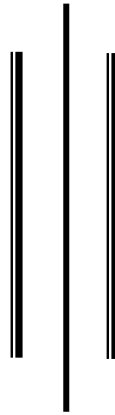
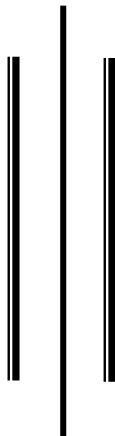


**SEISMIC VULNERABILITY OF BUILDING**  
**A CASE STUDY OF ILAM MUNICIPALITY**



**A DISSERTATION**

Submitted to the Central Department of Geography, Faculty of  
Humanities and Social Sciences in Partial Fulfillment of  
Requirement for the Master's Degree in Geography



By

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**Approved by**

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## Abbreviation

A	Adobe
Bc	Brick in Cement
Bm	Brick in Mud
Ca	Campus
CBS	Central Bureau of Statistics
Co	Commercial
DG	Damage Grade
DUDBC	Department of Urban Development and Building Construction
ERA	Earthquake Risk Assessment
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GIS	Geographical Information System
GPS	Global Positioning System
H	Hospital
HAZUS	Hazard United State
HH	Households
HR	Hotel Restaurant
IR	Irregular
ISC	International Seismological Centre
ITC	International Institute of Geo-information Science and Earth Observation
JICA	Japan International Cooperation Agency
LRMP	Land Resource Mapping Project
MBT	Main Boundary Thrust
MCT	Main Central Thrust
MMI	Modified Mercally Intensity
MuAN	Municipal Association of Nepal
NSET	National Society for Earthquake Technology
OALD	Oxford Advance Learners Dictionary
OI	Office Institute

P	Police Station
PESH	Potential Earth Science Hazard
PGA	Peak Ground Acceleration
PGD	Peak Ground Deformation
R1	Regular (ratio less than 1:3)
R2	Regular (ratio more than 1:3)
RADIUS	Risk Assessment tools for Diagnosis of Urban Areas against Seismic Disasters
Re	Residential
RS	Remote Sensing
SA	Spectral Acceleration
Sc	Stone in Cement
Sch	School
SD	Spectral Displacement
Sm	Stone in Mud
UNDP	United Nations Development Program
VDC	Village Development Committee

## **CHAPTER I INTRODUCTION**

### **1.1 Background of the study**

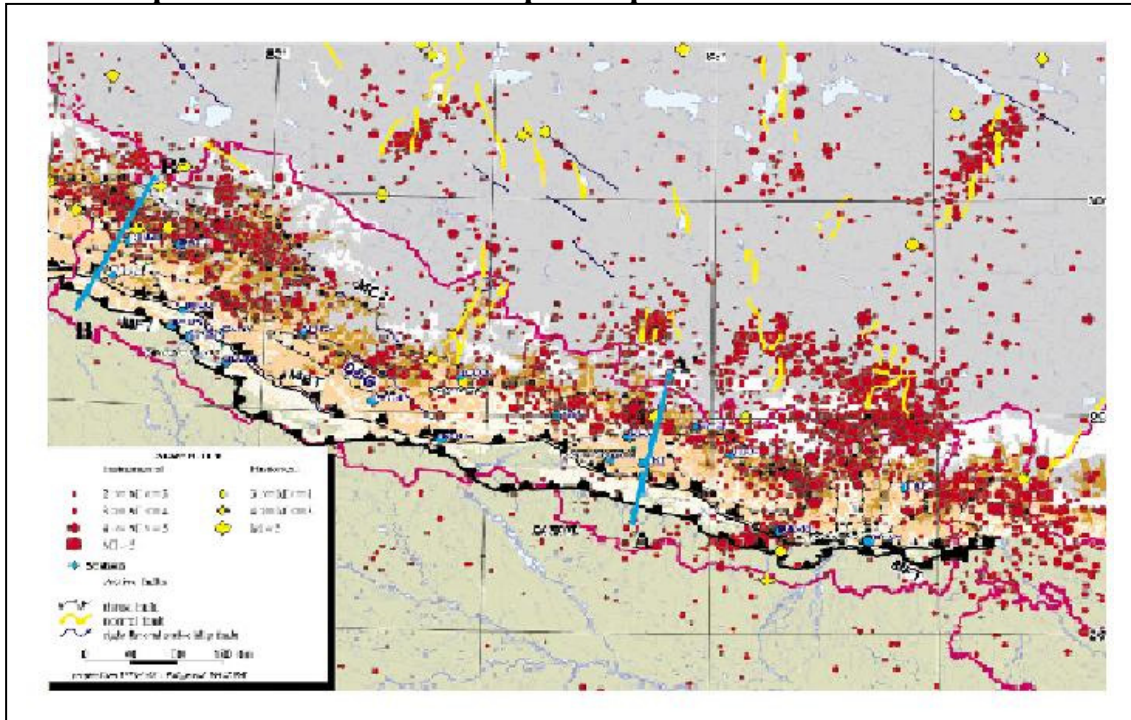
Earthquake is a sudden and violent movement or fracture within the earth followed by the series of shocks resulting from it. According to Oxford Dictionary, Earthquake is a sudden and violent shaking of the earth's surface. Earthquake as sudden ground motion or series of motion can originate in a limited region of the earth and spread from this point in all directions (Davis & Gupta, 1990; Gupta & Shing 1990 cited in Jimmie 2006).

Earthquake is remained one of the world's major disaster, they occur frequently and result in people death falls. Thousands are injured and coping economic loss. Earthquake, above 5 Richter scale in magnitude are more dangerous. It can destroy building, road, bridge and other physical structure and life and property also.

Earthquake can be caused by different activities; mainly two causes (natural and manmade) are responsible for earthquake. Volcano, landslide and tectonic movement are the natural causes of earthquake. Most of the stress that cause earthquakes can be explained by the theory of plate tectonics. According to this theory, the crust of the earth is broken up into many tectonic plates something like a cracked egg shell. Unlike an egg shell, however the earth's plates are not fixed in one location, but raft above a partially molten layer of the earth which is about 60 miles deep. Where the edges of the plates meet, stresses build up and earthquake occurs (<http://www.earthquake.com>). Nuclear tests and huge constructions activities are the manmade causes of earthquake.

Nepal lies in Himalayan region and the Himalayan region is probable area of earthquake. So Nepal is highly earthquake probable area of the world. Map 1.1 shows the probable seismic hazardous area of Nepal.

**Map 1.1: Seismic hazard map of Nepal**



Source: NSET – Nepal

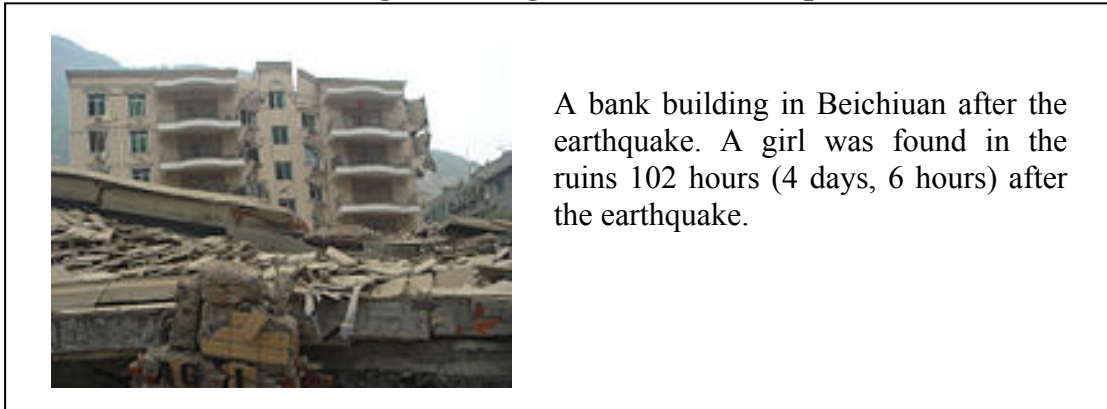
Within the last 33 years (1971-2003), Nepal experienced 22 earthquakes with magnitudes ranging from 4.5 to 6.5 Richter scale. In this time span about 34000 buildings were destroyed and 56000 were damaged. More than 126 million dollars were lost because of earthquakes during this time span. (NSET, 2004).

The major parts of losses in this period were due to 1988 earthquake. It is an earthquake with magnitude of 6.6 on the Richter scale hitting eastern Nepal with the epicenter in Udayapur. A total of 721 people were killed, 6453 injured and 22328 houses collapsed and about 49045 houses were damaged (Jimee, 2006).

In the Sichuan region of China, a great earthquake with 7.9 Richter scale occurred in 12 May 2008. It has 19 kilometer depth from the earth surface. About 69,176 people killed, 374,142 people injured and 17,415 people are missing. The earthquake left about 4.8 million people homeless. On May 25 2008, a major earthquake of 6 Richter scale hit northeast of the Qingchuan of China causing eight deaths, 1000 injuries, and destroying thousands of buildings (<http://www.earthquake.usgs.gov>)

Photo 1 shows the damage buildings of Sichuan earthquake of China, 2008 and photo 2 shows the damage in the Lalitpur area of 1934 earthquake.

**Photo 1.1: A damage building of Sichuan earthquake, China**



Source: <http://www.earthquake.usgs.gov>

**Photo 1.2: Lalitpur area in 1934 earthquake**



Source: NSET Nepal

In 14 June 2008, in eastern Honshu of Japan a great earthquake of 7.2 Richter scale occurred and two persons were died, about 100 people were injured and 87 people are missing. (Kantipur National Daily, June 15, 2008)

In the last 22 years (2037 to 2059 B.S.), only Himalayan area of Nepal experienced 7 earthquakes from 5 to 6.5 on the Richter scale (Paryabaran Monthly, 2007).

Map 2 shows the seismic hazard area of the world. South west and south east Asia, western part of North and South America are highly probable area of earthquake

**Map1.2: Global seismic hazard map**



Urban areas, which are center for huge population concentration, economic and industrial activities are the most vulnerable location for earthquake disaster. The magnitude of earthquakes in cities and towns are incomparably high than in other area.

The rapid urbanization process in Asia has a great concern where municipal governments are facing shortage of resources and infrastructure (MuAN, 2007) However Nepal's urban population is growing at a rate of about 5 percent per year against the national growth rate of 2.3 percent (Sharma, 2001) hence Nepalese municipalities are in the threshold of resource crisis to meet the increasing demands of urban services.

## **1.2 Statement of problem**

Earthquake is one of the most dangerous natural hazards, which destroyed at any time and area to object life and property. It is highly unpredictable in time and space compared to other disaster. Evidently the losses and damage of

earthquakes is extremely high compared to other type of hazards. Nepal, due to its location, it is tectonically in very active area. So the earthquake hazard is comparatively very high in this area. However such losses and damage can be minimized if proper preparedness plan is formulated and implemented. In order to develop such preparedness plan an assessment of the potential risk and vulnerability along with the perception of local people is necessary. It is also important to study and evaluate the vulnerability of existing infrastructure system and find out the probable losses during the earthquake. Most of the losses of life and property are caused by concentration of the building located at seismically weak area. So it is necessary to know that, what is the level of susceptibility of building to earthquake hazard? What are the socio-economic and environmental factors responsible for higher level of risk? Which area is most vulnerable? So, seismic risk assessment of the population and building are most important to estimate the expected losses of property and life. This information could provide the basis to develop strategies for reducing the risk and vulnerability of earthquake hazards. Therefore this study was proposed with the following objectives.

### **1.3 Objective of the study**

The overall objective of this study is to assess the building vulnerability for earthquakes and the specific objectives of this study are:

- To determine the collapse and damage probability of building under the different probable earthquake scenario.
- To delineate the vulnerable house/ built-up location.
- To identify the factors responsible for increasing risk of building by earthquake hazards.

### **1.4 Significance of the study**

Nepal lies in an active seismic zone but most of structures are constructed without consideration of seismic hazards. Since the seismic events cannot be prevented, it is more important to study and evaluate the vulnerability of existing infrastructure system and find out the expected losses during an earthquake. In

every earthquake most of the loss of life and property is caused by damage of the highly concentrated building located in a seismically active areas. Hence, seismic vulnerability assessment of buildings is most important to forecast the expected losses. It is also important to identify the factors responsible for increasing vulnerability and risk. Such information would help to make disaster management plans to government and other key stakeholders.

### **1.5 Limitation of the study**

Due to lack of time and resources, the research has some limitation. For example, building conditions were registered by visual observation only. Interviews with local people were contained only to head of households and detailed observation is needed to improving the information. Information of prohibited area can not be collected in the field study, such as; Army Camp. This study is confined in Ilam municipality so the findings do not necessarily represents the situation of other remaining 57 municipality in the country.

### **1.6 Structure of the study**

This dissertation is organized into six chapters: The first one contains the introduction of the study. It includes general background, objectives, significances of the study and limitation of study.

The second chapter describes the research methodology that has been adopted to fulfill objectives of the research. It also includes a discussion on the GIS tools that has been used for the study. It includes conceptual framework, source of information, HAZUS and PESH method, data processing and analytical techniques.

Chapter three is about literature review. This chapter also tries to define terms and terminology which are related to the field of hazards, risk and vulnerability.

The fourth chapter is about the introduction of the study area. It describes the location, landuse/ landcover, geological condition, drainage pattern, climatic condition, soil condition and population distribution of the study area.

The fifth chapter is about the characterization (distribution) of building data. It describes about its characteristics (foot print of building, space use, material use, building geometry, age, attachment etc).

Chapter six is the analytical part of the report. This chapter analyses the field data integrating with GIS and draws conclusion. It also uses the HAZUS method to find out the vulnerability condition for various scenarios. The last chapter contains the conclusion drawn upon this study and recommendation.

### **1.7 Selection of the study area**

Ilam municipality was selected for this study. NSET has provided financial as well as technical support to carryout study in Ilam municipality. Though Ilam municipality was selected purposively, it was expected that it represents other municipalities, located in the mountain areas of Nepal and the results and findings may apply to other municipalities too.

## CHAPTER II METHODOLOGY

### 2.1 Background

The amount of damage to buildings caused by an earthquake depends upon the amount of acceleration, velocity and displacement experienced at a particular site created by earthquake and the strength of the buildings to resist these forces (Ambrose & Vergun, 1999; cited in Guragain, 2004). There are various factors in a building itself like: materials used, age of building, number of stories, method of construction etc. which are responsible to cause the damage of the building. So, it is necessary to identify different parameters and use different techniques for measurement of such parameters. The methods and techniques used in this study are discussed below.

### 2.2 Building classification

There are 36 categories of building in HAZUS method to calculate the vulnerability of buildings according to the use of construction material, height and other parameters. Following this method, the buildings in the study area were classified in to six categories according to local situation of the use of construction material and other condition of buildings. Such as:

- **Adobe:** These buildings are mainly made of sun dried brick with mud. They are found mostly in the urban periphery and some can still be found in urban core area.
- **Brick in Cement:** These building are made by brick with cement. This is the most common type of building in the urban area. Most of such buildings were constructed after 1988 in the study area.
- **Brick in mud:** These buildings are made by fried brick with mud. A few such type of building are find in the study area
- **Wooden:** These types of building were made by timber.
- **Stone mud:** These are the most common type of building in rural area. They are constructed by stone with mud.

- **Bamboo, Tin, Wood (Temporary) Building:** It is also a type of building in rural area. These types of building were made by bamboo and mud. It is assumed as safety from earthquake.

Depending upon the age of the building, it was categorized in to three categories mainly:

- **A1: (< 20 years):** Buildings that are constructed within 20 years from now.
- **A2: (20 to 100 years):** Buildings that are constructed within 20 to 100 years from now.
- **A3: (>100 years):** Buildings that are constructed 100 years ago from now.

The buildings were classified into three categories depending on the geometry (shape).

- **R1 (<=1:3):** Regular shaped buildings with a length width ratio  $\leq 1:3$
- **R2 (>1:3):** Regular shaped buildings with a length width ratio  $> 1:3$
- **IR:** Irregular shaped buildings.

If the buildings are too close together, pounding induced by resonance may occur between the adjacent structures and add to the destruction therefore it is necessary to have some distance between the two buildings. If the buildings are attached and their floors are high, the building may vulnerable. But in another case where the floor heights are short, it makes low vulnerable. Depending on these criteria, buildings in the study area has been classified in to two categories, such as:

- **At:** Building attached to the other buildings.
- **Sl:** Adjacent buildings separated from each other.

Considering on the crackness of the building in the study area, these are classified in to two categories; cracked buildings and without crack buildings.

Scale of the vulnerability is shown in the table 2.1 below.

**Table 2.1: Scale of vulnerability**

Parameters	Scale of vulnerability		
	High	Medium	Low
Use of construction materials	Adobe ,Brick in mud	Stone in mud	Brick in cement, Bamboo, Tin, Wood
Geometry	(IR) Irregular	(R2) Regular (> 1:3 ratio)	(R1) Regular (< 1:3 ratio)
Attachment of building	Attached	-----	Separate
Cracks in building	Crack	-----	Without Crack
Age of building	A3	A2	A1

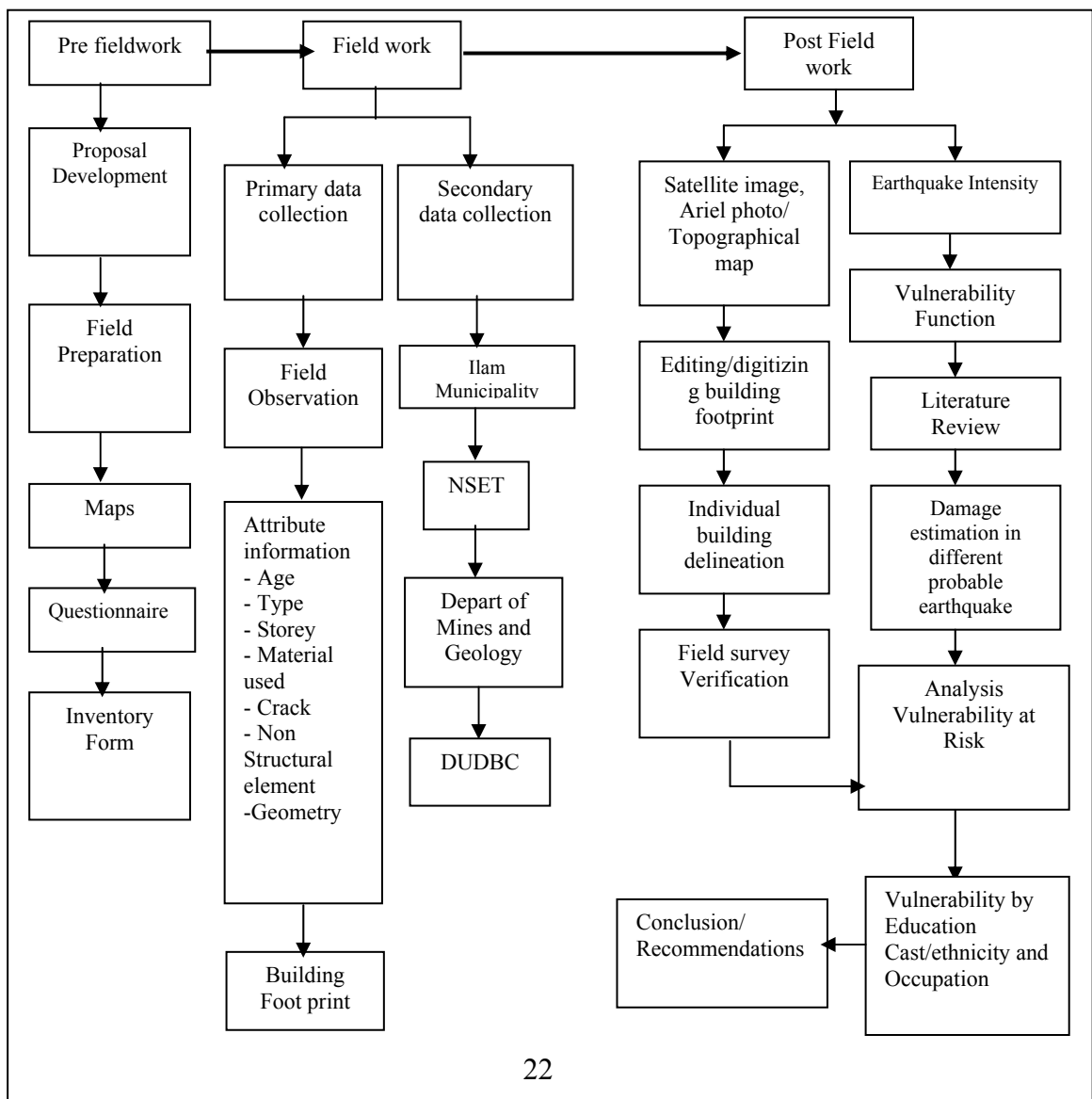
Where: A3= > 100 years, A2= 20 to 100 years, A1 < 20 years,

Above table 2.1 shows the assumed scale of vulnerability of different building parameters, which is categorized in to three classes.

### 2.3 Research sequence and components

The research work for this study is mainly divided into three sections as shown in the Figure 2.1.

**Figure 2.1: Research sequence and component**



First part considers the pre-field work which included proposal development, field preparation, map collection and digitizing, questionnaire preparation and inventory sheet development. The second part is related to field work. During the field work, primary and secondary data were collected and field observation was made. The third part of the study is the analytical work including editing, verification and damage estimation.

### **2.3.1 Pre field work**

The study started with a review of previous research about earthquake loss estimation and related aspects. The main findings were incorporated in the research proposal and formulating the major objectives to address the existing research problem. Ilam municipality was selected as the study area. Building footprint was used as the main base image to delineate the building units in the field, which was taken from Department of Urban Development and Building Construction (DUDBC), Kathmandu and Ilam municipality. The study area was divided in to 25 different blocks and the resulting map was printed in large scale to make easy to identify the building in the field area. But these blocks are not interpret in the data analysis and result because it has been made to make easy data collection process.

Inventory sheet for data collection were prepared to collection information of different building parameters like the geometry, height, age soft story, crack, building separation, attachment of other building, non structural element such as water tank, tower etc, building material etc.

### **2.3.2 Field work**

A field study of 40 days was conducted from 28 October to 08 December 2007. During the field survey individual building were identified visually and traced in the field map and given unique identity consisting of block number and building ID. The buildings which were not identified in the field were deleted and new buildings constructed were added to the field maps and along with it large building polygons were separated. The drawing of new buildings and the

separation of large building polygons into separate building units was done manually without using precise measuring because of the limited time available.

### **2.3.3 Post field work**

The building footprint (ground shape of building) map was digitized and edited according to the need. New buildings were added by digitizing with the help of GIS tools and large polygons of the building were separated. Each building footprint was numbered with its unique building ID assigned during the field survey. All attribute information of the buildings were entered in excel format and then converted in to dbase file for the GIS format. After completion of the GIS Map work, buildings vulnerability analysis was done. Vulnerability functions describing the relation between seismic intensity and the damage rate of the building types are necessary for building damage estimation. For this: each building's vulnerability level was calculated by comparing different building parameters like age, structure, geometry, height of the buildings etc. with the help of the Damage Grade Matrix prepared by NSET and JICA under the National Building Code Project.

### **2.4 Vulnerability and damage estimation**

For the estimation of damage to the building, a vulnerability function describing the relation between seismic intensity during the earthquake event and structure of the building is necessary. Damage and collapse probability has been calculated with the help of the earthquake intensity, attribute information of building and damage grade matrix.

### **2.5 Data processing and accuracy**

The available data from primary and secondary sources has been processed by using descriptive statistical techniques. All spatial data has been analyzed in arc View GIS and Microsoft excel format to calculate the vulnerability of buildings.

### **2.6 Data analysis**

Some parameters of HAZUS and FEMA methods have been used for the calculation of building vulnerability and damage.

The analysis of seismic vulnerability of building is based on an assessment of three factors.

- Seismic intensity on geological condition
- Soil liquefaction
- Slope instability and landslide

In this study, these factors are used to identify vulnerable condition and impact of disruption in terms of direct damage. Estimates of direct damage to building expressed in terms of percent value.

Direct damage is defined as damage resulting from ground shaking, landslide and liquefaction. For each building damage may be vary from 0 to 1 (0% to 100%). It has been divided into three categories- High, Medium and Low.

In this study it is estimated using:

- Estimates of ground shaking intensity provided by the seismic hazard model.
- Inventory data of the buildings.
- And, vulnerability condition that related to seismic intensity and site conditions to expected damage. The analysis approach for computing direct damage due to these factors proceeded as follows:

The different probable of loss and collapse was estimated by overlaying the building data with the intensity map of the study area and categorized the building in different earthquake intensity area.

### **2.6.1 HAZUS**

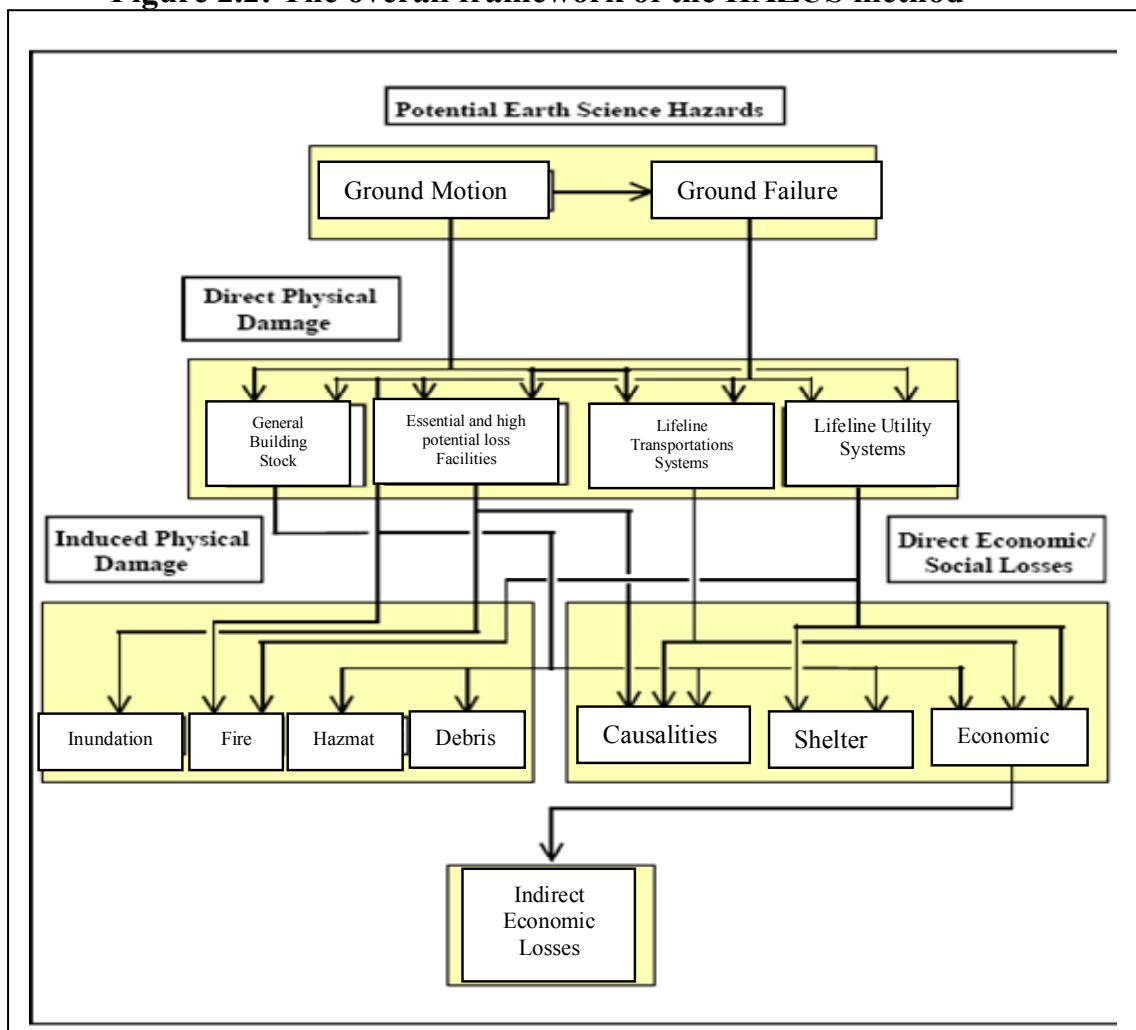
United States Federal Emergency Management Agency developed HAZUS method to provide individual, business, and communities with information and tools to work proactively to mitigate hazards and prevent losses resulting from all disasters.

Using GIS technology, HAZUS allows users to compute estimates of damage and losses that could result from an earthquake to support FEMA's mitigation

and emergency preparedness efforts. HAZUS is being expanded into HAZUS-MH, a multi hazard methodology with new modules to estimate potential losses from wind and flood hazard. In addition to estimating losses, HAZUS contains a database of economic census, building stock, transportation facilities, local geology and other information that can be used for a number of steps in the risk assessment process.

The framework of the method includes each of the components shown in Figure 2.2, which are potential earthquake hazards, direct physical damage, induced physical damage, direct economic/social loss and indirect economic loss. These factors are related with each other. In general, each component will be required for loss estimation. However, the degree of sophistication and associated cost will vary greatly by user and application.

**Figure 2.2: The overall framework of the HAZUS method**



Source: NSET- Nepal

### **2.6.2 PESH**

A Potential Earth Science Hazard includes ground motion, ground failure due to liquefaction and landslide and surface fault rupture and tsunamis. Ground motion is quantified in terms of peak ground acceleration (PGA) and spectral acceleration (SA), and ground failure is quantified in terms of permanent ground displacement (PGD). For computational efficiency and accuracy, earthquake losses are generally computed using location specific values of ground shaking and there are interpolated between PGA, PGV and spectral acceleration contours respectively.

**PGA:** The peak ground acceleration is the maximum acceleration experienced by a modeled particle in terms of location of the places due to earthquake motion. Thus, it is a level of ground motion severity experienced at site due to an earthquake (Georisk, 2004).

**SA:** It refers what is experienced by any type of infrastructures services. It is a modeled particle on a mass less vertical rod having the same natural period of vibration as the building. The unit of spectral acceleration is g (gravity).

**SV:** It is defined as deprivation of the displacement record with respect to time.

**SD:** The spectral displacement (SD) is illustrated as displacement of a modeled particle on a certain damping mass-less rod, which is driven on its base by the seismic record.

### **2.7 HAZUS used in the present study**

In this model, earthquake intensity and characteristics of building used to calculate the damage and collapse probability of the building. All of these data have spatial component and location, GIS is a proper tool for their integration and analysis to get the result.

To estimate the damage of individual building, firstly; the earthquake magnitude at the location of the building should be calculated by use of relationship in term

of PGA, PGV or PGD. In the second step, characteristics of the building such as: crack, age, height, geometry etc. has been taken and given different weight to different building parameter. The total number of weight divided in to three classes and it categorized in to three vulnerability class from the damage grade matrix according to construction material of building.

## CHAPTER III

### LITERATURE REVIEW

#### **3.1 Concept of seismic hazard and risk**

A number of terms have been frequently used in the study of vulnerability and risk.

**Disaster:** A serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses. Disasters often result in great damage, loss or destruction. Disasters occur when hazards meet vulnerability (Blaikie, 1994). Disasters can be characterized by the scope of an emergency. An emergency becomes a disaster when it exceeds the capability to manage it.

**Hazard:** Hazard refers generally to physical characteristics that may cause an emergency or potentially damaging physical event, phenomenon or human activity which may cause loss of life and property damage (Smith, 2001). For example, earthquake, volcanoes, flood, landslide are all hazards.

Hazards can include latent conditions that may represent future threats and can have different origins-geological, hydro-metrological, biological, human and technological process (UNDP, 2004). Hazards can be combined in their origin and effects. Each hazard is characterized by its location, intensity, frequency and probability.

**Earthquake hazard:** An earthquake is a sudden shift or movement of the earth's crust caused by the release of stress accumulated along geologic faults or volcanic activity (Pandey, 1998). On the surface, this is manifested by a moving and shaking of the ground, and can be massively damaging to poorly built structures. The most powerful earthquakes can destroy even the best built of structures. Most earthquakes occur at fault zones where tectonic plates collide against each other. They are capable of killing hundreds of thousands of people. Earthquakes, also called temblors (OALD, 2007), can be so tremendously

destructive; it's hard to imagine they occur by the thousands every day around the world, usually in the form of small tremors.

Magnitude and intensity are two measurements to identify physical strength of earthquake.

### **Measure of earthquake magnitude and intensity**

Earthquake usually is “measured” using two different scales: the Richter magnitude scale and the Modified Mercalli intensity scale. As the names of these two scales indicate, one measures magnitude while the other indicates the intensity of the earthquakes motion at specific places around the earthquake epicenter. Since both scales measure very different things, they cannot really be related to one another or compared. However, since both are used, the concerned individual should have a general understanding of both. (FEMA, 1990)

**Earthquake magnitude:** The magnitude of earthquake measures the total seismically released energy, so it must also be related to ground acceleration of the area from where the energy is released.

**Earthquake intensity:** The effect of earthquake is assessed in terms of intensity. Intensity refers to the severity of ground shaking experienced at site. It is subjective measurement; however it includes all the earthquake variables which are magnitude, hypo central distance, attenuation media and local enhancing factor. It is generally greatest near the epicenter and decreases outwards from it. Intensity is usually expressed on the Modified Mercalli Intensity scale which ranges from I to IX. Earthquake magnitude and their effects is given the Table 3.1.

**Table 3.1: Scale of earthquake intensities and approximately corresponding magnitudes**

Intensity (MMI)	Description of characteristic effect	Maximum Acceleration (g)	Magnitude
I	Instrumental: detected only by seismometers	0.001	
II	Feeble: notice only by sensitive people	0.0025	
III	Slight: like the vibrations due to a passing truck, felt by people at rest, especially on upper floor.	0.005	3.5 to 4.2
IV	Moderate: felt by people while walking,	0.01	4.3 to 4.8

	rocking of loose objects including standing objects		
V	Rather strong: felt generally; most sleepers are awakened and bell rings	0.025	
VI	Strong: trees sway and all suspended objects swing: damage by overturning and falling of loose objects	0.05	4.9 to 5.4
VII	Very strong : general alarm, wall cracks, plaster falls	0.1	5.5 to 6.1
VIII	Destructive: car driving seriously disturbed, masonry fissured, chimney falls, poorly constructed building damaged	0.25	6.2 to 6.9
IX	Ruinous: some houses collapse where ground begins to crack and pipes break open	0.5	
X	Disastrous: ground cracks badly, many building destroyed and railway lines bent, landslides on steep slopes	0.75	7 to 7.3
XI	Very disastrous: few building remain standing, ridges destroyed, all services( railway, pipes and cables ) out of action, great landslides and floods	1.0	7.4 to 8.1
XII	Catastrophic: total destruction, objects thrown into air, ground rises and fall in waves		>8.1

Source: Pandey, 1999

Scientists assign a magnitude rating to earthquakes based on the strength and duration of their seismic waves. A quake measuring 3 to 5 would be considered minor or light; 5 to 7 is moderate; 7 to 8 is major, and 8 or more is great.

**Vulnerability:** Vulnerability is a set of conditions and process resulting from physical, social, economical and environmental factors which increase the susceptibility of a community to the impact of hazards, (UNDP, 2004). Positive factors that increase the ability of people and the society they live in to cope effectively with hazards that increase their resilience or reduce their susceptibility are considered as capacities.

**Risk:** Risk is the probability of harmful consequences or expected loss (Khanal et al., 2004). Another definition of Risk is the potential or likelihood of an emergency to occur. Risk results from the interaction between natural/ human induced and vulnerable conditions.

This can be calculated by the equation.

Risk= probability of hazard\* vulnerability /capacity

### 3.2 Earthquake in Nepal

Nepal is seismically very active area and it has been experience a number of earthquake disasters in the past and potential seismic risk of the country is very high as well. Past records have shown that Nepal can expect earthquakes of magnitude 7.5-8 on the Richter scale every 40 years and one of magnitude 8+ in Richter scale every 80 years. The last great earthquake to strike the Nepal was in 1934 which had a magnitude of 8.3. It caused considerable damage to building along with great loss of lives. There had been many other devastating earthquakes in Nepal resulting in great economic loss and social disruption. The characteristics of earthquake since 1225 is given in the table 3.2 below:

**Table 3.2: Major earthquakes in Nepalese history**

Year	Date	Earthquakes epicenter	Human deaths	Human injured	Building Collapsed	Building Damaged
1255	7 Jun	NA	One third of total population including king Abhya Malla, killed		Many buildings and Temple collapsed	
1260	NA	NA	NA	NA	NA	NA
1408	NA	NA	Heavy		Heavy	
1681	NA	NA	NA	NA	NA	NA
1767	Jun	NA	NA	NA	NA	NA
1810	May	NA	Moderate		Heavy	
1823	NA	NA	NA	NA	NA	NA
	25 Sep	NA	NA	NA	NA	NA
1833	26 Aug	NA	NA	NA	18000 in Total	
	11 Jul	NA	NA	NA	NA	NA
	13 Jul	NA	NA	NA	NA	NA
	26 Sep	NA	NA	NA	NA	NA
1834	Sep-Oct	NA	NA	NA	NA	NA
1837	17 Jan	NA	NA	NA	NA	NA
1934	15 Jan	Bihar /Nepal	8519	NA	80893	126355
1980	4 Aug	Bajhang	46	236	12817	13298
1988	21 Aug	Udayapur	721	6453	22328	49045
1993	NA	Jajarkot	NA	NA	40 % of Buildings are estimated to be affected	
2002	NA	Mahottari	NA	41	NA	NA
2003	NA	Syangja	1	2	NA	NA
Note: "NA" indicates 'description not available'.						

Source: National Society for Earthquake Technology: 2006

On the basis of earthquake, Nepal is classified in different zones. In the north near the foot of high Himalaya a long linear crack called the Main Central Thrust (MTC) appears separating high Himalaya north with the midland of south. It passes through most of hot spring found in the belt. The fault is active and may produce higher order earthquakes i.e. similar to the earthquake in Bajhang 1990 (far west Nepal) where many people died and a lot of property and engineering structures were destroyed. The earthquake (6.7 Richter scale) which occurred on 21<sup>st</sup> august 1988 in eastern Nepal took a heavy loss of 730 human lives and several thousand houses.

Near the contact zone of midland and Chure hill, another linear crack is found which is generally called the Main Boundary Thrust (MBT) or fault. It runs from the east to west of Himalaya. It is also an active plane particularly in the west Nepal where pressure ridges and depressions are distinct (from the Babai river to the Karnali river) this is considered to generate earthquakes of about 8 Richter scale (Sharma 1988).

The new epicenter map of Nepal shows the distribution of earthquakes in the foothills of higher Himalayas. The Nepal Himalayan area has high seismicity judging by historical data, bulletins of the international seismological centre (ISC), and seismic data obtained from National Seismological Network. The epicenters are clustered around the ramp and the ramp beneath the Higher Himalayas behaves as asperity focusing the build up of stress during the interseismic periods. The modeling of leveling and GPS data (Jackson and Bilham 1994; Bilham et.al 1997 quoted Manandhar 2007) indicate that the flat and the ramp must be locked in the interseismic period. The continuous creep at depth beneath the Higher Himalaya is at a rate of 21 +/- 3mm/year, and this is close to long term slip rate on MFT. Only during the big earthquake, will the ramp and the flat be activated and transfer all the interseismic deformation to the mass frontal structure (Lave et. al. 1995; Lave and Avouac 2000m, quoted Manandhar 2007). Most of the epicenters are distributed between the MCT and MBT in plan and depths lies between 10 and 30 km. The average convergence

rate between the Indian plates southern, Tibet is considered to be 20 mm per year.

National Seismological Center of Nepal has recorded large earthquakes in the Himalayas like The Kangra- India earthquake of 1905, the Bihar-Nepal earthquake of 1934, and the Assam-India earthquake of 1950; those were all about 8.5 magnitude earthquakes, the biggest intercontinental earthquakes of the country. The geographical profiling of these events shows that bigger quakes haven't occurred in western or Central Nepal for the last 200 years (Between the Kathmandu and Deharadun) and that could be potential area for a big earthquake in future.

### **3.3 Seismic vulnerability assessment in Nepal**

Within the last 33 years (1971-2003), Nepal experienced 22 earthquakes with magnitudes ranging from 4.5 to 6.5 on the Richter scale. In this time **soon** about 34000 buildings were destroyed and 56000 buildings were damaged. More than 126 million dollars were lost because of earthquake during this time span. The major part of losses in this period was due to 1988 earthquake (NSET, 2004: cited in Jimée, 2006).

A study carried out by the National Society for Earthquake Technology –Nepal (NSET) under the Kathmandu Valley Earthquake Risk Management Project (KVERMP) shows that if an earthquake with the same shaking pattern and characteristics as the one in 1934 struck, approximately 40000 deaths and 95000 injuries will take place in the Kathmandu valley (Dixit et al., 1999, cited in Jimée 2006). KVERMP used limited information to come up with a scenario of potential damage to building in the valley, and demonstrated the need to undertake a systematic inventory of existing building to arrive at conclusion on the vulnerability of existing buildings to strong earthquake (Jimée, 2006).

Westen (2007) has estimated seismic loss estimation for Lalitpur, Nepal under the SLARIM project. The main objective of the study is to develop spatial information system for municipalities, which will allow local authorities to

evaluate the risk of natural disaster in their municipality, in order to implement strategies for vulnerability reduction. The methodology concentrates on the application of methods for hazard assessment, elements at risk mapping, vulnerability assessment, risk assessment and the development of GIS based scenarios for varying hazard scenarios and vulnerability reduction options, using structural and non-structural measures. For this database on the element at risk was prepared and high resolution satellite imagery, combined with extensive field data collection using mobile GIS were used.

Guragain (2004), carried out a study on "GIS for seismic building loss estimation, a case study, from Lalitpur sub- metropolitan city area Kathmandu". A building survey was performed to collect information on the material and occupancy types of building in this area. The study area was divided into 500 small clusters having homogeneous characteristics in terms of building occupancies and the predominant building information was collect from this cluster in percentage. These percentage values were converted in the number of building per cluster. The vulnerability relation developed by NSET Nepal and NGO working in Earthquake Vulnerability Reduction was used and a series of GIS operation were performed to link this relation to the building type in study area. Building damage estimation was carried out for three expected scenario earthquakes that were used in a JICA study in 2001. For the different earthquake scenarios, the total number of damage building were estimated ranging from 1654 to 22293 in the worse case scenario, which corresponds to an 8 Magnitude earthquake located close to Kathmandu.

Islam (2004), studied on population vulnerability of Lalitpur sub metropolitan city on the basis of building loss estimation by Islam (2004). This study was carried out with objectives to determine what factors are determining population vulnerability and to develop a method for the estimation of population distribution, both in space and time. The whole study has mainly three components, identifying the homogeneous units of buildings, estimating the spatial and temporal distribution of population and estimating the number of

casualties increase of an earthquake. The distribution of population has been converted to the number of casualties based on the building vulnerability. Using HAZUS method, the study shows that 16 different spatial distribution of different casualty for each earthquake scenarios.

Gulati (2006), studied with an aim to analyze the applicability of HAZUS model for assessment of earthquake risk assessment of buildings in India, Dehradun. The whole research work was divided into four sections. Review of risk assessment methods, hazard identification and generation of the dataset (seismic, ground motion, building response and damage functions) included in the study.

The reinforced Masonry (RM) and Unreinforced Masonry (URM) model classes from HAZUS have been selected as most representative buildings in the study. The damage probability matrix has been developed for four model building types by applying HAZUS methodology. Finally risks have been evaluated in terms of damage probability of each model building type for all four (slight, moderate, extensive and complete) damage states.

The results concluded the damage probability calculated by HAZUS method not gives very realistic results for earthquake risk evaluation in studied ward. The method gives good results at the broad level evaluation such as for risk evaluation of RM and URM class. The research also concludes the modification required on HAZUS defining the building inventory and simplifying the method of data collection in Indian context to adopt the HAZUS method more accurately in India.

Jimee (2006), in his study "Seismic vulnerability and capacity assessment at ward level, A case study of ward no 20 Lalitpur Sub-Metropolitan city Nepal" building damage and collapse probability were estimated for individual buildings considering their condition type and earthquake intensity using on existing damage matrix prepared by JICA and NSET. The estimation was made

for different possible earthquake scenarios defined by previous researcher. An effort was made to develop a method, which can be adopted by municipal authorities in order to assess the vulnerability and level of capacity of local people. It includes estimation of the building collapse probability and casualties for certain earthquake scenarios and measuring the capacity of local people to cope with earthquake risk in ward 20 of Lalitpur Sub-Metropolitan city.

The Japan international cooperation agency (JICA, 2002), carried out a detailed study on Earthquake Disaster Mitigation in the Kathmandu valley in 2001. In the JICA study, the methodology was implemented with specific focus on the community based on disaster mitigation, where communities were empowered through participatory decision making process.

Above previous works mentioned about the background efforts and methodologies. These are treated as the suggestive and guiding materials.

In the assessment of vulnerability and increasing risk of earthquake in municipal area, risk can be minimized by increasing capacity with indepth knowledge on vulnerability condition to the people. For this few assessment methods were used to focus on Kathmandu and Lalitpur. So, to find out the situation of the other municipality, it has been use some of the techniques.

An introduction to the study area is given the next chapter.

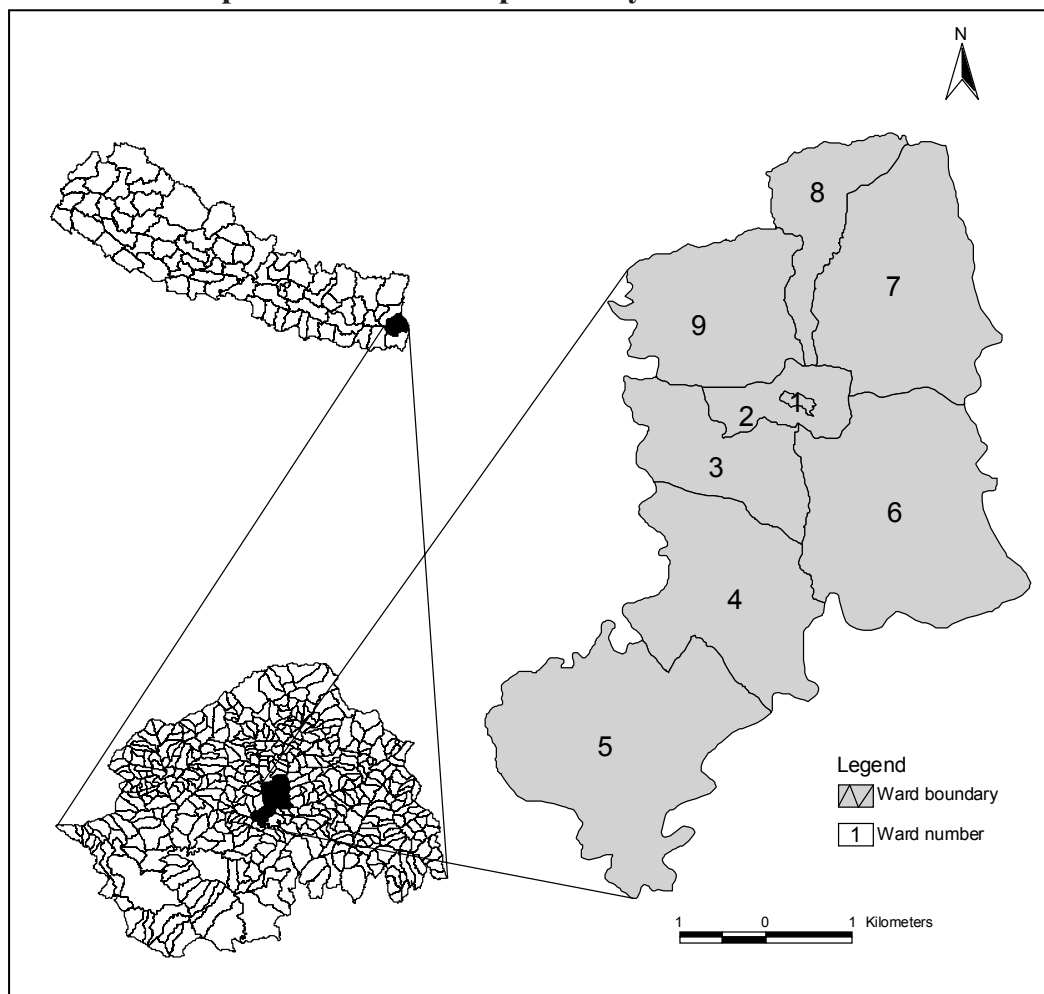
## CHAPTER IV

### INTRODUCTION OF THE STUDY AREA

#### 4.2 Geographical location

Ilam municipality is located in the east of Nepal (Map 4.1). It is headquarters of the Ilam district. This municipality was constituted in the year 2015 B.S. The altitude ranges from 401m to 1407m from the mean sea level. Geographically, this municipality is located at  $26^{\circ} 56' 46''$  N latitude to  $87^{\circ} 56' 46''$  E longitude. The boundary of municipality is Maikhola in the east, Puwakhola in the west, Barbote VDC in the north and Maikhola and Puwakhola in south. The total area of this municipality is 27.0 sq km. About 2.7 sq km of the total area has been occupied with urban built up area.

**Map 4.1: Location map of study area**



The Ilam municipality, headquarters, of Ilam district is called as the “queen of hill” due to its beauties, cool and peaceful environment. It is a touristic place of

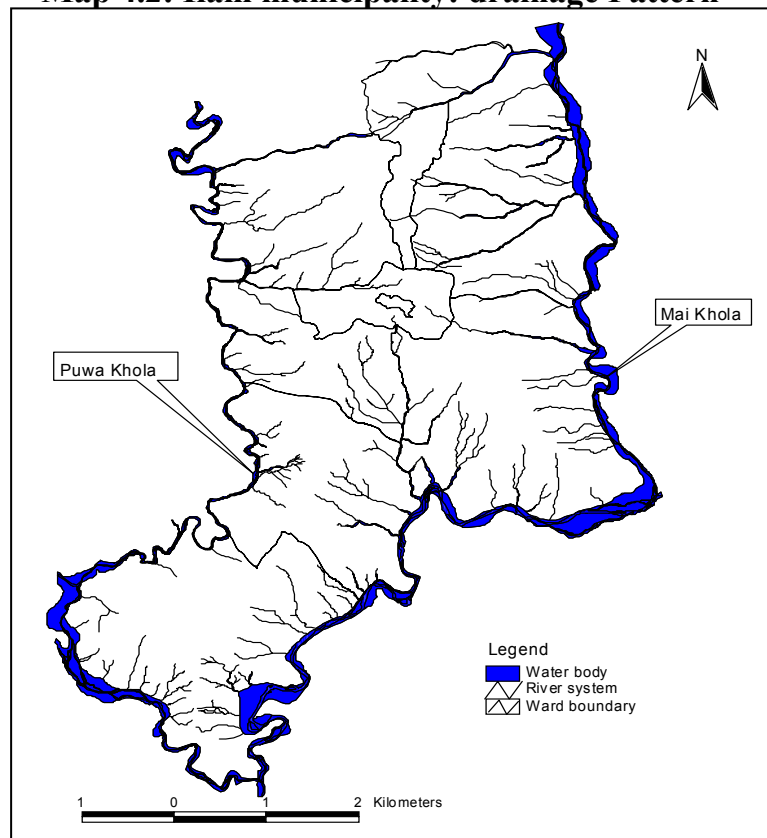
the country. Historical tea garden and various temples Seti devi, Narayansthan, Maisthan, Gumbadanda and like other religious places have added extra energy in tourism of Ilam. Its natural beauty too has made it as major center in the east of Nepal for tourism industry.

Ilam municipality is also rich in social and physical infrastructure, which has contributed a lot in the rise of its Gross Domestic Product (GDP). Agriculture is the major economic source of this municipality. Therefore, agriculture has become the strongest pillar for the economic development of Ilam municipality. Earthquakes are most destructive in these regions with poor building code enforcement and high seismic vulnerability of construction. Steeply sloping land and loss of grass and forest cover have also increased the susceptibility for landslides and other disasters.

#### 4.2 Drainage pattern

The main rivers are Maikhola in the east and Puwakhola in the west of the municipality. The drainage system of the municipality is shown in the Map 4.2.

**Map 4.2: Ilam municipality: drainage Pattern**

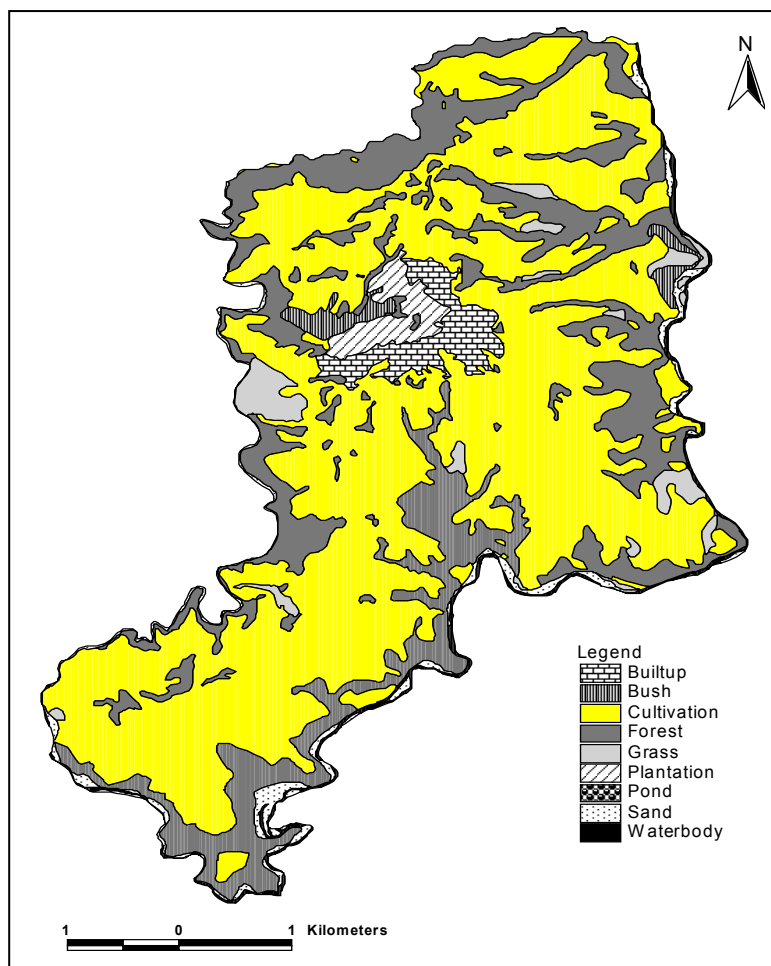


Source: Topographical Survey Map, 2007

### 4.3 Land use/land cover

The land use pattern of the area is diverse. The main types of land use/land cover are forest, cultivated land, tea garden, shrub land and settlement area, it is shown in Map 4.3.

**Map 4.3: Ilam municipality: land use/land cover**



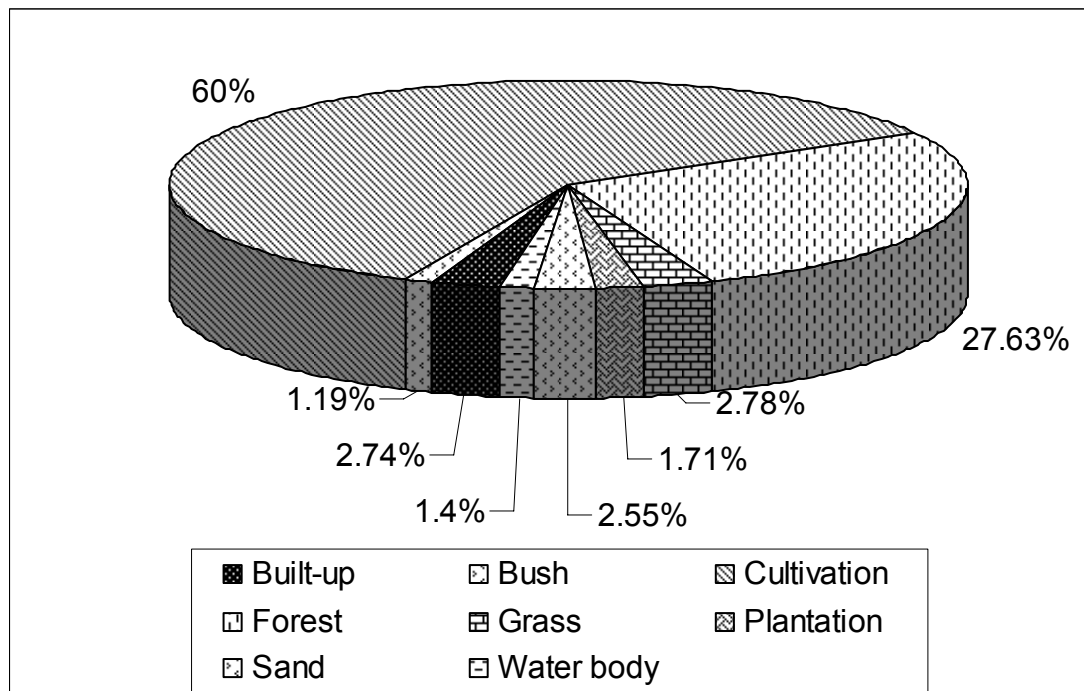
Source: Topographical Survey Map, 2007

**Table 4.1: Land use/land cover**

Land use Type	Area (Sq Km)	Percent (%)
Cultivation	16.03	60.00
Forest	7.38	27.63
Grass	0.74	2.78
Built-up	0.73	2.74
Sand	0.68	2.55
Plantation	0.46	1.71
Water body	0.39	1.40
Bush	0.32	1.19
Total	26.73	100.00

In the study area, conversion of forest land to cultivated land is being accelerated due to population growth. About 60 % of the total land is under cultivation. Table 2 and Figure 1 show the distribution of landuse/ landcover of the study area. Cultivated land is extensively distributed in the western part of the study area. Other parts of the area are rocky terrain which are covered with forest and shrub land which is shown in table 4.1.

**Figure 4.1: Ilam municipality: landuse/ landcover**



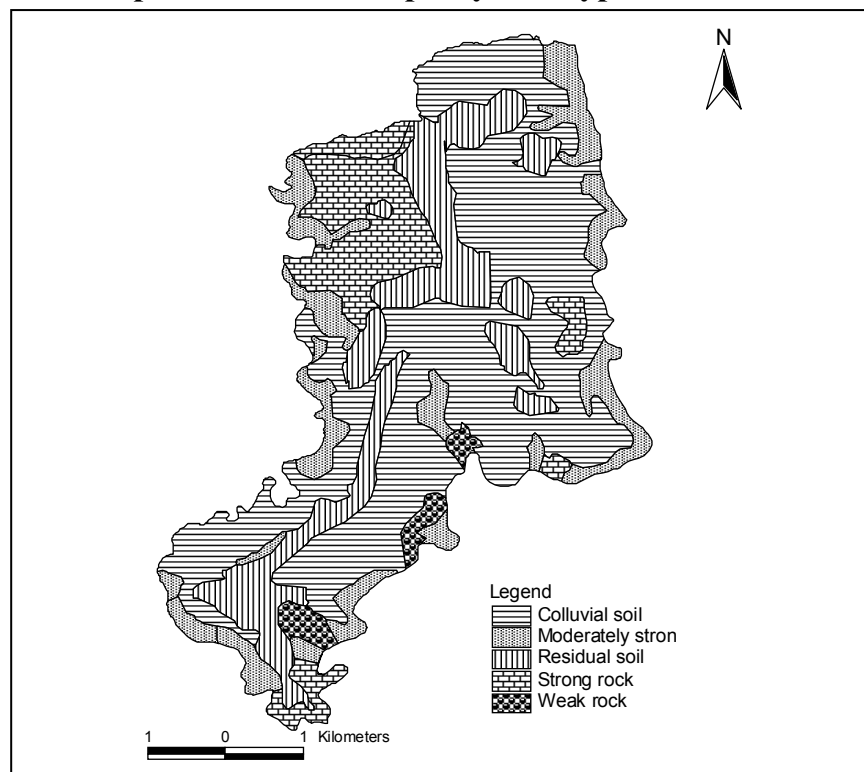
#### 4.4 Climatic conditions

Ilam municipality lies in sub-tropical climatic area. However, climate varies with altitude and aspects. The average temperature of this area is 21<sup>0</sup>c and the average rainfall is 2500mm.

#### 4.5 Soil types

Soil is an important aspect of terrain analysis. The spatial arrangements of the soil are not evenly distributed in this area. Colluvial soils are predominant types of soils in the area. Soil of the study area are classified according to their origins, i.e. alluvial, colluvial and residual soil etc. soil depth of the area is categorized as shallow(1-3), medium(3-6m)and thick(>6m). The map 4.4 shows the different types of soils of the study area.

**Map 4.4: Ilam municipality: soil types**



Source: Chamlagain and Dangol, 2002

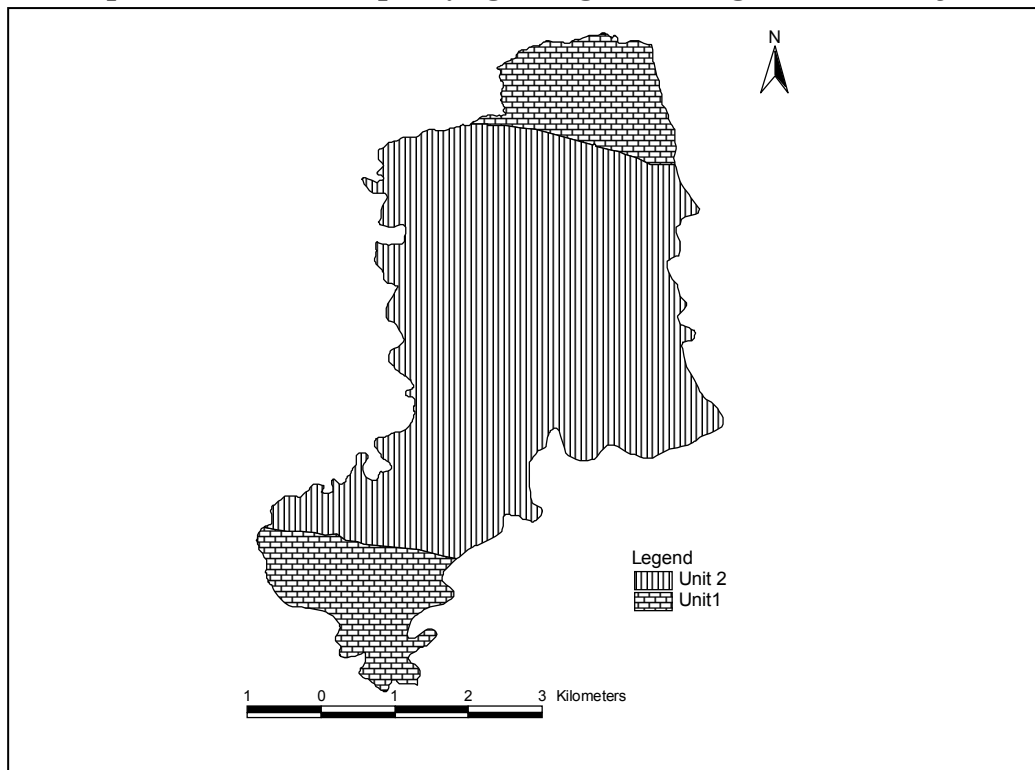
#### **4.6 Geological setting.**

Geology of the study area is dominated by the Precambrian to Cambrian Kyanite and sillimanite bearing genesis, biotype schist, Metaquartzite, amphibolites, calc silicate genesis, orthogenesis and angiogenesis. The Mahabharata crystalline of the eastern Nepal are apparently continuous with the Darjeeling genesis of the Sikkim Himalayan (Chamlagain and Dangol, 2002).

Available geological information indicates that great earthquakes with magnitudes in excess of 8.0 have occurred on the area. In addition, extensive but more moderated seismicity has been associated with the same seduction zone.

Almost all of the areas pass directly through the fault areas. The fault is believed capable of producing earthquakes as large as magnitude 8.0. A large earthquake on the fault is of potentially catastrophic proportions.

**Map 4.5: Ilam municipality: geologic setting of the study area**



Source: Chamlagain and Dangol, 2002

Unit 1= Garnet kyanite, sillimanite gnesis and gray quartzite.

Unit 2= Garnet kyanite sillimanite gnesis, orthogenesis and white colored, course grained fractured quartzized.

#### 4.7 Population

The total population of the municipality is 16246, living in 3311 houses (Table 4.3). Among total population 7899 are female and 8337 are male. In this municipality, 84.6% of total populations are Hindus, 12.8% Buddhist, 2.0% Kirat and 0.6% others (MuAN 2007).

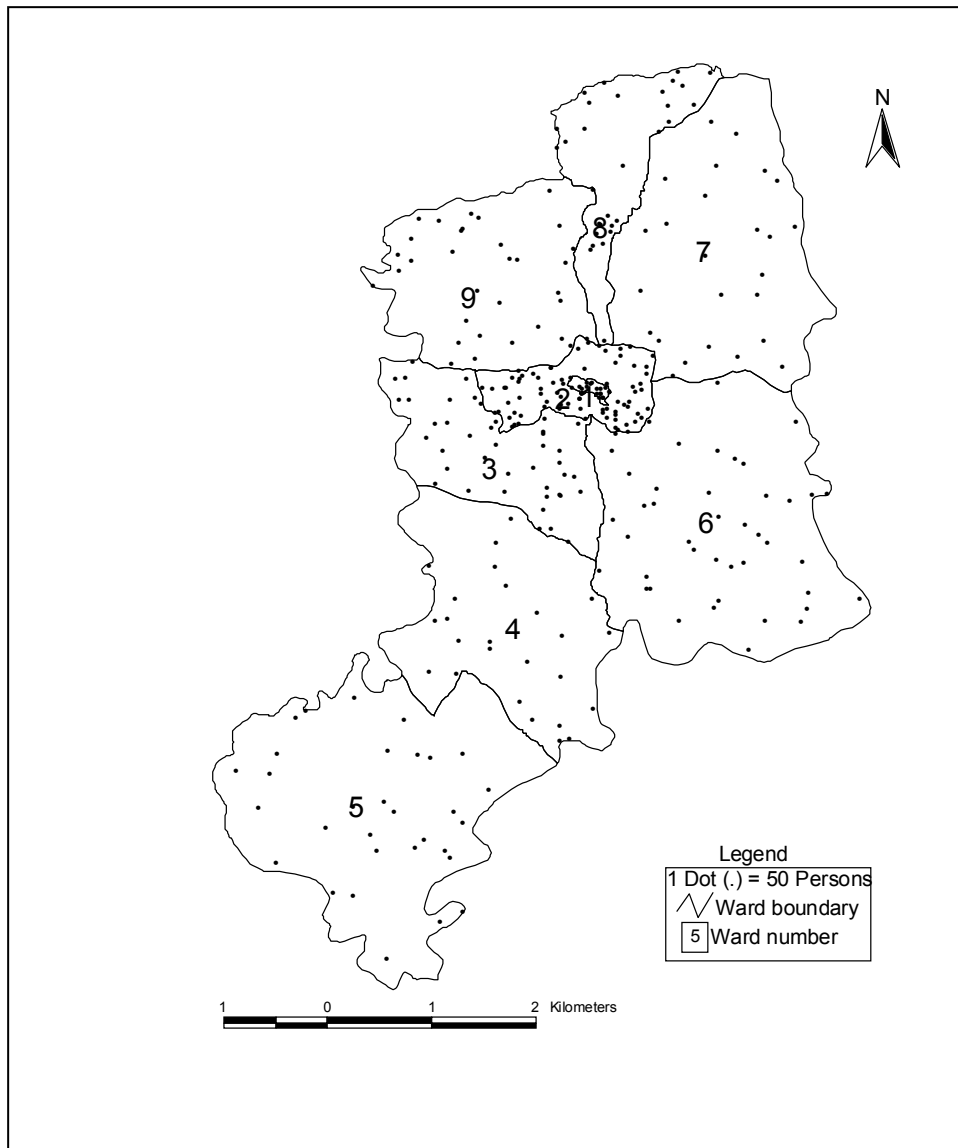
**Table 4.2: Ward wise population distribution**

Ward No	Population(2058)			No. of household (2062)
	Male	Female	Total	
1	502	462	964	159
2	1995	1789	3784	643
3	1062	971	2033	383
4	649	660	1309	307
5	780	769	1549	359
6	1104	1044	2148	459
7	627	620	1247	249
8	660	694	1464	329
9	848	890	1738	423
Total	8337	7899	16246	3311

Source: Ilam municipality, 2007

Above Table 4.2 shows the population distribution of the Ilam municipality. According to data the highest number of population are in the ward no 2 with 3784 followed by ward no. 3 with 2033. Similarly the lowest no. of populations are in ward no 1 with 964. Map 4.6 shows the distribution of the population in Ilam municipality.

**Map 4.6: Ward wise population distribution**



## CHAPTER V

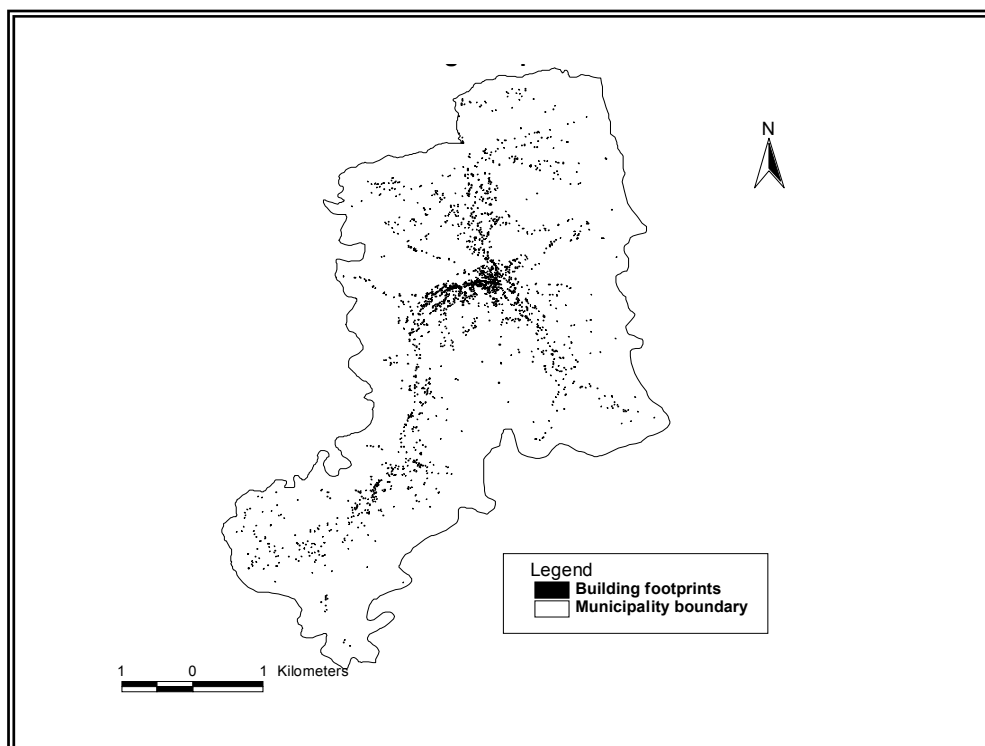
### CHARACTERIZATION OF BUILDING

#### 5.1 Introduction

Seismic vulnerability of building is highly dependent on the space between buildings, age of building, geometry of buildings and materials used for constructions. A brief description of the buildings in Ilam municipality is given in this chapter.

Since the study was focused on determining the building vulnerability during an earthquake episode it is important to have information of the buildings where people live. So inventory for the building in the study area was prepared during the fieldwork. All individual buildings were observed very closely and were traced in the building footprint map. Along with this building details like structural type, number of story, shape, age, crack, roofing types, existence of soft story, building attachment, existence of non structural element, space use were recorded in the inventory sheet designed.

**Map 5.1: Building foot prints**



Source: Department of Urban Development and Building Construction, Revised based on field information

The building footprint map prepared by the Department of Urban Development and Building Construction and Ilam municipality was in the form of blocks and not at the level of individual buildings so during the field work they were separated at the level of individual buildings by visual observation. Some buildings which did not exist in the field but were indicated in the map, due to demolition or wrong interpretation of the images, were deleted and the new constructed building which were not present in the map were traced out during the fieldwork.

## 5.2 Buildings and use of space

In the study area, there are 3575 total buildings containing 6783 separate floors. About 87.7 percent of all floors are used for residential purposes and 3.4 percent are used for commercial and also 3.4 percent used for the purpose of office/institute. About 5 percent of the buildings are used for other different purpose. (See Table 5.1)

**Table 5.1: Building floors classified by space use**

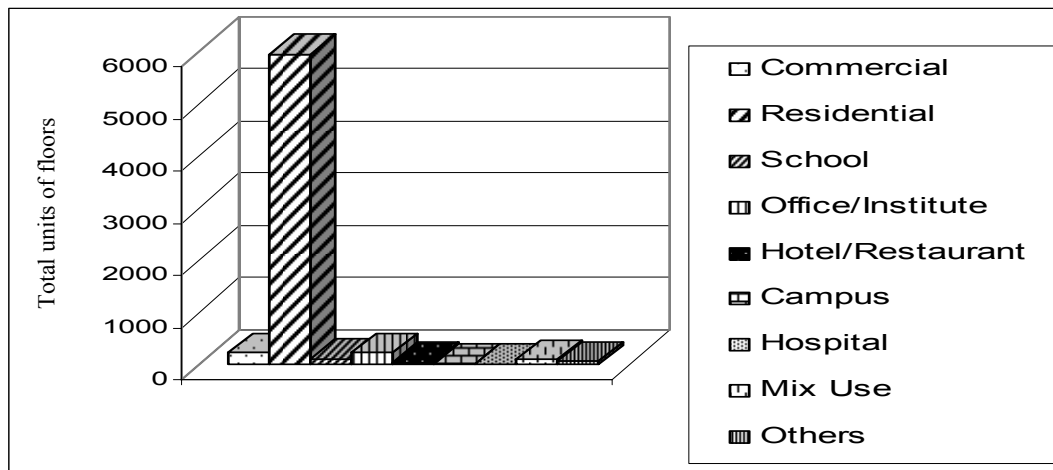
Floors	Co		Re		Sc		OI		Mx		Hr		Ca		H		Others		Total	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
1st	198	86	3032	51	74	68	122	52	64	63	20	36	11	73	14	74	71	100	3606	53
2nd	23	10	2559	43	31	28	85	36	31	30	20	36	3	20	5	26	0	0	2757	41
3rd	10	4	317	5	4	4	23	10	6	6	12	21	1	7	0	0	0	0	373	5
4th	0	0	38	1	0	0	4	2	1	1	4	7	0	0	0	0	0	0	47	1
Total	231	100	5946	100	109	100	234	100	102	100	56	100	15	100	19	100	71	100	6783	100

Source: Field survey, 2007

Where: Co=Commercial, Re= Residential, Sc= School, OI= Office/Institute, Hr= Hotel/ Restaurant, Ca= Campus, Mx= Mix, H= Hospital.

Most of the first and second floors are used for residential purpose. Nearly 51 percent of the first floors and 43 percent of the second floors are used for residential purpose and 86 percent of the commercial floors found on the first floors. Similarly 72 percent of the hotel/restaurant and 88 percent of the office/institute are used in second floors. Following Figure 4 shows the classified building by space use.

**Figure 5.1: Building floors classified by space use**



### 5.3 Age of the buildings

In the study area, we tried to divide different buildings according to different construction periods (time). But we try to presumption the age of the building and classified into three categories to find out the old and newly constructed building. For example; building aged less than 20 years are new buildings which are generally made by brick and cement, where as 20 to 100 years old buildings are named old building which are generally made by stone and mud. Similarly, the buildings which have age more than 100 years are classified as oldest buildings. In the study area, out of total 3575 buildings 2413 (67.5 percent) were new buildings which were made within the last 20 years and 1149 buildings (32.1 percent) of the total were built within 20 to 100 years as well as only 13 buildings (0.4 percent) were found in the study area made before 100 years. Most of the new buildings were made by brick in cement and most of the other buildings were made by stone, mud, wood and other materials.

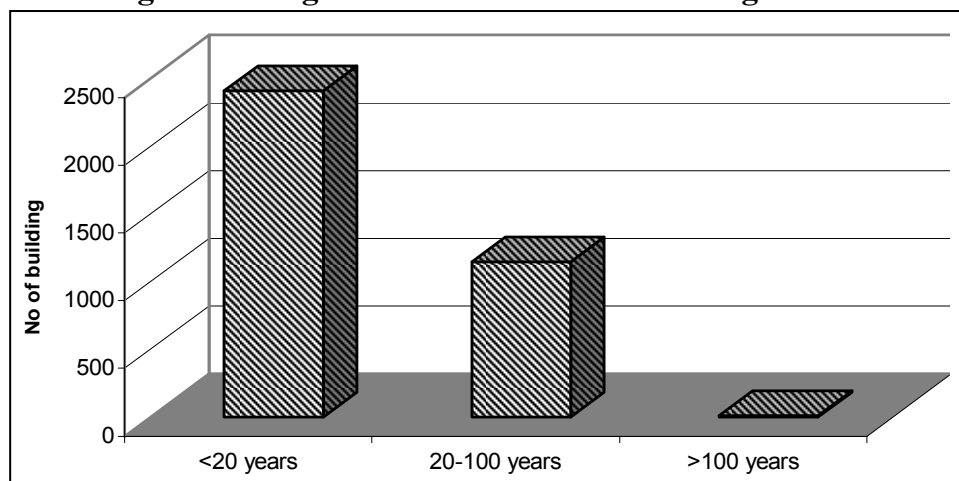
According to age of building, old buildings are more vulnerable than others newly constructed building (Table 5.2).

**Table 5.2: Age classification of the buildings**

Age of the buildings	No. of Buildings	Percent
<20 years	2414	67.5
20-100 years	1148	32.1
>100 years	13	0.4
Total	3575	100.0

Source: Field survey, 2007

**Figure 5.2: Age classification of the buildings**



#### 5.4 Buildings heights

During an earthquake episode, building experiences acceleration, velocity and displacement of varying frequencies in a same period. This natural frequency of the building depends on its height and stiffness. In general greater the height of the building higher is the vulnerability. Building height in the study area is taken as the number of floors. It is shown in the Table 5.3 below.

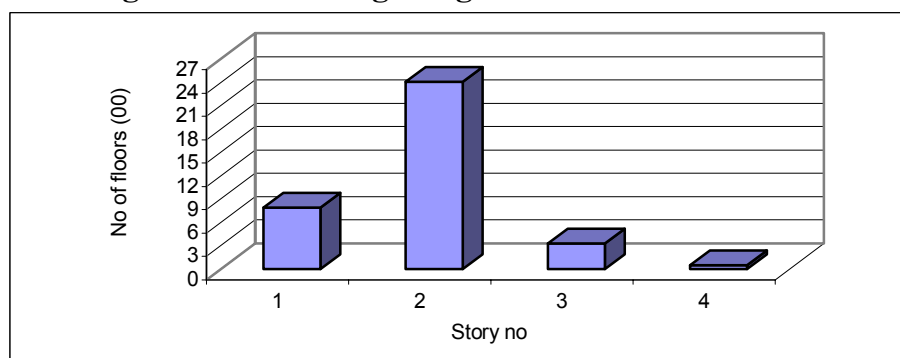
**Table 5.3: Buildings height**

No. of Story	No. of building	Percent
1	789	22.07
2	2410	67.41
3	330	9.23
4	46	1.28
Total	3575	100

Source: Field survey, 2007

Basically it was observed in the fields that number of floors ranged from 1- 4. Most of the buildings in the study area have 2 floors (about 67 percent) and 1 floors building are 22 percent (Figure 5.3).

**Figure 5.3: Buildings heights**



## 5.5 Building geometry

To estimate the damage of buildings in certain magnitude of earthquake episodes, geometry of the building also plays the main role. Buildings having large length to width ratio, large height to width ratio and large offset in plan and elevation, or irregular shaped building suffer greater damage during earthquakes than regular buildings (Guragain 2004). National building code in Nepal suggest that to decrease the building vulnerability, building should be regular in plan, elevation and length width ratio of the building must be less than 3(NBC, 1994). In the study area 3215 buildings (89.9 percent) were found with regular shape (length width ration <1:3), 46 buildings (1.3 percent) buildings were found with the ratio of >1:3 and 314 buildings (8.8 percent) of the total buildings were found irregular shape (Table 5.4).

**Table 5.4: Building geometry**

Shape	No of Building	%
Irregular	314	8.8
Regular<1:3	3215	89.9
Regular >1:3	46	1.3
Total	3575	100.0

Source: Field survey, 2007

## 5.6 Construction material

Use of material for house construction also depends on loss of building during the earthquake period. Wall material, floor and roofing system control the strength of the building and poor material increase the vulnerability of the building in the period of earthquake episodes.

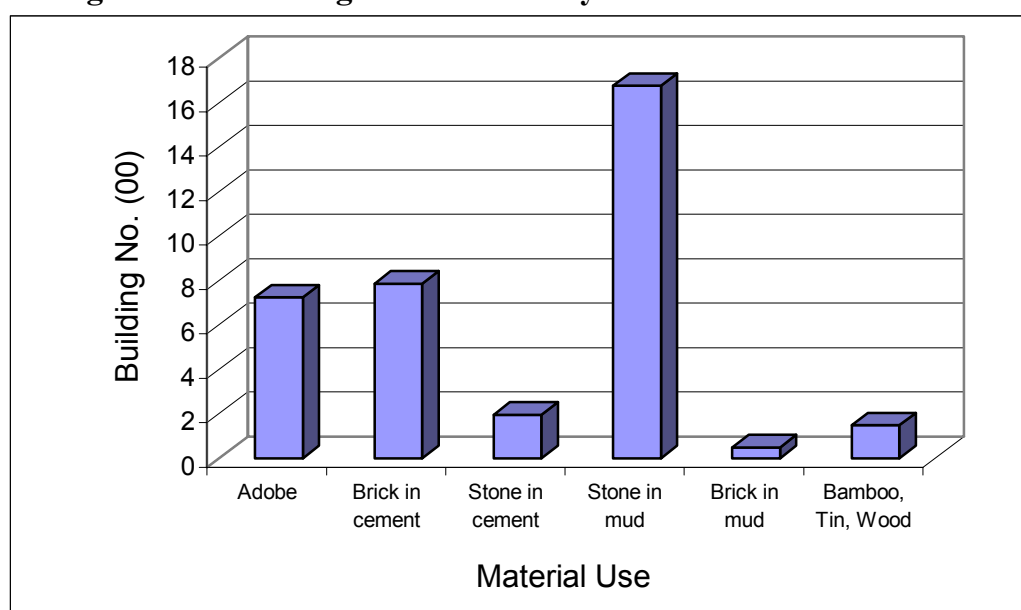
In the study area, 46.88 percent of the total buildings were found with stone in mud, 21.96 percent brick in cement, 20.22 percent adobe and about 11 percent with other construction materials. (Table 5.5 and Figure 5.4).

**Table 5.5: Building classification by construction materials**

Construction material	No. of building	Percent
Adobe	723	20.22
Brick in cement	785	21.96
Stone in cement	195	5.45
Stone in mud	1676	46.88
Brick in mud	49	1.37
Bamboo, Tim, Wood	147	4.11
Total	3575	100.00

Source: Field survey, 2007

**Figure 5.4: Building classification by construction materials**



### 5.7 Cracks and attachment

In the earthquake period, poor condition (weak construction material, crack etc.) of the building are more vulnerable don't need large shaking than the buildings without cracks. Wall cracks are more dangerous for the building damage in the period of earthquake. Therefore the study tries to find out the visible crack of the building to assess the damage probability of buildings.

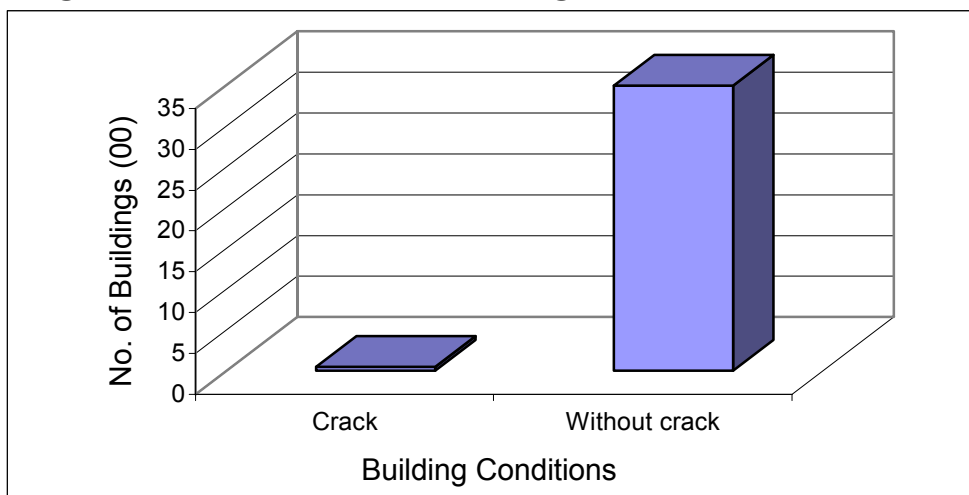
**Table 5.6: Condition of the buildings**

Condition	No of building	Percent
Crack	52	1.5
Without crack	3523	98.5
Total	3575	100

Source: Field survey, 2007

In the field study, it was found that 1.5 percent of the total buildings were observed with the wall crack diagonal, horizontal or vertical, which is shown in Table 5.6 and Figure 5.5.

**Figure 5.5: Condition of the buildings**



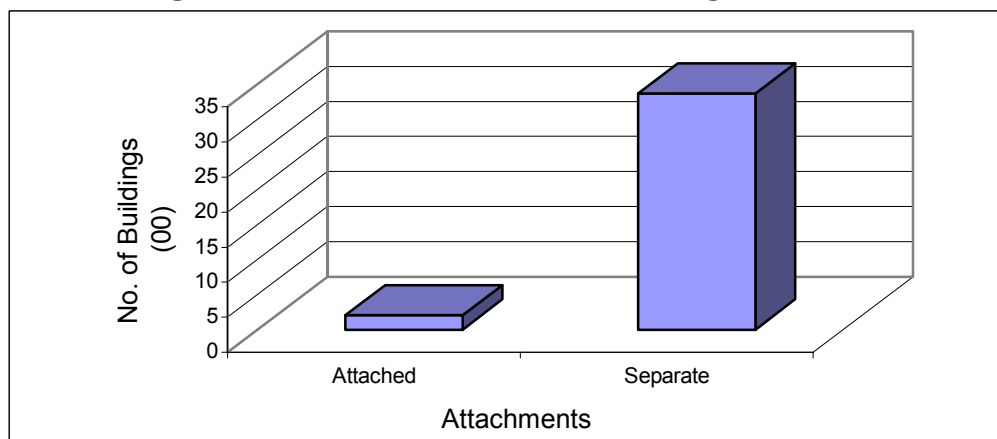
Building attachment and separation also play important role for the vulnerability of the building because attached buildings are more vulnerable than separate building. In the study area, it was found that, 6 percent of the total buildings were attached with the other nearest building and about 94 percent were found separate building. (Table 5.7).

**Table 5.7: Attachments of the buildings**

Condition	No of building	Percent
Attached	203	5.7
Separate	3372	94.3
Total	3575	100.0

Source: Field survey, 2007

**Figure 5.6: Attachments of the buildings**



## **CHAPTER VI**

### **BUILDING VULNERABILITY ASSESSMENT**

#### **6.1 Introduction**

One of the main objectives of this study is to estimate the vulnerability of the building in the different probable earthquake scenario of study area Ilam municipality. It depends on the different building parameters like age, height, construction materials, geometry, soft story, separation of the building and geological condition. For the estimation of building damage in different probable earthquake scenario, building damage matrix which considers only building type, building height and earthquake intensity prepared by NSET and JICA 2001.

#### **6.2 Building damage matrix**

Depending on the earthquake intensity and building strength, a building may suffer partial damage or completely collapse of the building during the earthquake period. When earthquakes intensity is considered constant the damage grade is directly related to the building strength, which is directly related to the material and construction type (JICA, 2002). The building inventory report prepared by NSET divided buildings into seven major classes. But the current study, the buildings of the study area has been divided into six classes: adobe, brick in cement, and brick in mud, wooden, stone mud and temporary building (Bamboo, Tin)

Building damage grade matrix has been developed from building fragility curves of Nepal building code and JICA studies for different type of buildings. This damage grade matrix gives the different grade to the building for different earthquake intensity. The matrix can be used to know how the different building types behave in different earthquake scenarios. The number of the matrix represent the percentage of the buildings that will partially damage or completely collapse or what a degree it would be effected. The percentage of the building depends on the ranges of the peak ground acceleration percentage in different earthquake scenarios (MMI). The value of buildings damage or

collapse may differ in different type of construction materials. The number of partial damage refers reparability and totally collapse indicates the building unreparability.

**Table 6.1: Damage probability matrix for different types of buildings.**

Earthquake Scenarios (MMI)		Intensity VI			Intensity VII			Intensity VIII			Intensity IX		
Building Types	PGA (%)	5_10			10_20			20_35			>35		
	Probability range	Min	Mid	Max	Min	Mid	Max	Min	Mid	Max	Min	Mid	Max
AD	Total collapse	2	6	10	10	23	35	35	45	55	55	64	72
	Partial damage	5	10	2	15	25	35	20	30	40	20	30	40
BM	Total collapse	00	3	6	6	14	21	21	31	41	41	51	62
	Partial damage	3	6	8	8	17	25	25	27	28	28	35	42
BC	Total collapse	00	1	1	1	3	5	5	12	18	18	23	27
	Partial damage	00	6	11	1	16	31	31	38	45	45	56	68
RCC	Total collapse	00	1	2	2	5	8	8	14	19	19	27	35
	Partial damage	00	2	4	4	10	16	16	27	38	38	52	65

Source: NSET Nepal (Modified from existing damage matrix for different buildings parameters, the value represents the percentage of the buildings).

Note: Min = Minimum, Med= Medium, Max= Maximum.

AD= Adobe, BM= Brick in mud, BC= Brick in cement, RCC= Reinforced concrete cement

### 6.3 Comparative analysis of building parameters

Ground vibration is most effective events during the earthquake period. Most of the damage of buildings was caused by heavy and weak construction materials. For the current study the building damage estimation is carried out in individual building level so that it is possible to indicate the probability of suffering damage of collapse of an individual building in the study.

In this study the building estimation was carried out for individual building indicate the probability of damage or collapse of individual building in the study area. The parameters were also compared with each other using pair wise method. In the table value “1” means a parameter has less importance in comparison to other, “2” means more important and “0” means same or no comparison. Finally the individual scores were summed for the individual

weight and divide the individual weight with individual score to calculate the comparative weight. To calculate the final weight, multiply the individual weight with the comparative weight in different description of the buildings parameters. The final weight ranges from 0-1, i.e. crack (0.190), soft story (0.175), geometry (regular: 1 :< 3, 0.080, irregular: 0.159), Age (20-100 years: 0.048, > 100 years: 0.095), building separation (separate: 0.056, attached: 0.111) etc. the higher value is the vulnerability than the less value. For comparison between parameters no engineering analysis were made but it was just based on educative judgment or researcher’s knowledge and experience.

In order to calculate the building vulnerability classes, weights were assigned to building characteristics according to their contribution to the vulnerability. For example for geometry regular (ratio<=1:3), regular (ratio >1:3), Irregular, weights 0 means no vulnerable, 0.089 means medium vulnerable and 0.178 means high vulnerable were assigned respectively.

**Table 6.2: Pair wise comparison of building parameters**

Building parameters	Age	Crack	Soft story	Geometry	No of Story	Building separation	Individual weight	Comparative weight
Age	0	1	1	1	1	1	5	0.111
Crack	2	0	2	2	2	2	10	0.222
Soft story	2	1	0	2	2	2	9	0.200
Geometry	2	1	1	0	2	2	8	0.178
No of Story	2	1	1	1	0	2	7	0.156
Building separation	2	1	1	1	1	0	6	0.133
Total weight							45	1.000

Source: NSET Nepal, modified in the current study.

**Table 6.3: Weights for building parameters/conditions for earthquake vulnerability**

S.N.	Building condition	Description	Individual weight	Comparative weight	Final weight
1	Age	A1(<20 years)	0	0.111	0.000
		A2 (20-100 years)	0.5		0.056
		A3 (>100 years)	1		0.111
2	Crack	Yes	1	0.222	0.222
		No	0		0.000
2	Geometry	Regular (<=1:3)	0	0.178	0.000
		Regular (>1:3)	0.5		0.089
		Irregular	1		0.178
3	Soft Story	Yes	1	0.200	0.200
		No	0		0.000
4	No of story	1	0	0.156	0.000
		2	0.2		0.031
		3	0.5		0.078
		4	1		0.156
6	Bid separation	Separate	0.5	0.133	0.067
		Attached	1		0.133
	Total			1.000	

#### 6.4 Building vulnerability

The various vulnerability classes (High, Medium and Low) for the individual buildings were mined using the weightage assigned to each building parameter and characteristics that contributed to the vulnerability of the building. The vulnerability rang from 0-1. To calculate the vulnerability classes the weight divided in to three levels (0-0.15 low, 0.15-0.30 medium and >0.30 high). Finally the level rang of the vulnerability was used to calculate the building damage and collapse probability of individual building with the reference to building damage grad matrix and intensity of the earthquake.

In the study area, out of total 3575 buildings, 3032 found to be in low vulnerability, 510 buildings were observed medium class and only 33 buildings in the high vulnerability. According to construction materials 649 of the total Adobe buildings found to low vulnerability class, 65 and 9 buildings were found medium and high vulnerability class accordingly. Like that their details of

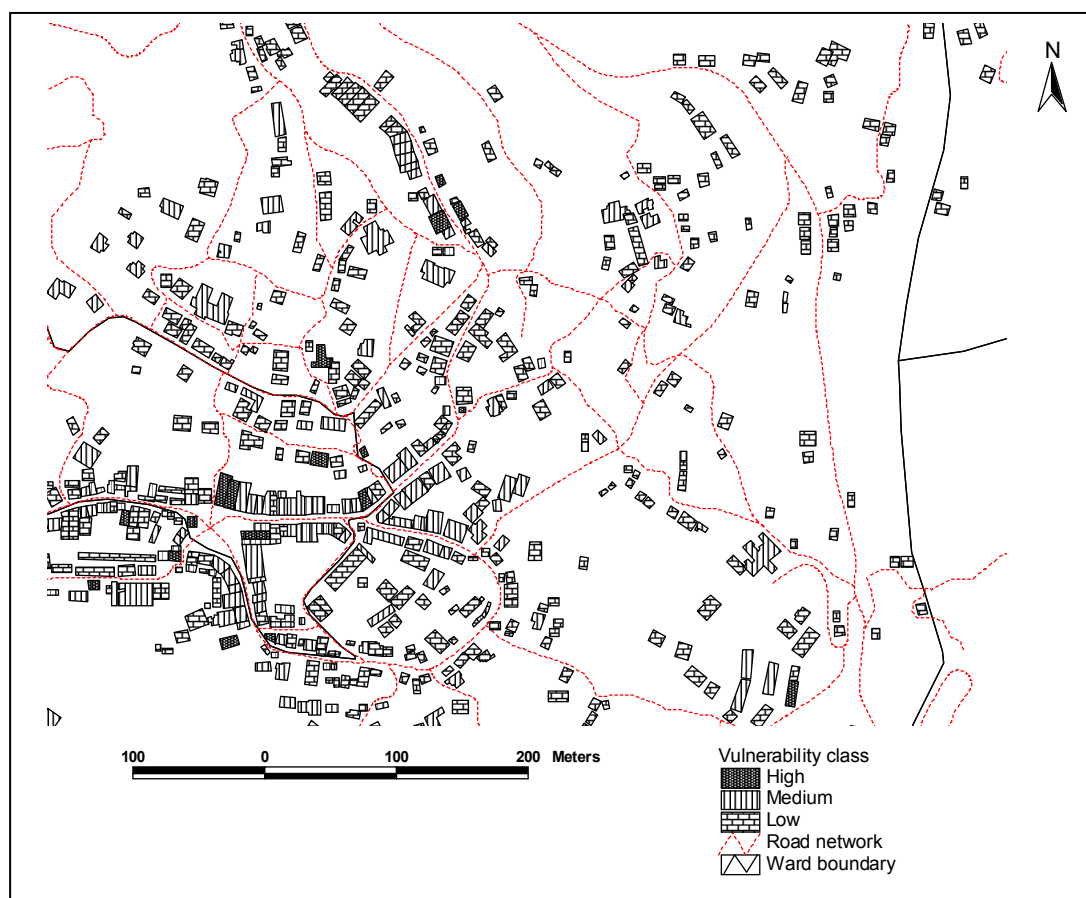
vulnerability level of building structure type are given in the table 6.4 and map 6.1 below.

**Table 6.4: Vulnerability class of buildings by types**

Building Type	Vulnerability Classes						Total
	Low	%	Medium	%	High	%	
Adobe	649	22.12	65	10.37	9	64.29	723
Brick in cement	546	18.61	228	36.36	11	78.57	785
Brick in mud	22	0.75	25	3.99	2	14.29	49
Stone in cement	145	4.94	47	7.50	3	21.43	195
stone in mud	1537	52.39	131	20.89	8	57.14	1676
Temporary Building	133	4.53	14	2.23	0	0.00	147
<b>Total</b>	<b>3032</b>	<b>103.34</b>	<b>510</b>	<b>81.34</b>	<b>33</b>	<b>235.71</b>	<b>3575</b>

Source: Field survey, 2007

**Map 6.1: Building vulnerability class**



#### 6.4.1 Vulnerability according to age of building

In the current research, three vulnerability classes were calculated under the building age. It is categorized into three classes i.e. A1= < 20 years, A2= 20 to 100 years and A3 = > 100. According to age category, 0.21 percent of the total A1 buildings were high vulnerable. 9.90 percent were medium class and highest number (89.89%) of the total building were low vulnerable in the study area.

Like this, 2.00 percent of the total A2 building were high vulnerable, 23.43 percent were medium and 74.56 percent of the buildings were low vulnerable in this category.

Similarly, in the context of A3 buildings, 38.46 percent were high vulnerable, where as 15.38 percent of the total building were medium vulnerable as well as 46.15 percent buildings were found in the low vulnerability classes.

According to this data, the oldest buildings (A3) are more vulnerable then A2 and A1. The overall relation between age and vulnerability of building is given in the table 6.5 below:

**Table 6.5: Vulnerability according to age of building**

Age	Vulnerability according age of building						Total	Percent
	High	Percent	Medium	Percent	Low	Percent		
A1	5	0.21	239	9.90	2170	89.89	2414	100.00
A2	23	2.00	269	23.43	856	74.56	1148	100.00
A3	5	38.46	2	15.38	6	46.15	13	100.00

Source: Field survey, 2007

Where: A1= buildings < 20 years, A2 = buildings 20-100 years, A3 = buildings > 00 years

#### 6.4.2 Vulnerability according to story of building

According to number of story of the buildings, among the total four stories buildings, 6.52 percent were high vulnerable, 4.55 percent of the total three stories buildings, 0.42 percent of two stories buildings and 0.63 percent of the total one stories buildings were high vulnerable. It was found that, 93.48 percent of total four stories, 29.39 percent of three stories, 10.59 percent of two stories and 14.56 percent of one stories buildings were medium vulnerable in the study area. Like this, in the low vulnerability classes, the three stories buildings

consisted 66.06 percent where as 89.00 percent of the total two stories building and 84.81 percent of one story buildings were found in this classes but there are no four stories building in this category. In this way, we can conclude that, four stories building were more vulnerable (high vulnerable) than the three and two stories buildings, it is shown in the table 6.6 below:

**Table 6.6: Vulnerability according to story of building**

Story no	Vulnerability class						Total	Percent
	High	Percent	Medium	Percent	Low	Percent		
1	5	0.63	115	14.56	670	84.81	790	100.00
2	10	0.42	255	10.59	2144	89.00	2409	100.00
3	15	4.55	97	29.39	218	66.06	330	100.00
4	3	6.52	43	93.48	0	0.00	46	100.00

Source: Field survey, 2007

### 6.5 Damage probability

Building damage and collapse probability was calculated in several steps for building loss estimation. Individual buildings were identified in the different vulnerability class Good, Average and Weak according to building characteristics. The level of vulnerability were considered in the building damage grade matrix (Which is prepared by NSET and JICA) to differentiate the range of damage and collapse probability for individual building. In the damage grade matrix low vulnerable represents “Good” medium vulnerable “Average” and high vulnerable shows the “Weak” condition of the building. Damage grade of the building was taken only for VII and VIII intensity of earthquake as they are most likely magnitude of earthquake that probable has to occur in the study area. The intensity map prepared with the help of geological condition and seismic hazard contour map prepared by United State Geological Survey (USGS) America. Probable damage grade of different building typology is given in table 6.7 below.

**Table 6.7: Probable damage grade of different buildings typology**

Building Type:1 Adobe, Stone in Mud and Brick in Mud						
MMI		VI	VII	VIII	IX	X
Damage Grades for Different Classes of Buildings	Weak	DG4	DG5	DG5	DG5	DG5
	Average	DG3	DG4	DG5	DG5	DG5
	Good	DG2	DG3	DG4	DG4	DG5
Building Type:2 Brick in Cement, Stone in Cement and Well built Brick in Mud						
MMI		VI	VII	VIII	IX	X
Damage Grades for Different Classes of Buildings	Weak	DG2	DG3	DG4	DG5	DG5
	Average	DG1	DG2	DG3	DG4	DG5
	Good		DG1	DG2	DG3	DG4
Building Type:3 Reinforced Concrete Ordinary Moment Resisting Frame (< 3 Story)						
MMI		VI	VII	VIII	IX	X
Damage Grades for Different Classes of Buildings	Weak	DG1	DG2	DG3	DG4	DG5
	Average		DG1	DG2	DG3	DG4
	Good			DG1	DG2	DG3
Building Type:4 Reinforced Concrete Ordinary Moment Resisting Frame (>= 3 Storied)						
MMI		VI	VII	VIII	IX	X
Damage Grades for Different Classes of Buildings	Weak	DG1	DG2	DG4	DG5	DG5
	Average		DG1	DG3	DG4	DG5
	Good		DG1	DG2	DG3	DG4

Source: National Society for Earthquake Technology- Nepal (NSET) 2004 Kathmandu

Note: Based on total vulnerability scale, houses were divided in to three categories;

Weak = >0.40, Average = 0.20 -0.40, Good = < 0.20

In the study area it is found that, 212 of the total buildings (5.93 percent) are in the category of the heavy damage (Total collapse), 1982 buildings (55.4 percent) in partially damage (Gaps in wall, parts of the building may collapse), 528 of the total building (14.8 percent) large and deep cracks in walls, fall of chimneys and other buildings are in categories with probability of slightly or moderately damage.

It is found that under the intensity VIII 6.66 percent of the total building are in DG 5 class (total collapse) and most of the building (61.4 percent) are in DG 4,

17.9 percent of the buildings are in DG 2 and 14.8 percent buildings are in DG 3. Other buildings are slight condition.

Similarly, for the intensity VII, 7.14 percent of the buildings are in DG 4 (destruction), 68.4 percent of the buildings are in DG 3 (heavy damage) and other buildings in slight and moderate damage category.

Temporary buildings (made by Bamboo, Tin and Wood) which are mostly one story (ground floor) are negligible or no visible effect for this intensity of earthquake has given DG “0” according to educative judgment of the researcher. It is out of the damage grade matrix and engineering proof but it is included in the total number of building and percentage of the damage. It is shown in the table 6.8 below.

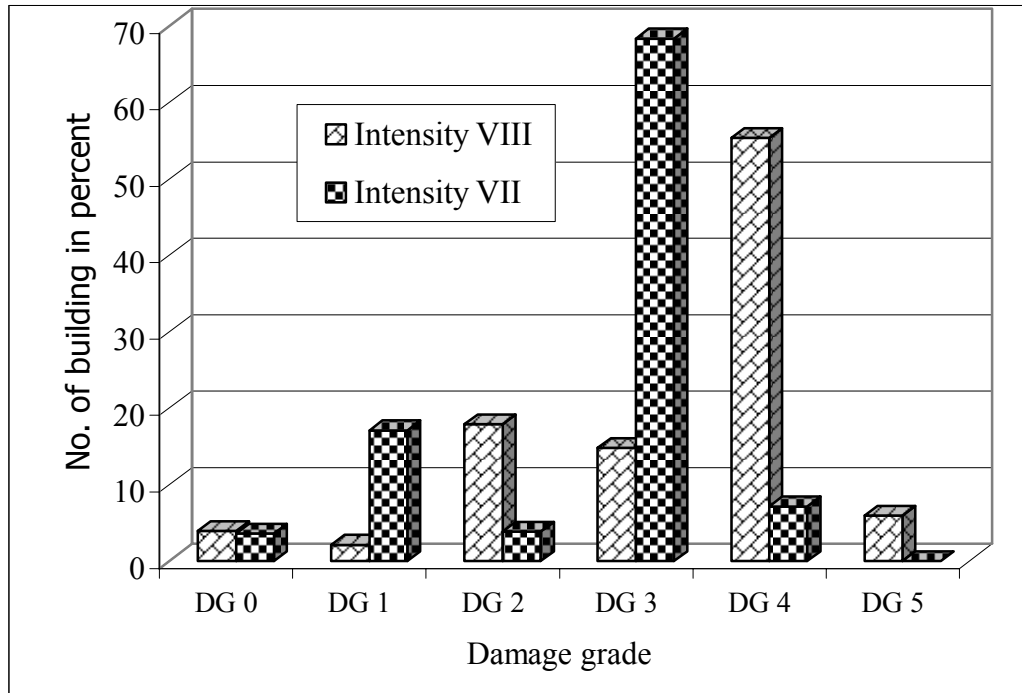
**Table 6.8: Damage grade of building in different earthquake Intensity**

Building type	Intensity VIII						Intensity VII						Total
	DG 0	DG 1	DG 2	DG 3	DG 4	DG 5	DG 0	DG 1	DG 2	DG 3	DG 4	DG 5	
Adobe	0	0	0	0	578	71	0	0	0	71	3	0	723
Brick in cement	0	0	497	215	11	0	0	49	13	0	0	0	785
Brick in mud	0	0	0	0	22	27	0	0	0	0	0	0	49
Stone in cement	0	0	127	45	3	0	0	18	2	0	0	0	195
stone in mud	0	0	0	0	1340	114	0	0	0	197	25	0	1676
Temporary Building	125	8	0	0	0	0	14	0	0	0	0	0	147
Total	125	8	624	260	1954	212	14	67	15	268	28	0	3575

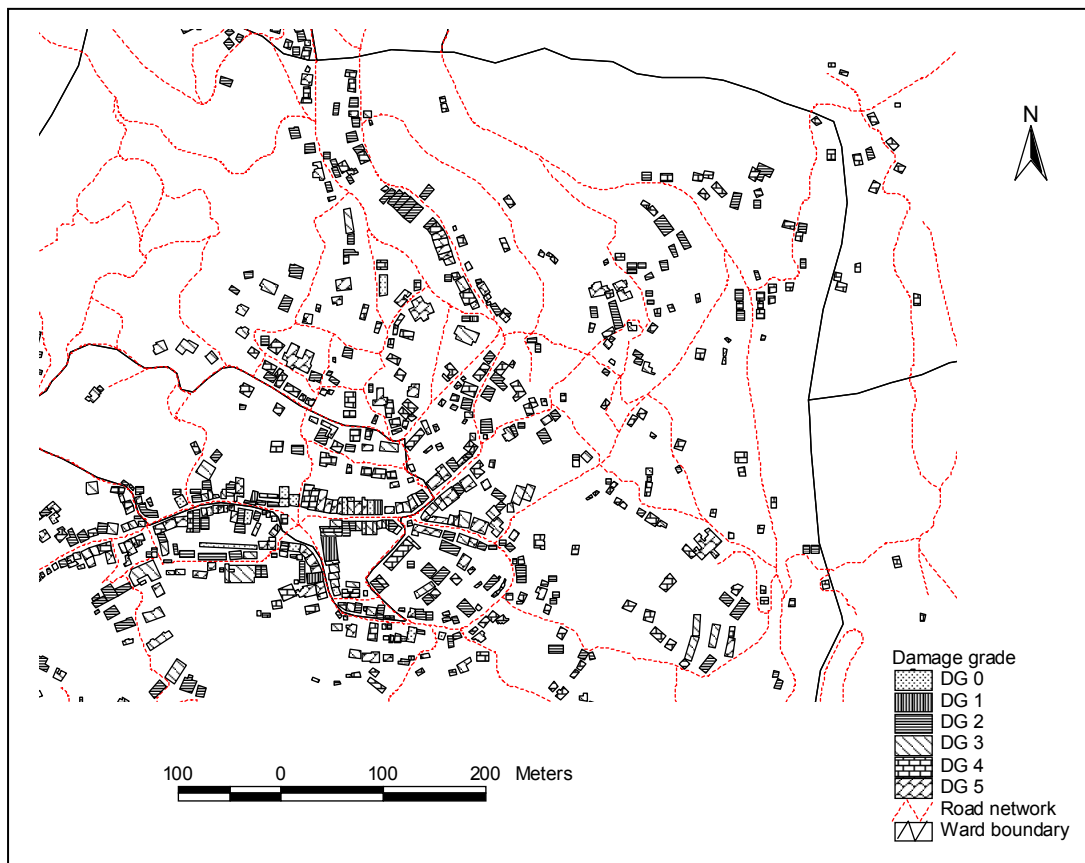
Source: Field survey, 2007

Note: DG 0: “No Visible effect”, DG 1: “Slight Damage”, DG 2: “Moderate Damage”, DG 3: “Heavy Damage”, DG 4: “Destruction” and DG 5: “Total damage/Collapse”.

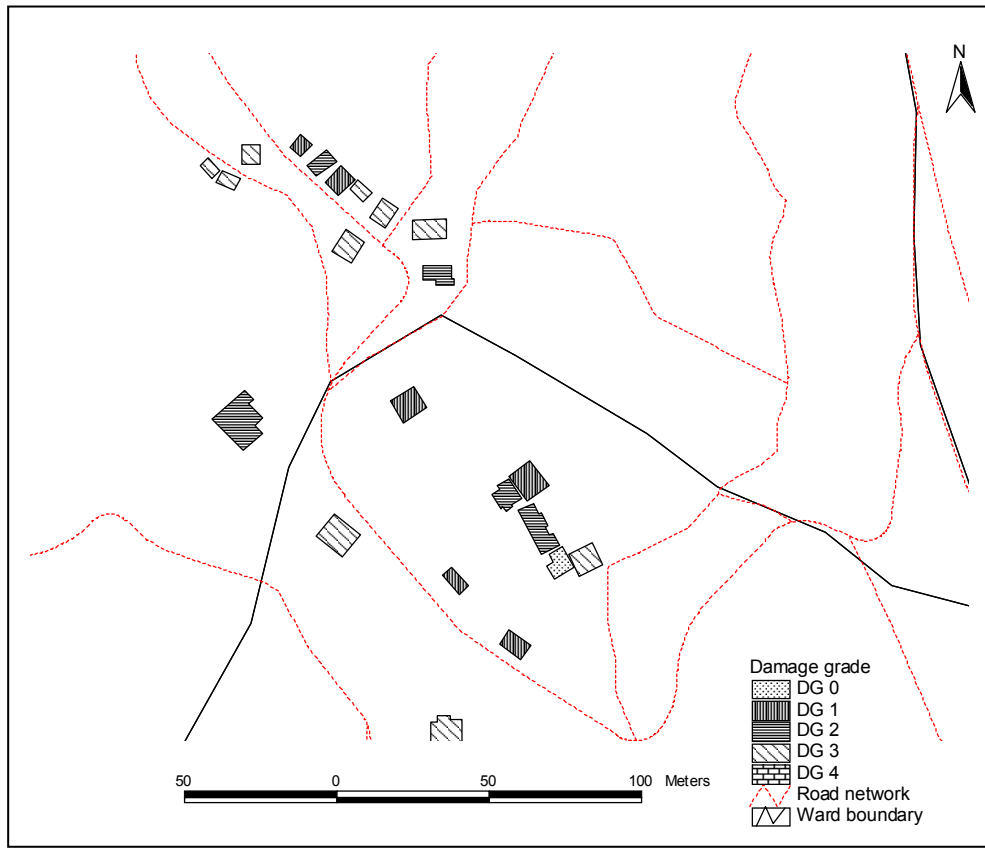
**Figure 6.1: Damage grade of building under intensity VIII and VII of earthquake**



**Map 6.2: Damage grade of building under the intensity VIII of earthquake**



**Map 6.3: Damage grade of building under the intensity VII of earthquake**



### 6.5.1 Totally collapse and partially damage

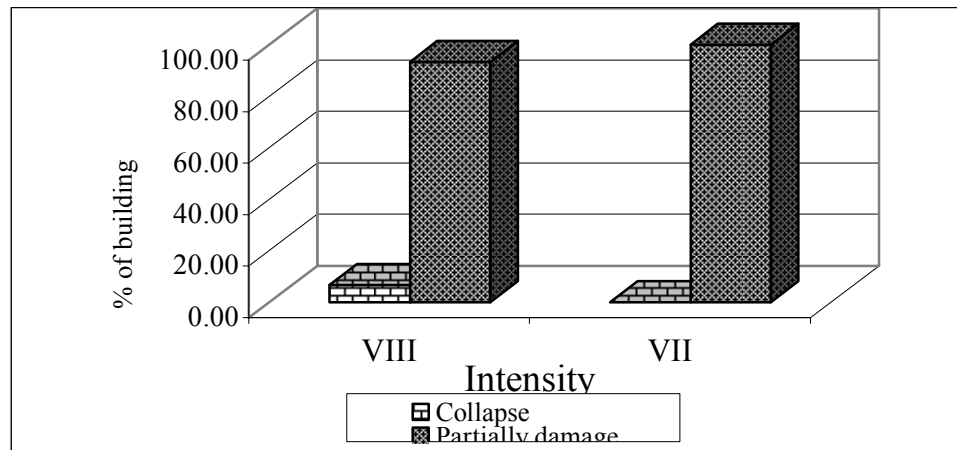
To classify the total building of the study area according to collapse and partially damage, it is found that under the intensity of VIII, 212 of the total building (6.66 percent) are found in completely collapse probability category and 2971 buildings (93.34 percent) are found in partially damage probability category.

Similarly, under the intensity VII, it is found that 392 of total building (100%) are in the partially damage category and there were no building found to totally collapse or there were no building in the damage grade 5. See table 6.9.

**Table 6.9: Collapse and damage probability in different intensity**

Intensity	Collapse	Percent	Partially damage	Percent
VII	212	6.66	2971	93.34
VII	0	0.00	392	100.00

**Figure 6.2: Collapse and damage Probability in different intensity**



### 6.5.2 Building damage by types

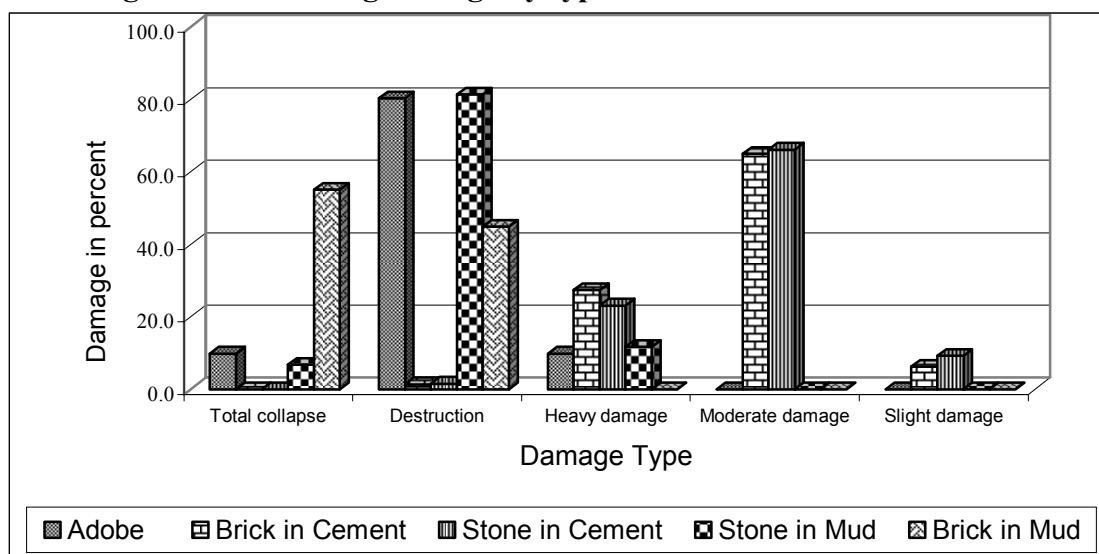
The damage of building according to their construction material or typology was calculated from the damage grade. Under the magnitude of VII and VIII earthquake, 9.82 percent of the Adobe, 6.80 percent of Stone in Mud, 55.10 will completely collapse (DG 5). 80.36 percent of Adobe buildings 1.40 percent Brick in Cement 1.54 percent of Stone in Cement, 81.44 percent of Stone in mud and 44.90 percent of Brick in Mud will partially damage (destruction, DG 4) and 9.82 percent of Adobe, 27.39 percent of Brick in Cement, 23.8 percent of Stone in Cement, 11.75 percent of Stone in Mud building are under the heavy damage or DG 3. Like this, 64.97 percent of Brick in Cement, 66.15 percent of Stone in Cement are suffered in moderate damage as shown in table 6.10.

**Table 6.10: Building damage by types**

Damage type	Adobe	Brick in Cement	Stone in Cement	Stone in Mud	Brick in Mud
Total collapse	9.82	0.00	0.00	6.80	55.10
Destruction	80.36	1.40	1.54	81.44	44.90
Heavy damage	9.82	27.39	23.08	11.75	0.00
Moderate damage	0.00	64.97	66.15	0.00	0.00
Slight damage	0.00	6.24	9.23	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00

Note: All values are in percent

**Figure 6.3: Building damage by types**



### 6.5.3 Damage probability of School, Hospital and Office Institute.

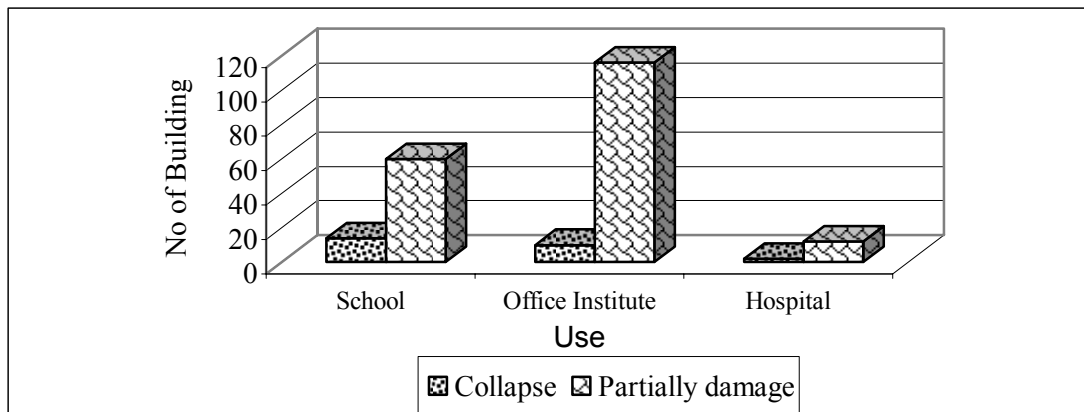
School is the social concentration center of the rural and urban area. School can provide more awareness programme to the community. Management of the public schools is largely depending on the responsibility of the local community. Usually very low budget is available with the school management. On the other hand, school can be a shelter for the deliverance in the earthquake period. But most public schools in Nepal have been built up of stone in mud and abode without engineering design. So, they have more chance to damage and collapse in the period of earthquake. Similarly, office and institute are the social service center of the country, but it has been also constructed without engineering judgments. So they have a great chance to damage and collapse in the earthquake period. Like this hospital is an important center for treatment of injured and patient. It is more important to preserve the public life at the time of earthquake, so it must be well constructed.

**Table 6.11: Damage probability of school, hospital and office institute.**

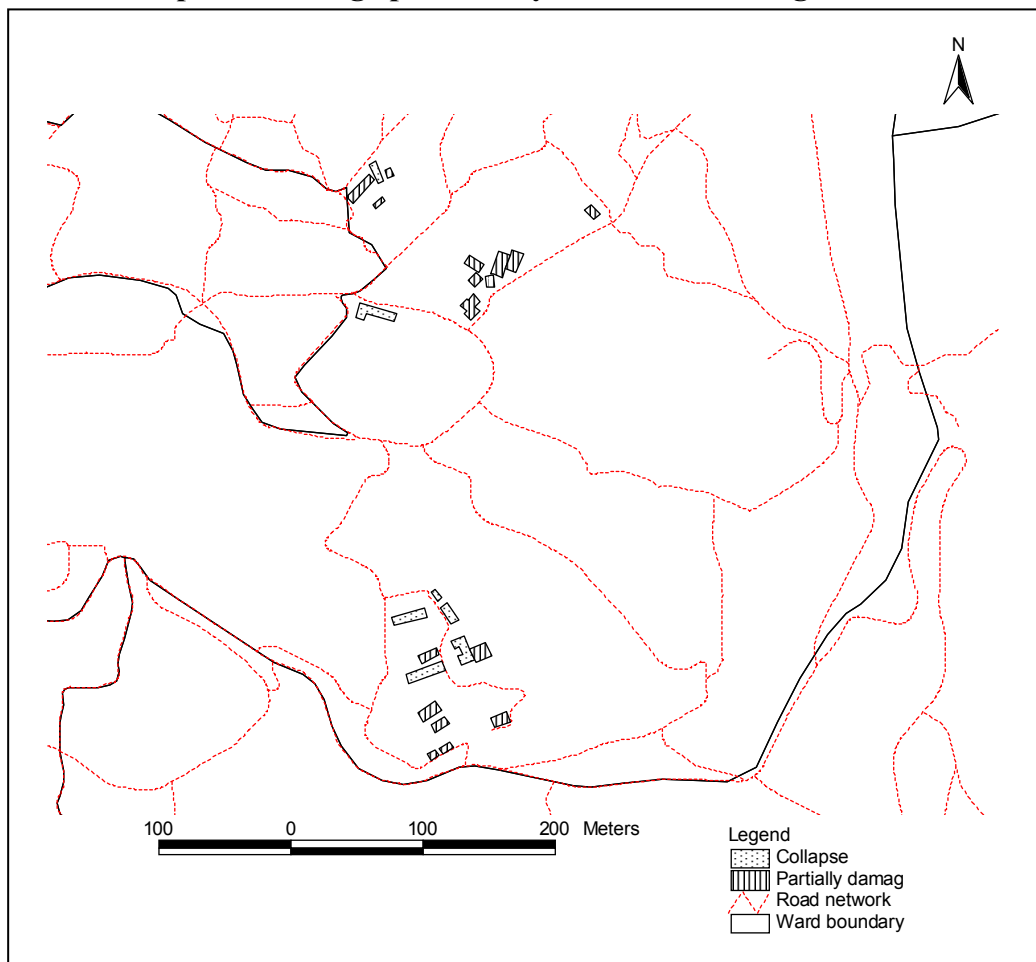
Use	Damage type		Total
	Collapse	Partially damage	
School	14	60	74
Office Institute	10	116	126
Hospital	2	12	14

Above table 6.11 shows the damage and collapse of School, Office Institute and Hospital. It was found that, out of total 74 school buildings, 14 buildings were found in collapse probable situation. Most of the adobe and old buildings were found in collapse probability. In the total 126 Office Institute buildings, 10 buildings were found in totally collapse probability and 2 building of the Hospital were found under the collapse probability.

**Figure 6.4: Damage probability of school, hospital and office institute.**



**Map 6.4: Damage probability of school buildings**



#### 6.5.4 Building loss by geological type

To calculate the collapse and partially damage probability of building in the study area, unit 2 (garnet kyanite sillimanite gnesis, orthogenesis and white colored, course grained, fractured quartzite) type of geological condition has high probability of buildings collapse then the unit 1 (Garnet-kyanite, sillimanite gnesis and gray quartzite) type of geological condition. 6.36 percent of the total buildings are under the collapse probability in unit 2 and 2.51 percent of the total buildings has high probability of collapse in unit 1, are shown in table 6.12 below.

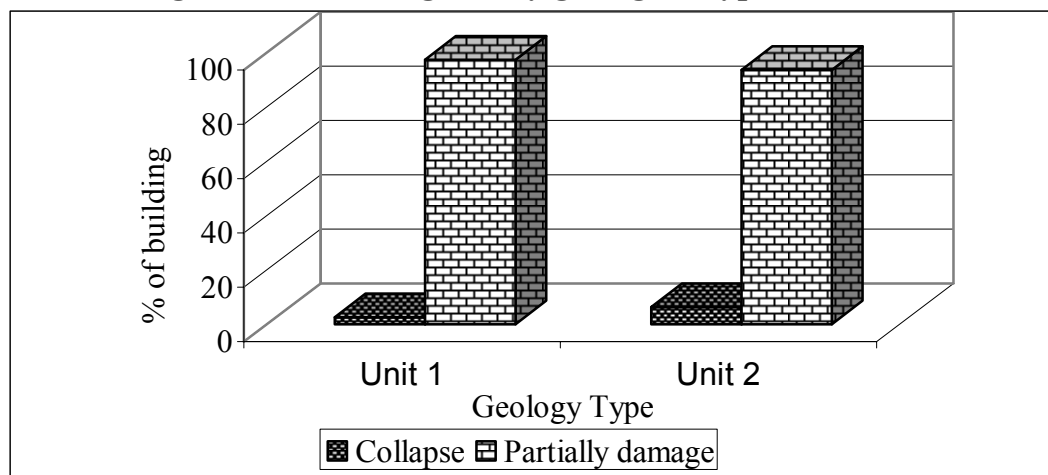
**Table 6.12: Building loss by geological type**

Geology type	Collapse	Percent	Partially damage	Percent	Total	Percent
Unit 1	10	2.51	388	97.49	398	100
Unit 2	202	6.36	2975	93.64	3177	100

Note: Unit 1= Garnet-kyanite, Sillimanite gnesis and Gray quartzite

Unit 2 = Garnet Kyanite sillimanite gnesis, Orthogenesis and White colored, Course grained, Fractured quartzite

**Figure 6.5: Building loss by geological type**



#### 6.5.5 Damage probability with education and occupation

In this study, damage probabilities of the population (household head) were calculated under the education level and occupation of the people. The education level is categorized into three classes (illiterate, literate and above primary level) and occupation is categorized in to two groups (agriculture and non agriculture). It is shown in the table 6.13 below:

**Table 6.13: Percent of household head with level of education and occupation by damage probability of home.**

Damage probability	Education			Occupation	
	Illiterate	Literate	Above primary	Agriculture	Non agriculture
Totally collapse	10.94	3.85	8.00	6.19	14.29
Partially damage	89.06	96.15	92.00	93.81	85.71
Total	100.00	100.00	100.00	100.00	100.00

According to data, there were 10.94 percent of the total illiterate people (household head) found in the totally collapse probable building followed by above primary level with 8.00 percentages. On the other hand, 96.15 percent of the total literate people were found under the partially damage probable building. 92.00 percent and 89.06 percent of the total above primary level and illiterate were lived under the partially damage probable building respectively.

#### **6.5.6 Probability of damage on Caste/ Ethnic groups**

In the study area, there are found diversity in cast and ethnic groups. The table 6.16 shows the damage probability of house owned by different cast/ethnic groups with partially damage and completely collapse probability class.

**Table 6.14: Number and percent of caste/ ethnic groups by damage probability.**

Ethnicity	Completely collapse		Partially damage		Total	
	No	%	No	%	No	%
Limbu	5	29.41	12	70.59	17	100.00
Magar	2	20.00	8	80.00	10	100.00
Dalit	2	14.29	12	85.71	14	100.00
Newar	2	9.09	20	90.91	22	100.00
Tamang	2	9.09	20	90.91	22	100.00
Rai	2	13.33	13	86.67	15	100.00
Braman	4	4.76	80	95.24	84	100.00
Chhetri	2	2.86	68	97.14	70	100.00
Gurung	0	0.00	6	100.00	6	100.00
Lama	0	0.00	6	100.00	6	100.00

Source: Field survey, 2007

According to the data, 29.41 percent of Limbus live in totally collapse probable building followed by Magar and Dalit with 20.00 and 14.29 percent accordingly.

Similarly, the total Gurungs and Lamas were found in partially damage probable building. 97.14 percent of Chhetri and 95.24 percent of Braman were also found in this category.

At last, it is concludes that, Limbu, Magar and Dalit were lived in more hazardous buildings than Tamang, Braman, Chhetri comparatively.

### 6.5.7 Building damage probability by Ward

Ilam municipality is the headquarter of the Ilam district. Most of the buildings were closely concentrated in this area. The municipality is divided in to 9 wards. There is no equal distribution of building in different ward.

**Table 6.15: Building loss on ward wise distribution**

Ward No	Totally collapse	Partially damage	Total
1	17.76	82.24	100
2	12.66	87.34	100
3	6.01	93.99	100
4	3.54	96.46	100
5	1.20	98.80	100
6	3.78	96.22	100
7	3.98	96.02	100
8	3.73	96.27	100
9	2.35	97.65	100

Note: All values are in percent

Above table 6.15 shows the partially damage and completely collapse probable buildings on ward wise distribution.

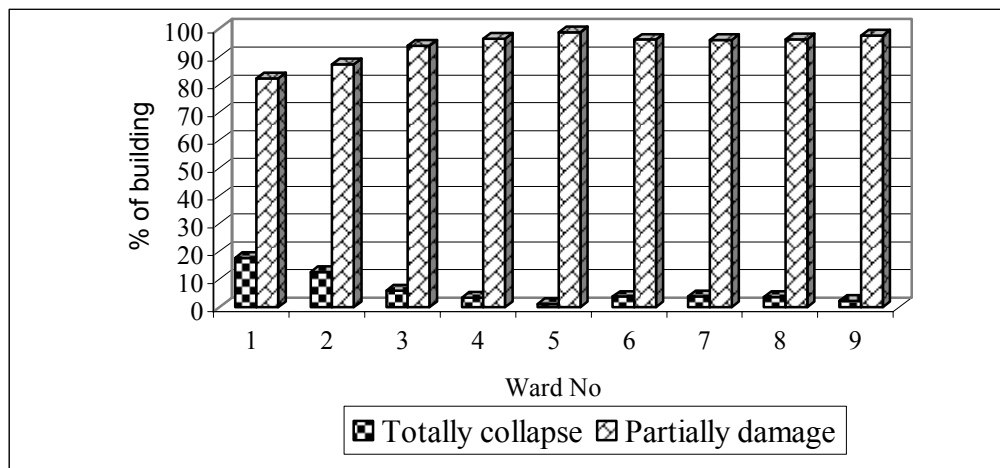
Ward no 1 had highest number of completely collapse probable building with 17.76 percent is followed by ward no 2 with 12.66 percent. Ward no 5 and 9 had lowest number of building in this category considered 1.20 and 2.35 percent respectively.

On the other hand, 98.8 percent of the total building of ward no 5 were found to be damage partially as well as ward no 9 had 97.65 percent building on this category is followed by ward no 4 with 96.46 percent where as the lowest

number of the building were found in ward no 1 and 2 with 82.24 and 87.34 percent in partially damage probable class respectively.

According to data, ward no 1 and 2 are more vulnerable area for the different intensity of earthquake. Ward no 5 and 9 are less vulnerable then others comparatively.

**Figure 6.6: Building loss on ward wise distribution**



### 6.6 Affecting factors to increase the building vulnerability

During the earthquake period, geological condition is an important cause for the surface vibration. Earth vibration plays the main role for the building damage and collapse. Vibration effects in weak geological setting than the hard comparatively. According to geological condition of the study area, the earthquake intensity VII and VIII effects mostly.

On the other hand, construction materials and physical condition of the buildings play important role to increase the probability of damage and collapse. Weak construction material has high probability to damage and collapse the building in earthquake period. Like this, height and geometry also play vital role in vulnerability of earthquake. Irregular shape and tall buildings are more vulnerable than regular shape and small building. Clustered settlements are more vulnerable for the earthquakes, because probably vulnerable buildings can effects to other nearest non vulnerable building in the earthquake period.

## CHAPTER VII

### CONCLUSIONS AND RECOMMENDATIONS

#### 7.1. Conclusions

Seismic Vulnerability assessment of building in Ilam municipality was carried out the main objective of building loss and collapse probability estimation under the different earthquake scenarios and find out the factors affecting to increase the loss and collapse of the building. For this, it used the existing damage grade matrix prepared by NSET and JICA. On this damage grade matrix, the collapse or damage rate of a building highly depend on its condition and other building parameters like height, construction materials, age, geometry and separation of building etc. firstly different building parameter and characteristics that contributed to the vulnerability for building were identified. These parameters were classified in to different categories, for example: building geometry was categorized in to 3 classes' i.e.R1 (Regular <1:3 length width ratios), R2 (Regular >1:3 length width ratios) and IR (Irregular).

For the estimation of the damage grade of the building, the vulnerability of each building was considered. The probability of damage and collapse of the building is highly depends on its physical condition as well as other building parameters are also equal important for the building vulnerability. On the other hand, earth vibration is mainly depends on the geological condition and loss of the building is closely related to the earth vibration on earthquake period. So weak geological condition and weak construction materials are important factors to increase the probability of damage or collapse of building.

There is less effect of education to reduce the vulnerability of building damage in the period of earthquake because above primary level of educated persons are lived in high vulnerable building than the only literate people, or they neglected the natural disaster. In the cast/ethnicity, Limbus are in more vulnerable building than other ethnic group Gurung and Lama. 29.41 percent of limbus and 20

percent of Magar are lived in completely collapse probable building but no one Gurung and Lama are lived in such type of buildings.

The result shows that most of the buildings have a high probability of damage and collapse by a strong earthquake with an intensity of VII in the study area. Mainly the buildings of the core area of urban (Ward no 1 and 2 of Ilam Municipality) were found to be most vulnerable or ward no 1 and 2 are high probable area for the loss or collapse of building, where the buildings are closely concentrate than urban periphery. Ward no 9 and 5 are less vulnerable area than other wards.

In the estimation of the building damage or collapse, 6.66 percent of the total buildings were found in high vulnerability condition. These buildings will be totally collapse in intensity VIII of earthquake. Similarly, brick in mud and adobe buildings are more vulnerable and it has high probability to damage or collapse. Brick in cemented building (less then two stories) have less probability to damage or collapse. Building height and geometry are also important parameters to loss building in the earthquake period.

It is important to state here that the current study is based on some parameter of the earlier developed methods. But the approach which was followed in course of collecting the information of building is only educative judgment; there is no engineering proof.

## **7.2. Recommendations**

- The earthquake hazard cannot be controlled but its impact can be reduced by following building code while constructing buildings.
- Probability of damage and collapse of building can be reduced using the earthquake resistance method in the construction period.
- Awareness programmes should be included in educational programme, because there is less effect of education in earthquake vulnerability. But it is not enough parameter of analysis of vulnerability.

- Regarding this building damage estimation, there is no scientific method to collect data; it only depends on educative guess and local experience. This study considered other existing damage matrix of the buildings. So there is needed for a scientific analysis of those components for the better analysis of building vulnerability to earthquake.

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[www.earthquake.usgs.gov](http://www.earthquake.usgs.gov) 2065/03/02

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## Annex 2: Index of Short form

INDEX								
Building type	Use	Shape	Age	Attachment	Roofing system	Potential near by hazards	Non structural element	Physical Condition
A: Adobe	Rs: Residential	R1: Regular (<1:3)	A1: <20	SL: Separated	CGI: Steel	T: Tree	Hb: Hording board	V: Vulnerable
BC Brick in cement	Co: Commercial	R2: Regular (>1:3)	A2: 20 -100	At: Attached	Cn: Concrete	EP: Electric Pole	T: Towers	AV: Average
RC: Reinforce Concrete	Sc: School	IR: Irregular	A3: >100		Th: Thatch		OT: overhead water tank	G: Good
W: Wood	H: Hospital				S: Sleet			
SC: Stone in Cement	P: Police station				W: Wood			
BM: Brick in mud	C: Club							
SM: Stone in mud	HR: Hotal Restaurant							
	OI: Office Institute							
	Ind: Industry							
	Mx: Mix							

### Annex 3: Probable Damage Grade of Different Building Typology

Damage Grade as per EMS 98	Damage Grade as per Nepal National building code
<p>Grade 1 (DG1) Negligible to Slight Damage (No structural damage, slight no structural damage)</p> <p><u>Masonry buildings</u></p> <ul style="list-style-type: none"> <li>➤ Hair-line cracks in very few walls</li> <li>➤ Fall of small pieces of plaster only</li> <li>➤ Fall of loose stones from upper parts of buildings in very few cases.</li> </ul> <p><u>Reinforced Concrete Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Fine cracks in plaster over frame members or in walls at base</li> <li>➤ Fine cracks in partitions and infills</li> </ul>	<p>Grade 1: Slight Damage</p> <ul style="list-style-type: none"> <li>➤ Fine cracks in plaster</li> <li>➤ Fall of small pieces of plaster</li> </ul>
<p>Grade 2 (DG2): Moderate Damage (Slight structural damage, moderate non-structural damage)</p> <p><u>Masonry Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Cracks in many walls</li> <li>➤ Fall of fairly large pieces of plaster</li> <li>➤ Partial collapse of chimneys</li> </ul> <p><u>Reinforced Concrete Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Cracks in columns and beams of frames and in structural walls</li> <li>➤ Cracks in partition and infill walls: fall of brittle cladding and plaster</li> <li>➤ Falling mortar from the joints of wall panels</li> </ul>	<p>Grade 2: Moderate Damage</p> <ul style="list-style-type: none"> <li>➤ Small cracks in walls</li> <li>➤ Fall of fairly large pieces of plaster</li> <li>➤ Pan tiles slip off</li> <li>➤ Cracks in chimneys</li> <li>➤ Parts of chimney falls down</li> </ul>

<p>Grade 3 (DG3): Substantial to Heavy Damage (Moderate structural damage, heavy non-structural damage)</p> <p><u>Masonry Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Large and extensive cracks in most walls</li> <li>➤ Roof tiles detach; chimneys fracture at the roof line; failure of individual non-structural elements (Partitions, gable walls)</li> </ul> <p><u>Reinforced Concrete Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Cracks in columns and beam column joints of frames at the base and at joints of coupled walls</li> <li>➤ Spalling of concrete cover, buckling of reinforced rods</li> <li>➤ Large cracks in partition and infill walls, failure of individual infill panels</li> </ul>	<p>Grade 3: Heavy Damage</p> <ul style="list-style-type: none"> <li>➤ Large and deep cracks in walls</li> <li>➤ Fall of chimneys</li> </ul>
<p>Grade 4 (DG4): Very Heavy Damage (Heavy structural damage, very heavy non-structural damage)</p> <p><u>Masonry Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Serious failure of walls; partial structural failure of roofs and floors</li> </ul> <p><u>Reinforced Concrete Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Large cracks in structural elements with compression failure of concrete fracture of rebar; bond failures of beam reinforce bars; tilting of columns</li> <li>➤ Collapse of a few columns or of a single upper floor</li> </ul>	<p>Grade 4: Destruction</p> <ul style="list-style-type: none"> <li>➤ Gaps in wall</li> <li>➤ Parts of buildings may collapse</li> <li>➤ Separate parts of the buildings loose their cohesion</li> <li>➤ Inner walls collapse</li> </ul>

<p>Grade 5 (DG5): Destruction (Very heavy structural damage)</p> <p><u>Masonry Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Total or near total collapse</li> </ul> <p><u>Reinforced concrete Buildings</u></p> <ul style="list-style-type: none"> <li>➤ Total or near total collapse</li> </ul>	<p>Grade 5: Total Damage</p> <ul style="list-style-type: none"> <li>➤ Total collapse of building</li> </ul>
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#### **Annex 4: Building Typology**

Building classes	Index	Description
Adobe	A	Sun dried bricks with mud mortar
Brick in Mud	BM	Brick with mud mortar
Brick in Cement	BC	Brick with cement or lime mortar
Stone in Mud	SM	Stone with mud mortar
Stone in Cement	SC	Stone with cement

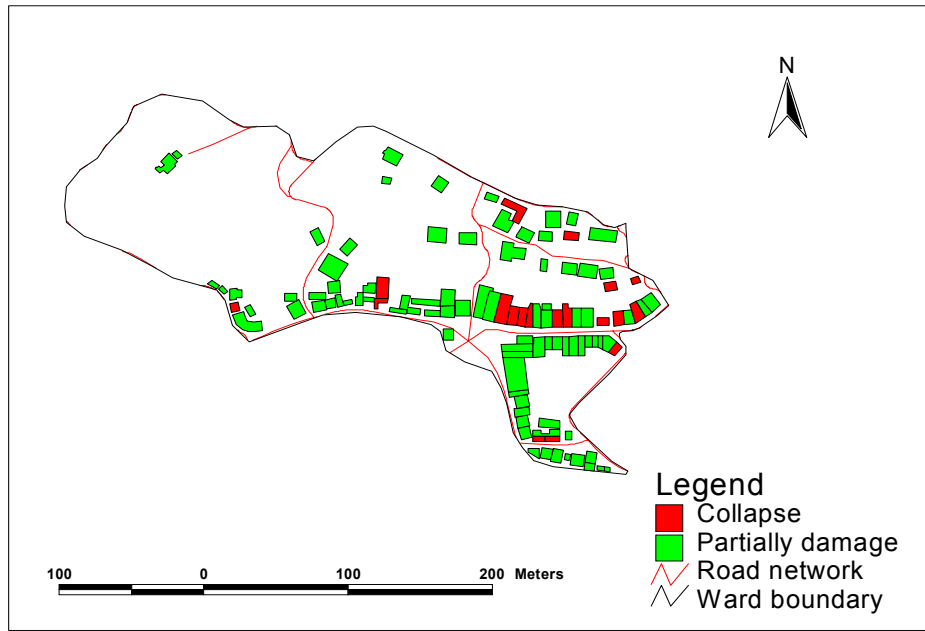
### Annex 5: The Modified Mercalli Scale

Intensity	Description of damage
I	Not felt by people, only detected by seismographs
II	Felt only by a few persons at rest, especially on upper floors of buildings
III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to passing of a truck. Duration estimated.
IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all many frightened. Some heavy furniture moved; a few instances fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction: slight moderate in well-built ordinary structures; considerable damage in poorly built badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structure; well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted of foundations.
X	Some well-built wooden structures destroyed: most masonry and frame structures destroyed with foundations. Rails bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

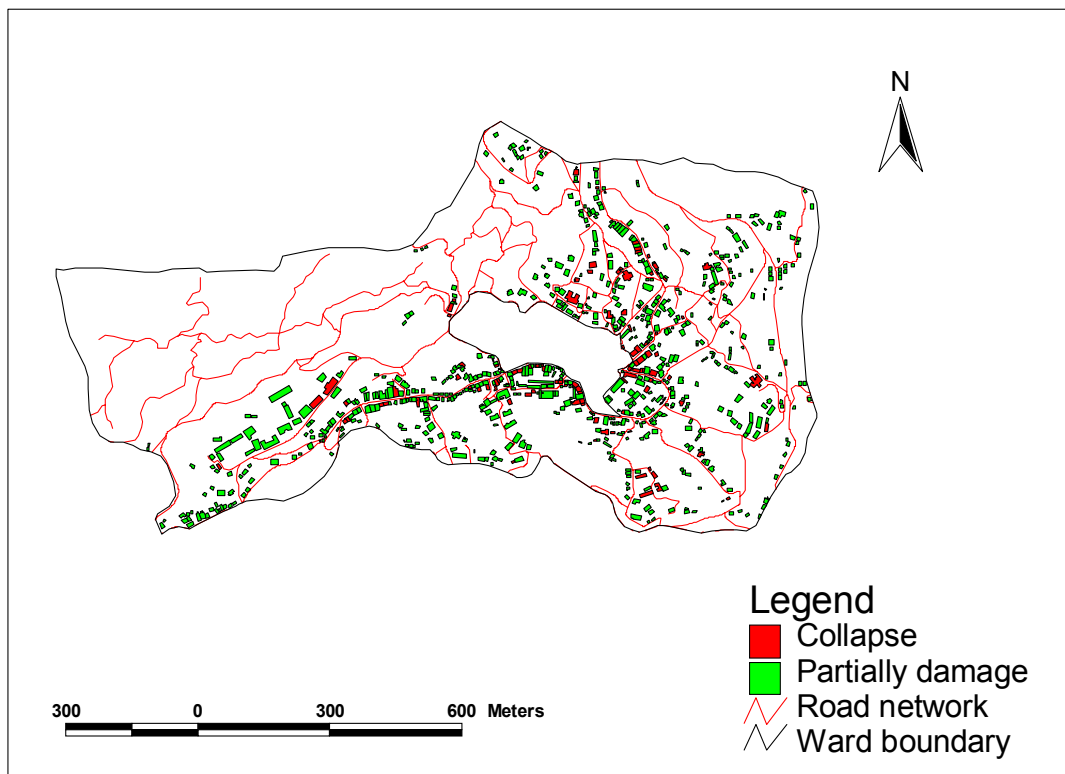
## Annex 6: Seismic Hazard Map of Nepal



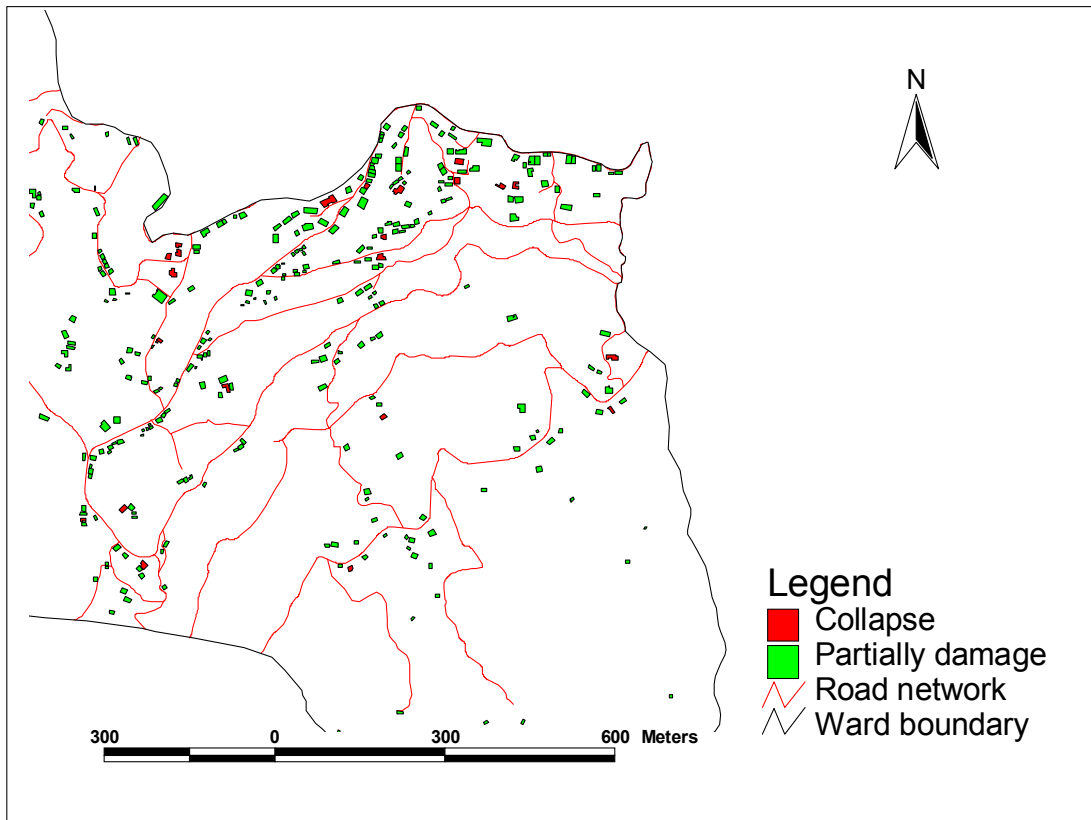
**Annex 7: Damage and collapse building of ward No. 1, Ilam municipality**



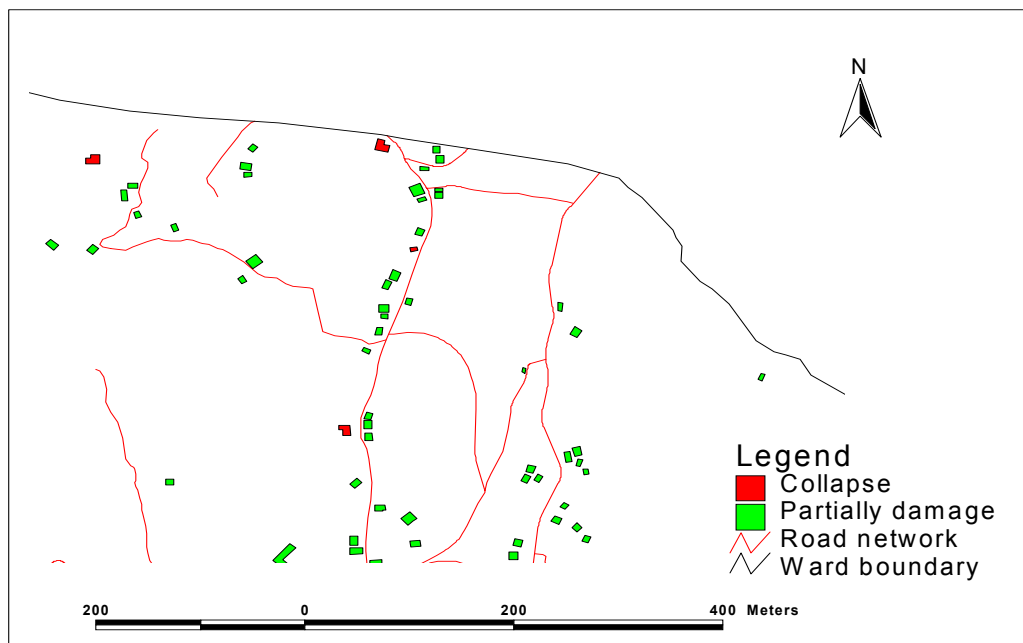
**Annex 8: Damage and collapse building of ward No. 2, Ilam municipality**



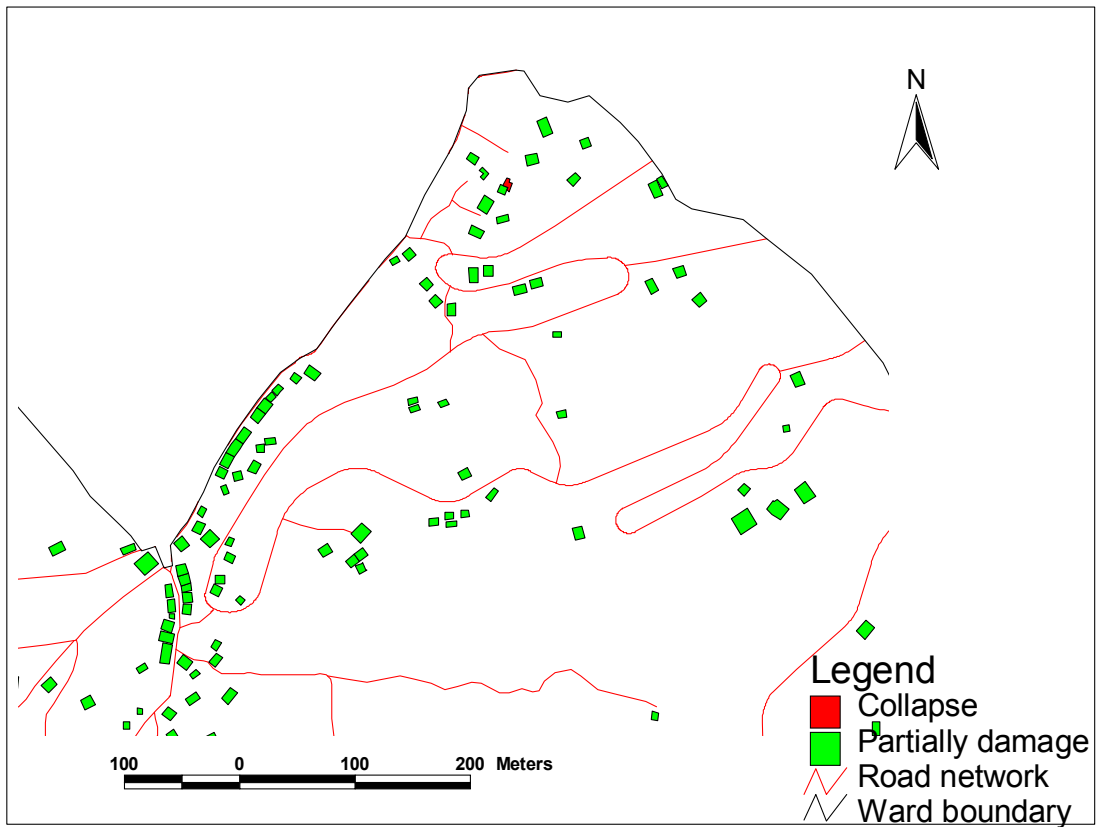
**Annex 9: Damage and collapse building of ward No. 3, Ilam municipality**



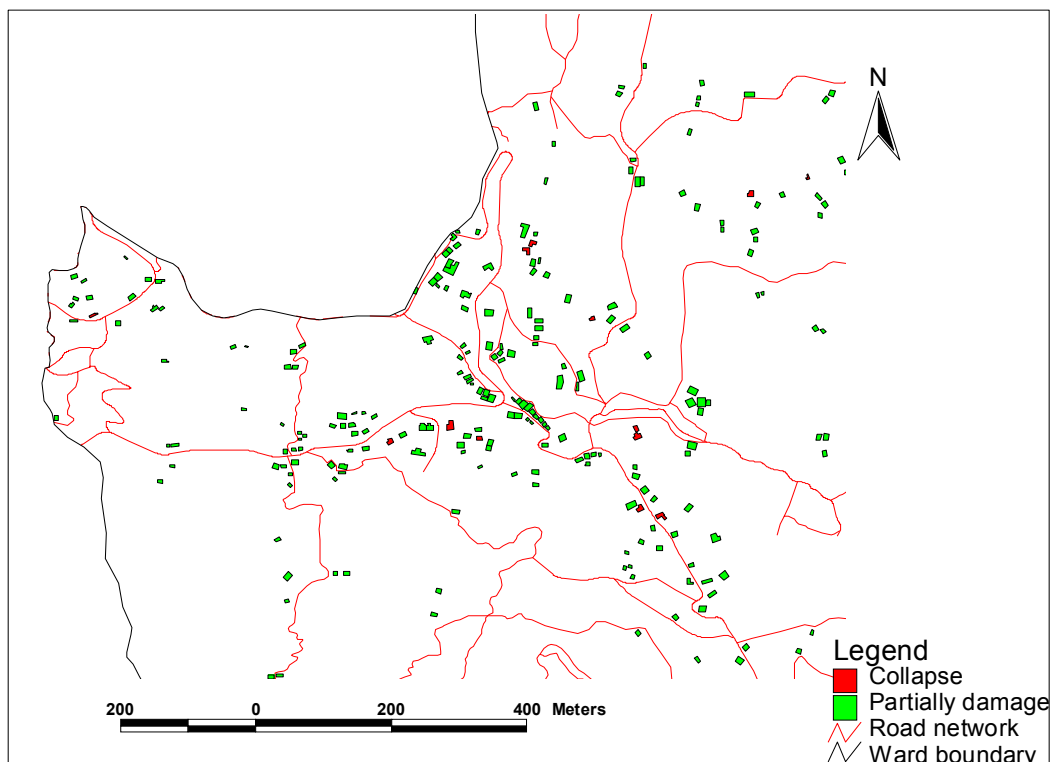
**Annex 10: Damage and collapse building of ward No. 4, Ilam unicity**



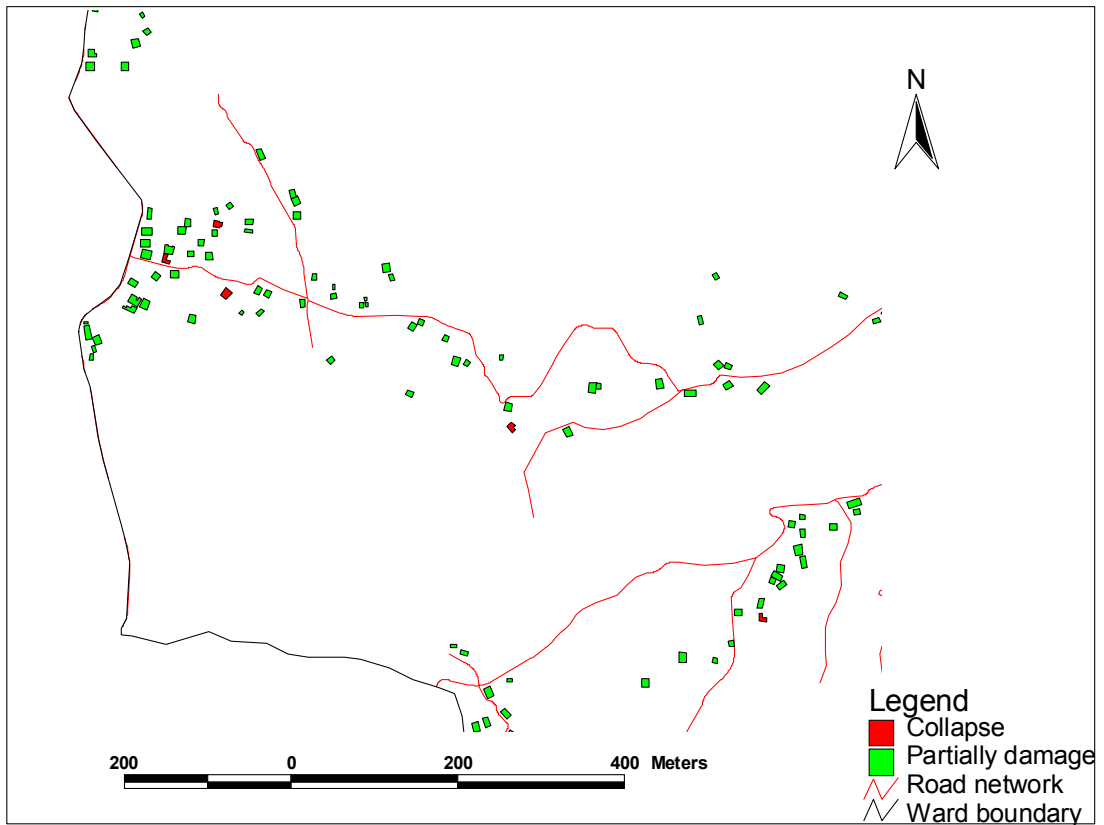
### Annex 11: Damage and collapse building of ward No. 5, Ilam municipality



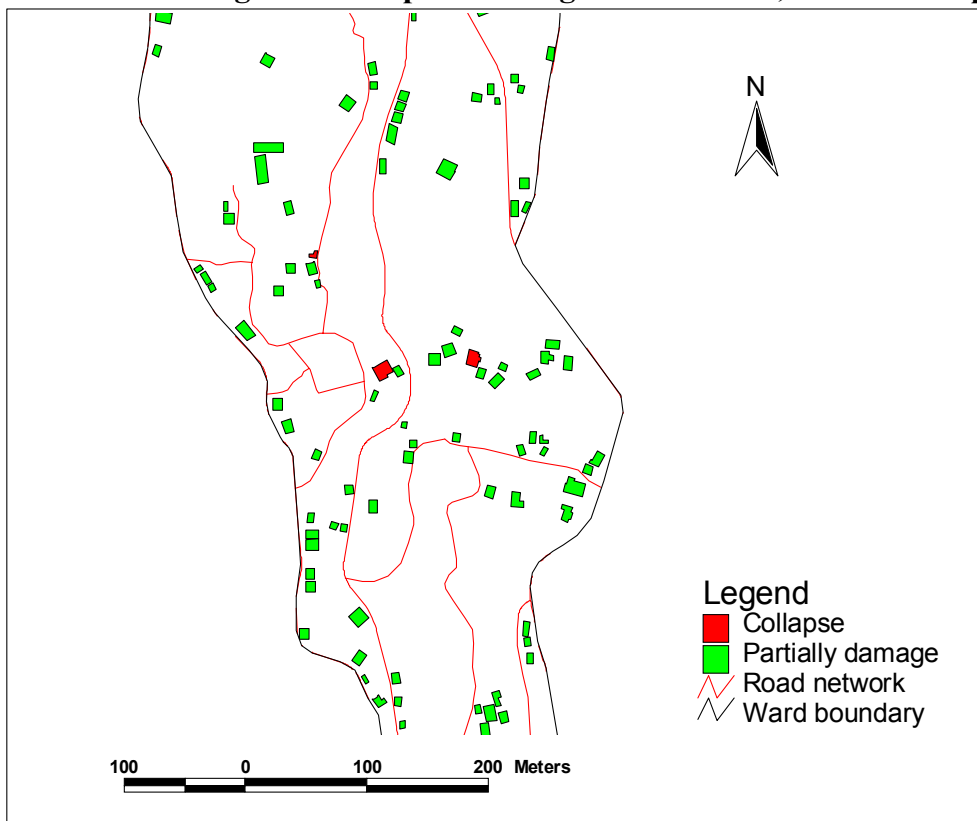
### Annex 12: Damage and collapse building of ward No. 6, Ilam municipality



### Annex 13: Damage and collapse building of ward No. 7, Ilam unicipality



### Annex 14: Damage and collapse building of ward No. 8, Ilam Municipality



**Annex 15: Damage and collapse building of ward No. 9, Ilam municipality**

