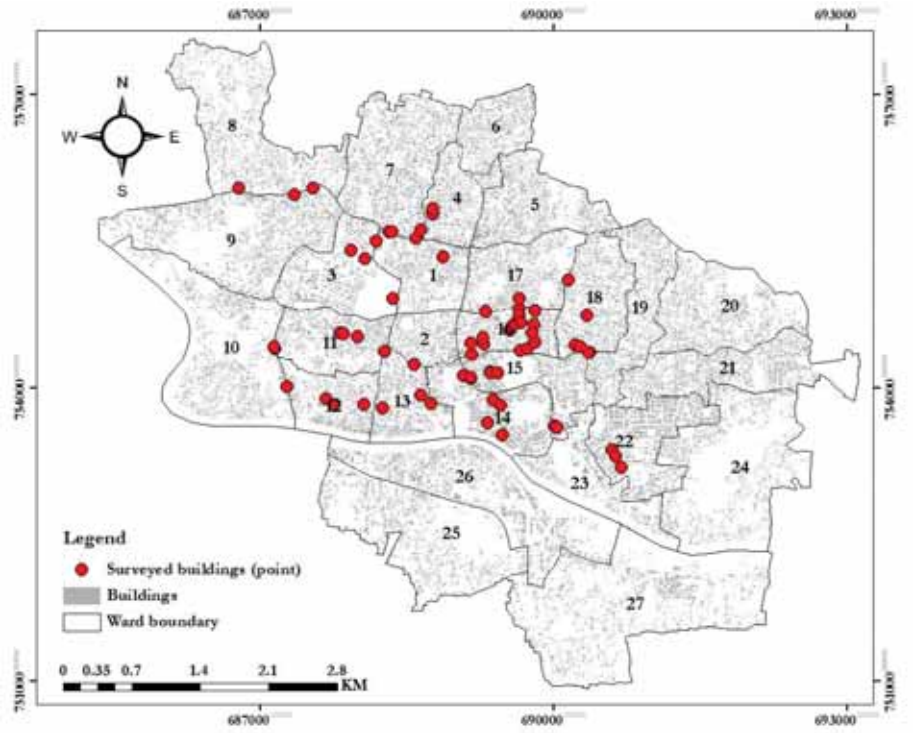


Figure 4-1: Sampled household of the field survey

4.3.2 Scenario selection

This study focused on the effect of population changes in different scenarios of the day and year. Four scenarios in a year were chosen to understand the variations of population in a year: weekday scenario, weekly holiday scenario, strike day scenario and Ramadan day scenario. There are other scenarios for example the Bengali New Year Day, Eid day, national (or government) holiday etc. are not considered. The national holiday scenario shows the same like weekly holiday scenario, but during the New Year and Eid day less people stay at home. Therefore these scenarios were not considered. Another reason is the willingness of the people to answer. So the selection was limit to the four above mentioned scenarios. The reason behind the selection of these four scenarios is that they show a large variation in population distribution over the day. Each scenario has its own character.

4.3.3 Residential and commercial space survey

For the mixed-use building survey, a structured questionnaire was used. The components in the questionnaire for the residential households and commercial were different (see Appendix B). In this study forty eight (48) mixed-use buildings were surveyed. The residents in a household were asked about the demographic composition of the family, total number of family members and their activity pattern, for instance the presence and absence in the house in different time periods of the day, and on special occasions like weekly holiday and other special day like strike day (see Table 4-2). It was also tried to investigate where people are when they are not at home. During the interview, it was tried to interview representatives of all the households in a building. If one of the residents (tenants) in a building didn't want to answer the questions or were not present they were considered as "no response". In the survey 48 buildings, 120 households were surveyed. In case of commercial or office, one employer in the shop was interviewed. The average time required to complete a house hold is 30 minutes and for a building it is more than 2 hours, depending on the household's response. See Figure 4-2 about some examples of sampled buildings.

Figure 4-2: Examples of sampled mixed-use buildings

4.3.4 School survey

A total of twenty (20) primary and high schools were surveyed to understand the distribution of the pupils, teachers and other staffs members in the school during the school hours and non-school hours. Here mainly the teachers of the school (headmaster, assistant headmaster or any other teacher) were asked the structured questions (See Figure 4-3 and see Appendix C) to know the school's built-up area, total number of student, total number of staff, scenarios of presence and absence in different special days of a year (See Table 4-2).

Figure 4-3: A: Interviewing a school teacher in Blue Bird School; B: Typical classroom in Mirza Zangal Girls High Schools; C: Sylhet Model School in the city

Table 4-2: Surveyed items during the field work

Occupancy class	Surveyed items
A. Mixed-use building	
- Residential part	a. Name of the respondent b. Address and GPS coordinate c. Floor surveyed d. No of floors e. Specific building use f. Floor area g. No of household member h. Occupation of each household member i. Presence in the house in 2 hour intervals in four different scenarios (weekday, weekend, strike day, Ramadan days)
- Commercial part	a. Name of the respondent b. Name of the shop/ office c. Total number of staff d. Working hour e. No of shift (if any) f. Presence of people in every 2 hour interval
B. School	
	a. Name of the school b. Location and GPS coordinate c. No of structures d. No of floors e. No of staffs present in different scenarios of a year f. No of students present in different scenarios of a year

4.3.5 Database preparation for surveyed buildings

The collected data was stored immediately in digital format after the field work. All the questionnaires had a serial number based on the date of the survey and the household number. GPS coordinates were also

recorded in the questionnaire sheet and later on used to identify the location of the buildings. The serial number was the primary key to identify the buildings and household and entered in Microsoft Access and then further processing was done in Microsoft Excel. For spatial analysis this data were exported to Arc GIS10.

4.4 Calculation of floor space

Floor space of a building is required to calculate the average person in 100 m^2. It helps to calculate the accurate area for person.

- Mixed-use building: To calculate the population per 100 m^2 for day-time and night-time, at first the number of floors that had been surveyed were calculated. A portion of the floor (or say fraction of the floor) which doesn't have any response (because people were not present, or didn't want to respond) was excluded from the calculation. The most common type of mixed-use buildings in the study area are shops or other commercial activities (grocery, tailoring, dentist, coaching center, small offices, travel agency etc.) on the 1st floor (ground floor) and residential apartments on the upper floors. After the calculation of the surveyed floor, the floor space was calculated. In Figure 4-4 a typical mixed-use building is shown. In this example on the 1st floor there are shops and the other three floors are residential unit. In the upper three floors there are 6 apartments. There was no response from two households among these six. Therefore when the floor space calculated these two apartments information was not included.

  In this example building,
  Floor area = 111 m^2

  No of floor = 4

  No of floor surveyed = 3 = (1+1+0.5+0.5)

  Floor space surveyed = 3×111 = 334 m^2

  Total population in the morning (6 AM to 8 AM) in a normal weekday = (5+ 4+5+5+6) = 25

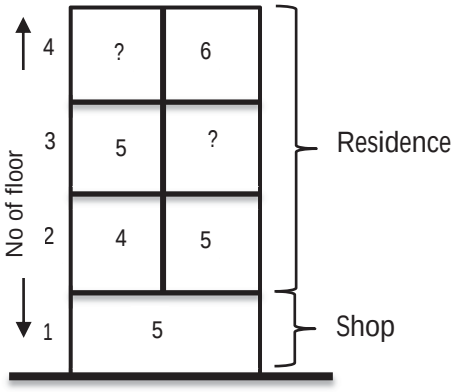


Figure 4-4: Floor space calculation for a typical mixed-use building

The same calculation was followed for other time periods of the day and other temporal scenarios for example weekly holiday, strike day and Ramadan day.

- Schools: From the field survey the floor area for each of the school buildings and the total number of persons were collected. Floor space was calculated by multiplying the floor area and number of floors. As most of the schools have more than one building, total floor space was calculated by adding the floor space of each of the school buildings. For example the calculation of Blue Bird School is shown in Table 4-3:

Table 4-3: Calculation of person per 100 m^2 for school with more than one building

School building Id	Floors	Area (in m^2)	Floor Space = (Area* Floors) (in m^2)
3001	1	208.58	208.58
3001	3	206.75	620.25
3001	4	1205.12	4820.47
Total floor space			5649.30

4.5 Calculation of person per 100 m^2 in day-time and night-time

According to CDMP(2009b), the number of people in each occupancy class was calculated using an average number of people in each floor area multiplied by the floor space of the building. This is an approximation method developed by ATC-13 (Applied Technology Council, 1985). The details of the process are described below.

- Mixed-use buildings: After the calculation of the floor space and the total population in two hour time intervals, the number of persons per 100 m^2 for each building was calculated using the equation (i), and (ii). As per the CDMP report the average space for person was calculated using the weighted average method. Here person per floor space was multiplied to convert the floor space to unit area of 100 m^2. The time period was aggregated to two groups: day-time and night-time. According to the CDMP (2009b) report, day-time and night-time was considered from 8 AM to 6 PM and 6 PM to 8 AM respectively. The average number of person per 100 m^2 was calculated for day-time (8 AM to 6 PM) and night- time (6 PM to 8 AM) by adding the average value for specific time period and divided by the number of time periods using the equations (iii) and (iv) respectively. The same procedure was followed for night-time average person per 100 m^2 calculation.

$$\textit{Weighted arithmatic mean for person in 2 hour interval,} \quad X = \frac{1}{N} \times \sum_{i=1}^{N} \frac{Xi \times Ai}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(i)$$

$$\textit{Average persons per 100 m2 for 2 hour interval,} \quad Xa = \frac{X}{A} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(ii)$$

$$\textit{Day} - \textit{time average persons per 100m2} = \frac{\sum_{i=1}^{5} Xa}{\sum_{i=1}^{5} \textit{no of time period}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(iii)$$

$$\textit{Night} - \textit{time average persons per 100m2} = \frac{\sum_{i=1}^{7} Xa}{\sum_{i=1}^{7} \textit{no of time period}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(iv)$$

- Schools: For schools, the time-wise population distribution was divided into two groups: school hour and non-school hour. Most of the schools in Sylhet start at 10 AM. But few schools also start between 7:30 to 8 AM and finishes at 4 PM. Therefore the school hour was considered as day-time (from 8 AM to 6 PM) and rest of the time considered as night-time.

$$\textit{Day time average persons per 100 m2} \quad = \frac{1}{N} \times \sum_{i=1}^{20} \left(\frac{Xiday}{Ai}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots(v)$$

$$\textit{Nightime average persons per 100 m2} \quad = \frac{1}{N} \times \sum_{i=1}^{20} \left(\frac{Xinight}{Ai}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots..\ldots(vi)$$

Where, X_i = number of people per using area of the building i
X_{iday}= number of people in the school in day time
X_{inight}= number of people in the school in night time
X_a= person per 100m^2
A_i = using area of the building i (in m^2)
N= number of sampled schools/buildings.

4.6 Population distribution in different scenarios

The population was distributed according to the different occupancy classes, which means it only considers the people who are inside a building at a certain point in time. The available data do not take into account how many people are outside the building, and/or are coming to the city or leaving the city (see Figure 4-5).

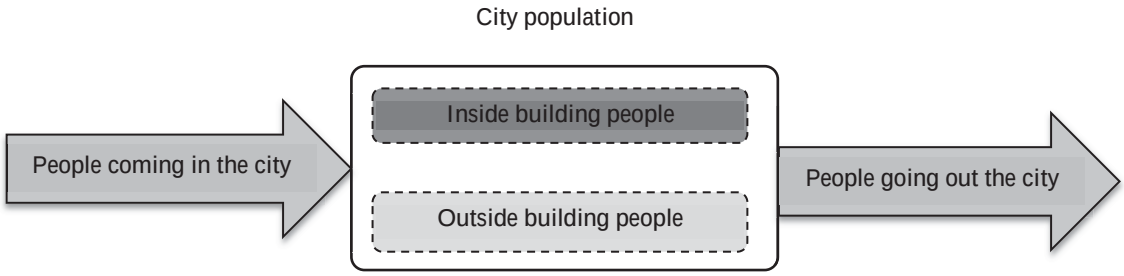


Figure 4-5: Boundary condition of the population distribution modeling in the study

4.6.1 Day-time and night population calculation per building

The day-time and night-time average population distribution of the buildings was calculated using the Table 4-4 from the CDMP vulnerability report (2009b). After that again the day and night-time population was calculated by using the newly calculated average value for mixed-use building and school, instead of using the previous study result. There are twenty seven occupancy types in the study area and this calculation was done for each of them. Then the existing result was compared with the new result. The details are described in chapter 5.

4.6.2 Population distribution modeling

After the calculation of total day-time and night-time population for the whole city, this population was considered as population in normal working day. Based on this assumption, this population was distributed to the whole city according to the respective occupancy class. Presence (in percentage) of the people in the building for every 2 hours interval for four different scenarios was approximated based on the expert judgment and field survey experience. To estimate the population in different occupancy class some real life factors were considered which might have effect on the distribution. The detail description is explained in chapter 6.

4.6.3 Population distribution impact on population loss estimation analysis

The next step after the population modeling is to analyse the impact of population distribution in different time period of the day and year on population loss estimation. At first a relationship from HAZUS methodology was used for loss estimation. In the next step, the ERN-vulnerability curve module of CAPRA was used (CAPRA, 2012). The reason behind to use this software is that it has the human vulnerability curve based on the building types. The earthquake hazard intensity was used from the CDMP study. In the ERN-vulnerability curve the intensity level (ground motion) is given in Peak Ground Displacement (PGD) (cm), Spectral acceleration (Sa) (g) or Spectral Displacement (Sd) (cm). However the ground motion information was available in PGA (gal) and Sa (gal) from the previous study. In this research, the spectral acceleration (gal) at T=0.3 sec was used to get the minimum and maximum loss of life in one specific scenario earthquake (see Appendix A2). There were several steps followed to calculate the loss of life are given below and see Figure 4-6 for the schematic diagram of the steps.

- At first the building types used in this study were adapted to the ERN-vulnerability curve types. For this, building types were combined based on the construction material and technique.
- One special kind of building type was not found in the ERN-vulnerability curve, thus its population was not included in the analysis.
- Then the population of each of the building type was calculated for four different temporal scenarios.

- In hazard intensity map, for five different scenario earthquake minimum and maximum spectral acceleration (Sa) was given for T=0.3 second. This value was used for the minimum and maximum population loss.
- For the minimum and maximum intensity, the vulnerability value was identified from the vulnerability curve for each type of buildings. The human vulnerability value is expressed in death ratio (MDR).
- These minimum and maximum values were multiplied with the total number of people in certain type of buildings in different time period of the day.

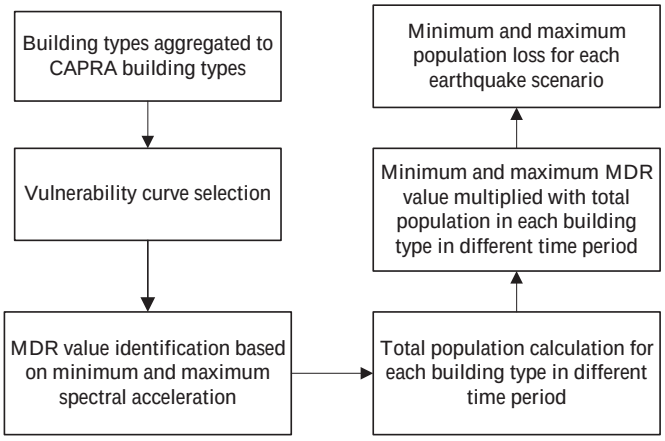


Figure 4-6: Steps followed for population loss estimation using CAPRA vulnerability curve

Table 4-4: The average number of occupants per building floor area in each occupancy classes from CDMP study

SI No.	Occupancy	Occupancy class description	Population per 100 m^2	
			X ± σ	
			Day-time	Night-time
1.	RES1	Single family dwelling	2.62	3.93
2.	RES2A	Minimum standard housing (<25 occupants)	5.88 ± 6.47	10.26 ± 11.57
3.	RES2B	Minimum standard housing(25-100 occupants)	10.04 ± 10.92	22.90 ± 23.06
4.	RES2C	Minimum standard housing (>100 occupants)	2.63 ± 1.47	4.02 ± 2.92
5.	RES3A	Multi family dwelling (<10 units)	2.65 ± 2.62	4.37 ± 3.59
6.	RES3B	Multi family dwelling (10-19 units)	3.40 ± 2.62	5.61 ± 3.59
7.	RES4	Hotel/Motel	3.64 ± 3.30	6.13 ± 5.82
8.	RES5	Institutional dormitory	3.59 ± 4.18	5.79 ± 5.48
9.	RES6	Substandard housing	22.25 ± 21.05	45.13 ± 35.75
10.	COM1	Small shops and markets	7.18 ±7.11	1.07 ± 3.32
11.	COM2	Large shops and markets	5.21 ± 5.66	0.64 ± 1.07
12.	COM3	Automobile workshop	11.13 ± 11.02	1.71 ± 1.76
13.	COM4	Office (professional or technical service)	5.02 ± 5.43	0.69 ± 1.12
14.	COM5	Banks		
15.	COM6	Hospitals	23.63 ± 9.38	20.53 ± 6.94
16.	COM7	Clinic/ Doctors chamber	3.78 ± 4.69	1.83 ± 0.69
17.	COM8	Restaurant and entertainment	43.01 ± 27.56	1.35 ± 1.33
18.	COM9	Theatres/Community centre	36.30 ± 29.86	3.02 ± 4
19.	COM10	Mixed-use (residential and commercial)	5.59 ± 5.71	4.18 ± 4.66
20.	IND1	Heavy (plastic, rubber car) industry	3.45 ± 5.50	2.53 ± 5.03
21.	IND2	Light (Textile and garments factory) industry		
22.	IND3	Food/drug/chemical processing factory		
23.	AGR1	Farm house, poultry farm, dairy farm	7.01 ± 11.03	0.13 ± 0.21
24.	REL1	Mosque/ temple	44.06 ± 38.57	1.12 ± 6.87
25.	GOV1	Government office, post office, telephone office, water pump house	9.31 ± 9.21	3.60 ± 4.67
26.	EDU1	Primary school, High school, Religious school	30.95 ± 23.99	4.24 ± 6.64
27.	EDU2	Collage, University	22.86 ± 9.15	0.02±0.02

* X= Average ; σ = Standard deviation Source: CDMP (2009b)

5 EVALUATION OF THE EXISTING DATA AND POPULATION DISTRIBUTION

It is mentioned in section 4.2 that there is inconsistency in the existing datasets (in building occupancy and structural type) and how they improved. In this chapter findings from the evaluation and improvement will be discussed in two sections. The internal inconsistency of the existing datasets and inconsistency with the field survey done by researcher will also be discussed. In another section the results from the improved data will be compared with the existing data.

5.1 Internal inconsistency in existing data sets

5.1.1 Building occupancy

During data evaluation it was found that in building occupancy classification there are some inconsistencies in the existing datasets. The inconsistencies also present in the sampled buildings surveyed by the CDMP. 10% of the total building and 28% of sampled buildings were not properly assigned to their respective class, which might have impact on the earthquake risk assessment study. In Figure 5-1, one part of the study area where CDMP's surveyed buildings are showed and red colours of the building indicated as wrong building occupancy class (see also Appendix D). Because of the wrong classification of the building use, obviously there will be difference in the total number of people. This kind of misclassification over estimates or underestimates the number of occupants in a building as well as increases or decreases the vulnerability of the people in a building. For loss assessment study it is very necessary to know the accurate number of people in a building.

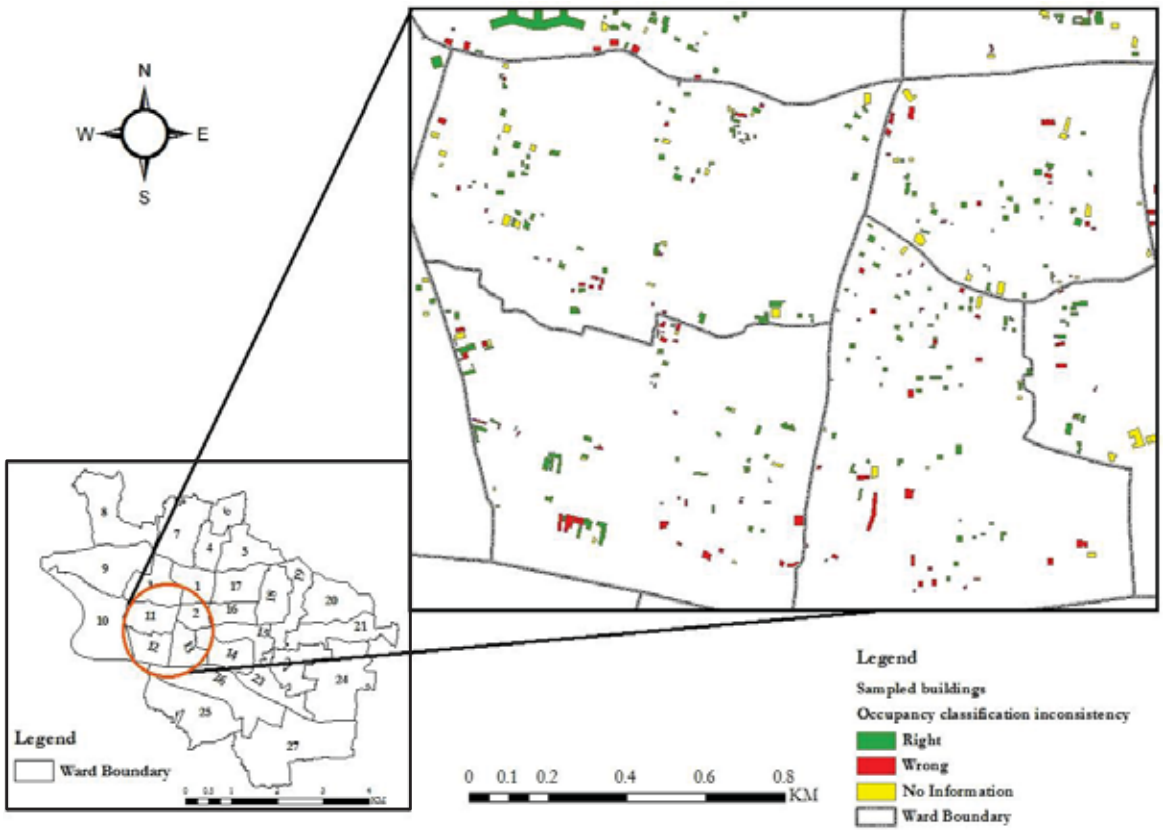


Figure 5-1: Building occupancy misclassification in CDMP's sampled buildings in one part of Sylhet city

5.1.2 Structural type

For 4% of the total buildings in Sylhet city and 6% of CDMP's sampled buildings, the structural type was not correct. For example some *semi pucca* buildings (brick structure but roof is with tin) were classified as concrete structures or tin shed buildings were classified as brick buildings with masonry structure, steel structure, cement or concrete structure. The structural type classification used in the CDMP study also depends (see Appendix E) on the building height. Some misclassifications were found because of the inappropriate floor number assignment e.g. single story buildings were classified as multi story buildings or vice versa. This misclassification has impact on the earthquake risk assessment because the nature of shaking depends on the building characteristics (construction material, height, construction technique etc.)

5.2 Validation with the field data

For the validation, the buildings that were sampled during the field work of 2012 were used. So the attribute information is considered correct for these buildings.

5.2.1 Building occupancy class

As there are a lot of inconsistencies found in the occupancy class distribution from the CDMP building foot print map, the collected field data was used to validate this status. Among the sampled buildings from the field survey, 67% of the school buildings and only 21% of the mixed- use buildings had the correct occupancy classes (see Figure 5-2). Overall 54% of the sampled buildings did not have the correct occupancy class.

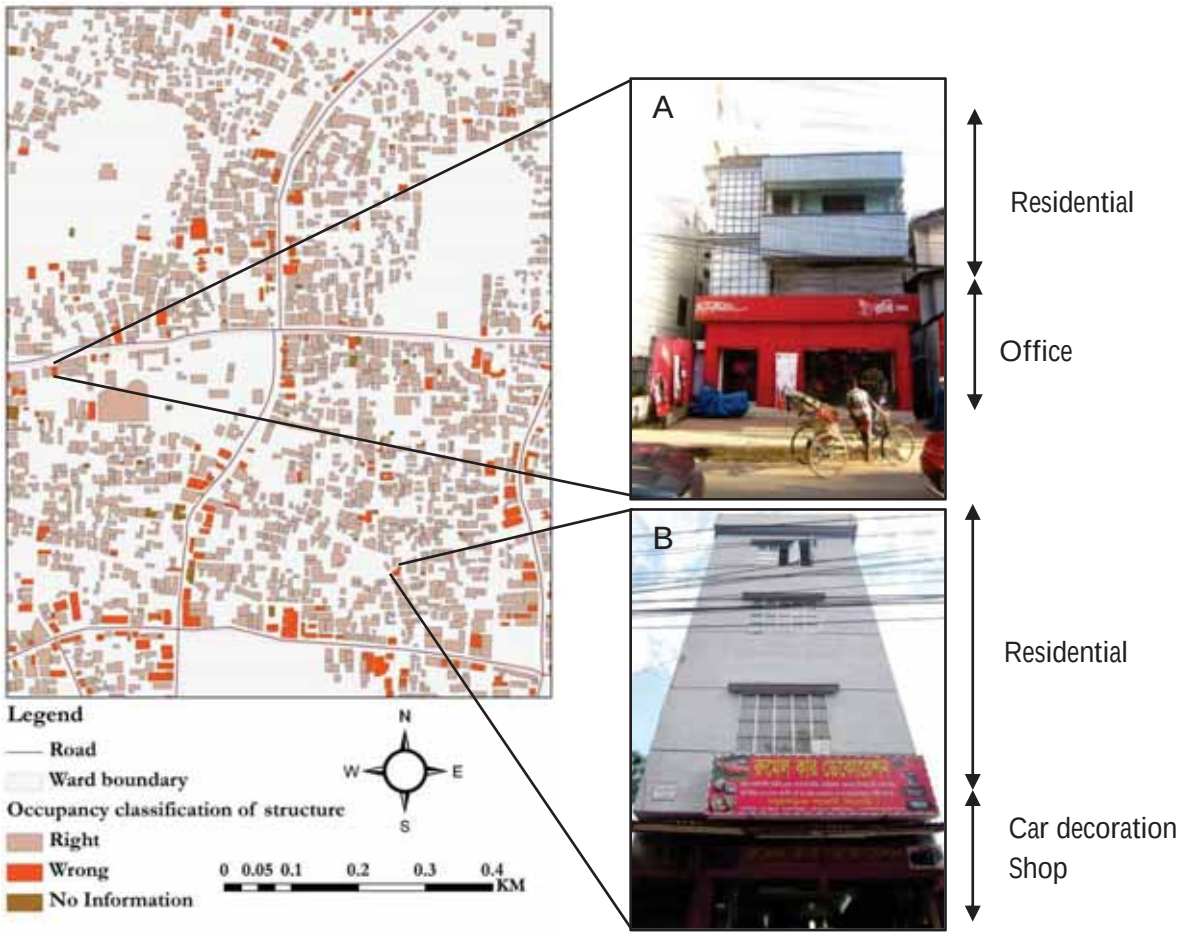


Figure 5-2: Example of misclassified occupancy in the sampled building: A & B classified as residential house instead of mixed-use buildings

5.2.2 Structural type

The structural type classification is based on the material used and the number of floors of the building. During the field work the construction material and number of floors was carefully observed. From the comparison it was found that among the 99 surveyed buildings for 16 buildings (16.2 %) the structural type was different from the previous study (see Figure 5-3). One of the main reasons could be that the building had been expanded between the two surveys. Another reason could be that a new building was made between the two dates. For example, in the CDMP data one building was BFL (brick in cement mortar with flexible roof) type but during the field work it was found that the type was changed to a reinforced concrete building (C4M) with 4 stories.

Figure 5-3: Structural type misclassification: A &B (mixed-use building) classified as BFL building; C (a school) classified as C4M instead of C4L

5.3 Comparison of the average number of occupants with existing data

The vulnerability assessment study by CDMP project also calculated the population per 100 m^2 for twenty seven (27) occupancy classes in Sylhet. The Table 5-1 describes the average number of person per floor space for school and mixed-use building from the field survey and CDMP study.

- Mixed-use buildings: The CDMP study shows that for mixed-use buildings the average is 5.59 (or 6 persons) in day time and 4.18 (or 4 persons) at night. The results from the field survey indicate that during day time the average is 3.46 (or 4 persons) and at night it is 3.14 (or 3 persons). The low standard deviation expresses that the number of occupants in 100 m^2 is very close to the mean. On the other hand the standard deviations are very high in the existing data, which indicates that there was a lot of variation in the population densities for mixed-use buildings in the CDMP survey. These values vary due to the sample size, collection method and variation in the distribution of the people in the sampled buildings.

- Schools: The average number of people per 100 m^2 in day-time is 58.74 (59 persons) and in night-time it is 0.31. But in the CDMP study the average value in day and night is 30.95 and 4.24 respectively. One of the surveyed school operates also in the evening, where the total population is 22 (including staff) from 5 pm to 8 pm and nobody stays after that. In another school, the caretaker lives with his family members in the school compound. Among the other surveyed schools, nobody stays at night in nine schools. In seven schools 1-2 persons stay as night guard in the building or in the whole school compound.

Table 5-1: The average number of occupants per 100 m^2 floor area in each occupancy classes

Building occupancy	No of Sample		Number of occupants per 100 m^2 ($X \pm \sigma$)			
	Field survey	CDMP study	Day-time		Night-time	
			Field survey	CDMP study	Field survey	CDMP study
Mixed-use building	48	184	4.15±0.83	5.59±5.71	3.14±1.25	4.18±4.66
Primary and High school	19	37	58.74±35.20	30.95±23.99	0.31±1.02	4.24±5.64

5.4 Day-time and night-time population distribution using exisiting data and improved data

The inconsistencies in the building occupancy class and structure type were corrected in the CDMP dataset. After improving the database the total number of population was changed considerably. The total population was increased by 11% in day-time and 8% population in night-time (see Table 5-2). Therefore it can be said that the risk of the people also increased in the day-time than night-time than before.

Table 5-2: Comparison of total population between the original and improved building footprint

	Day -time (in number)		Night-time (in number)	
	Total	Average	Total	Average
Existing data	492790	9.45	453327	8.68
Improved data	546700	10.38	490370	9.39

From the analysis it was found that the day time population is 8.7% higher than the night time population using the existing data, in contrast the day time population is 11.5% higher than the night time population using the improved dataset. The difference in day time and night time population probably indicates that a significant number of people come to the city for work purposes or otherwise during the day-time. Unfortunately, no data was available to verify this. In Appendix F the total number of population in different time period of the day and in different occupancy class are given.

The average number of occupants per 100 m^2 from the CDMP study and improved data was used to calculate the population in different occupancy classes for day-time and night-time in the whole city. It gives the overview of the day-time and night-time population scenarios in the whole study area (see Figure 5-4).

Few of the wards have high population both in day and night-time because the use of the structures. Among them ward 14 is taken as example in Figure 5-5. This ward mainly consists of offices, shops, markets or other commercial uses. It has also residential hotel which contains large number of population in night- time and less population in day-time. The total number of population in this ward during day time is 34000 and at night-time 19000, therefore in daytime more than 50% people come to this part of the city.

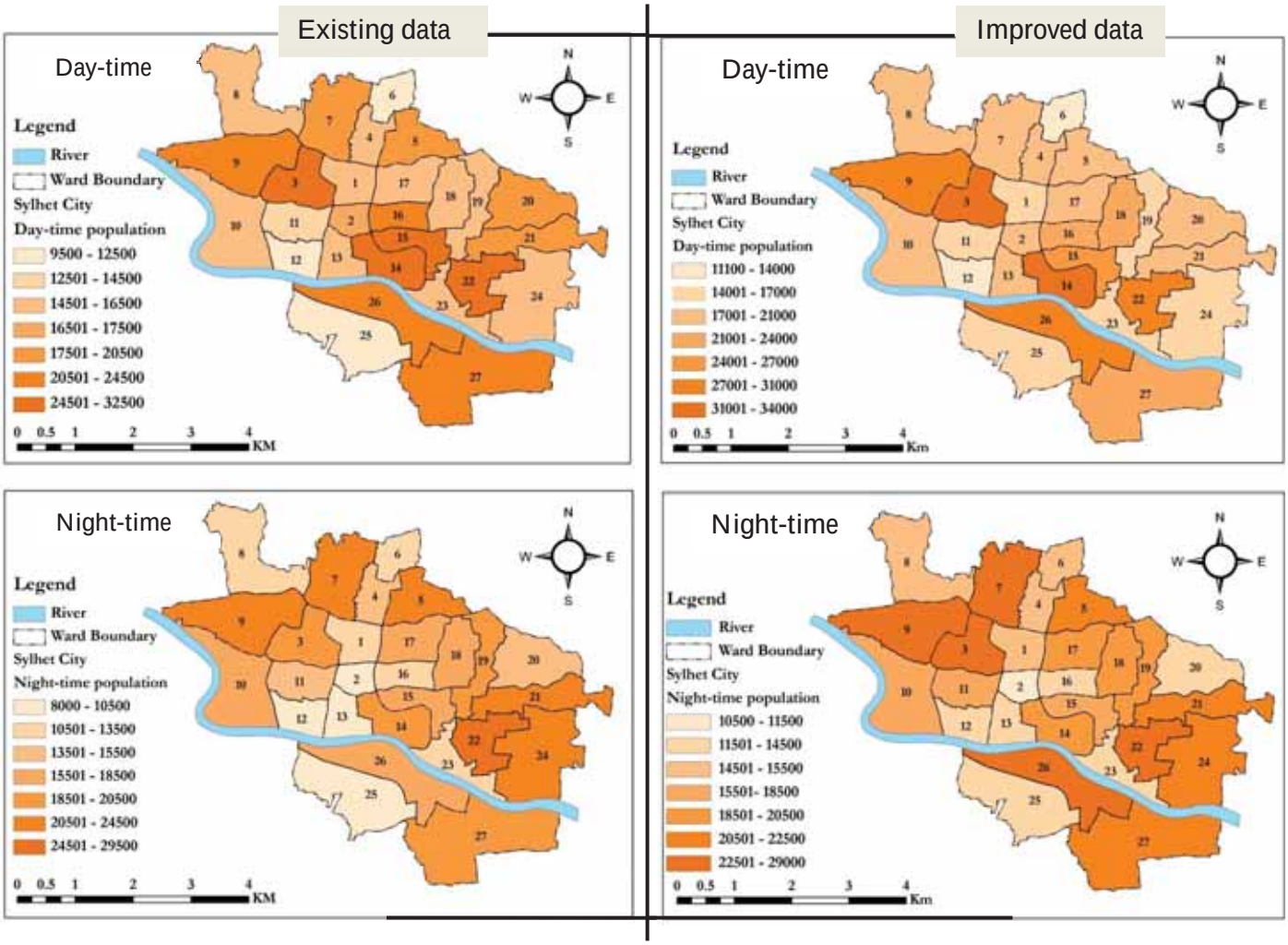


Figure 5-4: Ward wise scenarios of day-time (top) and night-time (bottom) population using existing data (left) and using improved data (right)

5.5 Population distribution scenarios in mixed-use building

a) Week day: From the collected population data it was found that the number of people varies in different times of the day due to their activity. In the week days, usually from 8 AM people used to go to their working place or school. As in this research the mixed-use buildings are studied, people from different location are coming to the shops and offices to do shopping or to join their working places. Figure 5-6 depicts that there is fluctuations of the population distribution in the buildings in the different time of the day. Mainly in the working hours most of the people come and at night (mainly after 8 PM) people start to leave their working place. Mainly housewives, old family member (or inactive people), unemployed persons and children (age less than 5 years) stay at home most of the day.

b) Strike day: Strikes are very common in Bangladesh due to the political instability. Often the political (opposition) party or other pressure group calls a strike (dawn to dusk) against an unfavorable action of the ruling government. On average every year the number of strike days varies from 20-30 days. More details about the strike scenarios can be found in a report of UNDP-Bangladesh(2005). Sylhet is a relatively small city, and most of the offices and markets are located in the center of the city (Zindabazar). If a strike is announced by the opposition party it affects the whole city. Strikes seriously affect the economy.

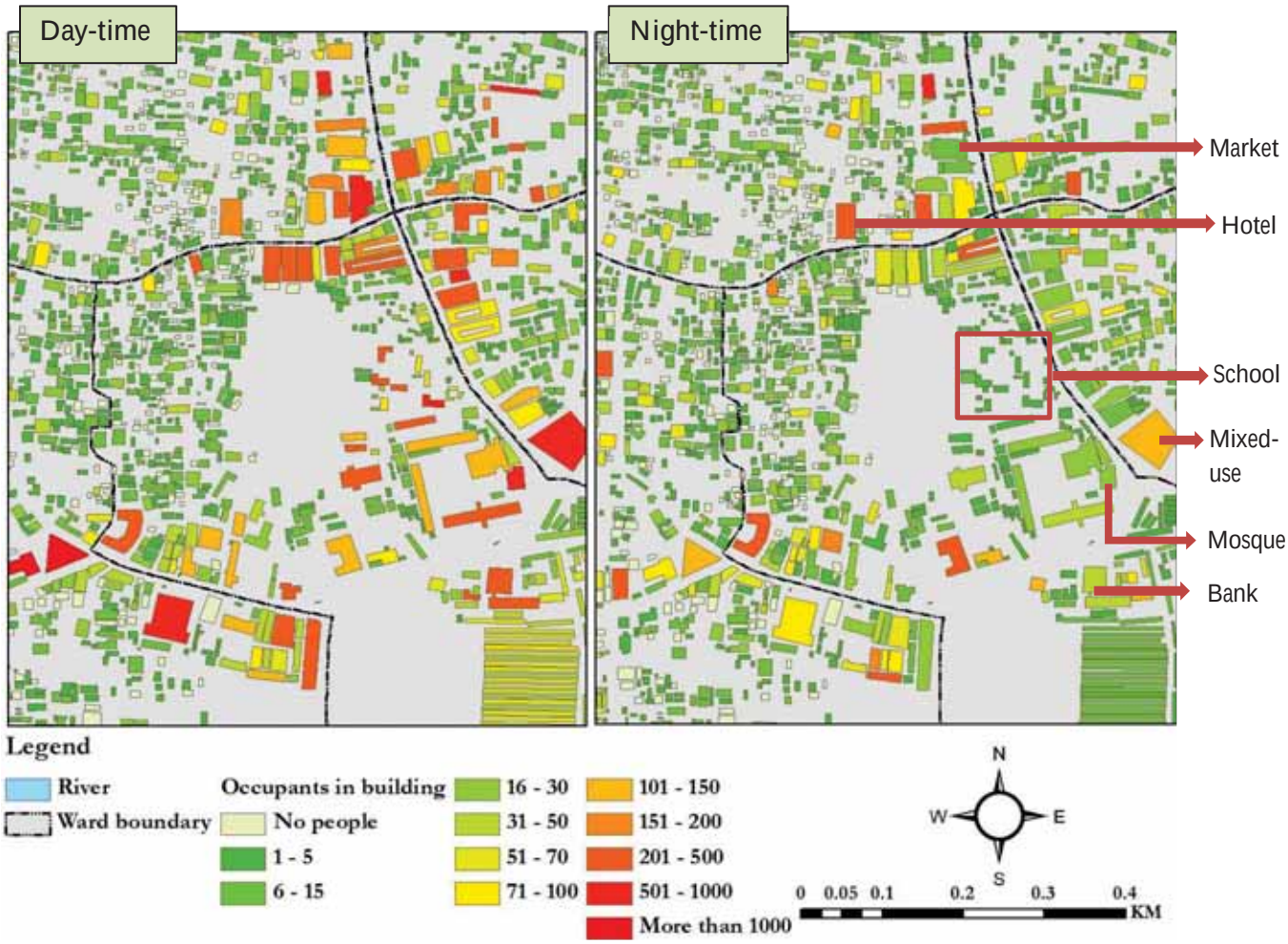


Figure 5-5 : Day-time (left) and night-time (right) population distribution scenarios in one part of ward 14

People who are working in the government, banks, offices and schools are obliged to go to their work. So in this day it was found from the discussion with the people that most of the people that do business and who's working place is far from their houses, do not go to work on such days. But the businessman who's house is very near or within the neighbourhood which might not be affected by the strike (easy to go by foot) usually keep their shop open.

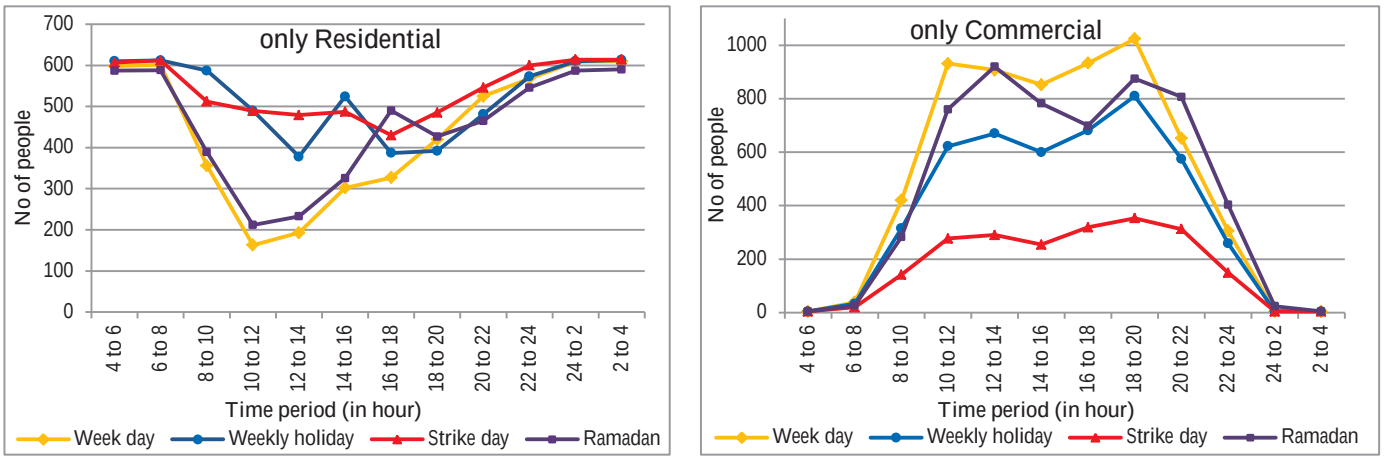


Figure 5-6: Presence of the population in surveyed building during different time period of the day for four scenarios

c) Ramadan Days: The period of the Ramadan is 30 days in a year. During these days, the office hours usually start later and end earlier (10 AM to 3 PM) than the normal working day. But the markets remain open till 12 PM or some times more. Most of the cases people also like to go for shopping in the evening because after one months of the Ramadan, people celebrate Eid-Ul Fitr which is one of the big religious festivals. Male are used to go for prayer at night to the mosque (8 PM to 10 PM).

d) Weekly holiday: In Bangladesh the weekly holiday is observed on Friday and Saturday. The government offices mainly close in these two days, but local shops and a number of shops in the market remain open during holidays. They mostly open their shop between 2 PM to 4 PM. On the other hand some private offices, markets and shops remain open in Saturday. On Friday there is a special prayer for male from 12 AM to 2 PM, so in this time period most of the Muslims go to the mosque. Figure 5-6 clearly depicts the variation in that time period. Some people used to go out with their family in the evening for refreshment to their relatives home. In the holiday most of the marriage ceremony, anniversaries, birthday, or any kind of get together also celebrated.

By analysing these four temporal scenarios it was found that there is some variations in the person per 100 m^2 for day and night-time. Table 5-3 describes the variations in four temporal scenarios in a year for day and night-time

Table 5-3: Comparison of person per 100 m^2 in different scenarios of the year in mixed-use building

Scenarios	Day-time (per 100m^2)	Night-time (per 100m^2)
Weekday	4.15 ± 0.83	3.14 ± 1.25
Ramadan days	3.98 ± 0.97	3.20 ± 1.32
Weekly holiday	3.88 ± 0.37	2.99 ± 0.90
Strike day	2.71 ± 0.19	2.55 ± 0.34

5.6 Population distribution scenarios in school

From the data analysis it was found that on average about 80% student and almost 100% of the staff (teachers and other office staff) present in the school in the normal weekdays. Most of the schools remain open during the Ramadan days. Besides the regular class some schools (Govt. Agrogami Girls High School, Moinnunessa Girls High School, Mirza Zangal Girls High School) are only open for special classes for the class VIII, IX and X students.

During strike days the schools cannot function normally, as parents usually do not send their children to school on these occasions. As a result most of the schools are un-officially closed. There is an exception in one school where during a strike day students come to the school, because most of the students live close to the school compound, whereas most of the other schools people have to travel much further At least 78% of the staff tries to come for the attendance and they stay in the school till at least 2 PM. Generally government school teachers come to the school on a strike day. But sometimes the authorities accept the absence of the staff whose house is far from the school.

After analysing the collected data it was found that there are enormous differences among the four temporal scenarios in a year. Table 5-4 gives an overview of the variations in the person per 100 m^2 for the schools.

Table 5-4: Comparison of person per 100m^2 in different scenarios of the year in school

Scenarios	Day-time (per 100m^2)	Night-time (per 100m^2)
Weekday	58.75± 35.20	0.31 ± 1.02
Ramadan day	48.53 ± 36.61	
Strike day	4.76 ± 8.75	
Weekly holiday	0.25 ± 0.35	

6 POPULATION DISTRIBUTION MODELING

This chapter provides the result of the population distribution modeling approaches for different scenarios. It also tries to explain the factors which might affect the population distribution in different period of the day.

6.1 Weekday scenario

It is normal working days in a year. In Bangladesh 241 days (excluding Friday, Saturday and government holiday) in a year is the standard working days which is applicable for the government offices and banks. There are different factors which might affect the distribution of the people in a building based on their occupancy classes. Considering those factors the population were distributed to the buildings, these factors are given in Table 6-1.

Table 6-1: Factors affecting population distribution in weekday

Occupancy	Factors
Residential	Working hour is from 9 AM to 5 PM, people starts going out at least from 8 AM.
Commercial	Market opening time is from 10 AM to 10 PM. People presence in market gradually increases from 12 AM till 10 PM, particularly from 6 PM to 8 PM most people come to the market or shop after their office.
Educational institution	School hour is usually 10AM to 4PM.
Religious places	Prayer time People usually gather in the mosque or other religious places in the specific prayer time. For example in the mid of the day (12 AM to 2 PM) and in the evening (4 PM to 7 PM) people come to the mosque for prayer. Few people also go to the mosque in the dawn of the day (5 AM to 6 AM).
Restaurant/recreational	Gradual increase in the restaurant. The percentage of the people is moderate in the morning but it increases gradually in the afternoon (usually after 12 AM till 4 PM), mainly because of the lunch. On the other hand in the recreational places in the morning time less people present but it increases gradually.
Industry	Working hour is also started from 9AM, most of the worker present.
Hospitals/ doctors chamber	Presence of patient and visitors: Generally people come to visit a doctor in the evening. So the percentage of the presence in the doctor's chamber is relatively less in day-time than night-time but the hospital it is most of the time remains same.

Figure 6-1 illustrates the population distribution scenario of the study area from 8AM to 10AM and 4PM to 6PM and the difference in the population from 8AM to 12AM and 4PM to 8PM. The positive value indicates the population has increased (↑) in those wards from 8 AM and negative value indicates that the population has decreased (↓) from those wards from 8 AM to 10AM. Ward number 3, 7, 9, 22 and 26 shows decreases of population from morning, because these wards are mainly residential. As a consequence the population density increases in the commercial area for example in wards 12, 13, 14 and 25. From the analysis it was found that mixed-use buildings are mostly along the road side. Therefore the population density remains high in few wards during 4PM to 8PM. In most of the wards the population are increasing, since some school close between 4 PM and people started coming to home from office or outside. Usually most of the people present at home after 10 PM, but a certain amount of people who works in the market stays out for long. Therefore after 12 PM almost all the residents are present at home. The population in different time period shows the presence of maximum number of people in a typical working day.

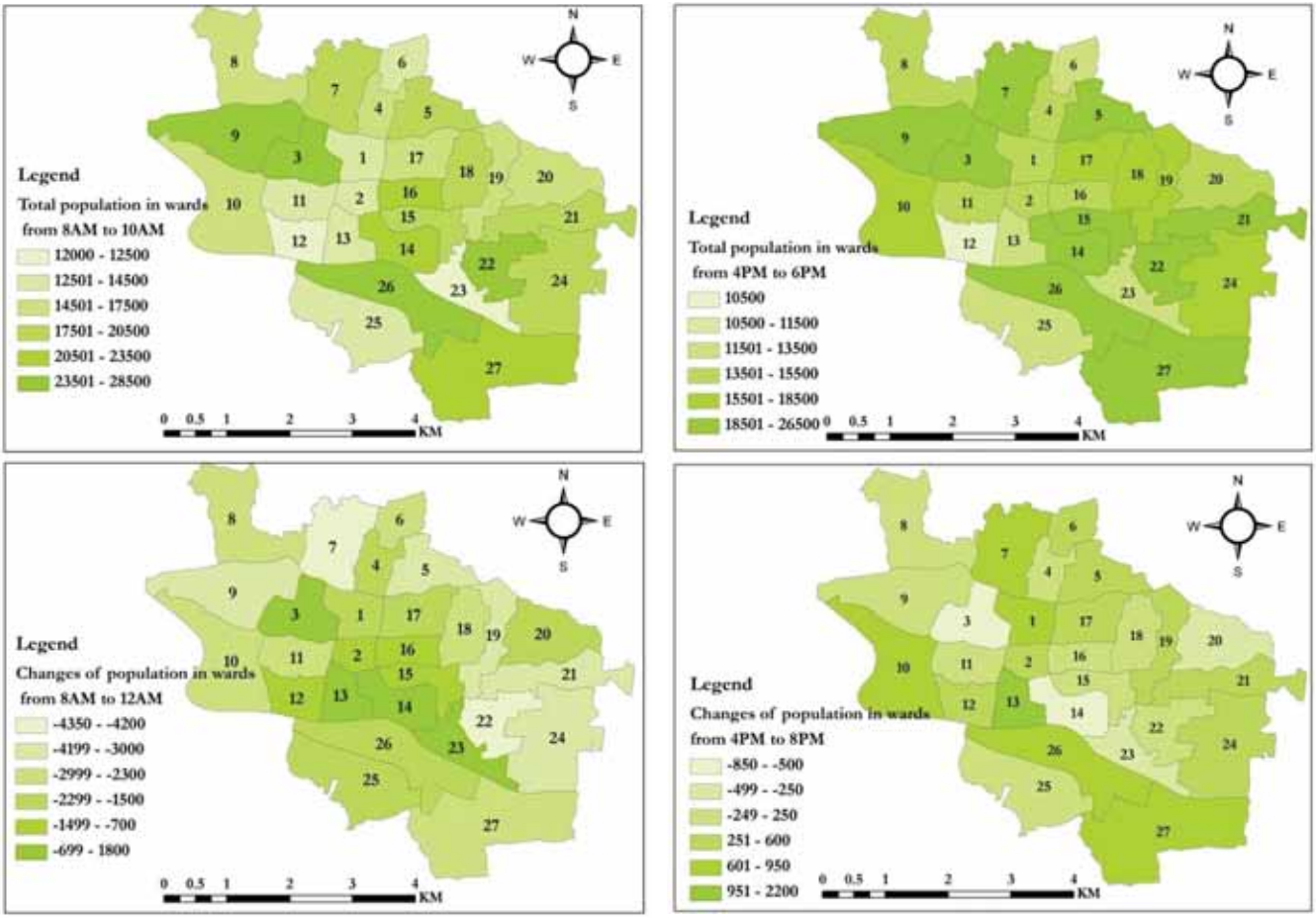


Figure 6-1: Population in weekday from 8AM to 10AM (left-top) and from 4PM to 6PM (right-top); difference from 8AM to 12AM (left-bottom) and difference from 4PM to 8PM (right-bottom) in the study area at ward level

6.2 Strike day scenario

Strike day is a very common phenomenon in Bangladesh as an alternative way to protest any corrupted action of the government. Most of the case it becomes very restricted and there is no transportation facilities available in the road because of the vandalism and arson attack on the vehicles by the people who are in favour of the strike. It disrupts the mobility of the people. Therefore the distribution of the people also varies from one occupancy class to another. The factors which govern the distribution pattern are given below in Table 6-2.

Table 6-2: Factors affecting population distribution in strike day

Occupancy	Factors
Residential	Population presence is very high at home except the people who engaged in government job or bank and students remain at home. Certain percentage of people (at least 5%) goes to take out procession in support or oppose the strike.
Commercial	Markets close in the strike day. Few shops open after strike and also close earlier than normal working days.
Educational institution	Absence of the student, only staffs present
Religious places	Prayer time is as usual
Restaurant/recreational	Percentage of the people is very less in the morning till strike breaks (usually after 4 PM)
Industry	Working hour is also started from 9AM, but less worker present because of no transportation facility
Hospitals/ doctors chamber	Presence of patient and visitors is less in the morning. In the evening the rate increases because vehicles start again after the strike.

Figure 6-2 describes the population distribution scenarios in a strike day. Figure 6-2 (A), (B) describes the distribution of population and differences of population from 10AM to 12AM and 12 AM to 2 PM and (C), (D) depicts the scenario in one commercial part of the study area (ward 14) for the mentioned time periods. The commercial area has great impact during the strike day. All the markets remains closed to protect from the sabotage, therefore there is nobody present in structures during the strike period. However some people are obliged to go to their offices (especially government worker, banker) and it is clear that in the banks the number of population ranges from 150-250. In contrary students couldn't come to the school because parents do not feel safe to send them in this situation. Therefore the presence of population becomes very low in educational institutions. But in the mosque people come during the prayer time. Usually most of the mosque/ religious places are located in the neighbourhood or people can go the mosque by walking.

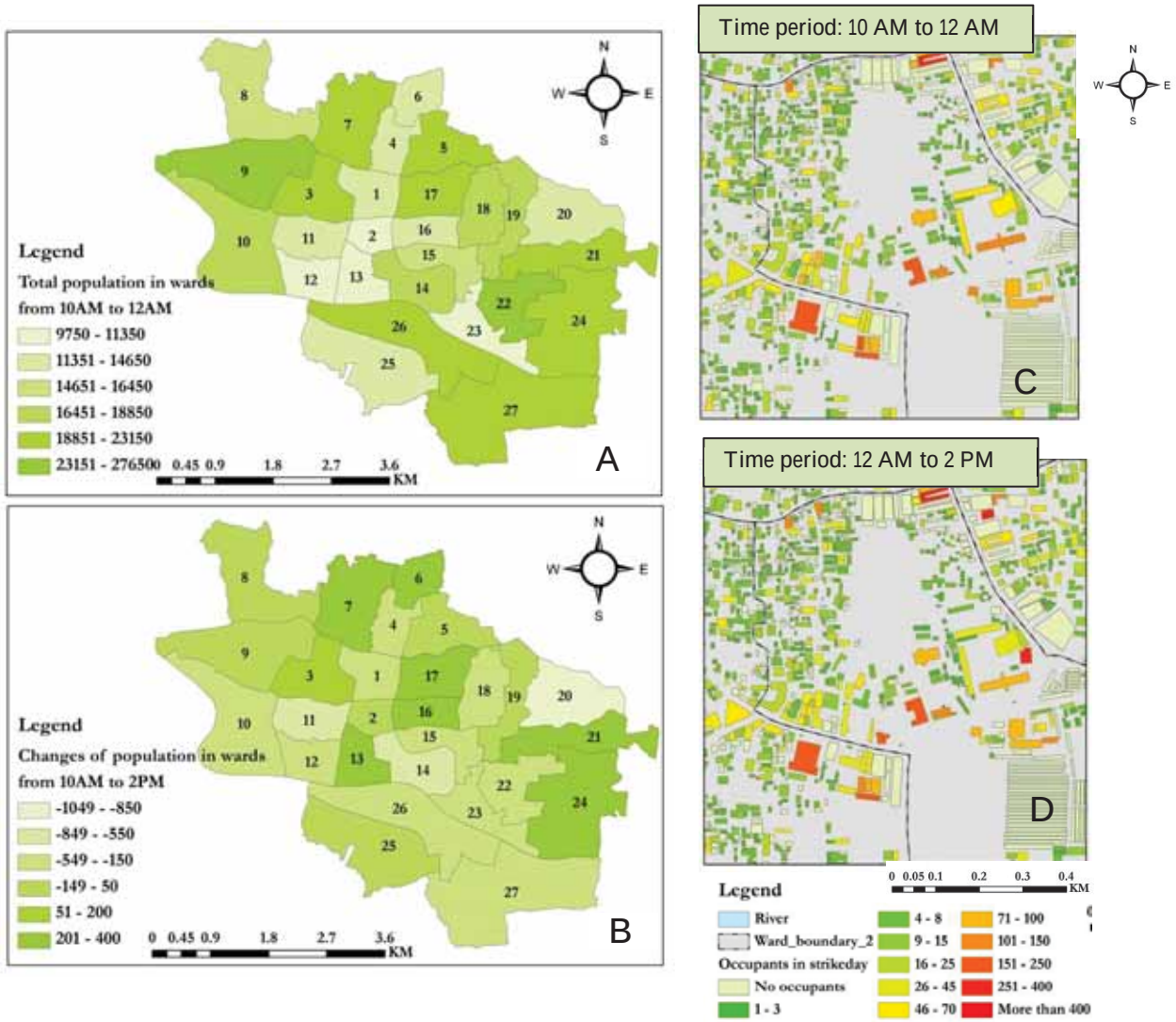


Figure 6-2: Population distribution scenario during strike day

A: Distribution in 10AM to 12AM and B: Changes of population from 10 AM to 2PM in ward level, C: Population distribution in time period 10AM to 12AM (top) and D: Population distribution in time period 12 AM to 2PM (bottom) in one of the commercial part of the study area

Figure 6-3 gives an impression that how a strike day varies from the normal working day. In the normal working day the population varies up to 1,000 in some of the commercial building. But in the strike day this value is relatively very low (up to 40).

6.3 Ramadan day scenario

The population distribution during the Ramadan days varies significantly in different occupancy. In Sylhet about 87% people are Muslim (BBS, 2012) and during the Ramadan days it has some influence also on the population distribution in different building occupancies. There are several reasons behind this distribution, which are highlighted in Table 6-3.

In Figure 6-4 it is seen that some buildings having more than 500 people because these are shopping mall and market. Therefore there is always high population density. But from the other commercial use building (e.g. banks, office) population started to leave after the office hour, therefore population density becomes low. Figure 6-5 shows the total population distribution in some specific time periods at ward level. After 10 PM people started to come to the home as a result the population in the building as well population in the respective wards are increasing. One important feature is the Eid shopping during the Ramadan day, which makes lot of difference in the markets, shops and residential houses.

Figure 6-3: Differences in population distribution in weekday (top) and strike day (bottom)

Table 6-3: Factors affecting population distribution during Ramadan day

Occupancy	Factors
Residential	Changes in working hour from 10 AM to 3 PM. Eid shopping i) Women usually go for Eid shopping after 11 AM when the markets open and try to come back before *Iftar*[2]. ii) Most of the time people also go to the market after Iftar (after 6 PM).
Commercial	Market opening time is from 10 AM to 12 PM or sometimes more. People presence increases continuously from 11 AM till late night, particularly from 6 PM to 11 PM the number of population is twice as more as day-time population.
Educational institution	Less population than normal
Religious places	Prayer time is as usual like normal days, but there is a special prayer during Ramadan night (around 8 PM to 10 PM); male use to go to the mosque to say the prayer in group.
Restaurant/recreational	Percentage of the people is very less in the morning but it increases gradually in the evening (usually after 4 PM). Because in the Ramadan people do fasting therefore most of the food shops are closed
Industry	Works on schedule basis
Hospitals/ doctors chamber	Presence of patient and visitors is as usual but generally visitors and patients come to the hospital/ chamber after 6 PM.

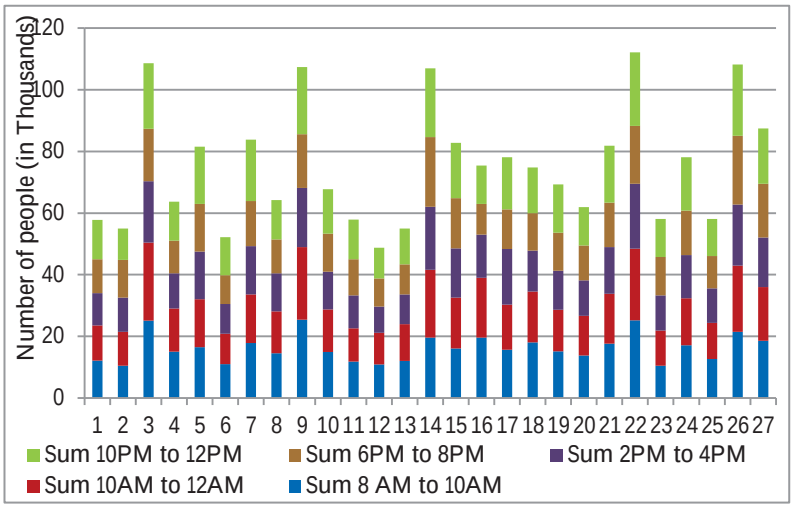


Figure 6-5: Distribution of total number of people in different time period of Ramadan day

Figure 6-4: Day-time and night-time scenarios in one part of the study area

[2] Iftar means the food when Muslim people break the fasting during the Arabic month Ramadan after the sunset

6.4 Weekly holiday scenario

It is already mentioned in section 5.5 that generally Friday and Saturday are the government holiday in Bangladesh. In these two days mostly the banks, government offices and few other private offices remains closed. There are total 105 days government holidays in Bangladesh. For most of the educational institutions Friday is considered as holiday. Except these weekly holidays, there are twenty four (19) government or public holidays. Most of the case the government holiday and weekly holiday scenarios are similar. There are lot of variation in the population distribution in different occupancy classes than the weekday. There are some reasons behind this. They are given in Table 6-4.

Table 6-4: Factors affecting the changes in the population distribution in weekly holiday

Occupancy	Factors
Residential	Weekly shopping: Till 11 AM most of the people usually stay at home. After that they go to shops to buy daily necessary items from mainly the open market. Social gatherings: Certain percentages of people also attend some programs in the afternoon (12 AM-4PM)
Commercial	Different shopping malls and markets remain closed and open after 4 PM
Educational institution	All educational institutions remain close in the weekly holiday
Religious places	Friday prayer: 12 AM to 2 PM most of the Muslim people come to say the special prayer on Friday. Other prayer time: In the evening (4 PM to 8 PM) there are three more prayer, also in this time the percentage of presence is considerable.
Restaurant/recreational	Social gatherings: In the restaurant or other recreational places the percentage of the people is much higher than the normal days. It is very common in Bangladesh that in Friday or weekly holiday most of the marriage ceremony, birthday, and get together program arranged in this day.
Industry	The industrial works do not continue during the holiday especially in Friday. Therefore there is no person present in these places. But in the poultry farm some people work on schedule basis.
Hospitals/ doctors chamber	In the evening people mainly come to visit the patient. Also doctors chamber open in the evening (from 5 PM to 10 PM). So the percentage of the presence is relatively higher than the morning time.

Figure 6-6 shows the comparison of the population changes in weekly holiday and week day scenario for three time periods in a day at ward level. Because of the less movement in Friday and Saturday, the variation is also remarkable from the working day in different time period especially from 2PM to 6PM.

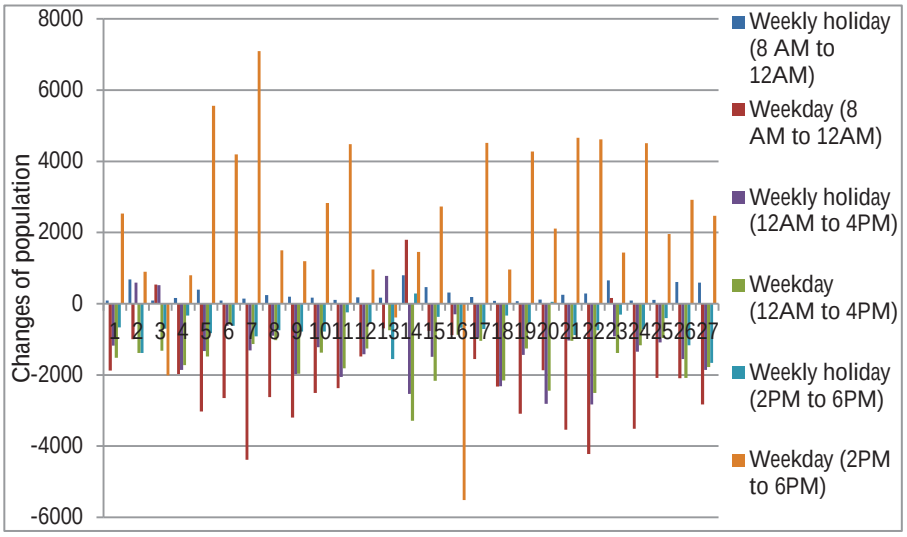


Figure 6-6: Weekly holiday and weekday scenario comparison in Sylhet

Figure 6-7 describes how the population changes from 4PM to 8PM in weekday and weekly holiday. It is clear that in the residential wards the density is very high in weekly holiday than weekday.

It was found from the analysis that in the office buildings and other commercial buildings there are few people in the holiday than the working days. However in the residential buildings the opposite scenario found, since most of the people stays at home and they passes their leisure time or do other activities.

Figure 6-8 shows the results of the population modeling for four temporal scenarios in different time period. In Ramadan day population fluctuates a lot during the day-time periods. On the other hand in strike day population variation is stable relative to other temporal scenarios of a year. The analysis also shows that in the weekday from 2PM to 4PM and in Ramadan day 6PM to 8PM lowest number of people present in the building. That means in these time periods most of the people are in street or outside the building. It was found that in Ramadan days in the evening more than 20% people are outside the building. On the other hand in weekly holiday and strike day less people are in outside and average percentage is about 3-8%. In the weekday afternoon about 18% people are not in the building. All the results of the population distribution modeling are given in Appendix F.

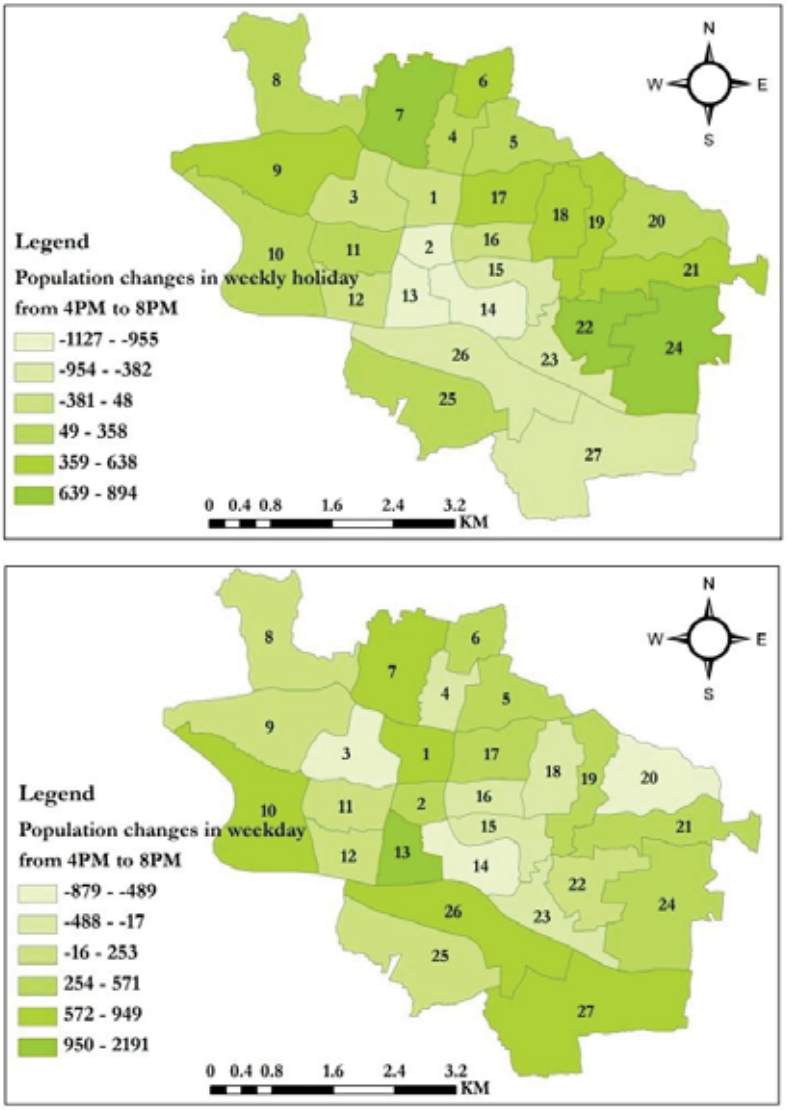


Figure 6-7: Comparison of the weekly holiday and weekday scenario between 4PM to 8PM

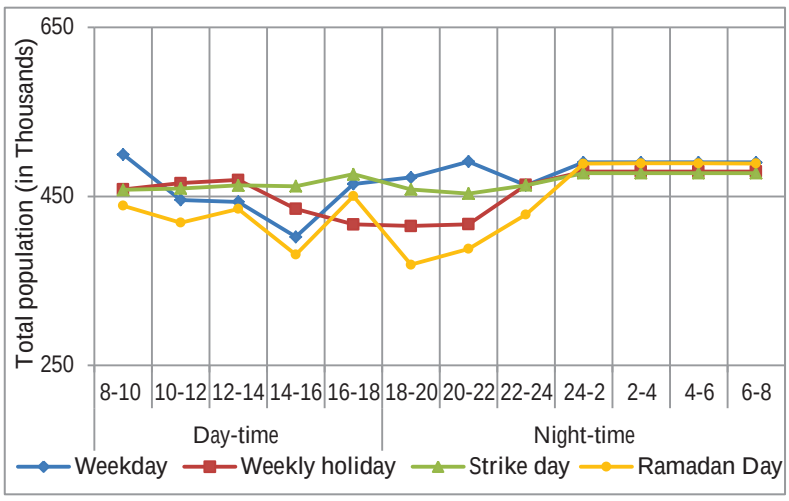


Figure 6-8: Total population distribution over different time period of the day in four temporal scenarios

7 IMPACT OF POPULATION DISTRIBUTION SCENARIOS ON POPULATION LOSS ESTIMATION

This chapter deals with the impact of population distribution on loss estimation. Here the loss estimation was done in two ways: one is using a relationship between building type and severity level of injury from HAZUS and another is directly using CAPRA vulnerability values. All the analysis results are discussed below.

7.1 Impact of population distribution on loss using the severity value from HAZUS

To analyse the impact of population distribution in different time period of the day on population loss estimation, a percentage of injury severity level value was used. The level of severity of the affected people was classified based on the level of injury state. And the building damage state was classified in to four states (collapse, extensive damage, moderate damage, slight damage) for two main building types: (masonry and other structural types). The percentage of building damage estimation value from CDMP study was used (for four damage state) & the empirical relation with injury levels of HAZUS was applied, but with new population distribution. A summarized table from HAZUS methodology of FEMA (2003) (see Appendix F) was used here. These percentage values were then multiplied with the number of people in each damage state and in time period 12AM to 2PM (day-time) and 12PM to 2AM (night-time) in the masonry building and other structural type for four temporal scenarios in a year. This gives number of affected people in different injury levels. For each scenario the minimum and maximum expected loss were calculated.

In Figure 7-1, different level means the injury severity level (also explained in chapter 3). The number of causalities is higher in weekday than the other scenarios.at night (minimum 18866 and maximum 24544) and the lowest loss was found in day-time of Ramadan day. This estimation was done for worst earthquake scenario Dauki fault with magnitude 8.5. In comparison with the CDMP result this result gives more casualties. According to CDMP's study the highest loss of life was 20,000 in night-time and 14,000 in day-time for worst earthquake scenario.

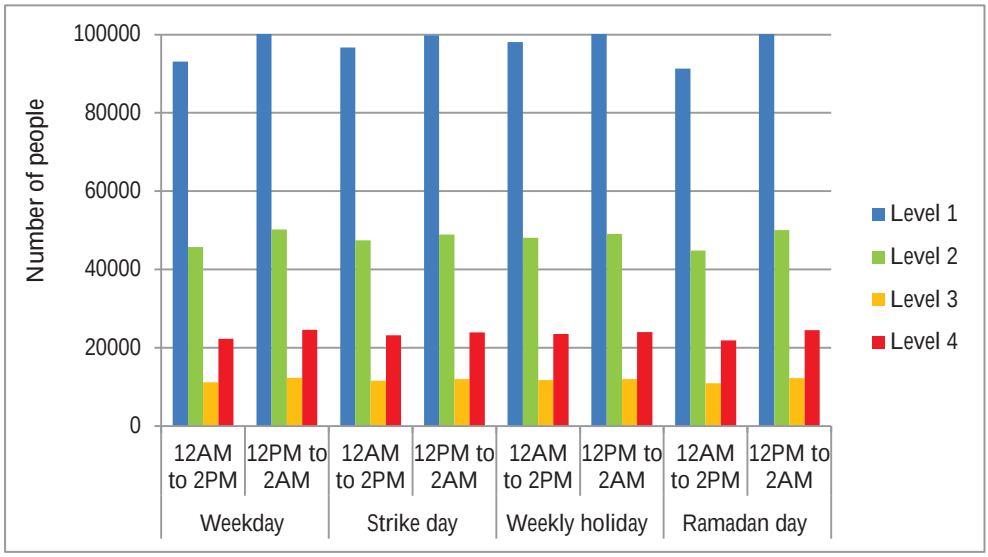
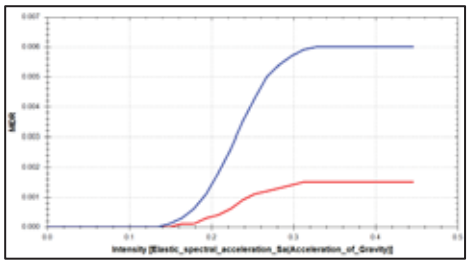


Figure 7-1: Population loss calculation using the percentage value of HAZUS

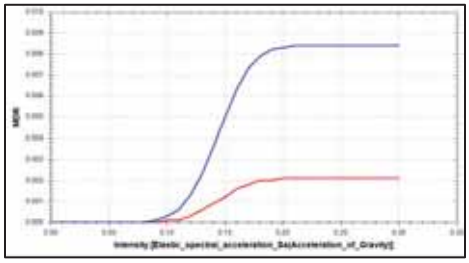
7.2 Impact of population distribution using CAPRA vulnerability curve

The impact of different population distribution scenarios were analysed by using the population distribution data and the minimum and maximum value of spectral acceleration. The vulnerability values were taken from the CAPRA software. Figure 7-2 shows the curves which were used in this analysis for unreinforced masonry building (M34L, M34M), reinforced concrete building (RC1L, RC1M, and RC1H), steel (S3L), and wooden building (WL) where L, M and H indicate the height of the building (low, medium and high respectively). In these curves the uncertainty is also considered (red lines). The mean death ratio used from these curves is given in Appendix G.

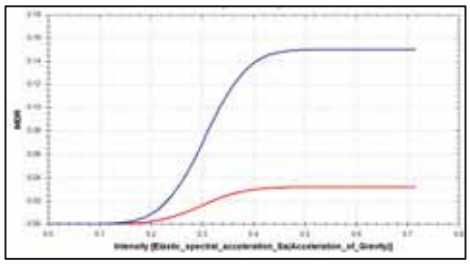
M34L (human vulnerability curve)



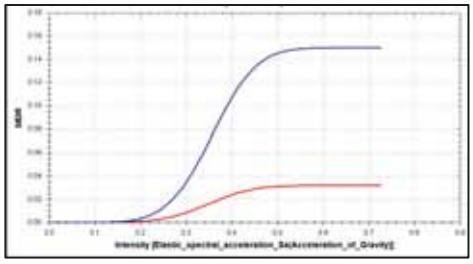
M34M (human vulnerability curve)



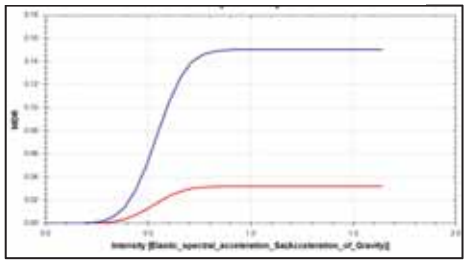
RC1L (human vulnerability curve)



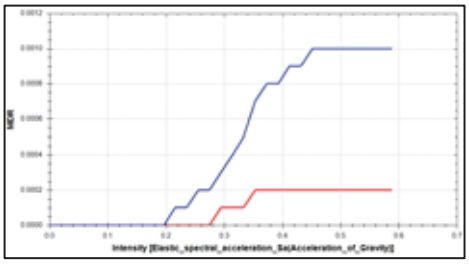
RC1M (human vulnerability curve)



RC1H (human vulnerability curve)



S3L (human vulnerability curve)



WL(human vulnerability curve)

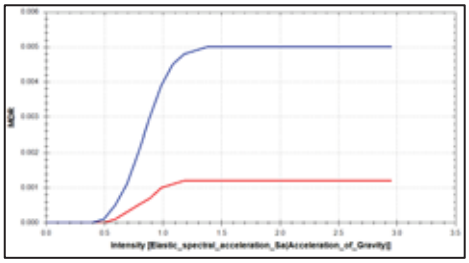


Figure 7-2: Human vulnerability curve used for loss estimation

The analysis on loss estimation shows that there is a difference in population loss in different temporal scenarios in a year. The loss is enormous for each of the cases. The findings from the scenario analysis are given below:

a) Comparison among the earthquake scenarios

- Among the five earthquake scenarios four of them show more casualty than the PBF-3 scenarios with magnitude 8.3. In this scenario, the number of casualties is relative lower than the others because of the intensity of the earthquake to the city. The range of intensity in this scenario is 0.26g to 0.44g.

- In Figure 7-3 six different time periods in a day were considered because in these time periods most of the variation of the people was found.
- Here the maximum and minimum mean death is equal for most of the scenario. Because in the CAPRA vulnerability curves after a certain intensity value the MDR remains constant (see Figure 7-2). In most of the earthquake scenarios the minimum and maximum values are very close to each other, therefor e the MDR values are also same.

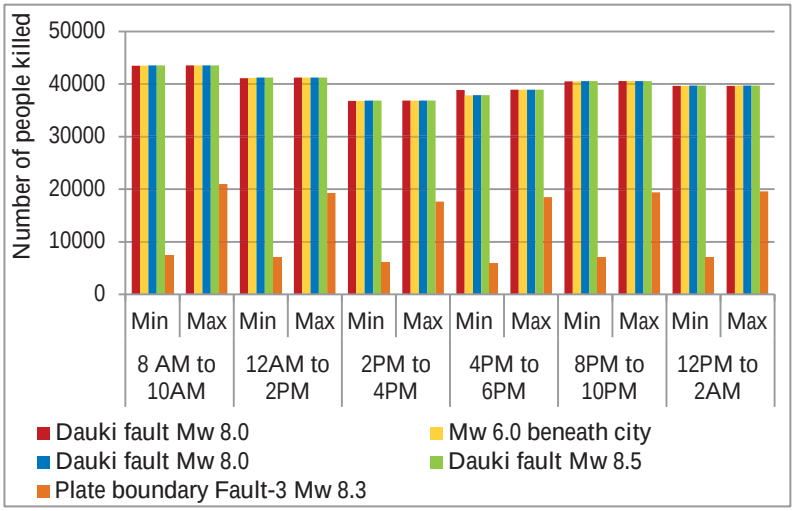


Figure 7-3: Comparison of minimum and maximum losses among the different earthquake scenarios in weekday

b) Comparison among temporal scenarios in a year

- In case of different temporal scenarios of the year the weekday scenarios are the worst. In Figure 7-4 the maximum number of casualty in different time period of the day is shown.
- In the weekday scenario the worst scenario was found in 8 AM to 10 AM in the morning, the casualty amount is more than 43,000.
- Ramadan day scenarios and weekly holiday scenarios shows most casualty in the mid of the day than the other time period.

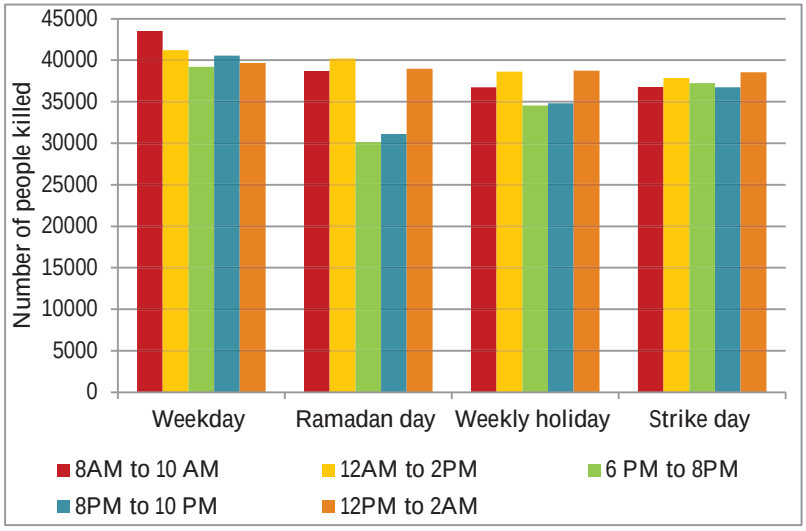


Figure 7-4: Comparison of four temporal scenarios in different time period of the day

- However in weekly holiday, in the morning (8AM to 10AM) the casualty rate is lowest than other. One reason is the less amount of total population in the city.
- Strike day scenario shows relatively equal amount of loss in different time period. But the worst scenario found in 4 PM to 6 PM in the evening (38900). The one reason behind the exception is usually in strike day most of the people are already come to home from outside or people may come in to the city for different purposes.
- Out of all the temporal scenarios, in the day-time the lowest loss is in weekly holiday but at night-time the lowest loss is in strike day.
- The probability or chance of an earthquake occurrence during these temporal scenarios was calculated. It was found that in weekday the probability of occurrence is very high at night (30%) and day (22%) also, whereas in weekly holiday the occurrence is 20% at night and 14% in day (see Table 7-1). Thus the people are more vulnerable in weekday for an earthquake event. During the calculation all mutually exclusive days are not considered, for example the month Ramadan has 30 days which includes weekday and weekly holiday. Therefore in probability calculation the weekly holidays were excluded, likewise others.

Table 7-1: Chance of occurrence of an earthquake event during different temporal scenarios

Scenarios	Day-time	Night-time
Weekday (191 days)	21.8%	30.5%
Weekly holiday (124 days)	14.2%	19.8%
Ramadan day (20 days)	2.2%	3.2%
Strike day (30 days)	3.4%	4.7%

c) Comparison among the time periods

- Each of the time periods shows a high number of casualties but in the morning 8 AM to 10AM and at night 8PM to 10PM during a weekday these are the highest. Because in the morning most of the people go to their work place and some people also come to the city from outside for school and official work. So the casualty rate is higher in this time period. Vice versa after the office hour people started to come to home and leave the city. Therefore the casualty rate is relatively decreases than the morning time but higher than midnight.
- On the other hand less population loss found in the building during 2PM to 4PM in a working day. From Figure 7-4 it is clear that among the four scenarios, in Ramadan day lowest population loss found at night-time 6PM to 8PM and also 8PM to 10 PM.

d) Comparison among the building types

- The analysis shows that the density of the people is higher in reinforced building type and brick masonry building than other building types. More specifically, in the day-time, total 76% people are inside the low rise reinforced buildings and low rise brick masonry buildings. But the people inside the reinforced concrete buildings are more vulnerable to earthquake because the trap percentage is very high. As a result, this type of building contributes 60% of total loss during the earthquake.
- The wooden buildings and steel structures do not result in that many casualties as the other building types. But if any high rise and earthquake non-resistant buildings located beside this kind of building, people would be certainly affected due to their spatial location and building collapse.

- Since in this analysis one building type was not included for that reason the population of this building (in day-time 23610 and night-time 34912) were also not considered. Thus it can be concluded that the expected number of population might be increased if this building type was in consideration.

Therefore from the analysis it is apparent that due to the difference in time of the day the loss varies considerably. It also depends on the amount of people in the building and what type of buildings people are occupying in a specific time period.

The loss estimation result shows different human loss from both approaches. It was found that using the CAPRA vulnerability curve and HAZUS relationship value, about 9% and 5% of the total people will be killed. It is already mentioned that one building type and its population was excluded in the loss calculation using the CAPRA vulnerability curves, but in the HAZUS method all the building types were included, though the number of people killed is extremely higher in CAPRA approach.

In the CAPRA vulnerability curve, the parameter trap percentage and death factors were changed to experiment the effect on the loss estimation and it gives enormous differences from the previous result. Because of the different parameters in the vulnerability curve the value changes a lot. These values were taken from Alam, et al.(2008). They used 10% trap people and 30% killed people for unreinforced masonry building (1 storied) and 20 % trap and 30 % killed people for unreinforced masonry building more than 2 storied, 5% trap and 20% killed people for all reinforced masonry building and 3% trap and 10 % killed people for wood and steel structure. From Figure 7-5, it is clear that the loss of life decreased a lot from the other two approaches as well as from the CDMP study results. The highest loss (8600) found in week day from 8PM to 10 PM whereas without changing any parameter value the loss was 43,500 for 8AM to 10AM. This result always shows the highest population loss at night-time than day- time.

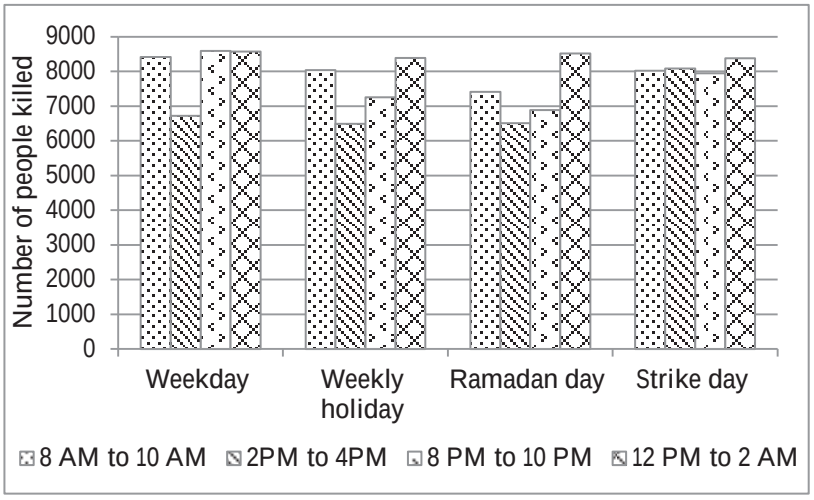


Figure 7-5: Number of person killed in different temporal scenario using CAPRA vulnerability curve

Therefore it can be summarized that it is necessary to have proper building type classification and associated vulnerability curve with the relevant parameter (trap percentage, death factor etc.) which affect the population loss estimation enormously.

8 DISCUSSION AND CONCLUSIONS

This chapter discusses about the key findings based on the analysis and results and also tries to summarize the research objectives. It also discusses about the limitations of the research and some recommendations based on the limitations.

8.1 Discussion and conclusions

In this research the population dynamics with every 2 hours interval was used to model the population distribution in order to get the spatio-temporal population exposure to earthquake risk assessment in the Sylhet city. The buildings are always in threat of earthquake hazard but people are moving. Therefore their risk to earthquake varies from time to time. The result shows that there is potential difference in the population distribution among different time period which increases the risk of the people with respect to time period. In order to conclude the whole analysis, the key features and findings are discussed below:

8.1.1 Uncertainty in population distribution

Risk assessment study deals with lot of uncertainty. The high standard deviation in the existing data indicates that there are a lot of uncertainties. The coefficient of variation (CV)[3] for different occupancy class explains that ratio of standard deviation and mean is very high, which means high variance between the mean and standard deviation. For example, in CDMP's study the CV for mixed-use building is 1.02 and for school 0.77 in day-time, which indicates high variations in the data. It has impact on the total population calculation also. On the other hand the new person per floor area for mixed-use building and school building shows lower CV than the CDMP's study which indicates less uncertainty and gives better result than the previous study.

The CDMP project carried out this study for three main cities in Bangladesh, which are vulnerable to earthquake. The density of the building is too high in Bangladesh and it is difficult to collect the building information and different earthquake related information from the short duration survey. Two reasons affect the uncertainty: one is sampling of the building and another is lack of resources. However it is possible to reduce the uncertainty from the population data but earthquake hazard itself has also large degree of uncertainty. Therefore if the uncertainty issues from the population data and other exposure data can be reduced, a relatively more reliable risk assessment result will be obtained.

8.1.2 Wrong classification: implication towards the loss estimation

- Impact of the wrong building occupancy classification

Since this research was focusing on the population distribution, a wrong building occupancy classification has large impact on it as well as on the loss estimation. The buildings which are wrongly classified might have high susceptibility to damage or population loss and injury level. This kind of misclassification propagates at the level of vulnerability. This study found that 10% of the buildings are misclassified which is quite a higher percentage, since the population density varies according to the building use. Therefore in future studies more emphasis should be given on the mapping and characterization of the building type classification.

[3] The coefficient of variation (or CV= Standard deviation/ Mean) is a simple standard measure of uncertainty.

- Impact of the wrong building structural type classification

The wrong classification of the structural type has also a large impact upon the risk assessment as well as casualty estimation. The vulnerability of a building depends upon the construction material and techniques. Population vulnerability is also depends on the structural type. Non-engineered buildings are more vulnerable than the engineered building for earthquake but peoples in the reinforced building are more vulnerable than other structural type. Therefore misclassification will do the wrong estimation in building damage assessment and associated population casualty. To reduce the disaster risk, repair and retrofitting processes are different from one building type to another building type. Therefore it is required to have a good database on this matter.

8.1.3 Distribution of population in different temporal scenarios

In this study, statistical modeling was used to distribute the population in the building. A correlation between the population density and occupancy classes was developed in the CDMP study and this statistical approach was used. Distribution of the population varies from day-time to night-time in different occupancy classes. Mainly the variations in the commercial uses are remarkable. In the residential buildings during day-time at least 2 persons are present while others go to the school, college or respective working places. Survey result shows notable variations among different scenarios in a year. Each of the scenarios shows distinct population distribution throughout the year. But the strike day and Ramadan day scenarios shows diverse distribution than the weekday scenario even these scenarios also covers the weekday of the year. The probability of an earthquake event during these two days is lower than weekday scenario.

In the strike day, population distribution fluctuates more in educational institutions than the other occupancy classes. As a consequence more people are in the residential buildings. Distribution of the people also decreased in the mixed-use building, markets, banks etc. because people do not come except emergency.

In the Ramadan day the population density increases mainly in the commercial building (markets, shops specially the cloths, fabrics, tailoring etc.) and decreases in the food shops, restaurant, different recreational centres during day-time. Number of population also increases in the street due to the temporary markets in the road side footpath. Another changes also found in the working hour of the office and banks, therefore the amount of people of also varies than the regular working days.

This study didn't take into account how many people are coming to the city or going out to the city (section 4.6); therefore it cannot approximate the expected amount of people. But it is considered that less people go out and more people come in to the city.

Sylhet is one of the densely populated cities in Bangladesh. Form the population modeling it was found that in different time period different amount of people are in the building. This is also valid for different scenarios in a year. Since people are always moving from one place to another, they use the street and due to the high traffic congestion people stayed in the street than the expected time. It was found that in some specific time period the amount of people in the street or outside the building is more. Another important factor for large amount of people in the street is the open market (market in the footpath). It was found from the analysis that in the Ramadan day and weekday about 20% people remains outside the building in some specific period of the day and in the strike day and weekly holiday less people are in outside. But to estimate exactly how many people are in the street, it requires different data, which was not available for Sylhet city.

8.1.4 Factors affecting population loss estimation

Vulnerability function and earthquake intensity

To analyze the impact of changes in population distribution for the different scenarios on the population loss estimation, vulnerability curve from CAPRA software package and hazard intensity information from CDMP study was taken. For loss estimation vulnerability function plays important role. In case of Bangladesh, no vulnerability curve developed yet. Therefore CAPRA vulnerability curves were used and building types were aggregated to CAPRA building type based on the building construction material. But the specific building types are often not available and they are also often very uncertain due to large differences within a given building type. Different building types have different trap percentage and death factor, as a consequence the population death ratio also varies. There is also other parameters related to vulnerability, any change in the given parameter shows different mean death value. The CAPRA curves are dubious and there is no reference literature or explanation for the given curves and building types. But the CAPRA curves considered the uncertainty and the CV of the standard deviation and mean shows low variation (between 20%-25%) for each building type. On the other hand, in HAZUS two-step approach followed with two uncertain steps for loss estimation. But this result shows similar result like CDMP study.

Time period and number of population

Different scenarios in a year sketched different loss of life in the same time period. For example in the morning 8AM to 10AM the loss is highest in working day, but it is less in other scenarios. The loss is 15% less in both strike day and weekly holiday and 11 % less in Ramadan day compared to weekday scenario in the morning. The loss is also affected by the underestimations and overestimations of the number of people in a building.

From the analysis it was found that population loss estimations are truly affected by the changes in trap percentage, earthquake intensity and population distribution in different buildings. The loss also might vary depending on the possible earthquake location in relation to residential areas. If the earthquake epicenter lies within or near a densely residential area then there will be higher loss.

8.2 Limitations of the research

There are some limitations of the research. They are pointed out below:

- This study cannot calculate absolute values for population distribution and loss estimation. It is difficult, if not possible to validate whether the populations distribution values that have been modeled at a given time of the day or of the year are correct, as one cannot get an instantaneous picture of the population at a given moment, using field investigation, or remote sensing.
- The average values per floor space used in this study are based on a limited number of samples. A stratified sampling technique was adopted in this research as is the common approach in this type of studies. Population density is linked to building occupancy classes. The classification of these occupancy classes is arbitrary, and in practice there are many more types of buildings than used in the analysis. Many buildings deviate considerably from others in the same class in terms of the population density and occupancy classes. That's why overestimation and underestimation is also found.
- This study does not consider the traffic flow or presence of the people in the street because there is no specific data for the study area.
- The CAPRA vulnerability curve always doesn't represent proper building types in Bangladesh and it shows much aggregated building type. Thus the loss estimation results might deviate from the real scenario.

8.3 Recommendations

a) Improvement of population distribution modeling

The improvement in the spatial and temporal population distribution data helps to produce more accurate population modeling. Some recommendations can be considered to improve the population distribution modeling:

- A promising new development could be the used e.g. mobile phone detection algorithms that could identify how many mobile phone users are present in a certain area. Unfortunately such data are not available in Bangladesh for security reasons.
- Considerations of the population distribution in the street and their activity pattern. Because in Bangladesh lot of people works outside the building.
- Population modeling can be further improved by using up to date population data and improved structure use.

b) Improvement of vulnerability curve

- The loss estimation process is not complete without the vulnerability curve. Therefore it is important.to develop and improve the vulnerability curve for different building types in Bangladesh.

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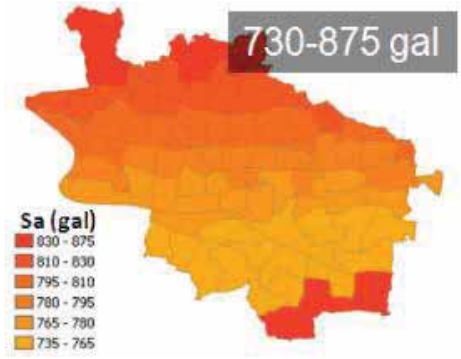
APPENDICES

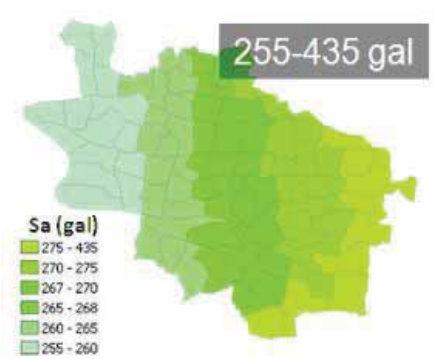
Appendix A1: Earthquake fault parameters for empirical attenuation analysis used in CDMP study

Fault name	Mw	Depth to top of fault (km)	Dip (degree)	Down-dip rupture width (km)	Fault type
Madhupur fault	7.5	10	45	42	Reverse
Dauki fault	8.0	3	60	43	Reverse
Plate boundary fault-1	8.5	3	20/30	337	Reverse
Plate boundary fault-2	8.0	3	20	137	Reverse
Plate boundary fault-3	8.3	3	20/30	337	Reverse

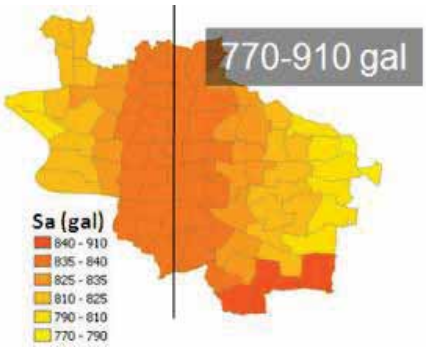
Appendix A2: Spectral Acceleration (T=0.3 sec) in Sylhet used for loss estimation



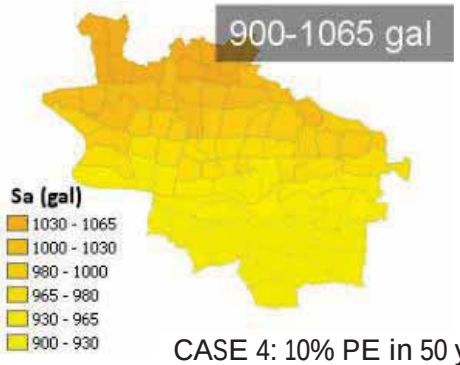
CASE 1: DF with M_w 8.0



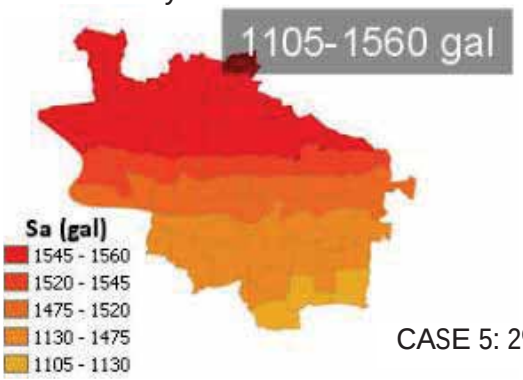
CASE 2: PBF-3 with M_w 8.30



CASE 3: M_w 6 underneath the city



CASE 4: 10% PE in 50 years



CASE 5: 2% PE in 50 years

Appendix B: Questionnaire for the residential houses

Analysing population distribution and its effect on earthquake loss estimation in Sylhet, Bangladesh

1. Name of the respondent: ……2. Floor Surveyed: ……
3. Locality: …… 4. GPS Coordinates: ……
5. Date: …… 6. House No: …… 7. Road No: ……
8. Building use:☐Residential and Commercial ☐Residential and factory ☐ Residential and shop ☐ Office and Service 9. No of floor: …… 10. Floor area (in sq. m): ……..
11. Temporal distribution of members:

No.	Age	Sex	Educational level	Occupation	Presence in the house											
					6-8 am	8-10am	10-12 am	12-2 pm	2-4 pm	4-6 pm	6-8 pm	8- 10 pm	10-12 pm	12-2 am	2-4 am	4-6 am
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																

*Age: 1. below 5 2. 5- 10 3. 11-15 4. 16-20 5. 21- 30 6. 31- 40 7. 41- 50 8. 51-60 .9 Above 60

* Sex: 1. Male 2. Female * Education: 1.Illiterate 2.Primary school 3. Secondary 4. Higher Secondary 5. Degree and above 6. Technical education 7. other

*Occupation: 1. Housewife 2. Service holder 3. Student 4. Business 5. Unemployed 6. Doctor 7. Engineer…8. Servant

12. Number of people present during the Ramadan day:

No.	Age	Sex	Educational level	Occupation	Presence in the house											
					6-8 am	8-10am	10-12 am	12-2 pm	2-4 pm	4-6 pm	6-8 pm	8- 10 pm	10-12 pm	12-2 am	2-4 am	4-6 am
1																
2																
3																
4																
5																
6																
7																
8																

13. Number of people present during Strike day:

No.	Age	Sex	Educational level	Occupation	Presence in the house											
					6-8 am	8-10am	10-12 am	12-2 pm	2-4 pm	4-6 pm	6-8 pm	8- 10 pm	10-12 pm	12-2 am	2-4 am	4-6 am
1																
2																
3																
4																
5																
6																
7																
8																

*Age: 1. below 5 2. 5- 10 3. 11-15 4. 16-20 5. 21- 30 6. 31- 40 7. 41- 50 8. 51-60 .9 Above 60

* Sex: 1. Male 2. Female * Education: 1.Illiterate 2.Primary school 3. Secondary 4. Higher Secondary 5. Degree and above 6. Technical education 7. other

*Occupation: 1. Housewife 2. Service holder 3. Student 4. Business 5. Unemployed 6. Doctor 7. Engineer…8. Servant

14. Number of people present during Weekly holiday:

No.	Age	Sex	Educational level	Occupation	Presence in the house											
					6-8 am	8-10am	10-12 am	12-2 pm	2-4 pm	4-6 pm	6-8 pm	8- 10 pm	10-12 pm	12-2 am	2-4 am	4-6 am
1																
2																
3																
4																
5																
6																
7																
8																

*Age: 1. below 5 2. 5- 10 3. 11-15 4. 16-20 5. 21- 30 6. 31- 40 7. 41- 50 8. 51-60 .9 Above 60

* Sex: 1. Male 2. Female * Education: 1.Illiterate 2.Primary school 3. Secondary 4. Higher Secondary 5. Degree and above 6. Technical education 7. other

*Occupation: 1. Housewife 2. Service holder 3. Student 4. Business 5. Unemployed 6. Doctor 7. Engineer…8. Servant

Appendix C: Questionnaire for school

Analysing population distribution and its effect on earthquake loss estimation in Sylhet, Bangladesh

Date of the survey:

A. Information about the Respondent

1. Name of the respondent:
2. Designation:

B. Information about the School

1. Name of the school:
2. Location/GPS coordinates of the school:
3. Number of floors:
4. Number of buildings
5. Built up Area:
6. Capacity of the school:

C. Information about the Staff

1. Total no of staffs:
2. Male staff:
3. Female staff:
4. Total staff in morning shift:
5. Total staff in day shift:
6. Staff during holiday:
7. Staff during festival (Ramadan/Eid) time:

D. Information about the Student

1. Students in morning shift:
2. Students in day shift:
3. Students during festival (Ramadan/Eid) time:

Appendix D: Inconsistency in building occupancy classification

Sl. No	Occupancy Class	Right Classification	Wrong Classification	No information	Total
1.	Single family dwelling	1157	235		1392
2.	Minimum standard housing (<25 occupants)	107	23		130
3.	Minimum standard housing (25-100 occupants)	9	18		27
4.	Minimum standard housing (>100 occupants)	7	1		8
5.	Multi family dwelling (<10 units)	743	153		896
6.	Multi family dwelling (10-19 units)	2	11		13
7.	Hotel/Motel	0	11		11
8.	Institutional Dormitory	2	4		6
9.	Substandard housing	3	15		18
10.	Small shops and market	68	187		255
11.	Large shops and market	0	23		23
12.	Personal and repair services	1	6		7
13.	Office (professional and technical services)	0	19		19
14.	Banks	1	2		3
15.	Hospitals	1	5		6
16.	Clinic/ Doctors chamber	2	2		4
17.	Restaurant and entertainment	1	6		7
18.	Theatres/Community centre	0	9		9
19.	Mixed-use (residential and commercial)	18	136		154
20.	Heavy (plastic, rubber car industry)	1	0		1
21.	Light (Textile and garments factory)	0	0		0
22.	Food/drug/chemical processing factory	1	15		16
23.	Farm house, poultry farm, dairy farm	0	0		0
24.	Mosque/ temple	8	51		59
25.	Government office, post office, telephone office, water pump house	0	0		0
26.	Primary school, High school, Religious school	8	38		46
27.	Collage, University	0	7		7
Sub Total		2140	977	377	3117
Total					3494
Percentage		61%	28%	11%	

Appendix E: Classification of building structural types used in CDMP study

SI No.	Structural type	Label	Height		Description
			Name	Stories	
1	C1	C1L	Low-rise	1-3	Concrete moment frames are buildings with reinforced concrete columns and beams and designed by engineers. The building in this class contains no significant volume of wall that contributes to total stiffness of the building
		C1M	Mid-rise	4-7	
		C1H	High-rise	8+	
2	C2	C2L	Low-rise	1-3	Concrete shear walls are buildings that lateral force resisting system are mainly from shear walls. The examples for shear wall are including lift core and structural wall.
		C2M	Mid-rise	4-7	
		C2H	High-rise	8+	
3	C3	C3L	Low-rise	1-3	Concrete frame with masonry infill walls are buildings with reinforced concrete columns and beams and designed by engineers. The building in this class contains the significant amount of masonry in filled wall that contribute to total stiffness of the building.
		C3M	Mid-rise	4-7	
		C3H	High-rise	8+	
4	C4	C4L	Low-rise	1-3	Concrete slab column frames are reinforced concrete building which lateral force resisting system consisted of slab and column
		C4M	Mid-rise	4-7	
		C4H	High-rise	8+	
5	S1	S1L	Low-rise	1-3	Steel moment frame are similar to concrete moment frame however columns and beams are made of steel instead of reinforced concrete.
		S1M	Mid-rise	4-7	
		S1H	High-rise	8+	
6	S3	S3	Low-rise	1	Steel truss with steel column consists of the roof truss and the steel column. Gravity load of the roof truss are transferred to ground by steel column. The weak link of this structure usually found in the connection between roof truss and steel column.
7	LC	LCL	Low-rise	1-3	Lightly reinforced concrete frames are those reinforce concrete building that contains the minimum structural members to sustain the gravity loading. These buildings are not usually designed by engineer. The main characteristics of these building are small column sizes (usually 9-10") and heavily overhanging.
		LCM	Mid-rise	4-7	
		LCH	High-rise	8+	
8	BC	BCL	Low-rise	1-3	Brick in cement mortar masonry with concrete floor are masonry buildings with concrete slab and structural masonry wall and no confined reinforced concrete column.
		BCM	Mid-rise	4-7	
9	BF	BFL	Low-rise	1-3	Brick in cement mortar masonry with flexible roof are similar to the one with concrete floor. However, due to lacking of rigid diaphragm that confines the masonry wall, its seismic behaviour is considered poorer.
10	STC	STC	Low-rise	1	Steel truss with concrete column consists of the roof truss and the concrete column. Gravity load of the roof truss are transferred to ground by concrete column. The weak link of this structure usually found in the connection between roof truss and concrete column.
11	STM	STM	Low-rise	1	Steel truss with masonry wall consists of the roof truss and the masonry wall. Gravity load of the roof truss are transferred to ground by masonry wall. The weak link of this structure usually found in the connection between roof truss and masonry wall.
12	TSL	TSL	Low-rise	1-3	Tin shed is minimum standard structure constructed by tin shed for wall and roof.
13	BAL	BAL	Low-rise	1-3	Bamboo refers to building which use bamboo as structural component to resist both the lateral and gravity loads

Appendix F: Population distribution modeling scenarios in different occupancy class and in different wards for four temporal scenarios

1. Population distribution in different occupancy classes in different time period of the day (Weekday)

Occupancy class	Total building	Weekday													
		Day-time	Night-time	8AM to 10 AM	10AM to 12AM	12AM to 2PM	2PM to 4PM	4PM to 6PM	6PM to 8PM	8PM to 10 PM	10PM to 12 PM	12PM to 2AM	2AM to 4AM	4AM to 6AM	6AM to 8AM
RES 1	29798	86828	130199	103502	78119	65099	65099	104159	110669	117179	117179	130199	130199	130199	130199
RES2A	1967	35701	62295	49176	37377	31147	31147	49836	52951	56065	56065	62295	62295	62295	62295
RES2B	180	10127	23099	18148	13860	11550	11550	18479	19634	20789	20789	23099	23099	23099	23099
RES2C	13	309	472	362	283	236	236	377	401	424	424	472	472	472	472
RES3A	6476	56595	93328	74219	55997	46664	46664	74663	79329	83996	83996	93328	93328	93328	93328
RES3B	93	3154	5204	4105	3122	2602	2602	4163	4423	4683	4683	5204	5204	5204	5204
RES4	78	3004	5059	2023	506	506	506	506	3035	3541	5059	5059	5059	5059	5059
RES5	37	1237	1996	399	200	200	200	200	1198	1397	1996	1996	1996	1996	1996
RES 6	3449	61082	123893	98558	74336	61946	61946	99114	105309	111504	111504	123893	123893	123893	123893
COM1	3247	27195	4053	5439	13598	19037	19037	19037	16317	16317	8159	4053	4053	4053	4053
COM2	257	18302	2248	1830	7321	7321	9151	14642	10981	10981	7321	2248	2248	2248	2248
COM3	237	3323	511	332	665	1329	1994	1994	1329	332	332	511	511	511	511
COM4	205	6012	826	1804	4809	3607	3020	601	826	826	826	826	826	826	826
COM5	54	3059	420	918	2447	1835	1529	306	420	420	420	420	420	420	420
COM6	49	18065	15695	10839	12646	12646	12646	14452	12646	10839	10839	15695	15695	15695	15695
COM7	50	1636	792	327	327	327	491	982	1309	818	818	792	792	792	792
COM8	108	15544	488	6218	4663	7772	6218	9326	10881	9326	9326	488	488	488	488
COM9	7	4970	413	50	149	994	994	994	4473	4473	413	413	413	413	413
COM10	1081	19570	14807	13326	17613	17613	17613	15656	16634	17613	18591	14807	14807	14807	14807
IND1	8	52	38	44	49	49	49	5	38	38	38	38	38	38	38
IND2	5	59	43	50	56	56	56	6	43	43	43	43	43	43	43
IND3	290	2521	1849	2143	2395	2395	2395	252	1849	1849	1849	1849	1849	1849	1849
AGR1	72	417	8	375	375	375	292	42	8	8	8	8	8	8	8
REL1	416	55627	1482	2830	2806	38943	5593	27847	16728	16729	1475	1482	1482	1482	1482
EDU1	382	82782	437	73597	73597	77686	73597	4089	431	431	431	431	431	431	437
EDU2	105	28074	25	25267	25267	25267	25267	2807	25	25	25	25	25	25	25
GOV1	34	1347	521	674	1078	1078	943	269	521	521	521	521	521	521	521
Total	48698	546591	490199	496554	433660	438280	400833	464804	472409	491169	463131	490194	490194	490194	490200

2. Ward wise population distribution in different time period of the day (weekday)

Ward No	Weekday													
	Day-time	Night-time	8AM to 10 AM	10AM to 12AM	12AM to 2PM	2PM to 4PM	4PM to 6PM	6PM to 8PM	8PM to 10 PM	10PM to 12 PM	12PM to 2AM	2AM to 4AM	4AM to 6AM	6AM to 8AM
1	16133	14937	14233	12361	12537	11015	13551	14262	14848	14352	14937	14937	14937	14937
2	20301	10519	14101	13104	14232	12852	13753	14288	13865	12820	10513	10513	10513	10513
3	31752	24757	25327	25864	25514	24198	22186	21354	21097	20810	24757	24757	24757	24757
4	17628	15195	16940	14965	15143	13420	14216	14198	14892	14073	15195	15195	15195	15195
5	19721	21476	19301	16272	15933	14453	20011	20443	21319	20503	21476	21476	21476	21476
6	11137	14917	12725	10072	9302	8720	12913	13387	14013	13668	14917	14917	14917	14917
7	18271	24313	20445	16067	14907	13780	20870	21640	22794	22200	24313	24313	24313	24313
8	17353	15314	16731	14105	13908	12886	14386	14519	15102	14621	15253	15253	15253	15253
9	29181	26068	28402	25209	24467	22501	23699	23889	24989	23925	26068	26068	26068	26068
10	17309	17293	16836	14327	14178	12805	15632	16334	17106	15771	17289	17289	17289	17289
11	14685	15518	13632	11262	11778	9963	14441	14509	15074	14190	15510	15510	15510	15510
12	12773	11776	12340	10857	11011	9757	10716	10969	11514	10822	11764	11764	11764	11764
13	17698	12721	13975	13283	13015	12269	11881	14072	14680	12264	12709	12709	12709	12709
14	33726	19660	23070	24865	25636	22353	23807	22928	23786	20881	19655	19655	19655	19655
15	24585	17960	18879	18118	19053	16886	19614	19574	20245	18066	17960	17960	17960	17960
16	23625	13793	21356	20480	20011	19139	13629	13433	14024	13148	13793	13793	13793	13793
17	17040	19910	16728	15174	14240	13201	17723	18207	19090	18448	19910	19910	19910	19910
18	21380	18057	20109	17781	17831	15673	16635	16607	17483	16493	18056	18056	18056	18056
19	16196	18841	17201	14113	13560	12300	16573	16952	17872	17181	18841	18841	18841	18841
20	18439	14359	15600	13728	14859	12420	14531	14042	14712	13385	14359	14359	14359	14359
21	19303	21855	20459	16917	15973	14933	19592	20163	21130	20424	21855	21855	21855	21855
22	29367	28630	28403	24183	23975	21468	26088	26302	27643	26426	28596	28596	28596	28596
23	16760	11642	12385	12549	13279	11893	13328	13024	13403	12398	11616	11616	11616	11616
24	16990	21168	19388	15879	14979	13813	18318	18827	19835	19226	21165	21165	21165	21165
25	14681	14071	14400	12313	12089	11125	13087	13142	13667	13020	14071	14071	14071	14071
26	29079	24691	25495	23403	23671	21584	24503	25271	26129	24189	24686	24686	24686	24686
27	21597	20930	21299	18468	18425	16649	19122	20071	20856	19826	20930	20930	20930	20930
Total	546708	490370	499758	445720	443506	402054	464804	472408	491169	463131	490194	490194	490194	490194

3. Population distribution in different occupancy classes in different time period of the day (Strike day)

Occupancy class	Total building	Strike-day													
		Day-time	Night-time	8AM to 10 AM	10AM to 12AM	12AM to 2PM	2PM to 4PM	4PM to 6PM	6PM to 8PM	8PM to 10 PM	10PM to 12 PM	12PM to 2AM	2AM to 4AM	4AM to 6AM	6AM to 8AM
RES 1	29798	86799	130198	123688	123688	117178	123688	123688	117178	117178	123688	127594	127594	127594	127594
RES2A	1967	35701	62295	59180	59180	56065	59180	59180	56065	56065	59180	61049	61049	61049	61049
RES2B	180	10127	23099	21944	21944	20789	21944	21944	20789	20789	21944	22637	22637	22637	22637
RES2C	13	309	472	448	448	424	448	448	424	424	448	462	462	462	462
RES3A	6476	56595	93328	88662	88662	83996	88662	88662	83996	83996	88662	91462	91462	91462	91462
RES3B	93	3154	5204	4944	4944	4683	4944	4944	4683	4683	4944	5100	5100	5100	5100
RES4	78	3004	5059	1518	253	253	253	1012	1518	1518	1518	1518	1518	1518	211743
RES5	37	1237	1996	1796	1597	1198	1597	998	998	1597	1597	1796	1796	1796	1796
RES6	3449	61082	123893	117698	117698	111504	117698	117698	111504	111504	117698	121415	121415	121415	121415
COM1	3247	27195	4053	0	0	0	0	0	5439	5439	2720	4053	4053	4053	4053
COM2	257	18302	2248	0	0	0	0	0	1830	1830	1830	2248	2248	2248	2248
COM3	237	3323	511	0	0	0	0	0	332	332	332	511	511	511	511
COM4	205	6012	826	1804	2405	1804	1202	301	826	826	826	826	826	826	826
COM5	54	3059	420	918	1223	918	612	153	420	420	420	420	420	420	420
COM6	49	18065	15695	10839	10839	9033	10839	12646	12646	12646	12646	15695	15695	15695	15695
COM7	50	1636	792	164	164	164	327	491	1146	1146	1146	792	792	792	792
COM8	108	15520	487	1552	3104	3104	4656	4656	9312	9312	4656	488	488	488	488
COM9	7	4970	413	50	149	248	497	497	994	994	413	413	413	413	413
COM10	1081	12779	12025	12586	13699	13699	13699	14677	13699	13699	13699	14807	14807	14807	14807
IND1	8	52	38	36	36	36	36	5	38	38	38	38	38	38	38
IND2	5	59	43	41	41	41	41	6	43	43	43	43	43	43	43
IND3	290	2521	1849	1765	1765	1765	1765	252	1849	1849	1849	1849	1849	1849	1849
AGR1	72	417	8	292	292	292	292	21	8	8	8	8	8	8	8
REL1	416	55627	1482	1112	1112	27813	1669	16688	11125	5563	1482	1482	1482	1482	1482
EDU1	382	6707	437	1656	1656	1656	1656	1656	437	437	437	437	437	437	437
EDU2	105	28074	25	5615	5615	5615	5615	5615	25	25	25	25	25	25	25
GOV1	34	1347	521	269	674	674	674	67	521	521	521	521	521	521	521
Total	48698	463672	487416	458576	461187	462950	461993	476304	457844	452880	462768	477689	477689	477689	167867

4. Ward wise population distribution in different time period of the day (Strike day)

Ward No	Strike day													
	Day-time	Night-time	8AM to 10 AM	10AM to 12AM	12AM to 2PM	2PM to 4PM	4PM to 6PM	6PM to 8PM	8PM to 10 PM	10PM to 12 PM	12PM to 2AM	2AM to 4AM	4AM to 6AM	6AM to 8AM
1	13986	14859	13654	13546	13781	13528	14073	13913	13775	13950	14179	14179	14179	14179
2	17203	10456	9267	9772	9789	10553	11028	12453	12385	10992	10211	10211	10211	10211
3	26853	24720	21109	21056	20922	22054	23227	21574	21674	22185	24375	24375	24375	24375
4	13400	15142	14561	14613	15030	14619	15249	14307	14062	14509	14903	14903	14903	14903
5	17889	21292	19955	20086	20055	20218	20868	20163	19962	20433	20992	20992	20992	20992
6	10613	14891	14051	14094	13796	14154	14408	13767	13678	14199	14630	14630	14630	14630
7	17693	24244	23062	23115	22761	23140	23615	22357	22181	23115	23841	23841	23841	23841
8	16351	15204	14987	15135	15102	15306	15717	14602	14479	14687	14956	14956	14956	14956
9	22314	25997	24915	24969	24919	24932	25543	24146	23865	24735	25547	25547	25547	25547
10	15188	17218	16439	16478	16641	16539	17068	16035	15840	16338	16947	16947	16947	16947
11	13522	15463	14360	14399	15050	14515	15380	14622	14335	14699	15193	15193	15193	15193
12	9768	11737	11086	11099	11423	11115	11365	10992	10809	11151	11531	11531	11531	11531
13	14010	12630	11421	11328	11029	11304	11421	11721	11658	11602	11985	11985	11985	11985
14	27124	19296	17217	17122	17960	16756	17694	18332	17970	17941	18745	18745	18745	18745
15	20599	17767	15770	15729	16270	15875	16803	16728	16460	16605	17244	17244	17244	17244
16	18487	13651	14064	14135	13854	14180	14384	12732	12713	13039	13531	13531	13531	13531
17	15553	19834	18823	18869	18524	18818	19145	18332	18198	18875	19495	19495	19495	19495
18	15181	18031	17179	17198	17744	17217	18010	16893	16605	17161	17701	17701	17701	17701
19	13927	18808	17767	17771	17745	17788	18298	17298	17114	17842	18444	18444	18444	18444
20	15415	14333	13731	13768	14816	13811	14770	13686	13322	13640	14081	14081	14081	14081
21	17193	21767	20747	20851	20473	20911	21309	20399	20257	20880	21434	21434	21434	21434
22	25783	28448	27481	27574	27966	27579	28602	26614	26254	27182	28050	28050	28050	28050
23	13403	11270	9946	10065	10420	10227	10899	10989	10832	10780	11204	11204	11204	11204
24	14328	21119	20034	20053	19846	20069	20536	19392	19219	20076	20750	20750	20750	20750
25	13309	14044	13501	13514	13531	13546	13858	12992	12894	13302	13760	13760	13760	13760
26	25554	24514	22383	22759	23004	22917	22924	23336	23096	23238	23906	23906	23906	23906
27	19197	20850	20164	20286	20499	20321	20109	19976	19729	20098	20534	20534	20534	20534
Total	463843	487588	457676	459381	462950	461993	476304	458350	453363	463251	478170	478170	478170	478170

5. Population distribution in different occupancy classes in different time period of the day (weekly holiday)

Occupancy class	Total building	Weekly holiday													
		Day-time	Night-time	8AM to 10 AM	10AM to 12AM	12AM to 2PM	2PM to 4PM	4PM to 6PM	6PM to 8PM	8PM to 10 PM	10PM to 12 PM	12PM to 2AM	2AM to 4AM	4AM to 6AM	6AM to 8AM
RES 1	29793	86828	130199	123689	123689	110669	110669	104159	97649	97649	117179	127595	127595	127595	127595
RES2A	1967	35701	62295	59180	59180	52951	52951	49836	46721	46721	56065	61049	61049	61049	61049
RES2B	180	10127	23099	21944	21944	19634	19634	18479	17324	17324	20789	22637	22637	22637	22637
RES2C	13	309	472	448	448	401	401	377	354	354	424	462	462	462	462
RES3A	6476	56595	93328	88662	88662	79329	79329	74663	69996	69996	83996	91462	91462	91462	91462
RES3B	93	3154	5204	4944	4944	4423	4423	4163	3903	3903	4683	5100	5100	5100	5100
RES4	78	3004	5059	3035	2023	1012	2529	1012	2023	3035	3035	3035	3035	3035	3035
RES5	37	1237	1996	1796	1796	998	1597	998	1198	1397	1996	1996	1996	1996	1996
RES6	3449	61082	123893	117698	117698	105309	105309	99114	92920	92920	111504	121415	121415	121415	121415
COM1	3247	27195	4053	1360	2720	5439	5439	8159	10878	10878	10878	4053	4053	4053	4053
COM2	257	18298	2248	915	1830	1830	1830	3660	5490	5490	5490	2248	2248	2248	2248
COM3	237	3323	511	166	166	166	166	332	1329	1329	1329	511	511	511	511
COM4	205	6012	826	661	661	496	578	578	826	826	826	826	826	826	826
COM5	54	3059	420	336	336	252	294	294	420	420	420	420	420	420	420
COM6	49	18065	15695	10839	10839	9033	11742	11742	12646	12646	12646	15695	15695	15695	15695
COM7	50	1636	792	327	327	327	491	818	1146	1146	1146	792	792	792	792
COM8	108	15544	488	3104	4656	9312	10864	7760	9312	9312	4656	488	488	488	488
COM9	7	4970	413	50	248	2485	4473	2485	4473	4473	1988	413	413	413	413
COM10	1081	18296	14099	14807	18591	17613	17613	15656	16634	17613	18591	14807	14807	14807	14807
IND1	8	52	38	36	49	49	49	5	38	38	38	38	38	38	38
IND2	5	59	43	41	56	56	56	6	43	43	43	43	43	43	43
IND3	289	2521	1849	1756	2395	2395	2395	252	1849	1849	1849	1849	1849	1849	1849
AGR1	72	417	8	167	208	208	208	208	8	8	8	8	8	8	8
REL1	417	55627	1482	1112	1146	44501	1113	11125	16688	16729	1475	1482	1482	1482	1482
EDU1	382	352	437	437	437	349	437	437	431	431	431	431	431	431	431
EDU2	105	28074	25	25	25	20	25	25	25	25	25	25	25	25	25
GOV1	34	1347	521	521	521	260	469	469	521	521	521	521	521	521	521
Total	48693	462884	489492	458057	465596	469517	435083	416813	414844	417075	462031	479401	479401	479401	479401

6. Ward wise population distribution in different time period of the day (weekly holiday)

Ward No	Weekly holyday													
	Day-time	Night-time	8AM to 10 AM	10AM to 12AM	12AM to 2PM	2PM to 4PM	4PM to 6PM	6PM to 8PM	8PM to 10 PM	10PM to 12 PM	12PM to 2AM	2AM to 4AM	4AM to 6AM	6AM to 8AM
1	13977	14917	13827	13917	14263	13091	12426	12495	12716	13996	14362	14362	14362	14362
2	17081	10503	10037	10724	12202	12791	11410	12365	12443	11971	10267	10267	10267	10267
3	26524	24748	21158	21249	19796	20314	19613	19775	19878	21847	24465	24465	24465	24465
4	13164	15182	14365	14531	15075	13213	12879	12549	12598	14089	14903	14903	14903	14903
5	18138	21429	20283	20677	20485	19157	18327	17970	18066	20308	21023	21023	21023	21023
6	10627	14911	14116	14209	13555	12938	12319	11841	11850	13709	14630	14630	14630	14630
7	17797	24296	23062	23208	22285	20970	20055	19161	19186	22218	23841	23841	23841	23841
8	16508	15286	14614	14855	14831	13933	13191	12881	12930	14471	14966	14966	14966	14966
9	21895	26050	24618	24819	24478	22501	21721	21100	21125	24150	25567	25567	25567	25567
10	15174	17274	16244	16414	16729	15508	14723	14585	14619	16129	16955	16955	16955	16955
11	13546	15504	14507	14618	15454	13400	13161	12942	12972	14270	15204	15204	15204	15204
12	9602	11766	11119	11301	11676	10259	9715	9720	9737	10902	11536	11536	11536	11536
13	13900	12698	11485	11660	12170	12954	11402	12372	12575	12776	12155	12155	12155	12155
14	27367	19567	17568	18366	19899	17365	17657	18784	19122	20399	18955	18955	18955	18955
15	20687	17911	16302	16767	17703	16210	15837	16517	16722	17880	17385	17385	17385	17385
16	18368	13757	12897	13214	12807	12515	11845	11797	11868	13303	13551	13551	13551	13551
17	15595	19891	18749	18934	18189	17235	16523	15994	16035	18442	19509	19509	19509	19509
18	14720	18050	17110	17189	17844	15523	15189	14707	14720	16534	17703	17703	17703	17703
19	13810	18833	17813	17889	17530	16093	15538	14928	14949	17212	18454	18454	18454	18454
20	15219	14352	13545	13666	15198	12386	12436	12289	12298	13360	14081	14081	14081	14081
21	17210	21833	20763	21012	20304	19269	18392	17754	17786	20440	21435	21435	21435	21435
22	25881	28584	27110	27400	27643	24811	24062	23330	23399	26454	28055	28055	28055	28055
23	13934	11547	10686	11344	11817	10901	10594	11099	11313	12062	11288	11288	11288	11288
24	14211	21156	20061	20153	19459	18113	17404	16651	16668	19321	20750	20750	20750	20750
25	13253	14064	13247	13356	13242	12160	11757	11550	11585	13206	13786	13786	13786	13786
26	25646	24646	22988	23598	23955	22401	21233	21905	22094	24287	24033	24033	24033	24033
27	19170	20909	19947	20537	20942	19082	17422	17804	17837	19861	20539	20539	20539	20539
Total	463005	489663	458220	465605	469531	435095	416830	414863	417092	463599	479401	479401	479401	479401

7. Ward wise population distribution in different time period of the day (Ramadan day)

Occupancy class	Total building	Ramadan day													
		Day-time	Night-time	8AM to 10 AM	10AM to 12AM	12AM to 2PM	2PM to 4PM	4PM to 6PM	6PM to 8PM	8PM to 10 PM	10PM to 12 PM	12PM to 2AM	2AM to 4AM	4AM to 6AM	6AM to 8AM
RES 1	29798	86799	130198	91139	78119	65099	78119	97649	65099	65099	104159	130198	130198	130198	117178
RES2A	1967	35701	62295	43606	37377	31147	37377	46721	31147	31147	49836	62295	62295	62295	56065
RES2B	180	10127	23099	16169	13860	11550	13860	17324	11550	11550	18479	23099	23099	23099	20789
RES2C	13	309	472	330	283	236	283	354	236	236	377	472	472	472	424
RES3A	6476	56595	93328	65330	55997	46664	55997	69996	46664	46664	74663	93328	93328	93328	83996
RES3B	93	3154	5204	3643	3122	2602	3122	3903	2602	2602	4163	5204	5204	5204	4683
RES4	78	3004	5059	1012	253	253	253	2023	2023	2529	4047	4047	4047	4047	4047
RES5	37	1237	1996	399	200	200	200	200	1198	1397	1796	1996	1996	1996	1796
RES6	3449	61082	123893	86725	74336	61946	74336	92920	86725	99114	99114	123893	123893	123893	111504
COM1	3247	27195	4053	2720	10878	10878	13598	16317	21756	21756	19037	4053	4053	4053	4053
COM2	257	18302	2248	1830	7319	7319	7319	10979	14639	14639	12809	1830	2248	2248	2248
COM3	237	3323	511	665	1329	1329	665	332	1662	1662	665	511	511	511	511
COM4	205	6012	826	3006	4809	3006	1804	301	826	826	826	826	826	826	826
COM5	54	3059	420	1529	2447	1529	918	153	420	420	420	420	420	420	420
COM6	49	18065	15695	10839	13549	13549	10839	10839	10839	12646	14452	15695	15695	15695	15695
COM7	50	1636	792	327	327	327	491	491	818	982	792	792	792	792	792
COM8	108	15520	487	487	487	487	6208	12416	9312	9312	487	487	487	487	487
COM9	7	4970	413	4	12	124	124	12	207	207	413	413	413	413	413
COM10	1081	19570	14807	13326	17613	17613	17613	15656	17613	17613	17613	14807	14807	14807	14807
IND1	8	52	38	44	49	49	36	5	38	38	38	38	38	38	38
IND2	5	59	43	50	56	56	41	6	43	43	43	43	43	43	43
IND3	290	2521	1849	2143	2395	2395	1765	252	1849	1849	1849	1849	1849	1849	1849
AGR1	72	417	8	375	375	250	292	42	8	8	8	8	8	8	8
REL1	416	55627	1482	1113	1113	44501	5563	33376	38939	44501	1482	1482	1482	1482	1482
EDU1	382	82782	437	66226	66226	66226	16556	8278	437	437	437	437	437	437	437
EDU2	105	28074	25	25267	25267	25267	14037	2807	25	25	25	25	25	25	25
GOV1	34	1347	521	674	1078	674	539	269	521	521	521	521	521	521	521
Total	48698	546537	490198	438977	418875	415276	361952	443622	367194	387822	428550	488768	489187	489187	445138

8. Ward wise population distribution in different time period of the day (Ramadan day)

Ward No	Ramadan day													
	Day time	Night time	8AM to 10 AM	10AM to 12AM	12AM to 2PM	2PM to 4PM	4PM to 6PM	6PM to 8PM	8PM to 10 PM	10PM to 12 PM	12PM to 2AM	2AM to 4AM	4AM to 6AM	6AM to 8AM
1	16300	14926	12155	11417	11631	10490	13387	10995	11489	12777	14773	14778	14778	13473
2	20300	10519	10524	10933	11183	11145	14080	12212	12309	10133	10420	10462	10462	9740
3	33385	24757	25097	25347	25147	19323	19786	16924	18584	21299	24755	24757	24757	23205
4	18127	15156	15056	13953	14382	11433	13887	10606	11044	12671	15195	15195	15195	13737
5	19720	21476	16549	15501	15298	15485	19319	15423	15954	18577	21424	21444	21444	19498
6	11137	14917	11005	9807	9084	9693	12206	9388	9780	12258	14917	14917	14917	13479
7	18271	24313	17807	15782	14780	15725	19833	14575	14951	19900	24312	24313	24313	21953
8	17353	15314	14552	13558	13317	12366	13956	10943	11354	12831	15247	15250	15250	13844
9	29179	26068	25389	23632	23129	19180	22714	17411	18147	21826	26068	26068	26068	23561
10	17309	17293	14939	13765	13741	12306	14794	12287	13210	14423	17285	17285	17285	15659
11	14685	15518	11845	10826	11639	10628	13872	11694	12566	12909	15498	15499	15499	14080
12	12772	11776	10952	10174	10559	8556	10407	9098	9836	9975	11760	11760	11760	10655
13	17697	12721	12023	11968	11318	9623	11193	9756	10340	11651	12531	12538	12538	11479
14	33725	19660	19591	22055	24319	20441	23510	22582	23862	22230	19337	19457	19457	17978
15	24584	17960	16046	16519	17948	16003	19057	16267	16843	18009	17742	17819	17819	16345
16	23624	13793	19668	19310	18879	14050	13127	9957	10319	12386	13776	13793	13793	12565
17	17846	19910	15723	14587	13755	13910	16860	12837	13096	16877	19886	19897	19897	18020
18	25797	18057	18020	16516	17130	13300	16347	12087	12486	14887	18057	18057	18057	16288
19	16195	18841	15112	13561	13270	12592	15888	12390	13072	15607	18827	18832	18832	16989
20	18438	14359	13780	12884	14522	11498	14295	11378	11953	12390	14341	14359	14359	12971
21	19303	21855	17660	16124	15215	15185	18726	14466	14957	18380	21854	21855	21855	19751
22	29367	28630	25232	23264	23479	20981	25168	18777	19275	23912	28589	28596	28596	25887
23	16760	11642	10500	11429	12461	11356	13164	12510	13184	12307	11475	11532	11532	10733
24	16990	21168	17108	15295	14614	13972	17466	14418	15603	17352	21165	21165	21165	19091
25	15117	14071	12626	11745	11673	10637	12331	10522	11205	12010	14060	14062	14062	12706
26	29078	24691	21474	21473	21720	19915	23507	22260	23792	23088	24548	24571	24571	22441
27	24276	20930	18544	17452	17463	15942	18403	17431	18611	17888	20925	20926	20926	19010
Total	557336	490319	438976	418875	421655	375735	447281	369193	387822	428550	488768	489186	489186	445137

Appendix G: Tables used for loss estimation

1. Mean death ratio for different types of building in different earthquake scenario

Spectral acceleration (SA in g) with T=0.3 sec

Earthquake scenarios	Intensity (g)		Building type							
			M34L		M34M		RC1L		RC1M	
	Minimum	Maximum	MDR	MDR	MDR	MDR	MDR	MDR	MDR	MDR
Dauki fault	0.744	0.892	0.006	0.006	0.0084	0.0084	0.15	0.15	0.15	0.15
Plate boundary Fault-3	0.260	0.443	0.0045	0.006	0.0084	0.0084	0.03	0.046	0.0157	0.12
Mw 6.0 beneath city	0.785	0.927	0.006	0.006	0.0084	0.0084	0.15	0.15	0.15	0.15
Dauki fault	0.917	1.085	0.006	0.006	0.0084	0.0084	0.15	0.15	0.15	0.15
Dauki fault	1.126	1.590	0.006	0.006	0.0084	0.0084	0.15	0.15	0.15	0.15

Earthquake scenarios	Intensity (g)		Building type					
			RC1H		S3L		WL	
	Minimum	Maximum	MDR	MDR	MDR	MDR	MDR	MDR
Dauki fault	0.744	0.892	0.1434	0.1494	0	0.0001	0.0015	0.0031
Plate boundary Fault-3	0.260	0.443	0.0006	0.0249	0	0	0	0.0001
Mw 6.0 beneath city	0.785	0.927	0.1464	0.15	0	0.0001	0.002	0.0034
Dauki fault	0.917	1.085	0.1498	0.15	0.0001	0.0001	0.003	0.0044
Dauki fault	1.126	1.590	0.15	0.15	0.0002	0.0008	0.0043	0.005

2. Building damage and severity classes relationship from HAZUS

A: Total number of people in two different structural types

Building type		Most structural types	Masonry
Total building		38472	13735
Population present in the buildings			
Weekday	12AM to 2 PM	174899	233566
	12PM to 2 AM	268607	256628
Strike day	12AM to 2 PM	217997	228829
	12PM to 2 AM	244953	249341
Weekly holiday	12AM to 2 PM	218056	228944
	12PM to 2 AM	251474	250457
Ramadan day	12AM to 2 PM	173252	233401
	12PM to 2 AM	261842	255367

B: Relationship between structural damage and population loss

Structural damage	Structural type	Affected people (in %)			
		Level 1	Level 2	Level 3	Level 4
Complete	Most structural types	40	20	3-5	5-10
	Masonry	40	20	5	10
Extensive	Most structural types	1	0.1	0.001	0.001
	Masonry	2	0.2	0.002	0.002
Moderate	Most structural types	0.2-0.25	0.025-0.03	0	0
	Masonry	0.35	0.4	0.001	0.001
Slight	Most structural types	0.05	0	0	0
	Masonry	0.05	0	0	0