CHAPTER 1 EARTHQUAKE DISASTER ASSESSMENT

1.1 Introduction

The ultimate purpose of this earthquake disaster assessment is to recognise the phenomena involved when an earthquake occurs near the Kathmandu Valley in the future. Through this assessment people can imagine 4W2H; Who, What, When, Where, How and How much, and identify the weak points and conduct planning for earthquake disaster management effectively, based on the past experience and current situation. And then if people can consider why these phenomena would occur, effective measures for how to cope with future earthquakes and to measure disasters in the Kathmandu Valley can be realised.

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. The distribution and resistance to earthquakes of each type of structure should be clarified. In a more detailed assessment, not only damage but also interactions between damages and psychological effects must be investigated.

One earthquake scenario was conducted a few years ago by a NGO for the Kathmandu Valley based on a very simple disaster assessment considering recurrence of the 1934 earthquake using available data. It was done in a couple of months by overlaying the damage and seismic intensity distribution in 1934 on the current topographic maps or lifeline facility lines. It provided an image of the future damage that would be caused by an earthquake in the Kathmandu Valley and has been useful for disaster management planning. In this study, we have more time and resources to gather and arrange the necessary data, and to adopt the latest knowledge and technologies and will provide a more detailed and more reliable assessment. Nevertheless, there are still limitations of data and time that prevent a complete assessment.

Also, in this study, the duration of time for reconnaissance, collection, processing and analysis of data has been short, and the available data are insufficient for analyses in this early stage. There are almost no official building inventory data for the Kathmandu Valley, so the total number of buildings was estimated from population and household distribution by the 1991 census. Building types have been estimated both from an inventory survey of only 1,000 buildings and from onsite observation of the main sites. Fragility curves covering the types of buildings existing in the Valley are insufficient. The age and height of buildings could almost not be assessed and, hence, were not taken into consideration. Therefore, although the latest knowledge and technologies have been introduced, there are various limitations in this assessment.

The assessment results will be presented using maps, figures and tables showing current status, estimated damage and influence caused by different scenario earthquakes. Thus, since the assessment results show an outline of current conditions and probable damage status in some areas, when examining the scenario and damage assessments, the above limitations should be taken into account. The team is strongly hoping that more detailed and appropriate data can be prepared in the next opportunity. The governments should prepare statistics of the various items required, not only for disaster management planning but also for usual and effective governmental management. This should be a fundamental issue.

Despite the limitations outlined above, the following presents a disaster assessment in the Kathmandu Valley for possible earthquake scenarios.

Basic unit for the study

The municipal wards and the VDCs are adopted as the basic units for the administration boundary in this study, because of the limitation and convenience of the available data.

For various analyses below, especially earthquake motion and ground condition, a grid with a mesh of 500m square was used because of the convenience of the following various analyses. 2,826 grid cells cover the whole valley area.

1.2 Earthquake

1.2.1 Seismicity

(1) Historical Earthquakes

Nepal lies on an active seismic zone ranging from Java – Myanmar – Himalayas – Iran and Turkey, where many large earthquakes have occurred in the past as shown in Figure 1.2.1.

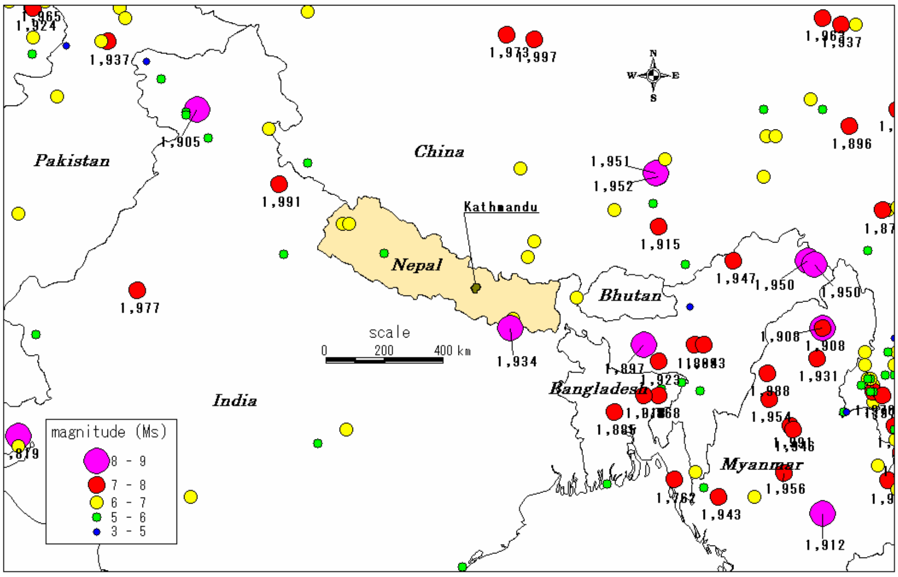


Figure 1.2.1 Hazardous Earthquake along Himalaya
Source: Utsu, 1990

The epicentral distribution map indicates the following characteristic in terms of earthquake distribution in Nepal as shown in Figure 1.2.2.

a) The three main tectonic lines, that are Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT), run across Nepal, and many of the earthquakes occurred in an area between MCT and MBT.

b) The seismicity is active in the West of Nepal.

c) The central part of Nepal has suffered relatively few earthquakes. Bilham et al. (1995) has pointed out that the zone may be a "seismic gap" that is accumulating stress, and that a huge earthquake could occur someday when the stress is relieved.

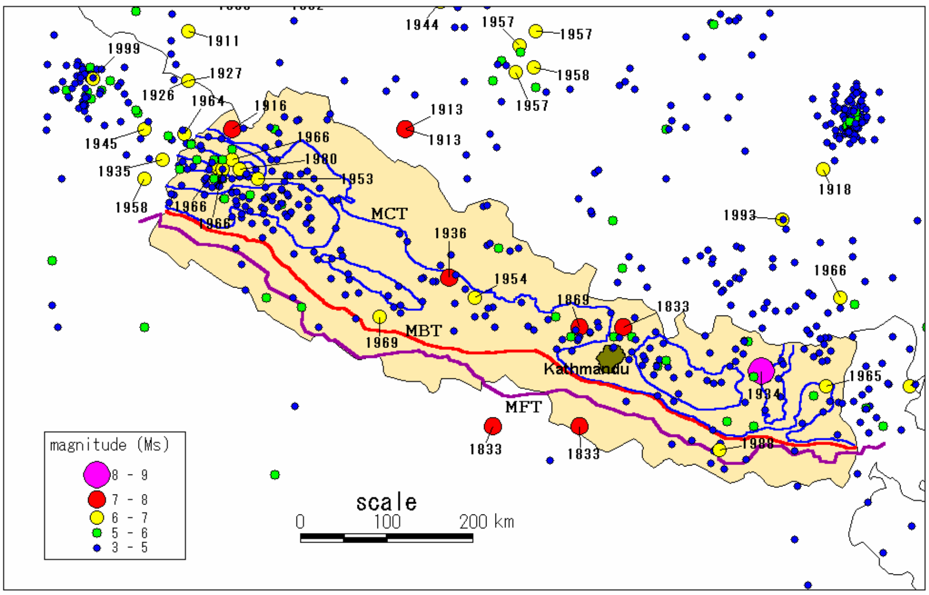


Figure 1.2.2 Epicentral Distribution around Nepal from 1255 to 2001 (Source: DMG)
*** Location of some epicentres have been adjusted, based on hazard records in Nepal**

The historical earthquake catalogue of UNDP/UNCHS (1994) also shows the high seismicity along the Himalaya and also the occurrence of huge earthquakes. Kathmandu has suffered damage due to earthquakes several times since 1833, as summarised below.

Among the earthquakes listed in Table 1.2.1, three earthquakes caused serious damage as summarised in Tables 1.2.2 to 1.2.4.

Table 1.2.1 List of Earthquakes near Kathmandu

Year	Month	Day	Ms	Latitude	Longitude	Epicentral Distance (km)	Assumed PGA (gal)
1833	8	26	7.0	28.00	85.00	38	137
1833	10	4	7.0	27.00	85.00	84	75
1833	10	18	7.0	27.00	84.00	151	47
1869	7	7	7.0	28.00	85.00	45	121
1934	1	15	8.4	27.55	87.09	177	88
1936	5	27	7.0	28.50	83.50	199	38
1954	9	4	6.5	28.30	83.80	163	34
1988	8	20	6.5	26.75	86.62	167	36

Source: UNDP/UNCHS (1994)
Location of 1833.8.26 earthquake is quoted from Bilhami (1995)
PGA were calculated by the Study Team

Table 1.2.2 Damage by the 1833. 8. 26 Earthquake

Area	Damaged houses	Human damage
Kathmandu	643	22 buried, 30 injured
Lalitpur	824	1 died
Bhaktapur	No specific amount	
Sankhu	236	18 died
Banepa	269	2 died
Total	18,000	-

Table 1.2.3 Damage by the 1934.1.15 Bihar-Nepal Earthquake

Region	Damaged Houses				Casualties
	Completely destroyed	Much fractured	Slightly fractured	Total	
Kathmandu	725	3,375	4,146	8,606	479
Outskirt of Kathmandu	2,892	4,062	4,267	11,221	245
Patan	1,000	4,170	3,860	9,030	547
Outskirt of Patan	3,977	9,442	1,598	15,017	1,697
Bhaktapur	2,359	2,263	1,425	6,047	1,172
Outskirt of Bhaktapur	1,444	1,986	2,388	5,818	156
Total	12,397	25,658	17,684	55,739	4,296

*: Population in the Valley was 306,909 and the number of houses was 66,440 in 1920
Source: Pandey and Molnar, 1988

Table 1.2.4 Damage by the 1988.8.20 Udayapur Earthquake

Region	Death	Injured		Private House Damage	
		Serious	Minor	Heavily	Partially
Kathmandu	0	0	3	0	200
Lalitpur	1	3	22	376	137
Bhaktapur	7	23	20	274	1,477

Recently, it was pointed out that there is high possibility that a huge earthquake will occur around the Himalayan region based on the difference between energy accumulation in this region and historical earthquake occurrence as shown in Figure 1.2.3.

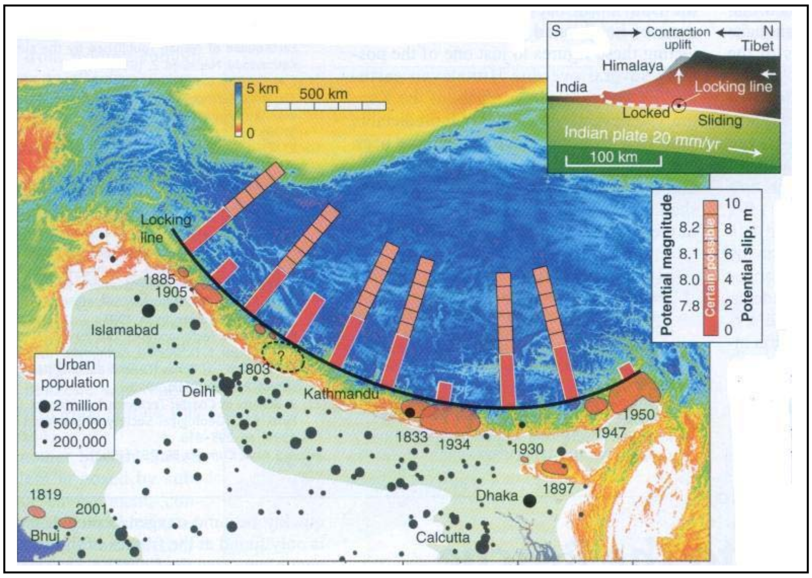


Figure 1.2.3 Danger Zone around Himalayan Region
From 'Himalayan Seismic Hazard' by R.Bilham, V.K. Gaur and P.Molnar (SCIENCE, Vol. 293, 2001)

(2) Micro Seismicity

The Department of Mines and Geology (DMG) has a telemeter seismological network in Nepal. This system consists of 17 nation-wide seismic stations. It is estimated that the detection threshold to be 2.0 of the Local Magnitude (M_L). The network detected about 11,000 local and regional events for 2.5 years. Pandey et al. (1999) reported the seismic features in Nepal based on the micro seismic observation as follows:

a) The main feature of the seismicity of Nepal is a belt of seismicity following the front of the Higher Himalaya.
b) Lateral variation along that belt may relate to the segmentation of the Himalayan arc.
c) The seismic records suggest a division into four 250 km to 300 km long segments with major junctions at about 82° and 87° E and a less obvious one at about 85° E.

1.2.2 Lineament in the Kathmandu Valley

There are several faults in the Kathmandu Valley. If one of them moves, part of the Valley will be severely damaged, even if the damaged area is not so large. The nature of damage from an earthquake in the Valley will be different from that of a huge earthquake that occurs outside the Valley. In order to identify the possible source of a small- to middle-scale earthquake occurring in the Valley, data about the lineament in the Valley were collected as shown in Figure 1.2.4. Data sources were as follows:

a) Engineering and Environmental Geology Map of the Kathmandu Valley (DMG, 1998)
b) Seismic Hazard Mapping and Risk assessment for Nepal (UNDP/UNCHS, 1994)
c) Yagi et al. (2000)
d) Aerial photograph interpretation by the Study Team

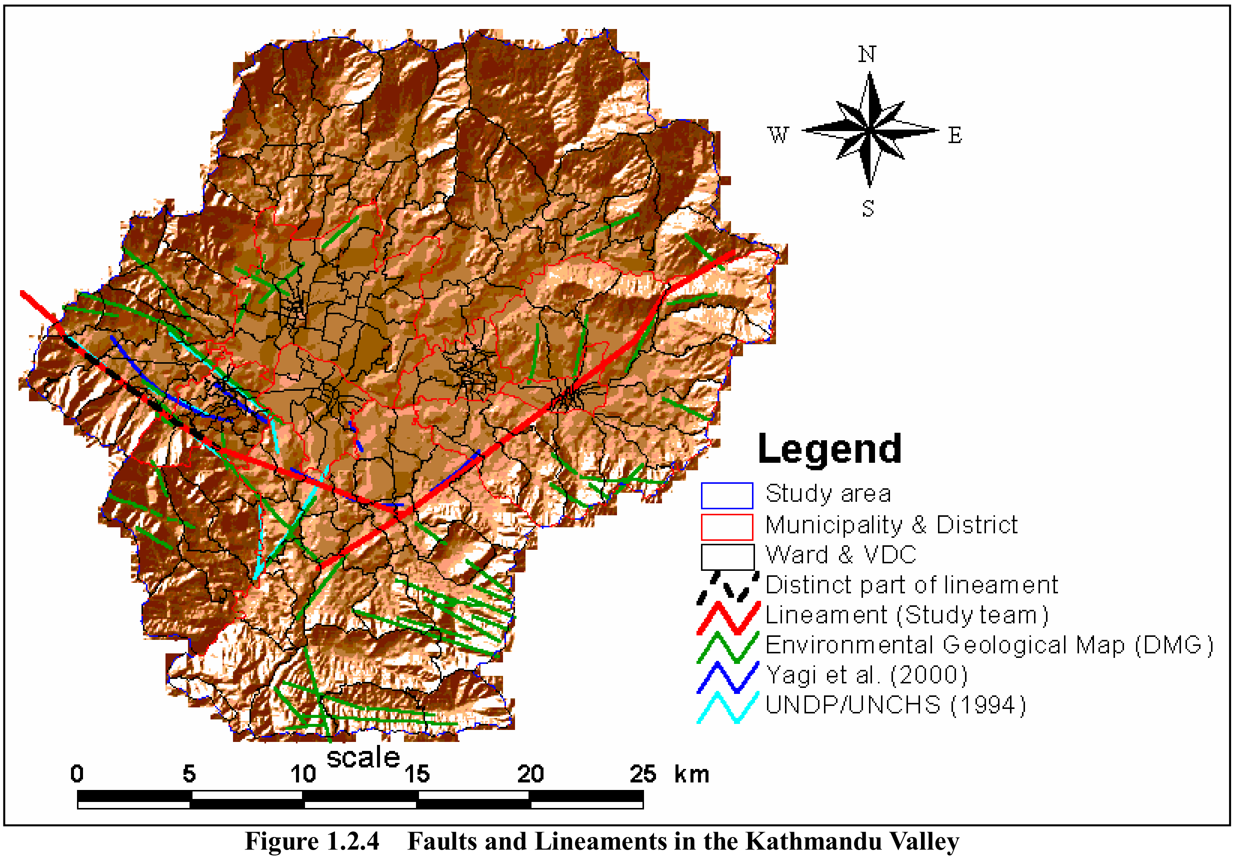


Figure 1.2.4 Faults and Lineaments in the Kathmandu Valley

1.2.3 Scenario Earthquake Model

The damage by an earthquake will be different depending on the type and location of the earthquake, such as a huge earthquake outside of the Valley and a small- to middle-scale earthquake within the Valley. Although it is difficult to predict when and where an earthquake will occur, two or three types of earthquakes should be taken into account in order to prepare earthquake scenarios for disaster mitigation planning.

The earthquake damage is strongly affected by the seismic intensity. The seismic intensity is larger if the earthquake magnitude is larger or the distance from the source area is smaller.

Therefore, not only the huge earthquake but also smaller earthquakes in shorter distances which have sufficient possibility to occur should be considered.

In this study, three fault models are newly selected based on the seismic, seismo-tectonic and geological condition around the Kathmandu Valley, and the fault model of 1934 Bihar-Nepal Earthquake is also included for comparison as shown in Figure 1.2.5.

a) Mid Nepal Earthquake
   This earthquake model has been set, based on the seismic gap in the middle of Nepal. According to Pandey et al. (1999), the segmentation boundary of Himalaya seismic zone exists between 82° and 85° E in mid Nepal. The fault surface of this earthquake corresponds to the east half of this segmented region. This is regarded as a huge earthquake.
b) North Bagmati Earthquake
   As shown in Figure 1.2.5, small earthquakes frequently occur just north of the Kathmandu Valley. This earthquake model has been set, based on this earthquake cluster. This is regarded as a middle-scale earthquake.
c) KV Local Earthquake
   This earthquake model has been set, based on a distinct part of the lineament in the Valley. This is regarded as a local earthquake underfoot.
d) 1934 Bihar-Nepal Earthquake
   This earthquake model has been set for effective comparison with the above three earthquakes, because most people in the Kathmandu Valley have an impression and/or memory of this earthquake.

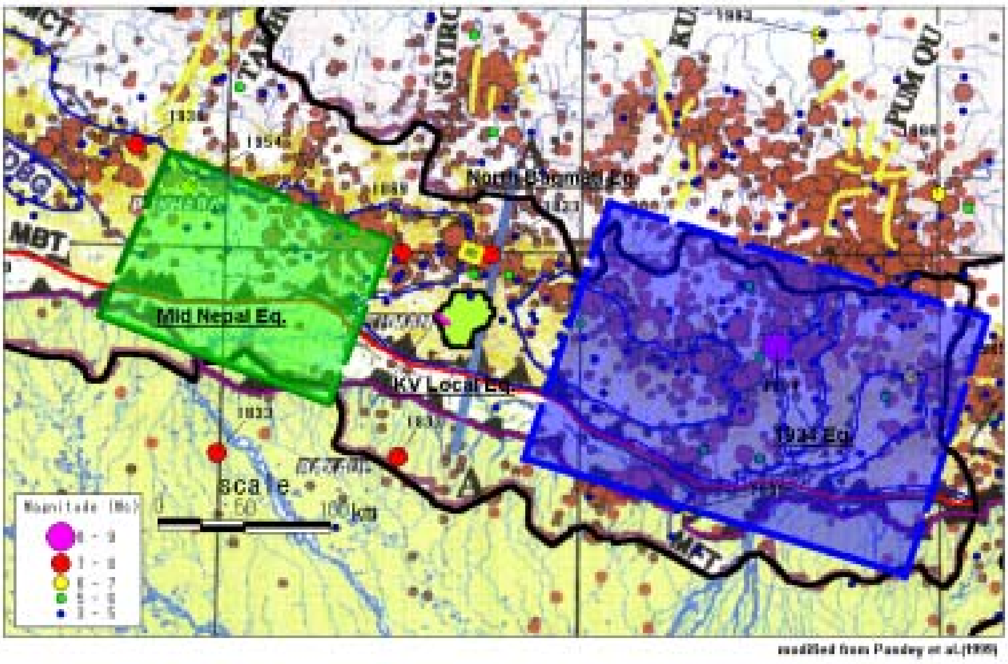


Figure 1.2.5 Scenario Earthquake Fault Model

It should be noted that these scenario earthquakes are selected only for the purposes of scenario presentation and not for the prediction of the next event. The parameters of the four scenario earthquakes are shown in Table 1.2.5.

Table 1.2.5 Scenario Earthquake Fault Model Parameters

Item		Mid Nepal Earthquake	North Bagmati Earthquake	KV Local Earthquake	1934 Earthquake
Fault surface	Length (km)	135	10	8	222
	Width (km)	95	9	(4)	150
	Azimuth (Clockwise from North) (degree)	290	290	308	286.5
	Dip angle (degree)	5	37	90	5
	Depth of upper edge (km)	5	10	(1)	5
Surface Wave Magnitude (Ms)		8.0	6.0	5.7	8.4
Moment Magnitude (Mw)		8.03	5.99	5.73	8.2
Origin	N (degree)	27.25	27.65	27.65	26.42
	E (degree)	84.62	85.27	85.27	87.80
Type of displacement		reverse slip	not specified	not specified	reverse slip

1.1 Ground Classification

The ground condition of the Kathmandu Valley was analysed and classified to establish the ground model for seismic analysis such as calculation of the amplification of seismic motion, evaluation of liquefaction and slope stability. The Study Team collected the related geological data and conducted drilling of five boreholes in order to collect essential ground properties such as shear wave velocity, density, N value, groundwater level and mean particle size.

1.3.1 Regional Geology

Nepal lies within the Himalayan mountain range formed by the northward subduction of the Indian plate under the Eurasia plate, and geological units accordingly extend E-W, bounded by north-trending thrust faults as shown in Figure 1.3.1.

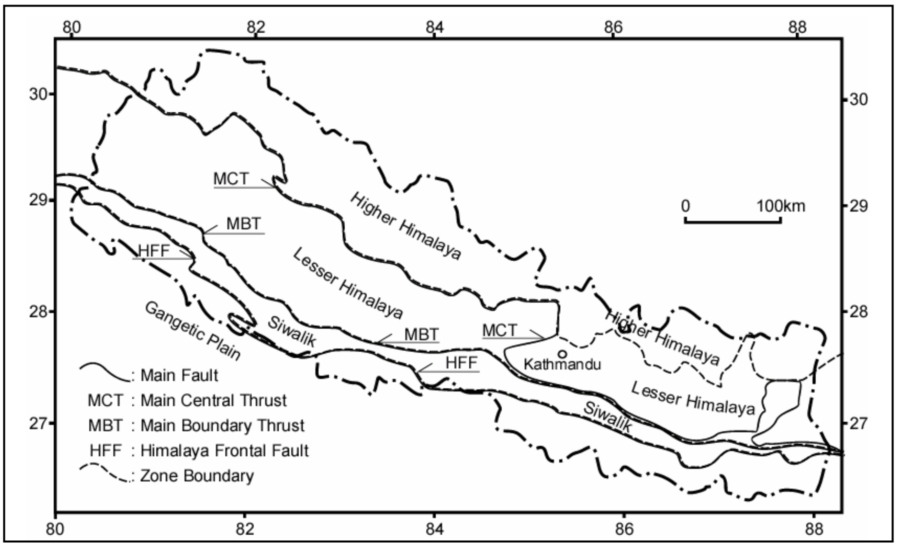


Figure 1.3.1 Geo-technical Zones of Nepal and Surrounding Area

The Kathmandu valley lies within a geological unit of the Lessor Himalaya which consists of Pre-Cambrian bedrock of some hundred million years ago. The bedrock crops out on the periphery of the valley, and thick unconsolidated sediments cover the central portion of the valley as shown in Figure 1.3.2.

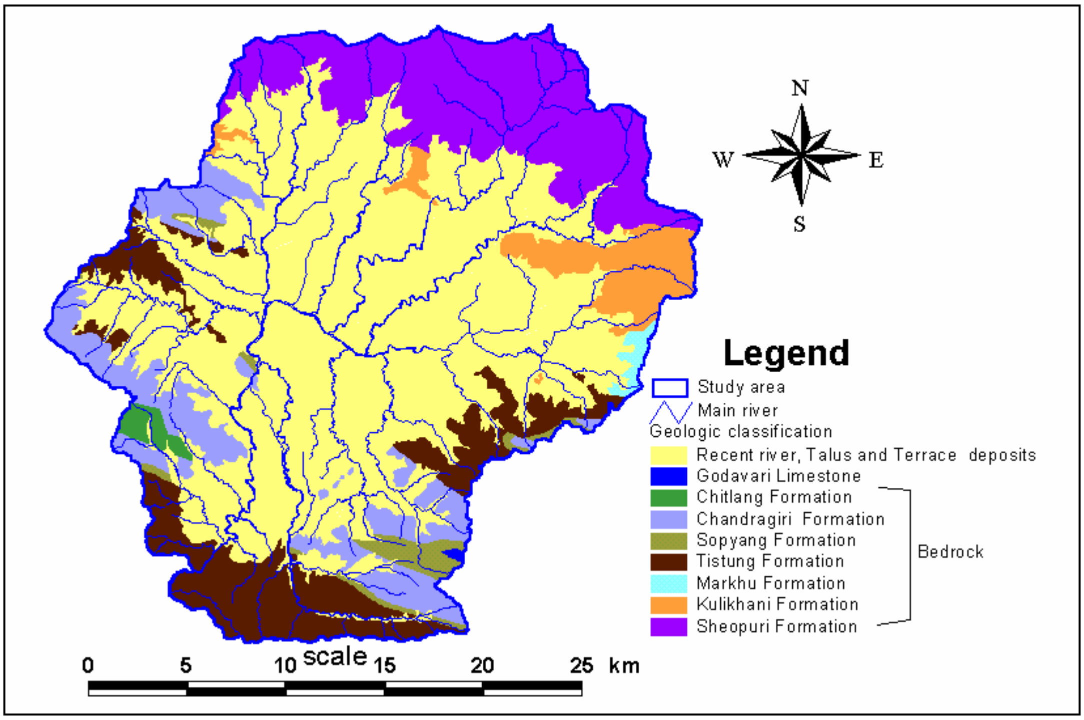


Figure 1.3.2 Geological Map of the Kathmandu Valley

The sediments are mainly fine-grained lake deposits of late Tertiary to Quaternary geological age (five million years ago or younger). The thickness of the sediments exceeds 500 m at the centre of the valley as shown in Figure 1.3.3.

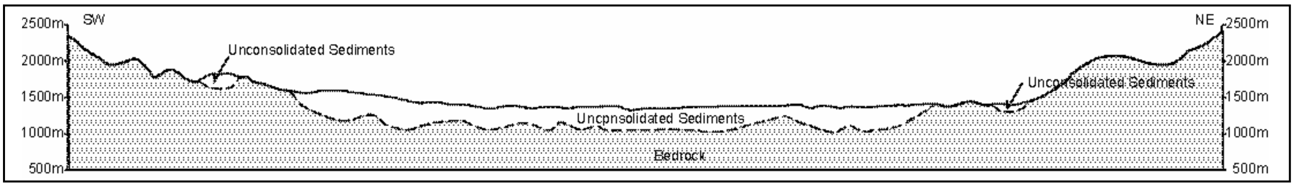


Figure 1.3.3 Geologic Section of the Kathmandu Valley

1.3.2 Ground Model

The following geological data were collected in the early stage of this study to establish the ground model.

a) Existing reports describing geology, N value, groundwater level, and physical properties of the ground. The collected reports are listed in Chapter 1.13.
b) Topographic maps on a scale of 1:25,000.
c) Aerial photographs on a scale of 1:50,000.
d) Original data collection through geological investigation in this study, such as drilling, standard penetration test, and PS logging.

The locations of boreholes are shown in Figure 1.3.4.

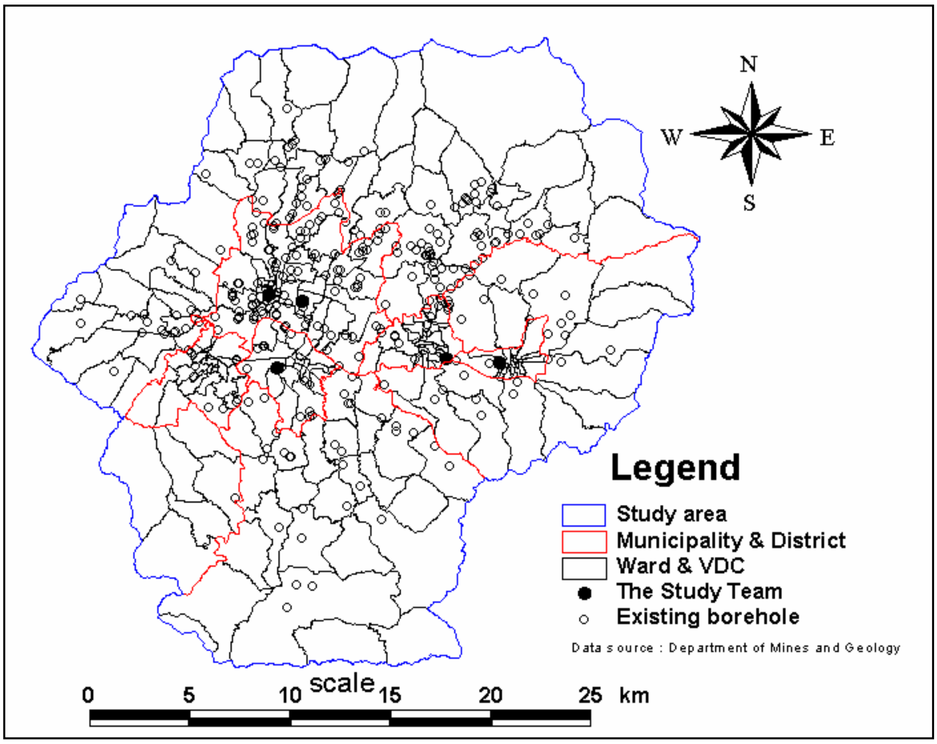


Figure 1.3.4 Locations of Boreholes

(1) Geomorphologic Classification

Geomorphologic classification has been done through aerial photograph interpretation. Geomorphologic features identified are in Table 1.3.1.

Table 1.3.1 Geomorphologic Feature in the Study Area

Feature	Description	Purpose
Recent river plain	Flat plane along major rivers	Geological classification for the calculation of amplification and the evaluation of liquefaction
Talus slope	Gentle slope of 5 to 15 degrees	
Terrace plane I	Flat to gentle plane with relative height of 5 m to 15 m	
Terrace plane II	"Patan surface" with relative height of 20 m to 50 m	
Terrace plane III	"Thimi surface" with relative height of 50 m to 80 m	
Terrace plane IV	"Gokarna & Boregaon surfaces" with relative height of 80 m to 160 m	
Terrace plane V	"Chapagaon & Pyanggaon surfaces" with relative height of 180 m to 240 m	
Rocky slope	Slope of more than 15 degrees	
Landslide feature		Evaluation of slope stability
Lineament		Setting possible earthquake

(2) Geological Classification

For the calculation of amplification and the evaluation of liquefaction, the study area has been divided into 2,826 grid cells of 500 m square. Based on geomorphologic classification and existing drilling results, the geological components on columnar section of each grid cell was determined.

As a result of the data examination, the 2,826 grid cells have been classified into 90 kinds of typical geological sections. These typical sections are shown in attached Table 1.3.2 and their spatial distribution map is shown in Figure 1.3.5.

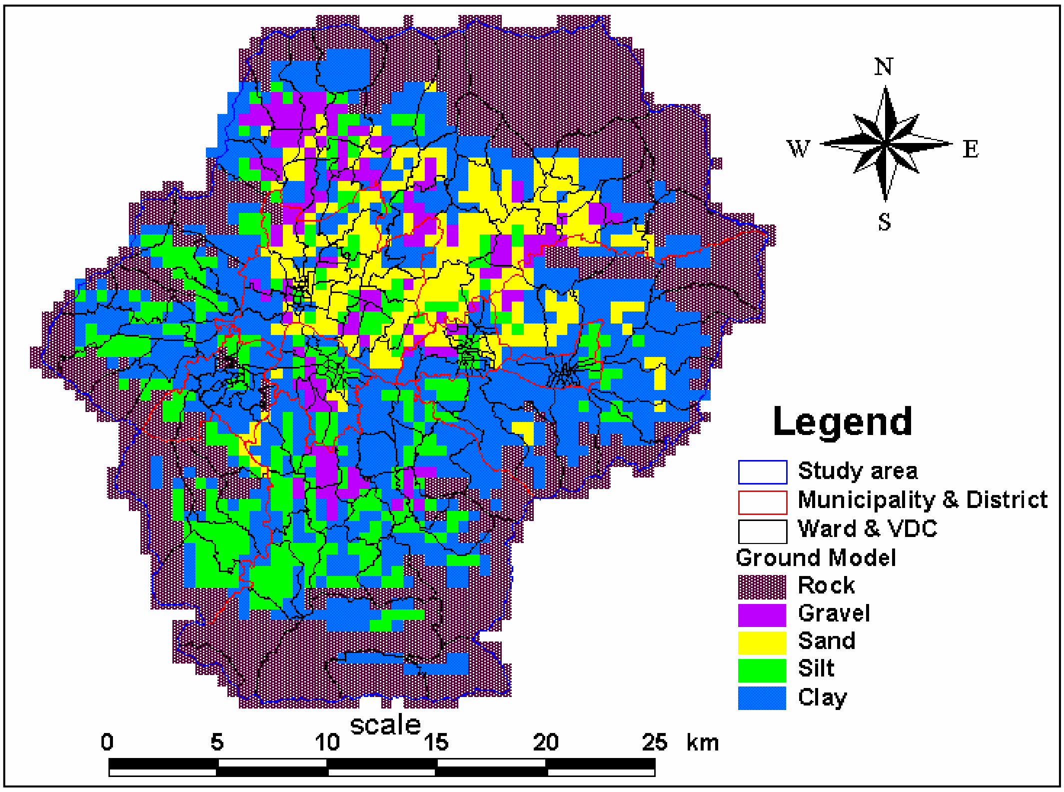


Figure 1.3.5 Ground Model for Seismic Analysis

1.3.3 Soil Properties of the Ground Model

Soil properties of the ground model to be set for this study are in Table 1.3.3.

Table 1.3.3 Soil Properties of the Ground Model

Property	Purpose
N value	The evaluation of liquefaction
Groundwater level	
D_{50} (Mean particle size) and Fc (Fine content)	
Vs (Shear wave velocity)	The calculation of amplification
Density	

(1) N Value

The availability of standard penetration test data, or N values, are limited in the study area, so the Study Team proceeded the existing data in order to reveal the relationship between N value and the layer depth of different types of geological material. N values for the evaluation of liquefaction within the typical sections were determined from the relationship as summarised in Table 1.3.4.

Table 1.3.4 Relation between N value and Depth

Category		Relation [N: N value, D: depth (m)]
1	Clay to clayey silt	N = 0.955 D
2	Silt to fine sand	N = 2.604 D
3	Medium to coarse sand	N = 2.901 D
4	Sand and gravel	N = 22.88 D

(2) Groundwater Level

Although natural groundwater levels are used for the evaluation of liquefaction, most of groundwater monitoring records in existing reports seems to show artesian groundwater levels which are not useful for the evaluation. Groundwater level for the evaluation of liquefaction in this study has been set based on estimated level shown in the JICA study report "Groundwater Management Project in the Kathmandu Valley."

(3) Mean Particle Size (D_{50}) and Fine Content (Fc)

Representative values of mean particle size and fine content are set as shown in Table 1.3.5, according to the laboratory soil test.

Table 1.3.5 Mean Particle Size and Fine Content

Category		Mean particle size D_{50} (mm)	Fine content Fc (%)
1	Clay to clayey silt	0.01	80
2	Silt to fine sand	0.05	60
3	Medium to coarse sand	0.20	20
4	Sand and gravel	1.00	5

(4) Vs (Shear wave velocity)

Shear wave velocities of five drilled boreholes have been measured by means of PS logging in this study since no other data are available on shear wave velocity. Based on the result of PS logging, the study team recognised that the relation between N values and shear wave velocities from previous test results in Japan shown in Figure 1.3.6 can be applied also in the Kathmandu Valley.

$N = 97\ Vs^{0.314}$

where; N: N value

Vs: Shear wave velocity (m/sec)

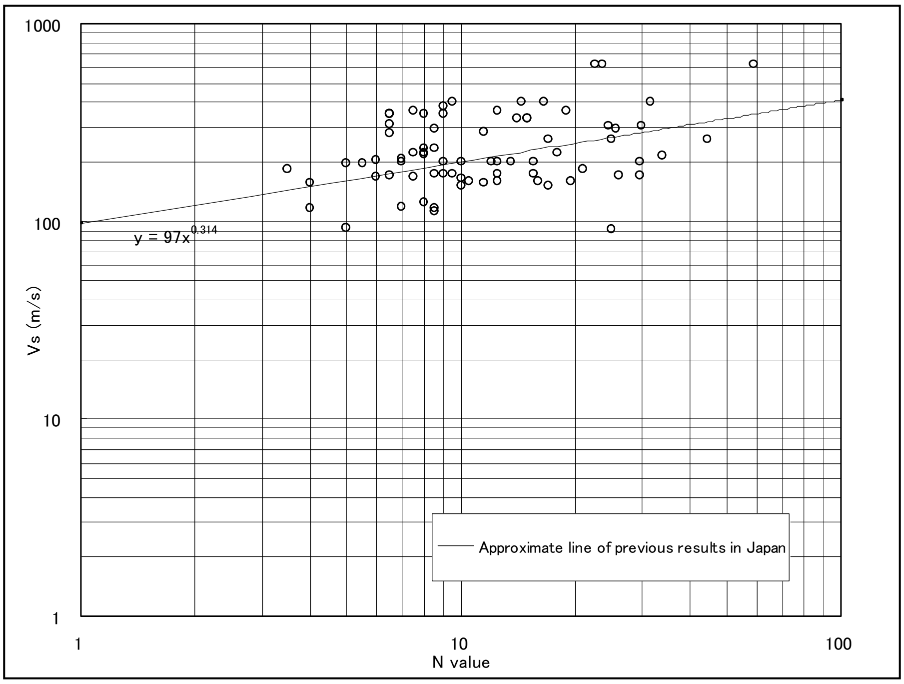


Figure 1.3.6 Relation between N Value and Shear Wave Velocity

(5) Density

Representative values of the densities are set as shown in Table 1.3.6.

Table 1.3.6 Density of Materials

Category		Shear wave velocity (m/sec)	Density (g/cm³)
1	Clay to clayey silt	Vs < 175	1.5
		175 ≤ Vs < 300	1.6
		300 ≤ Vs	1.7
2	Silt to fine sand	Vs < 200	1.6
		200 ≤ Vs < 350	1.7
		350 ≤ Vs	1.8
3	Medium to coarse sand	Vs < 200	1.7
		200 ≤ Vs < 350	1.8
		350 ≤ Vs	1.9
4	Sand and gravel	Vs < 200	1.9
		350 ≤ Vs	2.0

1.4 Earthquake Motion

1.4.1 Analysis Method

It is well known that the surface ground motion of earthquakes is heavily influenced by the subsurface ground condition, especially in areas covered by thick sediments. It is important to evaluate the differences in subsurface amplification site by site to know the distribution of earthquake motion across a wide area. The main portion of subsurface ground amplification is concerned with the layer some ten meters below the ground surface. Therefore, it is common to evaluate the earthquake motion at the engineering seismic bedrock at first and then multiply the subsurface amplification that is analysed separately using soil conditions as established as the ground model in the previous section. Thick sediments are underlying most of the study area, since the Kathmandu Valley was formerly a lake. This type of analysis concept was also adopted in this study. A flowchart for the analysis is shown in Figure 1.4.1.

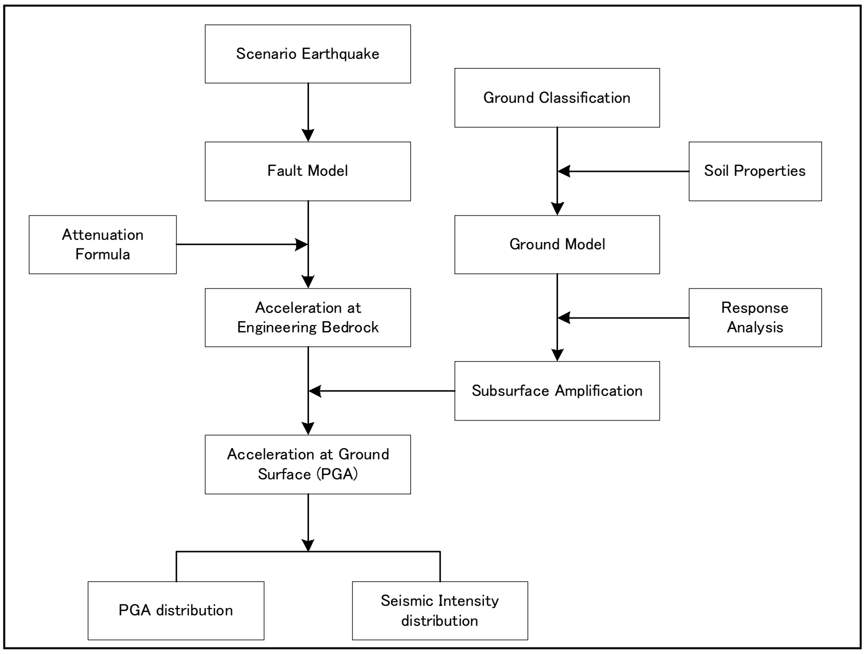


Figure 1.4.1 Flowchart for Earthquake Motion Analysis

Based on the fault model, which is explained in Section 1.1.3, acceleration at engineering seismic bedrock is estimated using empirical attenuation formula. The subsurface amplification factor is indispensable in order to assess the earthquake motion at the ground surface. For this purpose, the ground of the whole area was classified into several models. The ground model for numerical calculation was constructed from the ground classification and its soil properties. Based on this ground model and its soil properties, the subsurface amplification factor is analysed by a response analysis method. The acceleration at the ground surface (PGA) is calculated using both the acceleration at the engineering seismic bedrock and the subsurface amplification factor.

1.4.2 Acceleration at Engineering Seismic Bedrock

An attenuation formula was selected to evaluate the acceleration at engineering bedrock. In this study, the engineering bedrock was assumed to be the layer at which the shear wave velocity (Vs) exceeds 400m/s, which exists almost 100m deep from surface. Details are explained below in this section.

To select the most suitable attenuation formula from a number of existing ones, the earthquake motion data of the 1988 Udayapur earthquake were used. The requirements for the formula to be selected are follows:

a) Applicable to the ground condition of engineering bedrock in this study (Vs=400m/s).
b) Able to explain the observed or analysed earthquake motion of 1988 Udayapur earthquake.

Attached Figure 1.4.2 shows observed or analysed earthquake motion of 1988 Udayapur earthquake and several attenuation formulae. Observed data is the acceleration value converted from response spectral value by Structure Response Meter (SRR), though the calibration value for another region was used (Jain et al., 2000). Analysed data were derived from questionnaire analysis and liquefaction analysis by Fujiwara et al. (1990). The ground conditions applicability of the attenuation formulas in attached Figure 1.4.2 are listed in Table 1.4.1.

Table 1.4.1 Ground Condition Applicability of Attenuation Formula

Kawashima(1983)	Campbell(1997)	Abrahamson & Silva(1997)		Boore et al.(1997)	
	Hard Rock Cretaceous (Vs: 700 - 1050 - 1400m/s)	A) Rock (Vs>600m/s) or very thin Soil (<5m) over Rock	Rock	A) Vs 750m/s < (average over the upper 30m)	Rock Vs=620m/s
Class 1 (Rock) Alluvial <5m over Rock(Vs>300m/s) Dilluvial <10m over Rock	Soft Rock Tertiary (Vs: 375 - 540 - 700m/s)	B) Shallow Soil Soil 5-20m thick over Rock		B) Vs 360 - 750m/s (average over the upper 30m)	
Class 2 (Soil) Alluvial 5- 25m over Rock(Vs>300m/s)	Firm Soil firm or still Quaternary deposit >10m	C,D) Deep Soil Soil >20m thick over Rock	Deep Soil	C) Vs 180 - 360m/s (average over the upper 30m)	Soil Vs=310m/s
Class 3 (Soft Soil) Alluvial >25m over Rock(Vs>300m/s)	Soft Soil (Vs: 100 - 150 - 200m/s)	E) Soft Soil (Vs<150m/s)		D) Vs < 180m/s (average over the upper 30m)	

Sharma (2000)	Jain et al. (2000)	Joyner & Boore(1981)	Campbell(1981)	Abrahamson & Litehiser(1989)	Fukushima & Tanaka(1990)
Rock	Special for 1998 Udayapur Eq.	Several Ground condition	except Hard Rock	Several Ground condition	Several Ground condition

Based on this figure and table, the following formulae by Boore et al. (1997) are selected for this study.

$$\log_e Y = b_1 + 0.527 \cdot (M_w - 6) - 0.778 \cdot \log_e r - 0.371 \cdot \log_e \frac{Vs}{1396}$$

where , Y : acceleration (G)

b_1 : fixed number (-0.313 for strike slip, -0.117 for reverse slip, -0.242 for mechanism not specified

Mw : moment magnitude

$r = \sqrt{r_{jb}^2 + 5.57^2}$ r_{jb}: horizontal distance from the station to an epicentre (km)

VS : average shear wave velocity of surface 30 (m/sec)

The relation between peak ground acceleration and distance from an epicentre is shown in Figure 1.4.3.

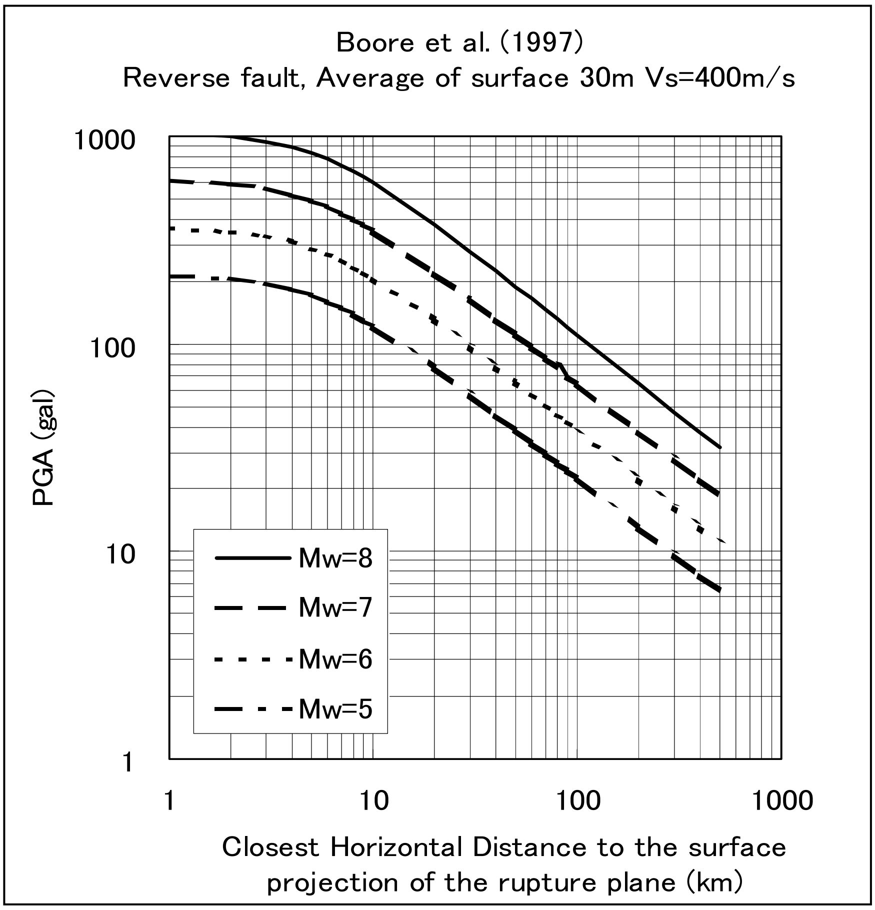


Figure 1.4.3 Relation between PGA and Distance

1.4.3 Amplification of Subsurface Ground

Ground condition for the estimation of amplification was shown in attached Table 1.3.2 and Figure 1.3.5. The amplification of the subsurface layer was analysed using one-dimensional response analysis. The ground model for response analysis was made from typical column data, by dividing into several layers based on the soil type and shear wave velocity. An example of the model is shown in Table 1.4.2. The non-linearity effect of soft soil was considered, using the standard soil non-linearity characteristics by Iwasaki et al. (1977) for clay and sand and that for gravel by Imazu and Fukutake (1986) because no data concerning soil non-linearity in Nepal were available.

Table 1.4.2 Example of Ground Model for Response Analysis (Ground model No.82)

Depth (m)	Soil	Vs (m/sec)	Density (g/cm^3)
0 - 2	Clay	110	1.5
2 - 7	Clay	160	1.5
7 - 15	Sand	290	1.8
15 - 38	Clay	270	1.6
38 - 95	Clay	350	1.7
95 -	Clay	400	1.7

The calculated result for amplification of acceleration at engineering seismic bedrock for each ground model is shown in Figure 1.4.4. Each line corresponds to a different ground model. The amplification factor is almost 1.0 to 2.0 and non-linear effect can be seen.

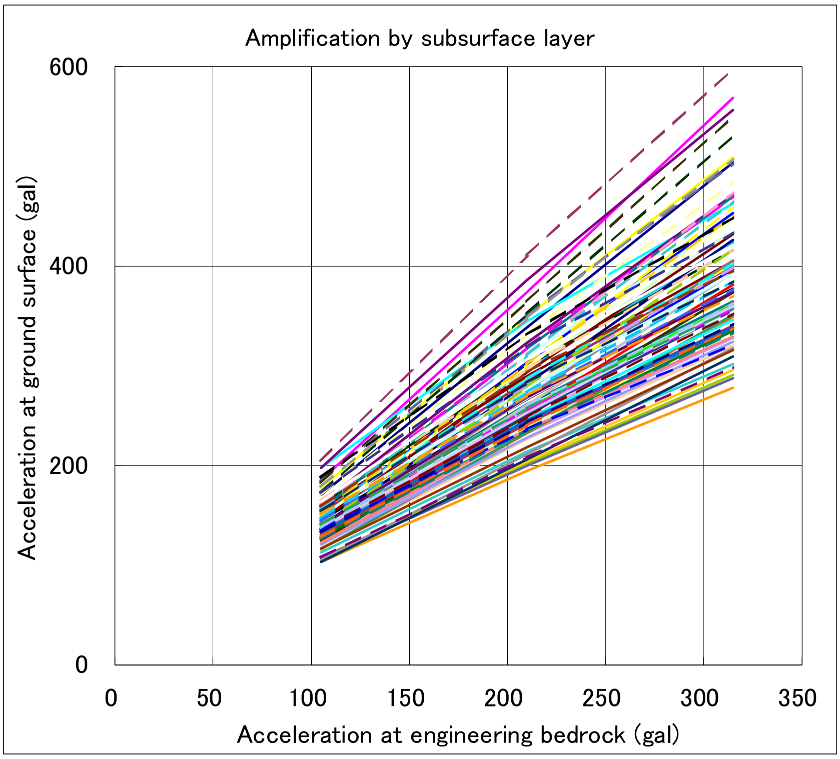


Figure 1.4.4 Amplification of Subsurface Layer

*: Each line shows the relation of each typical section

1.4.4 Peak Ground Acceleration and Seismic Intensity

Peak ground acceleration (PGA) and seismic intensity are calculated based on both acceleration at the engineering seismic bedrock and subsurface amplification factor.

(1) Peak Ground Acceleration (PGA)

The PGA distribution maps of each scenario earthquake are shown in attached Figures 1.4.5 and 1.4.6.

a) Mid Nepal earthquake: Except for the mountainous areas, the Valley would experience over 200 gal. Some areas would experience more than 300 gal.
b) North Bagmati earthquake: The whole Valley would experience less than 200 gal. The Valley would experience the smallest peak ground acceleration in these four scenario earthquakes.
c) KV Local earthquake: The area along the fault would experience over 300 gal.

The peak ground acceleration would decrease rapidly as distance increase from the fault line. The Valley would experience less than 100 gal in the mountainous area.

d) 1934 earthquake: The Valley would experience the largest peak ground acceleration in these four scenario earthquakes. Most part of the Valley would experience over 200 gal. Eastern part of the Valley such as Bhaktapur would experience more than 300 gal. And some areas would suffer more than 400 gal.

(2) Seismic Intensity

The seismic intensity in Modified Mercalli Intensity (MMI) scale was derived from PGA value. The seismic intensity is basically a subjective one, based on the human sensations or damage during an earthquake. The relations between seismic intensity and physical parameters, such as acceleration and velocity, were studied. In this study, the relation by Trifunac and Brady(1975) shown in Figure 1.4.7 was adopted. The seismic intensity distribution maps of each scenario earthquake are shown in attached Figures 1.4.8 and 1.4.9.

a) Mid Nepal earthquake: Except in mountainous areas, MMI VIII would be experienced in the Valley.
b) North Bagmati earthquake: Except in mountainous areas, the Valley would experience MMI VI or VII.
c) KV Local earthquake: The area along the fault would experience MMI IX. Other parts of the Valley, except the mountainous areas, would be experience MMI VII or VIII.
d) 1934 earthquake: Most part of the Valley would experience MMI VIII. And some areas in eastern part would suffer MMI IX.

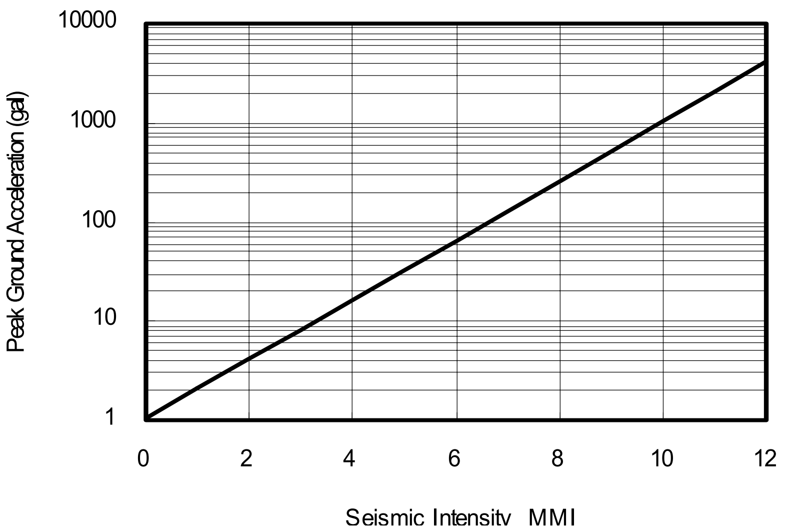


Figure 1.4.7 Relation between PGA and MMI by Trifunac and Brady (1975)

1.5 Liquefaction

1.5.1 Analysis Method

There are several grades of complexity which can be used to estimate liquefaction potential. Based on the "Manual for Zonation on Seismic Geotechnical Hazards" by TC4, ISSMFE (1993), the simplest grade is "Simple and synthetic analysis by using geological maps, topographical maps and histories of disaster". The most complex grade is described as "a detailed analysis using geological investigation results and numerical analyses". The procedure should be determined considering the objective of the estimation. In this study, soil properties and seismic motion are to be determined at the same levels of quality in the whole Study Area. Therefore, using some statistical method is appropriate.

The following information on soil properties and seismic motion were available in this study:

a) Ground classification with typical column.
b) Statistically compiled physical properties of soil.
c) Peak ground acceleration for scenario earthquakes.

Considering the above information, a combination of the F_L method (Japanese Design Specification of Highway Bridge, 1996) and the P_L method (Iwasaki et al., 1982) was adopted in this study. This method is commonly used in Japan for practical purposes. The flowchart of the liquefaction analysis used in this study is shown Figure 1.5.1.

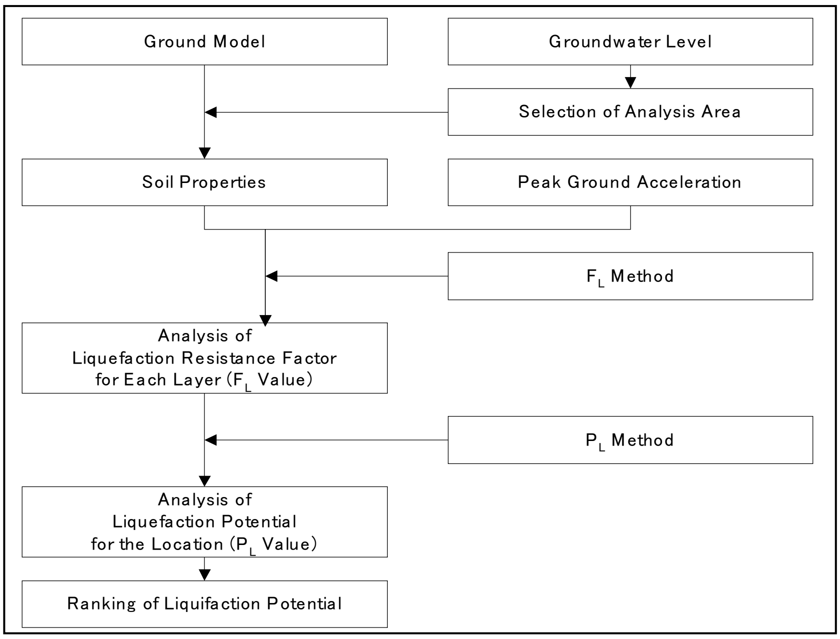


Figure 1.5.1 Flowchart of Liquefaction Analysis

1.5.2 Groundwater Model

The ground water level changes with the season, namely the level is low in the dry season and high in the rainy season. Based on the data on groundwater level by JICA(1990), the groundwater distribution in the dry season and the rainy season was estimated.

The F_L method defines that ground water level to be considered as less than 10 m from the ground surface. Figure 1.5.2 shows the distribution of groundwater level in the rainy season (High Water Level). The ground water level along the river was estimated to be less than five meters from the ground surface.

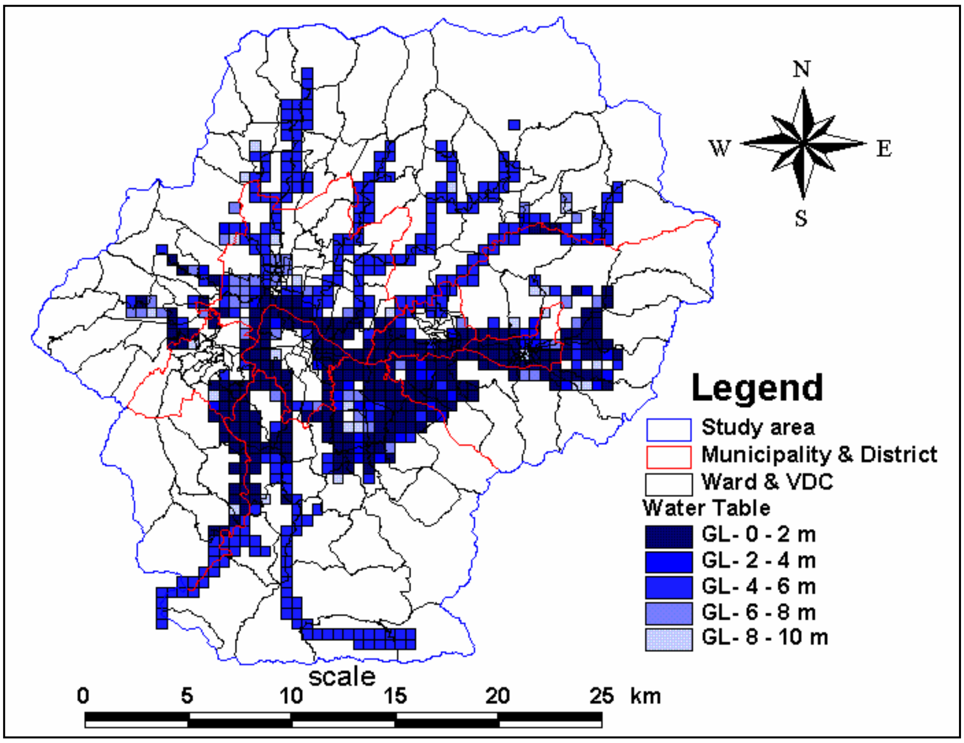


Figure 1.5.2 Groundwater Table Distribution

1.5.3 Liquefaction Potential

The liquefaction potential distribution maps in case of High Water Level are shown in attached Figures 1.5.3 and 1.5.4. It can be common that liquefaction potential is very low in most of the Valley. The following features of each scenario earthquake can be identified.

a) Mid Nepal earthquake: Moderate potential was identified in some areas along the Bagmati river.

b) North Bagmati earthquake: No part of the Valley would be liquefied because the distributes indicates only a very low liquefaction potential.

c) KV Local earthquake: A few grid cells close to the fault were judged to be

High potential. Along the Bagmati river, there are some grid cells with moderate potential.

d) 1934 earthquake: Moderate potential was identified in some areas along the Bagmati river. Compared with the result of Mid Nepal earthquake, the higher liquefaction potential areas can be identified.

1.6 Slope Stability

The controlling factors on slope stability are slope gradient, slope height, the conditions of materials (including joint condition for consolidated materials), and groundwater level. In general, the possibility of slope failure is higher on steeper and longer slopes, rather than gentler and shorter slopes. Although the conditions of materials and groundwater level on the slopes are also key factors for examining slope stability, few data on materials and groundwater are available on each slope to be examined. Therefore, examination on slope stability is accordingly based on slope gradient and slope height in this study.

Geomorphologically, the Kathmandu Valley is roughly divided into two areas, that are;1) a mountainous area surrounding the Valley and 2) a gentle area in the centre of the Valley.

In the mountainous area, the areas of slope failure have been shown on "Engineering and Environmental Geological Map". These areas of slope failure are re-shown on a slope susceptibility map in Figure 1.5.1. Although no detailed examination is done on slope stability in the areas of the slope failures, it can be said that there is high possibility of slope failure in these areas during earthquakes.

In the gentle area, narrow zones of steep slopes are seen along the edge of terrace surfaces. As a result of aerial photo interpretation, seven kinds of terrace surfaces were identified from a viewpoint of relative height, and the surfaces categorised into five groups as shown in Table 1.6.1.

Table 1.6.1 Terrace Surface and Relative Height

No.	Category of Terrace surface	Relative Height from Recent Riverbed [Average]	
1	Lower terrace surface	5 m – 15 m [10 m]	Lower
2	Patan surface	20 m – 50 m [35 m]	↑
3	Thimi surface	50 m – 80 m [75 m]	
4	Gokarna and Boregaon surfaces	80 m – 160 m [120 m]	↓
5	Chapagaon and Pyanggaon surface	180 m – 240 m [210 m]	Higher

Distribution of the slopes on the edge of terrace surfaces is shown on a morphologic classification map. Although slope gradient of each slope mentioned above is variable ranging from 30° to 90°, there is some relation between height and instability of the slopes. Considering the relation between height and instability of slopes, the slopes along the edge of the terrace surfaces can be classified on the basis of height in terms of instability. In case that higher terrace surface (5) lies on the lower surface (1), the relative height of the surface (5) should be 210 m – 10 m = 200 m. The width of each hazardous area was roughly determined to be twice as long as the relative height.

The grade of possibility of hazard was determined on the basis of relative height as shown in Table 1.6.2.

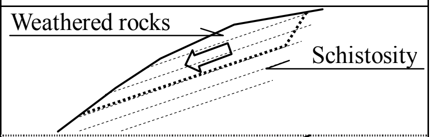
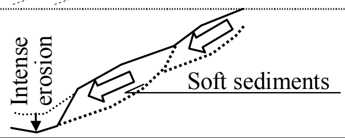
Table 1.6.2 Possibility of Slope Failure

Possibility	Gentle Area	Mountainous Area
	Relative height (RH)	Slope failure
Low	RH ≤ 15 m	-
Moderate	15 m < RH ≤ 50 m	-
High	50 m < RH	Identified on air-photos

Attached Figure 1.6.1 presents the above-mentioned hazardous areas and indicates the following characteristics.

a) In the mountainous area, many slope failures are seen on the northern area and south-western area in the Valley as summarised in Table 1.6.3.

Table 1.6.3 Characteristics of Slope Failure in the Mountainous Area

Area	Material	Cause of failures	Illustration
Northern Area	Weathered rocks	- Flaky nature (shistosity) of rocks, - Dip slope (schistosity is parallel to slope)	
South-west Area	Talus deposits (soft sediments)	- Soft nature of sediments - Intense erosion by the Bagumati River and its tributaries	

b) In general, 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/upper portions of the slope failures.

c) In gentle area, steep slopes, which have the high possibility of slope failure, show linear distribution in limited areas. Although no large-scale hazard would occur due to slope failure, caution will be necessary for particular residential or other important areas on/around the steep slopes.

1.7 Fundamental Social Data

1.7.1 Administrative Boundary

The Kathmandu Valley consists of three Districts of Kathmandu, Lalitpur and

Bhaktapur with an area of about 668 square kilometres, bordered by the ridgelines of mountains surrounding the basin. Each District consists of Municipalities and VDCs (VDC: Village Development Committee), and a Municipality and a VDC are divided into Wards as shown in Table 1.7.1 and Figure 1.7.1.

Table 1.7.1 Administrative Classification

	District	Municipality & VDC	Number of Wards
Kathmandu Valley	Kathmandu District	Kathmandu Municipality	35
		Kirtipur Municipality	19
		56 VDCs	9 Wards in a VDC in general
	Lalitpur District	Lalitpur Municipality	22
		26 VDCs	9 Wards in a VDC in general
	Bhaktapur District	Bhaktapur Municipality	17
		Madyapur/Thimi Municipality	17
		16 VDCs	9 Wards in a VDC in general
Total	3 Districts	5 Municipalities & 98 VDCs	110 Municipal Wards

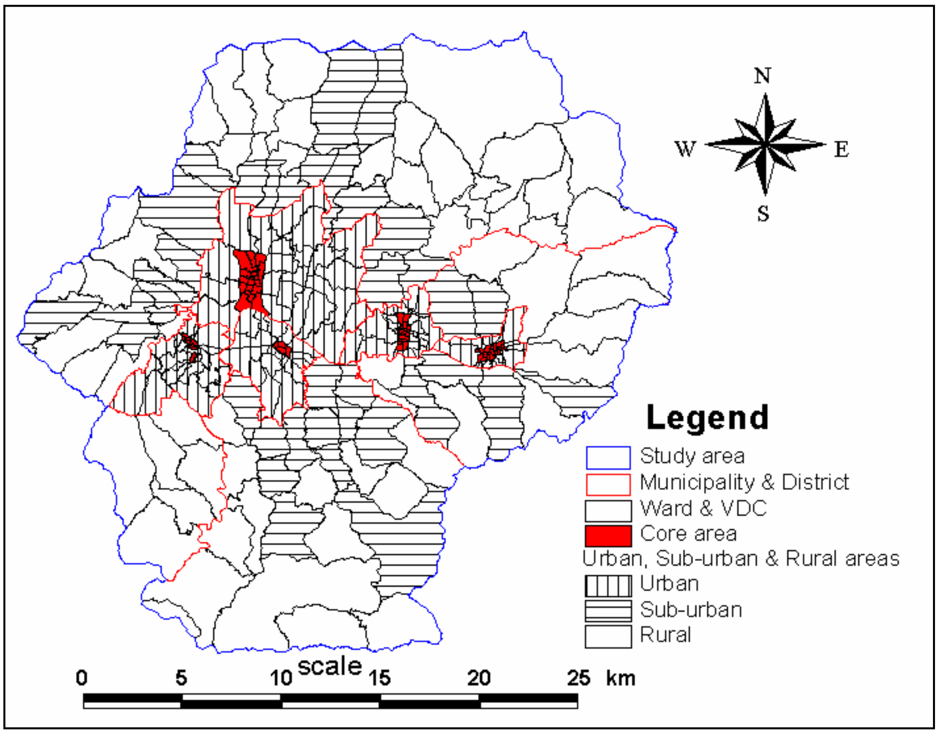


Figure 1.7.1 Administrative Boundary and Locality Classification

1.7.2 Locality Classifications

According to the Kathmandu Valley Town Development Committee and Gorkhapatra (the national daily newspaper), the Valley is divided into locality categories as follows.

(1) Urban area: urbanised area corresponding to five municipalities with mostly over 100 persons/ha population density.

a) Urban Core: The Urban area consists of

- Kathmandu Municipality: Wards 12, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30

- Kirtipur Municipality: Wards 4, 5, 6, 9, 10, 16, 17
- Lalitpur Municipality: Wards 9, 11, 12, 16, 18, 19, 21, 22
- Bhaktapur Municipality: Wards 7, 8, 9, 12, 13, 14, 16
- Madyapur/Thimi Municipality: Wards 1, 4, 6, 8, 10, 11, 12, 13, 14

b) Urban Fringe: remaining municipal area (Wards)

(2) Sub-urban Area: relatively urbanised and adjacent to the municipalities with 19 VDCs in Kathmandu District, 12 VDCs in Lalitpur District and 6 VDCs in Bhaktapur District

The sub-urban areas are not uniform in terms of building construction, building typologies, population density, and economic activity. Therefore, for the purpose of the building inventory survey, the sub-urban areas were classified into Core and Fringe areas. The former is relatively dense and more urbanised as compared to the latter. The Core areas include Balambu, Manamaiju, Naikap, Satungal and Thankot in Kathmandu District; Chapagaon, Harisiddhi, Imadol, Lubhu, Sainbhu, Siddhipur (Sanagaon), Sunakothi, Thaiba, and Thecho in Lalitpur District; and Duwakot and Katunje in Bhakutapur District.

(3) Rural Area: non-urbanised area consists of VDCs other than the Sub-urban VDCs.

The rural areas are classified into Core and Fringe areas for the purpose of the building inventory. The Core areas include Baad Bhanjayang, Bajrayogini, Dharmasthali, Phutung, Gokarna, Machhegaon, Matatritha, Sankhu, Tokha in Kathmandu District; Bungmati, Khokana, Lamatar, Lele in Lalitpur District; and Changunarayan, Nankhel and Tathali in Bhaktapur District.

1.7.3 Population and Households

The *Record on Nepalese Development NEPAL District Profile* (National Research Associates, 1999) forecasts the population and number of households for the year 1998 in the Kathmandu Valley, based on the results of the 1991 census as summarised in Table 1.7.2 and Figures 1.7.2 to 1.7.3.

Table 1.7.2 Population and Household Projection in the Kathmandu Valley

Area	Sq. km	Population	Household	Density	Person in H.H	Growth Rate
Kathmandu District	373.9	908,672	171,405	24.3	5.3	4.5
Kathmandu Municipality	50.5	578,738	111,711	114.5	5.2	
Kirtipur Municipality	18.0	43,803	7,928	24.4	5.5	
Kathmandu VDCs	305.3	286,132	51,766	9.4	5.3	
Lalitpur District	171.1	292,095	54,907	17.1	5.3	3.3
Lalitpur Municipality	15.4	145,696	28,537	94.4	5.3	
Lalitpur VDCs	155.7	146,399	26,370	9.4	5.6	
Bhaktapur District	122.6	187,059	29,891	15.3	6.3	0.8
Bhaktapur Municipality	6.9	64,927	9,714	94.7	6.7	
Madhayapur-Thimi M.	11.1	37,526	5,545	33.8	5.6	
Bhaktapur VDCs	104.7	84,606	14,632	8.1	5.8	
Total / [Average]	667.6	1,387,826	256,203	[20.8]	[5.4]	-

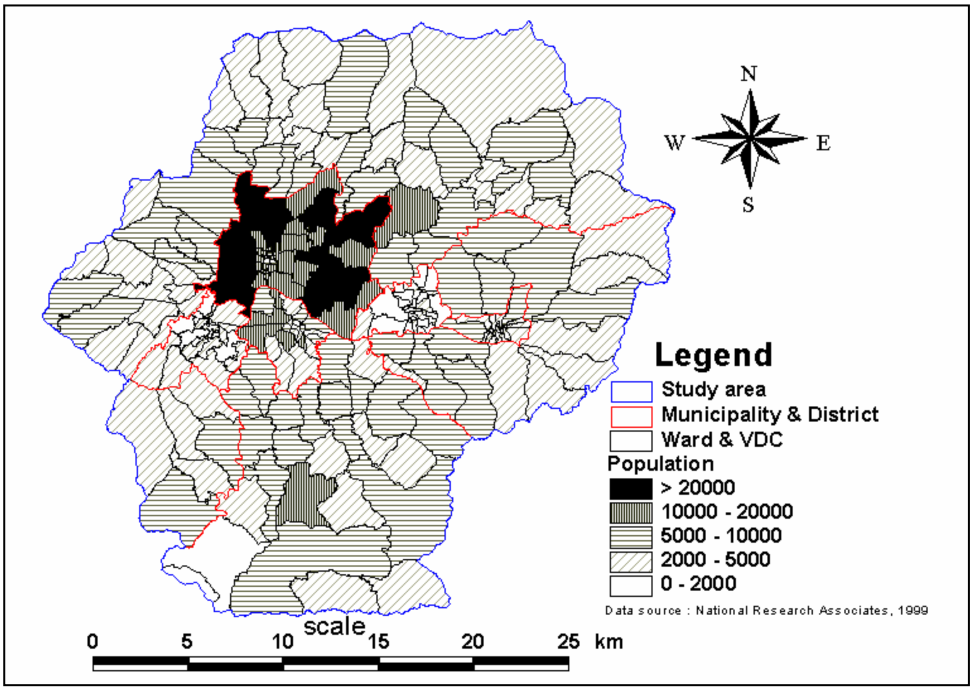


Figure 1.7.2 Population in Ward and VDC

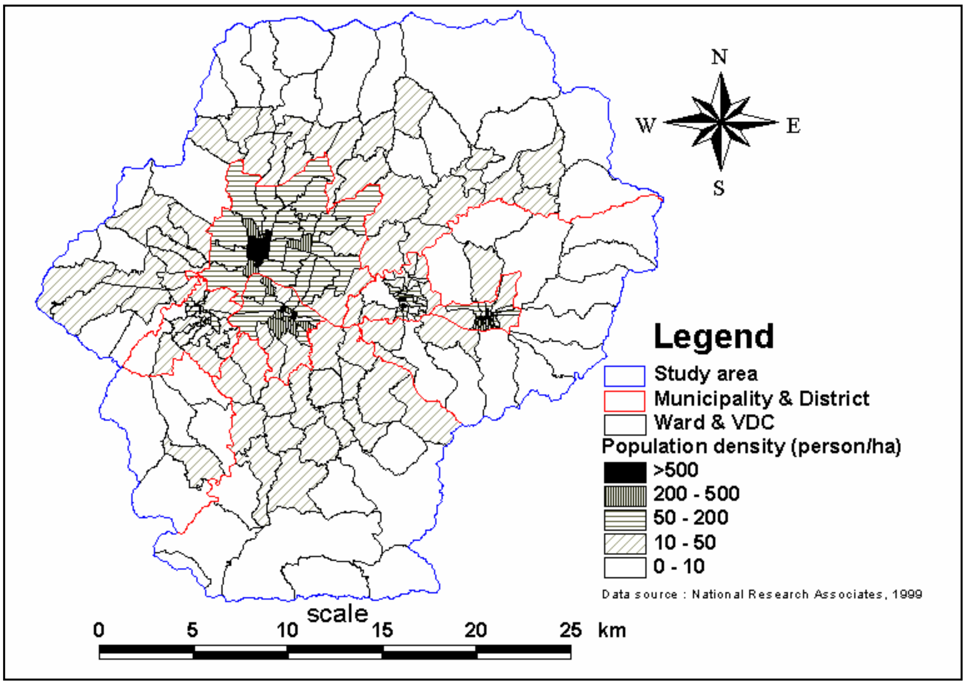


Figure 1.7.3 Population Density in Ward and VDC