

Seismic Loss Estimation for Sylhet City

by

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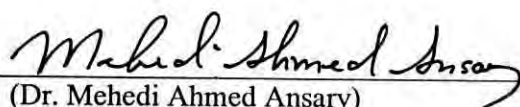
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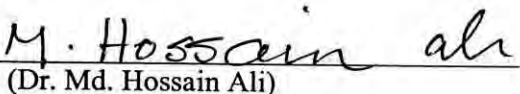
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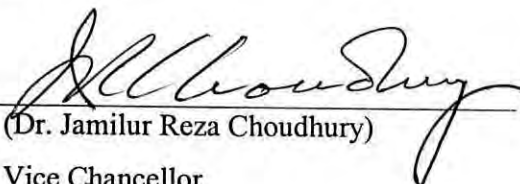

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.



Md.Rezaul Islam

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ABSTRACT

For accomplishing comprehensive regional seismic loss estimation, geographic information system (GIS) provides a perfect environment. A GIS has the capability to store, manipulate, analyze, and display the large amount of required spatial and tabular data. By using geographic information system to carry out regional multi-hazard seismic loss estimation for study area where reflection of ground shaking and the secondary site attributes of soil amplification, liquefaction and landslide are the salient features. The method to combine the different hazards is based on a weighted average approach. This dissertation also covers the development of a comprehensive inventory of building for the Sylhet City.

Sylhet City Corporation has twenty-seven Wards in its jurisdiction. Initially a GIS based Ward map is developed. 3611 buildings (14% of the total) are surveyed in the study area and water pipelines data are collected from City Corporation office. For microzonation purpose 167 boreholes with SPT data are collected from different relevant organizations. To verify those data nine boreholes up to a depth of 30m are carried out. Three past historical earthquakes 1885 Bengal earthquake, 1918 Srimangal Earthquake and 1897 Great Indian earthquake are used as scenario events for this study. Intensity value obtained for these events is calibrated against attenuation laws to check the applicability of the laws for the study area. Using these laws, bedrock Peak Ground Acceleration (PGA) values are obtained for study area for different earthquakes. Finally, a bedrock PGA value for the scenario events is selected.

PGA in the bedrock level in the study area and boreholes SPT data are used to develop a regional combined seismic hazard map based on site amplification as well as liquefaction and landslide potential hazard. This hazard map is then overlaid and combined with structural inventory maps to produce maps of regional damage distributions. Combining the map of damage distributions with a map of population distributions for the area results in final regional estimates of direct monetary loss such as building and water line distribution and non-monetary loss such as fatalities and injuries.

The investigations are carried out for two cases such as based on combined seismic hazard considering local site effects and based on hazard due to ground shaking alone. The expected damage factor for all building decreases from about 59% to about 51% when the effects of liquefaction and landslide are ignored. The total direct monetary-loss decreases by about 9%. However, there is a tremendous effect of liquefaction and landslide hazards over direct non-monetary loss as Fatalities and injuries increases by 49% and 43% respectively during night. The final seismic loss estimation appears to be reasonable when compared to recent large earthquakes in urban areas of the world. The GIS-based analysis is useful to engineers, planners, emergency personnel, government officials, and anyone else who may be concerned with the potential consequences of seismic activity in a given region.

TABLES OF CONTENTS

	Page
Declaration	III
Acknowledgements	IV
Abstract	V
Contents	VI
List of Figures	X
List of Tables	XVI
CHAPTER 1 INTRODUCTION	
1.1 Background	1
1.2 Objectives of Study	3
1.3 Methodology of the Study	5
1.4 Organization of the Study	6
CHAPTER 2 GEOGRAPHIC INFORMATION SYSTEM (GIS)	
2.1 General	7
2.2 Data Types and Database Management	7
2.3 Function of GIS in this Study	10
CHAPTER 3 LITERATURE REVIEW	
3.1 General	13
3.2 Administrative Boundary of Sylhet City Corporation	13
3.3 Regional Tectonics	15
3.4 Seismo-tectonic Setup	18
3.5 Major Seismic Sources	21
3.6 Historical Earthquakes	24
3.6.1 Cachar Earthquake of 1869	24
3.6.2 Bengal Earthquake of 1885	24
3.6.3 Great Indian Earthquake of 1897	25
3.6.4 Srimangal Earthquake of 1918	25
3.7 Relationship between Shear Wave Velocity (V_s) and SPT (N) Value	27
3.8 Attenuation Law of Peak Ground Acceleration	28

3.9	Seismic Zoning Maps	29
3.10	Soil Amplification	32
3.10.1	General	32
3.10.2	Analysis method for Amplification	33
3.11	Soil Liquefaction	37
3.11.1	General	37
3.11.2	Liquefaction Hazard Analysis Method	38
3.12	Landslide Hazard Analysis Method	45
3.13	Damage Distributions	47
3.13.1	General	47
3.13.2	Definition of Damage	47
3.13.3	Motion-Damage Relationships for Bangladesh	48
3.14	Analysis method for Seismic Damage Estimation of Service Pipes	50
3.15	Casualty Estimation Model	52
CHAPTER 4 COLLECTION OF BASIC DATA		
4.1	Fundamental Social Data	55
4.1.1	General	55
4.1.2	Updated Administrative Boundary of City Corporation	55
4.1.3	Population and Household of Sylhet City	59
4.1.4	Land Use Pattern in Sylhet City	63
4.2	Soil Data	64
4.2.1	General	64
4.2.2	SPT Data	65
4.2.3	Ground Water Data	67
4.2.4	Landslide Estimation Data	68
4.3	Building Data	71
4.3.1	General	71
4.3.2	Methodology of Building Survey	71
4.3.2.1	Survey Sites	71
4.3.2.2	Details of Survey Format	72

4.3.3 Results of the Survey Sites	75
4.3.3.1 General	75
4.3.3.2 Building Classification	76
4.3.3.3 Building Distribution According Classification	77
4.3.3.4 Construction Year of Buildings	81
4.3.3.5 Number of Stories and Building Area	81
4.4 Water Supply Pipelines	87
CHAPTER 5 SEISMIC HAZARD ANALYSIS	
5.1 General	91
5.2 Earthquake Analysis	91
5.3 Local Site Effects	98
5.3.1 Site Amplification Analysis	99
5.3.2 Liquefaction Analysis	108
5.3.3 Landslide Analysis	116
CHAPTER 6 SEISMIC HAZARD INTEGRATION	
6.1 General	119
6.2 Seismic Hazard Integration in the GIS Environment	119
CHAPTER 7 SEISMIC DAMAGE AND LOSS ESTIMATION	
7.1 General	142
7.2 Damage Estimation of Buildings	142
7.2.1 Building Damage Estimation Based on Analysis I	144
7.2.2 Building Damage Estimation Based on Analysis II	153
7.3 Damage Estimation of Water Pipelines	163
7.4 Human Casualty	172
7.4.1 Human Casualty Estimation Based on Analysis I	173
7.4.2 Human Casualty Estimation Based on Analysis II	183
7.5 Loss Estimation	195
7.6 Summary	197

CHAPTER 8	CONCLUSIONS AND SCOPE FOR FUTURE STUDY	
	8.1 Conclusions	198
	8.2 Scope for Future Study	201
References		204
Appendix A	Ward and Corresponding Mouzas of Sylhet City	212
Appendix B	Building Data Collection Format	220
Appendix C	European Macro Seismic Scale	222
Appendix D	Building Typologies of Sylhet City	230
Appendix E	Landslide Potential Areas of Sylhet City	234

LIST OF FIGURES

Figure		Page
Figure 1.1	Location Map of Study Area	4
Figure 2.1	The information systems composing a fully integrated geographic information system (after Frost, et al., 1992)	9
Figure 2.2	Mapping process for regional multi-hazard seismic loss estimation through GIS (Map Info)	12
Figure 3.1	Map showing 13 wards in Sylhet City Corporation (after 1996, Municipality)	14
Figure 3.2	Continued drift of the Indian Plate towards Asian Plate causes major Himalayan earthquakes (after Molnar and Tapponnier, 1975)	16
Figure 3.3	Estimated slip potential along the Himalaya (after Bilham et al., 2001)	17
Figure 3.4	Generalized tectonic map of Bangladesh and adjoining areas (after GSB, 1991)	19
Figure 3.5	Seismo-tectonic lineaments and faults capable of producing damaging earthquakes (after Ali and Choudhury, 1992; Whitney, 2004)	22
Figure 3.6	Isoseismal map of Srimongal Earthquake (1918)	26
Figure 3.7	Seismic zoning map of Bangladesh (after BNBC, 1993)	30
Figure 3.8	Updated seismic zoning map of Bangladesh (after Sharfuddin, 2000)	31
Figure 3.9	Schematic representation of procedure for computing effects of local soil conditions on ground motions (after Schnabel et al., 1971)	34
Figure 3.10	One-dimensional wave propagation system (after Schnabel et al., 1971)	35
Figure 3.11	Cyclic shear stresses on a soil element during ground shaking (after Iwasaki, 1982)	41
Figure 3.12	Procedure for determining maximum shear stress (after Seed et al., 1983)	41

Figure 3.13	Range of values of r_d for different soil profiles (after Seed et al., 1983)	42
Figure 3.14	Time history of shear stresses during earthquake (after Seed et al., 1983)	42
Figure 3.15	Correlation between field liquefaction behavior of Silty sands under level ground conditions and standard penetration resistance (after Seed et al., 1983)	44
Figure 3.16	Recommended curve for determination of C_N (after Murthy, 1991)	44
Figure 3.17	Vulnerability functions based on peak ground acceleration (after Aria, 2000)	49
Figure 3.18	The correlation between Damage Ratio and PGA values for pipeline diameters (after Chen et al., 2002)	51
Figure 3.19	Building occupancy at the time of earthquake (Coburn et al., 1992)	54
Figure 4.1	Map showing different Mahallas of ward 7	57
Figure 4.2	Map showing ward map of Sylhet City Corporation	58
Figure 4.3	Map showing population density map of Sylhet City	61
Figure 4.4	Map showing Borehole locations considered for this study	66
Figure 4.5	Map showing location of hill in Sylhet City Corporation	70
Figure 4.6	Map showing location of sample sites in the study area	73
Figure 4.7	Map showing regional distribution of dwellings in Sylhet City	80
Figure 4.8	Distribution of buildings types with construction year for core and fringe ward	82
Figure 4.9	Distribution of building types according to storey and floor area for core and fringe wards	83
Figure 4.10	Distribution of building according to their usage in core and fringe wards of study area	86
Figure 4.11	Map showing Distribution of lengths of pipelines according to material of Sylhet City	88
Figure 4.12	Distribution of lengths of pipelines according to material	90
Figure 4.13	Distribution of lengths of pipelines according to diameter	90

Figure 5.1	Flow Chart for Earthquake Analysis	92
Figure 5.2a	Distance versus PGA values for 1885 Bengal earthquake as to compare several attenuation formula	95
Figure 5.2b	Distance versus PGA values for 1897 Great Indian Earthquakes to compare several attenuation formula	96
Figure 5.2c	Distance versus PGA values for 1918 Srimangal Earthquake as to compare several attenuation formula	97
Figure 5.3	Map showing amplification factor at fundamental frequency for two sites of Sylhet City	100
Figure 5.4	Map of fundamental frequencies of Sylhet City	105
Figure 5.5	Map of amplification at fundamental frequencies of Sylhet City	106
Figure 5.6	Map showing regional distribution of amplification in Sylhet City	107
Figure 5.7	Flow chart of Liquefaction Analysis of the study area	108
Figure 5.8	Map showing Microzonation based on liquefaction potential index	114
Figure 5.9	Map showing regional distribution of liquefied areas of Sylhet City	115
Figure 5.10	Map showing landslide potential in Sylhet City	118
Figure 6.1	Flow chart for Combined Seismic Map	120
Figure 6.2	Map showing regional distribution of surface level peak ground acceleration in Sylhet City	121
Figure 6.3	Map showing regional distribution of ground shaking hazard (MMI _{GS}) in Sylhet City	122
Figure 6.4a	Map showing only 1.9 times amplified areas	127
Figure 6.4b	Map showing only 2.5 times amplified areas	128
Figure 6.4c	Map showing 1.9 times amplification plus liquefaction (high) areas	129
Figure 6.4d	Map showing 1.9 times amplification plus liquefaction (moderate)	130
Figure 6.4e	Map showing 2.5 times amplification plus liquefaction (high) areas	131
Figure 6.4f	Map showing 2.5 times amplification plus liquefaction (moderate)	132
Figure 6.4 g	Map showing 1.9 times amplification plus landslide (high) areas	133
Figure 6.4h	Map showing 1.9 times amplification plus landslide (moderate)	134
Figure 6.4 i	Map showing 1.9 times amplification plus liquefaction (high) plus landslide (high) areas	135

Figure 6.4j	Map showing 1.9 times amplification plus liquefaction (moderate) plus landslide (high) areas	136
Figure 6.4k	Map showing 1.9 times amplification plus liquefaction (high) plus landslide (moderate) areas	137
Figure 6.4l	Map showing 1.9 times amplification plus liquefaction (moderate) plus landslide (moderate) areas	138
Figure 6.4m	Map showing 2.5 times amplification plus liquefaction (moderate) plus landslide (high) areas	139
Figure 6.5	Map showing regional distribution of combined seismic surface level peak ground acceleration in Sylhet City	140
Figure 6.6	Map showing regional distribution of combined seismic hazard (MMT_F) in Sylhet City	141
Figure 7.1	Flowchart of damage estimation methodology for a given PGA and geo-code	143
Figure 7.2a	Map showing average expected damage factor (%) of EMSA type building based on Analysis I (MMI_F) in Sylhet City	146
Figure 7.2b	Map showing average expected damage factor (%) of EMSB1 type building based on Analysis I (MMI_F) in Sylhet City	147
Figure 7.2c	Map showing average expected damage factor (%) of EMSB2 type building based on Analysis I (MMI_F) in Sylhet City	148
Figure 7.2d	Map showing average expected damage factor (%) of EMSC type building based on Analysis I (MMI_F) in Sylhet City	149
Figure 7.2e	Map showing average expected damage factor (%) of EMSD type building based on Analysis I (MMI_F) in Sylhet City	150
Figure 7.2f	Map showing average expected damage factor (%) of EMSF type building based on Analysis I (MMI_F) in Sylhet City	151
Figure 7.3	Map showing total number of damaged building based on Analysis I (MMI_F) in Sylhet City	152
Figure 7.4a	Map showing average expected damage factor (%) of EMSA type building based on Analysis II (MMI_{GS}) in Sylhet City	155
Figure 7.4b	Map showing average expected damage factor (%) of EMSB1 type building based on Analysis II (MMI_{GS}) in Sylhet City	156

Figure 7.4c	Map showing average expected damage factor (%) of EMSB2 type building based on Analysis II (MMI _{GS}) in Sylhet City	157
Figure 7.4d	Map showing average expected damage factor (%) of EMSC type building based on Analysis II (MMI _{GS}) in Sylhet City	158
Figure 7.4e	Map showing average expected damage factor (%) of EMSD type building based on Analysis II (MMI _{GS}) in Sylhet City	159
Figure 7.4f	Map showing average expected damage factor (%) of EMSF type building based on Analysis II (MMI _{GS}) in Sylhet City	160
Figure 7.5	Map showing total number of damaged building based on Analysis II (MMI _{GS}) in Sylhet City	161
Figure 7.6	Buildings damage in Sylhet City due to combined seismic hazards (MMI _F) and Ground shaking hazard (MMI _{GS})	162
Figure 7.7a	Map showing Asbestos Concrete pipeline distribution of different diameter with combined seismic microzonation map of Analysis I (MMI _F)	165
Figure 7.7b	Map showing PVC pipeline distribution of different diameter with combined seismic microzonation map of Analysis I (MMI _F)	166
Figure 7.7c	Map showing Proposed pipeline distribution of different diameter with combined seismic microzonation map of Analysis I (MMI _F)	167
Figure 7.8a	Map showing Asbestos Concrete pipeline distribution of different diameter with combined seismic microzonation map of Analysis II (MMI _{GS})	169
Figure 7.8b	Map showing PVC pipeline distribution of different diameter with combined seismic microzonation map of Analysis II (MMI _{GS})	170
Figure 7.8c	Map showing Proposed pipeline distribution of different diameter with combined seismic microzonation map of Analysis II (MMI _{GS})	171
Figure 7.9 a	Map showing total number of deaths in morning based on Analysis I (MMI _F) in Sylhet City	175
Figure 7.9b	Map showing total number of deaths at noon based on Analysis I (MMI _F) in Sylhet City	176
Figure 7.9c	Map showing total number of deaths at night based on Analysis I (MMI _F) in Sylhet City	177

Figure 7.10a	Map showing total number of injuries in morning based on Analysis I (MMI _F) in Sylhet City	180
Figure 7.10b	Map showing total number of injuries at noon based on Analysis I (MMI _F) in Sylhet City	181
Figure 7.10c	Map showing total number of injuries at night based on Analysis I (MMI _F) in Sylhet City	182
Figure 7.11a	Map showing total number of deaths in morning building based on Analysis II (MMI _{GS}) in Sylhet City	185
Figure 7.11b	Map showing total number of deaths at noon building based on Analysis II (MMI _{GS}) in Sylhet City Corporation	186
Figure 7.11c	Map showing total number of deaths at night building based on Analysis II (MMI _{GS}) in Sylhet City Corporation	187
Figure 7.12a	Map showing total number of injuries in morning building based on Analysis II (MMI _{GS}) in Sylhet City	190
Figure 7.12b	Map showing total number of injuries at noon building based on Analysis II (MMI _{GS}) in Sylhet City	191
Figure 7.12c	Map showing total number of injuries at night building based on Analysis II (MMI _{GS}) in Sylhet City	192
Figure 7.13	Fatalities in Sylhet City due to combined seismic hazards (MMI _F) and Ground shaking hazard (MMI _{GS})	193
Figure 7.14	Injuries in Sylhet City due to combined seismic hazards (MMI _F) and Ground shaking hazard (MMI _{GS})	194

LIST OF TABLES

Table		Page
Table 3.1	Great historical earthquakes in and around Bangladesh	20
Table 3.2	Significant seismic sources and maximum likely earthquake magnitude in Bangladesh (after Bolt, 1987)	21
Table 3.3	Operational basis earthquake, maximum credible Earthquake and depth of focus of earthquakes for different seismic sources (after Ali and Chowdhury, 1992)	23
Table 3.4	Magnitude and distances of some major historical earthquakes around Sylhet (after Ansary, 2001)	23
Table 3.5	Empirical Relations Correlating SPT N-value and Shear-wave Velocity	27
Table 3.6	Published attenuation function	28
Table 3.7	Values of M1, M2, M3 and M4 for different types of buildings	53
Table 4.1	Population Growth Trend of Sylhet Municipal Area (after BBS, 1997 and UDD-UNCHS-UNDP, 1987)	60
Table 4.2	Ward, House hold, Ward areas, Population density, Housing units for Sylhet City	62
Table 4.3	Land uses in Sylhet 1985 (after UDD-UNCHS-UNDP, 1987)	63
Table 4.4	Location and Number of Borehole Data of Sylhet City	65
Table 4.5	Ground Water depth of different location of Sylhet City	67
Table 4.6	Location of hillocks within Sylhet City	68
Table 4.7	Definition of building typologies in Sylhet City	76
Table 4.8	Wall and Roof material used in Sylhet City Corporation (Source: Bureau of Statistics, 1991)	77
Table 4.9	Building-distribution patterns in Sylhet City	78
Table 4.10	Building distribution pattern according classification in the Sylhet City	79
Table 4.11	Weighted house area and floor space in study area	85
Table 4.12	Water pipe line distribution according diameter and material Sylhet City	89
Table 5.1	Some historical earthquakes with magnitude, epicentral distance and focal depth at Sylhet	93
Table 5.2	Shear Wave Velocities different location of Sylhet City	94

Table 5.3	PGA values (% of g) at bedrock level from different attenuation laws	98
Table 5.4	Results of Amplification factor and corresponding predominant frequency at different locations of Sylhet City	101
Table 5.5	Liquefaction Potential of different Locations of Sylhet City	109
Table 5.6	Summary of the liquefaction potential index	113
Table 6.1	Quantification rules for seismic hazard (after Stephanie and Kiremidjian, 1994)	125
Table 6.2	Combination of possible hazards due to scenario event equivalent to 1918 Srimangal Earthquake	126
Table 7.1	Ward wise building damaged distribution based on Analysis I (MMI_F)	144
Table 7.2	Ward wise building damaged distribution based on Analysis II (MMI_{GS})	153
Table 7.3	Water pipeline affected by different peak ground acceleration values based on Analysis I (MMI_F)	164
Table 7.4	Water pipeline damage estimation according diameter	168
Table 7.5	Estimated numbers of total fatalities based on Analysis I (MMI_F)	173
Table 7.6	Estimated numbers of injuries based on Analysis I (MMI_F) in study area	178
Table 7.7	Estimated numbers of fatalities based on Analysis II (MMI_{GS})	183
Table 7.8	Estimated numbers of injuries based on Analysis II (MMI_{GS})	188
Table 7.9	Direct monetary losses based on Analysis I (MMI_F) and Analysis II (MMI_{GS}) due to a scenario event equivalent to 1918 Srimongal earthquake	196
Table 7.10	Direct Non-monetary losses based on Analysis I (MMI_F) and Analysis II (MMI_{GS}) due to a scenario event equivalent to 1918 Srimongal earthquake	196



CHAPTER 1 INTRODUCTION

1.1 Background

Loss estimation is the quantification of earthquake loss. In the late 1980s well-founded loss estimation methods began to be employed in the insurance industry and, in the 1990s, gained support from the federal government with the development of the HAZUS earthquake loss estimation software by the National Institute for Building Sciences and the Federal Emergency Management Agency (Whitman et al., 1997)

Each destructive earthquake necessitates the importance of seismic hazard and risk analysis for estimating the consequences of an earthquake. Even though some progress in the area of seismic prediction has been made, earthquakes cannot be accurately predicted in time, magnitude, or location. However, even if an accurate prediction is possible, the earthquake occurrence and consequent damage potential cannot be prevented. Seismic hazard and risk cannot be completely eliminated; but it can be effectively analyzed and possibly reduced by combining the available regional geologic and geographic information with recent technological developments

To determine the damage and influence that would be caused by a future earthquake, data on current conditions, including the vulnerability of structures, must be identified. Necessary data include both natural conditions such as earthquake history, soils and geology, meteorological, topographical etc, and social condition of the population, buildings, urban structure, land use, infrastructure and lifeline facilities and so on.

Seismic hazard due to local site effects such as soil amplification, liquefaction, and landslide can be estimated by combining the available soil parameter data with the current hazard models or by making use of existing maps showing estimated levels of these collateral hazards. Regional building inventory, often stored in external database management systems, are combined with the seismic hazards to produce damage and loss distributions for the analysis region.

Regional seismic hazard and risk analysis is used not only for estimation of potential damage and loss to existing facilities, but also for planning locations and construction of future facilities and for analyzing and comparing the regional effects of various retrofit schemes. The GIS-based analysis is useful to engineers, planners, emergency personnel, government officials, and anyone else who may be concerned with the potential consequences of seismic activity in a given region. The results of a regional seismic hazard and risk analysis are usually presented in the form of microzone maps that serve as an effective means of transferring information from the scientific community to the professional community of decision makers involved in hazard and risk mitigation.

Alluvial layers, accumulated on hard rock through complex geological formation, underlie Bangladesh. According to historical data, north-eastern region, predominantly Sylhet, Mymensingh and Rangpur, experienced earthquakes at regular intervals that have caused large damage in the past. Recently, Bilham et al. (2001) have pointed out that there is high possibility that a large earthquake may occur around the Himalayan region. So there is a seismic gap that is accumulating stress, and that a large earthquake could occur someday when the stress is relieved.

Urban development has been rapidly progressing in Sylhet City Corporation without the development of proper disaster prevention systems against potential earthquakes. It is urgently necessary to prepare a regional earthquake disaster prevention plan on the basis of loss estimation in order to mitigate possible seismic damages in Sylhet City .

1.2 Objectives of Study

The purpose of this study is the development of a methodology for seismic loss estimation for Sylhet City Corporation by using Geographic Information System. To accomplish this purpose, firstly, maps showing local site effects such as soil amplification, liquefaction, and landslide are to be developed and combined for generating seismic hazard map. Secondly, this hazard map is to be superimposed and combined with structure inventory maps to produce maps visualizing regional damage distributions and to estimate the expected losses to the regional inventories. It is important to integrate the map of damage distributions with a map of population distributions resulting in regional assessment of direct monetary and non-monetary loss. Lastly, investigating the influence of secondary effects such as liquefaction and landslide over direct loss estimation. Figure 1.1 shows location map of the study area.

The loss estimation is useful at least in four ways:

- Improving our understanding of the seismic risk in the study area.
- Supporting enforcement of seismic provisions of building codes.
- Comparing the seismic risk with that of other natural hazards.
- Providing a baseline for earthquake policy development and the comparison of mitigation alternatives

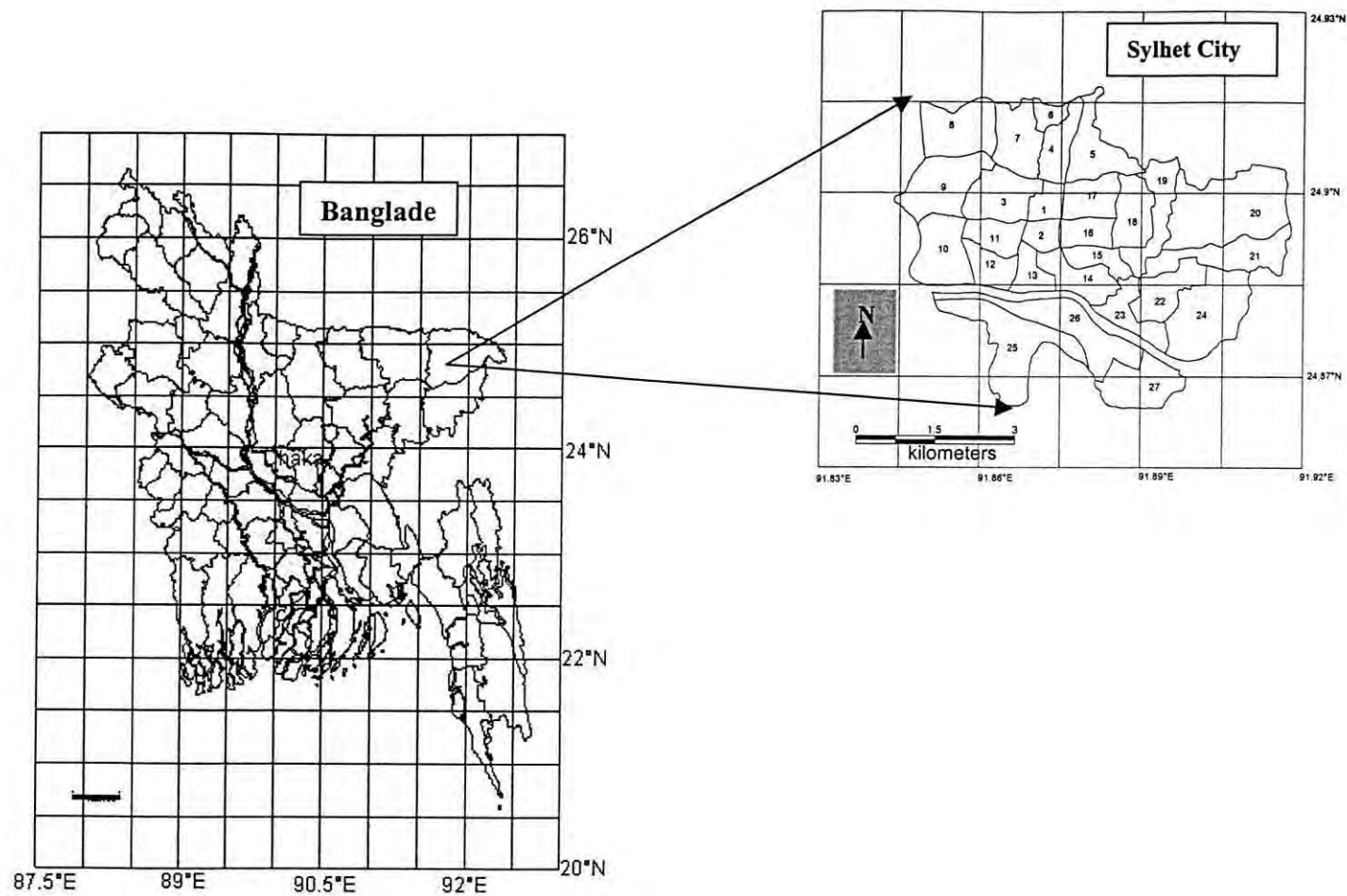


Figure 1.1. Location map of study area

1.3 Methodology of the Study

The research will develop a seismic loss model for Sylhet City based on local site effects, such as site amplification as well as liquefaction and landslide potential. The steps are:

- GIS-based-updated administrative boundary comprised of 27 wards, will be developed for the study area.
- SPT data for several sites of Sylhet will be collected from different relevant organizations. This data will be checked by nine 100 ft deep bore logs performed specially for this research.
- Location, height, slope and other relevant data of hill will be collected.
- Building inventory data of sample area of Sylhet City will be collected.
- Selection of earthquake source and estimation of the attenuation of earthquake ground motions in the bedrock level between the source and the region.
- Based on the soil data obtained in a previous step, seismic combined hazard map based on site amplification as well as liquefaction and landslides potential will be developed.
- These hazard maps will then be overlaid and combined with structure inventory map to produce maps predicting regional damage distributions.
- Combining the maps of damage distributions with a map of population distributions for the area results in final regional estimates of direct monetary loss such as building and water distribution system and non-monetary loss such as casualty together with injuries.
- Lastly, influence of collateral hazards on direct monetary loss and non-monetary loss will be investigated.

1.4 Organization of the Study

The remaining part of the study consist of seven chapters.

Chapter 2 gives a description of a geographic information system(GIS). Spatial data structures and the functional elements of an integrated GIS are discussed. Function of GIS for regional seismic loss estimation is also discussed.

Chapter 3 reviews background information (literature review) of the seismic environment, prevailing in Bangladesh as a part of the evaluation of seismic risk. Important tectonic features and seismic zoning maps of Bangladesh are discussed. Earthquake hazard, site amplification, soil liquefaction, landslides potential are described. Descriptions of damage and the motion-damage relationships are described here. A review of water line damage estimation is also discussed.

Chapter 4 deals with the collection of basic data and their collection methodology. The data includes collection of borehole data from different sources, statistical data of BBS such as population, household, building and wall materials, and sample building inventory data of several wards and water line distribution of Sylhet City .

Chapter 5 addresses earthquake analysis, assessments of the seismic hazards due to local site effects such as soil amplification, liquefaction and landslide potential are discussed in this section.

Chapter 6 GIS-based methodologies for combining site attributes through a weighted - average approach are presented.

Chapter 7 deals with the damage estimation of buildings as well as water distribution system and human casualties both for considering collateral hazard and without considering this scenario. Results and seismic microzonation maps for various stages of the analysis process are presented. Lastly, conclusions and scope for future effort are presented in chapter 8.

CHAPTER 2

GEOGRAPHIC INFORMATION SYSTEM AND SEISMIC LOSS ESTIMATION

2.1 General

There are many definitions for a geographic information system (GIS) and there seems to be a confusion as to what are the necessary components and capabilities of a true GIS. The most universal definition in the literature for a GIS is given by the Federal Interagency Coordinating Committee (1988) as "A system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems." Figure 2.1 is adapted from Frost, et al. (1992) and shows how different information systems work together of function as a fully - interacted GIS. Modern geographic information system technology has evolved from thematic cartography due of the combination of increased computational capabilities, refined analytical techniques, and a renewed interest in environmental/social responsibility. Throughout this evolution the primary goal has been to take raw data and transform it, through overlays and other analytical operations, into new information that can support the decision making process (Parent and Church, 1987). The remainder of this section gives a detailed overview of geographic information system.

2.2 Data Types and Database Management

Data associated with a geographic information system can be divided into two general categories: graphic data and non-graphic data. Graphic data are digital representation of map features, usually depicted as point, line, area, and annotation features. The graphic features can be stored in either vector or raster format. Coordinates of point and line locations represent vector data with rules for computing new coordinate locations and connecting the points as line or area features.

A uniform grid of cells or pixels depicts raster data. Most modern geographic information systems can handle both vector and raster representation of graphic data, but the vector format is generally preferred due to its efficiency in data storage and manipulation and its more attractive graphical display.

Non-graphic data are the attributes associated with the graphic data. They are stored in alphanumeric format and are representations of the characteristics, qualities, and relationships of map features and geographic locations. Non-graphic or tabular data can be stored in the given database within a GIS, although these databases are often limited in their ability to store very large amounts of data and in their functional capabilities. Most modern GIS programs have the ability to link both graphic and non-graphic data to tables of attribute information in an external high-level database management program.

Graphic data can be entered into a GIS through digitizing or photo-quality scanning an existing map. These two methods are the most time-consuming but they allow the user to have the most control and understanding of the accuracy and quality of the spatial data. Depending on the sophistication of the GIS, graphic data can also be entered in one of several digital file formats. A digital exchange file output from a computer-aided drafting system or a different geographic information system can be converted to a GIS map, although information such as line connectivity is often lost in the exchange due to the difference in system data structures.

Non-graphic data associated with digitized or scanned graphic data must usually be entered by hand, requiring the attribute data to be assigned to each individual feature. This is generally a very time-intensive procedure, but again it allows the user to have control and understanding of the accuracy and make-up of the feature attribute tables. The several possible digital file formats for conversion to a GIS map usually contain the relevant attribute information for the graphic data. Depending on the quality and source of the digital file, the non-graphic data may lose information in the conversion process or require extensive database manipulations to be useful. As explained above, attribute data can also be stored in external database management systems and linked to the

graphic data, requiring no exchange or conversion of information. If necessary, tabular data can be added to the GIS database by defining the table structure and then entering the data.

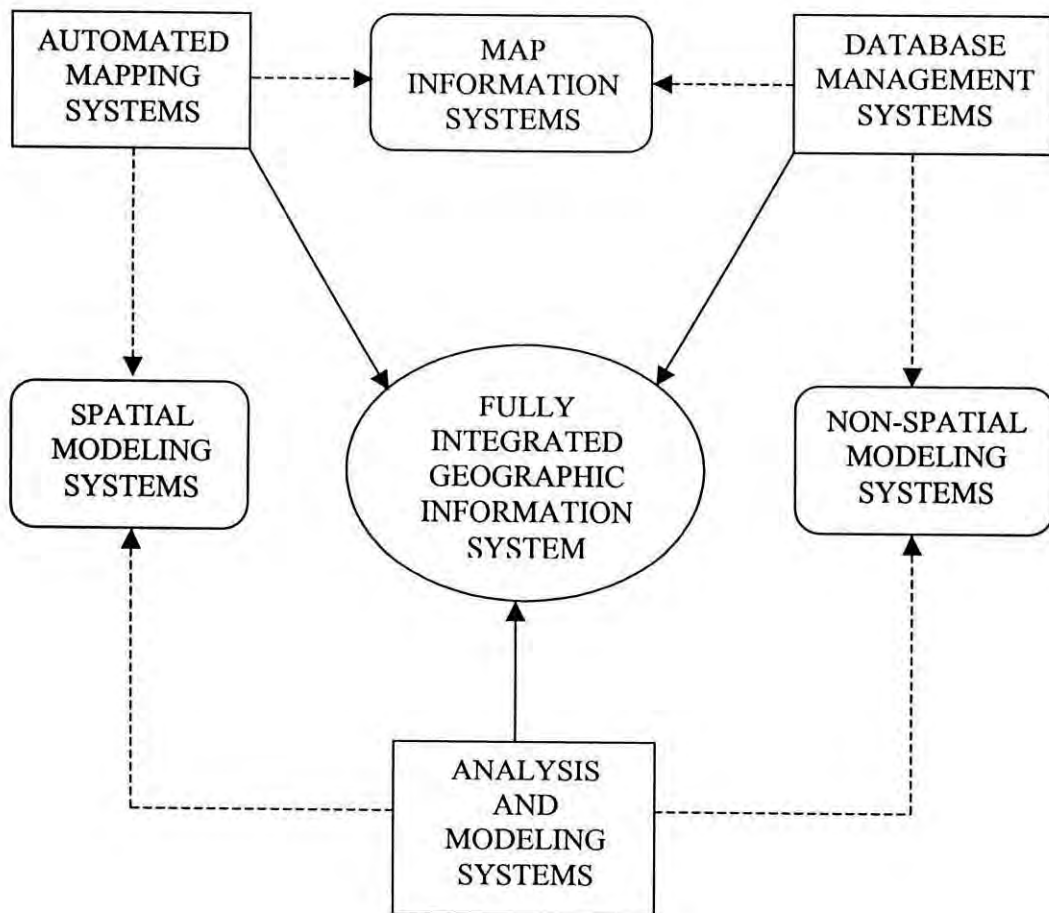


Figure 2.1. The information systems composing a fully integrated geographic information system (after Frost, et al., 1992)

2.3 Function of GIS in this Study

The regional earthquake hazard analysis requires a map of the region that identifies the potential seismic sources. This procedure typically requires several geologic and geographic maps of the region. The bedrock motion in the region resulting from the seismic event must first be determined. This is often done by applying one of the attenuation functions within the GIS or by linking the function as an external executable program. The GIS-based procedure for estimating regional bedrock motion is straightforward. Quantifying and integrating the seismic hazard due to local site effects (soil amplification, liquefaction, and landslide) is the main areas of development presented in this dissertation. The procedure involves developing models for each of the effects, assembling the necessary geologic and geographic maps and databases, applying the models either within the GIS or as linked external programs, and then overlaying and combining the resulting hazard maps.

The result obtained in the analysis is a regional damage distribution for the study area. Damage forecasting typically requires a detailed and accurate structural inventory for the region, a quantification of the regional seismic hazard, and ground motion damage relationship for each facility type. The spatial database structure of a GIS environment is ideal for this procedure. Structural inventory information can be stored in tables within the GIS database or in tables in an externally linked database management program. Relationships to estimate facility damage are typically applied within the GIS but can also be used through external program links. The general procedure involves combining maps of seismic hazard with maps of facility locations according to set motion-damage relationships, producing maps of regional damage distribution. The resulting maps are useful for purposes such as resource allocation and rehabilitation prioritisation.

Recent seismic events have demonstrated that the monetary loss resulting from earthquake damage to major metropolitan areas can run into the billions of dollars (Kiremidjian,1992). World-wide statistics of annual fatalities due to earthquakes are alarming. The final and most important result of a regional seismic hazard and risk analysis is the estimation of monetary and non- monetary loss distribution. As with damage forecasting, the GIS environment is ideal for estimating distributions. The procedure typically involves combining maps of damage distributions with maps and database tables of regional facility and population inventories according the relationships defining loss as a function of damage. The resulting microzone maps of regional loss distribution help to illustrate areas requiring further study for possible earthquake loss mitigation strategies. In this study "Map Info" software is used . The mapping process for regional multi-hazard seismic loss estimation through GIS is shown in Figure 2.2.

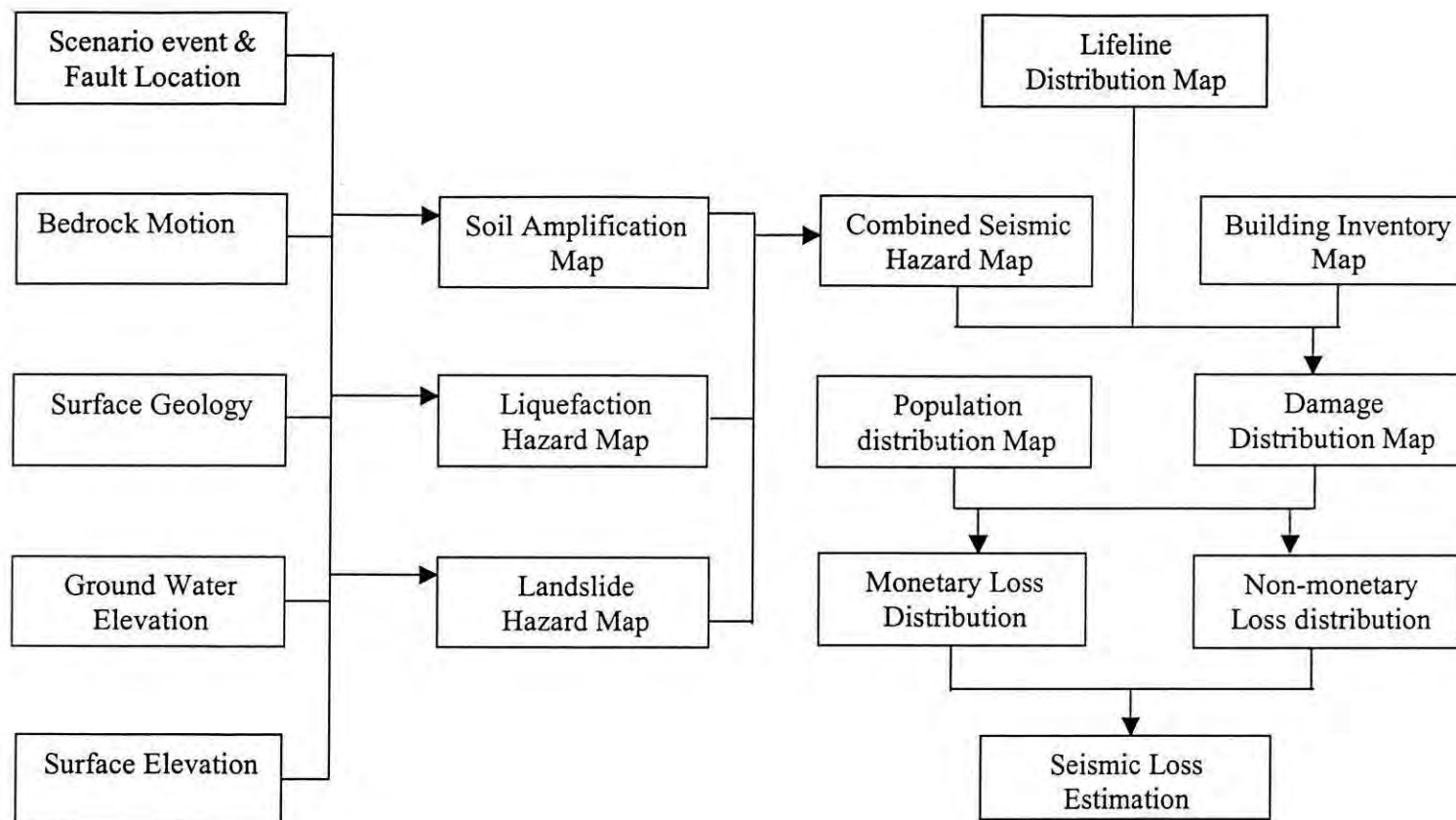


Figure 2.2. The mapping process for regional multi-hazard seismic loss estimation through GIS (Map Info)

3.1 General

Urban development is progressing rapidly in Sylhet City without the development of proper disaster prevention systems against potential earthquakes. It is urgently necessary to prepare a regional earthquake disaster prevention plan on the basis of loss estimation in order to mitigate possible seismic damages in Sylhet City. According to historical seismic data, Sylhet City has suffered from several strong earthquakes. This chapter presents a review of literature for developing methodology to conduct regional multi-hazard seismic loss estimation. The term multi-hazard refers to the consideration of ground shaking and the secondary site effects of soil amplification, liquefaction, landslide etc.

3.2 Administrative Boundary of Sylhet City Corporation

Companiganj, Gowainghat and Jaintiapur Upazilas bound Sylhet Sadar Upazila. It has an area of 517.43 sq. km. It consists of one municipality, 23 Union Parishads, 84 Mouzas and 689 villages. It was established in 1878. During 1991, area of Sylhet Municipality was 10.49 sq.km and other urban area was 43.92 sq.km. In 1996, Municipality area was divided into 13 wards and is shown in Figure 3.1. Recently, the Municipality is upgraded to City Corporation with 27 Wards and 210 Mahallas.

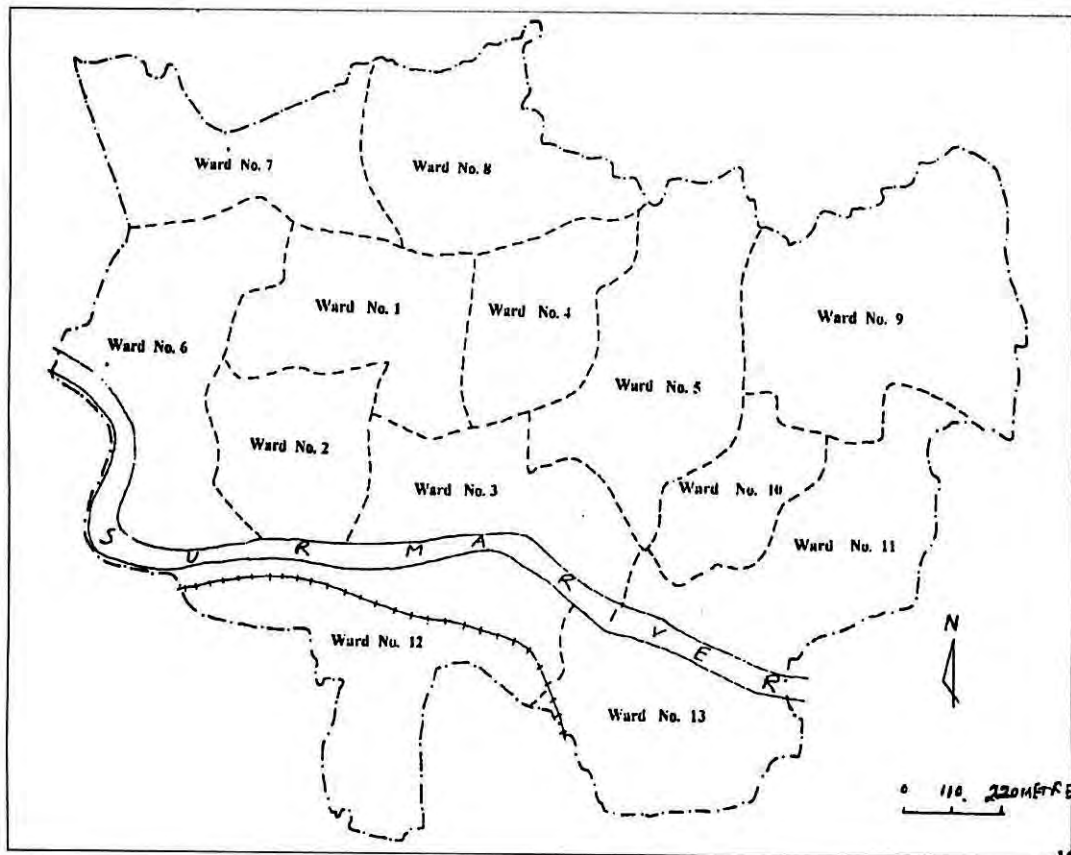


Figure 3.1. Map showing 13 wards in Sylhet City Corporation
(after Sylhet City Corporation, 1996)

3.3 Regional Tectonics

Plate tectonics provide a physically simple mechanism for large-scale horizontal motions of separate portions of the earth's crust. One of the central concepts of plate tectonics is that a small number of large plates of high strength lithosphere, move rigidly with respect to one another at rates of 1 to 20 cm/year over the low-strength asthenosphere.

According to Molnar and Tapponnier (1975), for the past 40 million years the Indian subcontinent has been pushing northward against the Eurasian plate at a rate of 5 cm/year, giving rise to the severest earthquakes and most diverse land forms known. Figure 3.2 shows continued drift of the Indian Plate towards Asian Plate causes major Himalayan earthquakes.

Recently, Bilham et al. (2001) has pointed out that there is high possibility that a large earthquake will occur around the Himalayan region based on the difference between energy accumulations in this region. So there is a seismic gap that is accumulating stress, and that a large earthquake may occur someday when the stress is relieved. Figure 3.3 shows the estimated slip potential along the Himalaya (after Bilham et al., 2001).

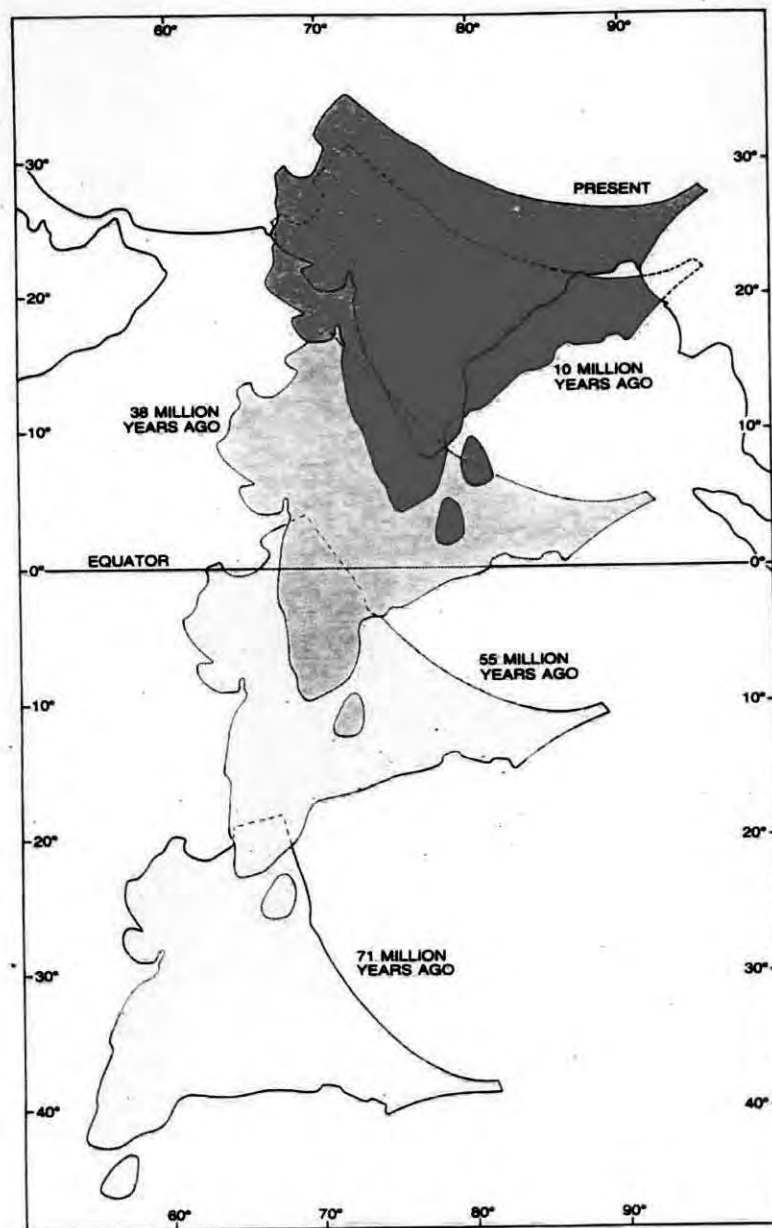


Figure 3.2. Continued drift of the Indian Plate towards Asian Plate causes major Himalayan earthquake (after Molnar and Tapponnier, 1975)

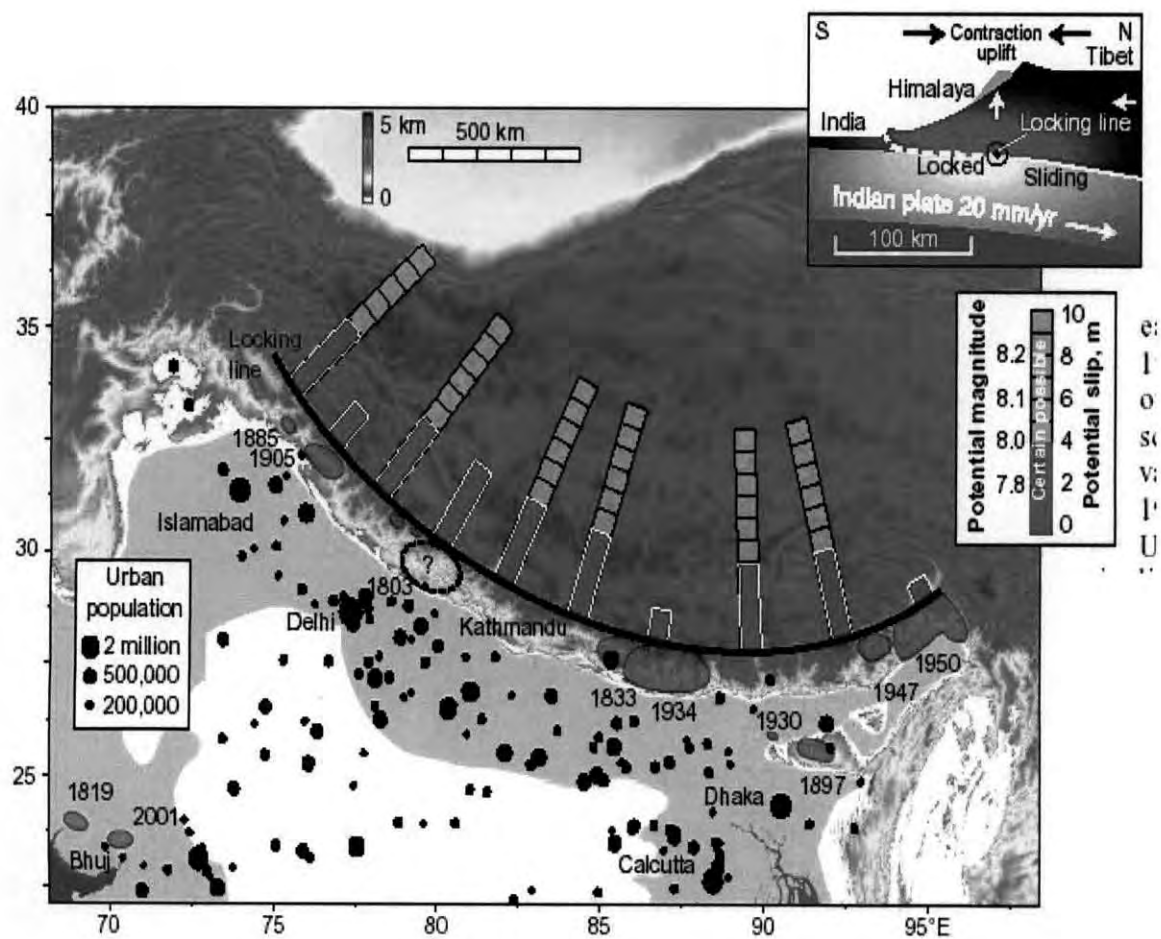


Figure 3.3. Estimated slip potential along the Himalaya (after Bilham et al., 2001)

3.4 Seismo-tectonic Setup

The generalized Tectonic map of Bangladesh and adjoining areas are given in Figure 3.4. The junction between the platform and the fore deep running southwest from Mymensingh to Calcutta (the Hinge line) is considered to be a zone of weakness. However, no association of the hinge with earthquakes has so far been established. The Fore deep is terminated in the northeast by a major fault, the Dauki fault at the southern margin of the Shillong Plateau. Some major earthquakes can be related to this fault. There are numerous faults particularly in the eastern part of the folded flank of the Fore deep. Here again there is no association with any major earthquake. Most recorded earthquakes had epicenter further east in Burma.

The eastern margin of the Indian plate is supposed to run through Myanmar, not far from the Bangladesh border, and northeast Assam (Arunachal Pradesh) is considered to be a corner of the northern and eastern margins of the plate. The Himalayan arc can be regarded as one of the most intensely active seismic regions of the world. In northeast India, the Shillong plateau and adjacent syntaxis between the two actuate structures is one of the most unstable regions in the Alpine-Himalayan belt and faced three major earthquakes of magnitude greater than 8.0 within the last two hundred years.

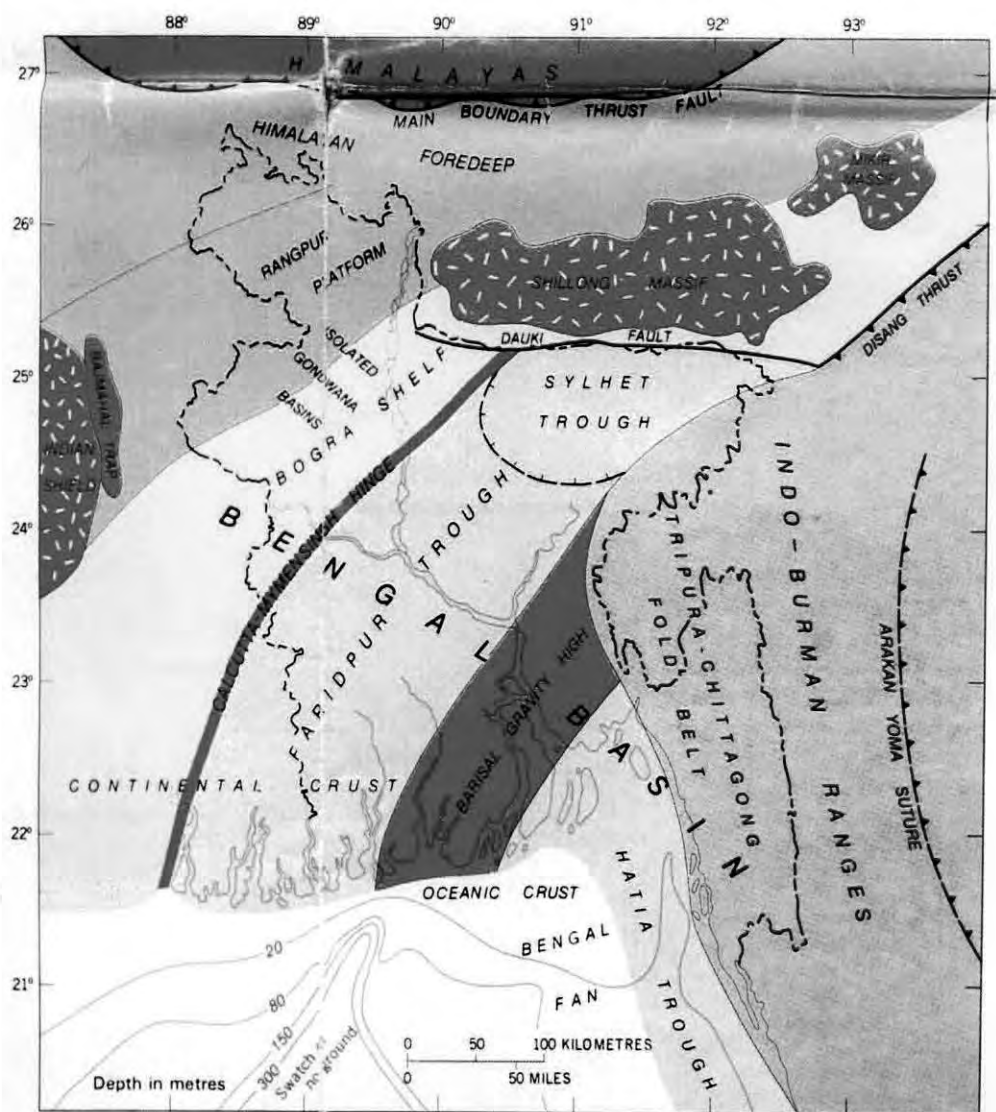


Figure 3.4. Generalized tectonic map of Bangladesh and adjoining areas (after GSB, 1991)

At present, the southernmost thrusting in the Himalaya-Shillong Plateau region could be taking place along the southern fringe of the plateau coinciding with the Dauki fault. Currently, it is believed that the Shillong plateau has a thrust plane beneath it and is undergoing southward thrusting against a concept of vertical tectonics along the Dauki fault. The Shillong plateau and its adjoining region including the northeastern part of Bangladesh have high seismic status. The seismic activity along the Dauki fault zone is comparatively lower and a seismic gap has been postulated along this fault zone. The major earthquakes that have affected Bangladesh since the middle of the last century is presented in Table 3.1.

Table 3.1 Great historical earthquakes in and around Bangladesh

Date	Name	Epicentre	Magnitude (M)
10-01-1869	Cachar Earthquake	Jantia Hill, Assam	7.5
14-07-1885	Bengal Earthquake	Sirajgonj, Bangladesh	7.0
12-06-1897	Great Indian Earthquake	Shillong Plateau	8.7*
18-07-1918	Srimangal Earthquake	Srimangal, Sylhet	7.6
02-07-1930	Dhubri Earthquake	Dhubri, Assam	7.1
15-01-1934	Bihar-Nepal Earthquake	Bihar, India	8.3

* Recently modified as 8.1(M) (Ambraseys, 2001)

3.5 Major Seismic Sources

The seismic hazard is typically determined using a combination of seismological, morphological, geological and geotechnical investigations, combined with the history of earthquake in the region. Bolt (1987) analyzed different seismic sources in and around Bangladesh and arrived at conclusions related to maximum likely earthquake magnitude (Bolt, 1987). Bolt identified the following four major sources:

- (i) Assam fault zone
- (ii) Tripura fault zone
- (iii) Sylhet fault zone
- (iv) Bogra fault zone

Recently, Whitney (2004) has added two major possible source zones, namely Shahzibazar Fault and Tanor Fault. Figure 3.5 shows seismotectonics lineaments and faults capable of producing damaging earthquakes. The magnitudes of earthquake suggested by Bolt is shown in Table 3.2 are the maximum magnitude generated in these blocks as recorded in the historical seismic catalogue. The historical seismic catalogue of the region covers approximately 250 years of (starting 1762) earthquake data. For example, the Assam and Tripura fault zones contain significant faults capable of producing magnitude 8.6 and 8.0 earthquakes respectively in future. Similarly maximum magnitude of 7.5 in Sub-Dauki fault zone and Bogra fault zones are not unlikely events.

Table 3.2 Significant seismic sources and maximum likely earthquake magnitude in Bangladesh (after Bolt, 1987)

Location	Maximum likely earthquake magnitude
Assam fault zone	8.0
Tripura fault zone	7.0
Sylhet fault zone	7.3
Bogra fault zone	7.0

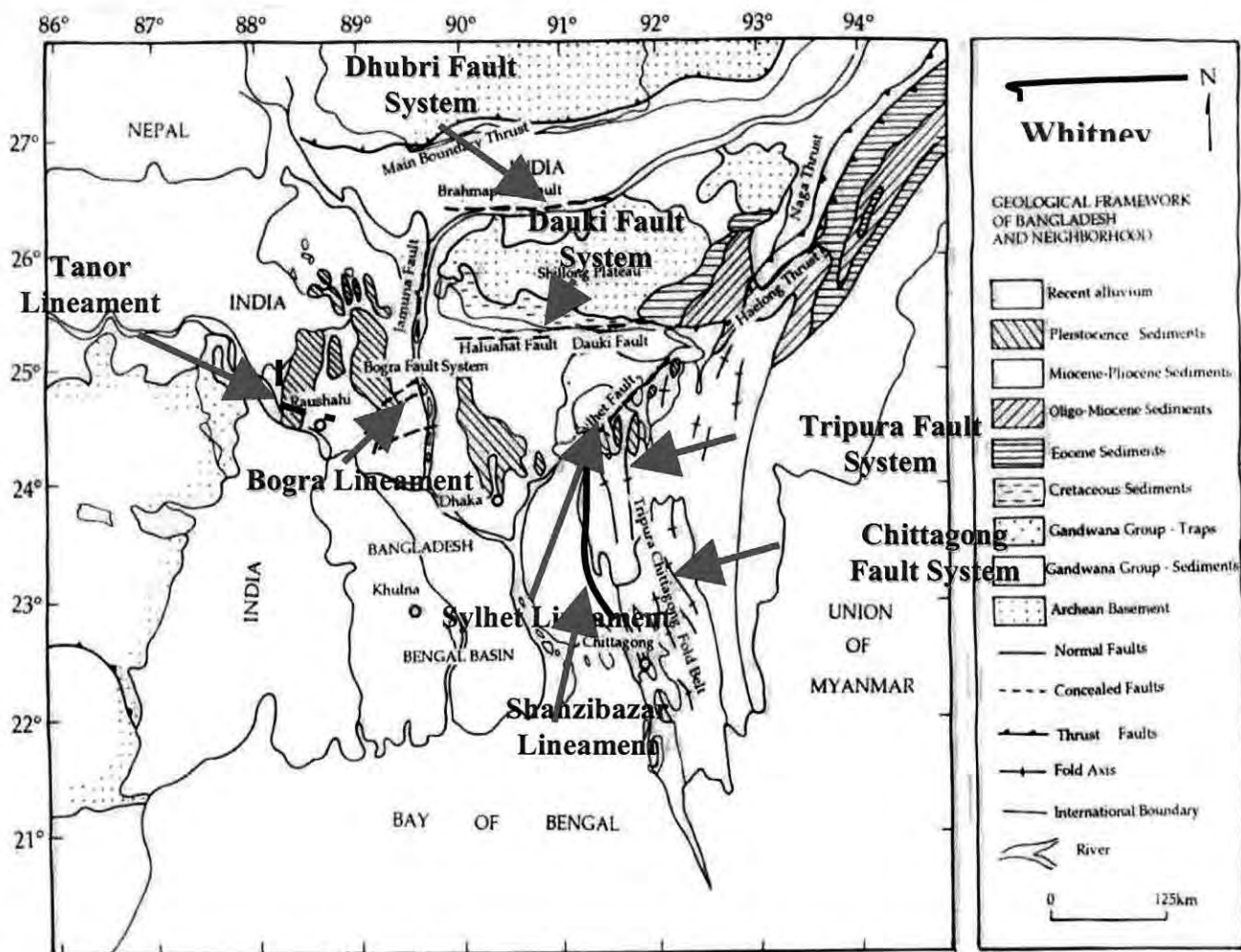


Figure 3.5. Seismo-tectonic lineaments and fault capable of producing damaging earthquakes (after Ali and Choudhury, 1992;Whitney, 2004)

After a thorough review of available data, Ali and Choudhury (1992) recommended magnitudes of Operational Basis Earthquakes and Maximum Credible Earthquakes as shown in Table. 3.3.

Table 3.3 Operational basis earthquake, maximum credible Earthquake and depth of focus of earthquakes for different seismic sources (after Ali and Chowdhury, 1992)

Location	Operational basis earthquakes (Richter)	Maximum Credible earthquakes	Depth of focus (km)
Assam fault zone	8.0	8.7	0-70
Tripura fault zone	7.0	8.0	0-70
Sylhet fault zone	7.3	7.5	0-70
Bogra fault zone	7.0	7.5	0-70

Reliable historical data for seismic activity affecting Indian subcontinent is available only for the last 450 years (Gupta et al., 1982). Recently developed earthquake catalogue for Bangladesh and surrounding area (Sharfuddin, 2001) showed most prominent historical earthquakes affecting Sylhet City as listed in Table 3.4.

Table 3.4 Magnitude, Fault sources and distances of some major historical earthquakes around Sylhet (after Ansary, 2001)

Name of Earthquake	Fault	Magnitude	Distance (Km)	Focal Depth (km)
1869 Cachar Earthquake	Tripura	7.5	92	56
1885 Bengal Earthquake	Bogra	7.0	234	72
1897 Great Indian Earthquake	Assam	8.7	151	60
1918 Srimangal Earthquake	Sub-Dauki	7.6	71	14

3.6 Historical Earthquakes

3.6.1 Cachar Earthquake of 1869

The Cachar Earthquake of January 10, 1869 occurred at 0500 hrs (GMT) is the first and one of the most destructive seismic events that North-East of Indo-Bangladesh experienced in the last two centuries. According to the seismic history of the region this zone has been the site of high seismic status due to Dauki fault. The main shock was strong enough to cause the collapse of many local traditional dwellings in Shilchar, Monipur and upper Burma region. This shock was followed by a series of aftershocks and the earthquake was associated with significant ground surface rupture. Details of casualties and homeless among the population and cost of damage were not communicated. The earthquake is classified as a heavy destructive event with a focal depth of about 56 km. Compilation and detailed analysis of the macroseismic information inferred from contemporary accounts has led to a re-estimation of intensities (Sabri, 2001). Maximum intensity has been re-evaluated at $I_0=IX\sim X$ and allocated to Monipur and Shilchar.

3.6.2 Bengal Earthquake of 1885

There was no seismographic record available for the Bengal earthquake of 1885. Only the felt reports and observed damage to buildings, boundary walls, factory chimney, tomb, cemetery, tower like octagonal mandirs with conical apex, earth fissures and vents were described in the report on the Bengal earthquake by Middlemiss (1885). According to the report, this earthquake was felt with violence throughout the Bengal province. The extent of felt areas extended westward into Chota Nagpur and Bihar, northwards into Shikim and Bhutan, and eastward into Assam, Manipur and Burma. The area over which it was sensibly felt may be roughly 6,00,000 sq. km. The area includes Daltongunge (in Palamow), Durbhanga (in Bihar). Darjeeling, Sibsagar, Manipur and Chittagong. The area covered has a radius of 490 km and the magnitude was 7.0 recalculated the magnitude of the earthquake (M_s) using Ambrasey's formula by Bolt (1987).

3.6.3 Great Indian Earthquake of 1897

Oldham (1899) as the head of the Geological Survey of India, directed and personally investigated the Great Indian earthquake of 1897. He defined a scale of intensity of six degrees. The area over which the shock was felt amounted to not less than 31,20,000 sq. km. This does not include the detached areas near Ahmedabad or any part of the Bay of Bengal, nor the large area in Tibet and Western China, over which the shock was certainly sensible. If the area included in these tracts are taken into consideration, the total area over which the shock was felt amounts to 45,50,000 sq. km., while the area over which known serious damage to masonry buildings occurred was not less than 3,77,000 sq. km.

3.6.4 Srimangal Earthquake of 1918

The 8th July 1918 earthquake is the first felt and recorded destructive seismic event in Bangladesh. A preliminary report of this earthquake was first published in the records of the "Geological Survey of India" in 1920. For a better understanding of the information contained in contemporary documents, the accounts were considered in context of the period concerned. That is, the political and socio-economic and demographic conditions, cultural and religious backgrounds and the characteristics of the building stock exposed to the shaking. Owing to the fact that there were exceedingly few Pucca buildings over the area which was seriously affected and the fact that such as do exist vary greatly in nature and strength to resist shock, it was found to be difficult to map isoseists. Most of the area where the earthquake was violent enough damaged all or nearly all brick buildings. The area consists either of jungle covered hills such as the Tippera Hill or of low lying land such as that seen in south Sylhet, practically all of which was under water at the time of the earthquake. Brick buildings were limited entirely to railway buildings and to those in isolated places such as Sylhet, Moulvi Bazar, Habiganj, Kishorganj, Brahmanbaria, Agartala etc. and the buildings and factories of the tea estates in the valley of south Sylhet. The Isoseismal map of Srimongal Earthquake shown in Figure 3.6.

Summarizing the results, following final data for the July 8 1918 earthquake has been obtained. Origin time 10h 22m 7s (GMT); instrument epicenter 91.2°E, 26.5°N (ISS); macroseismic epicenter at 91.8°E, 24.25°N; depth of focus=12 km to 14 km; maximum intensity I_0 = VIII-IX (EMS); magnitude, M_s =7.6

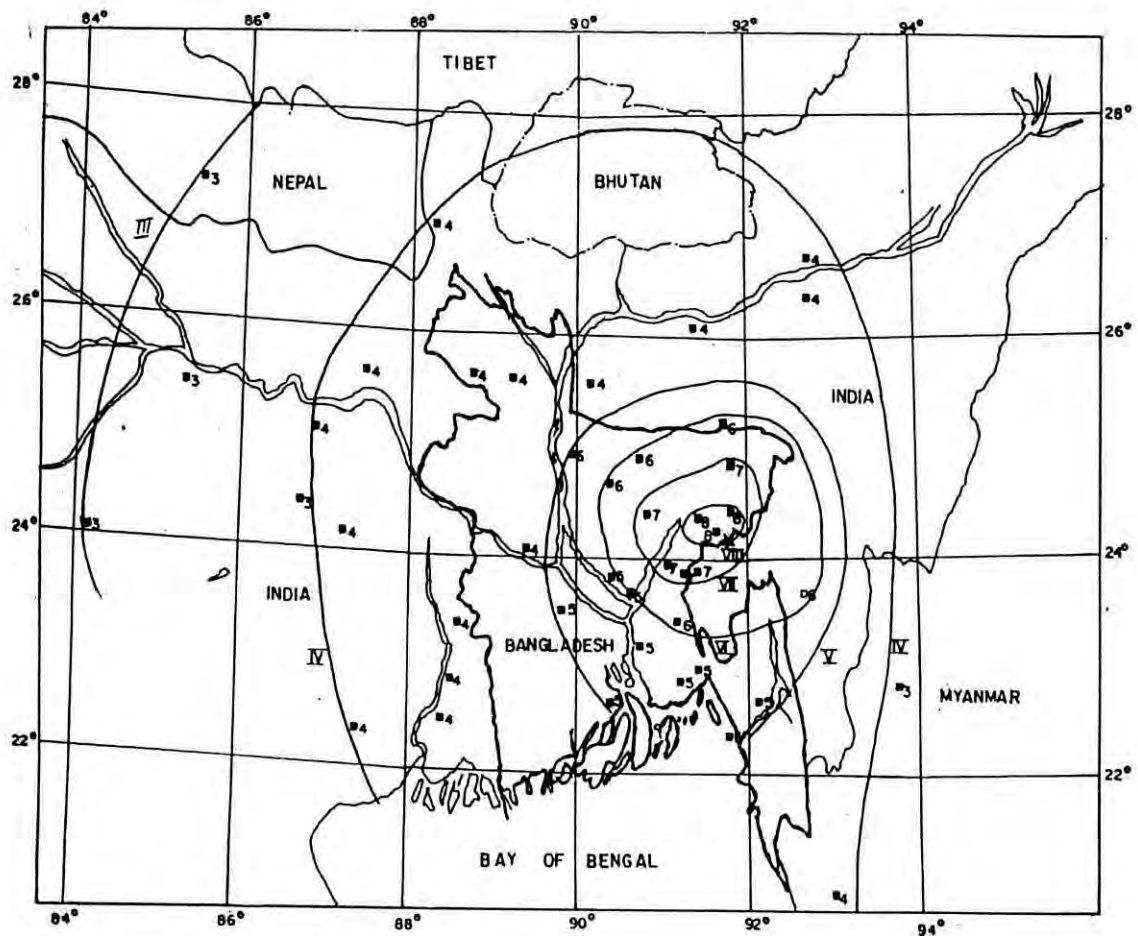


Figure 3.6. Isoseismal map of 1918 Srimongal Earthquake (after Sabri, 2001)

3.7 Relationship between Shear Wave Velocity (V_s) and SPT (N) Value

There are several empirical relations correlating the SPT-N values and shear-wave velocity (V_s) as shown in Table 3.5. One of the convenient ways to identify subsurface soil profiles is the use of penetration tests. The standard penetration test (SPT) has been widely used to investigate deposits in this regard. The empirical relations presented here will be used to convert SPT value into shear-wave velocity which is needed as one of the input parameters for the program SHAKE .

Table 3.5 Empirical Relations Correlating SPT N-value and Shear-wave Velocity

Researchers	Source	Equation
Imai and Yoshimura (1970)	TC4 (1993)	$V_s = 76 N^{0.33}$
Ohba and Toriumi (1970)		$V_s = 84 N^{0.31}$
Ohta and Goto (1978)		$V_s = 69 N^{0.17} D^{0.2} F_1 F_2$ In which, $F_1 = 1.0(H) ; \quad F_2 = 1.00 (\text{clay})$ $\quad \quad \quad = 1.3(P) \quad \quad \quad = 1.09 (\text{f. sand})$ $\quad \quad \quad \quad \quad \quad = 1.07 (\text{m. sand})$ $\quad \quad \quad \quad \quad \quad = 1.14 (\text{c. sand})$ $\quad \quad \quad \quad \quad \quad = 1.15 (\text{g. sand})$ $\quad \quad \quad \quad \quad \quad = 1.45 (\text{gravel})$
Imai (1977)		$V_s = a N^b$ $A = 102 \quad b = 0.29 (\text{H. clay})$ $\quad \quad = 81 \quad \quad = 0.33 (\text{H. sand})$ $\quad \quad = 114 \quad \quad = 0.29 (\text{P. clay})$ $\quad \quad = 97 \quad \quad = 0.32 (\text{P. sand})$
Okamoto et al. (1989)		$V_s = 125 N^{0.3} (\text{P. sand})$
Tamura and Yamazaki (2002)		$V_s = 105.8 N^{0.187} D^{0.179}$

V_s : Shear wave velocity (m/s) ; N: Corrected SPT blow count (N-value)

D: Depth (m) ; H: Holocene ; P: Pleistocene

f: Fine ; m: Medium ; c: Coarse ; g: Gravelly

3.8 Attenuation Law of Peak Ground Acceleration

The quantitative assessment of seismic hazard at any particular site within a region requires an attenuation law for the Peak Ground Acceleration (PGA). The maximum ground motion to be expected in the site constitutes a crucial problem in earthquake engineering. For Bangladesh, as in many other parts of the world, no PGA attenuation law has been developed, due mainly to the shortage of strong motion data. However, in order to assess the seismic hazard in this region, an attenuation law has been adopted from the literature. PGA attenuation relationships, predicting strong ground motions in terms of magnitudes, distance, site geology, and in some cases other factors, using various models and data sets are established for different parts of the world. Reviews of these laws are presented in Campbell (1997). Some of the published attenuation functions are presented in Table 3.6.

Table 3.6 Published attenuation function

Author	Law
Duggal (1989)	$y=227 \times 10^{0.308M} (d+30)^{-1.2}$
McGuire (1978)	$y=0.0306e^{0.89M} r^{-1.17} e^{-0.2S}$ Where S=0 for rock and S=1 for alluvium
Katayama (1974)	$\log y = 2.308 - 1.637 \log(r+30) + 0.411M$
Sadigh, et al. (1986)	$\ln y = -1.406 + 1.1M - 2.051(R + 1.353e^{0.406M})$ Where $M > 6.5$
Joyner and Boore (1988)	$\log y = 0.43 + 0.23(M - 6) - \log(r^2 + h^2)^{1/2} - 0.0027(r^2 + h^2)^{1/2}$; for rock
Ambraseys (1995)	$\log y = -1.43 + 0.245Ms - 0.001r - 0.786 \log r$ $r = (d^2 + 2.7^2)^{1/2}$
Boore et al. (1997)	$\ln y = -.2424 + 0.527(M-6) - 0.778 \ln r - 0.371 \ln V_s / 1.396$ where, $r = (r_b^2 + 5.57^2)^{1/2}$ r_b = epicentral distance in km, V_s = average shear wave velocity of surface 30 m

where y =PGA; M = surface magnitude; d =epicentral distance; r =hypocentral distance; h =focal depth

3.9 Seismic Zoning Maps

In Bangladesh, National Building Code (BNBC) published in 1993, a seismic zoning map for Bangladesh has been presented. The pattern of ground surface acceleration contours having 200 year return period forms the basis of this seismic zoning map. Bangladesh National Building Code (1993) placed Sylhet City area in Seismic zone 3 as shown in Figure 3.7. The seismic zones in the code are not based on the analytical assessment of seismic hazard and are mainly based on the location of historical data. An updated seismic map shown in Figure 3.8 based on analytical study was recently developed (Sharfuddin, 2001). This zoning was based on consistent ground motion criterion such as equal peak ground acceleration levels.

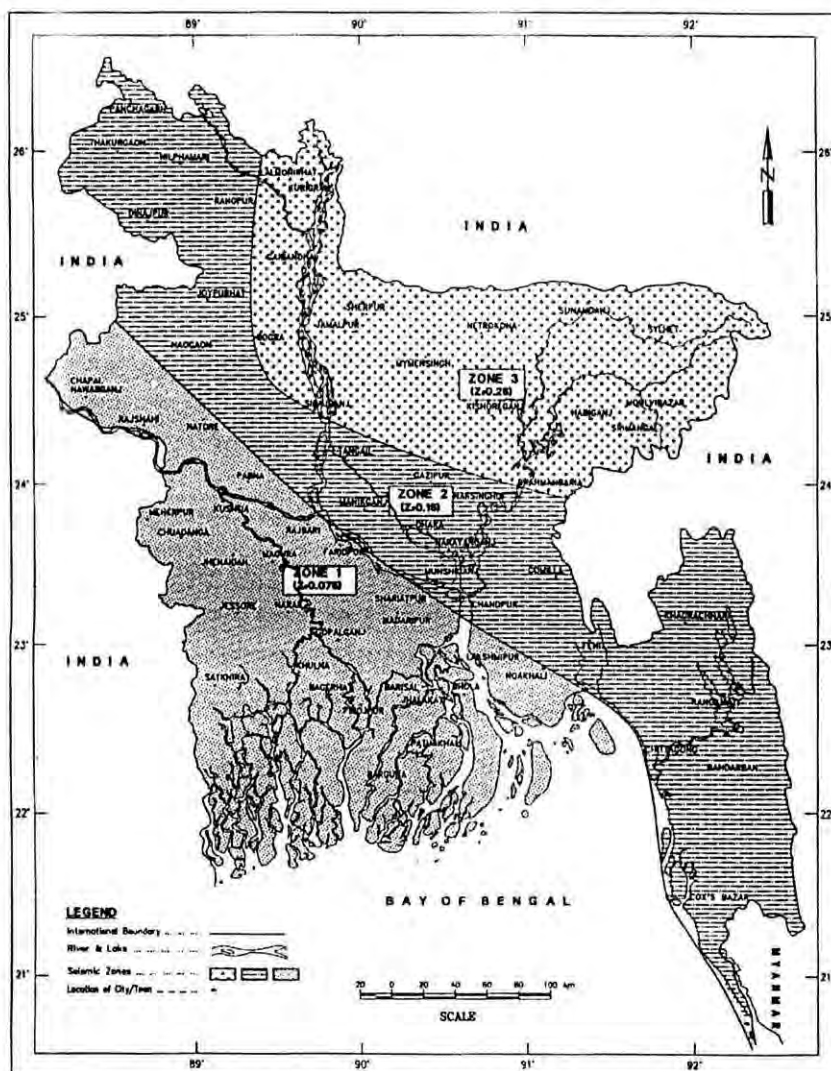


Figure 3.7. Seismic zoning map of Bangladesh (after BNBC, 1993)



Figure 3.8. Updated seismic zoning map of Bangladesh (after Sharfuddin, 2001)

3.10 Soil Amplification

3.10.1 General

The effect of local soil conditions on the amplitude and frequency content of earthquake motions has been the subject of considerable interest and research in recent years. Physically the problem is to predict the characteristics of the seismic motions that can be expected at the free surface (or at any depth) of a soil stratum. Mathematically the problem is one of wave propagation in a continuous medium. If the medium is linearly elastic and the geometry is relatively simple, analytical solutions can be obtained for any kind of waves. In practice, since the wave content of a potential earthquake is hard to predict, solutions are often limited to the simple case of shear wave propagating vertically.

When P and S wave reach the ground surface, most of their energy is reflected back in to the crust, so that surface is affected simultaneously by upward and downward moving waves. For this reason considerable amplification of shaking typically occurs near the surface and enhances the shaking damage at the surface. Different types of ground affected by the same earthquake waves may vary in their severity of ground shaking and consequent destructiveness by one or more degrees of intensity.

Certain building types are more vulnerable to different frequencies of ground motion vibration than others. Seismic micro zoning can show the frequency content of vibration due to different local ground condition. It can be used to ensure that a match does not occur between buildings vulnerable to certain frequencies of vibration and ground conditions that are likely to vibrate in that frequency range and thus avoiding building being damaged by 'resonance effect' in zones where the ground is likely to vibrate in certain frequency ranges. Buildings should be designed either to have frequencies of natural vibration well outside the critical range, or to be designed or to be designed for the much higher seismic forces they are likely to experience. The frequency map could also be used such as zone where restrictions might be imposed on building structures of 10 stores high, likely to have a natural period of about 1 seconds,

because the zone consists of deep deposits of soft soil that are also likely to have natural periods of vibration of about 1 second.

3.10.2 Analysis Method for Soil Amplification

The program SHAKE can compute the responses for a design motion given anywhere in the system. Thus accelerograms obtained from instruments on soil deposits can be used to generate new rock motions which, in turn, can be used as design motion for other soil deposits as shown in Figure 3.9 (after Schnable et al., 1972). The program also incorporates non-linear soil behaviour, the effect of the elasticity of the base rock and systems with variable damping.

The theory considers the responses associated with vertical propagation of shear waves through the linear visco-elastic system shown in Figure 3.10. The system consists of N horizontal layers which extend to infinity in the horizontal direction and has a halfspace as the bottom layer. Each layer is homogeneous and isotropic, and is characterized by the thickness, h , mass density, ρ , shear modulus, G , and damping factor, β .

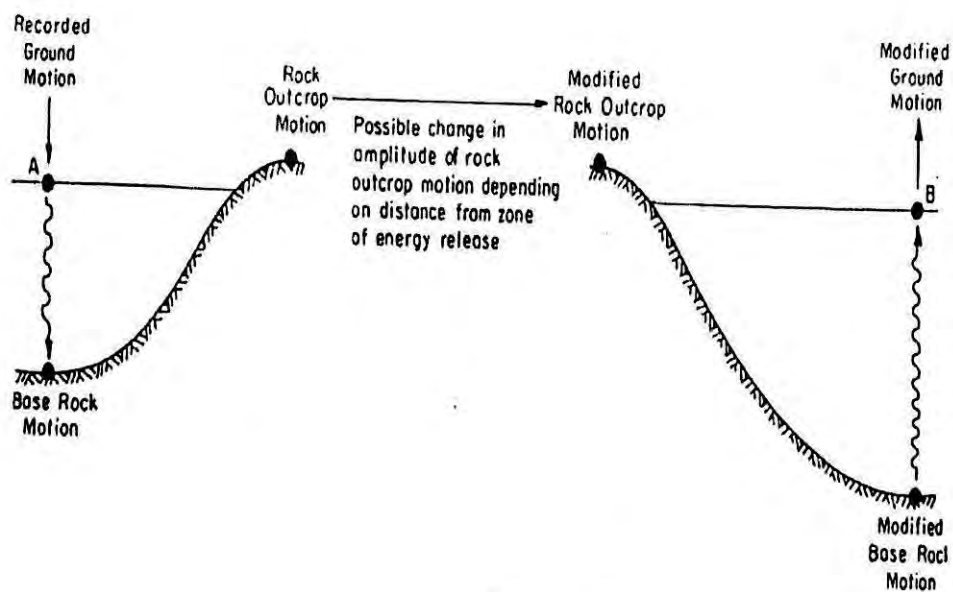
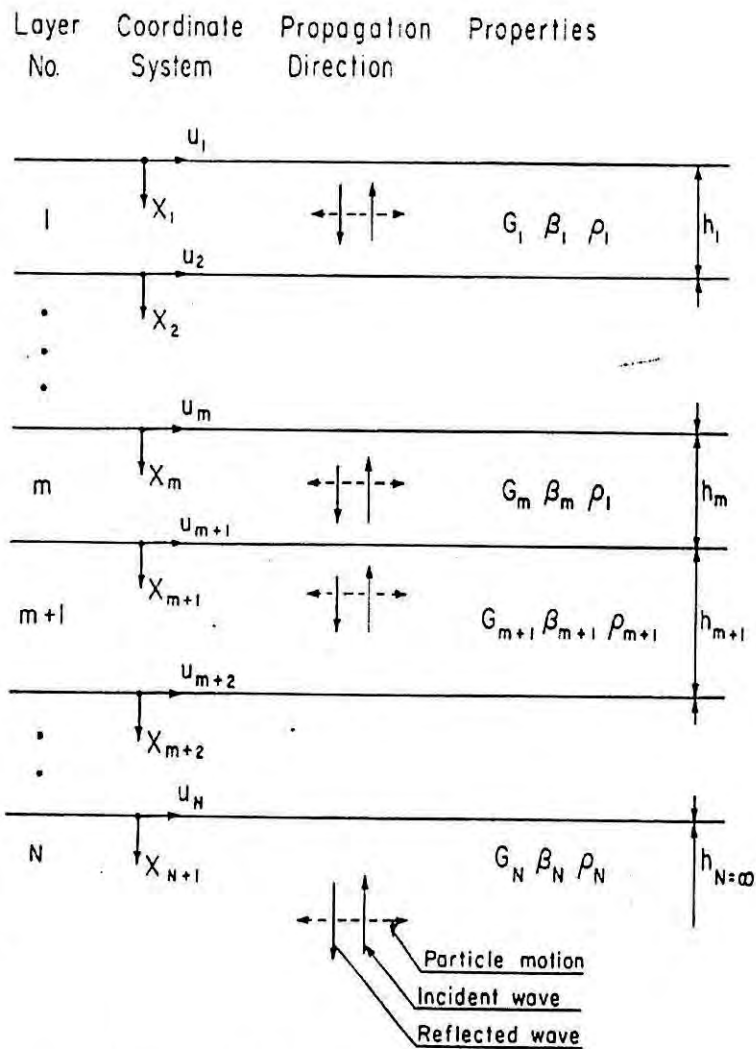


Figure 3.9. Schematic representation of procedure for computing effects of local soil conditions on ground motions (after Schnabel et al., 1971)



$$G^* = G + i\omega\eta = G(1 + 2i\beta)$$

Figure 3.10. One-dimensional wave propagation system (after Schnabel et al., 1971)

Computer Program SHAKE

Program SHAKE computes the responses in a system of homogeneous, visco-elastic layers of infinite horizontal extent subjected to vertically travelling shear waves. The system is shown in Figure 3.10. The program is based on the continuous solution to the wave- equation adapted for use with transient motions through the fast Fourier transform algorithm. The nonlinearity of the shear modulus and damping is accounted for by the use of equivalent linear soil properties using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer.

The following assumptions are implied in the analysis:

- The soil system extends infinitely in the horizontal direction. Each layer in the system is completely defined by its value of shear modulus, critical damping ratio, density, and thickness. These values are independent of frequency.
- The responses in the system are caused by the upward propagation of shear waves from the underlying rock formation.
- The shear waves are given as acceleration values of equally spaced time intervals. Cyclic repetition of the acceleration time history is implied in the solution.
- The strain dependence of modulus and damping is accounted for by an equivalent linear procedure based on an average effective strain level computed for each layer.

The program is able to handle systems with variation in both moduli and damping, and takes into account the effect of the elastic base. The motion used as a basis for the analysis, the object motion, can be given in any one layer in the system and new motions can be computed in any other layer.

The set of operations can be performed by the program:

- Read the input motion, find the maximum acceleration, scale the values up or down, and compute the predominant period.
- Read data for the soil deposit and compute the fundamental period of the deposit.
- Compute the maximum stresses and strains in the middle of each sub-layer and obtain new values for modulus and damping compatible with a specified percentage of the maximum strain.
- Compute new motions at the top of any sub-layer inside the system or outcropping from the system.

3.11 Soil Liquefaction

3.11.1 General

Soil liquefaction is often described as the loss of shear strength in soil due to elevated pore water pressure. Earthquake shaking induces shear stresses in the soil that cause the saturated cohesion less granular soil particles to rearrange and excess pore pressures to build up. The damaging effects of soil liquefaction have been well recognized since the Niigata and Alaska earthquakes of the early 1960s. The types of failures associated with liquefaction include:

- (i). Sinking or overturning of the structures,
- (ii). Excessive differential settlement of the structures,
- (iii). Sand boils; and
- (iv). Surface lateral spreading.

There are several factors that influence liquefaction such as the geologic history of the deposit, the depth of ground water table, the grain size distribution, the density of soil, and ground slope.

The basic cause of liquefaction of sands has been understood, in a qualitative way, for many years. If a saturated sand is subjected to ground vibrations, it tends to compact and decrease in volume; if drainage is unable to occur, the tendency to decrease in volume results in an increase in pore water pressure, and subsequently if the pore water pressure builds up to the point at which it is equal to the overburden pressure, the effective stress becomes zero, the sand loses its strength completely, it develops a liquefied state.

In more quantitative terms, it is now generally believed that the basic cause of liquefaction in saturated cohesion less soils during earthquakes is the build-up of excess hydrostatic pressure due to the application of cyclic shear stresses induced by the ground motions. These stresses are generally considered to be due primarily to upward propagation of shear waves in a soil deposit, although other forms of wave motions are also expected to occur. Thus, soil elements can be considered to undergo a series of cyclic stress conditions, the stress series being somewhat random in pattern but nevertheless cyclic in nature.

Liquefaction was observed in almost all earthquakes. Liquefaction phenomena were recorded and developed in many parts of the world where ground shaking is frequent and soils consists of loose fine sand under water table. Bangladesh is largely an alluvial plain consisting of fine sand and silt deposits. The ground water table is quite deep in most places except the areas near the rivers.

3.11.2 Liquefaction Hazard Analysis Method

A simple method suggested by Seed et al. (1983) was used here to evaluate a liquefaction resistance factor, F_L . In this method required parameters are SPT N-values, grain-size distribution curves of soils, overburden pressure, and estimated peak surface acceleration. The assessment of the liquefaction resistance factor at any depth by this method involves comparison of the predicted cyclic stress ratio (τ/σ'_o) that would be induced by a given design earthquake (L) with the cyclic stress ratio required to induce

liquefaction (R). For this method, F_L is calculated for a given depth by the following formula. Liquefaction is judged to occur at that depth if F_L is less than 1.0.

$$F_L = R / L \quad (3.1)$$

The shear stresses developed at any point in a soil deposit during an earthquake appear to be due primarily to the vertical propagation of shear waves in the deposit. If the soil column above a soil element at depth 'h' behaved as a rigid body, the maximum shear stresses on the soil element would be

$$(\tau_{\max})_r = (\gamma h)/g \cdot \alpha_{S\max} = \sigma_o/g \cdot \alpha_{S\max} \quad (3.2)$$

where

- σ_o = total overburden pressure
- $\alpha_{S\max}$ = estimated peak surface acceleration (in percentage of g)
- γ = Unit weight of the soil
- g = acceleration due to gravity;

Figure 3.11 illustrates the procedure for determining cyclic shear stress on a soil element during ground shaking and Figure 3.12 illustrates the procedure for determining maximum shear stress.

Because the soil column behaves as a deformable body, the actual shear stress at depth h, $(\tau_{\max})_d$, as determined by the ground response analysis will be less than $(\tau_{\max})_r$ and might be expressed by

$$(\tau_{\max})_d = r_d (\tau_{\max})_r \quad (3.3)$$

Where

r_d = a stress reduction factor with a value less than 1 given by $(1 - 0.015z)$ in which z = depth of ground surface in meters.

Computations of the value of r_d for a wide variety of earthquake motions and soil conditions having sand in the upper 50 ft. have shown that r_d generally falls within the range of values shown in Figure 3.13. It may be seen that in the upper 30 or 40 ft., the scatter of the results is not so great and, for any of the deposits, the error involved in using the average values shown by the dashed line would generally be less than about 5%. Thus to a depth of about 40 ft., a reasonably accurate assessment of the maximum shear stress developed during an earthquake can be made for the relationship given in equation (3.3) by using values of r_d to be taken from the dashed line in Figure 3.13.

The actual time history of shear stress at any depth in a soil deposit during an earthquake will have an irregular form such as that shown in Figure 3.14. From such relationships it is necessary to determine the equivalent uniform average shear stress. By appropriate weighting of the individual stress cycles, based on laboratory test data, this determination can readily be made. However, after making these determinations for a number of different cases it has been found that with a reasonable degree of accuracy, the average equivalent uniform shear stress, τ_{av} , is about 65% of the maximum shear stress, τ_{max} . Combining this result with the above expression for τ_{max} , the average cyclic stress ratio (τ_{av}/σ'_o) induced by an earthquake is given by the expression (Seed et al., 1983)

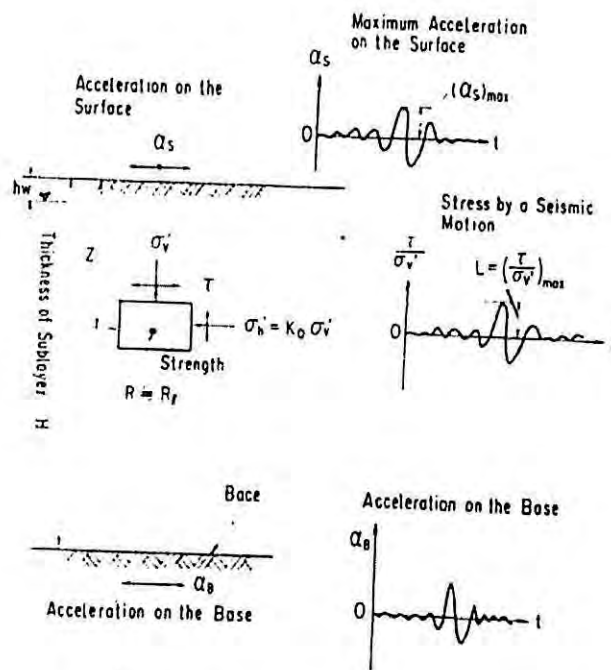


Figure 3.11. Cyclic shear stresses on a soil element during ground shaking (after Iwasaki, 1982)

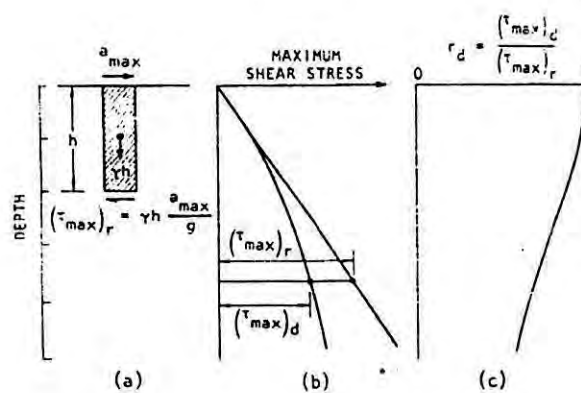


Figure 3.12. Procedure for determining maximum shear stress (after Seed et al., 1983)

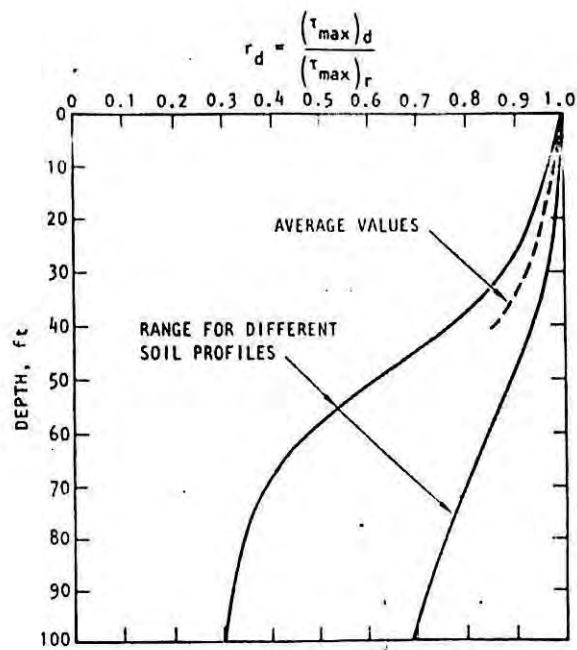


Figure 3.13. Range of values of r_d for different soil profiles
(after Seed et al., 1983)

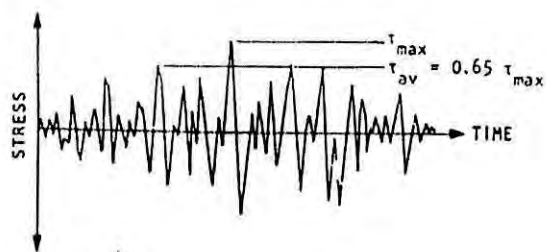


Figure 3.14. Time history of shear stresses during earthquake
(after Seed et al., 1983)

$$L = \tau_{av}/\sigma'_o = 0.65(\alpha_{Smax}/g)(\sigma_o/\sigma'_o) r_d \quad (3.4)$$

In which

σ'_o = effective overburden pressure

The cyclic stress ratio required to cause liquefaction has been evaluated using empirical relationship between cyclic stress ratio and N values. This curve is presented in Figure 3.15. Since the standard penetration resistance, N, measured in the field actually reflects the influence of the soil properties and the effective confining pressure, it has been found desirable to eliminate the influence of confining pressure by using a normalized penetration resistance N_1 , where N_1 is the measured penetration resistance of the soil under an effective overburden pressure of 1 ton per sq.ft. So, before using the graph in Figure 3.16, normalization to the field SPT-N value is needed as follows:

$$N_1 = C_N N \quad (3.5)$$

Where

N_1 = modified N values

C_N = a correction factor

The correction factor, C_N was provided by Murthy (1991) and presented here as Figure 3.16.

The severity of foundation damage caused by soil liquefaction depends to a great extent on the severity of liquefaction, which can not be evaluated solely by the F_L . Generally speaking, liquefaction under the following conditions tends to be severe if:

- The liquefied layer is thick
- The liquefied layer is shallow
- The F_L of the liquefied layer is far less than 1.0.

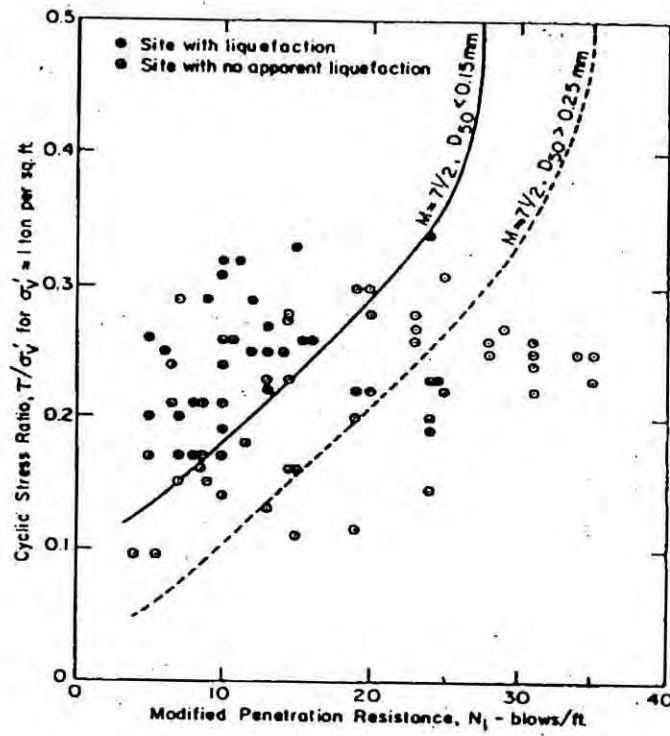


Figure 3.15. Correlation between field liquefaction behavior of Silty sands under level ground conditions and standard penetration resistance (after Seed et al., 1983)

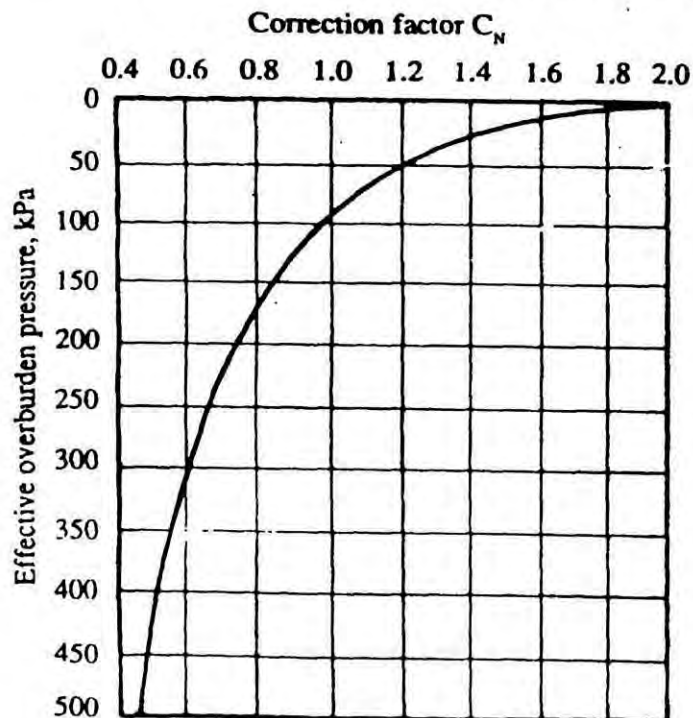


Figure 3.16. Recommended curve for determination of C_N (after Murthy, 1991)

In order to take care the above effect, the Japanese bridge code recommended a modification to the procedure suggested by Seed et al. (1983). In this modification, the factor of safety value, F_L against resistance to liquefaction have been computed for all the bore holes and these values have been subsequently been converted into liquefaction potential index (P_L). The P_L is given by the following equation (Iwasaki et al., 1982).

$$P_L = \int_0^{20} F(z) w(z) dz \quad (3.6)$$

Where

$$\begin{aligned} F(z) &= (1 - F_L) && \text{for } F_L \leq 1.0 \\ F(z) &= 0 && \text{for } F_L > 1.0 \\ W(z) &= (10 - 0.5 Z) && \text{for } z \leq 20 \text{ m} \\ W(z) &= 0 && \text{for } z > 20 \text{ m} \end{aligned}$$

The value of liquefaction potential, P_L indicates that a soil mass is susceptible to liquefaction if $P_L > 0$. If the value of P_L is large, the soil is very susceptible for liquefaction.

3.12 Landslide Hazard Analysis Method

The effects of earthquake-induced landslide have received much less research attention than the seismic effects of soil amplification and liquefaction. Landslide hazard is typically very difficult to quantify because landslides come in many forms and are caused by a variety of processes. The local site factors that affect landslides generally include slope stability, geology, slope angle, hydrological conditions, vegetation, land use, and severity of the earthquake. Most of these factors are necessary for the investigation of an individual slope, but for seismically induced landslide analysis on a broad regional basis, magnitude of the seismic event, and distance from the seismic source (Hansen and Franks, 1991).

As with liquefaction, regional landslide hazard has traditionally been analyzed in a qualitative manner utilizing expert opinion, although recently more quantitative geotechnical methods have been proposed. The qualitative methods typically produce microzone maps indicating the relative susceptibility of various regions to landslides with no investigation into the possible triggering mechanisms for the land movement. The maps often result from an expert analysis of regional factors such as previous landslide locations, geologic deposits, and topography.

The complicated nature of the landslide process has made regional estimates of this local site effect very difficult to define quantitatively. Most of the recent research in this field has focused on determining the critical level of a given ground motion parameter that will trigger landslide in various geologic deposits. Wiczorek, et al. (1985) models a landslide as a translational failure in an infinite slope with a depth of 3 meters. They define three classes of geological units, assign shear strength parameters for each class, and then perform stability analyses using dry and saturated conditions to obtain the static factor of safety (FS) for each class. Based on the static FS, the critical acceleration to begin the process of slope failure, a_c , is computed as

$$a_c = (FS - 1) g \sin \theta \quad (3.7)$$

Where

θ = The slope angle

FS = the factor of safety determined from a static slope stability analysis

g = the acceleration of gravity

These a_c values are compared to the regional estimates of surface peak ground acceleration to give a prediction for the occurrence of damaging earthquake-induced landslides in the area. There have been very few implementations of quantitative landslide hazard models in the GIS environment instead, a qualitative approach utilizing regional maps showing relative susceptibility of landslides in various geologic deposits will be used to describe earthquake-induced landslide hazard.

3.13 Damage Distributions

3.13.1 General

Damage assessment for a region typically depends upon three factors: the level of seismic hazard in the region, including the effects of local site conditions; the distribution of facilities in the region, according to earthquake engineering class; and the definition of functions that relate the expected levels of damage for the various earthquake engineering classes to the estimated levels of seismic hazards. There are several definitions for damage and also several relationships for estimating damage due to given levels of seismic hazard for various facility types.

3.13.2 Definition of Damage

There are several parameters used to express earthquake damage and the terms such as "damage ratio", "damage factor", and "damage index" have different meanings. Regional damage can be given, for example, in percent financial loss or percent of structures damaged to a certain degree. Damage to given structures can be described in terms of damage to the individual elements, often based on dynamic response measures. The term "damage index" is typically taken to mean the characterization of individual element (local) or entire structure (global) damage based on response parameters such as ductility ratio, inter-story drift, and dissipated energy (Park and Ang, 1985). These indices are generally too structure specific to be considered for regional damage description. The term "damage ratio" is typically defined as (Applied Technology Council, ATC-13, 1985):

$$\text{Damage Ratio (DR)} = \frac{\text{number of structures damaged}}{\text{total number of structures}}$$

The level of damage required for a building to be considered "damaged" is often ambiguous, and this type of ratio can typically be derived from other estimates of regional damage.

3.13.3 Motion-Damage Relationship for Bangladesh

Fragility curves are used in the FEMA/NIBS methodology to estimate damage to buildings resulting from ground shaking (Whitman et al, 1997). The fragility curves predict the probability of reaching or exceeding specific damage states for a given level of peak earthquake response. The probability of being in a particular state of damage, the input used to predict the building related losses, is calculated as the differences between fragility curves. Building fragility curves are lognormal functions that describe the probability of reaching or exceeding structural and non-structural damage states, given deterministic estimates of spectral responses, for example spectral displacement. These curves take into account the variability and uncertainty associated with capacity curves properties, damage states and ground shaking.

Fragility curves are used for estimation of damages of buildings in particular area. A number of fragility curves exist for Indian Buildings prepared by Arya (2000) and for Nepalese buildings prepared by Bothara et al. (2000). There also exist a number of fragility curves for different types of structure and for different earthquake intensities (Kircher et al., 1997; Fah et al, 2001; Yamazaki and Murao, 2000; Yamaguchi and Yamazaki, 2000; Bommer et al., 2002), but the Indian and Nepalese curves may be the most suitable for Bangladeshi structures, until Bangladeshi researchers develop their own fragility curves. In this study, fragility curves for the buildings are prepared by calibrating the existing fragility curves for Indian buildings prepared by Arya (2000) and for Nepalese buildings prepared by Bothara et al. (2000). Neither Arya (2000) nor Bothara et al (2000) mentioned the types of damages (i.e., collapsed or heavily or moderately damaged) to be estimated using those fragility curves. Segawa et al. (2002) used those curves after some calibration and quoted those curves to be developed for heavily damaged structures. Figure 3.17 shows the fragility curves modified from Arya (2000) and Bothara et al. (2000).

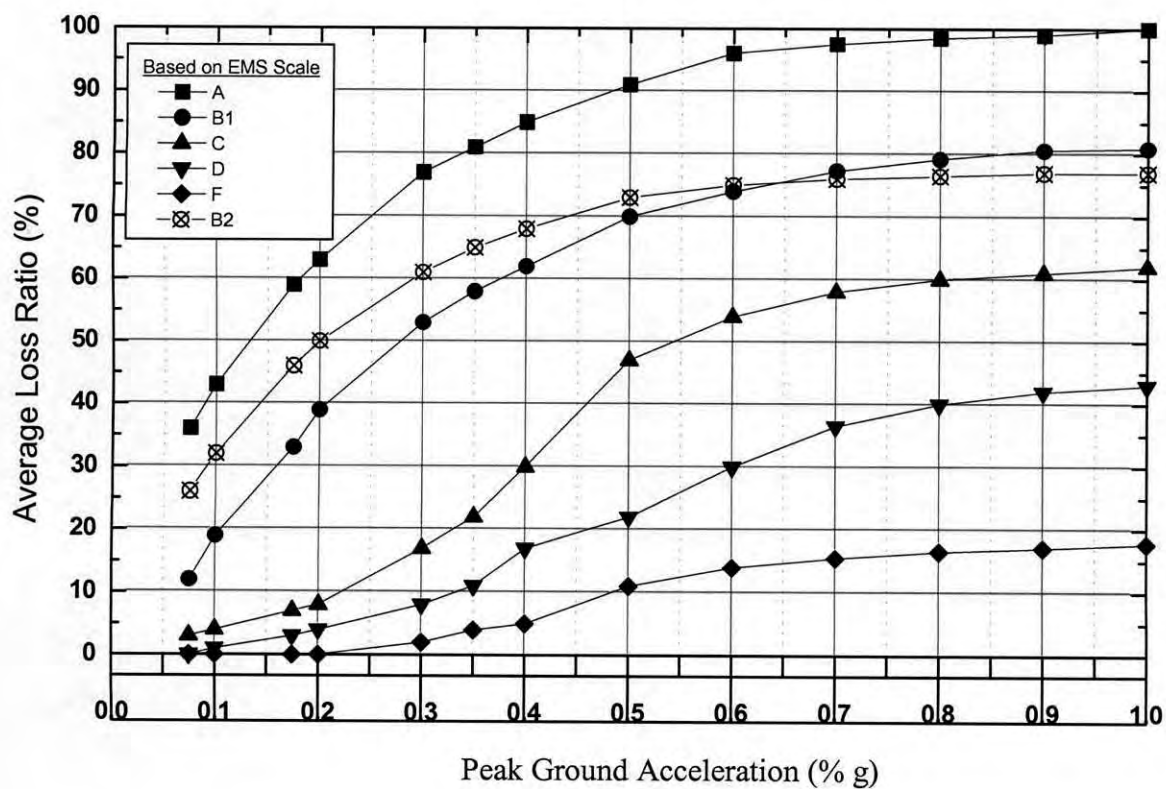


Figure 3.17. Vulnerability functions based on peak ground acceleration
(after Arya, 2000)

3.14 Analysis Method for Seismic Damage Estimation of Service Pipes

After the 1999, Ji-Ji Earthquake, more comprehensive pipe damage data were collected in Taichung City and a detailed analysis was made to examine the relationships between earthquake forces and the resulting damage (Chen et. al 2002). The pipelines were divided into three groups according to their diameters, namely pipelines with diameters $\leq 65\text{mm}$, $65\text{mm} < \text{diameters} < 150\text{ mm}$, and diameters $\geq 150\text{mm}$. This grouping was made because the pipes connecting distribution pipelines to gas meters of customers mostly had diameters between 25 and 65mm. Thus, the pipelines with diameter $\leq 65\text{mm}$ are classified as small pipelines in this study, and the length of this group was 237km (24% of all pipelines). The remaining pipelines were further divided into two groups, the pipelines with diameters greater than 150 mm as large pipelines and the pipelines with diameter between 65 and 150 mm as medium pipelines. The lengths of these two groups were 413.9km (42%) and 328.6km (34%), respectively.

In order to perform analysis, the study area is divided into a 1km*1km grid with pipelines enclosed in the grid, and the damage locations. For each group of pipelines, the damage ratio (DR) that is also denoted as the repair rates (RR) was calculated by dividing the numbers of damage by the total length of natural gas pipelines in each grid.

During the Ji-Ji earthquake, the time histories of ground accelerations indicated that the component in the east-west direction was the largest. The peak ground acceleration (PGA) values at the center of each grid were calculated using linear interpolation. The resulting RR and PGA pairs were then grouped into 5-8 intervals to arrive at representative RR and PGA values for each interval. The intervals were used in the following regression analysis. The results were shown in Figure 3.18. It can be seen that the regression lines for three different diameters followed a general trend, which was similar to that, obtained in the Northridge earthquake by Toprak (1998).

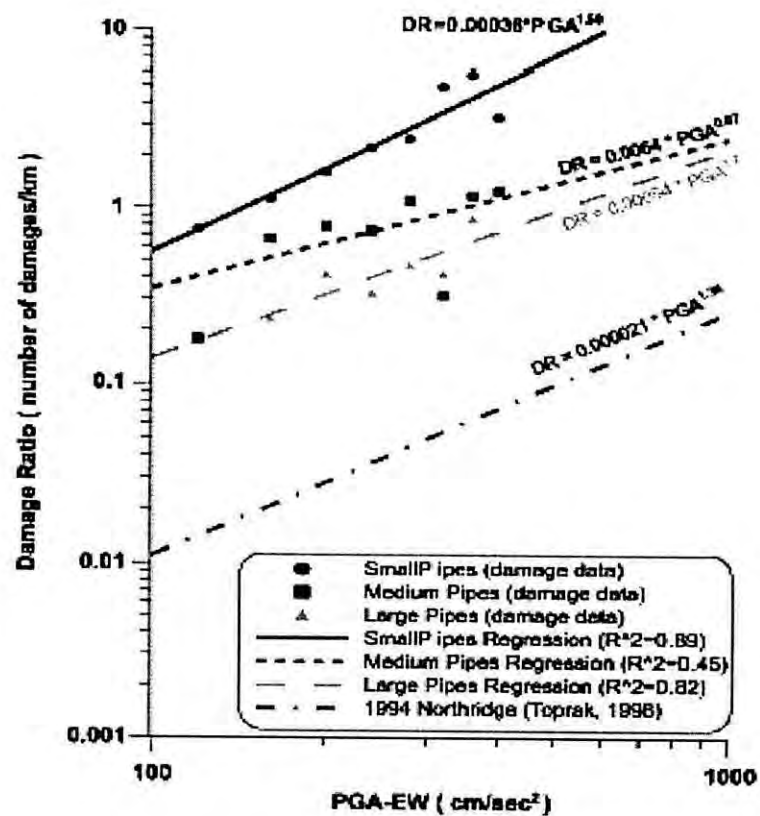


Figure 3.18. The correlation between Damage Ratio and PGA value for different Pipeline diameters (after Chen et al., 2002)

However, the analysis of Toprak was made on cast iron pipes of water distribution systems. Still, the RR of the natural gas pipelines (mostly steel pipes and PE pipes) of Taichung City was higher than those of Toprak's analysis. For the three groups of pipelines analyzed in this study, empirical damage Relations with respect to PGA is as follows:

$$DR = 0.00036 * PGA^{1.59} \quad \text{for } \Phi \leq 65 \text{ mm} \quad (3.8)$$

$$DR = 0.0064 * PGA^{0.87} \quad \text{for } 65 \text{ mm} < \Phi < 150 \text{ mm} \quad (3.9)$$

$$DR = 0.00054 * PGA^{1.2} \quad \text{for } \Phi \geq 150 \text{ mm} \quad (3.10)$$

Where Φ is the pipeline diameter. PGA the peak ground acceleration (cm/s^2)

3.15 Casualty Estimation Model

In order to assess the human casualty levels due to the earthquake, the estimates of average fatality and injury levels have been used. These figures have been derived by using a mortality prediction model for different categories of structures. This prediction model is based on investigation of casualty due to several major earthquakes that have occurred during last century (Coburn et al., 1992). The total number of people that may be killed due to damage of each building type can be represented by:

$$Ks_b = D_b * [M1_b * M2_b * M3_b * M4_b] \quad (3.11)$$

Where D_b is the total number of damaged household of type b , $M1$ is the occupant density and $M2$ to $M4$ are conditional probability factors to modify the potential casualty figures. The factor $M1$ represents the population per household. The factor $M1$ represents the population per household. $M2$ is the occupancy of buildings at the time of earthquake. The occupancy cycle proposed by Coburn and Spence (1992) was presented in Figure 3.19 for residential and business structures. Depending on the time

of the earthquake, the occupancy rate can be found from this figure. M3 is the proportion of occupants who are trapped by collapse of buildings. This depends on the type of building. M4 is the proportion of occupants who are either killed or injured in the earthquake. It was observed that collapsed multi-storied masonry and reinforced concrete buildings lead to death of a large number of trapped occupants, while collapsed masonry buildings lead to death of relatively small number of trapped occupants. Values of M1, M2, M3, and M4 are shown in Table 3.7

Table 3.7 Values of M1, M2, M3 and M4 for different types of buildings

Building types	M1	M2			M3			M4	
		Morning	Night	Noon	I=X	I=IX	I=VIII	Killed	Injured
A	6	0.62	0.78	0.42	0.40	0.30	0.20	0.15	0.25
B1	6	0.62	0.78	0.42	0.30	0.20	0.10	0.20	0.30
B2	6	0.62	0.78	0.42	0.60	0.40	0.20	0.40	0.50
C	6	0.62	0.78	0.42	0.60	0.40	0.20	0.40	0.50
D	6	0.62	0.78	0.42	0.60	0.40	0.20	0.40	0.50
F	6	0.62	0.78	0.42	0.10	0.05	0.00	0.00	0.05

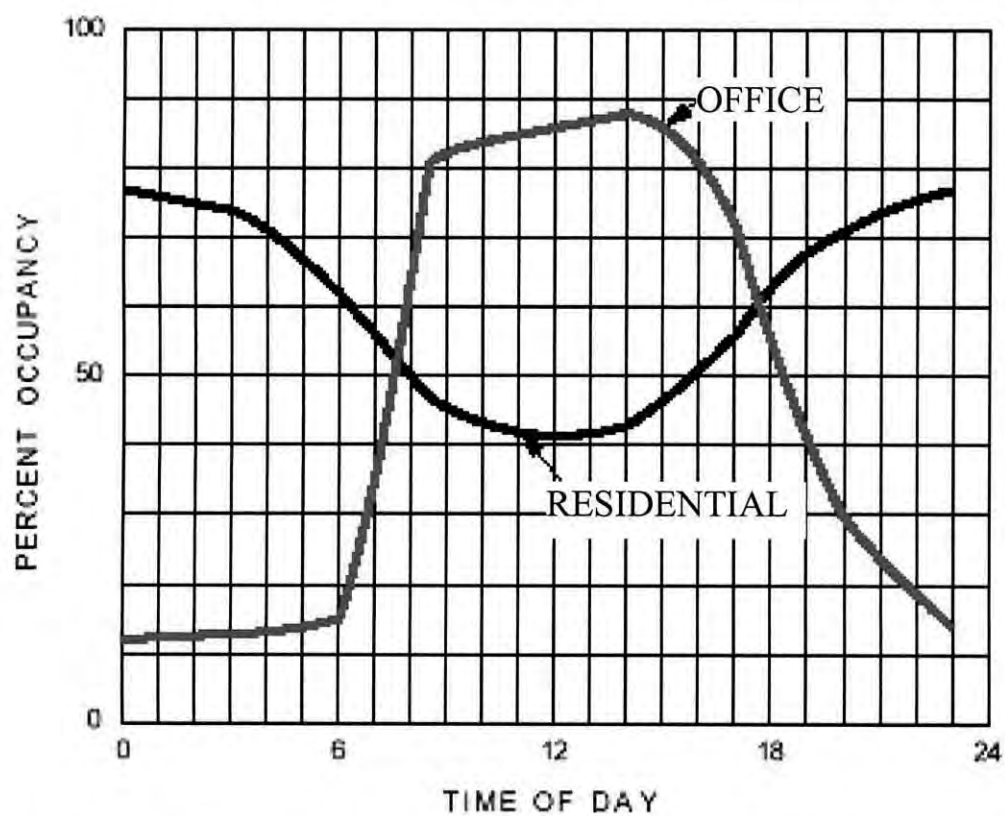


Figure 3.19. Building occupancy at the time of earthquake (after Coburn et al., 1992)

4.1 Fundamental Social Data

4.1.1 General

For seismic loss estimation, Geographic information system provides the ideal environment for conducting a comprehensive regional seismic hazard and loss estimation, consequently; GIS is considered to be the most valuable and powerful software for spatial data compilation, integration, analysis and graphical and non-graphical representation. The municipal ward is adopted as the basic unit for the administration boundary in this study because of the limitation and convenience of the available data. Census report 2001 is unpublished; hence census reports of 1991 are considered for this study. Study area is classified into Core and Fringe areas since area is not uniform in terms of settlement pattern.

4.1.2 Updated Administrative Boundary of City Corporation

An important issue in developing a regional seismic loss estimation model is the selection of an appropriate geographical reference, or geo-code, which will generally be driven by the availability of input data regarding soils conditions and building stock. Municipal areas are divided into wards and wards are divided into Mahallahs. For this study, Ward was adopted as geographical reference (geo-code) for the loss model. Sylhet Municipality had 5 wards until 1991; in 1996 it had 13 wards. In 2001 it had been upgraded to a city corporation with 27 wards. Ward map was collected from Sylhet City Corporation where total area is divided in to 13 wards is shown in Figure 3.1. The Sylhet City Corporation authority did not prepare updated map .

So it is decided to prepare an updated ward map. For this purpose, GPS value of different fringes site as well as core sites of the study area were collected. The existing city corporation map was scanned and was converted into digital map. Using this digital map and 2001 Mauza data (Appendix A) as well as consultation with the Sylhet City Corporation officials, a map containing 27 wards was developed. Figure 4.1 shows different mahallas of ward 7. Figure 4.2 show the updated ward map, which is prepared considering all mahallas as shown in Appendix A and from this updated map it is found that present area of municipality is 26.50 km².

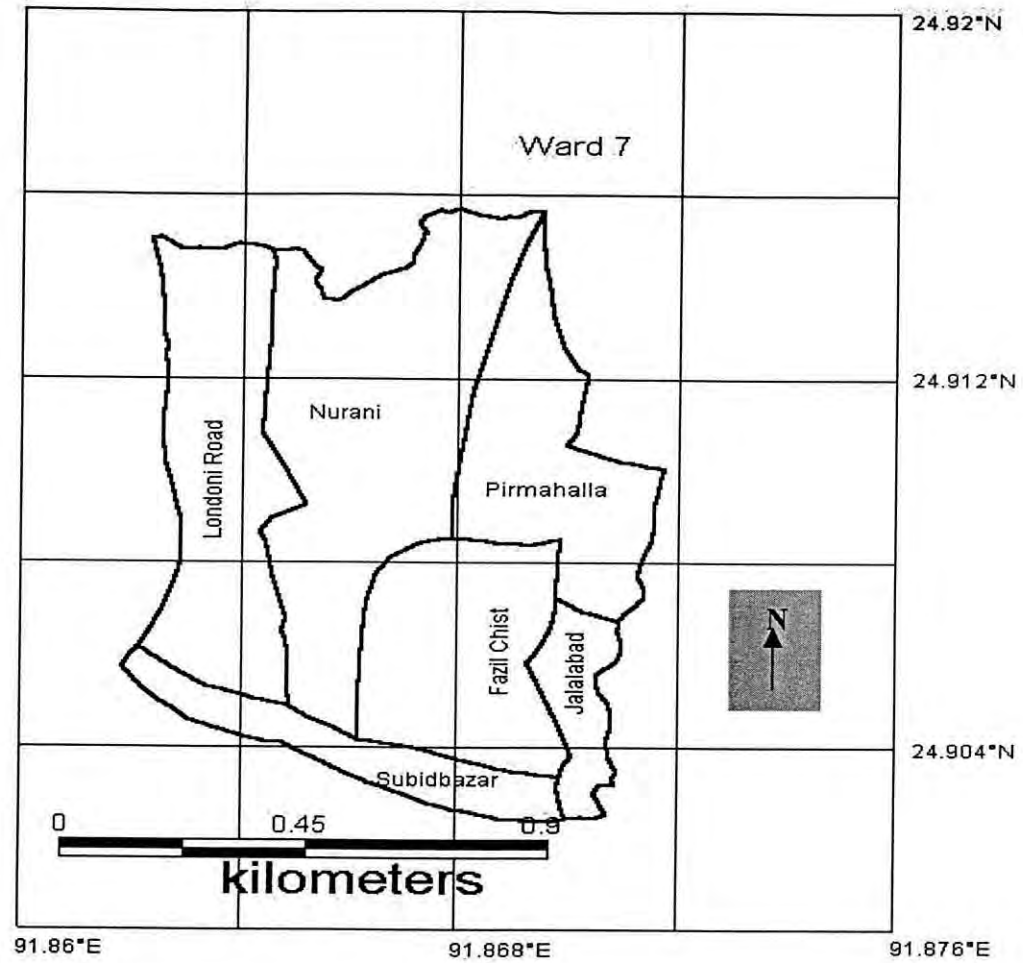


Figure 4.1. Map showing different mahallas of ward 7

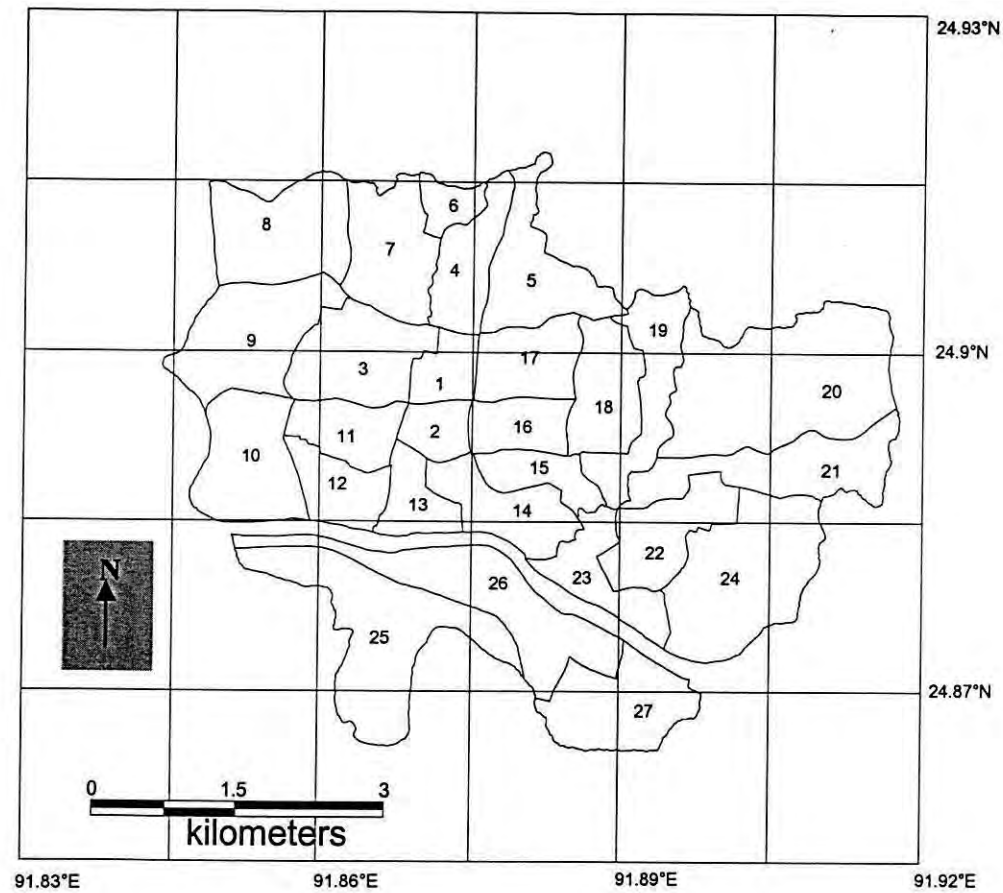


Figure 4.2. Map showing ward map of Sylhet City Corporation

4.1.3 Population and Household of Sylhet City

The growth rate of city population was slow until 1961. Since then the growth rate has increased rapidly experiencing 3.5% growth per annum during 1961-74, 4.8% during 1974-81, and nearly 5% during 1981-91. Population growth trend of Sylhet Municipal area is shown in Table 4.1. The increase of population in Sylhet city is largely due to migration, which during 1974-81 was 56% of the total increase in the city. The increase has been higher in the rural-urban fringe areas than in the inner city areas. It is estimated that the growth of population since 1991 has been faster.

During 1991 total population in municipality area together with other urban area was 234355 (BBS, 1991). Table 4.1 shows that population of Sylhet Municipal Area was 225541 in 1991. Considering this issue population data for 27 wards are estimated from BBS (1991) where Mahallah based population information are provided and it is found to be 209219. Appendix-A provides Mahallah and Mouza information of 27 wards. Annual growth rate during 1991 was 3.36% (BBS, 1991). Estimated population of 2003, in the City Corporation area is 311050. Household size in the urban area was 6.4 during 1991. Estimated ward wise population distribution, household, area and population density are shown in Table 4.2. The population density map is shown in Figure 4.3.

Table 4.1. Population Growth Trend of Sylhet Municipal Area
(after BBS, 1997 and UDD-UNCHS-UNDP, 1987)

Year	Population	Increase (%)	Annual Rate Of Growth (%)
1911	14457	4.0	0.39
1921	16912	16.9	1.58
1931	21435	26.7	2.4
1941	28128	31.2	2.75
1951	33124	17.7	1.65
1961	40644	22.7	2.07
1974	63417	35.9	3.5
1981	87922	48	4.8
1991	225541 (New boundary)	156	15.6

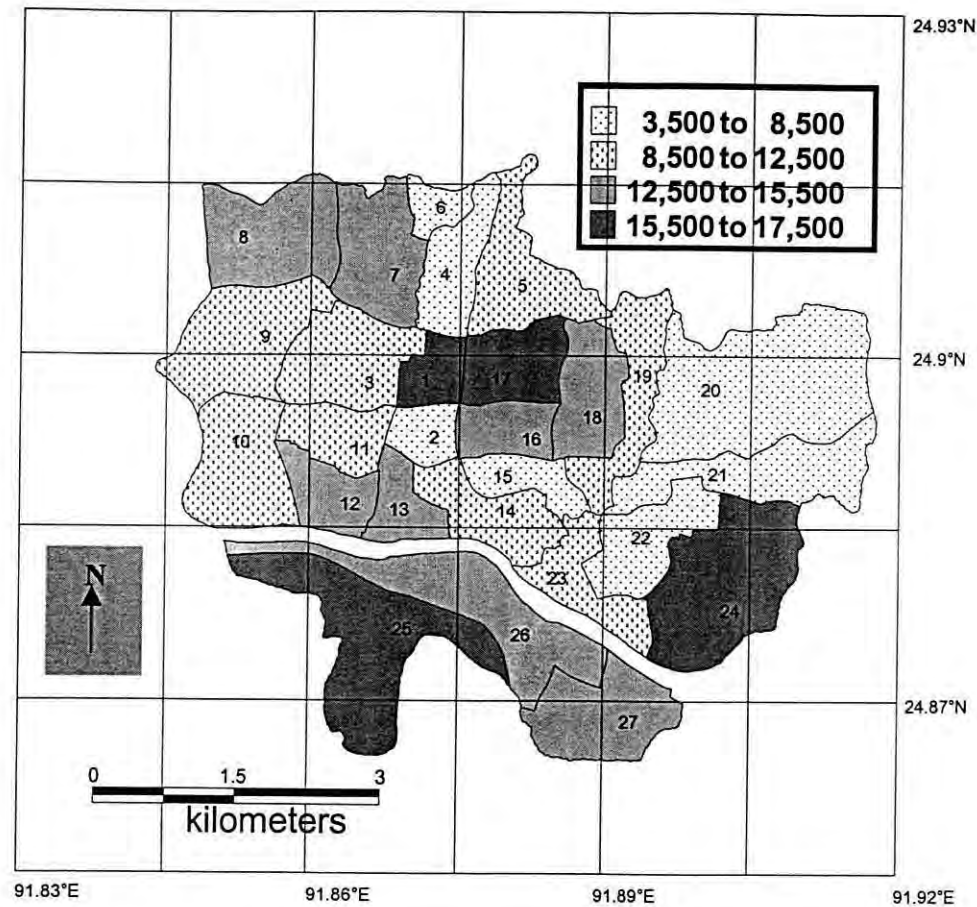


Figure 4.3. Map showing population density map of Sylhet City

Table 4.2. Ward, Household, Ward areas, Population density, Housing units for
Sylhet City

Ward No	Population, 03	House hold, 03	Area (km ²)	Density (Person/Km ²)
1	16721	2787	0.387768	43121
2	8364	1394	0.352439	23732
3	12227	2037	1.09469	11169
4	4008	668	0.719014	5574
5	11733	1955	1.05498	11122
6	8402	1400	0.261918	32081
7	14800	2466	1.04652	14142
8	13844	2307	1.84222	7515
9	9306	1551	1.5368	6055
10	11063	1843	1.19193	9282
11	8571	1428	0.595735	14387
12	14011	2335	0.576226	24315
13	12692	2115	0.461826	27482
14	12263	2043	1.02057	12016
15	6781	1130	0.471889	14370
16	13718	2286	0.522848	26237
17	16523	2753	0.754641	21895
18	15405	2567	0.858518	17944
19	10291	1715	0.919895	11187
20	8033	1338	2.61574	3071
21	7266	1211	1.20709	6019
22	3815	635	1.02446	3724
23	10988	1831	1.28589	8545
24	17329	2888	0.89411	19381
25	17066	2844	1.5015	11366
26	12656	2109	1.56068	8109
27	13174	2195	1.53369	8590

4.1.4 Land Use Pattern in Sylhet City

Of the total area of municipality, about two thirds are built-up while agricultural land, vacant space and water bodies take up another one-third. Table 4.3 shows land use pattern of Sylhet City.

Table 4.3. Land uses in Sylhet in 1985 (after UDD-UNCHS-UNDP, 1987)

Category of Use	Area in Acres	Percentage of Total Area
Residential	3759	51.5
Commercial	343	4.7
Educational	198	2.7
Health	184	2.5
Administrative	155	2.1
Industrial	86	1.2
Religious	25	0.3
Graveyard	23	0.3
Historic	16	0.2
Socio-Cultural	10	0.1
Agricultural	1568	21.5
Vacant space/open space/water bodies	931	12.8

Residential use takes more than 50% of the land while commercial use takes about 5%, educational and health together about 5%, administration takes 2.5%, and industrial takes only over 1%. Other uses take small proportions of land. At present, the most conspicuous developments are taking place in the form of luxury and expensive residential buildings and shopping centers. This is largely due to the remittances of non-resident Sylheteis living in the UK.

Bandar Bazar, being the busiest and commercially prominent place, is considered the central business district (CBD) of Sylhet town. Major commercial centers of the town are located in the areas of Bandar Bazar, Sheikh Ghat, Mew Market, Stadium Market, Kalighat, Hasan Market, and Zinda Bazar. Besides almost all the main streets are also shopping centers. A new commercial district is emerging on the road near Jalalabad Uposhohor. The industrial units are located at Vartokhola and at the BSCIC estate in the southern part of the town, with smaller constructions at Kadamtali Bus Stand and in Shekih Ghat. The major residential neighborhoods of the town are Kazitola, Kumarpara, Lama Bazar, Dargah Mahalla, Topkhana, and Jalalabad Upasahar. Upper and middle class neighborhoods are known as Paras and there is a name for each of such Paras. There are a number of slums located at different parts of the city, but mostly in the northern bank of Surma.

4.2 Soil Data

4.2.1 General

By using geographic information system, regional seismic loss estimation is the main objective of this study. Multi-hazard refers to the consideration of ground shaking and the secondary site effects of soil amplification, liquefaction, and landslide. Necessary data such as soils and geology, topographical etc, was collected from different relevant sources of Sylhet City and stored in Microsoft Excel. For assessment of landslide potential Geological Map and Aerial Photograph is essential, however; these are not available in the concerned authorities office. Considering above limitations this study is carried out.

4.2.2 SPT Data

A total of 167 boreholes SPT data were collected from different relevant organizations and used to study site amplification as well as soil liquefaction potential characteristics of municipality area. Among these data, 9 boreholes with SPT-N data up to a depth of 100 ft. were directly collected by BUET for checking the authenticity of other collected data. The typical available boring is up to a depth of 50 ft. Table 4.4 presents locations and number of borehole data from different areas of Sylhet City used for this study. Figure 4.4 shows borehole locations.

Table 4.4. Location and Number of Borehole Data of Sylhet City

Area Code	Locations	Location Code	Number of Data
Akhalia	University Campus, Kumargoan	A	12
Bagbari	Modina Market, Pathantula, Sagar dhigirpur, Subidbazar.	B	23
Amburkhana	Amburkhana Point, Housing Estate, Dargah, Jalalabad	Am	18
Zindabazar	Chouhatta, Tatipare, Zindabazar Point, Jallarpar, Jail Road, Nayasarak.	Z	26
Mendibag	Suphani Ghat.	M	17
Uposhahar	Block-A, B, C, D, E.	U	18
Tilagar	Tilagar Point, Majortila, Alutal, Shibgonj	T	20
Khasdabir	Mojumdari, Pirmahalla, Lichubagan, Choukidhighi.	K	20
Bondor	Taltala, Zero point of Sylhet, Station road, Kadamtali bus-stand.	Bn	07
Sylhet	Jalalabad, Law college, Bus-stand, Polytechnic, Londoni Road, Hazaribag, Tilagar Point	ST	9

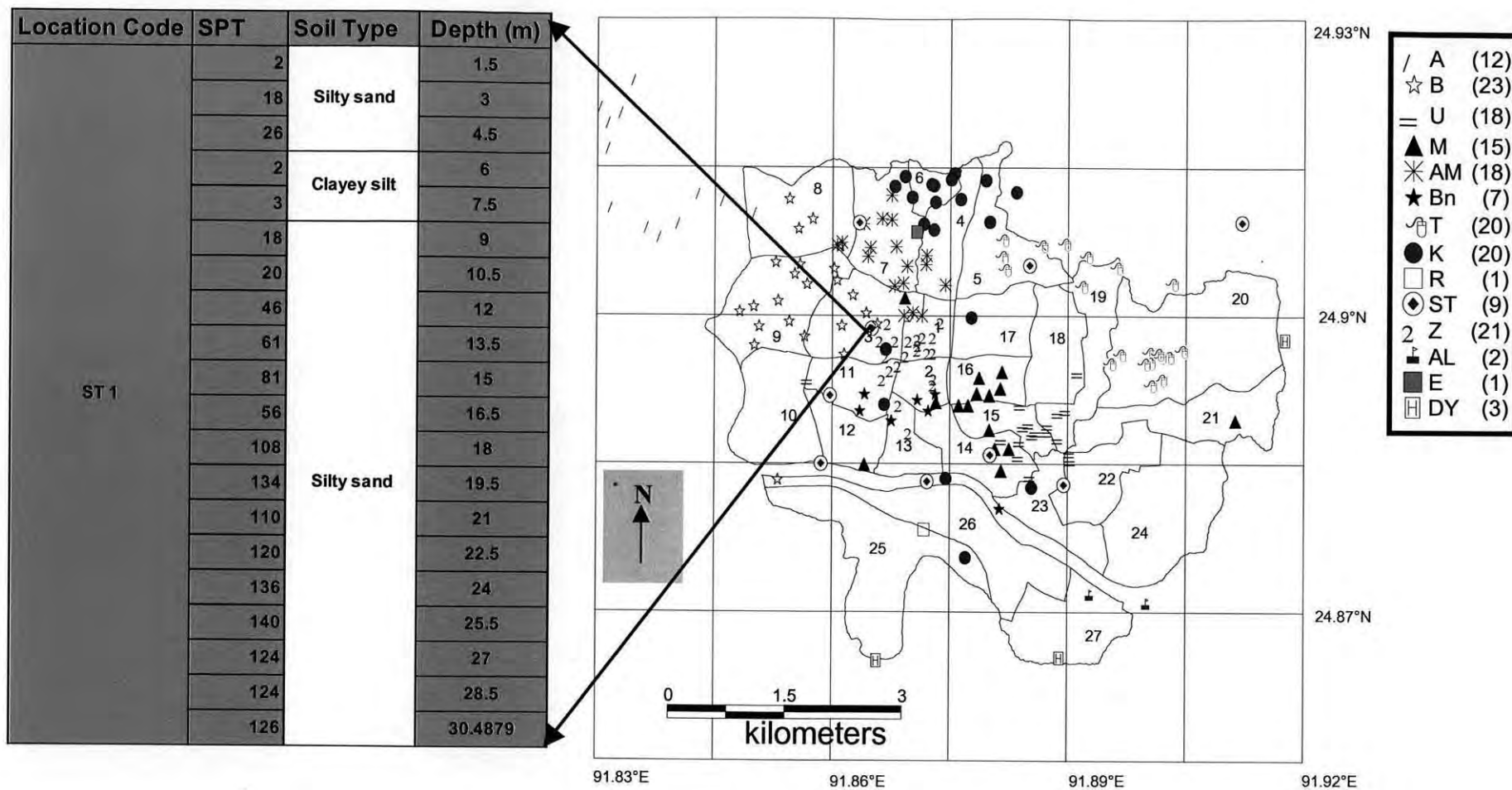


Figure 4.4. Map showing Borehole locations considered for this study

4.2.3 Ground Water Data

The ground water level changes with the season. Based on the data on ground water level after DPHE, the ground water distribution in the rainy season and the winter season are listed in Table 4.5. For liquefaction analysis F_L method defines that ground water level to be considered as less than 10 m from the ground surface.

Table 4.5. Ground water depth of different location of Sylhet City (after DPHE, 2003)

Location	Rainy season (m)	Winter season (m)
Akhalia	3.2	3.5
Bagbari	3.2	4.3
Amborkhana	3.5	4.5
Zindabazar	6.5	7.4
Mendibag	5.2	6.0
Uposhohor	5.5	6.0
Tilagar	4.7	5.7
Khasdabir	4.2	4.6
Bandar	0.90	1.5

4.2.4 Landslide Estimation Data

The eroded hills are mainly formed by the hill ranges and hillocks (locally called tila) appearing in the north east and south of Greater Sylhet and also round about the Sylhet town. These hill ranges attain a low elevation and have a gentle slope. Hillocks are scattered in Sylhet City Corporation. Among 27 wards some northern out fringe wards such as 5,7,8 belong some hillocks and some core wards such as 1,9,10,11,17,18,19,20 are also belong some hillocks. Figure 4.5 shows location of hill in Sylhet City. Hillocks of out fringe of Sylhet City Corporation have moderate slope and possess a nice vegetation so less probable of slope failure whereas in wards of core of the study area where tila possess near about right angle slope since urbanization is under increasing and which is most vulnerable to land slide potential and unluckily enough the risk is ignored by the city people who are poor and are living with landslide hazard and also yet to be awarded Table 4.6 present location together with height and slope of hillocks in City Corporation area.

Table 4.6. Location of hillocks within Sylhet City

Location	Height (Feet)	Slope angle (Degree)
Kajal Sha	30	70
Kajal Sha	20	45
Kajal Sha	10	45
Naya Sarak	30	45
Naya Sarak	32	60
Manik Pir	30	75
Manik Pir	30	65
Manik Pir	25	45
Mirbakshtola	25	45
Guor Gobinda Tila	25	85
Guor Gobinda Tila	25	80

Location	Height (Feet)	Slope angle (Degree)
Guor Gobinda Tila	20	75
Corer Para	20	75
Corer Para	25	90
Howladar Para	25	90
Howladar Para	25	90
Howladar Para	22	90
Howladar Para	21	90
Kazitula	20	45
Kazitula	25	45
Kazitula	25	45
Kazitula	30	75
Kazitula	20	90
Kazitula	18	45
Kazitula	24	60
Kazitula	20	60
Shahi Eidgha	21	90
Shahi Eidgha	30	80
Shahi Eidgha	25	60
Shahi Eidgha	20	90
Shahi Eidgha	30	75
Shahi Eidgha	30	60
Mitali R/A	25	75
Arambag	25	90
Arambag	25	90
Tilagar	15	60
Tilagar	20	60

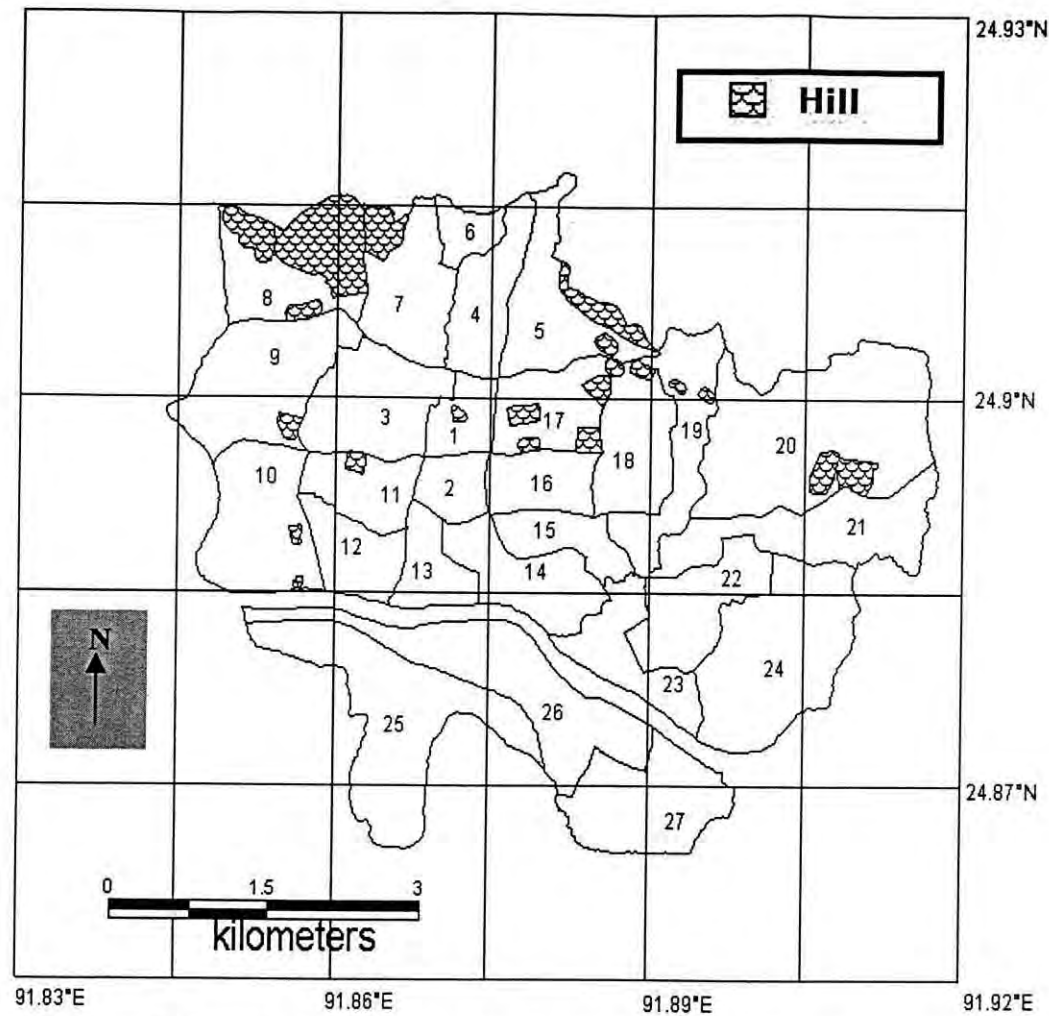


Figure 4.5. Map showing location of hill in Sylhet City

4.3 Building Data

4.3.1 General

A building Inventory is carried out by survey to clarify the nature of distribution and strength of buildings in the study area. The distribution of each type of building is also clarified to assess likely damage due to potential earthquake. The study area are not uniform in terms of building construction, building typologies, population density, and economic activity. Therefore, for the building survey, the area was classified in to Core and Fringe areas. The former is relatively dense and more urbanised as compared to the latter. There is no statistical data on the number of buildings in Sylhet City Corporation. It is assumed for some ward that number of building is equal to number of household and from survey of some core and fringe wards and together with BBS, 1991 data it is estimated that total number of building in study area is approximately 25992.

4.3.2 Methodology of Building Survey

The methodology adopted for the sample site survey consisted of several tasks that are described briefly below.

4.3.2.1 Survey Sites

Sylhet City Corporation is divided into 27 wards. For survey purpose 27 wards have clustered into four types. Group 1, clustered wards are 4, 5, 6, 7, 8, 9, and 19 where ward 7 is fully surveyed. Group 2, clustered wards are 1, 2, 3, 11, 15, 16, 17, and 18 where all wards are partially surveyed. Group 3, clustered wards are 10, 12, 13, 14, and 23 where wards 12,13 are partially surveyed and ward 14 is fully surveyed. Group 4, clustered wards are 20, 21, 24, 25, 26, 27, where no survey is conducted but data is collected from BBS (1991). Figure 4.6 shows location of surveyed wards. The main target is estimating the likely building damage due to the scenario earthquakes with a certain level of ground shaking: how the buildings are constructed and the likely response of the buildings to such shaking. Based upon such requisites, the following factors are considered.

4.3.2.2 Details of Survey Format

A survey format is developed for carrying out the pilot study survey. The format allowed for recording information from

- i) A structured interview with the house owner,
- ii) Visual observation of the condition of the buildings, and
- iii) Measurement of the geometry of the sample building with tape.

For the pilot study, interview was conducted and questionnaire format was developed. The format required recording response to some questions from the house-owner, and also recording certain data to be obtained from visual survey and tape measurements. In the Appendix-B a format of data collection questionnaire is attached.

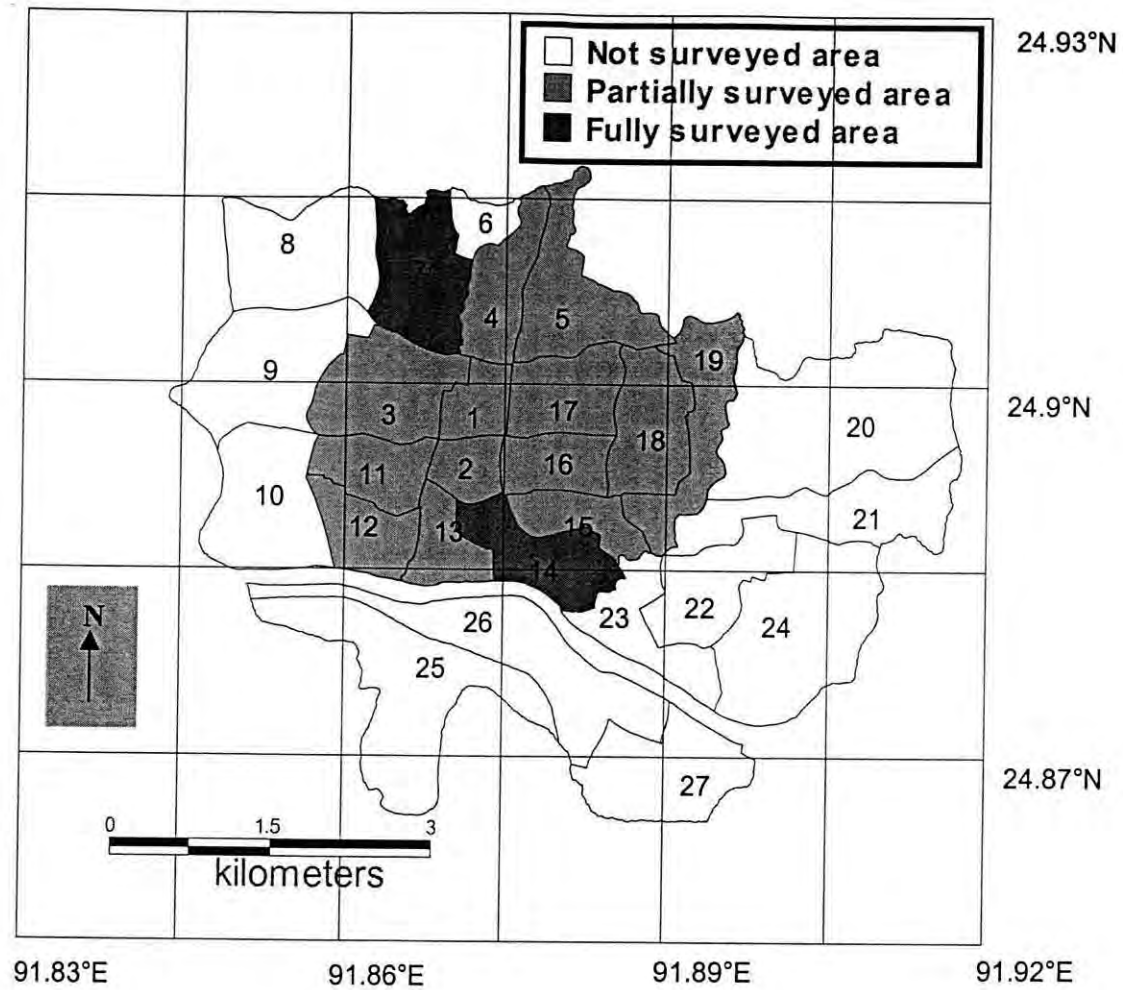


Figure 4.6. Map showing location of sample sites in the study area

The questions for the interview consisted of about 40 to 50 queries to clarify in detail the characteristics of the buildings, including such information as the owners, number of residents, location, age, extension, and experiences of cracks in the buildings. Visual inspection during the interview process yielded such data as the number of stories and the construction materials used, shape, usage, layout, soil, and topography. Tape-measurement yielded data on the geometry of the building that was used to prepare sketches and also road width in front of the house was measured. The format also allowed for recording surveyor's remarks and reference to photographs of the sampled buildings. There was also provision to check the existence of different lifelines.

The survey format consisted of three parts, notably, A) General Information, B) Building Details, and C) Lifeline Details. The following gives the details of each part of the survey format.

Part A: General information collected data on:

- 1) Information on House-owner
- 2) Location and address
- 3) Settlement type
- 4) Effects of previous earthquake/flood events, and
- 5) Process of building construction

Part B: Building details collected data on:

- 1) Construction date & registration (age, stories)
- 2) Current usage
- 3) Information on design and supervision
- 4) Existence of open space surrounding the buildings
- 5) Information on occupancy
- 6) Geometry (plan, area, information on door windows structural elements etc)
- 7) Site conditions (terrain type, building position with respect to adjacent buildings, potential local hazards)
- 8) Shape of buildings in plan and elevation, configuration problems

- 9) Information on foundation, construction materials (typology), details on walling materials and section, information on roof and floors
- 10) Presence of seismic-resistant features such as lintels, wall plate, roof band, corner bars, thorough stones
- 11) Defects in the buildings

Part C: Lifeline details collected data on:

Whether there is connection of water, gas, electricity and telephone, and the status of connecting roads.

4.3.3 Results of the Survey Sites

4.3.3.1 General

Since Sylhet is an old city, several engineered constructions are also very old and were constructed decades ago. Most buildings that are found in Sylhet are non-engineered are typically designed and constructed by people without appropriate technical qualifications. Such buildings are designed without any detailed analysis and may also be a poor quality. These buildings are made from brick masonry with lightweight roof. Other non-engineered buildings are made of light informal materials such as thatch, wood, GI sheets, and mud. These buildings are naturally expected to behave very poorly due to an earthquake. However, due to the lightweight nature of these structures, they are expected to trap fewer people, leading to lower casualty. A similar phenomenon has also been observed after 1993 Killari and 2001 Gujarat earthquakes in India where the loss of life among the poorest section of inhabitants, who mainly lived in thatch houses, have been found to be the lowest. In addition, several engineered building are designed or constructed improperly and may perform worse than expected during earthquakes. Recent study has shown that quality control during design and construction is a serious issue for antiseismic design even in developed countries.

4.3.3.2 Building Classification

The sample sites survey results helped to classify all buildings in Sylhet into six types based on their definition in European Macroseismic Scale (Grunthal, 1998). Table 4.7 defines the building typologies of Sylhet based on EMS as presented in Appendix-C. Appendix-D presents examples of those typologies.

Table 4.7 Definition of building typologies in Sylhet City Corporation Area

No	Types	Description
1	EMSA	Mud structures; roof material is either of GI sheet or polythene/straw/bamboo.
2	EMSB1	1-storied brick masonry of fired bricks with cement or lime mortar; roof is either of CI sheet or other materials.
3	EMSB2	1-storied brick masonry of fired bricks with cement or lime mortar with RCC roof. 2-storied or taller brick masonry of fired bricks with cement or lime mortar; roof is generally made of RCC slab. Some weak and old reinforced concrete frame.
4	EMSC	Reinforced concrete frame with low ductility; designed for vertical load only.
5	EMSD	Reinforced concrete frame with moderate ductility; designed for both vertical and horizontal loads.
6	EMSF	Mainly bamboo, wooden and steel structures.

4.3.3.3 Building Distribution According to Classification

3611 buildings (14% of the total) are surveyed in the study area. Table 4.8 shows wall and roof material of households in Sylhet City. From the jurisprudence the building distribution of the study area is clustered into four groups including different wards as mentioned Articles 4.3.2.1. The distribution pattern of building inventory is presented in Table 4.9.

Table 4.8. Wall and Roof material used in Sylhet City Corporation (after BBS, 1991)

Locality and wall material	Material of roof			
	Total house hold	Straw/bamboo/ Polythene	Tiles/C.I/Metal sheet	Cement
Total House	16143	944	10912	4287
Straw /Bamboo	3495	787	2708	-
Mud/Unburnt brick	1979	71	1908	-
C.I/ Metal Sheet	657	16	641	-
Wood	131	1	130	
Cement/Brick	9881	69	5525	4287

Table 4.9. Building-distribution patterns in Sylhet City

Group 1		Group 2		Group 3		Group 4	
Ward No: 4, 5, 6, 7, 8, 9, 19		Ward No: 1, 2, 3, 11, 15, 16, 17, 18, 22		Ward No: 10, 12, 13, 14, 23		Ward No: 20, 21, 24, 25, 26, 27	
Building Type	%	Building Type	%	Building Type	%	Building Type	%
A	0.51	A	0	A	12.26	A	12.26
B1	40.87	B1	36.62	B1	34.65	B1	34.65
B2	0.81	B2	6.58	B2	3.15	B2	0.42
C	50.57	C	48.22	C	23.14	C	26
D	0.24	D	0.58	D	0.27	D	0.14
F	7	F	8	F	26.53	F	26.53
Total	100%	Total	100%	Total	100%	Total	100%

Extrapolating BBS (1991), household data to 2004, it is estimated 25,992 dwellings exist in Sylhet City. Out of these, if it is averaged out it is clear that 6% Mud structures, 36% one storied brick masonry, 3 % two storied or taller brick masonry, 38.5% reinforced concrete frame with low ductility, 0.5% reinforced concrete frame with moderate ductility, and 16% mainly bamboo, wooden and steel structures exist. The results of the survey are summarized in Table 4.10. A result of the building distribution pattern in the study area is shown in Figure 4.7.

Table 4.10. Building distribution pattern according classification in the Sylhet City

Ward No	Housing Unit	EMSA	EMSB1	EMSB2	EMSC	EMSD	EMSF
1	1399	0	512	92	675	9	111
2	700	0	256	46	338	4	56
3	1022	0	374	67	492	6	83
4	335	2	137	3	169	1	23
5	980	5	400	8	496	2	69
6	702	4	287	6	355	2	48
7	1238	6	506	10	626	3	87
8	1157	6	473	10	585	3	80
9	780	4	319	6	394	2	55
10	926	114	321	29	214	3	245
11	715	0	262	47	345	4	57
12	1170	143	405	37	271	3	311
13	1061	130	368	33	246	3	281
14	1024	126	355	32	237	3	271
15	567	0	208	37	273	3	46
16	1147	0	420	75	553	7	92
17	1380	0	505	91	665	8	111
18	1287	0	471	85	621	7	103
19	858	4	351	7	433	2	61
20	670	82	232	3	174	1	178
21	608	75	211	3	158	1	160
22	317	0	116	21	153	2	25
23	919	113	318	29	213	3	243
24	1448	178	502	6	376	2	384
25	1425	175	494	6	371	2	377
26	1058	130	367	4	275	2	280
27	1099	135	381	5	286	2	290
Total	25992	1432	9551	798	9994	90	4127

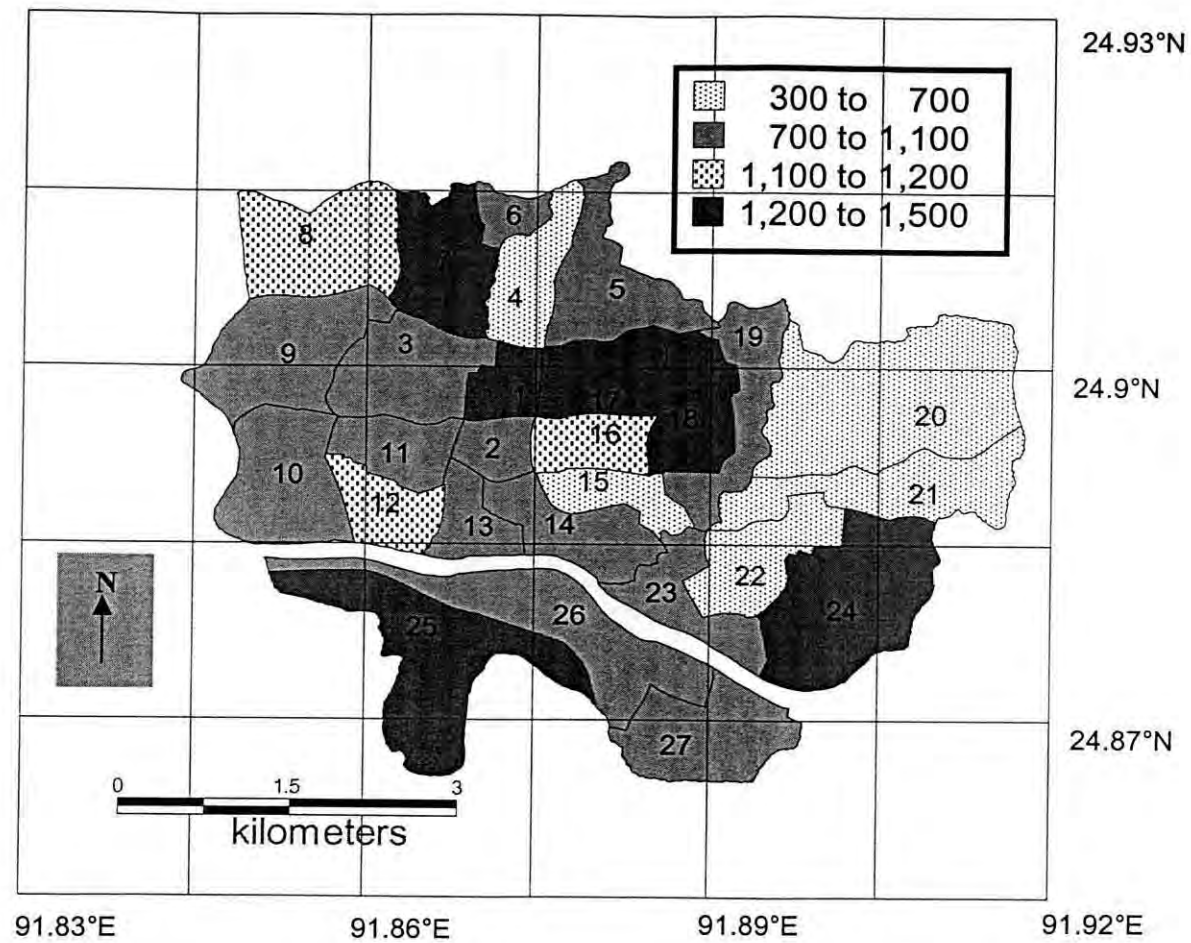


Figure 4.7. Map showing regional distribution of dwellings in Sylhet City

4.3.3.4 Construction Year of Buildings

Of the 3611 building samples, it appears that more than 62% of the building in Sylhet City area is less than 10 years. This fact shows the rapid urbanization and growth process in Sylhet City. However, about 4% of the buildings in Sylhet City area are more than 40 years old indicating to a higher vulnerability, especially if one considers that the predominant type of older buildings is of type EMSB. There are significant growths in EMSC constructions using RCC beam and column, which started only 20 or 30 years ago. Although some of these buildings are made of RCC, they are basically non-engineered and are extremely vulnerable. Figure 4.8 shows the construction year of building of the study area.

4.3.3.5 Number of Stories and Building Area

A majority of building including ward number 4, 5, 6, 7, 8, 9, 10, 20, 21, 24, 25, 26, 27 possess more than 85% is one storied building and the rest of building is 2-5 storied high. Also ward number 1, 2, 3, 11, 12, 13, 14, 15, 16, 17, 18, 19, 22, 23 possess more than 49% building is single-storied and the rest of building is 2-7 storied high.

Figure 4.9 shows the distribution of buildings in the areas according to number of stories and floor space. There is a lack of local awareness regarding the taller brick masonry structures beyond 3 stories, which are quite vulnerable against earthquakes. In the fringe wards including 1, 2, 3, 11, 12, 13, 14, 15, 16, 17, 18, 19, 22, 23 the average house sizes are comparatively smaller than the Core ward number 4, 5, 6, 7, 8, 9, 10, 20, 21, 24, 25, 26, 27. Second clustered people are comparatively affluent. House sizes in Sylhet City Corporation may also be decreasing due to division of the original plot among successors of the original owner, due to the local custom of succession of property and due to higher price of land here.

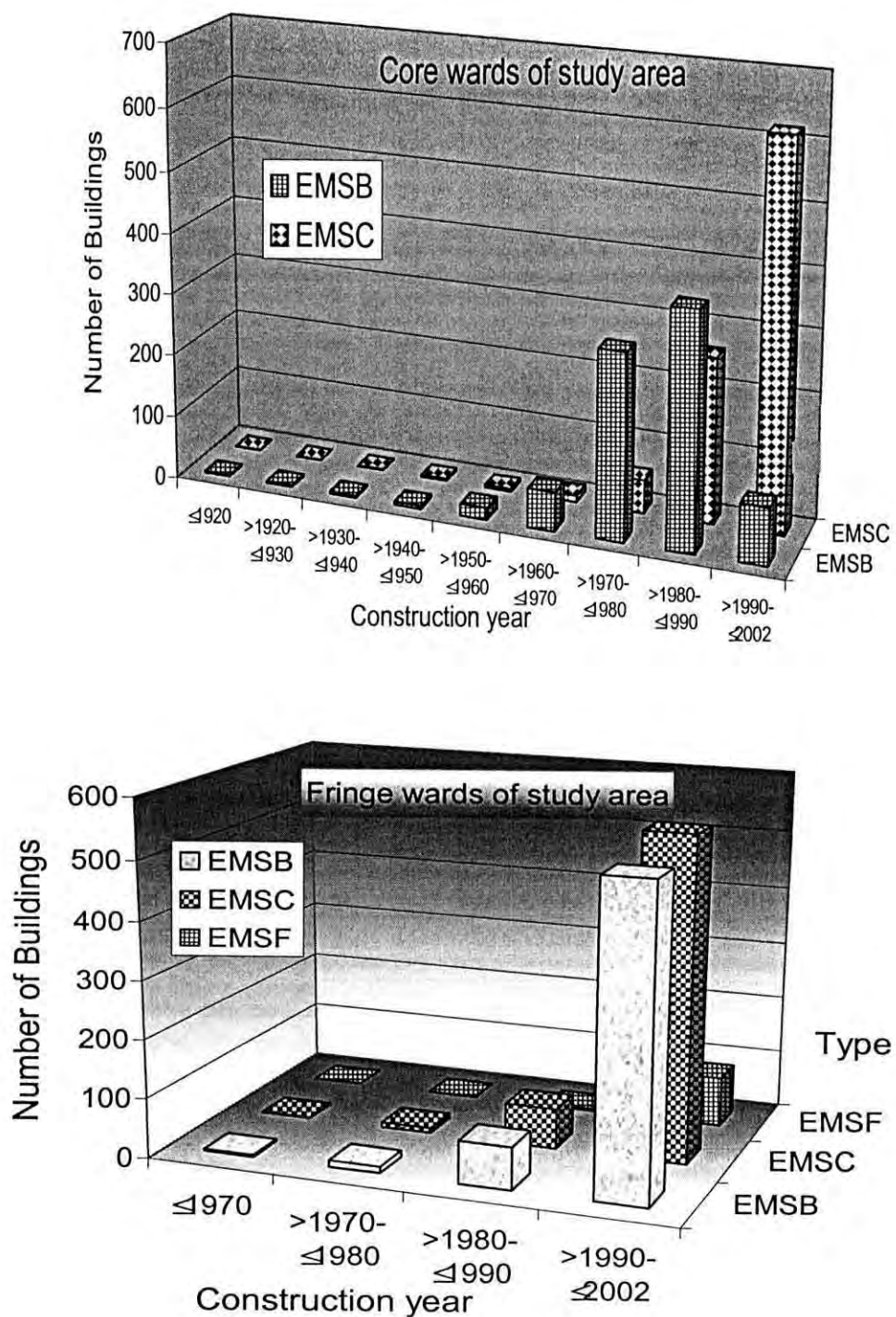


Figure 4.8 Distribution of buildings types with construction year for core and fringe ward in study area.

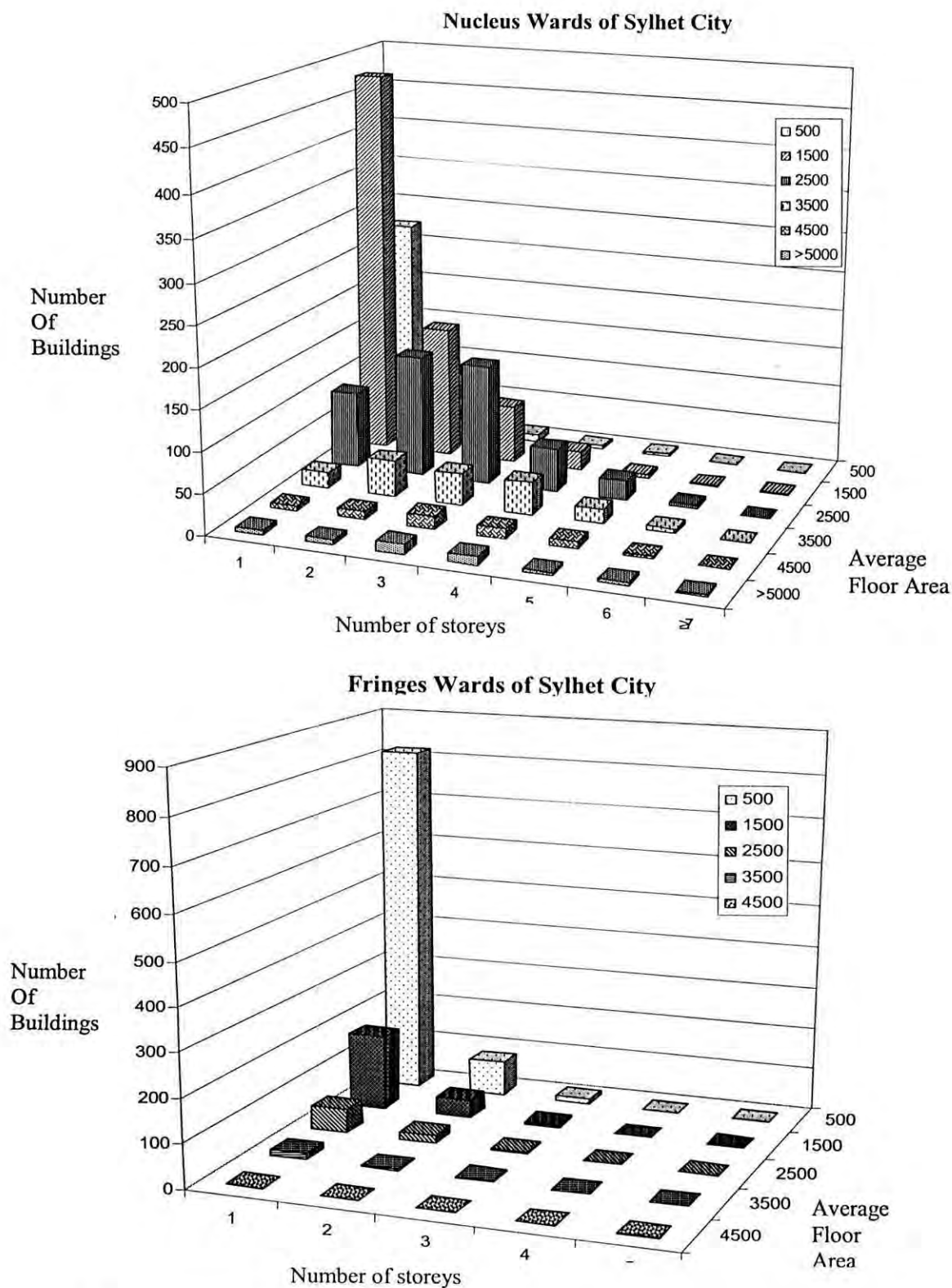


Figure. 4.9 Distribution of building types according to storey and floor area for core and fringe wards.

In the study area, for seismic loss estimation for building area it is required to know the average weighted house area as well as average weighted floor area. From survey results considering building type, building story, and some other factor, it clear that the average weighted house area is 134 m² and average weighted floor area is 273 m². Table 4.11 shows the ward wise distribution of house area and floor space in the study area. Because of rapid urbanization in Sylhet City, number of slum is increasing. According to the statistics of BBS (1991), 21% of Sylhet population lives in slums. Huq-Hussain (1996) reported that floor space per household for slum dweller's is 90sft for Dhaka, which is also assumed for Sylhet City. Combining this information for Sylhet, average floor area for each building is obtained to be 200 m². Figure 4.10 shows building use pattern. In this study all building is assumed as residential building because of simplicity of this study.

The weighted house area and floor area for each of the wards is estimated using the following equations.

$$A_j = \frac{\sum_{i=1}^5 N_i A_i}{\sum_{i=1}^5 N_i} \quad (4.1)$$

$$A_{\text{ward}} = \frac{\sum_{j=1}^7 ((\sum_{i=1}^5 N_i) A_j)}{\sum_{j=1}^7 (\sum_{i=1}^5 N_i)} \quad (4.2)$$

Where,

A_j = weighted area for each storey type ($j = 1, 2, 3, 4, 5, 6$ and >6 storey)

A_i = middle value of an area in a particular range

N_i = number of buildings corresponding to A_i

A_{ward} = weighted ward house area or floor space

Table 4.11.Weighted house area and floor space in study area

Ward No	Weighted House Area (sft)	Weighted House Area (m ²)	Weighted Floor Space (sft)	Weighted Floor Space (m ²)
1	1964	182.52	4568	424.53
2	1972	183.27	4695	436.38
3	1967	182.80	4648	431.97
4	908	84.38	1206	112.08
5	879	81.69	1113	103.43
6	878	81.59	1114	103.53
7	871	80.94	1087	101.02
8	875	81.31	1093	101.58
9	881	81.87	1120	104.08
10	873	81.13	1096	101.85
11	1965	182.62	4590	426.58
12	1959	182.06	4603	427.78
13	1967	182.80	4630	430.29
14	1967	182.80	4649	432.06
15	1977	183.73	4629	430.20
16	1957	181.87	4585	426.11
17	1967	182.80	4651	432.24
18	1974	183.45	4643	431.5
19	1969	182.99	4623	429.64
20	886	82.34	1127	104.74
21	884	82.15	1138	105.76
22	1966	182.71	4658	432.90
23	1962	182.34	4568	424.53
24	871	80.94	1088	101.12
25	870	80.85	1083	100.65
26	878	81.59	1109	103.06
27	877	81.50	1102	102.41

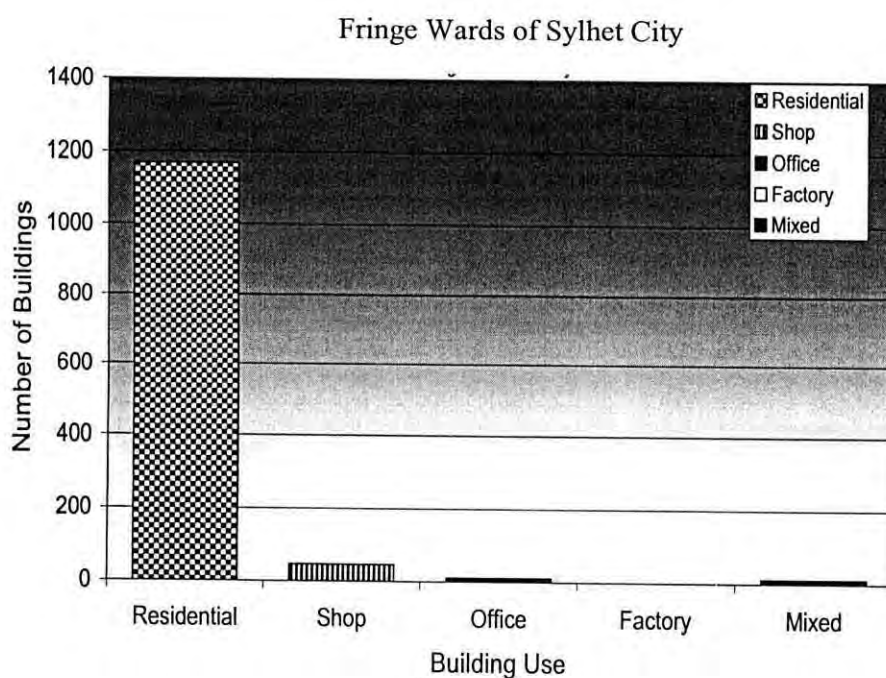
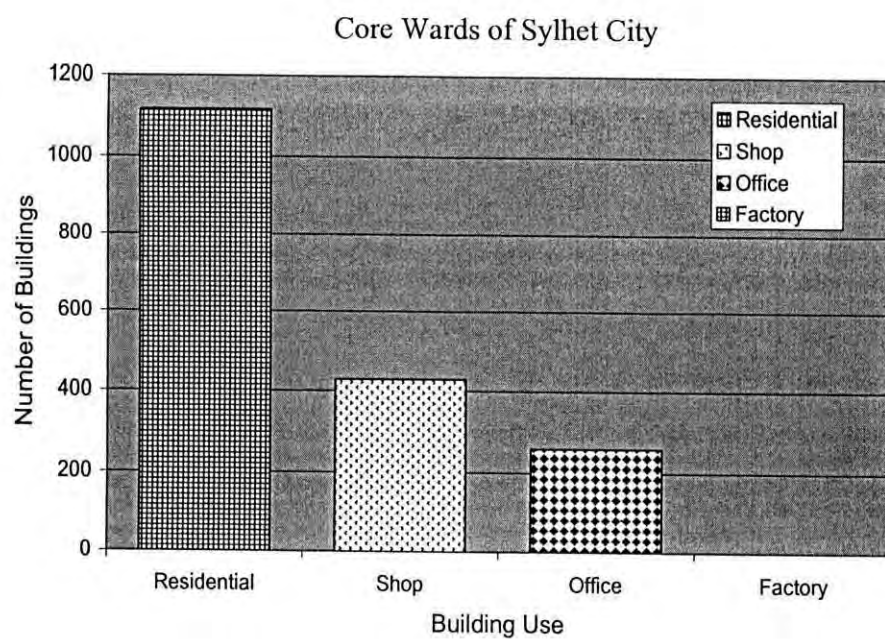


Figure 4.10 Distribution of building according to their usage in core and fringe wards of study area

4.4 Water Supply Pipelines

The Sylhet municipal water supply system has a capacity of more than 8,00,000 gallons (36,37,000 liters) per day of the 9 deep tube wells and a water treatment plant and the condition of the water treatment plant is very poor. There are 3 overheads and one underground tank of which 2 are operational.

The piped water system in Sylhet city serves about 3871 domestic connections and 156 commercial as well as industrial connections. Besides there are 2261 shallow tube-wells, 20 deep tube-wells, 504 DSP tube-well or Tara pump and 4 private rig wells (Sylhet City Corporation, 1998)

A paper drawing is available for the distribution water pipe network of the study area that is prepared by LGRD. The drawing is scanned and converted to digital format. Layers are separated according to the diameter of pipe and material. Basically, the length of pipeline installed exceeded 118 km. pipeline network is mainly composed of different types of material-polyethylene (PVC), asbestos concrete, Galvanized Iron, cast iron, Mild steel, and Ductile iron. In terms of pipeline lengths, the polyethylene are the longest with 44 km proposed water network length is 52 km which is assumed polyethylene for this study while the asbestos concrete pipes accounted for 12.5km, galvanized iron is 5.7 km, cast iron is 1.7 km, Ductile iron is 1 km, and mild iron is 1km.

Only the municipality is well served by water mains where 28.8% of the households have access to piped water. Water pipe line distribution of the study area is shown in Figure 4.11 and listed in Table 4.12. Pipeline distribution according to material and diameter is also shown in Figure 4.12 and Figure 4.13.

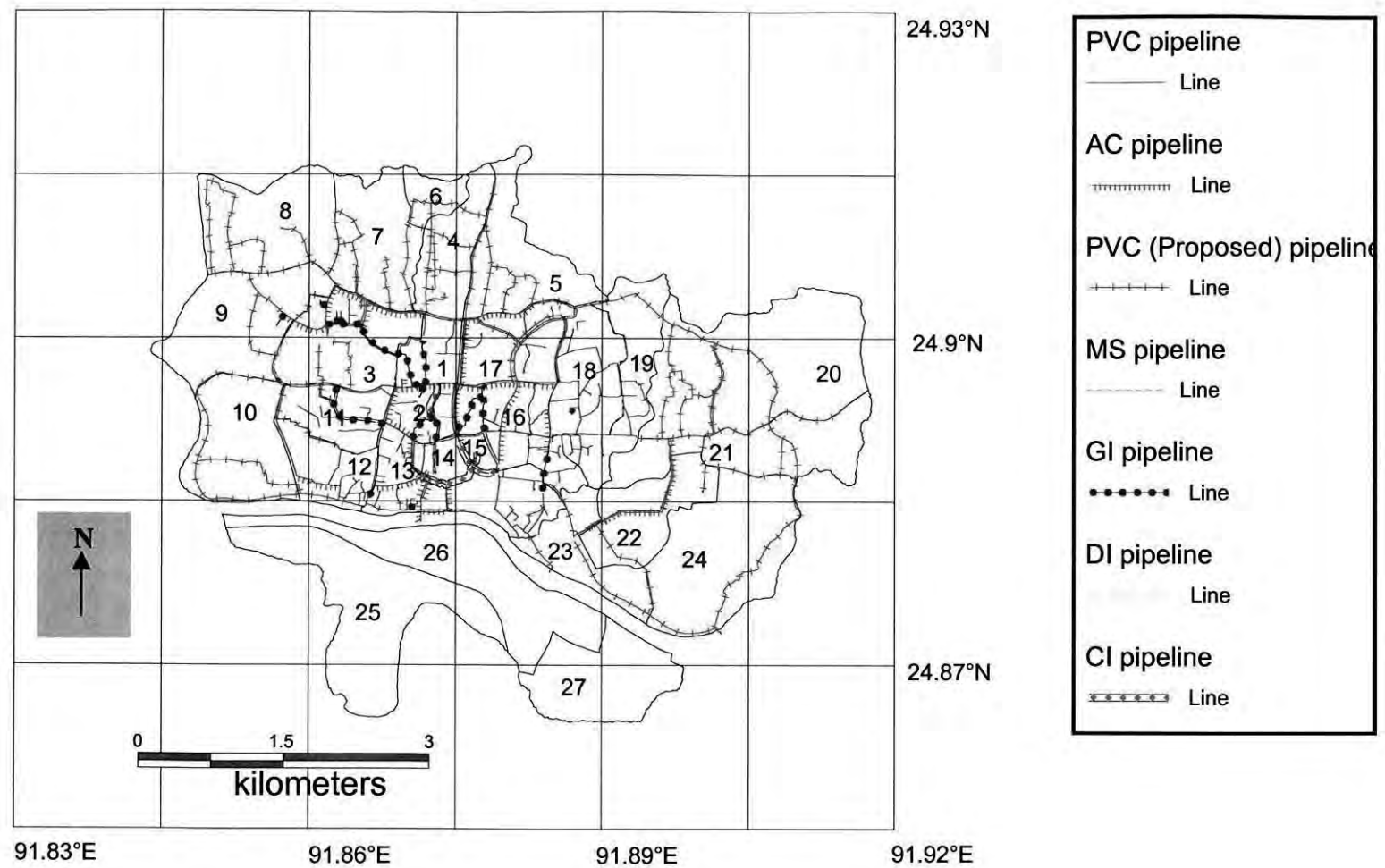


Figure 4.11. Map showing distribution of water pipeline according to material of Sylhet City

Table 4.12 Water pipe line distribution according to diameter and material in study area

Material	Diameter (mm)	Length (Km)
AC	100	0.25
AC	150	4.59
AC	200	3.47
AC	250	2.33
AC	300	1.92
CI	100	0.49
CI	150	0.53
CI	200	0.67
DI	300	1.04
GI	100	3.52
GI	150	0.33
GI	50	0.06
GI	200	1.87
MS	100	0.32
MS	150	0.41
MS	250	0.25
PVC	100	17.5
PVC	150	17.72
PVC	200	4.09
PVC	50	1.18
PVC	75	3.46
Proposed	100	14.9
Proposed	200	15.20
Proposed	150	22.09

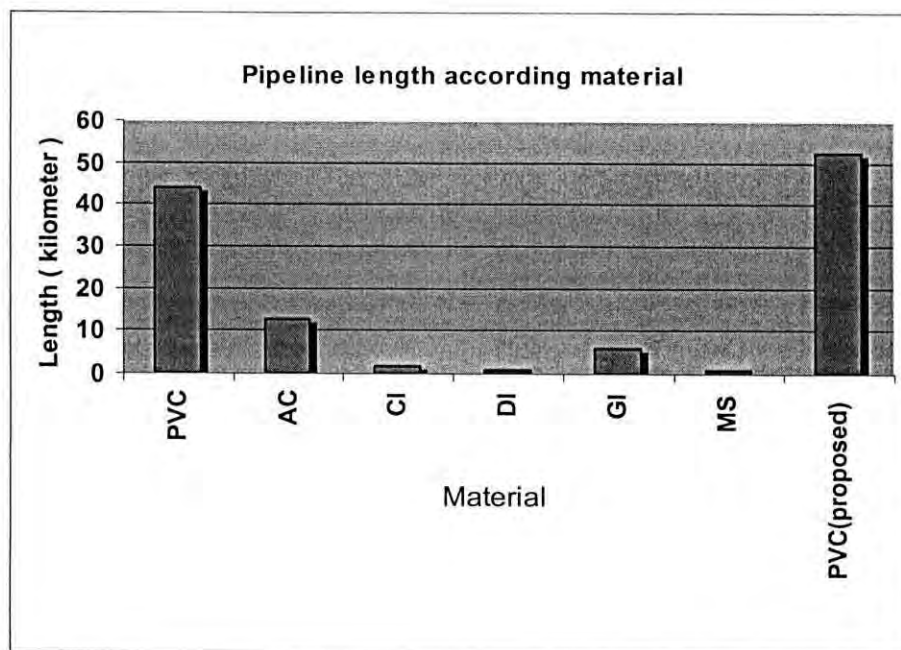


Figure 4.12 Distribution of lengths of pipelines according to material in the study area

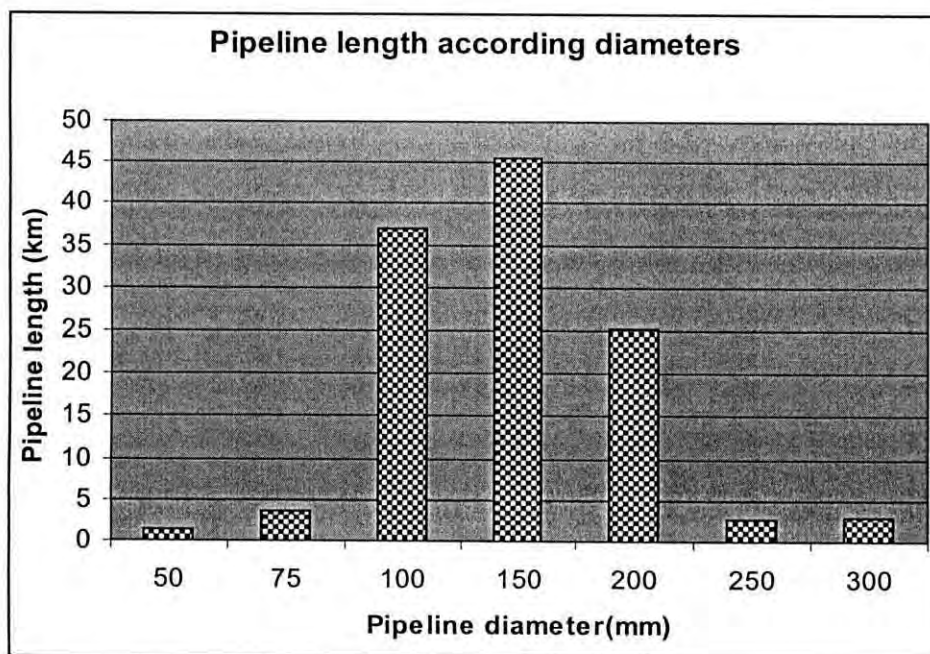


Figure 4.13 Distribution of lengths of pipelines according to diameter in the study area

5.1 General

It is well understood that earthquake damage to life and property results primarily from strong-ground shaking and indirect shaking-induced hazards such as liquefaction, and landslide etc. Severe earthquakes of the last decade in India, Mexico, Turkey, Taiwan, Armenia, and the United States have reemphasized the importance of local geologic site conditions in estimating the regional damage and consequent losses due to future major earthquakes. Seismic zonation map for strong-ground shaking, liquefaction, and landslide can play a significant role in mitigating the effects of earthquake in urbanized regions.

5.2 Earthquake Analysis

In the regional seismic loss estimation analysis it is needed to determine the bedrock motion in the region. The most common method involves the use of an empirical attenuation relationship. These relationships express a given ground motion parameter in a region as function of the size and location of an earthquake event. Applying statistical regression analyses to recorded data has developed numerous relationships in the past, typically. Often these relationships are developed with different functional forms and with different definitions of ground motion, magnitude, distance, and site conditions. Figure 5.1 Shows flow chart for earthquake analysis.

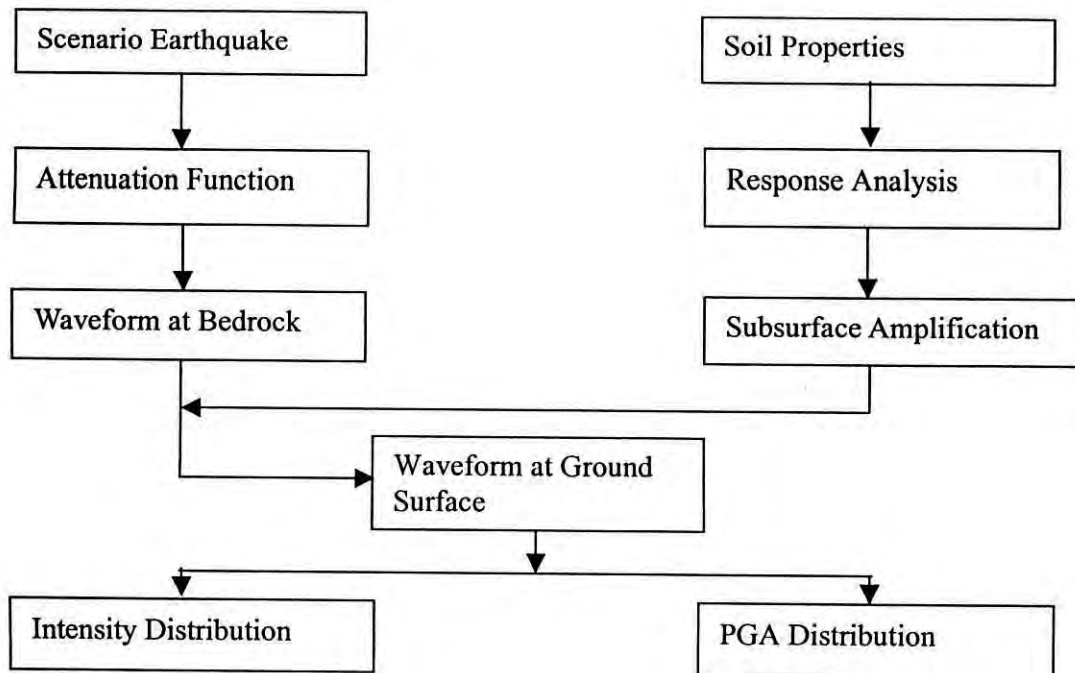


Figure 5.1. Flow chart for earthquake analysis

In Bangladesh, no PGA based attenuation law exists. To get engineering bedrock level (depth of 30 m) PGA, equations presented in Table 3.6 were used. Some famous historical earthquakes and its magnitude, epicentral distance, focal depth and intensity shows in Table 5.1 are considered to estimate PGA (%g) value in this study.

Table 5.1. Some historical earthquakes with magnitude, intensities, epicentral distance and focal depth at Sylhet

Name of Earthquake	Fault	Magnitude	EMS Intensity	Distance (Km)	Focal Depth (Km)
1869 Cachar Earthquake	Tripura	7.5	VIII	92	-
1885 Bengal Earthquake	Bogura	7.0	V	234	72
1897 Great Indian Earthquake	Assam	8.7	IX	151	60
1918 Srimangal Earthquake	Sub-Dauki	7.6	IX	71	14

To select the most suitable attenuation law for predicting rock motions, 1885 Bengal earthquake, 1897 Great Indian earthquake and 1918 Srimangal earthquake are considered. The requirements for selecting the attenuation law are as follows:

- (i) Applicable to the ground condition of engineering bedrock in this study ($V_s=200\text{m/s}$).
- (ii) Able to explain the observed or analyzed earthquake motion of 1885 Bengal earthquake, 1897 Great Indian Earthquake and 1918 Srimangal earthquake.

In this study, the engineering bedrock is assumed to be the layer at which the shear wave velocity (V_s) exceeds 200 m/s, which exist almost 30 m deep from the surface of the study area. The attenuation law of Boore et al. (1997) required shear wave velocity. In this study, shear wave velocity for 9 borehole data up to a maximum depth of 30m are calculated by using equation of Tamura and Yamazaki (2002) presented in Table 3.5. Table 5.2. Shows that the shear wave velocities vary from 250 m/s to 325 m/s.

Table 5.2. Shear Wave Velocities different location of Sylhet City

Location	Longitude	Latitude	Shear Wave Velocity (m/sec) At 30m depth
ST1	91.8634	24.9094	280
ST2	91.8650	24.8987	298
ST3	91.8895	24.8829	278
ST4	91.8597	24.8919	327
ST5	91.9121	24.9095	328
ST6	91.8851	24.9051	306
ST7	91.8801	24.8859	280
ST8	91.8721	24.8832	272
ST9	91.8586	24.8850	278

Distance versus PGA values for three earthquakes are plotted on log-log paper and are shown in Figures 5.2a, Figure 5.2b and Figure 5.2c. For intensity estimation, different isoseismal maps (Sabri, 2002) for the three historical earthquakes are used. From these isoseismal maps, the epicentral distances of different locations and their intensities are found. These intensities are converted into PGA by following Trifunac and Brady (1975) equation (5.1) and are plotted on previous figures.

$$\log (\text{PGA}) = 0.014 + 0.3 (\text{MMI}) \quad (5.1)$$

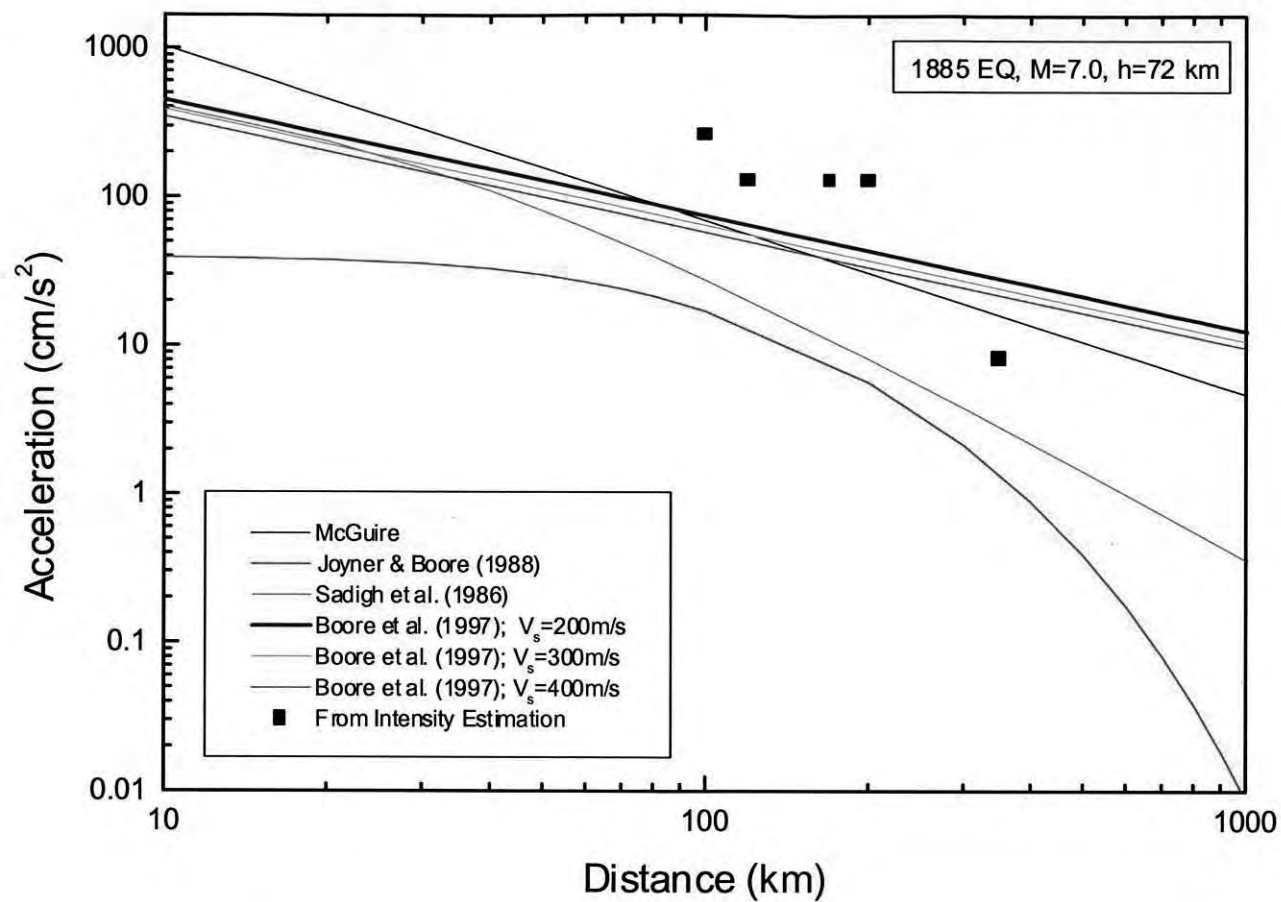


Figure 5.2a. Distance versus PGA values for 1885 Bengal earthquake to compare several attenuation laws

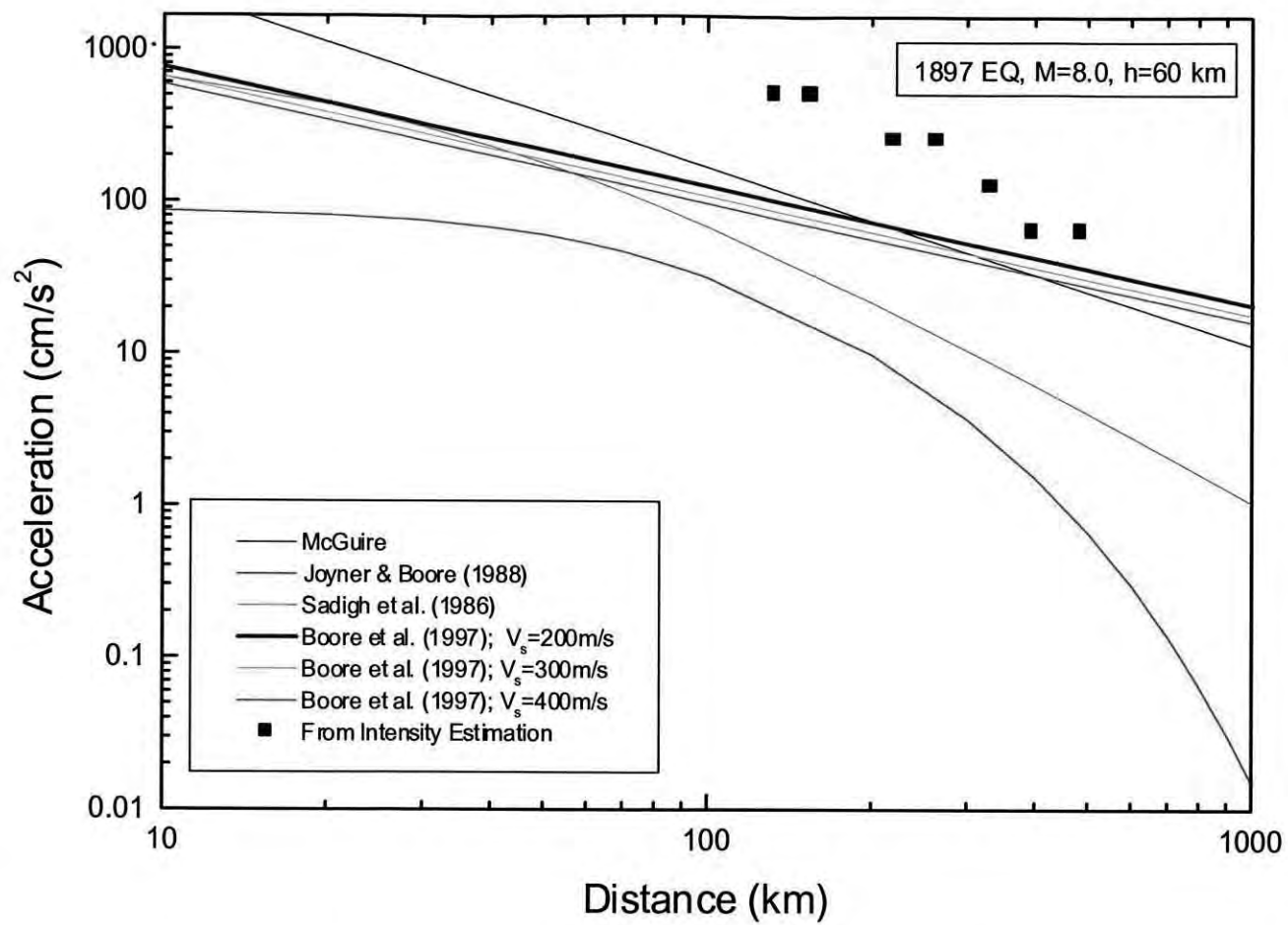


Figure 5.2b. Distance versus PGA values for 1897 Great Indian Earthquake to compare several attenuation laws

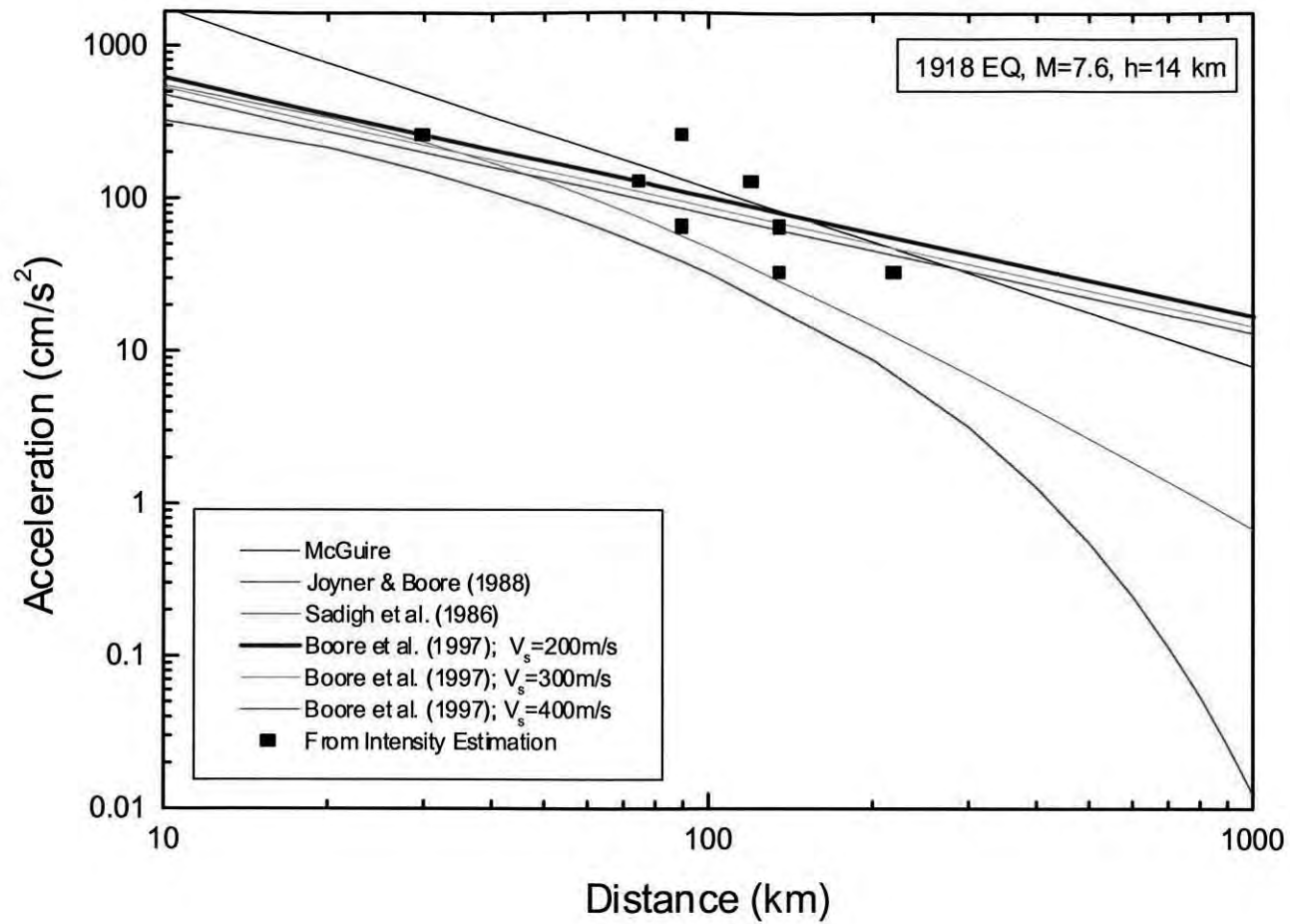


Figure 5.2c. Distance versus PGA values for 1918 Srimangal Earthquake to compare several attenuation laws

From these plots, it is found that McGuire (1978) as well as Boore et al. (1997) equations follow the PGA trend. Since, McGuire equation has already been used for Bangladesh for seismic hazard analysis (Sharfuddin, 2001) and due to its simple form it is selected for further use. Finally, 1918 Srimangal Earthquake with the highest PGA value 0.18g at bedrock level for Sylhet City is selected. Table 5.3 presents the PGA values at bedrock level from different attenuation laws for different scenario event.

Table 5.3. PGA values (% of g) at bedrock level from different attenuation laws for different for scenario event

Attenuation Law	PGA for Cachar Earthquake (1869)	PGA for Great Indian Earthquake (1897)	PGA for Srimangal Earthquake (1918)
McGuire (1978)	0.12g	0.10g	0.18g
Sadigh et al. (1986)	0.0106g	0.0328g	0.0238g
Joyner and Boore (1988)	0.0078g	0.0108g	0.0163g
Boore et al. (1997)	0.030g	0.017g	0.055g

5.3 Local Site Effects

Seismic zonation maps for strong-ground shaking, liquefaction and landslide can play a significant role in mitigating the effects of earthquakes. In Chapter 2 it is discussed how a geographic information system (GIS) provides an ideal environment for compiling and integrating regional databases of spatial geologic and geotechnical information for purposes of seismic zonation. The main aim of this research is the development of seismic hazard map considering local site attributes for estimating the seismic loss for Sylhet City.

5.3.1 Site Amplification Analysis

Vibration characteristics at different points of the study area can be estimated by employing one dimensional wave propagation program SHAKE. The computations are made in the frequency range 0 to 20 Hz at frequencies every 0.05 Hz interval. The loss of energy of seismic waves in the soil layers is also considered. An estimation of the fundamental frequency and the maximum value of the amplification are obtained of each site. Typical graphical representation of frequency versus amplitude is shown in Figure 5.3.

Table 5.4. Presents site amplification factor and corresponding predominant frequency at different locations of Sylhet City. Ground amplifications calculated in the frequency ranges less than 3 Hz (minimum and maximum values of amplification are 1.7 and 2.67, respectively), 3–6 Hz (minimum and maximum values of amplification are 1.13 and 2.67, respectively) and greater than 6 Hz (minimum and maximum values of amplification are 1.53 and 2.39, respectively). It can be seen that at less than 3 Hz, only the east and south-east sector shows comparatively high amplification of the ground motion; at 3–6 Hz most of the city area except small areas in the north-east, west and south-east shows lower amplification of the ground motion. For frequency above 6 Hz, apart from a few isolated points, the spectral amplification is also low.

By spatial interpolation between these points, a map of resonance frequencies over the whole study area is shown in Figure 5.4, and a map of the maximum amplifications observed at these fundamental frequencies is also shown in Figure 5.5. From the frequency map, ward areas of 1.9 times of amplification and 2.5 times amplification are separated respectively using GIS program. Figure 5.6 shows the map of 1.9 and 2.5 times amplified areas of Sylhet City.

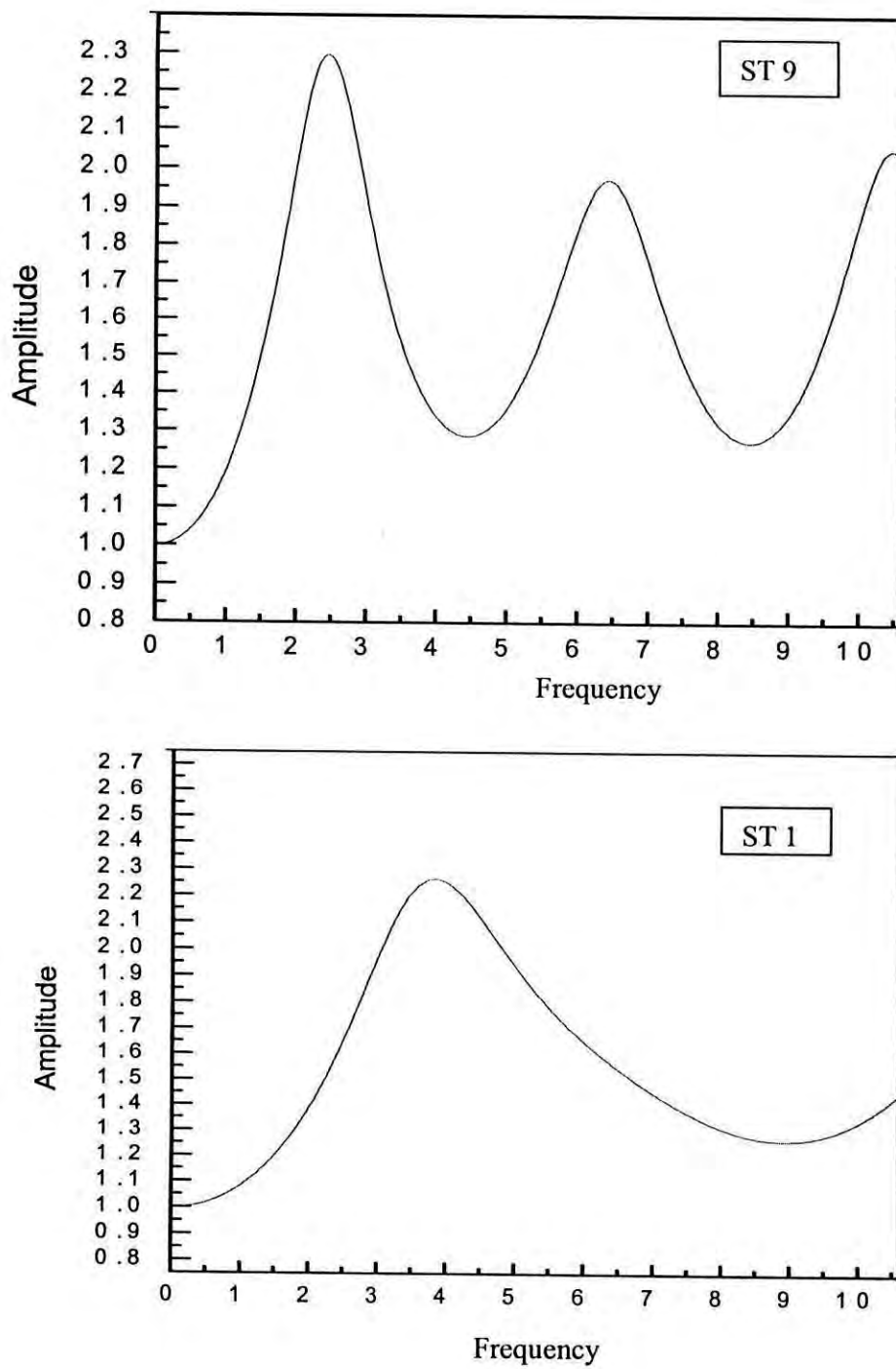


Figure 5.3. Showing amplification factor at fundamental frequency for different sites of Sylhet City

Table 5.4. Results of Amplification factor and corresponding predominant frequency at different locations of Sylhet City

Location Code	Longitude	Latitude	Predominant Frequency (Hz)	Amplitude
A1	91.8309	24.9213	5.71	2.5
A2	91.8319	24.9197	4.6	2.04
A3	91.8351	24.9240	6.37	2.22
A4	91.8335	24.9207	5.85	1.34
A5	91.8319	24.9171	6.29	2.04
A6	91.8322	24.9111	4.16	1.14
A7	91.8368	24.9091	5.92	2.16
A8	91.8384	24.9081	14.62	1.6
A9	91.8408	24.9095	6.59	1.57
A10	91.8434	24.9125	5.85	1.44
A12	91.8506	24.9106	6.59	1.53
B1	91.8545	24.9118	4.16	1.92
B2	91.8575	24.9098	4.38	1.91
B3	91.8557	24.9088	4.16	1.66
B4	91.8559	24.9052	4.6	2.1
B5	91.8602	24.9048	3.43	2.17
B6	91.8528	24.9054	4.31	2.16
B7	91.8500	24.9009	4.31	1.62
B8	91.8482	24.9004	4.09	1.5
B9	91.8507	24.8989	4.52	1.96
B10	91.8501	24.8970	4.31	1.41
B11	91.8531	24.8834	4.23	2.08
B12	91.8531	24.9015	4.46	1.73
B13	91.8568	24.9032	4.46	1.67
B14	91.8552	24.9042	4.46	1.74
B15	91.8545	24.8994	4.52	1.75
B16	91.8565	24.8979	4.52	1.6
B17	91.8615	24.8961	4.52	1.88
B18	91.8657	24.8992	4.68	1.58
B19	91.8643	24.9003	4.62	1.61
B20	91.8612	24.8990	4.52	1.63
B21	91.8626	24.9021	4.16	1.9
B22	91.8606	24.9036	4.31	1.93
B23	91.8610	24.9071	4.6	1.83
U1	91.8877	24.8885	2.83	1.86
U2	91.8891	24.8878	2.76	1.84
U3	91.8906	24.8864	2.69	2.28
U4	91.8907	24.8856	2.61	2.17
U5	91.8863	24.8885	2.54	2.3

Location Code	Longitude	Latitude	Predominant Frequency (Hz)	Amplitude
U6	91.8859	24.8882	2.91	1.98
U7	91.8916	24.8945	2.76	1.84
U8	91.8572	24.8937	2.76	2.2
U9	91.8901	24.8907	2.76	1.75
U11	91.8878	24.8892	2.83	1.73
U12	91.8854	24.8893	2.76	1.7
U13	91.8843	24.8912	2.54	2.66
U14	91.8847	24.8890	2.46	2.67
U15	91.8841	24.8860	2.76	1.77
U16	91.8856	24.8840	2.83	1.78
U17	91.8842	24.8875	2.76	1.88
U18	91.8819	24.8877	2.76	1.84
M1	91.8641	24.8849	3.2	2.25
M2	91.8815	24.8843	2.61	2.31
M3	91.8800	24.8884	2.98	2.06
M4	91.8773	24.8909	2.54	2.58
M5	91.8800	24.8919	2.91	2.26
M6	91.8814	24.8926	3.06	2.13
M7	91.8816	24.8943	3.2	1.92
M8	91.8787	24.8937	3.2	2.04
M9	91.8784	24.8921	2.69	2.29
M10	91.9113	24.8894	2.76	2.6
M11	91.8825	24.8865	3.06	2.06
M12	91.8807	24.8865	3.2	1.9
M13	91.8761	24.8909	2.98	1.93
M14	91.8732	24.8912	3.12	1.89
M15	91.8692	24.9018	2.98	1.97
AM1	91.8695	24.9050	4.82	1.66
AM2	91.8719	24.9052	4.23	2.06
AM3	91.8744	24.9031	4.23	1.9
AM4	91.8691	24.9000	4.75	1.53
AM5	91.8702	24.9003	4.38	1.8
AM6	91.8612	24.9074	4.46	1.86
AM7	91.8645	24.9060	4.38	1.82
AM8	91.8690	24.9033	4.6	1.56
AM9	91.8679	24.9030	4.38	1.93
AM11	91.8640	24.9093	7.91	2.12
AM12	91.8606	24.9071	7.69	2.39
AM13	91.8681	24.9070	8.04	1.96
AM14	91.8663	24.9098	8.06	2.15
AM16	91.8675	24.9122	3.57	2.05
AM17	91.8720	24.9061	4.09	2.02
AM18	91.8714	24.9000	4.23	1.81

Location Code	Longitude	Latitude	Predominant Frequency (Hz)	Amplitude
Bn1	91.8641	24.8921	3.57	2.54
Bn2	91.8635	24.8904	3.57	2.4
Bn3	91.8675	24.8894	3.79	2.25
Bn4	91.8708	24.8915	4.46	1.98
Bn5	91.8731	24.8921	4.46	2.21
Bn6	91.8722	24.8904	4.23	2.22
Bn7	91.8813	24.8805	4.09	1.95
T1	91.9001	24.8964	5.19	2.02
T2	91.9042	24.8966	5.12	1.88
T3	91.9025	24.8960	5.12	1.82
T4	91.9015	24.8960	4.52	2.21
T5	91.9030	24.9034	5.78	2.03
T6	91.8960	24.9050	5.55	1.81
T7	91.8813	24.9061	5.34	1.88
T8	91.8864	24.9072	4.31	2.22
T9	91.8893	24.9074	2.83	2.11
T10	91.8915	24.9031	4.97	1.81
T11	91.8921	24.9061	4.46	1.88
T12	91.9012	24.8963	4.6	2.01
T13	91.9001	24.8954	4.82	2.04
T14	91.9016	24.8937	3.79	2.47
T15	91.9003	24.8931	3.79	2.18
T16	91.8995	24.8953	3.35	2.5
T17	91.8964	24.8962	4.31	2.05
T19	91.8817	24.9048	3.94	2.31
T20	91.8814	24.9078	4.46	1.96
K1	91.8729	24.9132	4.01	2.07
K2	91.8726	24.9133	4.16	1.75
K3	91.8755	24.9144	4.16	1.85
K4	91.8731	24.9115	4.38	1.82
K6	91.8770	24.8755	4.23	1.95
K7	91.8751	24.9138	4.38	1.97
K8	91.8745	24.8835	4.16	1.77
K9	91.8854	24.8826	4.01	1.82
K10	91.8666	24.8910	4.09	1.96
K11	91.8668	24.8966	4.31	2.05
K12	91.8679	24.9131	4.31	1.92
K13	91.8692	24.9141	4.16	1.94
K14	91.8701	24.9120	3.72	2.13
K15	91.8716	24.9093	4.38	1.99
K16	91.8834	24.9125	5.41	1.89
K17	91.8800	24.9095	5.55	1.95
K18	91.8763	24.9118	4.23	1.59

Location Code	Longitude	Latitude	Predominant Frequency (Hz)	Amplitude
K19	91.8795	24.9137	14.98	2.08
K20	91.8777	24.8998	5.78	1.5
A11	91.8465	24.9118	9.83	1.88
U10	91.8891	24.8904	2.76	1.8
AM10	91.8648	24.9069	3.79	2.4
AM15	91.8675	24.9097	7.62	2.2
T18	91.8951	24.8953	3.43	2.67
K5	91.8729	24.9087	3.94	1.76
RAIL1	91.8717	24.8783	3.94	1.46
ST1	91.8634	24.9094	3.94	2.25
ST2	91.8650	24.8987	4.31	1.74
ST3	91.8895	24.8829	2.83	2.21
ST4	91.8597	24.8919	7.8	2.1
ST5	91.9121	24.9095	3.86	2.26
ST6	91.8851	24.9051	5.78	1.92
ST7	91.8801	24.8859	2.83	2.24
ST8	91.8721	24.8832	2.76	2.39
ST9	91.8586	24.8850	3.94	2.25
Z1	91.8686	24.8950	3.64	2.34
Z2	91.8683	24.8975	2.98	2.47
Z3	91.8687	24.8910	3.57	2.11
Z4	91.8731	24.8931	3.79	2.01
Z5	91.8732	24.8937	4.01	2.06
Z6	91.8724	24.8963	3.72	2.26
Z7	91.8711	24.8966	3.57	2.01
Z8	91.8712	24.8971	3.57	2.15
Z9	91.8711	24.8977	3.79	2.17
Z10	91.8700	24.8975	3.64	2.49
Z11	91.8696	24.8960	3.64	2.29
Z12	91.8676	24.8945	4.31	2
Z13	91.8666	24.8936	3.49	2.21
Z14	91.8670	24.8959	3.79	2.04
Z15	91.8663	24.8975	4.01	1.72
Z16	91.8673	24.8993	4.46	1.79
Z17	91.8700	24.8882	4.52	1.68
Z18	91.8718	24.8979	4.82	1.54
Z19	91.8731	24.8963	4.6	1.83
Z20	91.8731	24.8979	4.23	1.86
Z21	91.8741	24.8994	3.86	1.79
Alam1	91.9000	24.8708	3.72	1.71
Alam2	91.8928	24.8717	3.79	1.71
Epir1	91.8707	24.9085	3.73	1.74

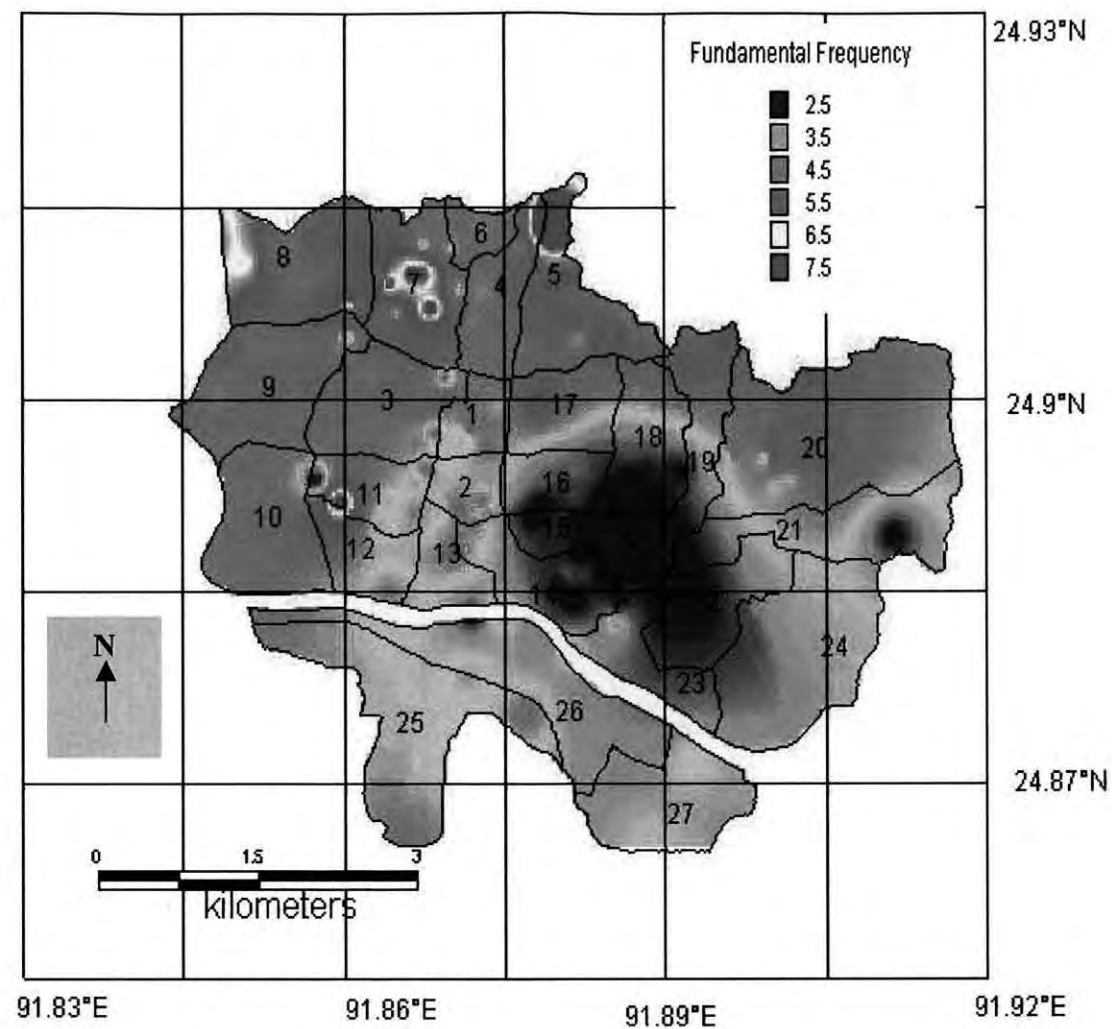


Figure 5.4. Map of fundamental frequencies of Sylhet City

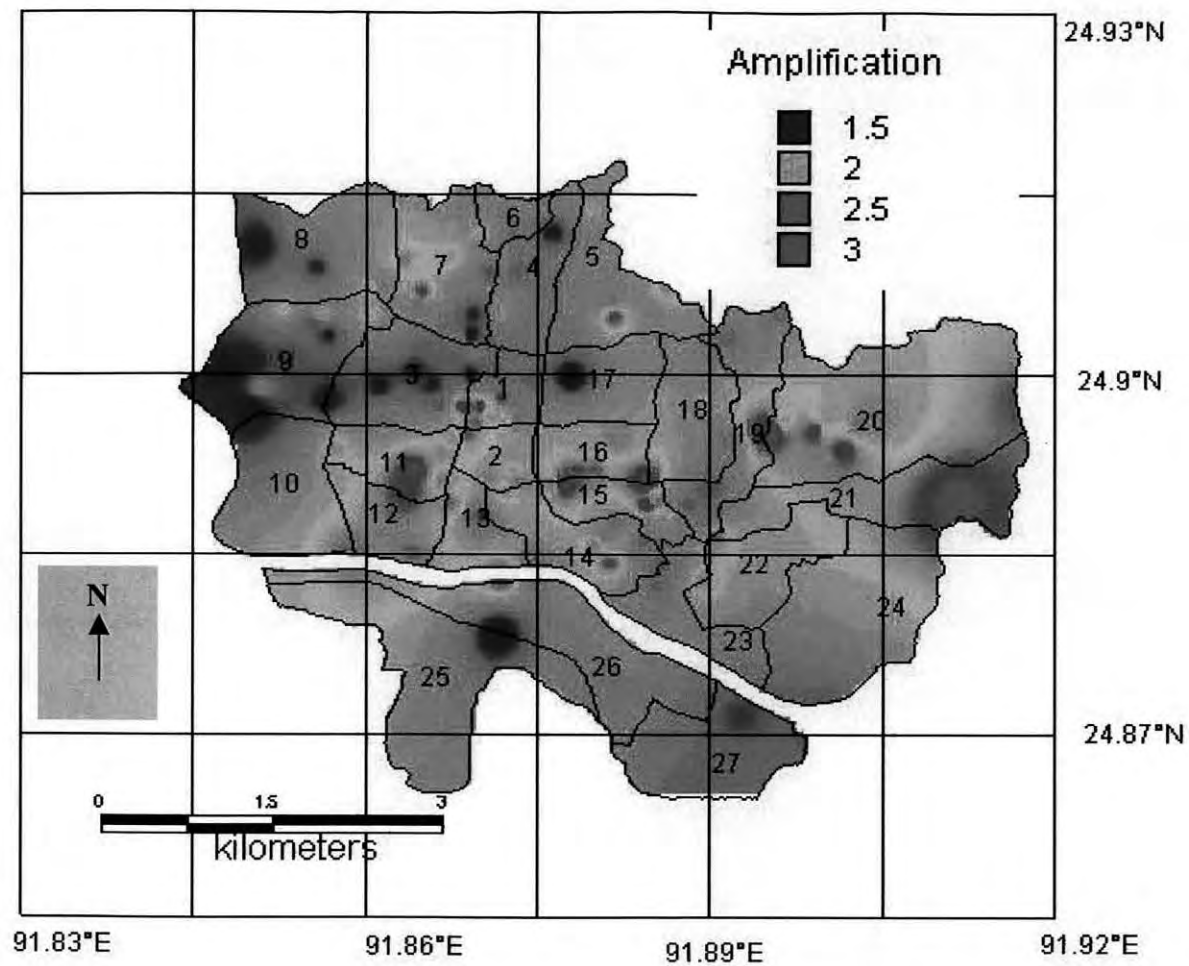


Figure 5.5. Map of amplification at fundamental frequencies of Sylhet City

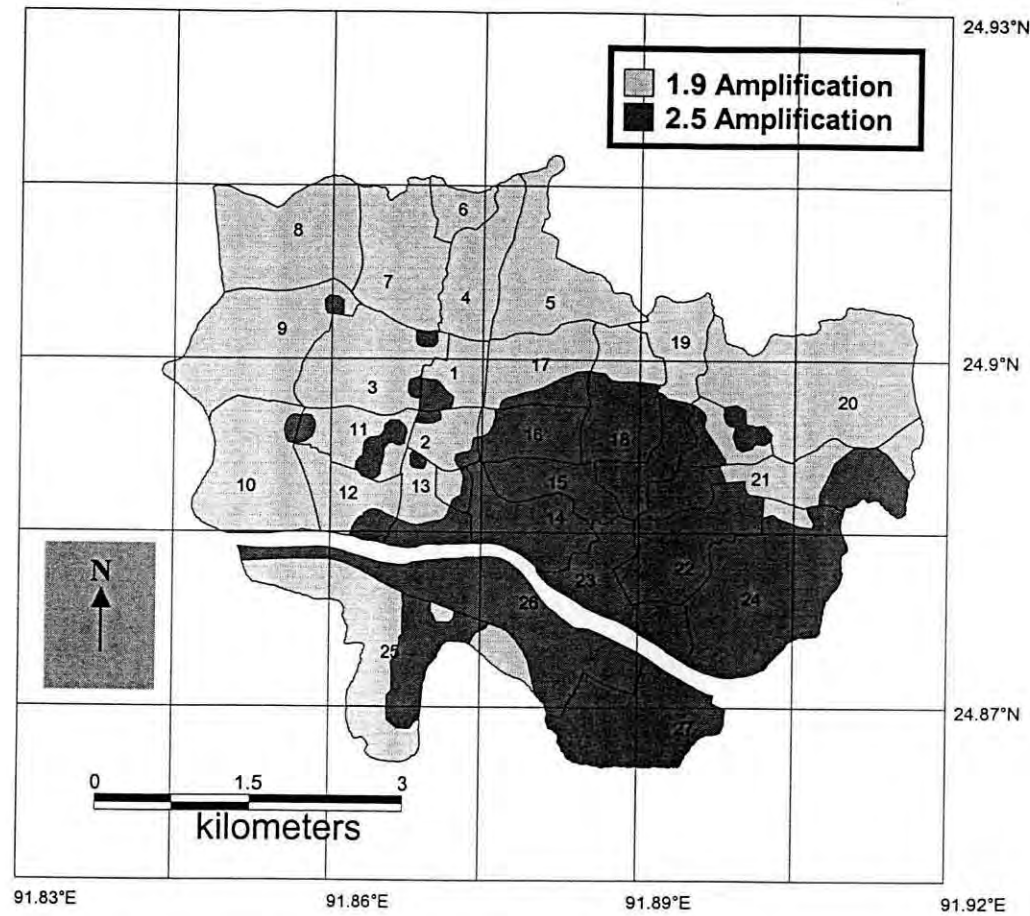


Figure 5.6. Map showing regional distribution of amplification in Sylhet City

5.3.2 Liquefaction Analysis

Borehole data from 167 points in Sylhet City was collected. Almost all the boring data include SPT N- values measured at 1.5 m interval. Table 4.5 shows the ground water level at different location of Sylhet City. The liquefaction resistance factor, F_L , for the top 20 m of soil, and the resulting liquefaction potential, P_L for the 167 sites were calculated. The flow chart of liquefaction analysis used in this study is shown in Figure 5.7. Result of Liquefaction potential was provided in a tabulated form in Table 5.5 and presented in Figure 5.8.

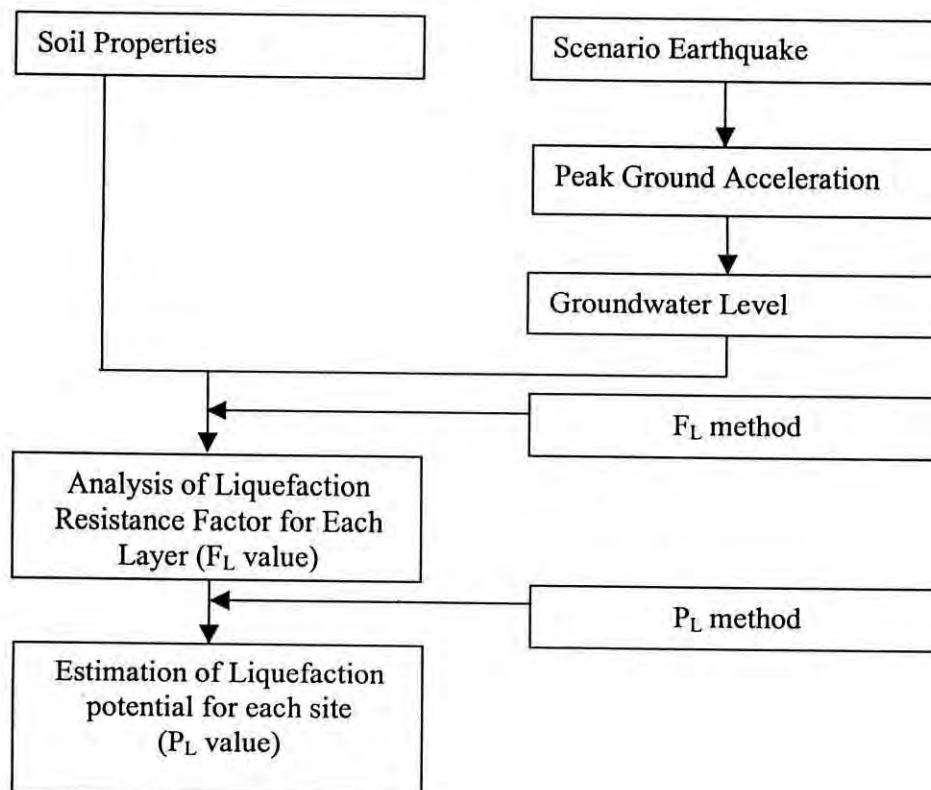


Figure 5.7. Flow chart of Liquefaction Analysis of the study area

Table 5.5. Liquefaction Potential of different Locations of Sylhet City

Location Code	Longitude	Latitude	Liquefaction Potential
A1	91.8309	24.9213	25.5
A2	91.8319	24.9197	18.2
A3	91.8351	24.9240	19.7
A4	91.8335	24.9207	35.9
A5	91.8319	24.9171	19.7
A6	91.8322	24.9111	40.3
A7	91.8368	24.9091	4.5
A8	91.8384	24.9081	0
A9	91.8408	24.9095	0.9
A10	91.8434	24.9125	5.6
A12	91.8506	24.9106	0
B1	91.8545	24.9118	0
B2	91.8575	24.9098	0
B3	91.8557	24.9088	0
B4	91.8559	24.9052	0
B5	91.8602	24.9048	0
B6	91.8528	24.9054	31.7
B7	91.8500	24.9009	0
B8	91.8482	24.9004	3.1
B9	91.8507	24.8989	6.3
B10	91.8501	24.8970	42.4
B11	91.8531	24.8834	45.4
B12	91.8531	24.9015	34.3
B13	91.8568	24.9032	8.2
B14	91.8552	24.9042	40.2
B15	91.8545	24.8994	44.2
B16	91.8565	24.8979	3.8
B17	91.8615	24.8961	26.5
B18	91.8657	24.8992	18.6
B19	91.8643	24.9003	11.8
B20	91.8612	24.8990	3.7
B21	91.8626	24.9021	37.8
B22	91.8606	24.9036	22.9
B23	91.8610	24.9071	17.9
U1	91.8877	24.8885	4.6
U2	91.8891	24.8878	10.6
U3	91.8906	24.8864	7.6
U4	91.8907	24.8856	13
U5	91.8863	24.8885	13
U6	91.8859	24.8882	0
U7	91.8916	24.8945	0

Location Code	Longitude	Latitude	Liquefaction Potential
U8	91.8572	24.8937	7.6
U9	91.8901	24.8907	0
U11	91.8878	24.8892	0
U12	91.8854	24.8893	0
U13	91.8843	24.8912	47.4
U14	91.8847	24.8890	19.1
U15	91.8841	24.8860	0
U16	91.8856	24.8840	0
U17	91.8842	24.8875	1.2
U18	91.8819	24.8877	2.4
M1	91.8641	24.8849	18.9
M2	91.8815	24.8843	14.2
M3	91.8800	24.8884	18
M4	91.8773	24.8909	21.4
M5	91.8800	24.8919	14.5
M6	91.8814	24.8926	20.9
M7	91.8816	24.8943	3.4
M8	91.8787	24.8937	17.5
M9	91.8784	24.8921	9.6
M10	91.9113	24.8894	6.7
M11	91.8825	24.8865	4.5
M12	91.8807	24.8865	0.6
M13	91.8761	24.8909	0
M14	91.8732	24.8912	5.2
M15	91.8692	24.9018	13.3
AM1	91.8695	24.9050	10.7
AM2	91.8719	24.9052	16.5
AM3	91.8744	24.9031	29.6
AM4	91.8691	24.9000	2.7
AM5	91.8702	24.9003	33.7
AM6	91.8612	24.9074	15.1
AM7	91.8645	24.9060	2.4
AM8	91.8690	24.9033	0.9
AM9	91.8679	24.9030	21.9
AM11	91.8640	24.9093	17.9
AM12	91.8606	24.9071	20.3
AM13	91.8681	24.9070	33.7
AM14	91.8663	24.9098	28.8
AM16	91.8675	24.9122	27.1
AM17	91.8720	24.9061	18.4
AM18	91.8714	24.9000	24.6
Bn1	91.8641	24.8921	21
Bn2	91.8635	24.8904	0
Bn3	91.8675	24.8894	0

Location Code	Longitude	Latitude	Liquefaction Potential
Bn4	91.8708	24.8915	14.1
Bn5	91.8731	24.8921	13.4
Bn6	91.8722	24.8904	27.3
Bn7	91.8813	24.8805	6.8
T1	91.9001	24.8964	20.4
T2	91.9042	24.8966	13.4
T3	91.9025	24.8960	4.8
T4	91.9015	24.8960	34.3
T5	91.9030	24.9034	3.3
T6	91.8960	24.9050	6.2
T7	91.8813	24.9061	19.6
T8	91.8864	24.9072	35.2
T9	91.8893	24.9074	12.4
T10	91.8915	24.9031	7
T11	91.8921	24.9061	6.3
T12	91.9012	24.8963	16
T13	91.9001	24.8954	21.4
T14	91.9016	24.8937	20.8
T15	91.9003	24.8931	25.2
T16	91.8995	24.8953	23
T17	91.8964	24.8962	11.4
T19	91.8817	24.9048	10
T20	91.8814	24.9078	14.3
K1	91.8729	24.9132	30.3
K2	91.8726	24.9133	2.4
K3	91.8755	24.9144	3.4
K4	91.8731	24.9115	11
K6	91.8770	24.8755	33.2
K7	91.8751	24.9138	31.1
K8	91.8745	24.8835	10.3
K9	91.8854	24.8826	1.6
K10	91.8666	24.8910	13.2
K11	91.8668	24.8966	23.3
K12	91.8679	24.9131	18.6
K13	91.8692	24.9141	17.6
K14	91.8701	24.9120	35.4
K15	91.8716	24.9093	19.5
K16	91.8834	24.9125	12.2
K17	91.8800	24.9095	30.3
K18	91.8763	24.9118	0
K19	91.8795	24.9137	0
K20	91.8777	24.8998	0
A11	91.8465	24.9118	3
U10	91.8891	24.8904	0

Location Code	Longitude	Latitude	Liquefaction Potential
AM10	91.8648	24.9069	14.1
AM15	91.8675	24.9097	4
T18	91.8951	24.8953	0
K5	91.8729	24.9087	8.9
RAIL1	91.8717	24.8783	8.6
ST1	91.8634	24.9094	6.8
ST2	91.8650	24.8987	3.4
ST3	91.8895	24.8829	18.5
ST4	91.8597	24.8919	0
ST5	91.9121	24.9095	0
ST6	91.8851	24.9051	7.4
ST7	91.8801	24.8859	6
ST8	91.8721	24.8832	4.5
ST9	91.8586	24.8850	0
Z1	91.8686	24.8950	0
Z2	91.8683	24.8975	0
Z3	91.8687	24.8910	0
Z4	91.8731	24.8931	0
Z5	91.8732	24.8937	0
Z6	91.8724	24.8963	0
Z7	91.8711	24.8966	0
Z8	91.8712	24.8971	9
Z9	91.8711	24.8977	11.2
Z10	91.8700	24.8975	9
Z11	91.8696	24.8960	0
Z12	91.8676	24.8945	0
Z13	91.8666	24.8936	10.6
Z14	91.8670	24.8959	37.7
Z15	91.8663	24.8975	20.8
Z16	91.8673	24.8993	8.8
Z17	91.8700	24.8882	0
Z18	91.8718	24.8979	11.5
Z19	91.8731	24.8963	15.2
Z20	91.8731	24.8979	5.1
Z21	91.8741	24.8994	5
Alam1	91.9000	24.8708	6.7
Alam2	91.8928	24.8717	22
Epir1	91.8707	24.9085	2

Summary of liquefaction potential is shown in Table 5.6. Figure 5.9 shows that 3.35 Km² area have low and very low Liquefaction potential, 13.70 Km² area have moderate liquefaction potential and 10 Km² area have high liquefaction potential. More than one thirds (37%) area will be affected severely by due to liquefaction if Srimongal Earthquake (1918) occurs again with same magnitude and same epicentral distance.

Table 5.6. Summary of the liquefaction Potential Index

Liquefaction Potential	Criteria	Explanation
High	$15 < PL$	Ground Improvement is indispensable
Moderate	$5 < PL \leq 15$	Ground Improvement is required. Investigation of important structures is indispensable
Low	$0 < PL \leq 5$	Investigation of important structures is required
Very low	$PL = 0$	No measure is required

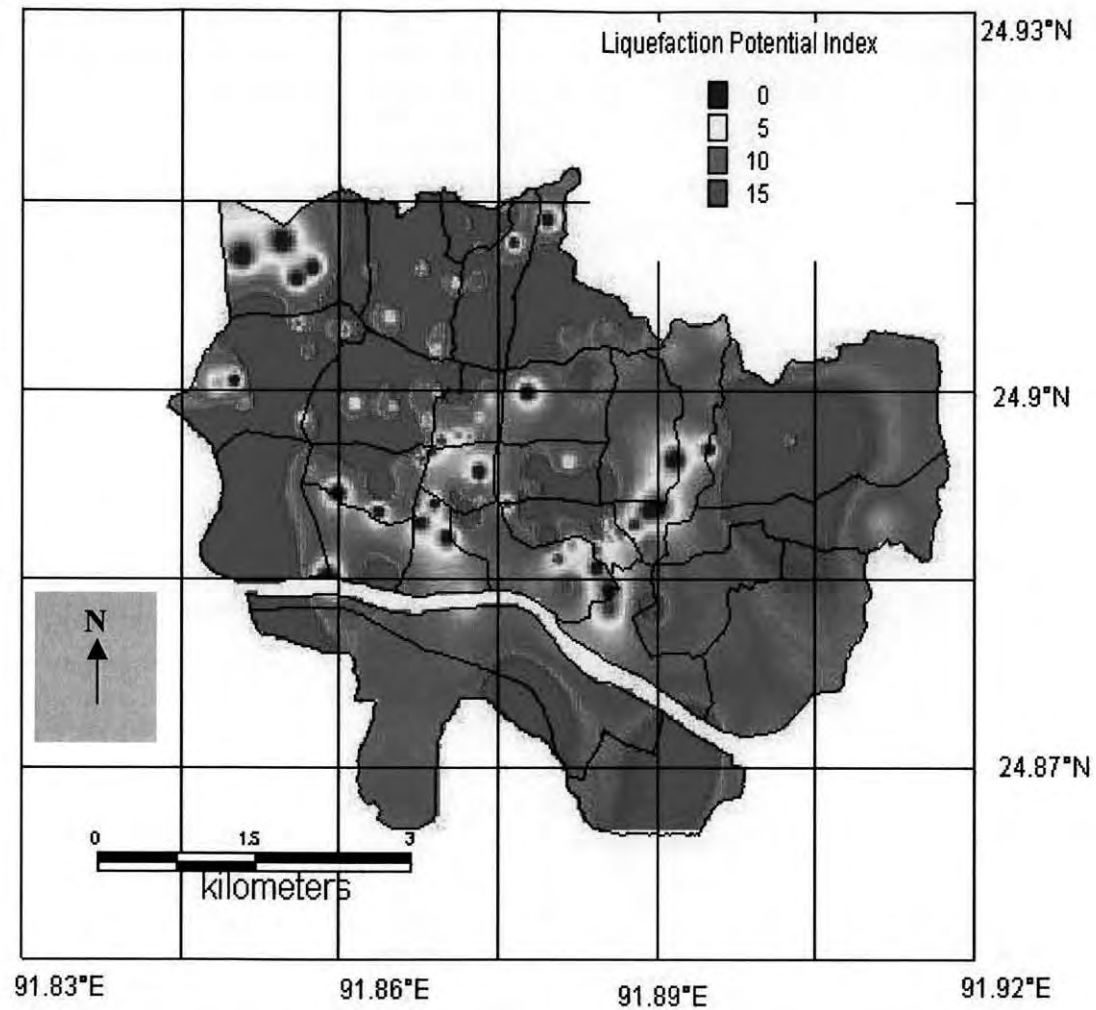


Figure 5.8. Map showing Microzonation based on liquefaction potential index

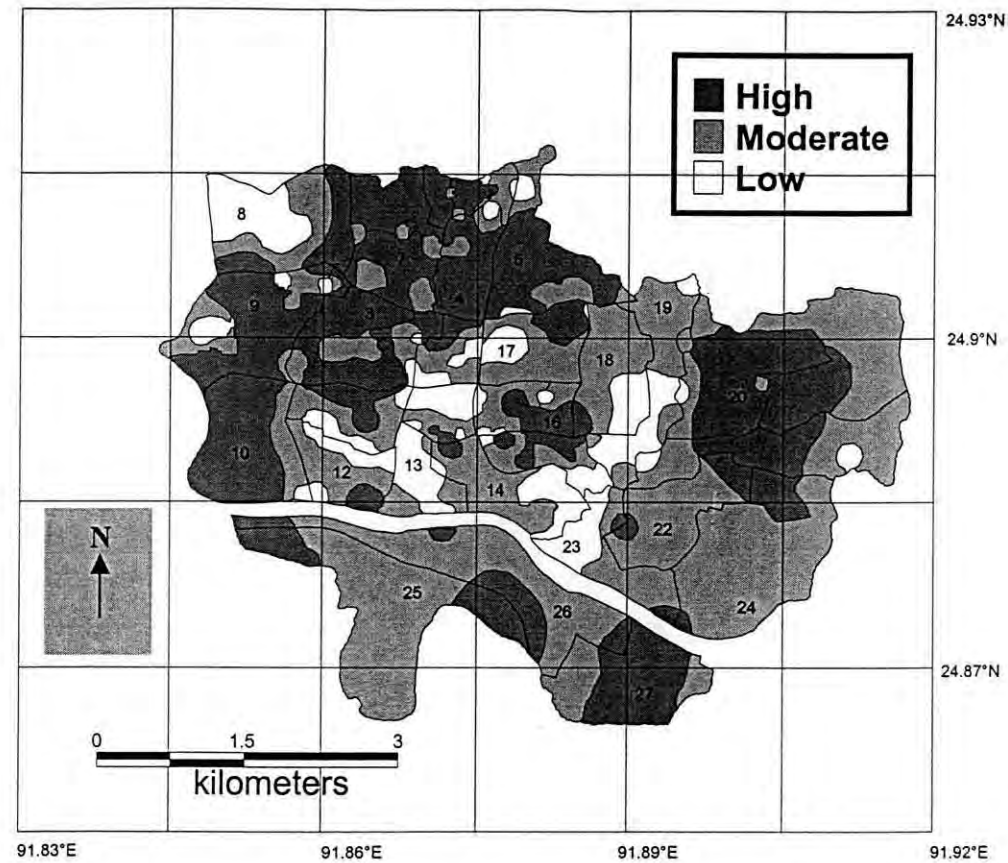


Figure 5.9. Map showing regional distribution of liquefied areas of Sylhet City Corporation

5.3.3 Landslide Potential Analysis

The overall stability failure mechanism is development of slip circles resulting in a deep sliding surface. This is a conventional soil mechanics stability problem. Pre-existing slip planes within the soil, cracker material can have a significant effect on slope stability. Stability analysis is carried out to evaluate the factor of safety against bearing capacity failure.

The program used for stability analysis is XSTABL, which is a fully integrated slope stability analysis program. XSTABL performs two dimensional limit equilibrium and analysis to evaluate the factor of safety for a layered slope using the simplified Bishop Method.

The strength parameters of the slope and foundation materials required for the analyses could be obtained from consolidated undrained direct shear tests performed on soil samples. The minimum values of undrained cohesion (c_u) and undrained angle of internal friction (ϕ_u) were used in the slope stability analyses. The values of c_u and ϕ_u used in all the analyses were 5 kN/m^2 and 31° , respectively and which is collected the test report of BTTB (BUET, 2002). The location of the water table in all the slope sections is assumed to be at a height of 10 ft above the toe of the slopes. The moist and saturated unit weights of the slope and foundation soils were taken as 18 kN/m^3 and 16 kN/m^3 respectively.

In conventional slope stability analyses, it is generally recommend that the factor of safety of slopes should be at least 1.0. From this viewpoint and from the results of stability analysis, it therefore appears that the entire slope has not adequate overall stability and that these slope sections are unstable under their normal operation conditions. From the slope stability analysis and using equation (3.7) of Chapter 3 landslides potential is categorized as high, moderate and low. In the study area only 2.4 km^2 , which is 9% of total city corporation area, occupy with hill. From the analysis it is concluded that 65% hill occupied area is likely to have moderate landslide potential and the rest of 35% area is likely to have high landslide potential index. In addition,

landslides might lead to slope instability is attributed to severe rainfall during monsoon periods, which is a local characteristic feature of the Sylhet region. Figure 5.10 shows landslide potential and Appendix E shows probable landslide potential hillside areas of Sylhet City.

In general, a few residential areas are located near the slope failures in the mountainous area, but caution regarding potential slope failure will be necessary for particular areas where houses are located on the lower portions of the slope failures.

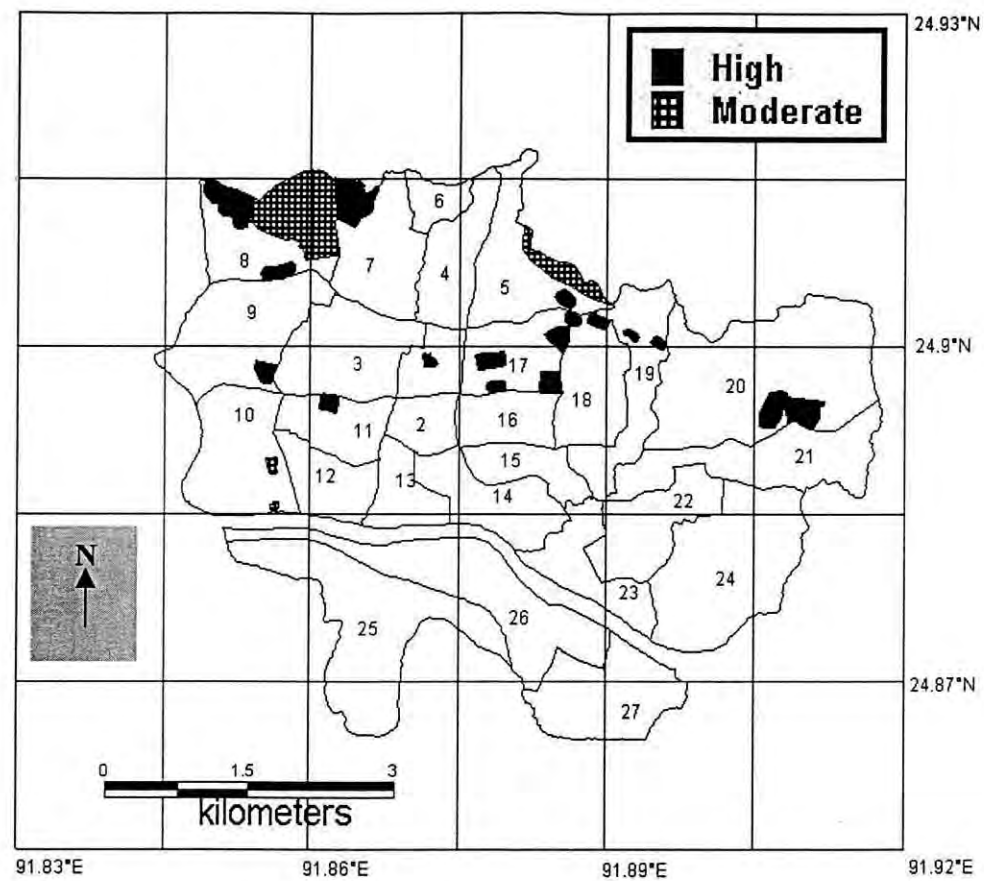


Figure 5.10. Map showing landslide potential in Sylhet City

6.1 General

The most important endeavor of this study is the estimation of seismic loss by integrating seismic hazards linked with the local site attributes of soil amplification, liquefaction, and landslide. It is not feasible to resolve how much of the damage can be discretely attributed to each local site effect, consequently the ultimate regional seismic hazard distribution is established on a weighted average combination of the hazards related with each effect.

6.2 Integration of Site Effects in the GIS Environment

Every analysis region is different; therefore the quantification of the secondary site effects and the weighting scheme for combining the various seismic hazards is heuristic, based on judgment and expert opinion about the influence of local site conditions in the region and the accuracy of the available geologic and geotechnical information. The basic steps are described below.

The bedrock-level ground shaking in the region is determined. The shaking is described in terms of peak ground motion values. The regional distribution of bedrock-level shaking is estimated as 0.18g, which is found from considering a scenario earthquake equivalent to 1918 Srimangal Earthquake using McGuire (1978) attenuation relationship. Bedrock level PGA is considered as constant since the study area is small. Figure 6.1 shows the flow diagram of integration of site effects. A map showing the distribution of the surface-level ground shaking in the region is developed first. Figure 5.6 shows the regional distribution of estimated PGA amplification factors based on the local geologic conditions in the study area. Figure 6.2 shows the regional distribution of surface-level PGA values. Figure 6.2 is produced just simple multiplication of the PGA at bedrock level with amplification factor shown in Figure 5.6.

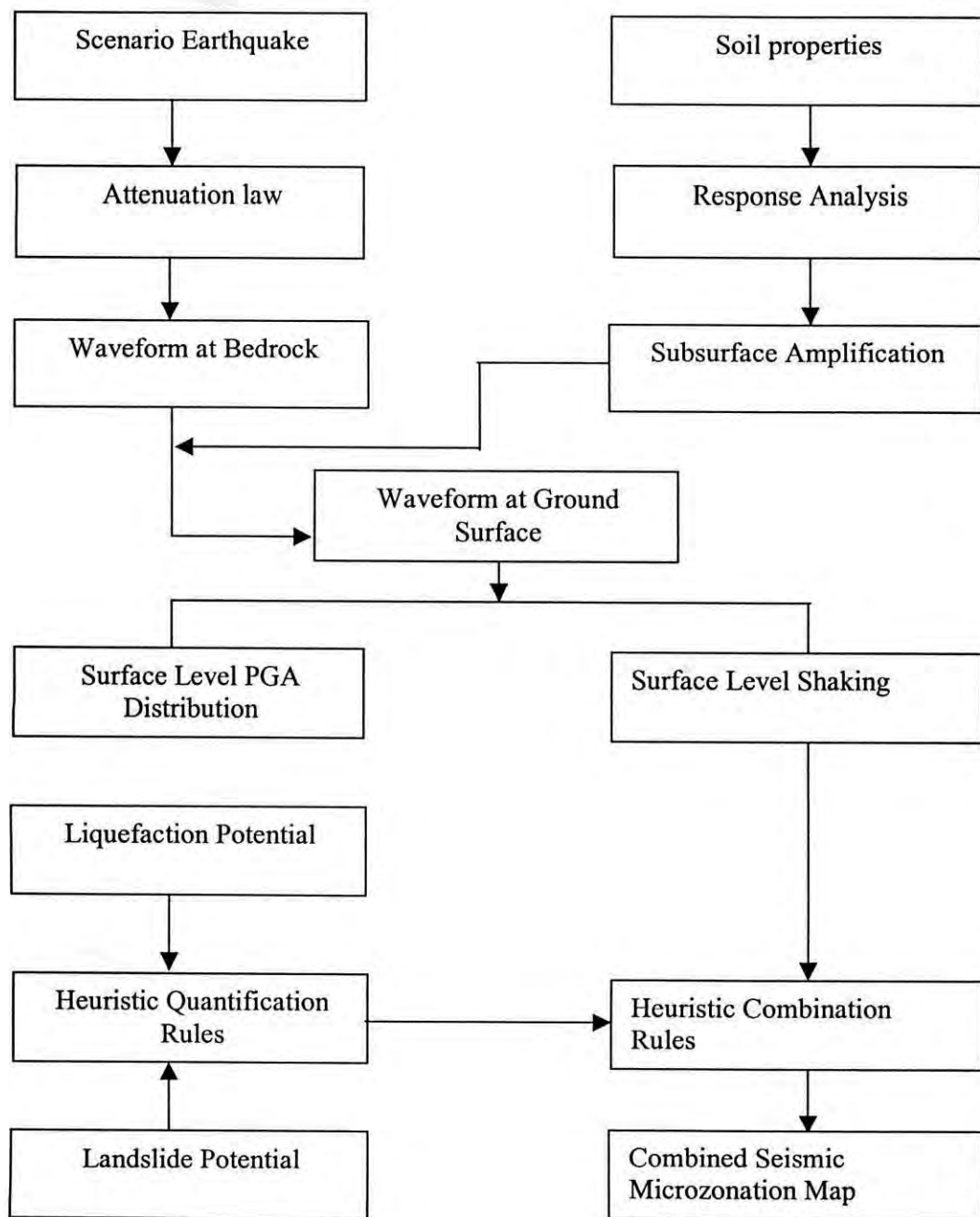


Figure 6.1 Flow chart for Combined Seismic Hazard Map

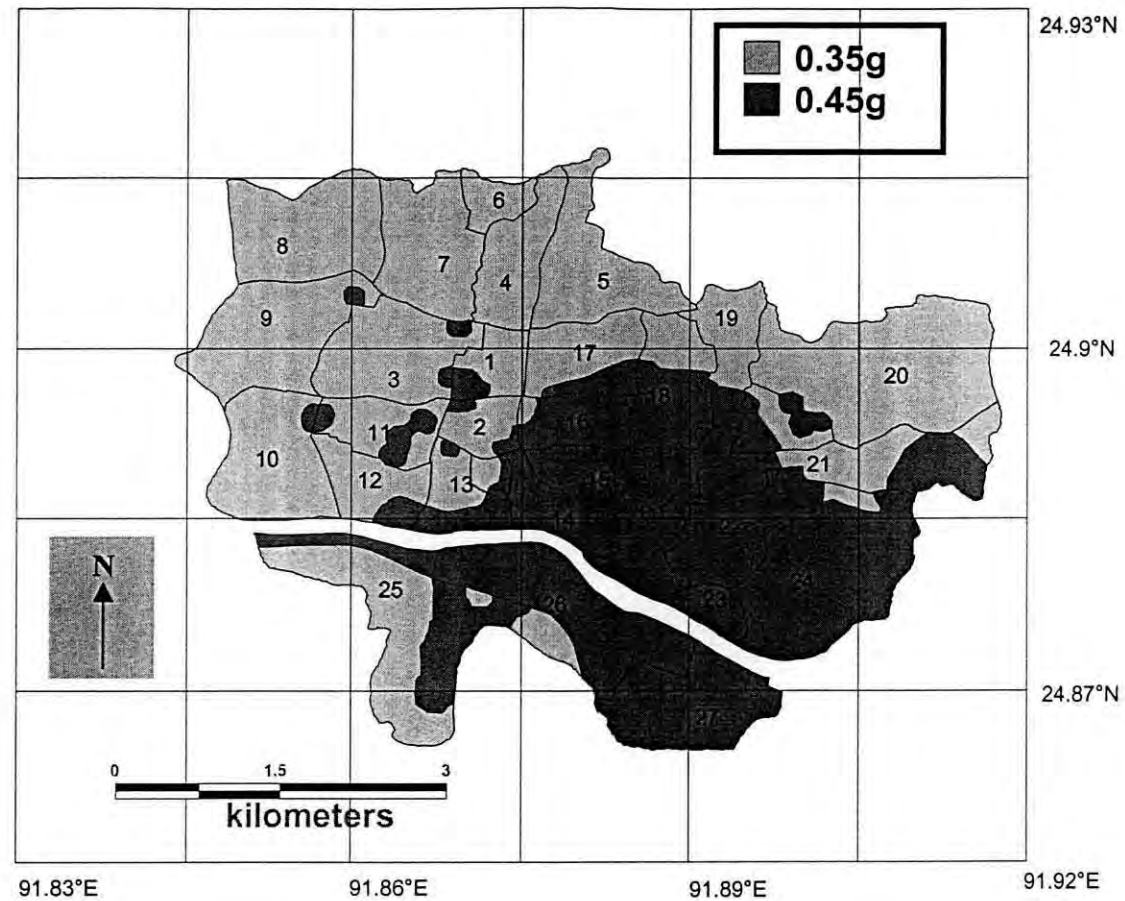


Figure 6.2. Map showing regional distribution of surface level peak ground acceleration in Sylhet City

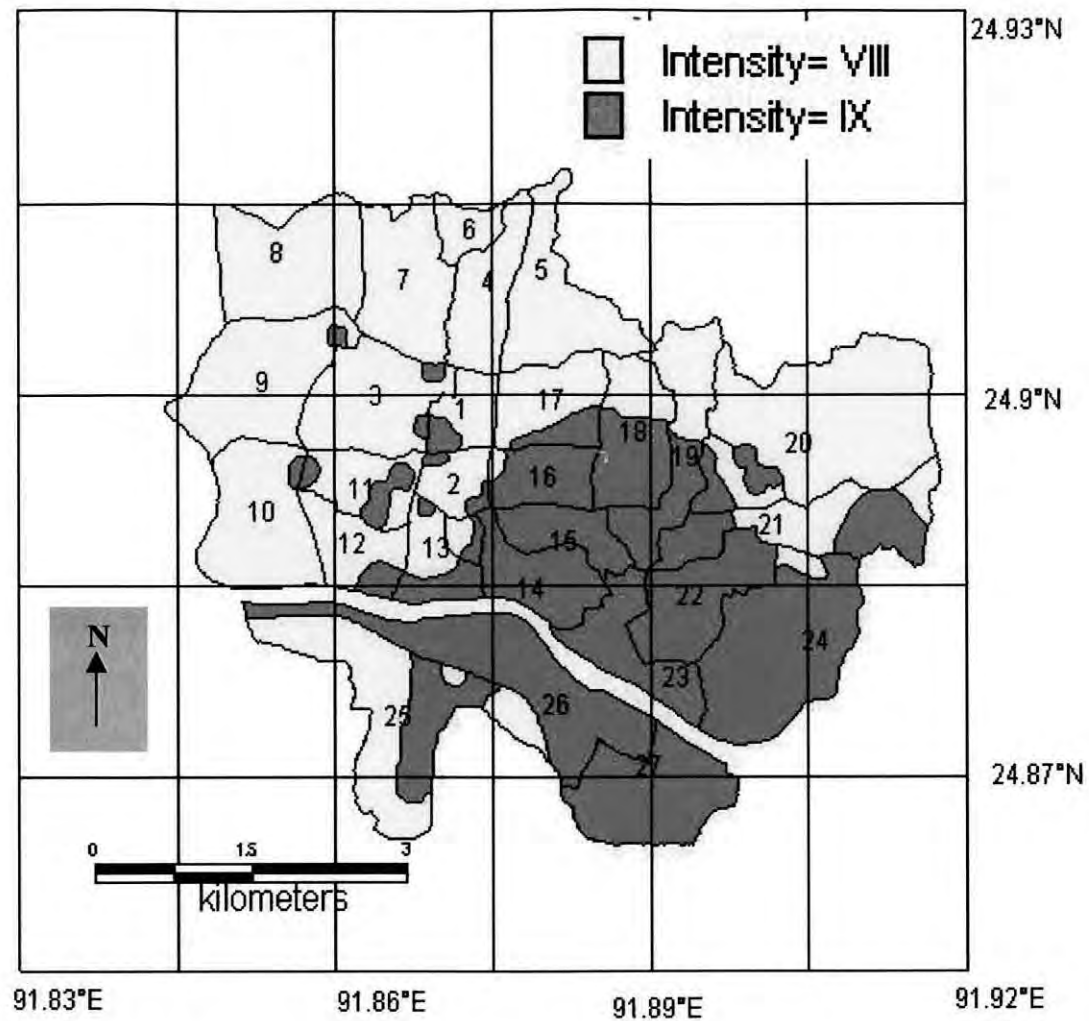


Figure 6.3. Map showing regional distribution of ground shaking hazard (MMI_{GS}) in Sylhet City

The seismic intensity is basically a subjective one, based on the human sensations or damage during an earthquake (Appendix C). It is assumed that the final combined seismic hazard would be quantified in terms of Modified Marcelli Intensity (MMI). This assumption allows for the use of relationships between MMI and structural damage for computing regional damages and losses. There are several relationships for converting PGA to MMI. The equation used here is developed by Trifunac and Brady (1975) and is given by equation (5.1)

Figure 6.3 shows the regional distribution of ground shaking hazard (MMI_{GS}). This map is developed by applying equation (5.1) to the map of surface-level PGA values as shown Figure 6.2. The MMI scale is subjective and assigned as integer values, therefore the MMI_{GS} values in Figure 6.3 are rounded to the nearest 0.5

Figure 5.8 shows the regional distribution of liquefaction potential in the study area. Table 5.6 is used to sort out liquefiable area and for simplicity it is categorized as high, moderate and low liquefaction potential as shown in Figure 5.9. Figure 5.10 shows the qualitative description of landslide hazard in the region. For simplicity, Areas are designated as having "high", "moderate" landslide potential.

The following heuristic rules are used to quantify the seismic hazard due to liquefaction:

For regions with liquefiable soils with high liquefaction potential

$$MMI_{LIQ} = MMI_{GS} + 2$$

For regions with liquefiable soils with moderate liquefaction potential

$$MMI_{LIQ} = MMI_{GS} + 1 \text{ and otherwise:}$$

$$MMI_{LIQ} = 0$$

To quantify the seismic hazard due to landslide (MMI_{LAN}), the following heuristic rules are used. For region designated as "high"

$$MMI_{LAN} = MMI_{GS} + 2$$

For region designated as "moderate"

$$MMI_{LAN} = MMI_{GS} + 1 \text{ and otherwise}$$

$$MMI_{LAN} = 0$$

The rules for combining the various hazards are based on expert opinion (after Stephanie and Kiremidjian, 1994) about the relative accuracy of the hazard information and the behavior of the local geology. For this study, it is assumed that the ground-shaking hazard is the most accurate followed by liquefaction, and landslide. Different types of structures, such as above ground and buried structures behave differently when subjected to local site effects. In this study, seismic hazard to surface structures such as building and buried water supply system is considered only.

Typically there are up to three hazards to be combined, ground shaking plus one or more of the secondary site effects hazards. For this study, four possible combinations and their assumed weights are shown in Table 6.1. The final combined hazard (MMI_F) is computed as a weighted sum of the various hazards. The weights in each rule must sum to 1.0. The additive factor in rules in Table 6.1 is to account for the increase in hazard due to two or more hazards occurring.

By over-laying the regional maps for each hazard shown in Figure 5.6, Figure 5.9, and Figure 5.10 in GIS environment, Sylhet City area is divided into 13 different affected areas, which is clarified in Table 6.2 and is also shown Figure 6.4a through Figure 6.4m.

Figure 6.5 shows the regional distribution of the final combined seismic peak ground acceleration and Figure 6.6 shows the regional distribution of the final combined seismic hazard (MMI_F) which is developed according to quantification rules as listed in Table 6.1. The final (MMI_F) values are rounded to the nearest 0.5 to account for the subjectivity of the MMI scale. From Table 6.2 it is concluded that Sylhet City will be affected on a weighted average 0.80g PGA if a scenario event equivalent to 1918 Srimangal Earthquake reoccurs.

Table: 6.1. Quantification rules for seismic hazard
(after Stephanie and Kiremidjian, 1994)

Rule	Possible hazards	Weighting scheme for Final combined hazard (MMI_F)
(a)	Ground shaking	$MMI_F = MMI_{GS}$
(b)	Ground shaking + Liquefaction	$MMI_F = .55 MMI_{GS} + .45 MMI_{LIQ} + .5$
(c)	Ground shaking+ Landslide	$MMI_F = .65 MMI_{GS} + .35 MMI_{LAN} + .5$
(d)	Ground shaking +Liquefaction+ Landslide	$MMI_F = .40 MMI_{GS} + .35 MMI_{LIQ} + .25 MMI_{LAN} + 1$

Notes:

1. MMI_F = Final Combined Hazard
2. MMI_{GS} = Ground Shaking Hazard
3. MMI_{LIQ} =Liquefaction Hazard
4. MMI_{LAN} =Landslide Hazard
5. MMI_F must be less than or equal 12

Table 6.2. Combination of possible hazards due to a scenario event equivalent to 1918 Srimangal Earthquake in Sylhet City

Possible Hazards	Combination Of Possible Hazards	Intensity	PGA	Area (Km ²)	Area (%)	Figure No
Ground shaking	1.9 times amplification	VIII	0.35g	1.45	5.5	6.4 a
	2.5 times amplification	IX	0.45g	1.55	5.8	6.4 b
Ground shaking + Liquefaction	1.9 times amplification plus liquefaction (high)	X	0.90g	6.98	26.2	6.4 c
	1.9 times amplification plus liquefaction (moderate)	IX	0.65g	5.75	21.7	6.4 d
	2.5 times amplification plus liquefaction (high)	X	1.15g	2.30	8.7	6.4 e
	2.5 times amplification plus liquefaction (moderate)	X	0.85g	6.95	26.2	6.4 f
Ground shaking+ Landslide	1.9 times amplification plus landslide (high)	X	0.85g	0.20	0.7	6.4 g
	1.9 times amplification plus landslide (moderate)	IX	0.70g	0.14	0.5	6.4 h
Ground shaking +Liquefaction+ Landslide	1.9 times amplification plus liquefaction (high) plus landslide (high)	XI	1.55g	0.36	1.4	6.4 i
	1.9 times amplification plus liquefaction (moderate) plus landslide (high)	X	1.20g	0.20	0.75	6.4 j
	1.9 times amplification plus liquefaction (high) plus landslide (moderate)	X	1.30g	0.32	1.25	6.4 k
	1.9 times amplification plus liquefaction (moderate) plus landslide (moderate)	X	1.0g	0.26	1.0	6.4 l
	2.5 times amplification plus liquefaction (moderate) plus landslide (high)	XI	1.60g	0.068	0.25	6.4 m

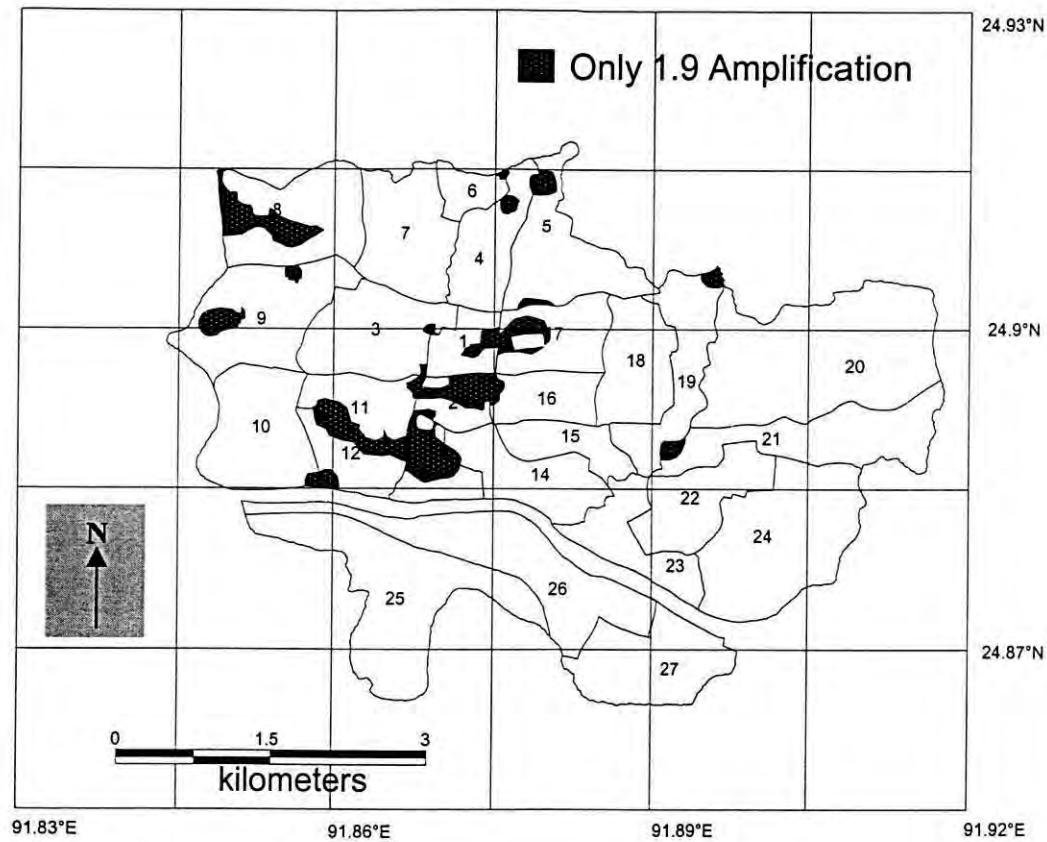


Figure 6.4 a. Map showing only 1.9 times amplified areas

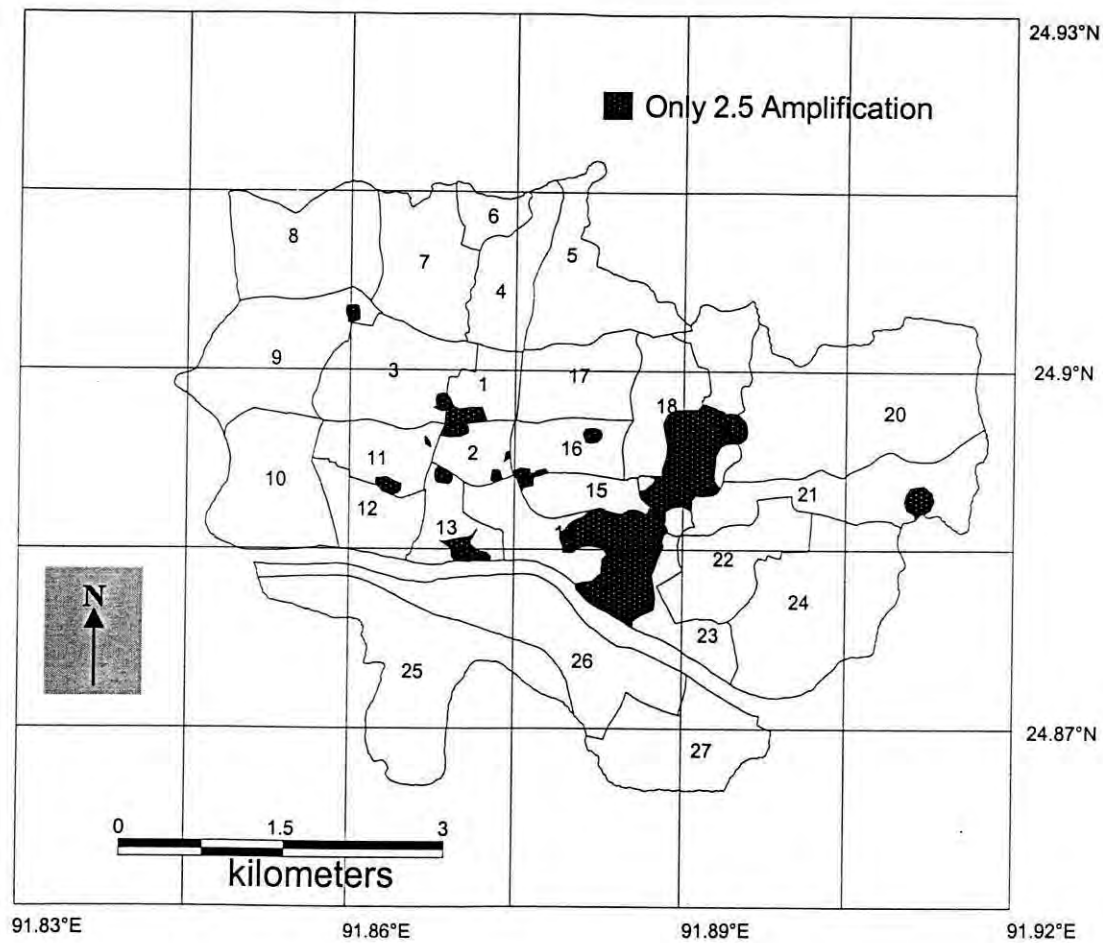


Figure 6.4 b. Map showing only 2.5 times amplified areas

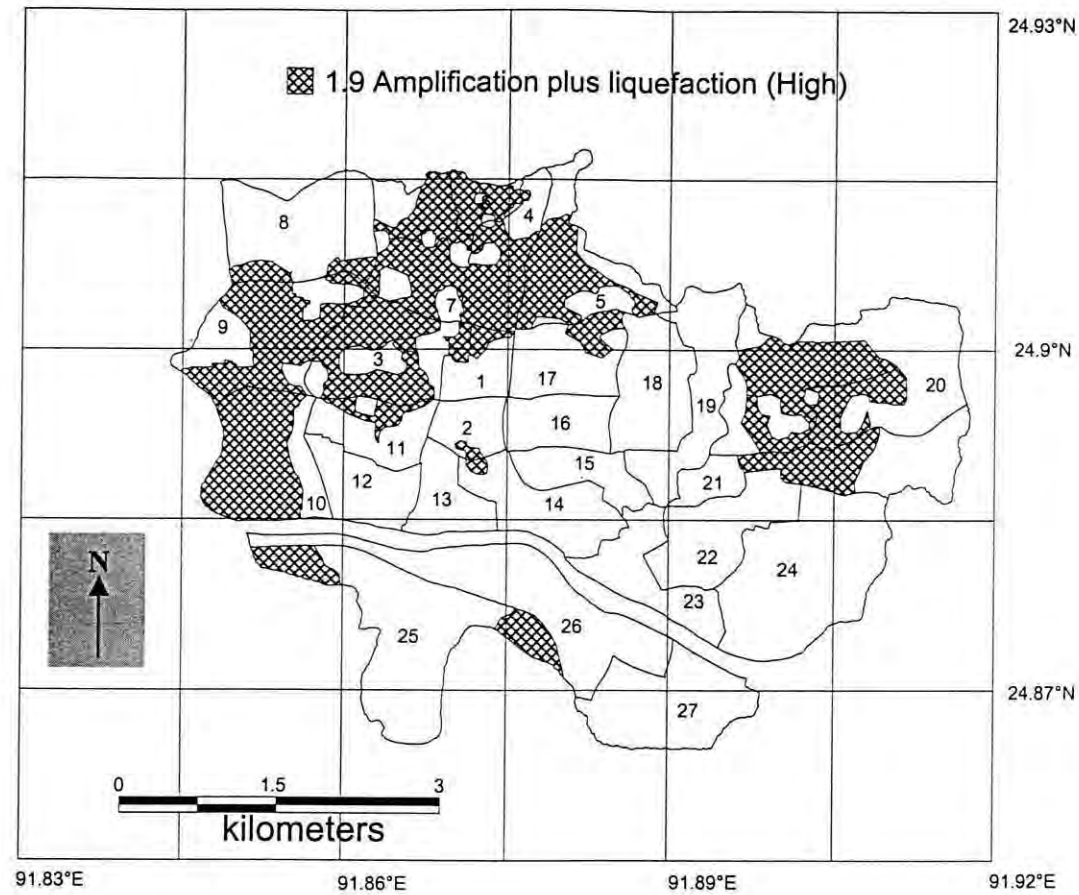


Figure 6.4 c. Map showing 1.9 times amplification plus liquefaction (high) areas

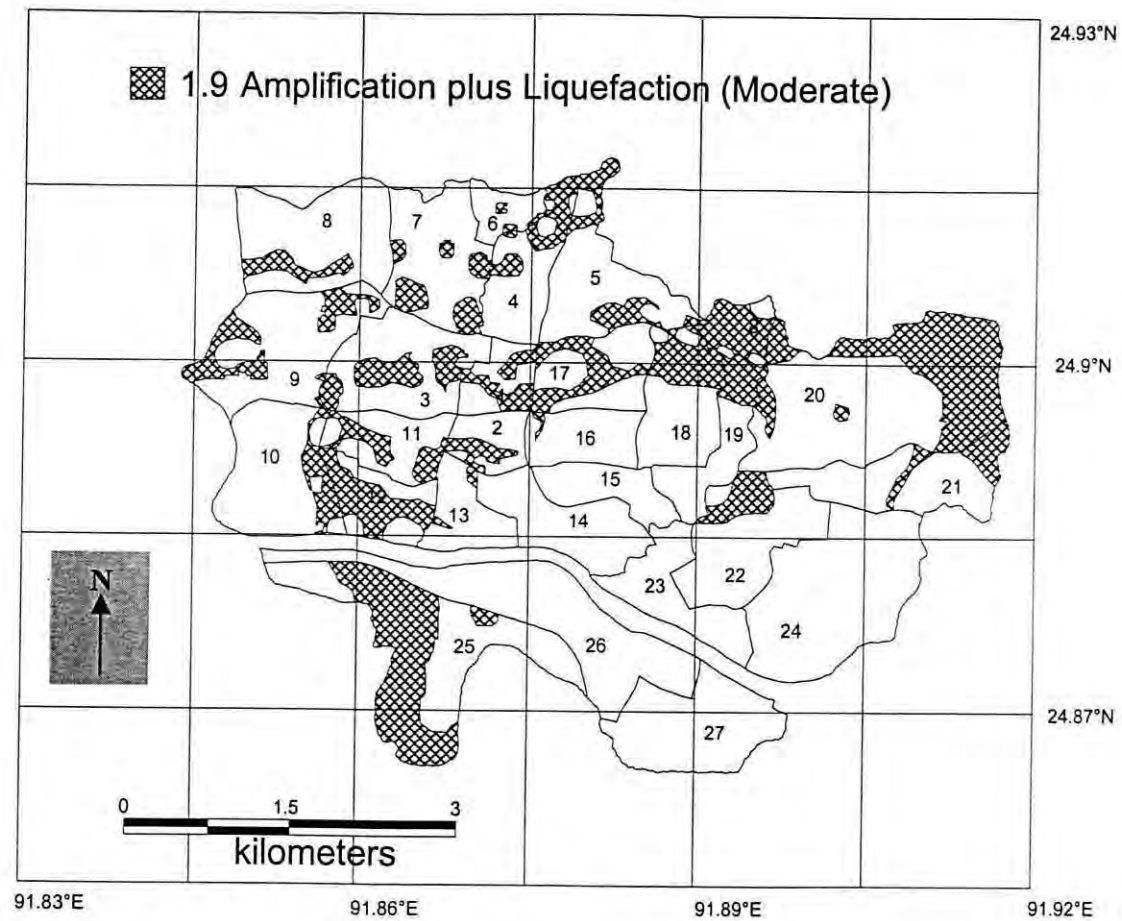


Figure 6.4 d. Map showing 1.9 times amplification plus liquefaction (moderate) areas

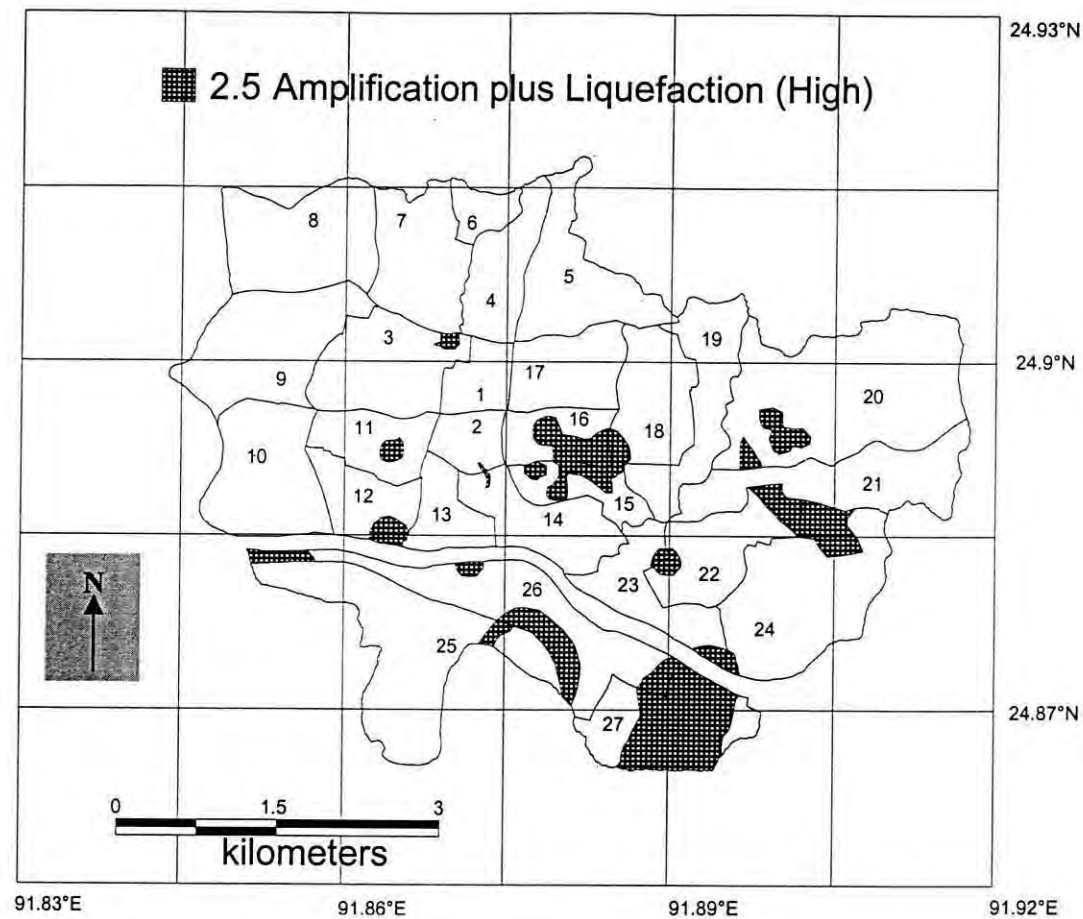


Figure 6.4 e. Map showing 2.5 times amplification plus liquefaction (high) areas

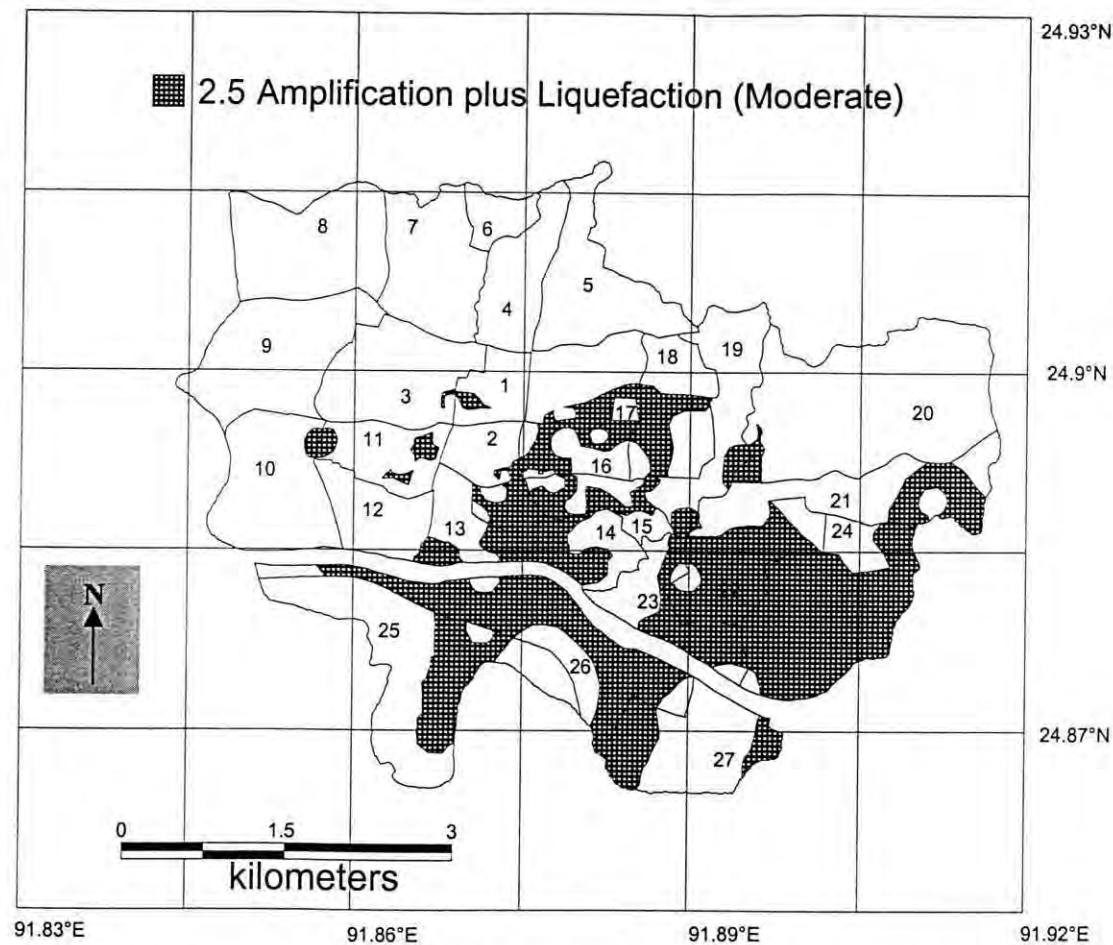


Figure 6.4 f. Map showing 2.5 times amplification plus liquefaction (moderate) areas

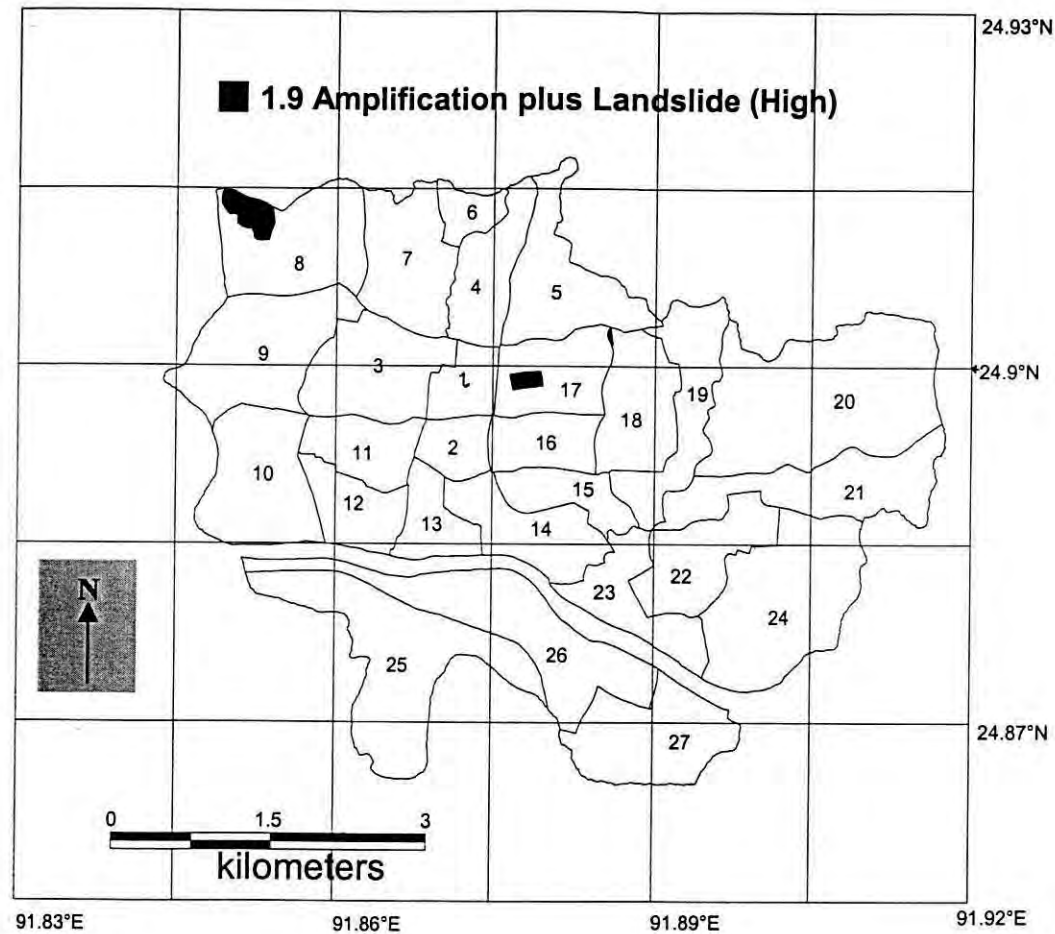


Figure 6.4 g. Map showing 1.9 times amplification plus landslide (high) areas

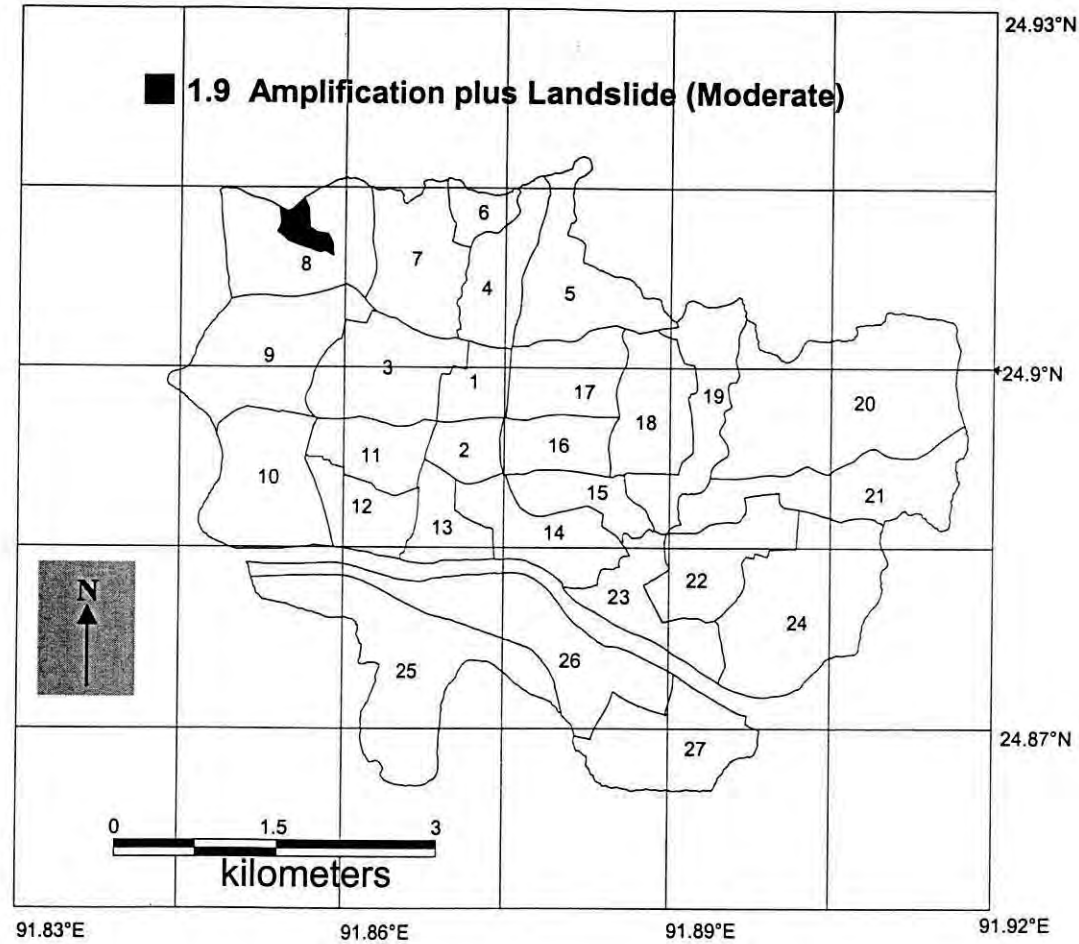


Figure 6.4 h. Map showing 1.9 times amplification plus landslide (moderate) area:

■ 1.9 Amplification plus Liquefaction (High) plus Landslide (High)

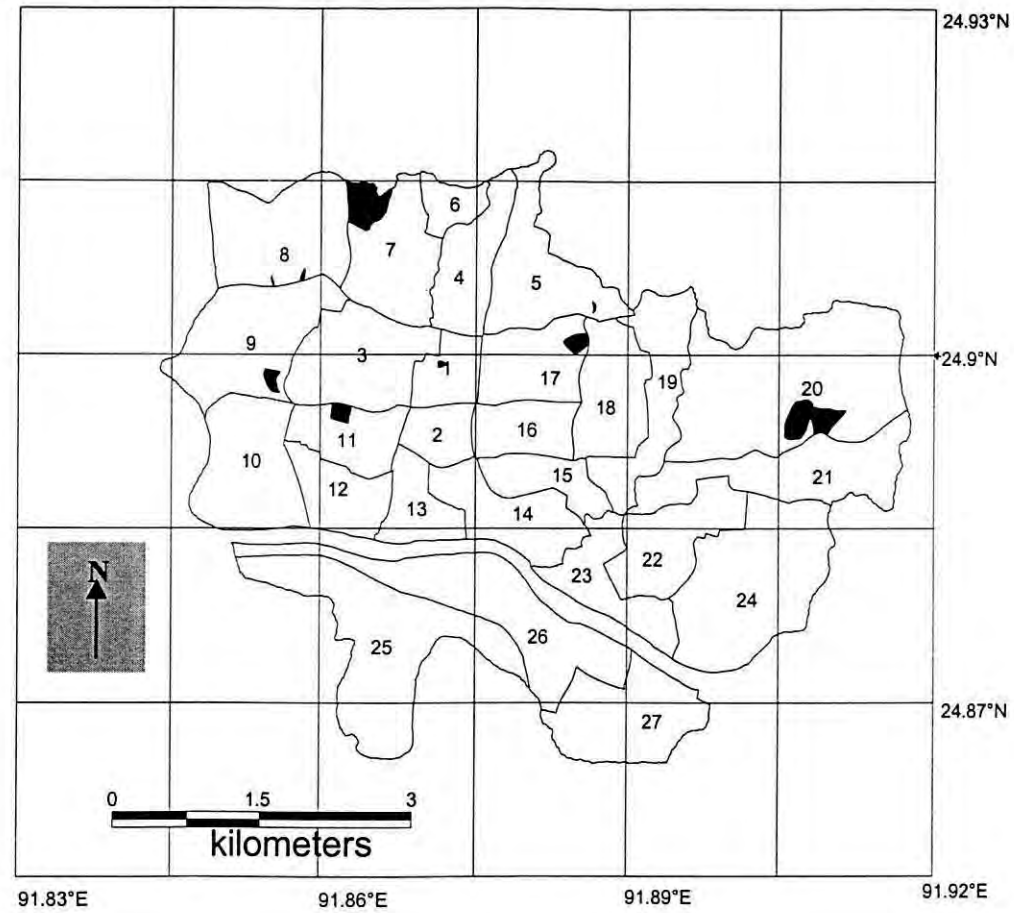


Figure 6.4 i. Map showing 1.9 times amplification plus liquefaction (high) plus landslide (high) areas

■ 1.9Amplification plus Liquefaction (Moderate) plus Landslide (High)

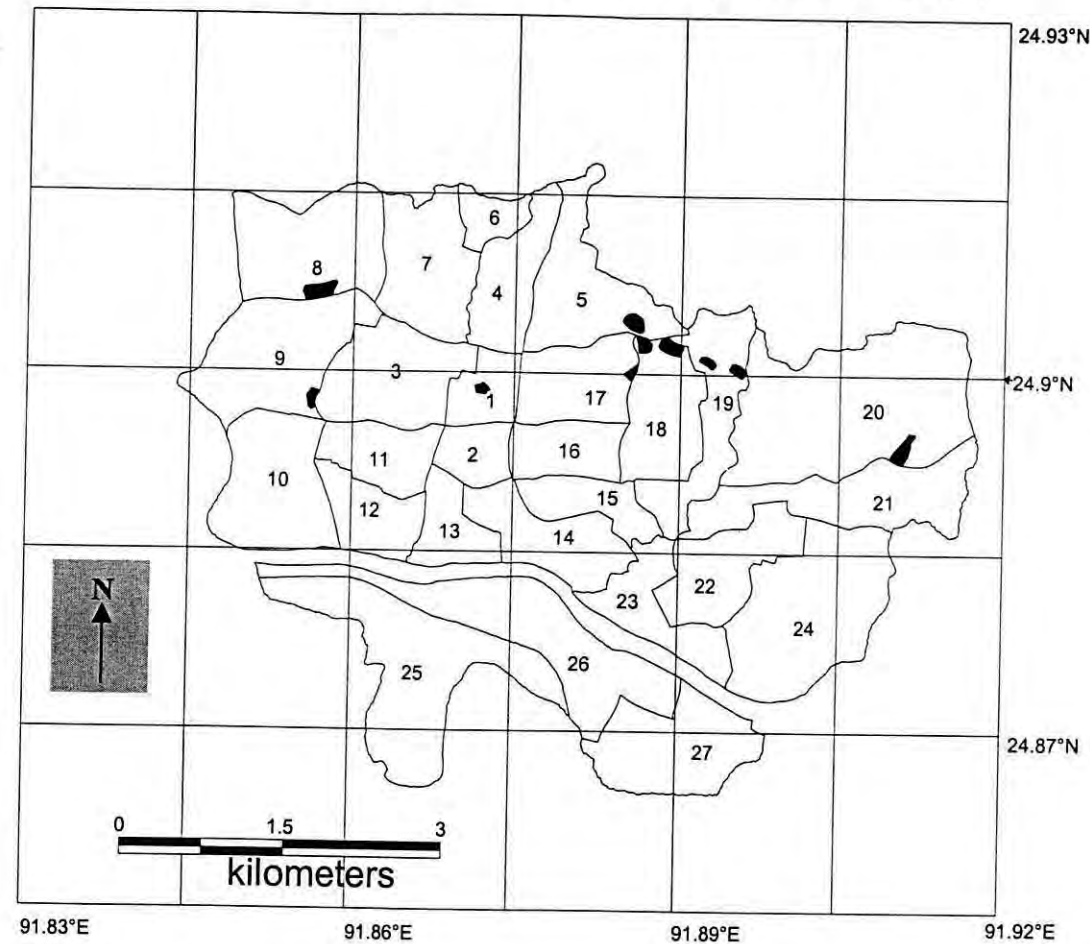


Figure 6.4 j. Map showing 1.9 times amplification plus liquefaction (moderate) plus landslide (high) areas

■ 1.9 Amplification plus Liquefaction (High) plus Landslide (moderate)

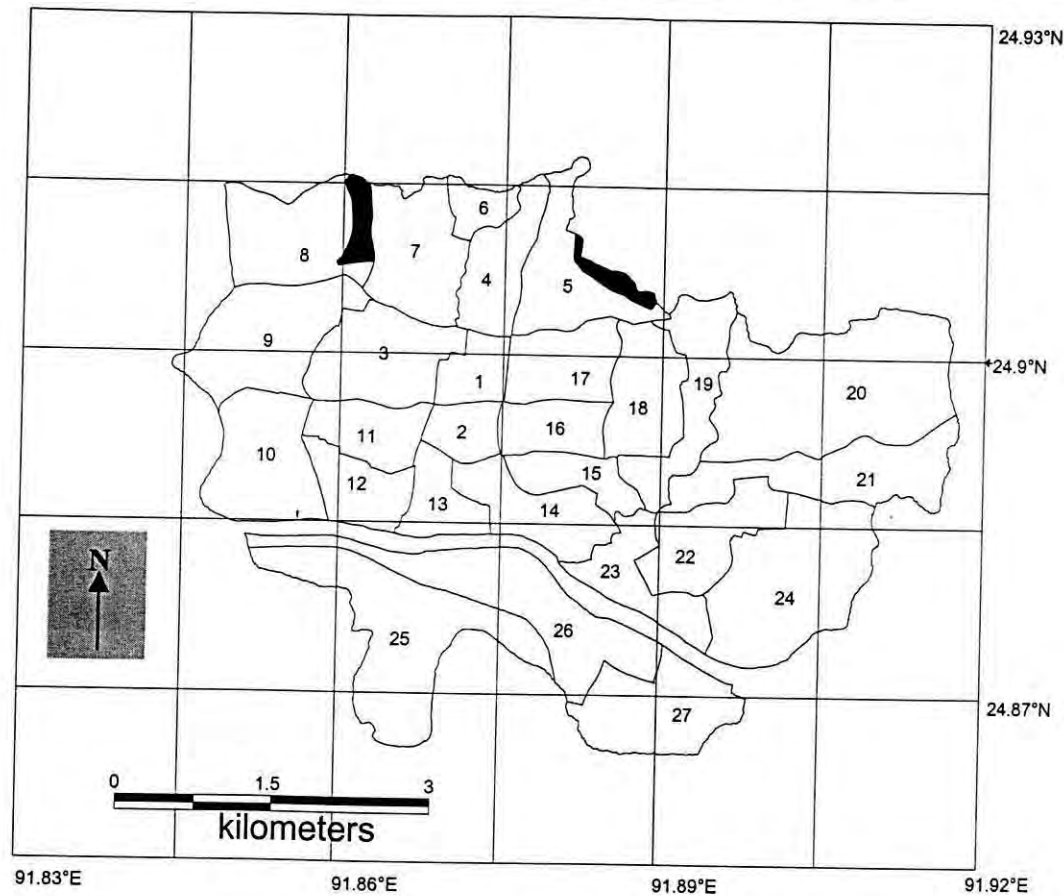


Figure 6. 4 k. Map showing 1.9 times amplification plus liquefaction (high) plus landslide (moderate) areas

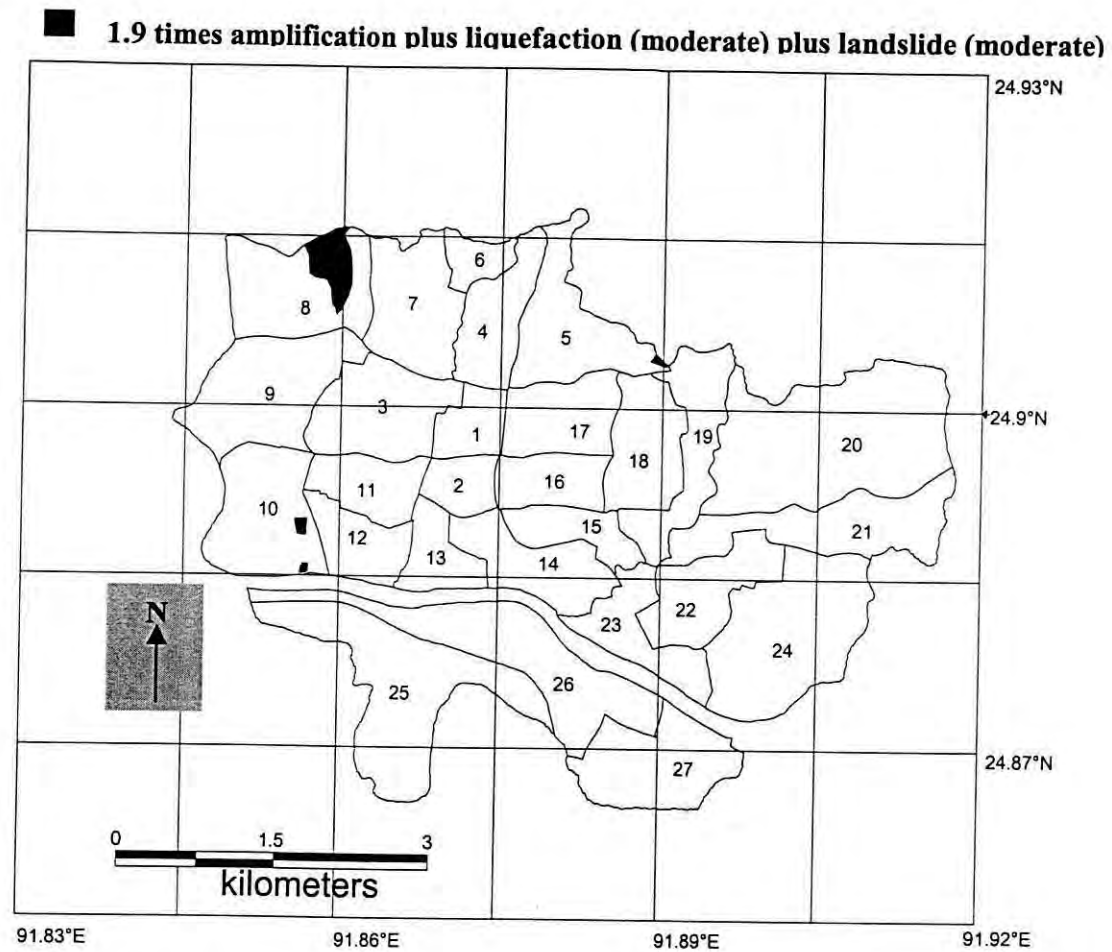


Figure 6.4 I. Map showing 1.9 times amplification plus liquefaction (moderate) plus landslide (moderate) areas

■ 2.5 times amplification plus liquefaction (moderate) plus landslide (high)

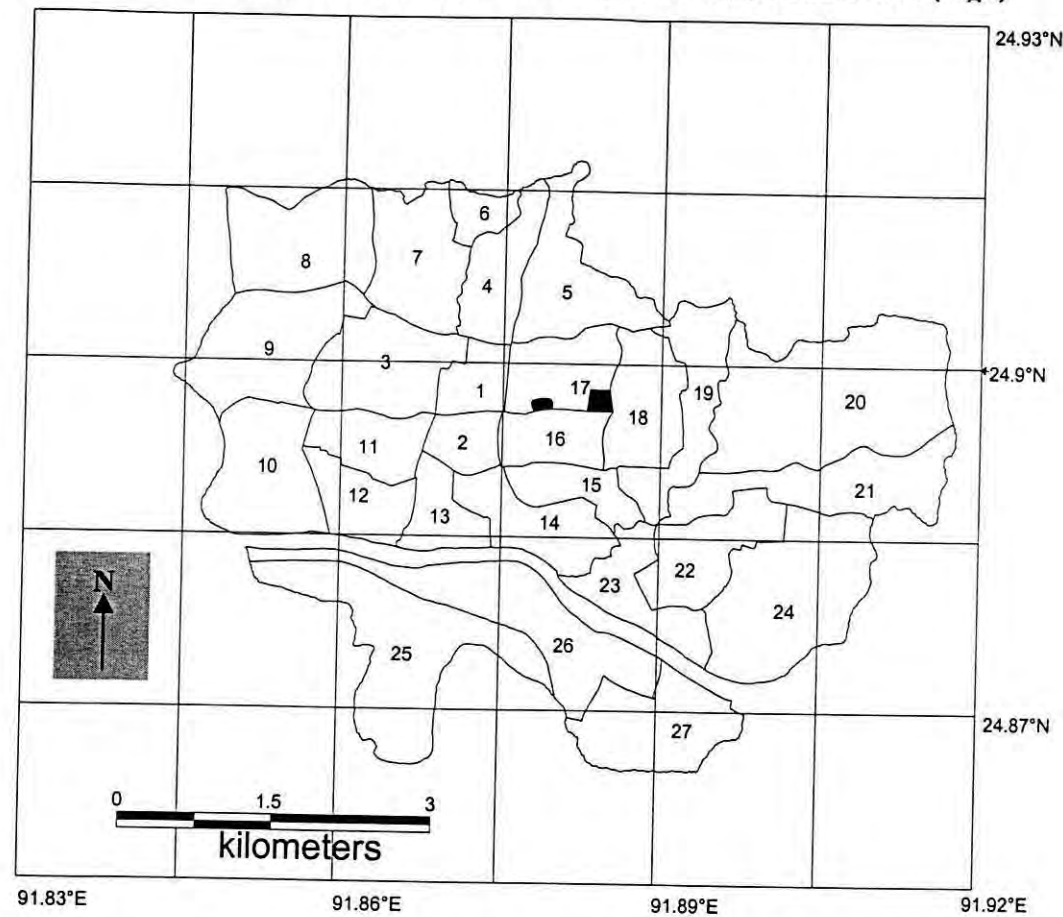


Figure 6.4 m. Map showing 2.5 times amplification plus liquefaction (moderate) plus landslide (high) area:

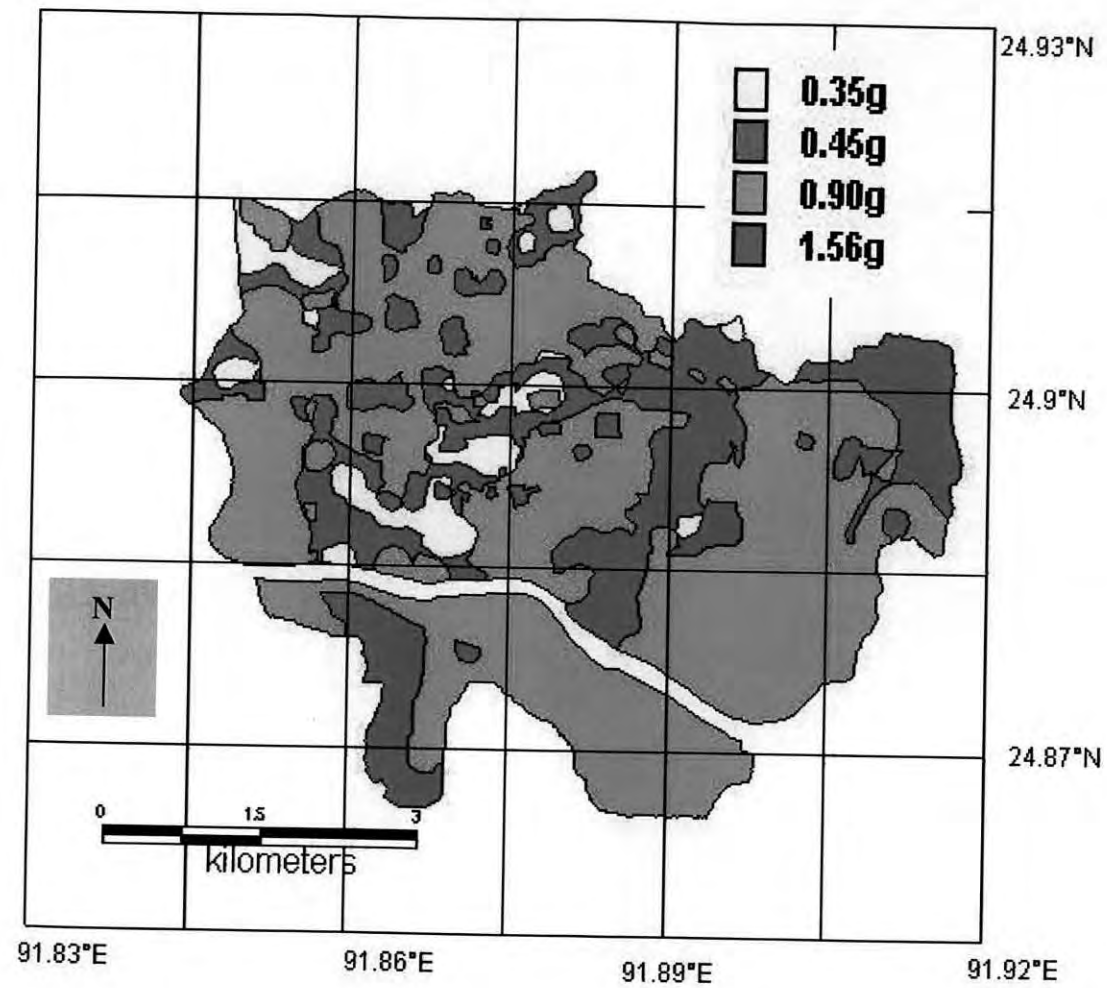


Figure 6.5. Map showing regional distribution of combined seismic peak ground acceleration in Sylhet City

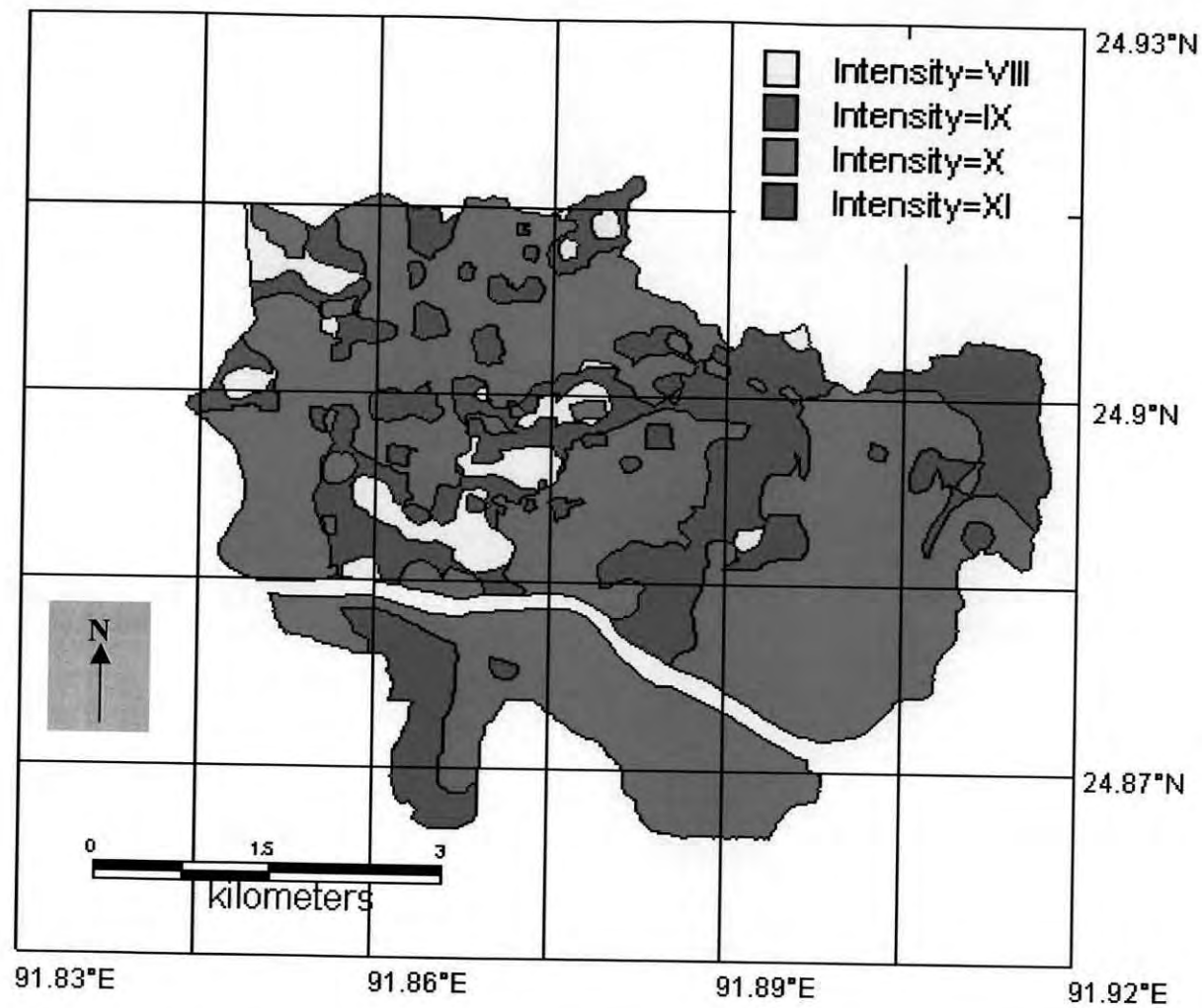


Figure 6.6. Map showing regional distribution of combined seismic hazard (MMI_F) in Sylhet City

7.1 General

Damage assessment for a region typically depends on factors such as the level of seismic hazard in the region, including the effects of local site conditions and the distributions of facilities in the region, according to earthquake engineering class. The estimation of regional seismic hazard, including local collateral hazards, and classification and the development of building inventory as well as the regional distribution of facility is described in earlier chapters. The purpose of this chapter is to provide an overview of the procedure for estimation of regional damage distributions in the GIS environment. There are several definitions for damage and also several relationships for estimation of damage due to given levels of seismic hazard for various facility type. The rest of this study deals with the estimation of damage and loss due to the scenario event. The investigations are carried out for two cases as follows:

Analysis I: Based on combined Seismic Hazard (MMI_F) considering local site effects.

Analysis II: Based on Ground Shaking Hazard (MMI_{GS}) alone

7.2 Damage Estimation of Buildings

It is to be noted that the result of this study are based on several simplifying assumptions. The analysis method and integration rules are chosen with the intent of using of GIS technology in a regional seismic hazard analysis and can easily be modified as additional information becomes available. A simplified methodology is used here to compute loss for building due to a scenario event equivalent to 1918 Srimangal Earthquake. Although the analysis presented here is simplified with some assumptions, the GIS based methodology can be extended to include more complex models as well as other inventory data. Figure 7.1 presents the detailed flowchart of damage estimation.

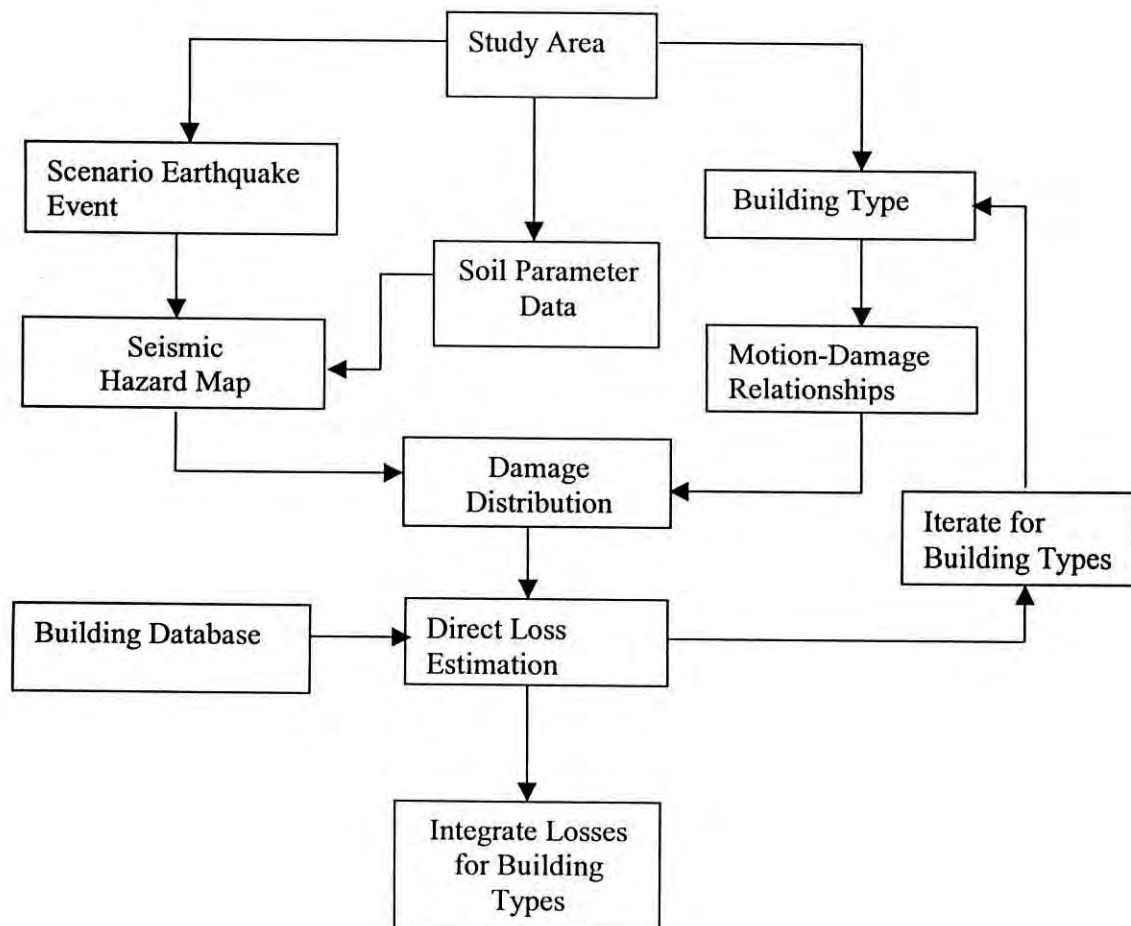


Figure 7.1. Flowchart of damage estimation methodology for a given Intensity and geo-code

7.2.1 Damage Estimation Based on Analysis I (MMI_F)

The grade of damage depends on the intensity of earthquake motion and the strength of the buildings. The strength of buildings has a close relation to the type of the building. Estimated building damage of 27 wards for combined hazard is presented in Table 7.1.

Table 7.1 Ward wise damaged buildings based on Analysis I of Sylhet City

Ward No	EMSA	EMSB1	EMSB2	EMSC	EMSD	EMSF	Total Damage
1	0	371	68	335	1	16	791
2	0	171	31	130	0	5	337
3	0	290	54	283	2	12	641
4	1	107	3	96	0	4	211
5	5	310	6	281	0	11	613
6	3	227	6	212	0	7	455
7	5	399	8	371	0	13	796
8	6	353	9	302	0	13	682
9	3	246	6	219	0	7	481
10	113	256	24	127	1	40	561
11	0	194	34	177	0	8	413
12	130	278	26	117	0	32	583
13	119	252	25	103	0	28	527
14	122	275	25	133	1	40	596
15	0	163	29	160	0	8	360
16	0	332	58	324	2	13	729
17	0	380	68	350	1	14	813
18	0	354	63	336	1	15	769
19	3	252	3	216	0	7	481
20	79	177	2	96	0	27	381
21	72	161	2	86	0	24	345

Ward No	EMSA	EMSB1	EMSB2	EMSC	EMSD	EMSF	Total Damage
22	0	94	16	94	1	5	210
23	109	245	22	118	0	37	531
24	177	407	5	233	1	65	888
25	167	375	6	202	0	54	804
26	130	297	4	170	0	48	649
27	135	308	3	178	0	49	673

Total estimated damage is about 15320 out of 25992 housing units within Sylhet City if local site effects are considered. On an average 59% of buildings are estimated to be damaged. Among different building types, A type damaged 96%, B1 type damaged 76%, B2 type damaged 76%, C type damaged 55%, D type damaged 12%, and F type damaged 15%. The damage for EMSB type, which comprises of single story and two or more storied brick masonry buildings is the highest and about 51% of the total damage. Building damage distribution according to type in the Sylhet City is shown in Figure 7.2a through Figure 7.2f. Total building damage distribution is also shown in Figure 7.3.

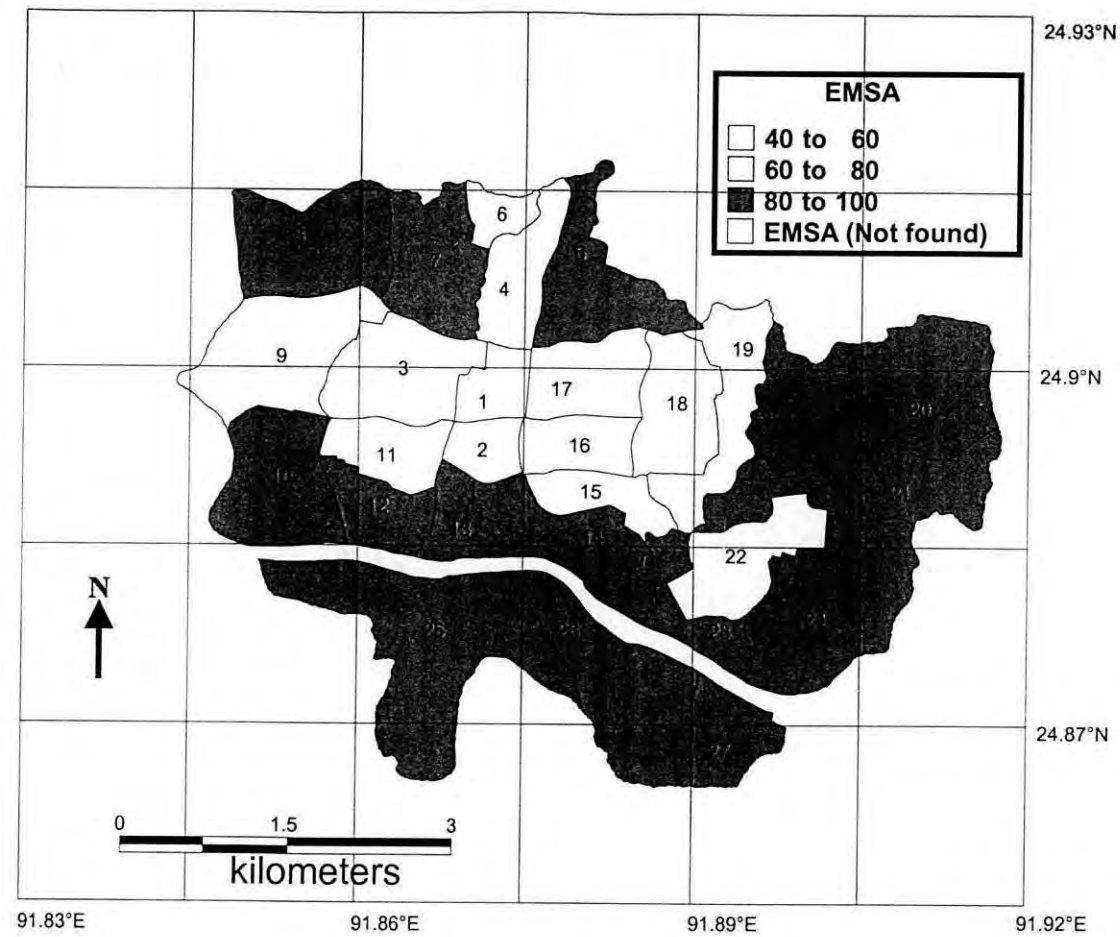


Figure 7.2a. Map showing average expected damage factor (%) of EMSA type building based on Analysis I (MMI_F) in Sylhet City

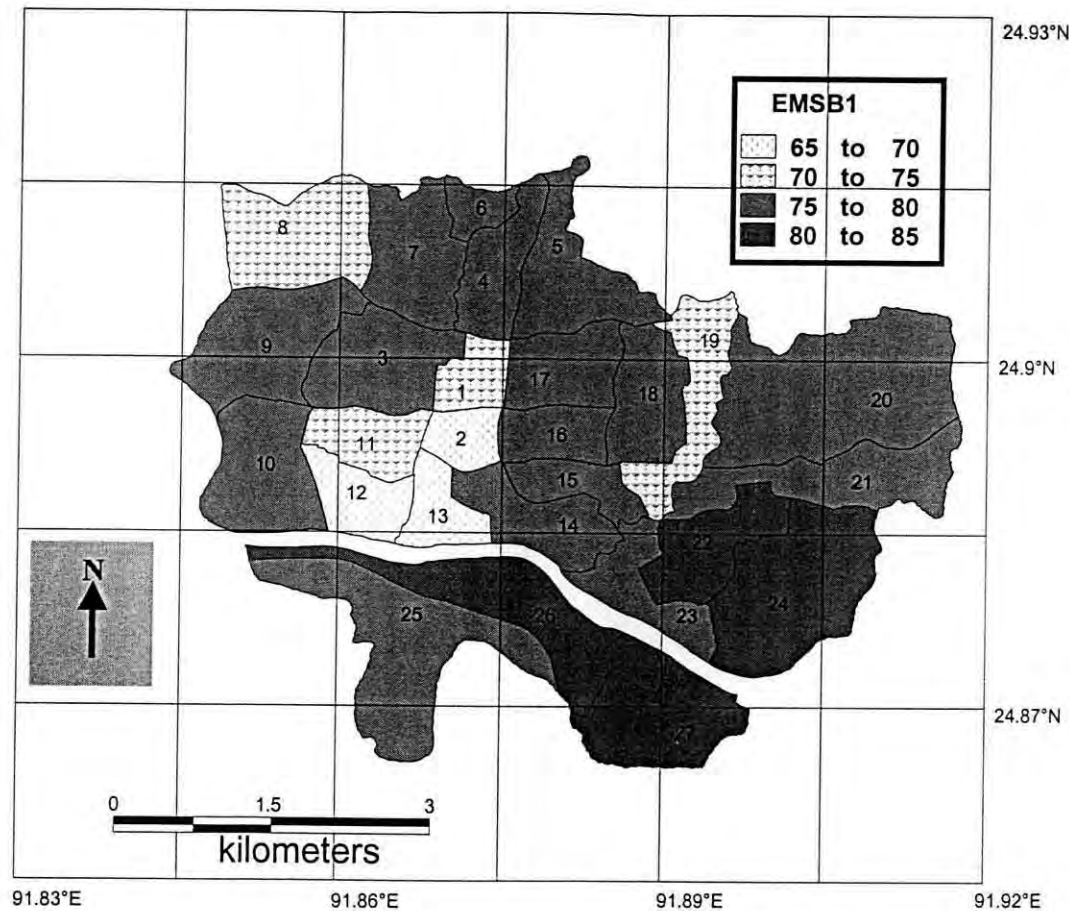


Figure 7.2b. Map showing average expected damage factor (%) of EMSB1 type building based on Analysis I (MMI_F) in Sylhet City.

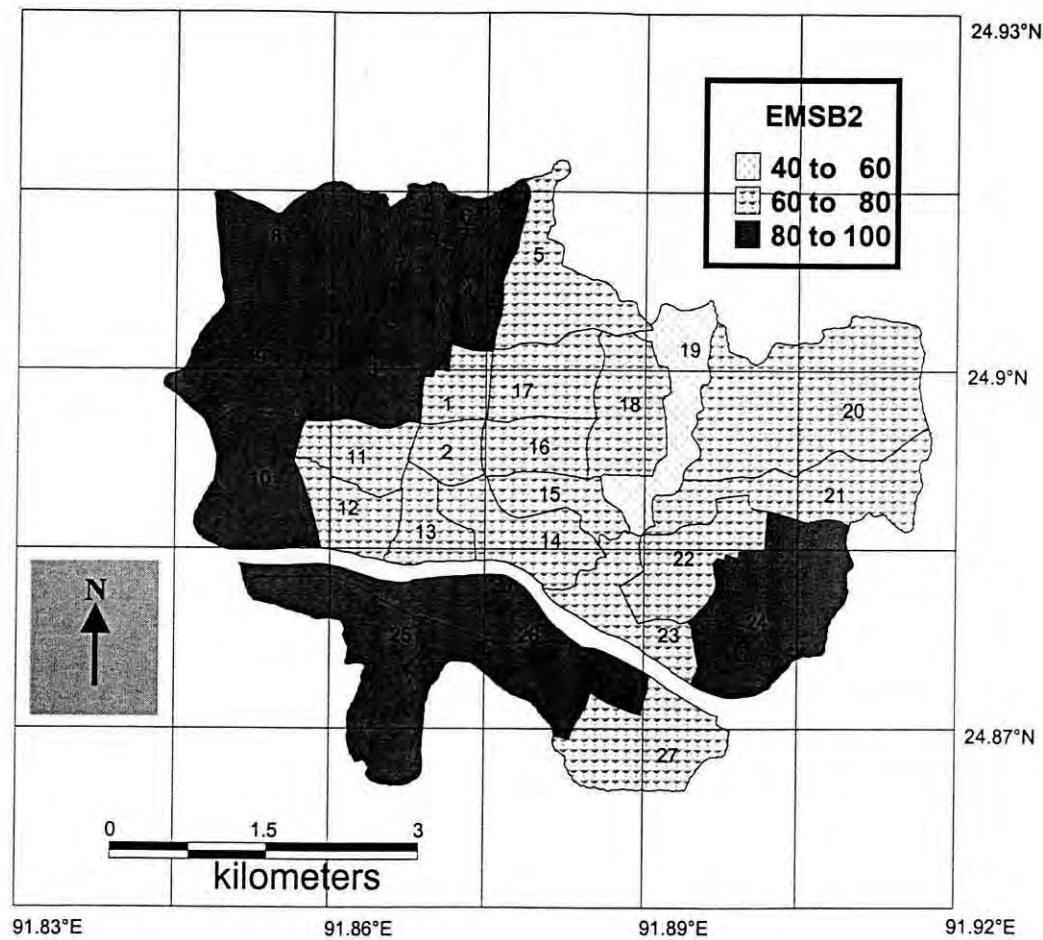


Figure 7.2c. Map showing average expected damage factor (%) of EMSB2 type building based on Analysis I (MMI_F) in Sylhet City.

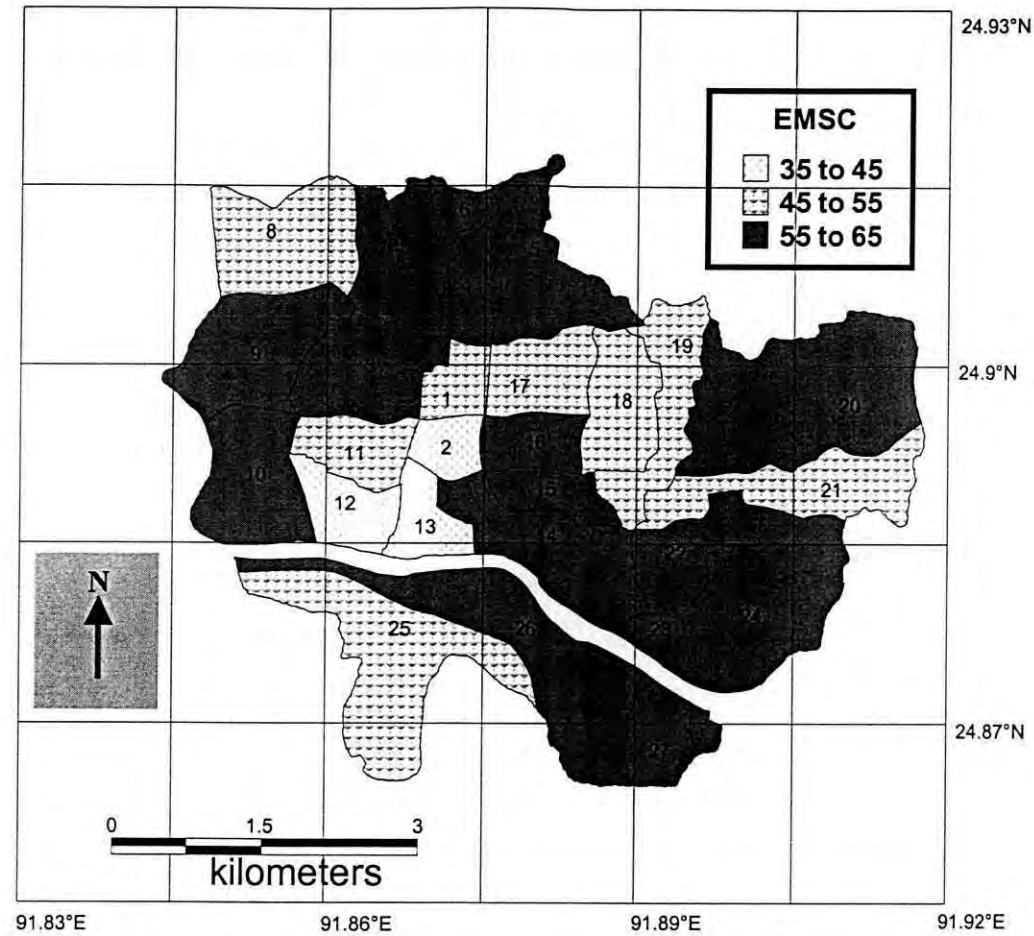


Figure 7.2d. Map showing average expected damage factor (%) of EMSC type building based on Analysis I (MMI_F) in Sylhet City.

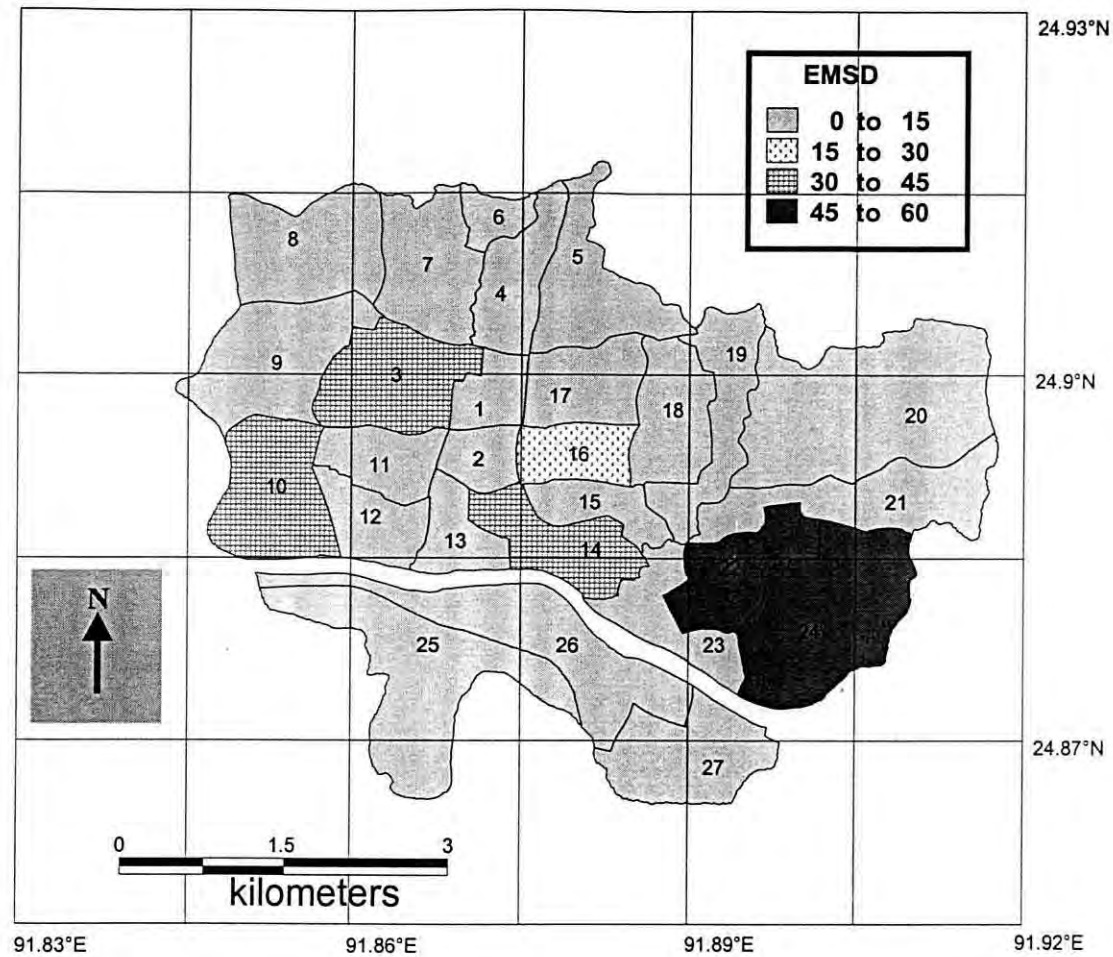


Figure 7.2e. Map showing average expected damage factor (%) of EMSD type building based on Analysis I (MMI_F) in Sylhet City.

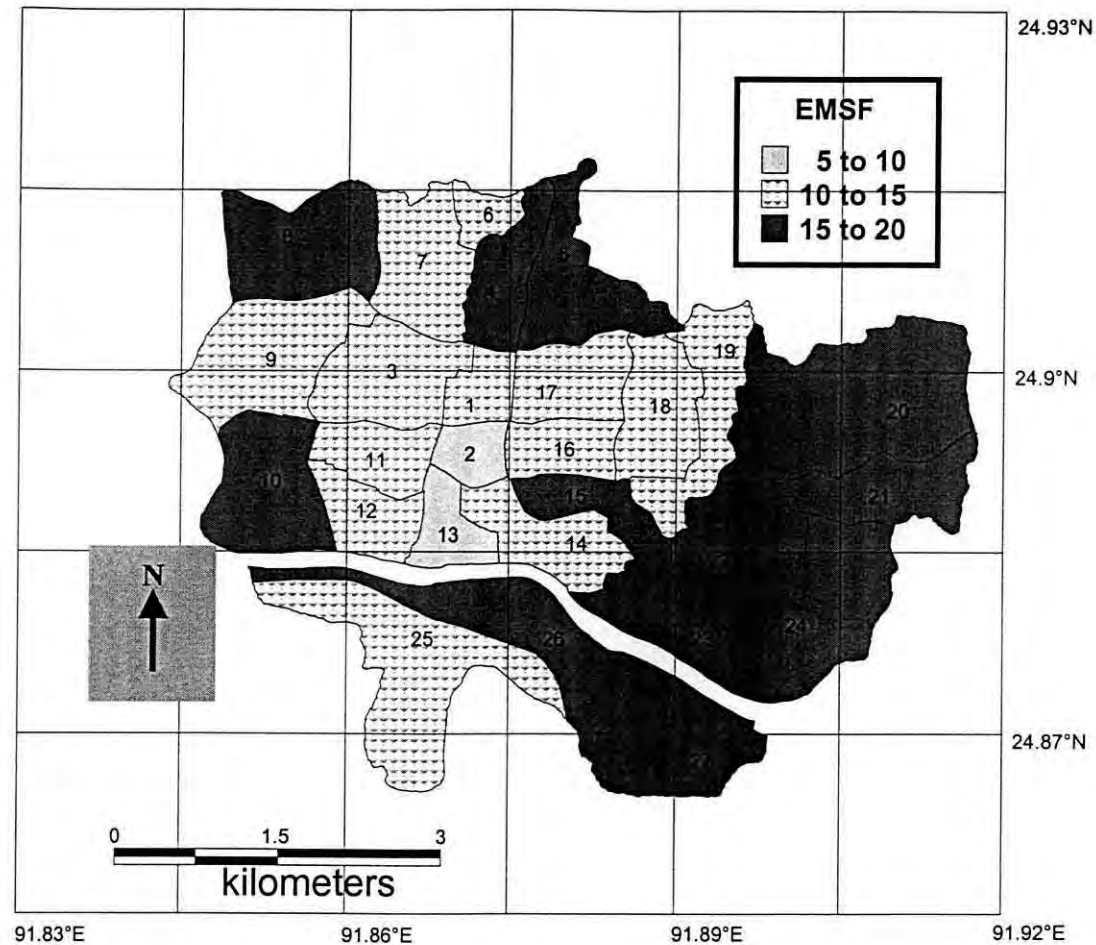


Figure 7.2f. Map showing average expected damage factor (%) of EMSF type building based on Analysis I (MMI_F) in Sylhet City

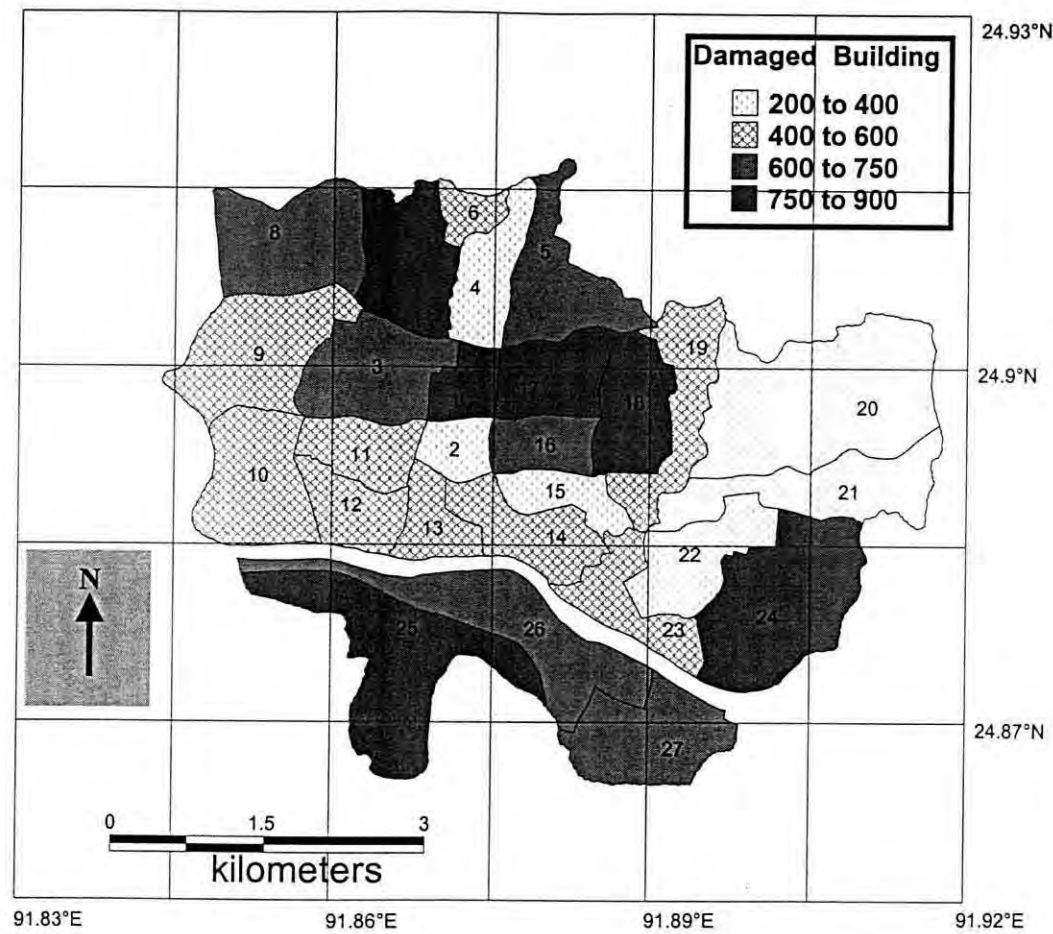


Figure 7.3. Map showing total number of damaged building based on Analysis I (MMI_F) in Sylhet City

7.2.2 Damage Estimation Based on Analysis II (MMI_{GS})

By ignoring collateral hazards such as liquefaction and landslide and only considering ground shaking (MMI_{GS}) hazard damage estimation for different types of building is given in Table 7.2.

Table 7.2 Ward wise damaged buildings based on Analysis II (MMI_{GS}) in Sylhet City.

Ward No	EMSA	EMSB1	EMSB2	EMSC	EMSD	EMSF	Total Damaged
1	0	343	67	313	0	14	737
2	0	161	32	151	0	5	349
3	0	246	51	215	1	8	521
4	1	97	2	81	0	3	184
5	5	265	6	228	0	7	511
6	3	183	4	160	0	5	355
7	5	338	8	281	0	10	642
8	6	329	8	271	0	9	623
9	3	217	6	180	0	5	411
10	106	219	24	91	0	30	470
11	0	185	33	158	0	4	380
12	121	267	27	120	0	37	572
13	120	240	25	110	0	33	528
14	117	242	25	103	0	33	520
15	0	137	27	121	0	4	289
16	0	290	55	246	1	10	602
17	0	338	67	310	1	13	729
18	0	314	60	277	0	12	663
19	3	238	3	200	0	5	449
20	76	155	2	71	0	21	325
21	68	139	2	64	0	19	292
22	0	73	15	70	0	3	161
23	104	216	22	92	0	30	464
24	163	336	5	160	0	46	710
25	161	331	5	157	0	46	700
26	110	251	4	141	0	33	539
27	124	249	3	118	0	35	529

Total estimated damage is about 13255 out of 25992 housing units with in Sylhet City. On an average 51% of buildings were estimated to be damaged. Among different building types, A type damaged 90%, B1 type damaged 67%, B2 type damaged 74%, C type damaged 45%, D type damaged 3% and F type damaged 9%. The damage for EMSB type, which comprises of single storey and two or more storied brick masonry structures was the highest and about 53% of the total damage. Building damage distribution according to type of building is shown in Figure 7.4a through Figure7.4f. Total building damage distribution is also shown in Figure 7.5. Figure 7.6 compares building damage (%) for Analysis I and Analysis II.

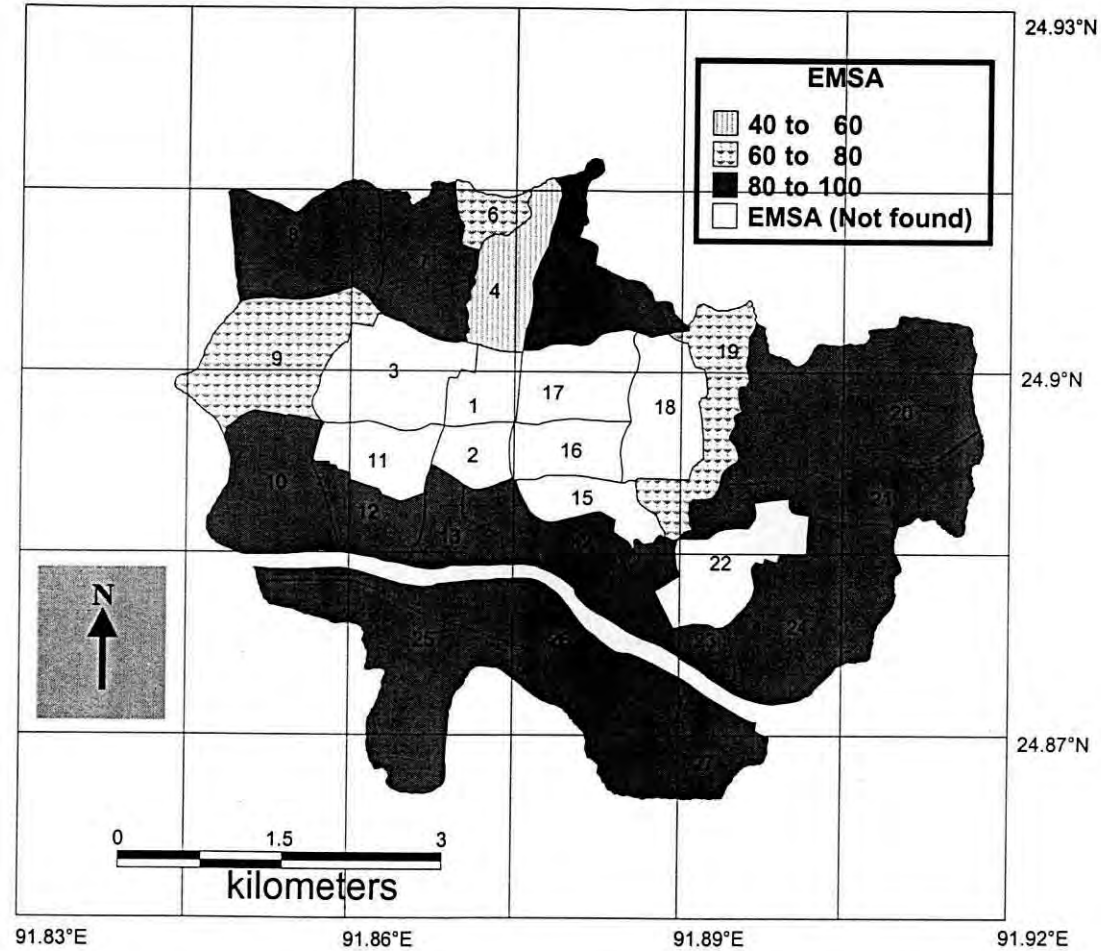


Figure 7.4 a .Map showing average expected damage factor (%) of EMSA type building based on Analysis II (MMI_{GS}) in Sylhet City.

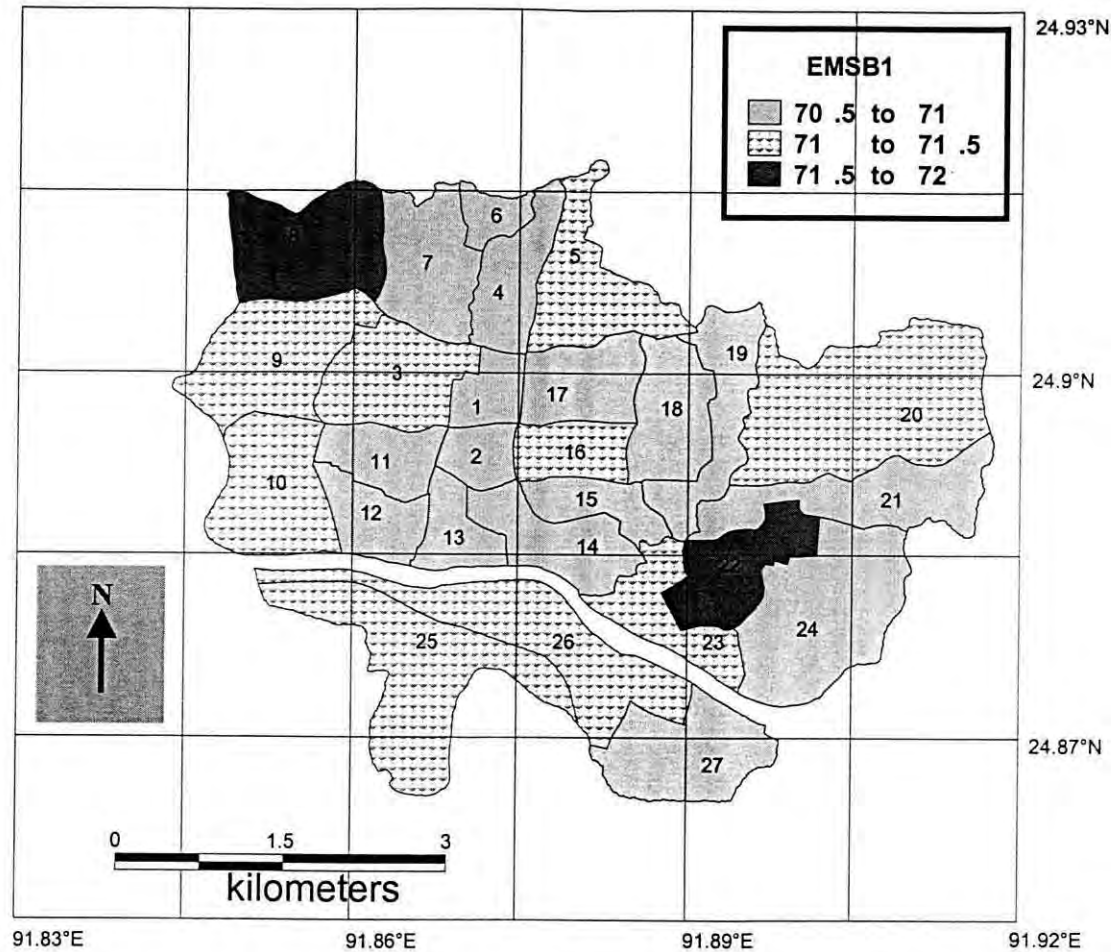


Figure 7.4 b. Map showing average expected damage factor (%) of EMSB1 type building based on Analysis II (MMI_{GS}) in Sylhet City.

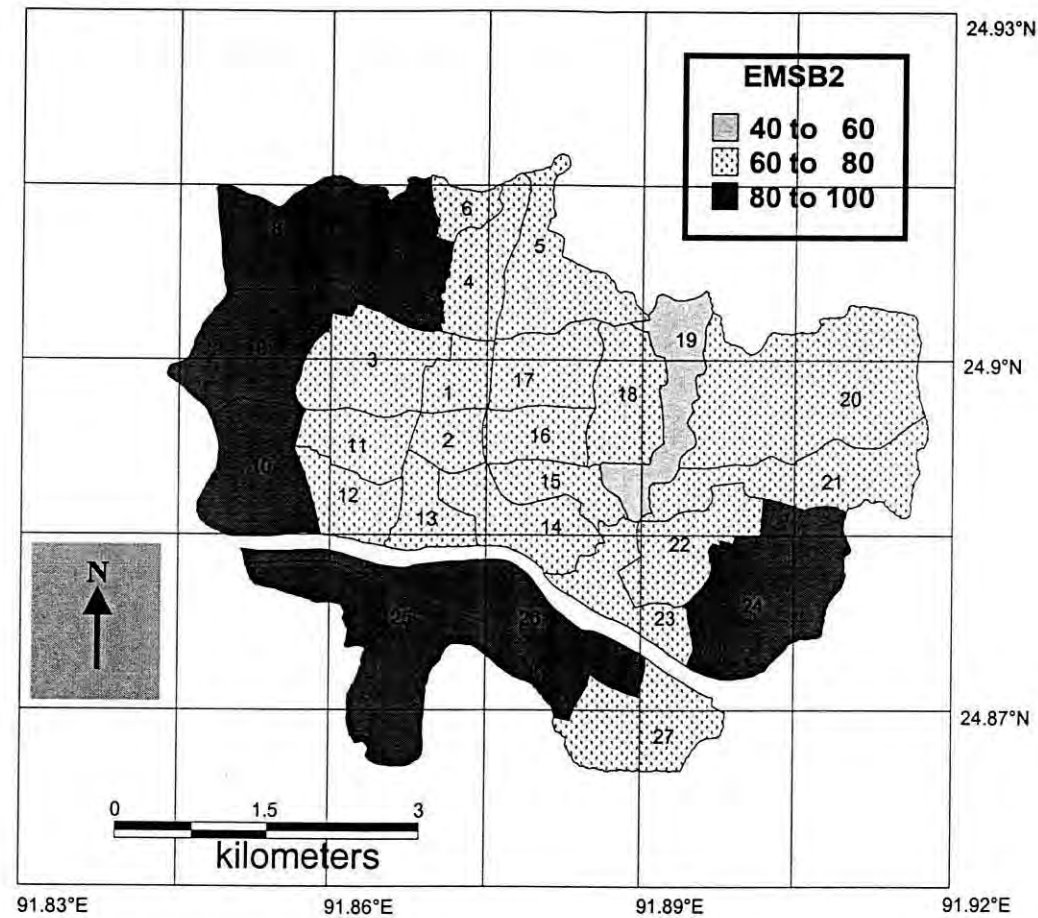


Figure 7.4 c .Map showing average expected damage factor (%) of EMSB2 type building based on Analysis II (MMI_{GS}) in Sylhet City.

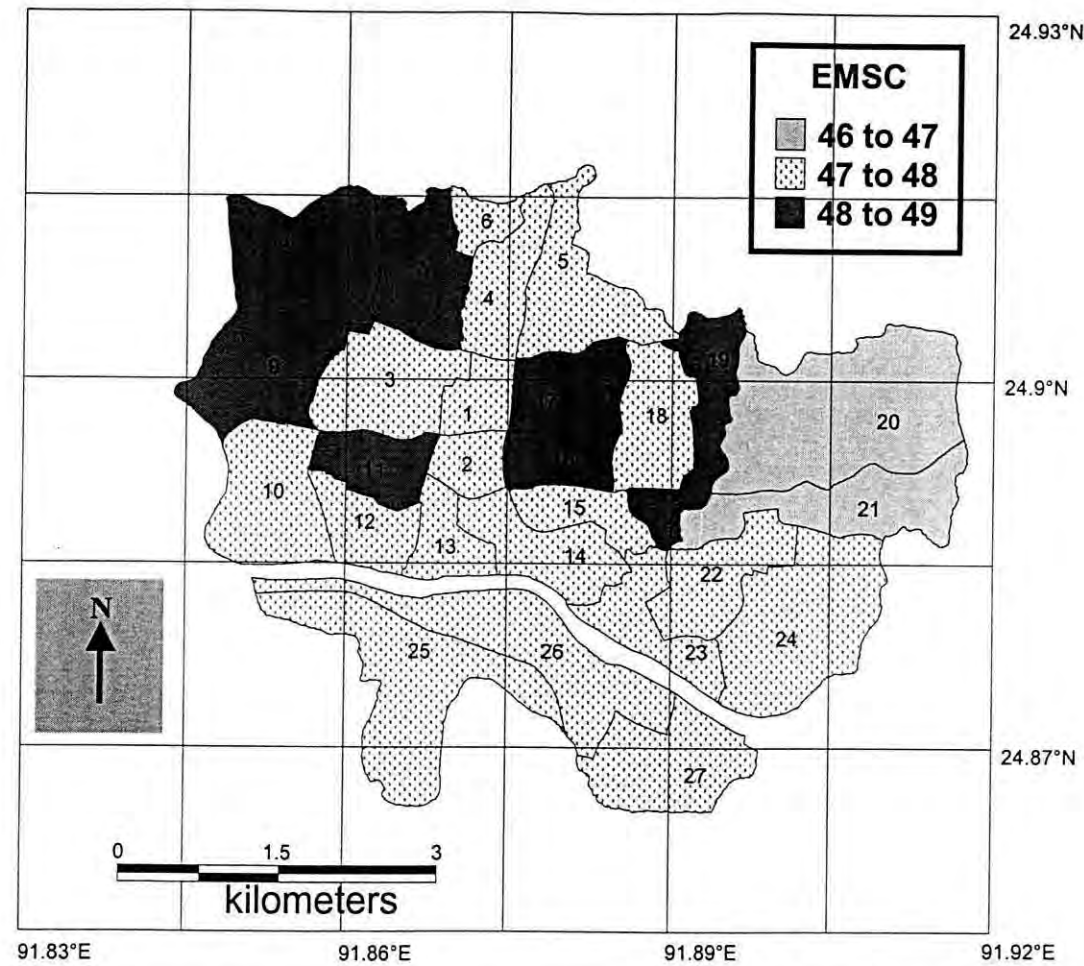


Figure 7.4 d. Map showing average expected damage factor (%) of EMSC type building based on Analysis II (MMI_{GS}) in Sylhet City.

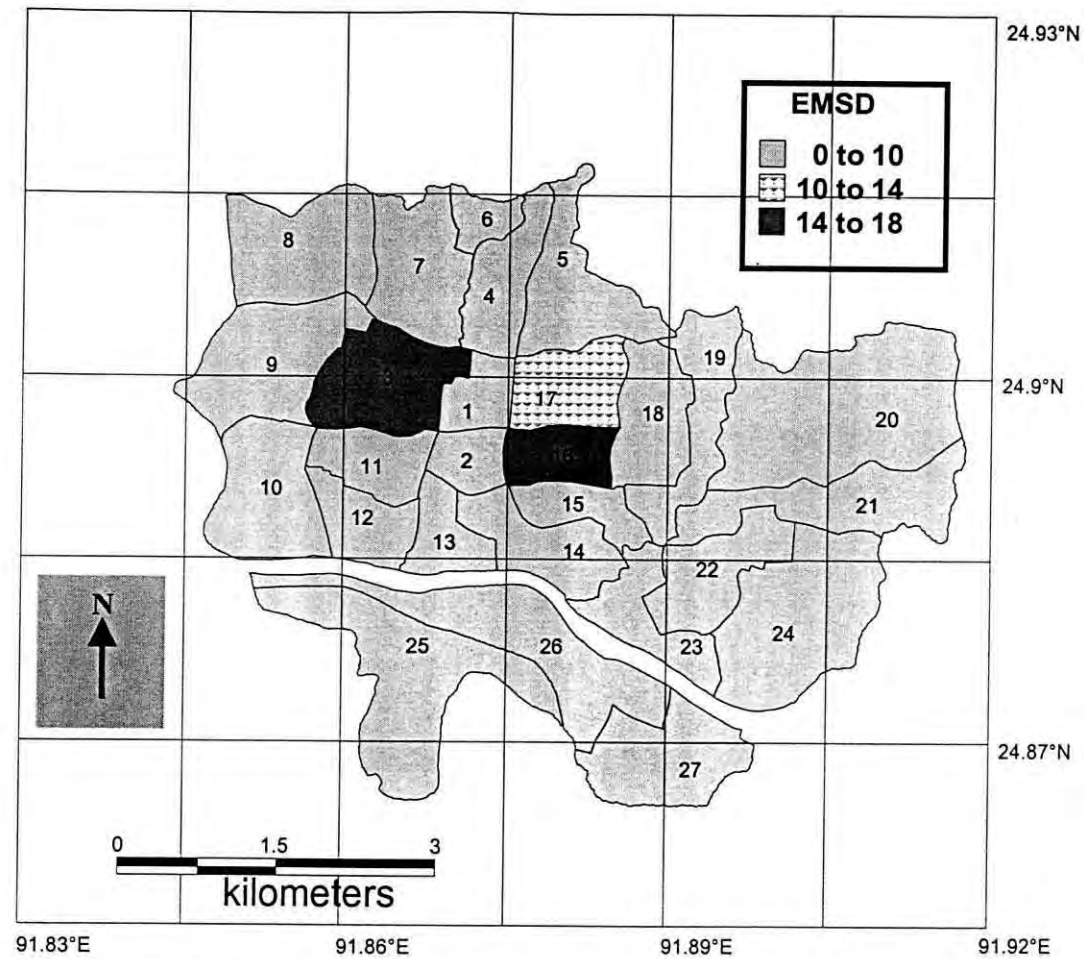


Figure 7.4 e. Map showing average expected damage factor (%) of EMSD type building based on Analysis II (MMI_{GS}) in Sylhet City.

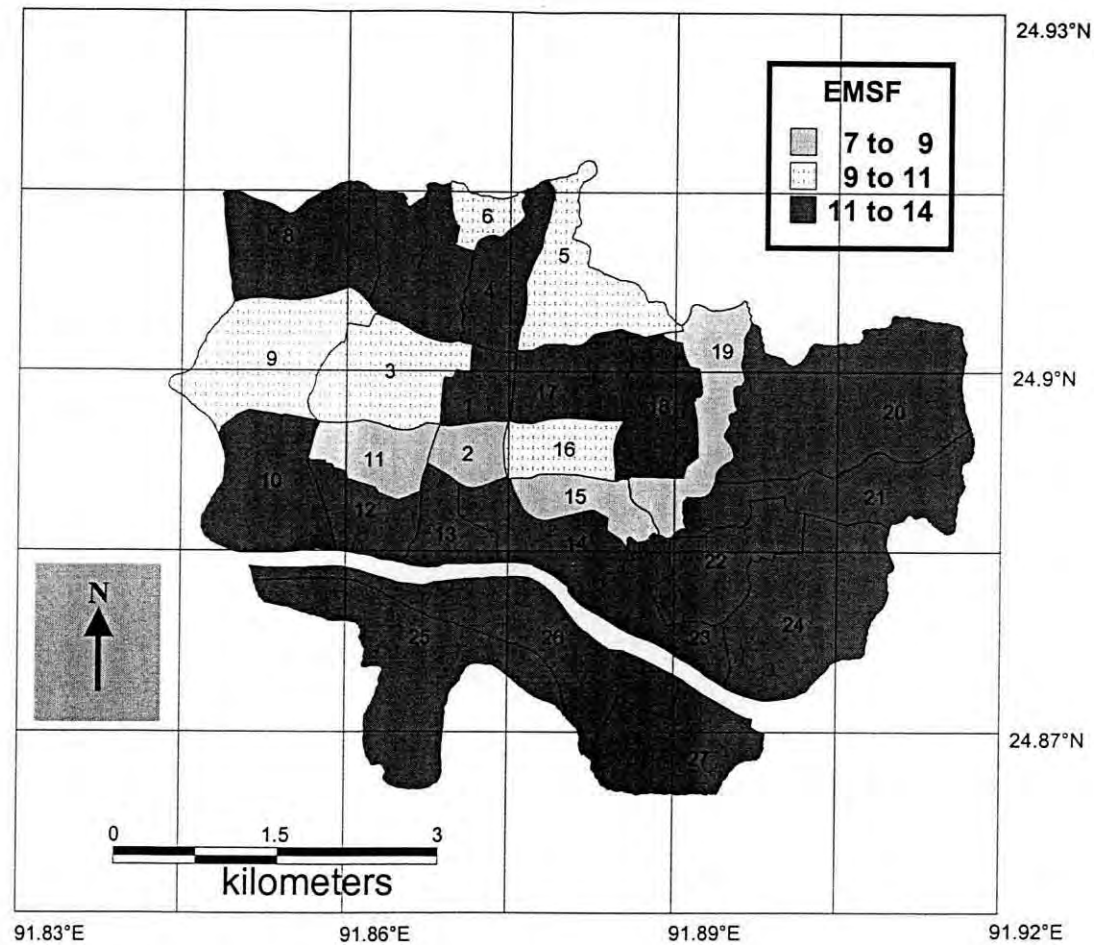


Figure 7.4 f. Map showing average expected damage factor (%) of EMSF type building based on Analysis II (MMI_{GS}) in Sylhet City.

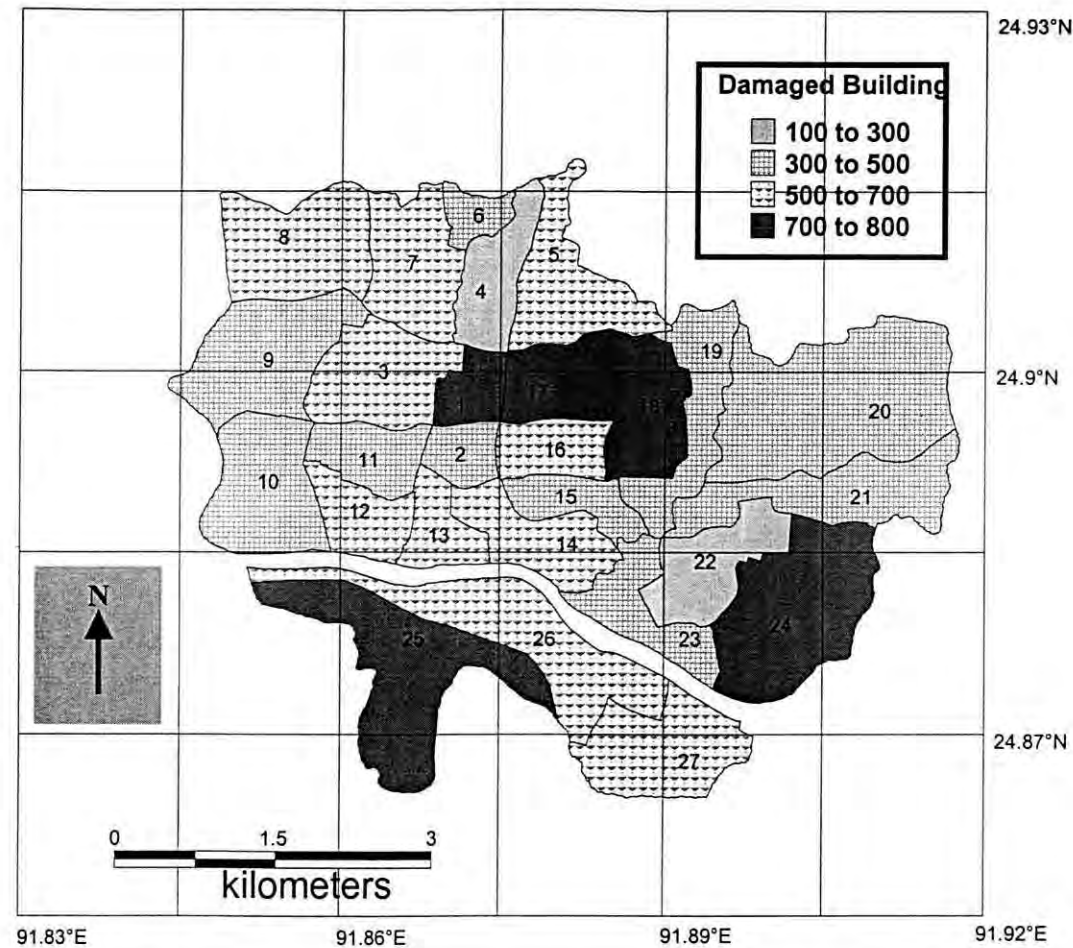


Figure 7.5. Map showing distribution of total damaged building based on Analysis II (MMI_{GS}) in Sylhet City.

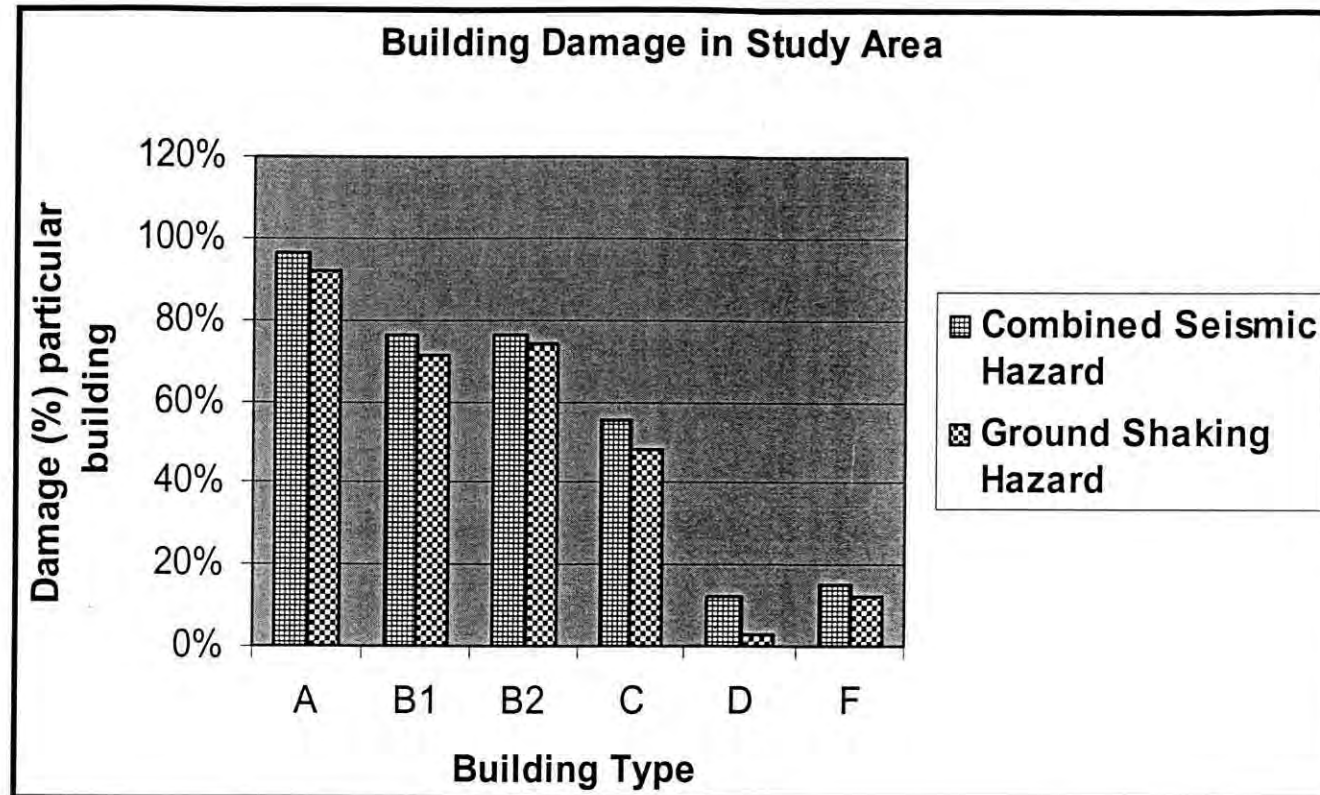


Figure 7.6. Buildings damage in Sylhet City Corporation based on Analysis I (MMI_F) and Analysis II (MMI_{GS})

7.3 Damage Estimation of Water Pipelines

Quantitative studies on seismic damage for water supply pipelines in Bangladesh are not available. Although the strength of the pipeline materials is not particularly different from that of the pipeline materials in other countries, it is considered that the construction quality of the joints always leads to problems. Damage of water pipeline of Sylhet City is based on some recent damage functions developed for different water line systems during Chi-Chi earthquake in Taiwan (2002).

The pipeline distribution map is overlaid with seismic microzonation map in GIS environment and pipeline length according to the peak ground acceleration as listed in Table 7.3. Asbestos Concrete, PVC and Proposed pipeline distribution of different diameter with combined seismic microzonation map is shown respectively in Figure 7.7a through Figure 7.7c in the study area. Material of proposed pipeline is not mentioned in the Existing water pipeline distribution map. For this analysis, proposed pipeline's material is assumed as PVC.

Pipelines is divided in to three groups according to their diameters, namely pipelines as With diameters $\leq 65\text{mm}$, $65\text{mm} < \text{diameters} < 150\text{mm}$, and diameters $\geq 150\text{mm}$. The pipelines with diameters $\leq 65\text{ mm}$ is classified as small pipelines in this study, and the length of this group is 1.25km (1% of all pipelines), The remaining pipelines are further divided into two groups, the pipelines with diameters greater than 150mm as large pipelines and the pipe line with diameter between 65 and 150 mm as medium pipelines. The lengths of these two groups are 77km (65%) and 40.5 km (34%), respectively.

Table 7.3 Water Pipeline affected by different peak ground acceleration values based on Analysis I (MMI_F)

Material	Diameter (mm)	Length (km)			
		0.35g	0.45g	0.9g	1.56g
AC	100	0.17	0.08	0	0
	150	0.8	1.6	2.18	0
	200	0	0.48	2.99	0
	250	0.48	0.97	0.87	0
	300	0.4	0	1.52	0
CI	100	0.3	0.16	0	0
	150	0	0.5	0	0
	200	0.06	0.61	0	0
GI	50	0	0	0.06	0
	100	0.18	1.37	1.75	0.21
	150	0	0.058	0.27	0
	200	0.13	0	1.1	0
MS	100	0	0.27	0	0
	150	0	0.19	0	0
	250	0.17	0	0	0
PVC	50	0.39	0.6	0.21	0
	75	0.97	0.61	1.89	0
	100	2.61	6.91	7.73	0.25
	150	1.15	4.33	12.24	0
	200	0.48	1.02	2.34	0.25
PVC (Proposed)	100	1.99	3.15	9.53	0.29
	150	0.44	4.72	17.48	0.28
	200	0	2.98	11.49	0.72
Total length		11.0	30.90	73.95	2

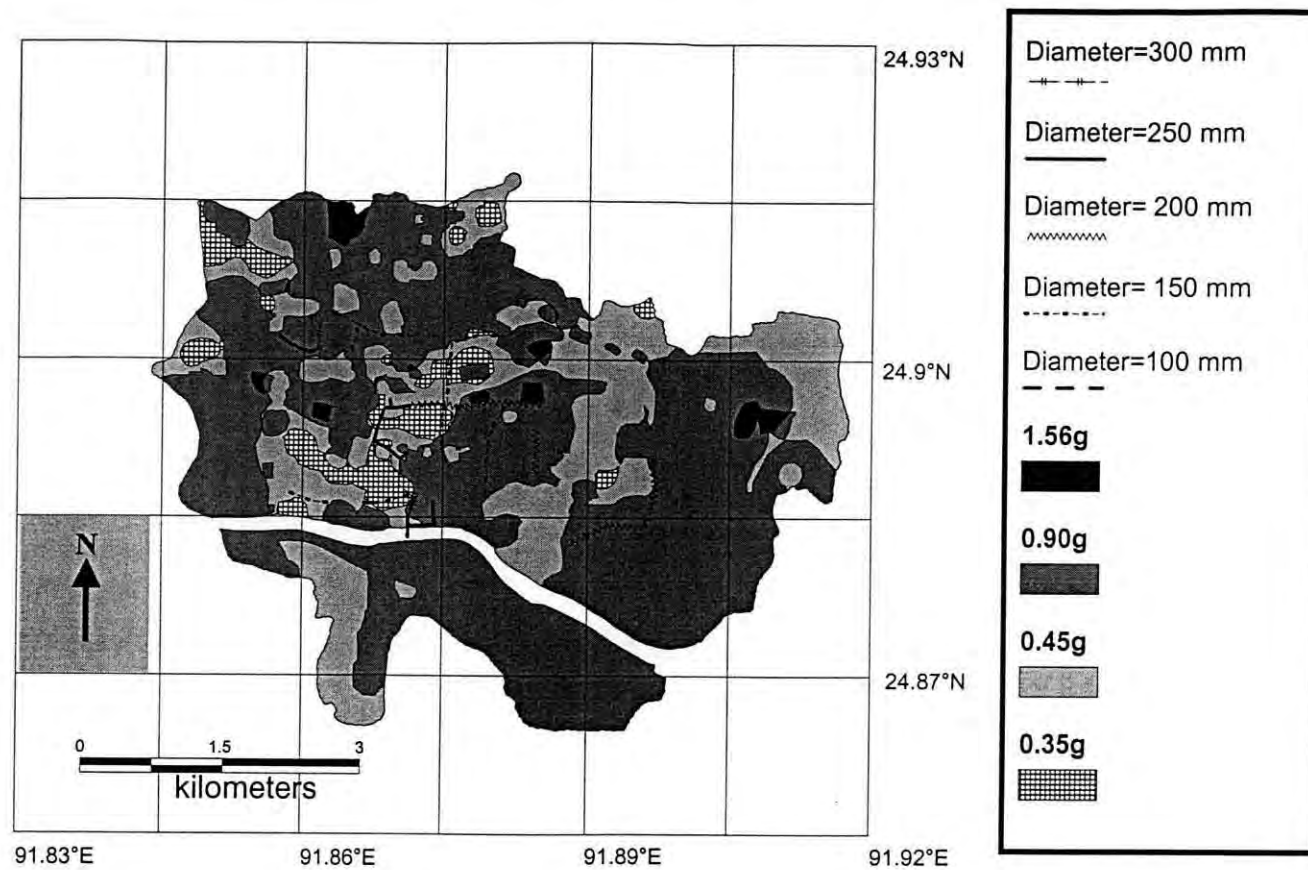


Figure 7.7 a .Map showing Asbestos Concrete pipeline distribution of different diameter with seismic microzonation map of Analysis I (MMI_F)

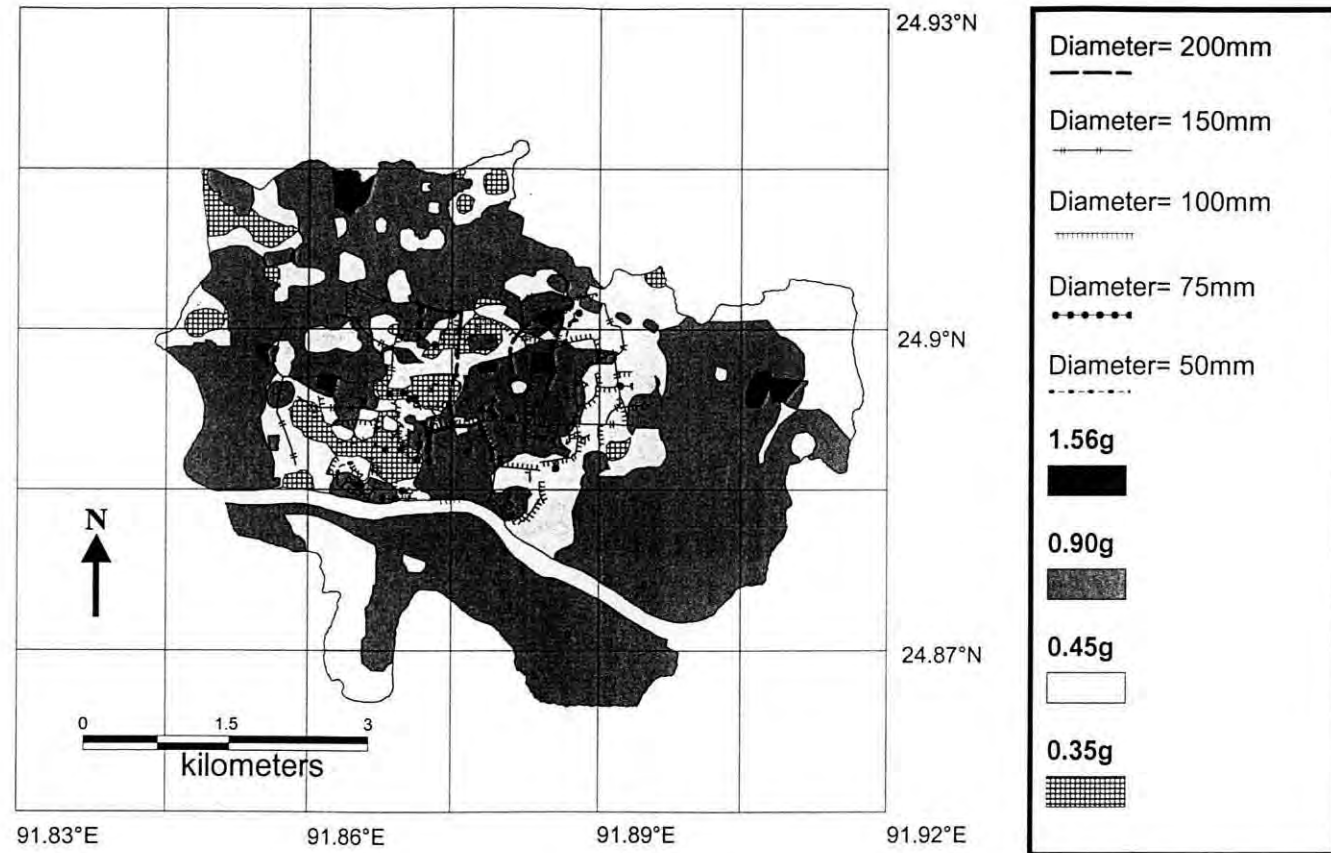


Figure 7.7 b. Map showing PVC pipeline distribution of different diameter with seismic microzonation of analysis I (MMI_F)

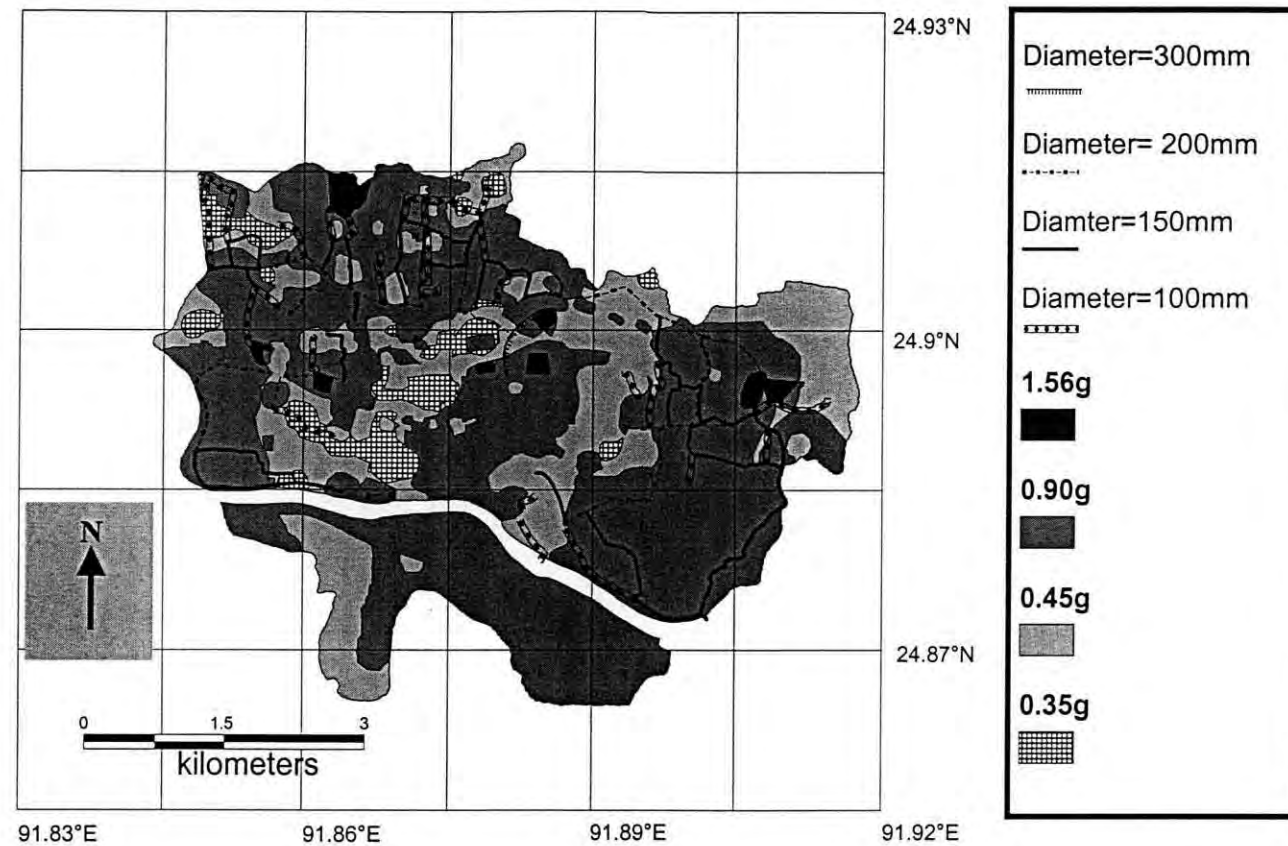


Figure 7.7 c. Map showing Proposed pipeline distribution of different diameter with seismic microzonation map of analysis I (MMI_F)

The location of intakes, reservoirs, treatment plants and other ground water wells have ignored in this study because of lack of data. In this study it is assumed that construction quality of joints always leads to problems Table 7.4 Shows water pipeline damage points according to diameter range.

Table 7.4 Water pipeline damage estimation according diameter

PGA	0.35g			0.45g		
Pipeline	DR	Length (km)	Repair no	DR	Length (km)	Repair no
Small	3.88	0.38	1	5.8	0.6	3
Medium	1	6.2	6	1.3	12.12	16
Large	0.6	4.1	2	0.8	16.8	13
PGA	0.90g			1.56g		
Pipeline	DR	Length	Repair no	DR	Length	Repair no
Small	17.4	0.28	5	42	0	0
Medium	2.35	21.3	50	3.8	0.75	3
Large	1.85	54	100	3.6	1.25	5
Total damage point =204						

The pipe performance parameter that is most significant in controlling the respective mechanism and pipe joints usually fail such as extension, compression, and rotation. In 1995 Kobe earthquake, approximately two thirds of the pipe failures were from joint extension or compression. One reason that other types of failures were minimized in Kobe is that 89% of the pipe was either ductile iron or welded steel. From Table 7.4 it is found that total number of damage point based on Analysis I is 204.

Similarly, it is also estimated number of damaged points based on Analysis II. Asbestos Concrete, PVC and proposed line distribution of different diameter with Ground shaking hazard map is shown respectively Figure 7.8a through Figure 7.8c. The number of damage points are 121 and seem to be less as in the study area basically used PVC pipe (81%) however PVC is better against horizontal forces due to its flexibility but construction joints is difficult and very poor.

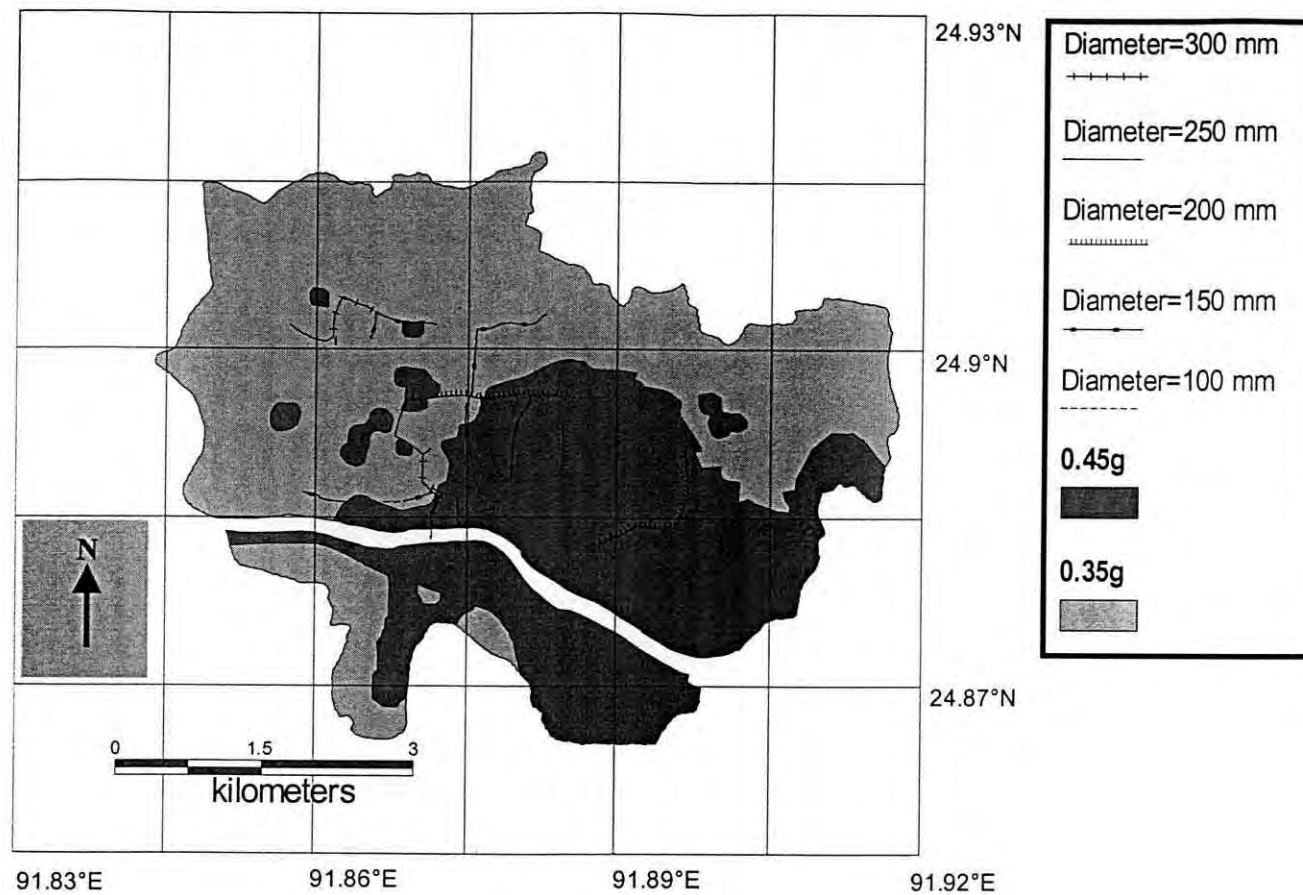


Figure 7.8a. Map showing Asbestos Concrete pipeline distribution of different diameter with seismic microzonation map of analysis II (MMI_{GS})

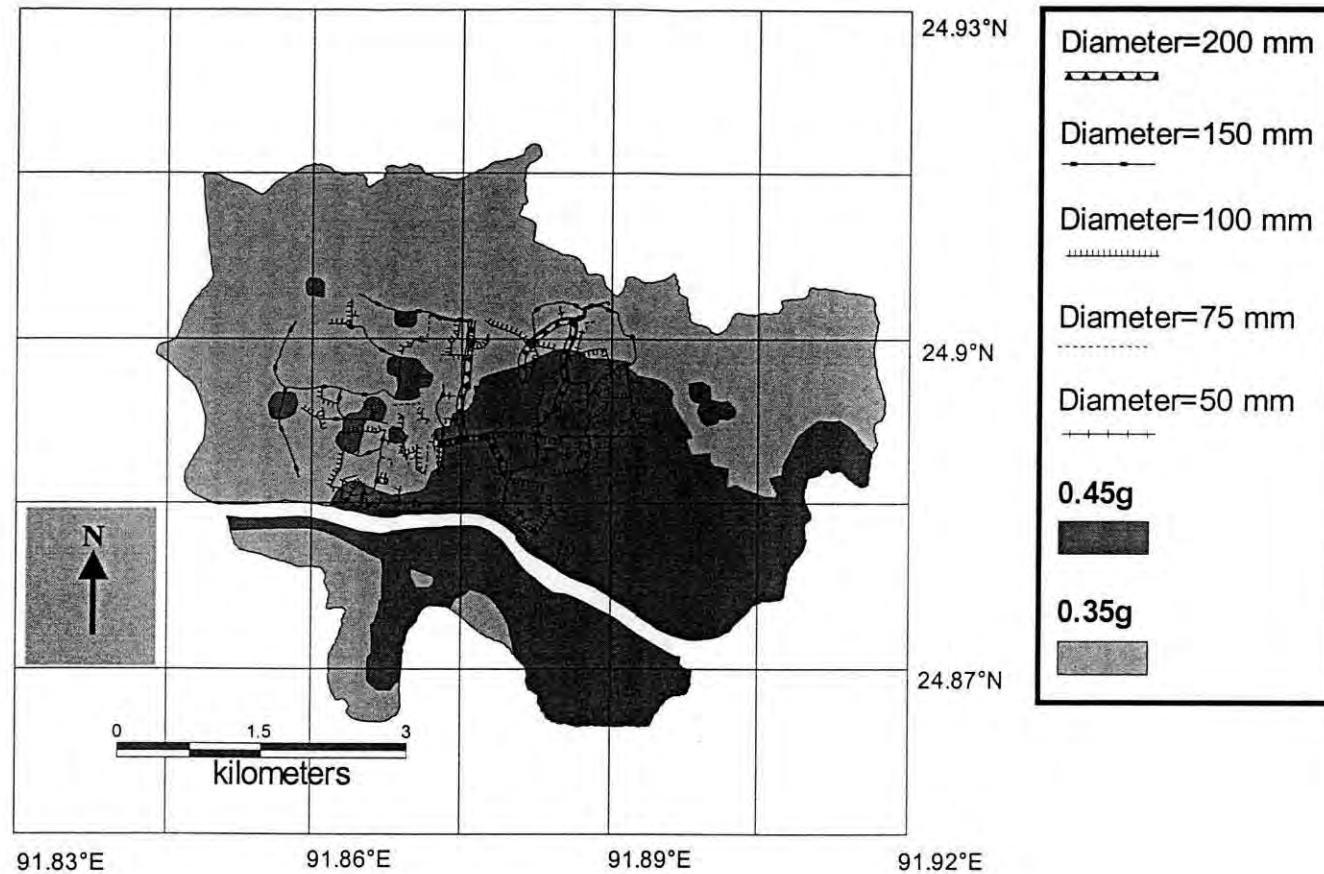


Figure 7.8b. Map showing PVC pipeline distribution of different diameter with seismic microzonation map of analysis II (MMI_{GS})

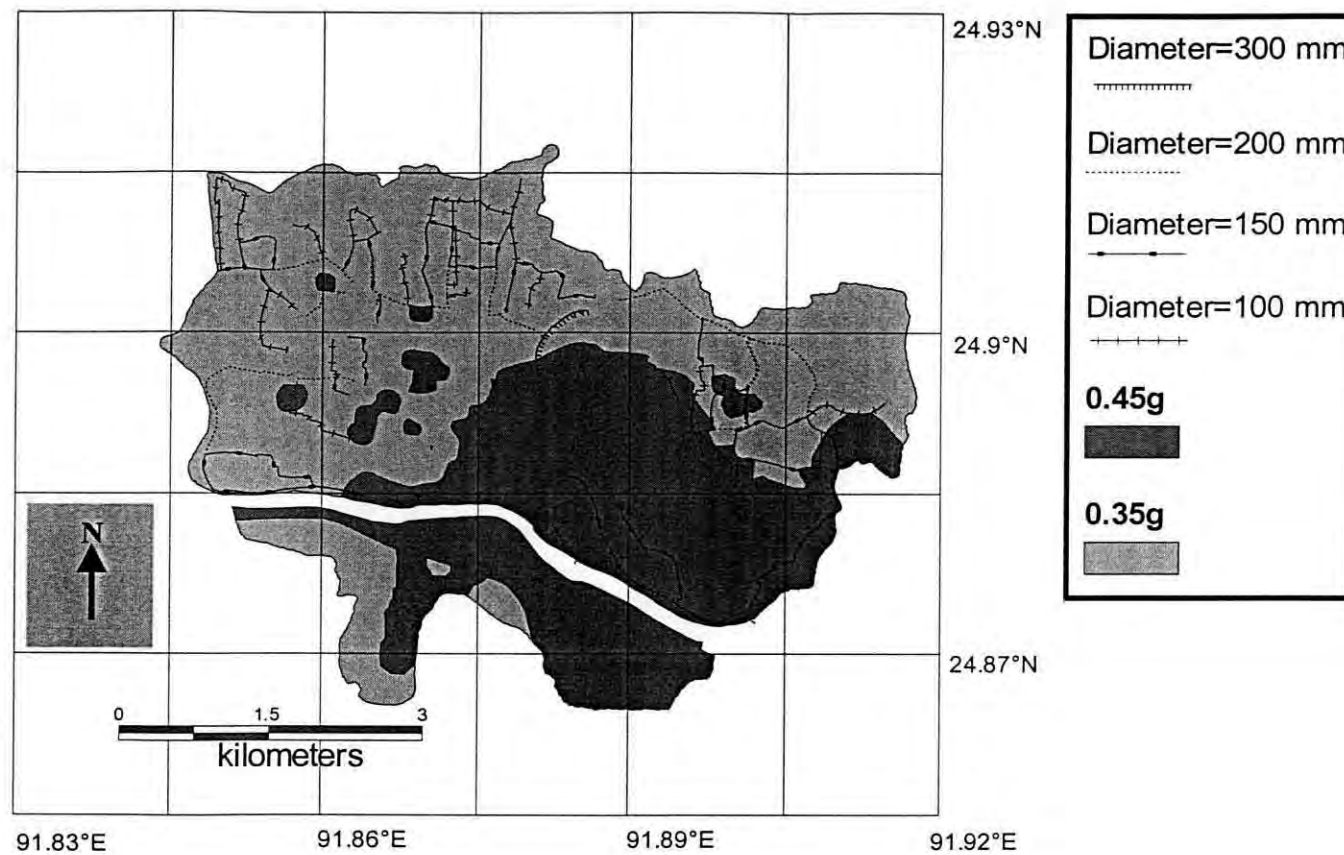


Figure 7.8c. Map showing PVC (proposed) pipeline distribution of different diameter with seismic microzonation map of Analysis II (MMI_{GS})

7.4 Human Casualty

Direct causes of earthquake casualties include collapse of buildings, fires, tsunamis, rock falls and landslides. The governing causes depend on the characteristics of the sites concerned. Fires are the main cause in locations such as Japan and California, where many wooden houses exist. Tsunamis should be emphasized in areas such as Sumatra of Indonesia. Human casualties due to building collapse are a general phenomenon observed in all areas subject to earthquake disasters. Building collapse will be the most notable caused of human casualty, particularly in Sylhet City area, because of the following reason. Tsunamis do not affect the site. Slopes of potential landslides are distributed only limited area. Fire do not causes severe affect, as wooden house is limited.

The study adopted the basic concept introduced by Coburn et al. (1992) for the estimation of casualties based on human casualties due to worldwide earthquake damages. Coburn et al's model is explained in Article 3.15. Table 3.7 shows the values of M1, M2, M3 and M4. Average household size for urban area is 6.4 (BBS, 1991) however, for this study it is assumed 6 for Sylhet City. The results of calculation in this study will vary according time cycle such as morning, noon and nighttime occurrence of the earthquake. Human casualties based on "Building damages". This damage includes damaged and collapsed buildings, excluding buildings destroyed by fire or tsunami.

7.4.1 Human Casualties Estimation based on Analysis I (MMI_F)

Human casualties if scenario event equivalent to 1918 Srimangal Earthquake reoccurs in that case based on Analysis I (MMI_F), the total number of estimated fatalities in 27 wards of study area according to time cycle of the day is estimated and presented in Table 7.5. The distribution of Fatalities of the study area is also shown in Figure 7.9a through Figure 7.9c

Table 7.5 Estimated numbers of total fatalities based on Analysis I (MMI_F) in Sylhet City

Ward No	Morning	Noon	Night
1	833	562	1046
2	269	186	337
3	808	550	1014
4	244	170	308
5	715	485	901
6	569	385	713
7	1012	685	1271
8	739	499	926
9	551	377	691
10	508	348	640
11	474	325	593
12	350	234	434
13	467	312	581
14	732	502	923
15	457	311	575
16	952	646	1199
17	984	666	1237
18	874	589	1098
19	438	300	552

Ward No	Morning	Noon	Night
20	316	216	397
21	343	238	432
22	288	196	362
23	614	418	775
24	1294	876	1627
25	761	515	959
26	888	601	1116
27	769	521	967

Total estimated number of fatalities for the scenario earthquake is 17,249 in the morning, 21,674 in the night and 11,713 in the noon. It is about 5.5%, 7.0% and 3.75% of the total population of Sylhet City based on Analysis I (MMI_F).

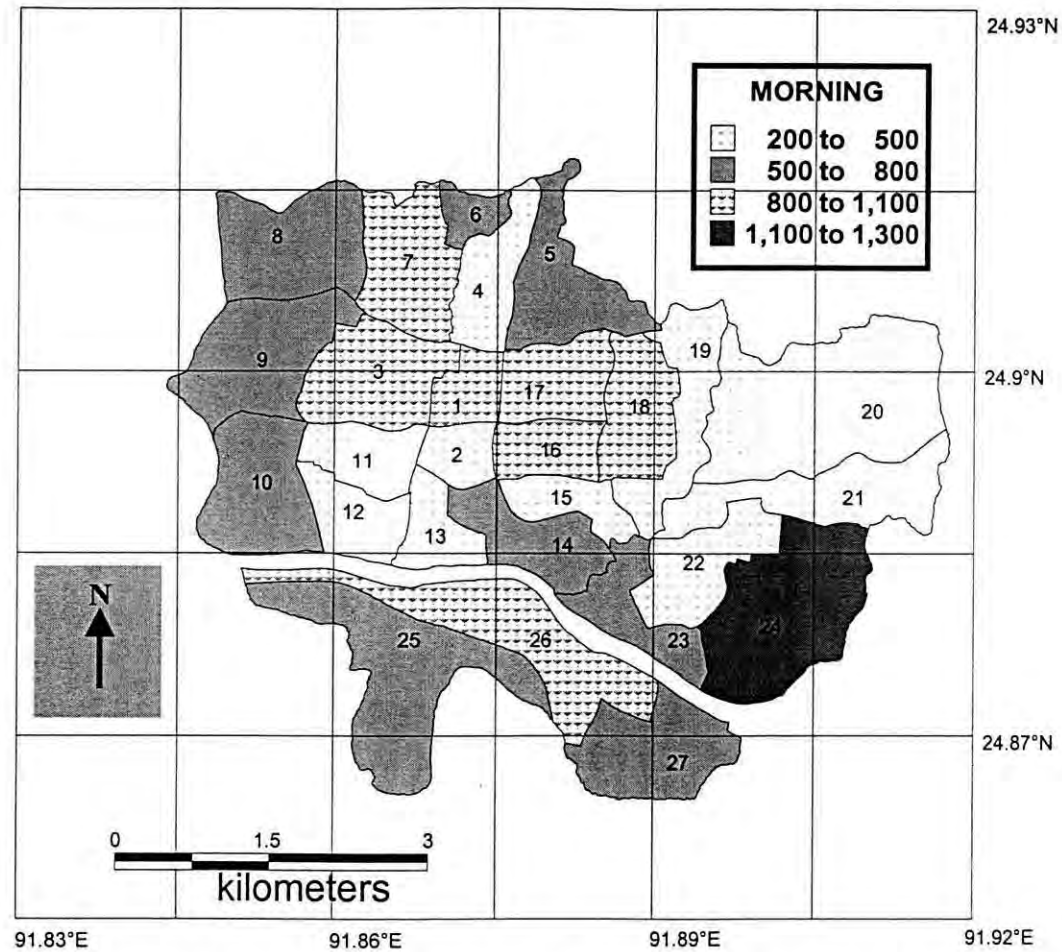


Figure 7.9a Map showing total number of deaths in morning based on Analysis I (MMI_F) in Sylhet City

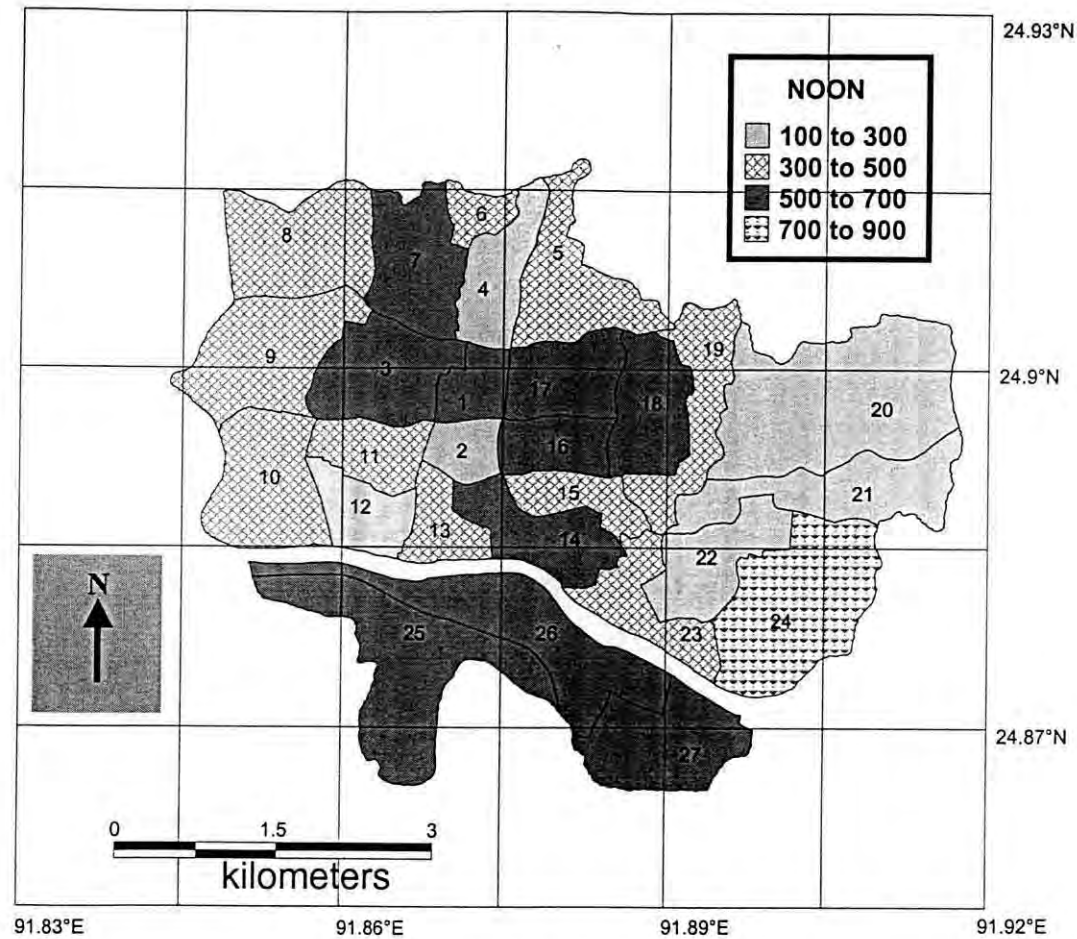


Figure 7.9b .Map showing total number of deaths at noon based on Analysis I (MMI_F) in Sylhet City

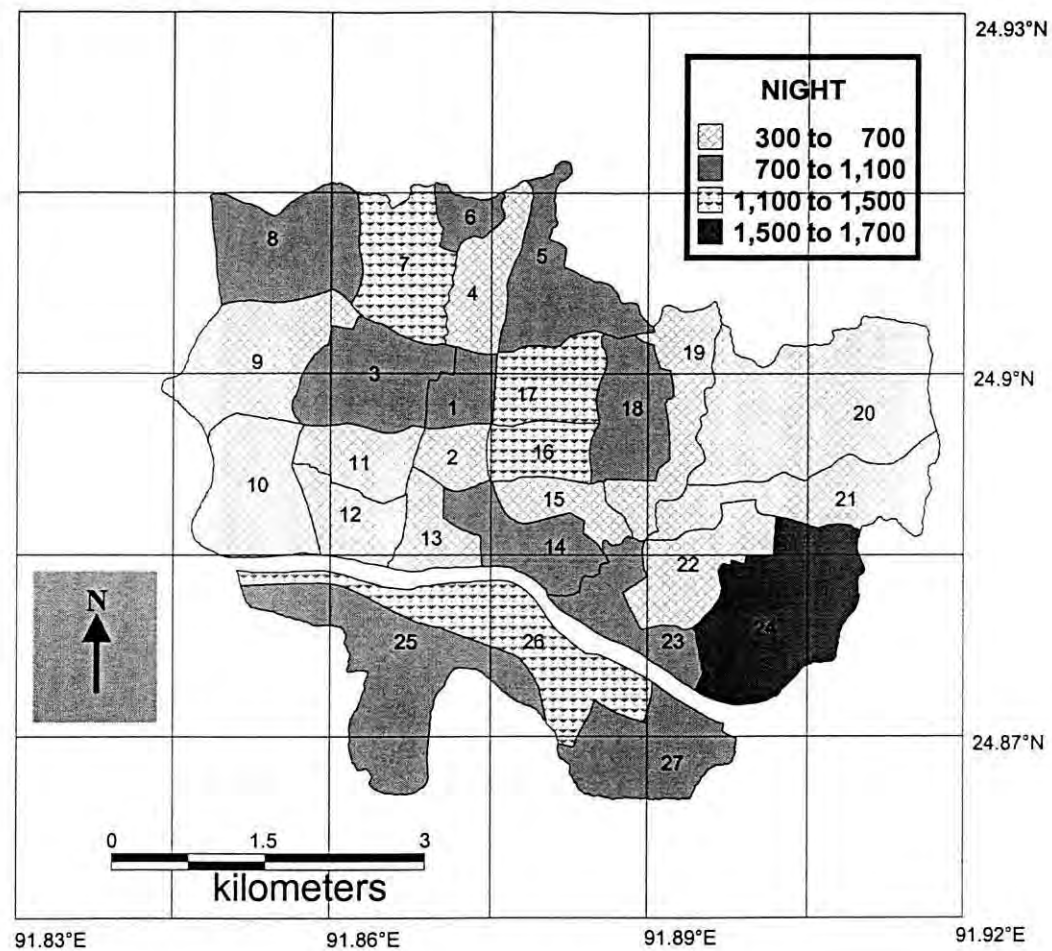


Figure 7.9c. Map showing total number of deaths at night based on Analysis I (MMI_F) in Sylhet City

Total estimated number of injuries for the scenario of earthquake is 20569 in the morning, 25,875 in the night and 13,979 in the noon. It is about 6.6%, 8.3% and 4.5% of the total population of Sylhet City, which is shown in Table 7.6 and injuries distribution according the ward, is also shown Figure 7.10a, through Figure 7.10c.

Table 7.6 Estimated numbers of injuries based on Analysis I (MMI_F) in Sylhet City

Ward No	Morning	Noon	Night
1	1078	731	1356
2	341	236	432
3	1039	707	1306
4	316	218	397
5	936	634	1176
6	737	503	926
7	1318	895	1658
8	966	655	1213
9	721	492	907
10	680	463	854
11	602	413	756
12	479	325	602
13	456	310	575
14	678	461	852
15	590	402	744
16	1231	834	1549
17	1276	863	1604
18	1133	768	1426
19	575	392	724
20	422	286	533
21	382	262	480
22	372	252	468
23	590	400	743

Ward No	Morning	Noon	Night
24	1124	762	1415
25	853	581	1074
26	820	554	1031
27	854	580	1074

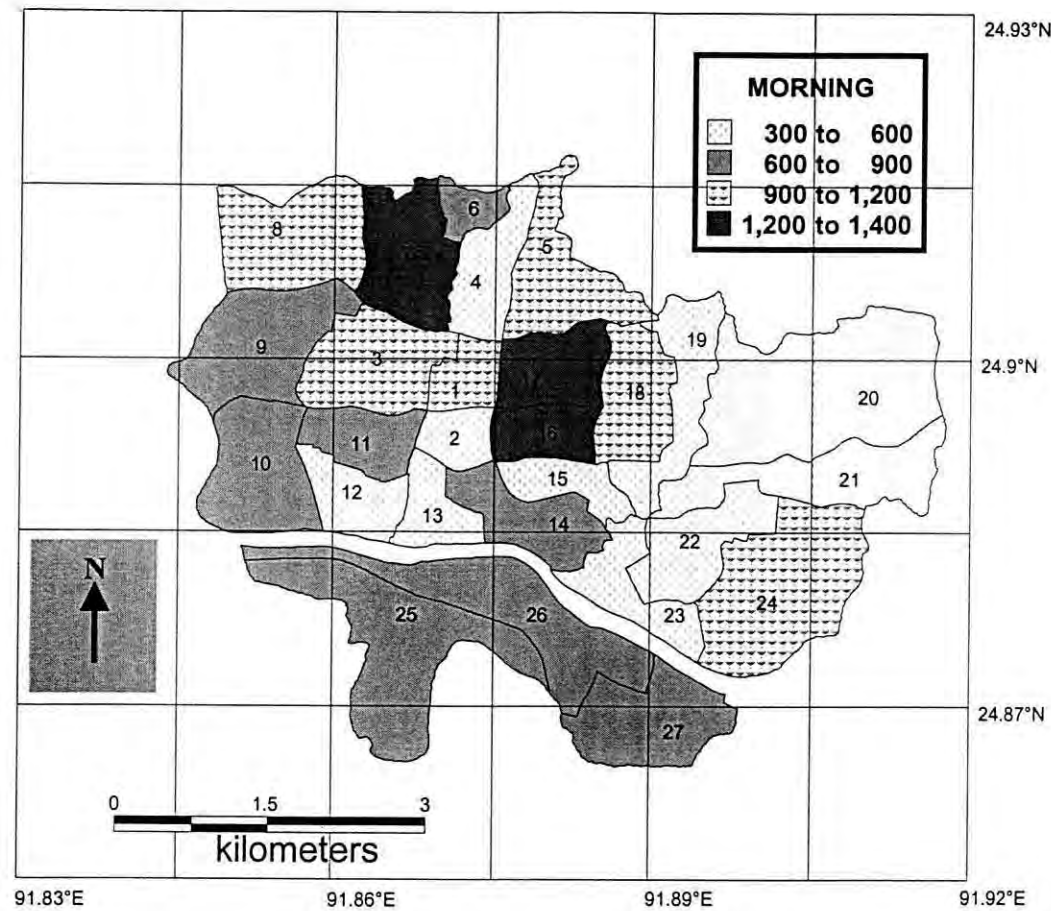


Figure 7.10a. Map showing total number of injuries in morning based on Analysis I (MMI_F) in Sylhet City

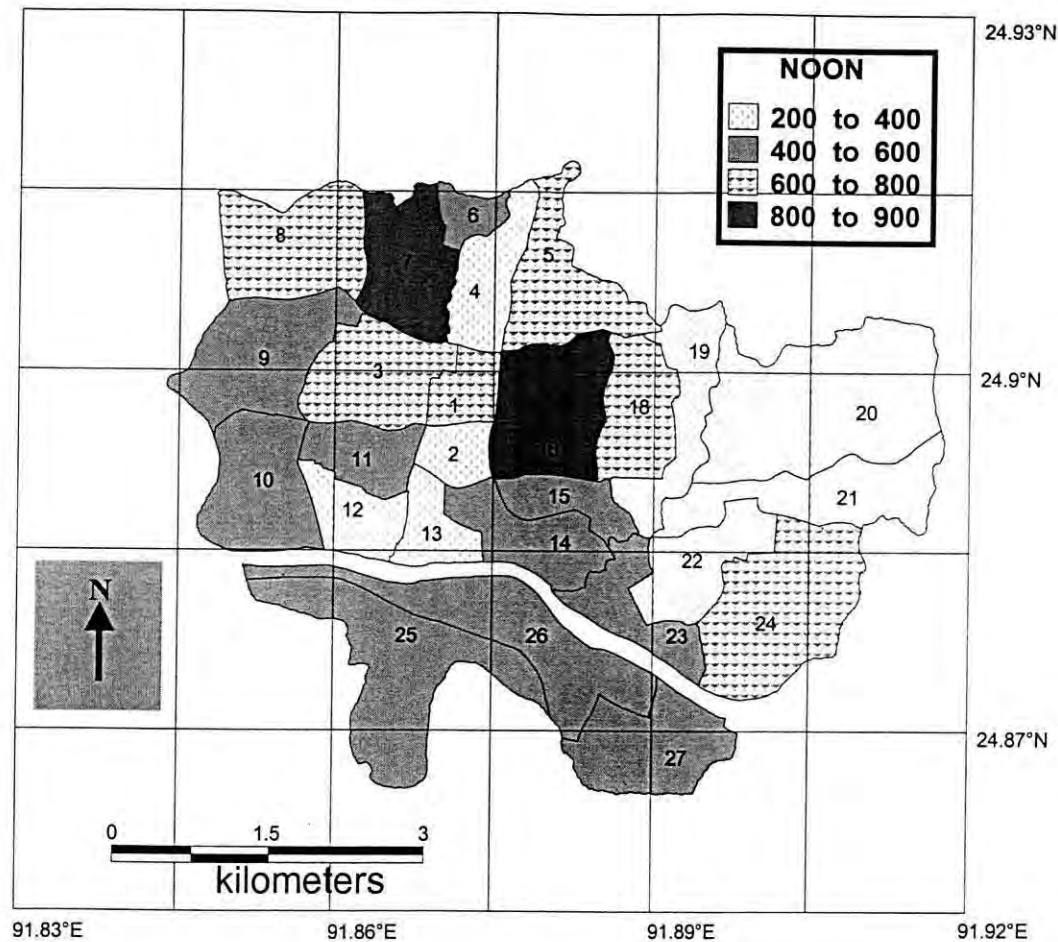


Figure 7.10b. Map showing total number of injuries at noon based on Analysis I (MMI_F) in Sylhet City

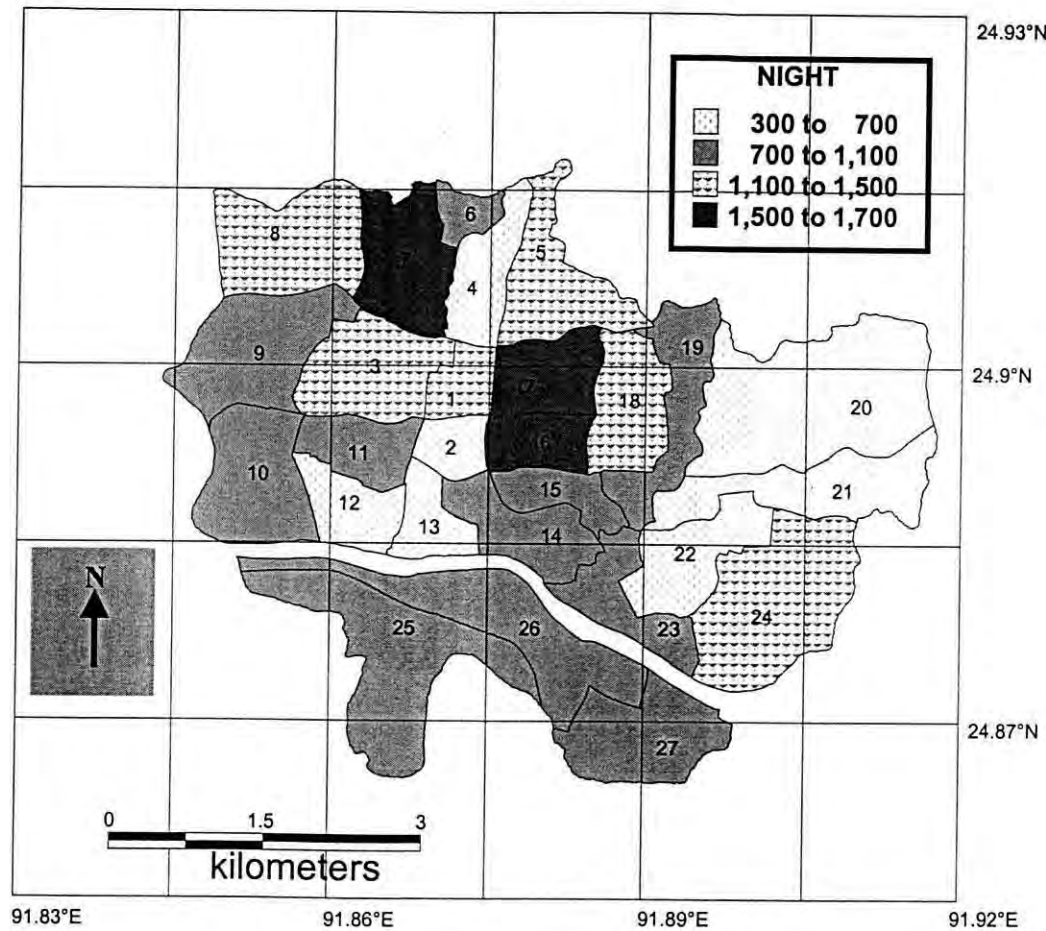


Figure 7.10c. Map showing total number of injuries at night based on Analysis I (MMI_F) in Sylhet City

7.4.2 Human Casualty Estimation Based on Analysis II (MMI_{GS}) in Sylhet City

The estimated fatalities during time cycle of a day due to only ground shaking hazard (MMI_{GS}) is given Table 7.7. The total numbers of fatalities in the morning are estimated 8826, in the night it is 11106 and in noon it is about 5983 and it is respectively 2.8%, 3.6% and 1.9% of the total population of Sylhet City Corporation .The distribution of fatalities is also shown in Figure 7.11a through Figure 7.11c

Table 7.7. Estimated numbers of fatalities based on Analysis II (MMI_{GS}) in Sylhet City

Ward No	Morning	Noon	Night
1	574	390	723
2	280	190	352
3	419	284	528
4	127	87	160
5	375	253	472
6	268	180	336
7	472	320	595
8	445	301	559
9	300	203	376
10	248	169	313
11	293	198	369
12	314	213	395
13	285	192	358
14	277	187	348
15	232	158	293
16	471	319	592
17	571	388	719
18	524	355	660
19	327	220	412
20	171	119	216
21	158	108	198

Ward No	Morning	Noon	Night
22	128	86	161
23	249	169	314
24	379	257	476
25	375	254	472
26	276	187	347
27	288	196	362

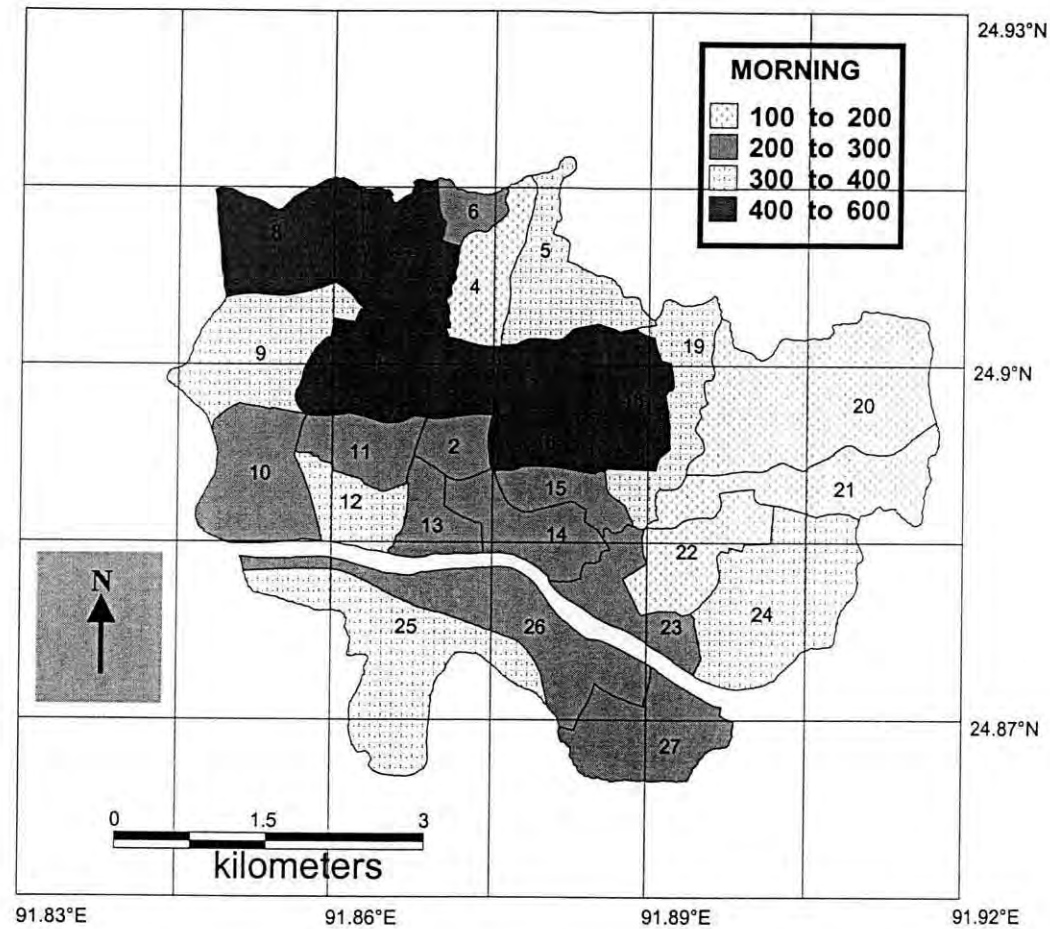


Figure 7.11a. Map showing total number of deaths in morning based on Analysis II (MMI_{GS}) in Sylhet City

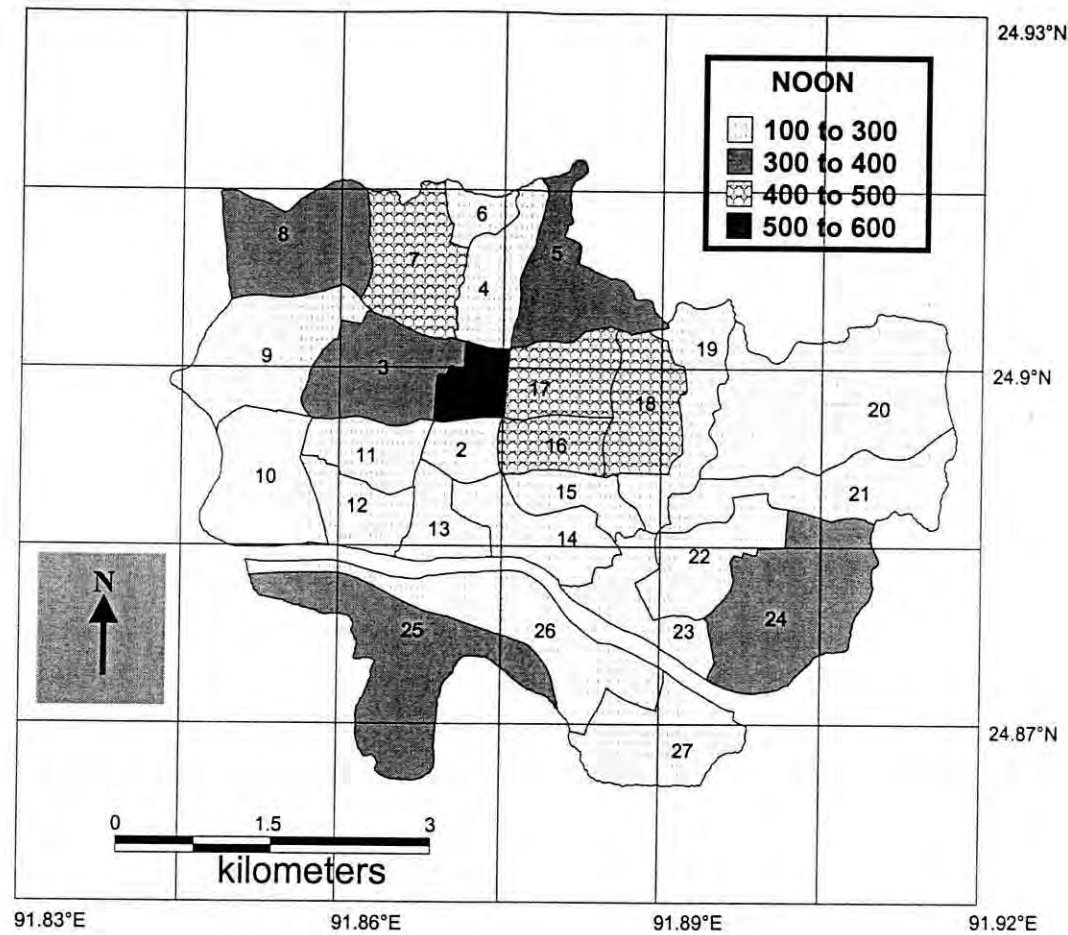


Figure 7.11b. Map showing total number of deaths at noon based on Analysis II (MMI_{GS}) in Sylhet City

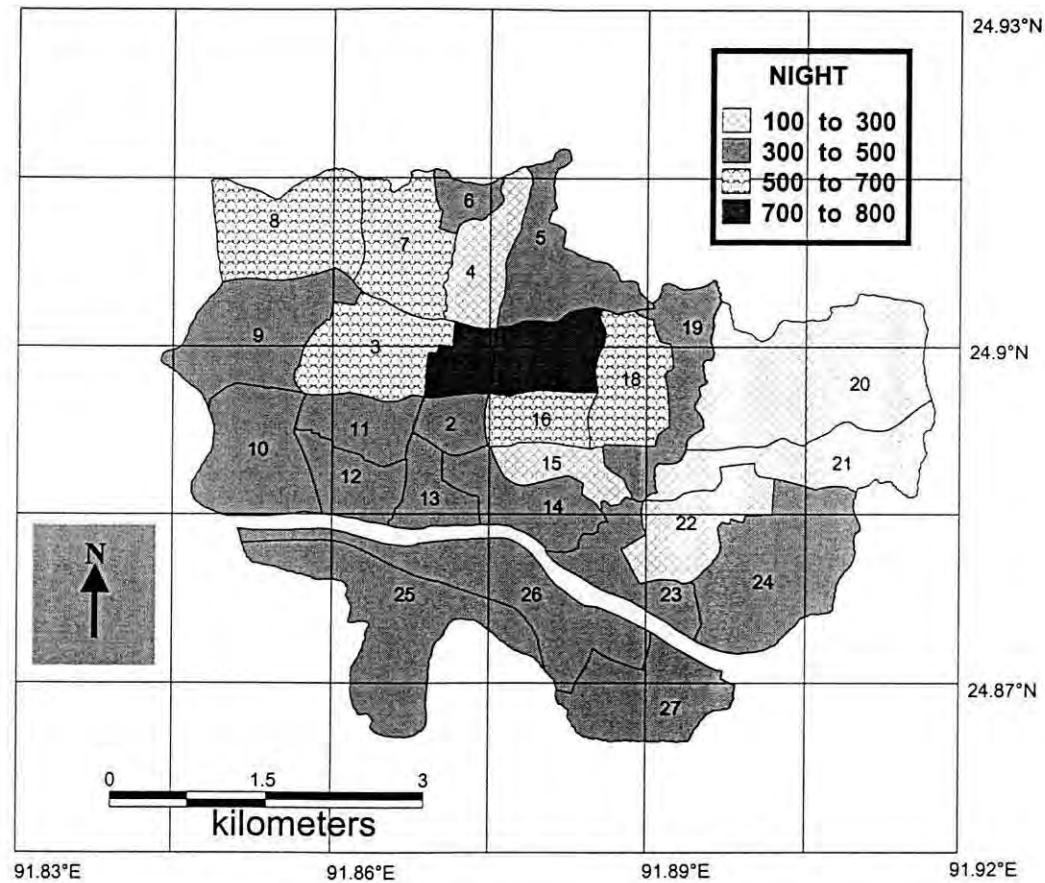


Figure 7.11c. Map showing total number of deaths at night based on Analysis II (MMI_{GS}) in Sylhet City

Again the total numbers of injuries in morning are about 11699, at night about 14721 and in noon it is about 7935 and respectively 3.75%, 4.7% and 2.5% of total population of Sylhet City, which is shown in Table 7.8. Distribution of injuries according ward is shown in Figure 7.12a through Figure 7.12c. If no collateral hazards are considered, 6.5% of total population in the morning, 8.2 % in night and 4.4% at noon will be estimated to be dead and injured. Figure 7.13 and Figure 7.14 compares fatalities and Injuries for Analysis I (MMI_F) and Analysis II (MMI_{GS}).

Table 7.8. Estimated numbers of injuries based on Analysis II (MMI_{GS}) in Sylhet City

Ward No	Morning	Noon	Night
1	740	501	931
2	362	247	456
3	541	367	681
4	165	113	209
5	491	331	617
6	350	238	441
7	618	420	778
8	581	393	729
9	390	265	490
10	344	234	433
11	377	255	475
12	434	294	547
13	391	266	493
14	382	260	481
15	300	202	377
16	611	415	768
17	735	498	924
18	679	461	854
19	426	288	535
20	238	161	302

Ward No	Morning	Noon	Night
21	217	148	273
22	167	114	210
23	343	233	432
24	524	354	659
25	514	348	646
26	382	259	480
27	397	270	500

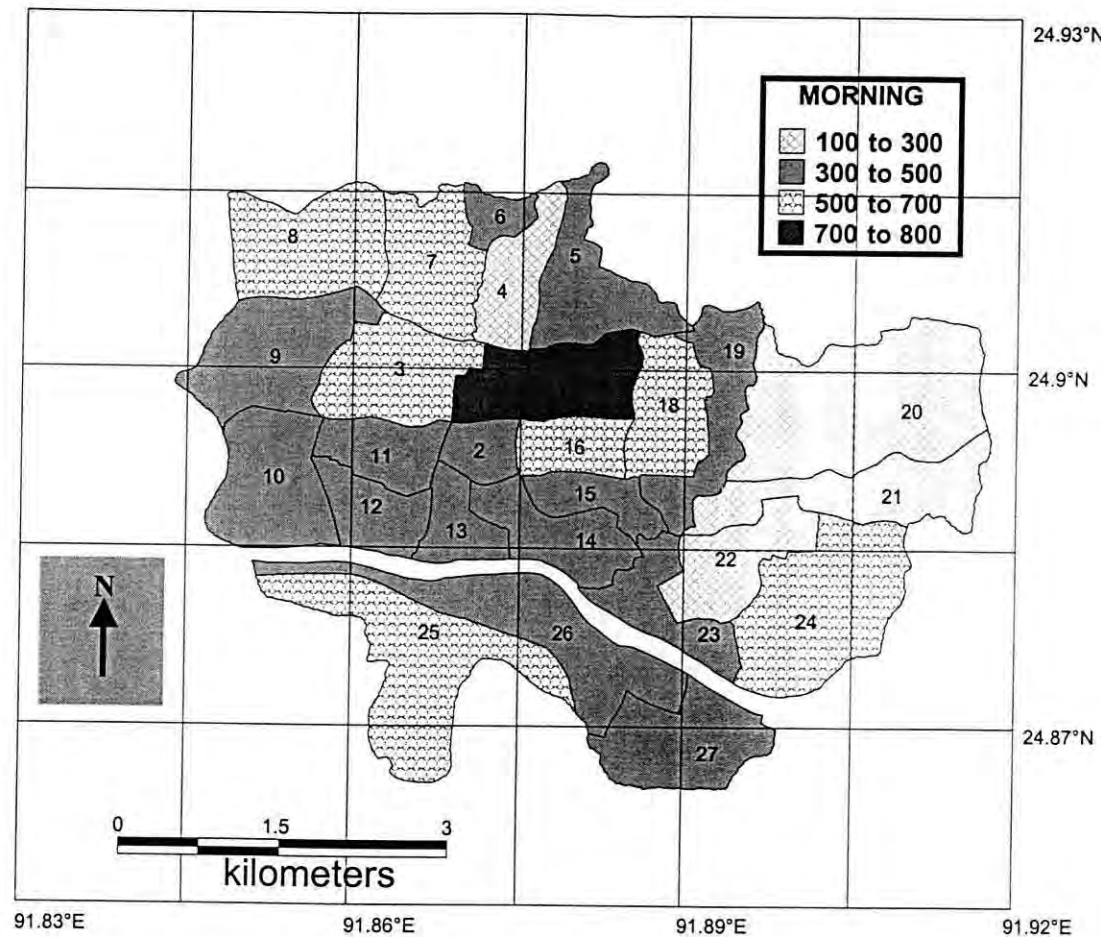


Figure 7.12a. Map showing total number of injuries in morning based on Analysis II (MMI_{GS}) in Sylhet City

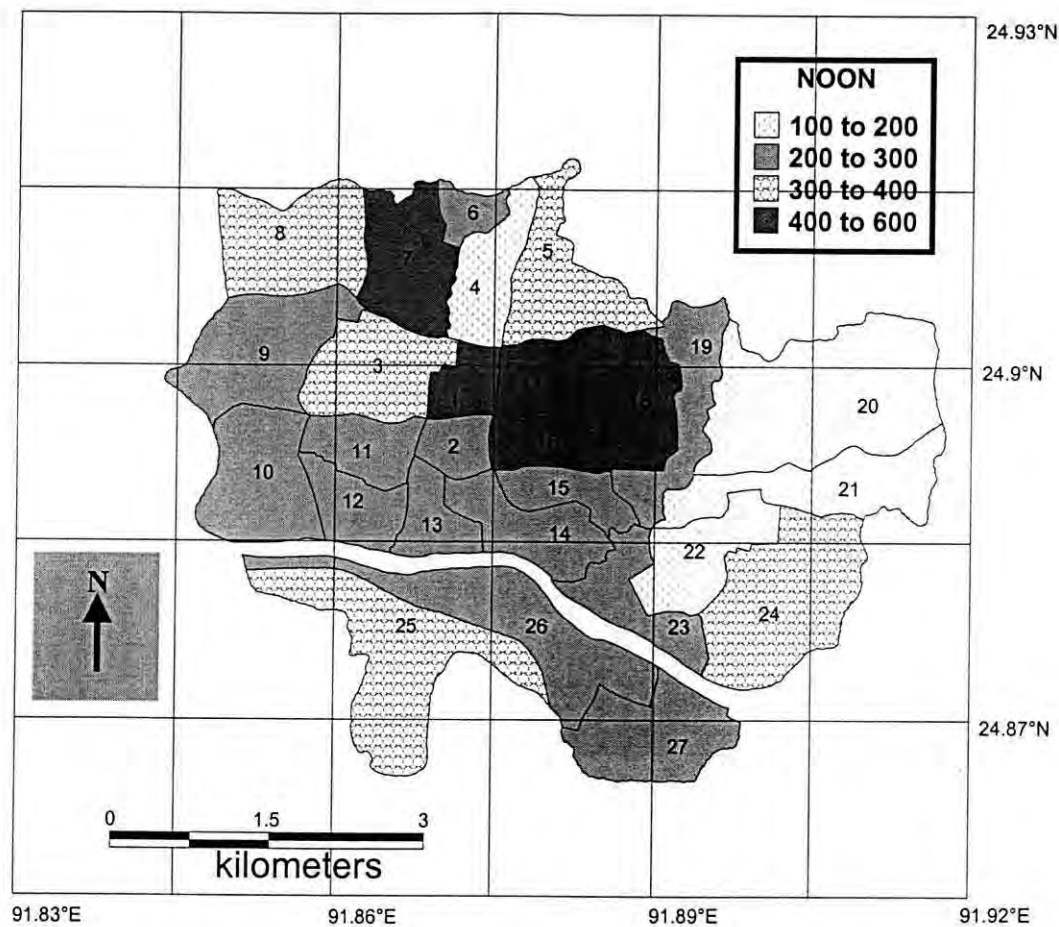


Figure 7.12b. Map showing total number of injuries at noon based on Analysis II (MMI_{GS}) in Sylhet City

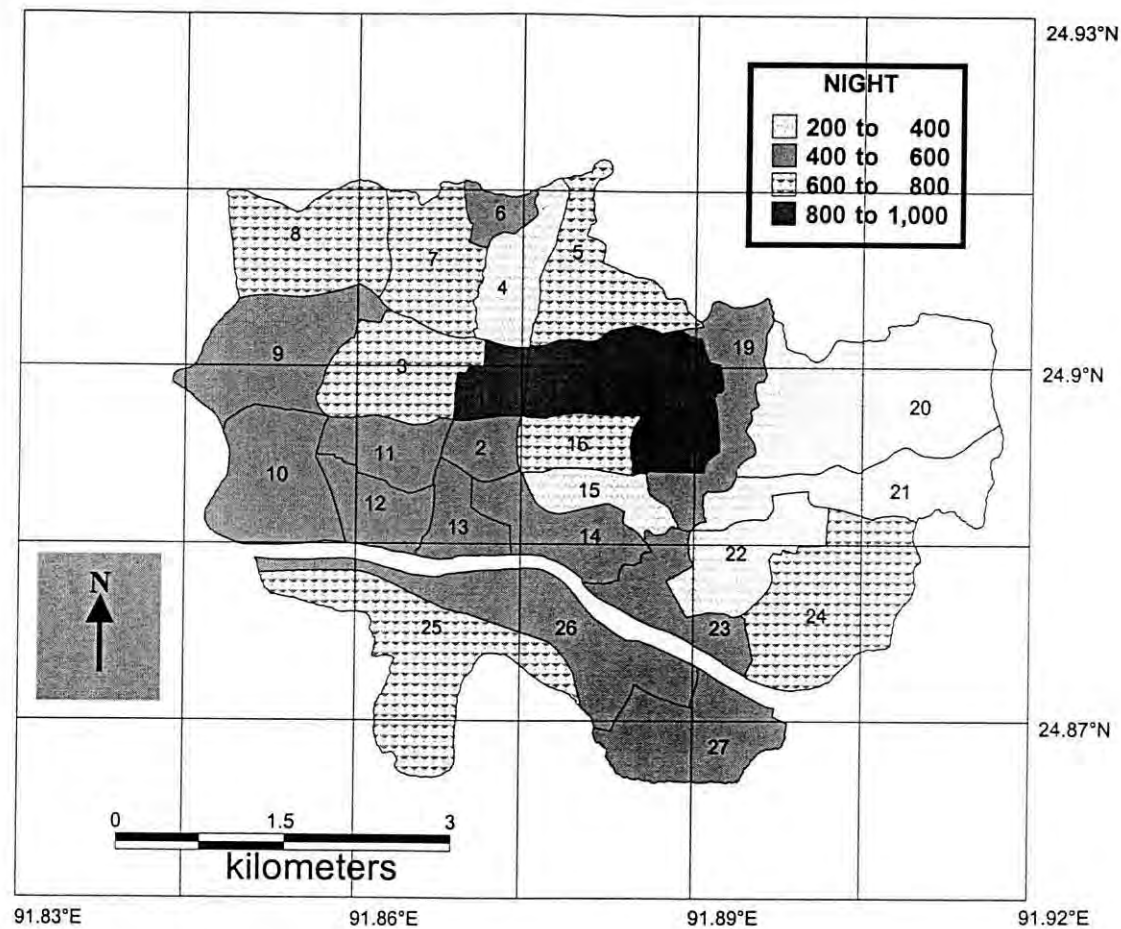


Figure 7.12c. Map showing total number of injuries at night based on Analysis II (MMI_{GS}) in Sylhet City

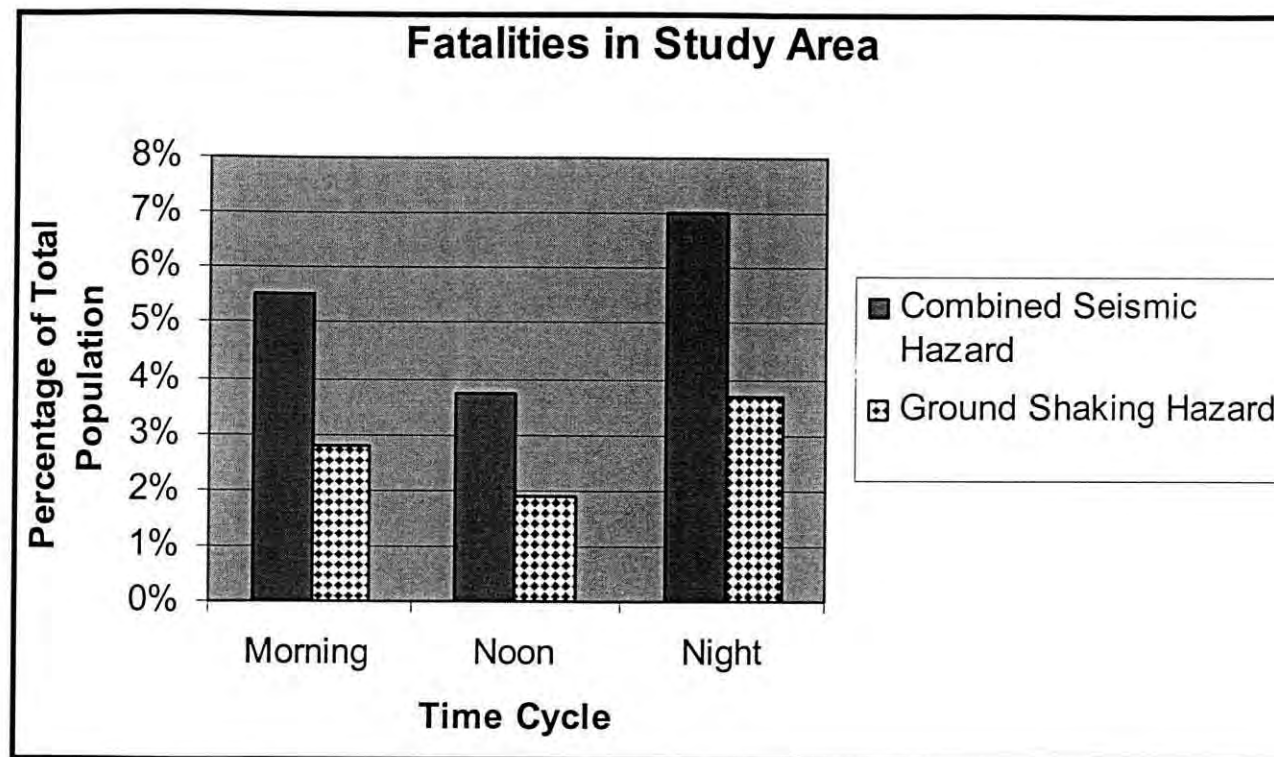


Figure 7.13. Fatalities in Sylhet City Corporation based on Analysis I (MMI_F) and Analysis II (MMI_{GS})

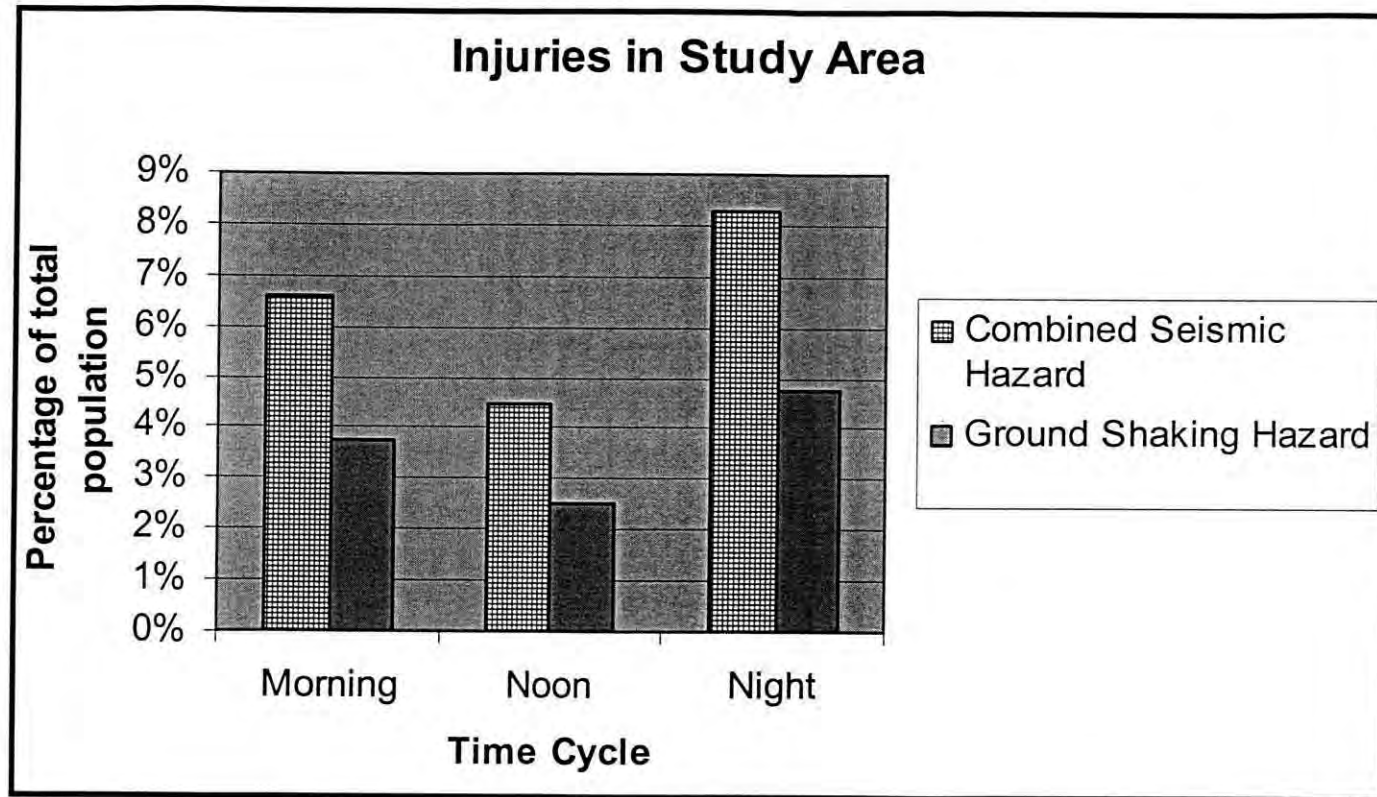


Figure 7.14. Injuries in Sylhet City Corporation based on Analysis I (MMI_F) and Analysis II (MMI_{GS})

7.5 Loss Estimation

This study introduces a methodology for earthquake loss estimation. Loss estimation is a first step in the mitigation of earthquake risk and is a quantification of the problem of earthquake loss. A damage scenario for Sylhet City is estimated in the preceding articles. Loss estimation, based on some previous findings from damaging earthquakes in India (Arya, 2000; Jain et al., 2002; NSET, 2000; Bommer et al., 2002), it was assumed that 25% total damaged buildings will be collapsed (damage grade G5 and G4) and 40% will be heavily damaged (damage grade G3). Also moderately damaged structures (damage grade G2) comprise 15% and low damaged structures (damage grade G1) comprise 20%.

Economic loss estimation for direct monetary loss such as building and for water pipeline distribution are presented in Table 7.9 and direct non-monetary loss such as fatalities and injuries are presented in Table 7.10. For loss estimation, all buildings are assumed as residential building. Table 4.10 shows that average floor area is 200 m² and apparently it seems high however, there exists considerations of storey.

The cost calculations are made based on the following assumptions that are suggested by concerned organizations.

Rebuilding cost per square meter =US dollar 100

Partial rebuilding for heavy damage per square meter=US dollar 40

Repair and retrofit for moderate damage per square meter =US dollar 15

Water pipeline repair per point =US dollar 250

Table 7.9. Direct monetary losses based on Analysis I (MMI_F) and Analysis II (MMI_{GS}) due to a scenario event equivalent to 1918 Srimongal Earthquake

Building Damage Grade	Analysis I (MMI _F)			Analysis II (MMI _{GS})		
	Physical damage	Loss in Us dollar Million	% Of Loss	Physical damage	Loss in Us dollar Million	% Of Loss
Total Collapse (G5)	3683	73.75	34	3372	67.4	33.5
Partial Collapse (G4)	5886	117.8	54	5388	107.42	54
Heavily damaged (G3)	2297	118.4	8	2094	16.75	8.5
Moderately damaged (G2)	3064	9.0	4	2791	8.4	4
Water pipe damage point	204	0.051	Negligible	121	0.031	Negligible
Total		219	100		200	100

Table 7.10. Direct non-monetary losses based on Analysis I (MMI_F) and Analysis II (MMI_{GS}) due to a scenario event equivalent to 1918 Srimongal Earthquake

Analysis I (MMI _F)					
Injuries			Fatalities		
Morning	Noon	Night	Morning	Noon	Night
20569	13979	25875	17249	11713	21674
Analysis II (MMI _{GS})					
Injuries			Fatalities		
Morning	Noon	Night	Morning	Noon	Night
11699	7935	14721	8826	5983	11106

7.6 Summary

This chapter presents seismic loss estimation for Sylhet City due to a scenario event equivalent to 1918 Srimangal Earthquake. Maps and database tables are shown at various stages of this study. The seismic hazard analysis details the estimation of ground shaking, the effects of the various collateral hazards, and the combination of all seismic hazards in the region.

The influence of collateral hazards is investigated in this study. The expected damage factor for all buildings decreases from 59% to about 51% when the effects of liquefaction and landslide are ignored. When collateral hazards are considered the total direct monetary-loss for all buildings and water pipeline are estimated 219 million US dollar and 200 million US dollar if secondary effects such as liquefaction and landslide are ignored.

Only, non-monetary loss considered in the study was casualties and injuries. The total number of major injuries was estimated at about 25875 and the total number of deaths is estimated at about 21674 if the collateral hazards is considered and if not, total number of major injures was estimated at about 14721 and the total number of deaths is estimated at about 11106 during night time.

This do not seem very high as compared to 1988 Armenian event, where 25,000 were killed in Spitak and Leninakan, mostly due to poor quality construction and the 1999 Marmara (Turkey) earthquakes, where 17,000 were killed in a rapidly urbanizing area where many mid-rise, soft story, reinforced concrete buildings collapsed, due largely to inadequate code enforcement [Scawthorn, 2000]

8.1 Conclusions

This study introduces a methodology for earthquake loss estimation. Loss estimation is a first step in the mitigation of earthquake risk and is a quantification of the problem of earthquake loss. This is for the first time comprehensive earthquake loss estimation for Sylhet City was carried out. In this study, the seismic risk analysis included consideration of primary hazards due to ground shaking and to local site effects such as soil amplification, liquefaction and landslide. The analysis incorporates structural inventories, motion-damage relationships, and loss modeling for estimation of regional damage and loss distributions. To develop the methodology, initially several database such as soil borelogs, building typologies, ward wise building information, City water system were collected. The database was stored within MS Access, and MS Excel platform for easy retrieval. In the GIS environment, maps representing regional geologic and geographic information are overlaid and their attributes are combined to produce intermediate maps of regional seismic hazards. These hazard maps are then overlaid and combined with structural inventory maps to produce maps predicting regional damage distributions. Combining the maps of damage distributions with maps of population distributions for the area results in final estimates of direct monetary and non-monetary loss. The investigations are carried for two cases as follows:

Analysis I: Based on Combined seismic hazard considering local site effects

Analysis II: Based on hazard due to ground shaking alone

- If an earthquake similar to 1918 Srimangal Earthquake occurs again at the same epicentral location, it is concluded that 65% area will be affected with PGA 0.90g, 28% area will be affected with PGA 0.45g, 5.5% area will be affected with PGA 0.35g and 1.5% area will be affected with PGA 1.56g.

- Total estimated damage is about 15320 out of 25992 housing units based on Analysis I in Sylhet City. Again based on Analysis II, estimated number of damaged structures is about 13255 out of 25992 housing units. The expected damage factor for all buildings decreases from about 59% to about 51% when the effects of liquefaction and landslide are ignored.
- Based on Analysis I, Estimated number of damage points are 204 and based on Analysis II, estimated number of damage points are 121. It is appeared low relative to types of losses (e.g., damage to buildings), since it only reflect those costs associated with the repair of damaged water distribution system. The damage function and data for other component such as intakes, reservoirs, treatment plants and other ground water wells are not available as a result loss for this component is not included in this study. In addition other costs, which may more accurately reflect the impact of damage or disrupted systems such as business losses due to water distribution disruption or fire damage resulting from loss of water supplies may be several factors higher than these repair costs.
- Only non-monetary loss is considered in the study are casualties and injuries. Based on Analysis I, Total estimated number of fatalities are 17, 249 in the morning, 21,674 in the night and 11,713 in the noon. It is about 5.5%, 7.0% and 3.75% of the total population of Sylhet City. In addition, Total estimated number of injuries for the scenario of earthquake is 20569 in the morning, 25,875 in the night and 13,979 in the noon. It is about 6.6%, 8.3% and 4.5% of the total population of Sylhet City.
- Based on Analysis II, it is also concluded that the total numbers of fatalities in the morning are estimated 8826, in the night 11106 and in noon about 5983 and it is respectively 2.8%, 3.6% and 1.9% of the total population of Sylhet City. Total numbers of injuries in morning are about 11699, at night about 14721 and in noon it is about 7935 and respectively 3.75%, 4.7% and 2.5% of total population of Sylhet City.

- Death and injured numbers are much higher however it is also appeared reasonable since among 10350 EMSB type buildings 7680 are much potential to be affected and whose damage factor is high. It is also reasonable when compared to 1988 Armenian event, where 25,000 were killed in Spitak and Keninakan, mostly due to poor quality construction and the 1999 Marmara (Turkey) earthquakes, where 17,000 were killed in a rapidly urbanizing area where many mid-rise, soft story, reinforced concrete buildings collapsed, due largely to inadequate code enforcement [Scawthorn, 2000].
- Based on Analysis I, total direct monetary-loss for all buildings and water pipeline are estimated 219 million US dollar and 200 million US dollar based on Analysis II. So, the total direct monetary-loss decreases by about 9% if collateral hazard are ignored in the analysis. So difference between this two scenario direct-monetary loss is not very high as in the fragility curve which is used for this study shows that PGA between 0.6g and 0.9g have very mild slope and after .90g PGA for all types of residential building curve is about to straight. However, there is tremendous effect over direct non-monetary loss as Fatalities and injuries increases during night by 49% and 43% respectively if collateral hazards are considered. This seems very reasonable, as study area is affected weighted average 0.80g PGA and 0.40g PGA based on Analysis I and Analysis II.
- This study is carried out only at Sylhet City Corporation area, which occupies 26.50 km² where as Sylhet Sadar Upazilla occupies 517.43 km². So only 5% area of Sylhet Sadar, which is with in the present study. It is believed that if potential earthquake trigger in northeastern part of Bangladesh, not only Sylhet City Corporation but also other part of this upazilla might be severally affected. Consequently, if loss estimation is done according above mention issues it is very realistic that total loss due to this scenario event might exceeds several billion US dollars which is also be interpolated from past earthquake such as during 1999, September 21, Taiwan city affected this earthquake caused at least 2,297 people killed, 8700 injured, 600,000 people left homeless, and about 82,000 housing units damaged.

8.2 Scope for Future Study

The study is covered with extremely wide-ranging subject; consequently several field of future study can be recognized for instance:

- For Bangladesh, no PGA attenuation law has been developed, due to shortage of strong motion data. In this study it is adopted the attenuation law (McGuire, 1978) for alluvial soil proposed by Public Works Research Institute (PWRI) in Japan. For Bangladesh it is urgent to establish PGA attenuation relationships, predicting strong ground motions in terms of magnitudes, distance, site geology, and other factors, using various models and data sets.
- In this study, soil amplification was modeled by a simple multiplication factor; liquefaction and landslide were modeled with a qualitative description of high, moderate, and low potential. SPT-N values are converted into shear-wave velocities using empirical correlation developed by Tamura and Yamazaki (2002) for soils of other countries. It is needed that shear-wave velocity should be directly estimated for different soils using cross-hole, down-hole or blasting techniques. Then correlation should be developed for the SPT-N values of local soils with shear-wave velocities. Grain Size Analysis specially, the mean particle diameter, D_{50} and fine contents are important data for every 1 meter depth for proper liquefaction analysis. Landslide hazard is typically very difficult to quantify because landslides come in many forms and are caused by a variety of processes. The local site factors that affect landslides generally include slope stability, geology, slope angle, hydrological conditions, vegetation, land use, and severity of the earthquake. Most of these factors are necessary for the investigation of an individual slope, however, in this study landslide analysis on a broad regional basis, the factors are typical limited to slope angle, magnitude of the seismic event and distance from the seismic source. More quantitative models for these site effects that can be applied over a large region are needed.

- The process for integration the various sites attributes in a GIS-based regional analysis is shown in this study by simplifying assumptions in order to carry loss estimation model. Improvements are needed in the models together with the quantification of the hazards. The heuristic weighted average approach to the hazard integration can also be improved. The analysis and modeling capabilities of the GIS provide an ideal environment to conduct sensitivity studies that will help to refine different hazard combination schemes.
- The motion-damage relationships exist for India's Buildings prepared by Arya (2000) and Nepale's buildings prepared by Bothara et al. (2000) is used for this study by assuming that building pattern is same as India and Nepal in Bangladesh and use modified Mercalli Intensity (MMI) as the ground motion parameter. New relationships that estimate damage as a function of measured structural response, not only for buildings, but also for all types of lifeline and non-building facilities, as well as non-structural components is to be developed for Bangladesh.
- Morbidity model developed by Coburn and Spence (1992) surveyed worldwide earthquake damages to identify the relationship between building damages and human casualties .The occupancy cycle proposed by Coburn and Spence (1992. Might not be consistent for Bangladesh However, in worldwide survey Bangladesh was not included. The number of deaths is much higher than thus observed during any earthquake in the Bangladesh. Improved models are needed especially for Bangladesh by considering Structure type, as influence the number of deaths and injures because different structural systems have different failure modes. Some systems may fail suddenly and catastrophically; others may fail more slowly allowing time for evacuation of occupants.

- Public facilities are important for seismic disaster management plan. Governmental facilities will function as headquarters for the disaster management. Police stations and traffic Police function as centres for maintaining public and traffic order. Fire fighting stations functions as the main bodies for fire fighting and rescue operations. Hospitals are essential facilities for the treatment of casualties and injuries. School will be used as refugee camps. Therefore, all public facilities are required to have much more seismic resistance than the residential buildings. However, public facilities data are not available. So detailed study is needed for public facilities.
- Monetary loss due to building damage and non-monetary loss due to casualties and injuries are the only losses considered in this dissertation. Loss of functionality and other in-direct losses such as clean up and financing of repairs is very hard to estimate, by each new earthquake provides more empirical data for model development. Economists and business managers rather than structural engineers best make improvements to these types of loss models. There are very few models for non-monetary losses such as casualties, unemployment and homelessness. As with in-direct loss models, improvements to the non-monetary loss models are best made by sociologists and socio-economists.

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Appendix A
Ward and Corresponding Mouzas of Sylhet City

Ward No	Mahalla	Mouza
1	1. Ambarkhana Phachim 2. Rajar Galli 3. Darshan Deuary 4. Dargha Mahalla 5. Jarnarpar 6. Miah Fazil Chist 7. Mirer Maidan 8. Chowhatta	Sylhet Municipality J.L.No -91
2	1. Kazi Elias 2. Zinda Bazar 3. Kuritola 4. Jallar Par 5. Mirza Jungle (Part) 6. Daria Para 7. Poler Par 8. Sarashpur 9. Khetri Para	Sylhet Municipality J.L.No- 91
3	1. Police Line 2. Munshipara 3. Keyapara 4. Subid Bazar 5. Kazalshah R/A 6. Kazalshah Osmani Medical Area 7. West Kazal Shah	Sylhet Municipality J.L.No- 91
4	1. Housing Estate 2. Monipuri Para 3. Datta Para 4. Kona Para 5. Ghar Dhuar 6. Hanitula	Sylhet Municipality J.L.No- 92
5	1. Ambarkhana Bhoro Bazar 2. Ghoai Para 3. Khasdabir 4. Khalba Khani 5. Hazaribag 6. Roy Hossain 7. Whapda Colony	Sylhet Municipality J.L.No- 92
6	1. Pir Mohalla 2. Sayed Mugni 3. Mali Para Badam Bhagicha 4. Chowki Dekhi West 5. Cowki Dekhi East	Amborkhana J.L.No - 92

Ward No	Mahalla	Mouza
7	1. West Pir Mohalla 2. Jalalabad R/A 3. Fazil Chist 4. Subid Bazar East 5. Bania Mahal 6. Hatar Hoar 7. Umar Katighar 8. Mugli Tula 9. Subid Bazar (Naya Bosti) 10 Subid Bazar Shayef Khan Road	Bag Bari J.L.No-.90
		Ambar Khana J.L.No-.92
8	1. Bramon Shason 2. Colony-1 3. Colony-2 4. Colony-3 5. Noaha Para (Part) 6. Cuchar Para 7. Halidar Para (Part) 8. Kali Bari 9. Pan Tola 10. Hari Khai 11. Churar Para 12. Choror Para 13. Darjee Para 14. Cari Para 15. Chandhi Girdja 16. Vhatoa Para 17. Pathan Tula East 18. Pathan Tula West	Bramon Shason J.L No.- 77
		Tara Pur Tea Garden J.L.No. 76
		Bagbari J.L.No- 90
9	1. Bag Bari 2. Shagor Digir Par 3. Norshing Tila 4. Actim School Road 5. Nogoar 6. Khulia Para 7. Dhancuter Par 8. Ahakhalia Bazar 9. Nihari Para 10. Akhalia (Part)	Khosba Akalia J.L.No- 88 Bagbari J.L.No.-90
10	1. Kani Shail 2. Mojumder Para 3. Ghashi Tula 4. Wapda 5. Dhaor 6. Kola Para	Bagbari J.L.No- 90

Ward No	Mahalla	Mouza
	7. Hiaboron	
11	1. Laldighir Par 2. Kajal Shaha 3. Shachilapur 4. Lama Bazar 5. Bil Par 6. Vhatalia 7. Noha Para 8. Modhu Shahid 9. Rikabi Bazar 10. Khuar Par (North)	Sylhet Municipality J.L.No -91
12	1. Itakhola 2. Vanghaticor 3. Sheikh Ghat Ist Part 4. Sheikh Ghat 2 nd Part 5. Sheikh Ghat 3 rd Part 6. Sheikh Ghat 4 th Part 7. Saudagartala 8. Sheikh Ghat Colony 9. Kuarpur (South)	Sylhet Municipality J.L.No- 91
13	1. Topakhana 2. Girjear Phachim 3. Taltola (South) 4. Teli Hoar 5. Machudighir Par 6. Mirjajangal South 7. Jamtola 8. Ramerdighirpar 9. Monipuri Rajbari 10. Lamabazar 11. Khuliatula 12. Muglitula 13. Sheikh Naser Ali 14. Kazirbazar 15. Chadni Ghat	Sylhet Municipality J.L.No- 91
14	1. Dhupa Dighirpar South Part 2. Khastoghar 3. Chali Bondor Phachim 4. Chararpar 5. Kamalghar 6. Amjad Ali Road 7. Carpastula 8. Khalighat 9. Laldighir North Part	Sylhet Municipality J.L.No- 91

Ward No	Mahalla	Mouza
	10. Bondor Bazar (Mohazanpatty) 11. Brokhomoiy Bazaar 12. Sheikh Ziaullah 13. Taltola (North) 14. District Judge And District Administrator Office, Sylhet 15. Jallarpar	
15	1. Puran Lane 2. Barutkhana 3. Jail Road 4. Betbartula 5. Pancha Khana 6. Nondai Patty 7. Parbat Khana 8. Lalbazar 9. Dhupadigirpar East Par 10. Chandanitula 11. Mirabazar South 12. Chalibandar East 13. Supanighat 14. Jartorpur 15. Nyorpul 16. Joynogor 17. Noyapara	Sylhet Municipality J.L.No -91
16	1. Howapara 2. Tatipara 3. Khandokar Para 4. Noyasarak 5. Charadigirpar 6. Mojlis Amin 7. Kumarpura West 8. Showdagar Tula 9. Khandaura 10. Dhopadigir North Part 11. Nyorpul 12. Christian Mission 13. Shah Chandha Gazi 14. Bethbartula (East Zinda Bazar) 15. Chowhatta South	Sylhet Municipality J.L.No-91
17	1. Kazi Jalal Uddin 2. Kazitula 3. Mohale Abdullah 4. Amborkhana East 5. Chandon Tula	Sylhet Municipality J.L.No -91

Ward No	Mahalla	Mouza
	6. Chowhatta North 7. Mir Boxtula 8. Manik Pir Road	
18	1. North Mirabazar 2. Augpara 3. Shahi Eidgha 4. Brojonath Tila 5. Jorparpar 6. Noyapara Jarnar Par 7. Jeerjary Para 8. Kumar Para (East) 9. Muktar Khakirmoni (Phachim) 10. Shakhari para 11. Byarpara 12. Sunatula 13. Roynogor Phachim	Sylhet Municipality J.L. No- 91
19	1. Darjee Para 2. Sonarpara 3. Darjee Bondha-1 4. Darjee Bondha-2 5. Alam Tula 6. Doptori Para 7. Roy Nogor (East) 8. Muktar Khakir Moni (East) 9. Kharpara 10. Dhulishai Eidgha	Sylhet Municipality J.L No - 91
20	1. Nath Para 2. South Baluchar 3. Kharadhi Para 4. Mojumdar Para 5. Aditha Para 6. Dhoper Bramohon Para 7. Shibgonj 8. Lakri Para 9. Sen Para 10. Vatatikor 11. Gopal Tila 12. Roy Nogor 13. Daspara 14. Debpara 15. Sadipur	Sadipur First Part J.L.No- 93
		Roy Nogor J.L.No -97

Ward No	Mahalla	Mouza
21	1. Chapar Bon Para 2. Sonar Para 3. Khondicor Para-1 4. Lama Para (South/West) 5. Badurlotka 6. Gonghadas 7. Bramonpara 8. Niskhor Para 9. Tikri Para 10. Kallanpur Shapla Bag 11. Raj Para 12. Kalashil 13. Thaiatikar (Golap Bag) 14. Takurpara 15. Khandicor Para-2 16. Vataticor (Part)	Roy Nogor J.L.No- 97
		Sadipur Second Part J.L.No -98
		Deb Pur J.L.No-96
22	1. Uposhohor 2. Tilabari	Sadipur Second Part J.L.No-98
		Tulticor J.L.No-99
23	1. Mashimpur 2. Mendibag 3. Dubrihaour 4. Dewanbag 5. Upocontho 6. South Sadipur	Sadipur Second Part J.L.No -98
24	1. Tulticor 2. Mirapara Pachim 3. Teroroton 4. Collanpur (Shaplabag) 5. Lama Para East 6. North Sadipur 7. Saiydanibag 8. Tyiaticor (Golapbag) 9. Gongadas (Hatimbag) 10. Sadarpara 11. Noyabazar 12. Kushy Ghat 13. Sadaticor	Debpur J.L.No-96
		Tultikor J.L.No-99
		Sadipur Second Part J.L.No -98
25	1. Gangu South West Part 2. Barokhola 3. Varthokhola South 4. Kaysthorail	Kazirkhola J.L.No-113
		Boroij Kandi J.L.No-116

Ward No	Mahalla	Mouza
	5. Mominkhola West 6. Kazirkhola 7. Daudpur 8. Khojarkhola	Vartho Khola J.L.No-112
		Momimkhola J.L.No-111
		Gudrail J.L.No-126
		Gotaticor J.L.No-110
26	1. Gangue (Part) 2. Jallowpara 3. Sadhur Bazar 4. Kodomtoli 5. Vartho Khola North 6. Momimkhola (East)	Khujarkhala J.L.No-113
		Baroiykandi J.L.No-116
		Varthokhola J.L.No-112
		Mominkhola J.L.No-111
		Gotaticor J.L.No-110
27	1. Alampur 2. Gotaatiocor 3. Pathantola 4. Paittopara 5. Sathghor 6. Hobinondi 7. Aharchacha Para 8. Crichan Para 9. Jogishashwon 10. Shamal Hasan 11. Mojlishpur	Hobinondi J.L.No-107
		Alampur J.L.No-109
		Moniprur J.L.No-108
		Gotaticor J.L.No-110

Appendix B
Building Data Collection Format

Date :

[illegible]

Signature of Surveyor:

Appendix C
European Macro seismic Scale

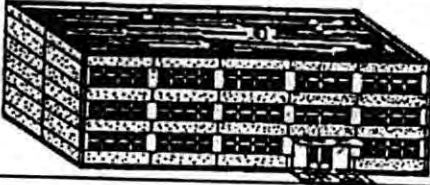
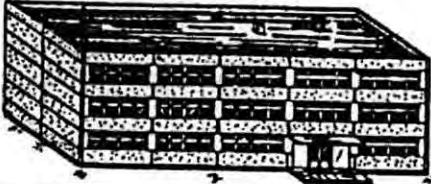
Vulnerability Table

Type of Structure		Vulnerability Class					
		A	B	C	D	E	F
MASONRY	rubble stone fieldstone	○					
	adobe (earth brick)	○	—				
	simple stone	—○					
	massive stone		—○	—			
	unreinforced brick / concrete blocks	—○	—				
	unreinforced brick with RC floors		—○				
	reinforced brick (confined masonry)			—○	—		
REINFORCED CONCRETE (RC)	RC without antiseismic design (ASD)	—○	—				
	RC with minimum level of ASD		—○				
	RC with moderate level of ASD			—○			
	RC with high level of ASD				—○		
WOOD	wooden structures <i>+ Bamboo</i>		—○	—			

DAMAGE GRADE

Table 2: Classification of damage to masonry buildings	
	Grade 1: Negligible to slight damage (no structural damage) hair-line cracks in very few walls; fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases only.
	Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) cracks in many walls; fall of fairly large pieces of plaster; parts of chimneys fall down.
	Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) large and extensive cracks in most walls; pantiles or slates slip off. Chimneys are broken at the roof line; failure of individual non-structural elements.
	Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage). serious failure of walls; partial structural failure.
	Grade 5: Destruction (very heavy structural damage) total or near total collapse.

DAMAGE GRADE

Table 3: Classification of damage to buildings of reinforced concrete	
	Grade 1: Negligible to slight damage (no structural damage) fine cracks in plaster over frame members and in partitions.
	Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) hair-line cracks in columns and beams; mortar falls from the joints of suspended wall panels; cracks in partition walls; fall of pieces of brittle cladding and plaster.
	Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) cracks in columns with detachment of pieces of concrete, cracks in beams.
	Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage). severe damage to the joints of the building skeleton with destruction of concrete and protusion of reinforcing rods; partial collapse; tilting of columns.
	Grade 5: Destruction (very heavy structural damage) total or near total collapse.

Definitions of intensity degrees

Arrangement of the scale:

- a) Effects on humans
- b) Effects on objects and on nature (excluding damage to buildings, effects on ground and ground failure)
- c) Damage to buildings

Introductory remark:

The single intensity degrees can include the effects of shaking of the respective lower intensity degree(s), also when these effects are not mentioned explicitly.

I. Not felt

- a) Not felt even under the most favorable circumstances.
- b) No effect.
- c) No damage.

II. Scarcely felt

- a) The tremor is felt only by a very few (less than 1%) individuals at rest and in an especially receptive position indoors.
- b) No effect.
- c) No damage.

III. Weak

- a) The earthquake is felt indoor by a few. People at rest feel a swaying or light trembling.
- b) Hanging objects swing slightly.
- c) No damage.

IV. Largely observed

- a) The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair etc.
- b) China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.
- c) No damage.

V. Strong

- a) The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.
- b) Hanging objects swing considerably. China and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. In a few cases windowpanes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.
- c) Damage of grade 1 to a few buildings.

VI. Slightly damaging

- a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.
- b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.
- c) Many buildings sustain damage of grade 1; a few suffer damage of grade 2.

VII. Damaging

- a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.
- b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
- c) Many buildings of vulnerability class B and a few of class C suffer damage of grade 2. Many buildings of class A and a few of class B suffer damage of grade 3; a few buildings of class A suffer damage of grade 4. Damage is particularly noticeable in the upper parts of buildings.

VIII. Heavily damaging

- a) Many people find it difficult to stand, even outdoors.
- b) Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.
- c) Many buildings of vulnerability class C suffer damage of grade 2. Many buildings of class B and a few of class C suffer damage of grade 3. Many buildings of class A and a few of class B suffer damage of grade 4; a few buildings of class A suffer damage of grade 5. A few buildings of class D suffer damage of grade 2.

IX. Destructive

- a) General panic. People may be forcibly thrown to the ground.
- b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.
- c) Many buildings of vulnerability class C suffer damage of grade 3. Many buildings of class B and a few of class C suffer damage of grade 4. Many buildings of class A and a few of class B suffer damage of grade 5. Many buildings of class D suffer damage of grade 2; a few suffer grade 3. A few buildings of class F suffer damage of grade 2.

X. Very destructive

Many buildings of vulnerability class C suffer damage of grade 4. Many buildings of class B and a few of class C suffer damage of grade 5, as do most buildings of class A. Many buildings of class D suffer damage of grade 3; a few suffer grade 4. Many buildings of class F suffer damage of grade 2; a few suffer grade 3. A few buildings of class F suffer damage of grade 2.

XI. Devastating

Most buildings of vulnerability class C suffer damage of grade 4. Most buildings of class B and many of class C suffer damage of grade 5.

Many buildings of class D suffer damage of grade 4. A few suffer grade 5. Many buildings of class F suffer damage of grade 3; a few suffer grade 4. Many buildings of class F suffer damage of grade 2, a few suffer grade 3.

XII. Completely devastating

Practically all structures above and below ground are destroyed.

Appendix D
Building Typologies of Sylhet City



Fazil Chist, EMSB1



28/5 Fazil Chist, EMSB2



28/5 Fazil Chist, EMSB2



Allahwala, Barut, khana, EMSB2



Modu Shahid Primary School,
EMSC



Tanti Para, EMSC



Jalalbad, EMSD



Sylhet Millennium, Zindabazar,
EMSD



Baluchar, EMS A



Nurani, EMSF



Nurani, Landslide Hazard



Nurani, Landslide Hazard



Abdul Gofur Primary School,
Jalalabad, EMS B2



Hazi Shamir Primary School, Eidgha
EMS B2



Mother Care Clinic, Stadium Road
EMS C



Ragib Rabeya Medical College
EMS C



Fire station, Taltala



Petrol pump, Mendibag

Appendix E
Landslide Potential Areas of Sylhet City



Shahi Eidgha, Hazaribag



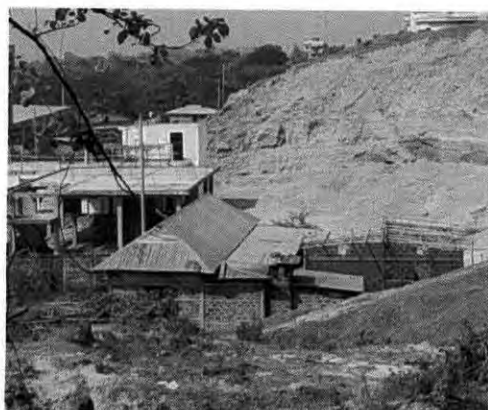
East Shahi Eidgha, Hazaribag



Corer Para



Howladar Para



Sadipur (Balu Char)



Arambag Residential Area

