GIS for Seismic Building Loss Estimation: A case study from Lalitpur Sub-Metropolitan city area, Kathmandu, Nepal

by

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Abstract

In order to be able to carry out a seismic building vulnerability assessment in the Lalitpur Sub-Metropolitan city area, in Kathmandu Nepal, a building survey was performed to collect information on the material and occupancy types of building in this area. The study area, with a size of 15.5 square kilometres was divided into 500 small clusters having homogeneous characteristics in terms of building occupancies and the predominant building information was collected from these clusters in percentages. After digitising and editing the available digital building footprint map, these percentage values were converted in the number of buildings per cluster. The vulnerability relation developed by NSET Nepal, an NGO working in Earthquake Vulnerability Reduction, was used and a series of GIS operations were performed to link this relation to the building types in the Lalitpur area. A Building damage estimation was carried out for three expected scenario earthquakes that were used in a JICA study in 2002. Two new earthquake hazard maps prepared by ITC MSc students were also used to find out the damaged buildings in the Lalitpur area. For the different earthquake scenarios, the total numbers of damaged buildings were estimated ranging from 1654 (6%) to 22293 (83%) in the worse case scenario, which corresponds to an 8 Magnitude earthquake located close to Kathmandu. The building loss estimation was in the same order as the one from the earlier study by JICA in 2002, however, the results are with more spatial detail, and are a basis for population loss estimation, and also setting up a system for building permits, which is one of the most important Earthquake vulnerability reduction measures which the Lalitpur Sub-Metropolitan City Office is advised to carry out.

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Abbreviations and Acronyms

AUDMP	Asian Urban Disaster Mitigation Project
BC	Load bearing brick masonry building with cement sand mortar
BM	Load bearing brick masonry building with mud mortar
DMTP	Disaster Management Training Programme
GHI	GeoHazard International
JICA	Japan International Cooperation Agency
KVERMP	Kathmandu Valley Earthquake Risk Management Project
KVMP	Kathmandu Valley Mapping Programme
KUDP	Kathmandu Urban Development Project
LSMCO	Lalitpur Sub-Metropolitan City Office
MHPP	Ministry of Housing and Physical Planning
NSET-Nepal	National Society for Earthquake Technology Nepal
RCC	Reinforced Cement Concrete framed building
UNDP	United Nations Development Program
UNCHS	United Nations Centre for Human Settlement

1. Introduction

1.1. General

Earthquakes are one of the most destructive natural hazards phenomenon, which may occur at any time without warning and can destroy buildings killing or injuring the inhabitants. The recent 26 December 2003 earthquake, in Bam in Iran, killed at least 30000 people inquired more than that and damaged 85 % of the buildings in a second and it is difficult to predict which city will be the next victim. In this aspect, it is always important to study the seismic hazard, vulnerability, and risk for the mitigation of future earthquake events. Since the seismic events cannot be prevented, it is more important to study and evaluate the vulnerability of existing infrastructure systems and find out the expected losses during an earthquake. In every earthquake most of the loss of life and property is caused by the damage of the highly occupied weakest buildings located in a seismically active area. Hence seismic risk assessment of the population and of buildings is most important to forecast the expected losses, which helps to make disaster management plans for the local authorities.

For vulnerability assessment, hazard, vulnerability and elements at risk are the common terms interrelated to each other.
Natural Hazard is defined as the probability of the occurrence, within a specified period of time and a given area, of a particular, potentially damaging phenomenon of a given severity/intensity (DMTP, 1994). A hazard becomes disaster when it turns into injuries, loss of life and damage to the infrastructures and properties. Ground shaking, ground rupture, landslides, liquefaction and tsunamis are the main earthquake induced hazards, which may cause series of secondary hazards like fire, flood, water pollution etc.

Vulnerability is defined as the degree of loss to a given element at risk (or set of elements) resulting from a given hazard at a given severity level and is usually expressed as a percentage loss or as a value between 0 to 1(DMTP, 1994). People or buildings or other elements, which would be affected by the hazard, if it occurred, are termed as the *elements at risk*.

The word *risk* refers to the expected losses (lives lost, persons injured, damage to property and disruption of economic activity) from a given hazard and is the product of hazard and vulnerability. If the earthquake hazard is expressed in intensity, then building risk or building damage can be expressed as
Risk (Damage)= (Earthquake intensity X Vulnerability X building type). Thus for the estimation of buildings damage by probable future earthquake events, all the three factor mentioned above should be studied equally precisely

1.2. Earthquakes in Nepal

Earthquakes have always been a serious threat for the population of Nepal. Seismicity is considered to be high in this region based on the frequency and strength of past earthquakes. Nepal has experienced a large number of devastating earthquakes in the past. The recorded history shows that earthquakes in 1255,1408,1810,1833, 1934, and 1980 and in 1988 were the major ones responsible for large number of loss of life and property in different part of the country (Table 1.1).

Table 1.1: Damage caused by past earthquakes in Nepal

Year	Date	Magnitude	Earthquake	Human		Collapsed	Damage
				Death	Injuries		
1993	-	-	Jajarkot	-	-	40 % of the buildings were estimated to be affected.	
1988	21 Aug	6.6	Udayapur	721	6453	22328	49045
1980	04 Aug	6.5	Bajhang	46	236	12817	13298
1934	15 Jan	8.4	Bihar/Nepal	8519	-	80893	126355
1837	17 Jan	-	-	-	-	-	-
1834	Sept-Oct	-	-	-	-	-	-
	26 Sept	-	-	-	-	-	-
	13 July	-	-	-	-	-	-
	11 July	-	-	-	-	-	-
1833	26 Aug	-	-	-	-	18000 in total	
	25 Sept	-	-	-	-	-	-
1823	-	-	-	-	-	-	-
1810	May	-	-	Moderate	Moderate	Heavy	
1767	Jun	-	-	-	-	-	-
1681	-	-		-	-	-	-
1408	-	-	-	Heavy	Heavy	Heavy	
1260	-	-	-	-	-	-	-
1255	07 Jun	-	-	One third of the total population including King Abhaya Malla killed		Many buildings and temples collapsed	

Source: (UNDP, 1994) Note: (-) indicates the information not available

In the 1934 earthquake, 19000 buildings were heavily damaged, 3800 people were killed and 1000 people were seriously injured only in Kathmandu valley (JICA, 2002). After 1934, the central part of Nepal (Kathmandu) has suffered few earthquakes and according to Bilham (1995) the zone may be a " seismic gap" and a huge earthquake could occur when the accumulated stress is released.

1.3. Problem statement

As stated above natural hazard becomes a disaster when it affects a human population. Rapid urbanisation to shelter the highly increasing population and also due to the global environment change, both natural hazard and the elements at risk have been increasing. In case of earthquake since it is more or less constant, the effects of its disasters in the world have increased because of increase in more vulnerable elements. In every earthquake, vulnerability is heavily concentrated in the areas where the buildings are of a poor quality.

The study area, Lalitpur, is a historic city and one of the municipalities in Kathmandu valley, located south of Kathmandu, the capital of Nepal. The core area of this municipality, also called Patan, is a very old city and dense area. For many years expansion of this city was limited and almost confined to the core centre surrounded by fertile agriculture land. But in the last few decades, rapid urbanization and building construction has been occurring in this area. From the study of satellite images and aerial photos it is observed that about 60 percent of the present houses were built during the last 35 years to form the present dense sub-metropolitan city. Very old buildings in the core area and new building construction without proper land use planning and without the practice of seismic building code have made this city more vulnerable to earthquakes. The lithology of Lalitpur, which is a thick soft lacustrine deposit, had made this city more hazardous as compared to other parts of the country.

Various institutions have carried out studies on earthquakes and risk assessment in Nepal and also in Kathmandu valley. After the 1988 earthquake, which destroyed 71373 buildings partly or totally and killed 721 people though out Nepal, it was realized that actions should be taken to improve the building construction system in Nepal. A detailed study was carried out in 1994 by the Ministry of Housing and Physical Planning (MHPP), with technical assistance from the United Nations Development Program (UNDP) and their executing agency, United Nations Centre for Human Settlement (UNCHS). This project produced a regional seismic hazard map of 1:1000 000 scale, a first approximation of risk assessment in Nepal. The project also prepared a National Building Code and made a document on alternative building materials and technologies in Nepal (UNDP, 1994).

Realizing the high risk and vulnerability of buildings in Kathmandu valley, another a 18 month project named The Kathmandu Valley Earthquake Risk Management Project (KVERMP) was completed in 1999. This project was implemented by the National Society for Earthquake Technology- Nepal (NSET-Nepal), GeoHazard International (GHI) and Asian Urban Disaster Mitigation Project (AUDMP). The project had the following four objectives (Carlos et.al, 2000).

1) To evaluate Kathmandu Valley's earthquake risk and prescribe an action plan for managing that risk;
2) To reduce the public schools' earthquake vulnerability;
3) To raise awareness among the public, government officials, the international community resident in Kathmandu Valley, and international organizations about Kathmandu Valley's earthquake risk; and
4) To build local institutions that can sustain the work launched in this project.

The project developed an earthquake scenario in Kathmandu valley and made an action plan which is now being implementing by NSET-Nepal (Dixit et.al, 2000).

The most recent study was carried out by a group of experts from the Japan International Cooperation Agency (JICA) in 2002 under the name *The Study on Earthquake Disaster mitigation in the Kathmandu Valley, Kingdom of Nepal.* The main objective of this study was to formulate a plan for earthquake disaster mitigation in the Kathmandu valley. In this project GIS was used for analysis and mapping.

In the previous studies, mentioned above, there was always lack of a detailed building database for vulnerability assessment. In KVERMP, vulnerability analysis was done taking 1183 samples of building data from different building occupancies and representative areas covering the whole Kathmandu valley. Although this was the first attempt to create a building database considering the seismic defects in building types, there were no spatial positioning, mapping and interpolation to form data sets to cover the study area.

In the JICA study, the number of buildings was assumed the same as the number of families, which was taken and interpolated from the 1991 census report. In their study the municipal wards were adopted as the basic administration units and building distribution was mapped in a more general way by visual observation using a mesh size of 500 m. (JICA, 2002). Urbanization and new building construction in this city have been increasing rapidly, which demands further more specific research in this field.

Spatial positioning of buildings is very important for disaster management planning for both pre and post earthquake phases. For the damage estimation it is essential to find out the relation between given level of intensity of earthquake and the various building type. Although every building will have a different behaviour in an earthquake, it is not always practical to observe each building in detail because of time and resources. Missing building data (drawing and design), uncertainty in quality of material and workmanship used during construction creates difficulties even if it is tried to detail the individual buildings. Therefore it is more practical to group buildings that have the same characteristics together and apply standard vulnerability relations. The question then arises how to map these buildings using remote sensing data and take the building information dividing the area in smaller homogeneous units useful for vulnerability assessment

1.4. Research objectives

- To develop a building inventory method based on remote sensing and field survey for rapid seismic vulnerability assessment.
    - ✓ To construct a spatial database with elements at risk (buildings) related features and attributes from satellite images, aerial photos and the field survey
- To develop and apply a methodology for the use of vulnerability functions for earthquake risk assessment of current building systems in Lalitpur.
    - ✓ To find out from literature appropriate vulnerability functions for similar types of buildings as in Lalitpur for each severity level (magnitude and intensity of earthquake) and apply it for the expected damages.
    - ✓ To find out from the earlier research the most probable earthquake scenarios. To correlate the building response to ground shaking and liquefaction in the study area
- To carry out building damage estimation for a number of expected future earthquake events

1.5. Research method

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 the earthquake and the strength of the buildings to resist these forces (Ambrose & Vergun, 1999). There are various factors in a building itself like method of construction and material type used, building configuration in plan and also in elevation, age, number of stories, size of the building etc. which are responsible to cause the damage to the building. Although for seismic design of a new building all these parameters are considered, for vulnerability assessment of existing buildings, it is very difficult, if not impossible, to take all these seismic factors into account to perform the analysis. Instead, according to available time and resources, analysis is done taking main building parameters. To estimate the damaged buildings in Lalitpur Sub-Metropolitan area for scenarios earthquake events, the methodology adopted in this research is given in the following paragraphs.

1.5.1. Building type classification

From the experience of past earthquakes and also from the structural analysis of buildings, it is found that the lateral loading system which is governed by construction methods and type of material used in the construction are the main reason to damage the buildings (UNDP, 1994). In Lalitpur area the following buildings types has been found which was classified in the previous KVERMP and in JICA study

- Adobe buildings
- Brick in mud buildings
- Brick in Cement buildings
- Reinforced Concrete Cement framed buildings

1.5.2. Building database generation

Since it was not possible to take individual building information form whole area, in the limited time, the building data from the field was taken in cluster ie. dividing the study area in smaller homogeneous zones. Building material types and also the building occupancies types information was taken in percentage from these clusters. Individual building layers was generated editing the existing digital footprint map and also digitising the new buildings on observing the images

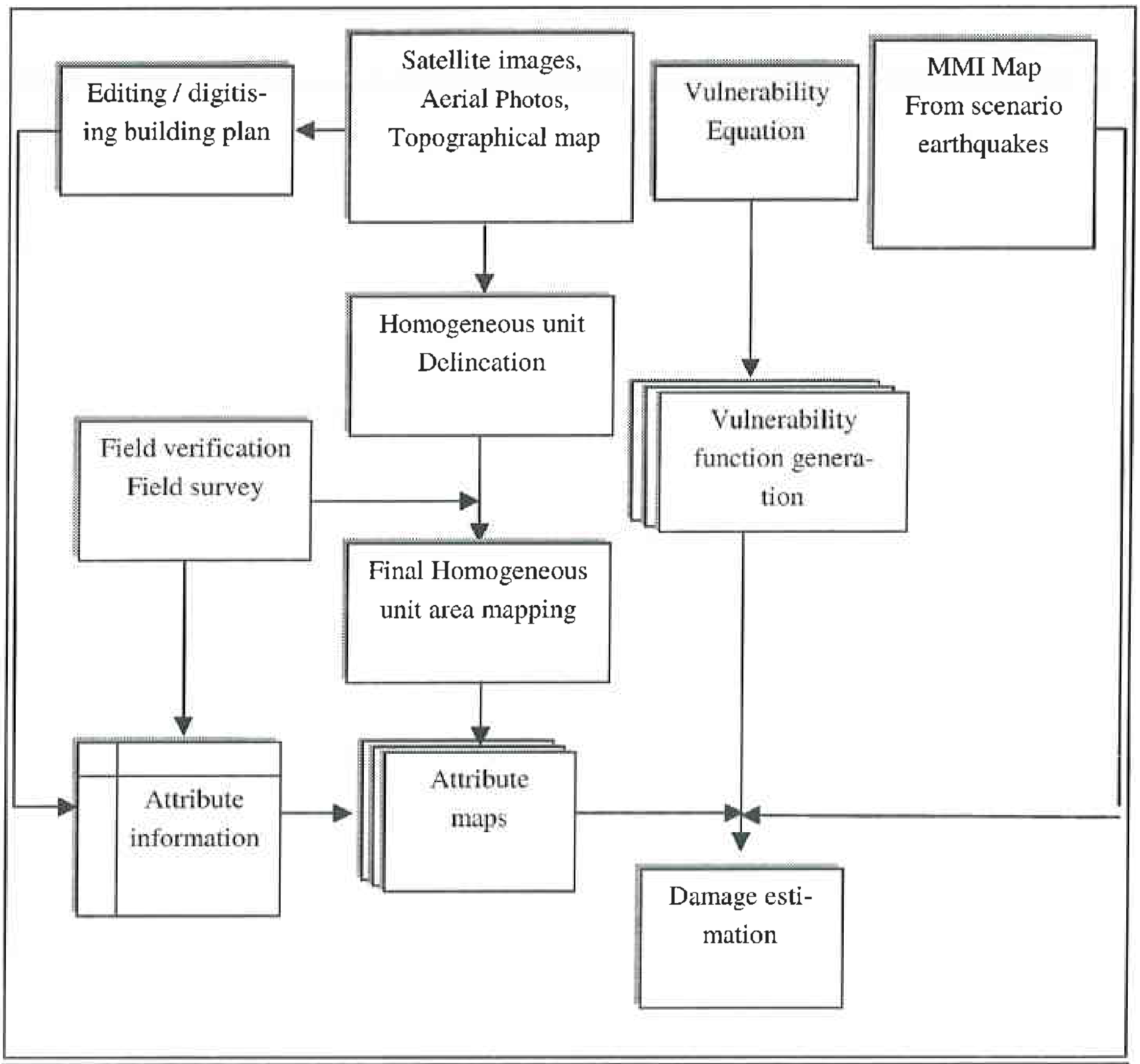


Figure 1.1: Research methodology flow chart

1.5.3. Earthquake hazard data

In this study, the different probable earthquake scenarios, and the corresponding earthquake intensities have been taken from earlier research that had been carried out by JICA in 2002. Damage estimation was also performed taking a new intensity zonation map and a liquefaction hazard map produced by two ITC MSc colleagues studying in the same area. The scale used for all of these intensity maps was Modified Mercalli Intensity (MMI scale).

1.5.4. Vulnerability function selection

For the estimation of damage to the building, a vulnerability function, describing the relation between seismic intensity during the earthquake event and the damage rate of the structures is necessary. The existing intensity-damage matrix of the area established during the preparation of the building code project and modified after the 1988 earthquake by JICA and NSET-Nepal has been used in this research.

1.5.5. Damage estimation

Building damage estimation was carried out for different earthquake scenarios. For each scenario earthquake, according to the vulnerability matrix, the following two types of building damage estimation were performed.

- Partial damage
- Total collapse

For each type of these damage grades, the number of damaged buildings was estimated for minimum and maximum probable values.

1.6. Outline of the Research

This research is designed in six chapters

Chapter 2 provides the overview of the different approaches for the use of GIS in building vulnerability and loss estimation for earthquakes that are given in literature.

Chapter 3 introduces the case study area, the Lalitpur Sub-Metropolitan area. The main building types and their vulnerability has been given in this chapter.

Chapter 4 outlines the methods and tools used for data collection and preparation. Building data generated after the calculation and analysis has been given in this chapter.

Chapter 5 is about the seismic building vulnerability assessment in Lalitpur area. The probable number of damaged buildings in different scenario earthquakes has been given in this chapter.

Chapter 6 concludes this study. In this chapter some recommendations has also been given for further studies.

2. GIS and Seismic building vulnerability assessment; a literature review

2.1. Introduction

A GIS is a spatial database and mapping system, which allows faster evaluation and analysis of large amounts of data. Using GIS software like ILWIS, it is possible to capture, manage, analyse and display many forms of spatially referenced information. In the context of seismic building vulnerability assessment, modelling approaches for different types of buildings and their respective damage parameters have to be developed. Again these data have to be linked to probable earthquake hazard data and after the analysis, the result has to be displayed geographically. All of these activities could be done effectively using GIS. GIS has been used worldwide to forecast the type and amount of losses that a city area could suffer after an earthquake. This chapter will give an overview of the different approaches for the use of GIS in building vulnerability and loss estimation for earthquakes that are reported in literature.

2.2. Earthquake Intensity

Earthquake Intensity is a measure of the degree of damage caused by an earthquake at a given place (UNDP, 1994). It describes the effect of an earthquake on the surface of the earth and integrates numerous parameters such as ground acceleration, earthquake duration and subsoil condition (Munich Re, 2000). It depends upon the strength of the earthquake, the distance of the location from the hypocentre and local subsoil conditions.

There is no instrument or mathematical basis to measure the earthquake intensity. Based on the observed effects on building and topography, intensity is assigned by the expert in this field. Various scales have been developed to measure and assign the earthquake intensity. In all of these scales, the definition of each degree has been given with an intensity value which ranges from non-felt or no damage to total damage. The following are the main earthquake intensity scales found used in different countries.

MM Scale: MM (Modified Mercalli) scale was developed by Wood and Newmann in 1956 for the use in North America. The scale is divided into twelve degree and ranges from not felt (I) to total damage (XII). This is the most widely used intensity scale internationally.

MSK Scale: MSK scale was developed by Medvedev, Sponheuer and Karnik in 1964. Like MM scale, it also has twelve degree ranging from I to XII.

RF Scale: It has ten-degree scale developed in 1883 by Rossi Forel.

JMA Scale: It is a seven-degree scale, which was developed in 1951 by Japan Meteorological Agency.

EMS 98: EMS 98 (European micro-seismic scale of 1998) was developed by European Seismological Commission. Similar to MMI or MSK, EMS-98 also has twelve scales. The major difference between the EM-98 and other intensity scales is the detail with which different terms used are defined in particular, building types, damage grades, and quantities.

The relation between these different types of scales is shown in figure 2.1.

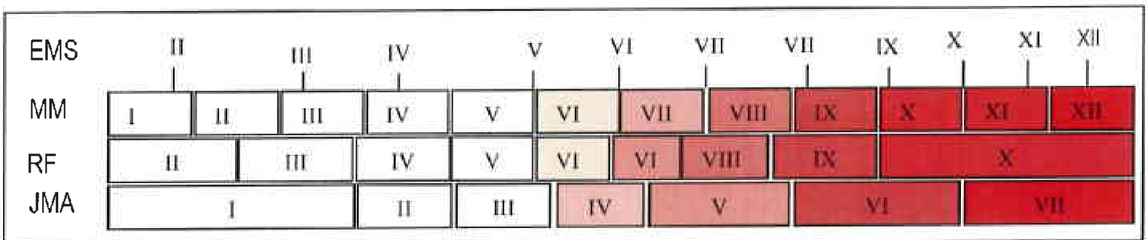
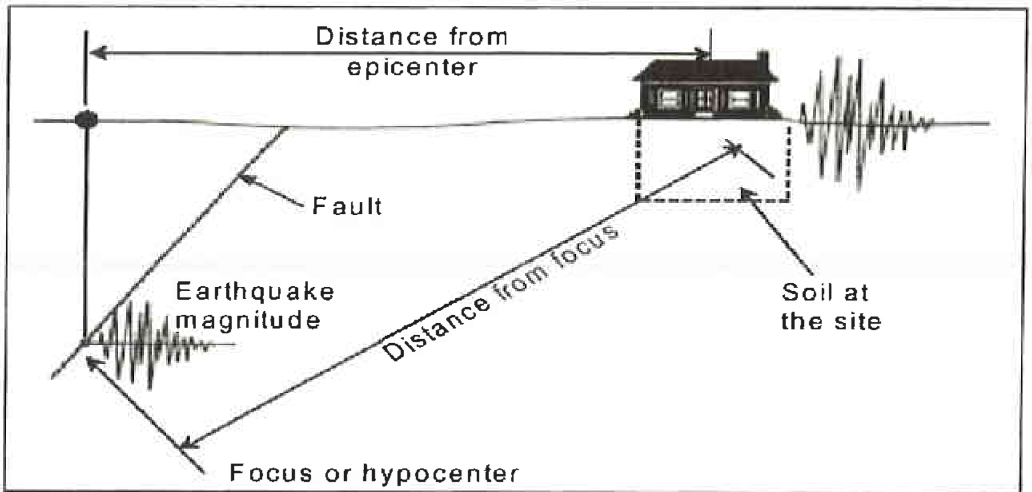


Figure 2.1: Types of earthquake intensity scales and their relationship
(Source: Munich Re)

2.3. Building characteristics and aspects

The factors that affect the building vulnerability can be subdivided in primary and secondary factors (UNDP, 1994). The sub-soil conditions and building construction materials are the primary factors affecting the building vulnerability. Even if an earthquake source is at the same distance, due to the high soil amplification, a building located on a thick soil deposit will get more damage as compare to a building lying on firm strata. Again two buildings with different material types will get damage differently at the same site due to the inherent material strength.

The secondary factors affecting the building vulnerability are the inherent deficiencies of a particular building type. Buildings with the same material type but with different variables like shape (in plan and in elevation), size, height, age, construction quality etc. will show different behaviour at the same site. The following sketch diagram (Figure 2.2) shows the factors affecting the vulnerability of a building.



Some of the main secondary factors affecting the building vulnerability has been given in the following sections.

2.3.1. Building configuration

The shape of buildings in plan and also the load distribution in different storeys should be kept symmetrical to reduce the torsional effect. Buildings having a large length to width ratio, large height to width ratio and large offset in plan and in elevation behave poorly and suffer greater damage than the regular ones. In a regular structure, inelastic demands produced by strong ground shaking tend to be well distributed throughout the structure, resulting in a dispersion of energy dissipation and damage but in irregular structures, inelastic behaviour can concentrate in the zone of irregularity resulting in rapid failure of structural elements in these areas (FEMA 303, 1997). To get a less damaging effect the building should be regular in plan and in elevation and the length and breadth ratio of the building must kept lesser than three (A thumb rule, NBC, 1994).

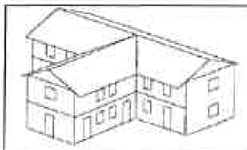
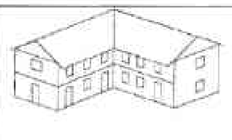
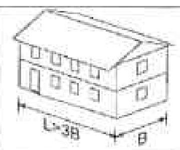
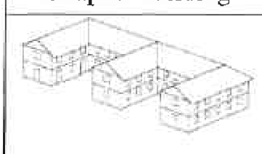
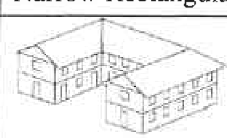
		
T-Shaped Building	L-Shaped Building	Narrow Rectangular (L> 3B)
		
E-Shaped Building	H-Shaped Building	U-Shaped Building

Figure 2.3: Examples of some irregular buildings in plan

2.3.2. Building height and Natural period of buildings

During an earthquake, the ground does not move in one direction but has chance to move in any of the direction. The buildings and other elements on the ground also have chance to vibrate in different direction and hence having multiple modes. Each of these modes has a period. Among these periods, the longest is called the structural natural period of vibration and the frequency associated to it is called the natural frequency (FEMA310, 1998). When the ground motion frequency during an earthquake happens to be close to or equal to building natural frequency, resonance occurs which amplify the building response. The natural frequency of an element is given by formula [1], where k is the stiffness of the building that depends upon building dimension, its shape and elasticity and m is mass of the building.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad [1]$$

The approximate fundamental period T, in seconds, is determined from the following equation:
T = 0.1N, where N is the number of storey (IBC, 2000). The approximate frequencies of different stories building is given in figure 2.4

Type of object or structure	Natural frequency (Hz)
One-story buildings	10
3-4 story buildings	2
Tall buildings	0.5 – 1.0
High-rise buildings	0.17

Figure 2.4: Natural frequency of buildings according to the story number

2.3.3. Building separation distance

Every building has its own natural frequency and in an earthquake a building can swing according to this frequency. If two buildings are at a distance, then they can sway freely and are not hampering to other. But if they are nearer then one may obstruct the other in its movement, which is called pounding (FEMA 310). Pounding can cause local crushing of the structures and failure of structural and non-structural elements located in the zone of impact. Impact can occur only if the separation of the adjacent structures is less than the sum of the maximum displacement response of the structures at the level of potential impact. The probable displacement of a building can be found out from the structural analysis. As a thumb rule, given in FEMA 310, the minimum separation distance between two buildings must be 4% of the height the buildings. This is based on the assumption that most structures will not drift more than 2% when responding the earthquake motion.

2.4. Building elements and damage grades

2.4.1. Building elements

A building is an assembly of structural and non-structural elements. A building is formed by joining walls, beams, columns, slabs and other elements. The global performance of a building is therefore the aggregation of performance of all of its components, which depends upon the individual characteristics. Building elements are classified into two classes, structural elements and non-structural elements (NBC, 1994).

Structural elements: Structural elements are those elements of the building that help to support the horizontal and vertical forces acting on it. There are mainly two types of structural systems found in buildings, which are:

- **Structural frame system**: In this system the structural load carrying elements are beams, columns and slab either made of steel or reinforced concrete.

- **Structural wall system:** The structural load carrying elements are walls made of reinforced concrete or masonry. Masonry is defined as the arrangement of masonry units, which may be brick; rectangular stone, or cement blocks laid to a bond and joined together with mortar.

- **Dual system:** In this system, reinforced concrete frames are combined with reinforced concrete or masonry walls to carry out vertical and horizontal forces. The masonry infill walls are intended to carry horizontal load by equivalent compression strut action.

Non-structural elements: Non-structural elements are those elements of buildings that are connected to structural system but without load carrying system. These elements include varieties of different architectural, mechanical, electrical components and other house contents. According to the response to the earthquake motion, these elements are classified into two classes; acceleration sensitive non-structural elements and drift sensitive non-structural elements (HAZUS, 99).

The elements that are primarily affected by building displacement are called the drift sensitive elements. Architectural elements like non-bearing partition walls, exterior wall panels, veneer and finishes etc are the drift sensitive non-structural elements.

The elements, which are primarily affected by building shaking, are classified as acceleration sensitive non-structural elements. Architectural element like cantilever and parapets, mechanical and electrical components like elevators, lighting fixers, storage tanks etc comprises this category. All the house contents like file cabinets; bookcases, computer, furniture etc are also the acceleration sensitive non-structural elements.

2.4.2. Damage grades

When exposed to the same seismic intensity during an earthquake, all buildings of the same material type will not necessarily show a similar type of damage because of variation in building strength, due to differences in shape in plan and elevation, quality of material used and workmanship in the construction (UNDP, 1994). The damage grades ranges from slight damage to total collapse, the percentage of which varies according to the earthquake intensity.

Damage grades in different types of buildings have been defined in different scales. The table 2.1 is an example of definition of different types of damages for masonry and RCC buildings defined in EMS- 98 scale.

Table 2.1: Damage grade for Masonry and RCC buildings

Grade	Damage type	Masonry Building	RCC Building
Grade 1 (DG1)	Slight damage	Hairline cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few	Fine cracks in plaster; fall of small pieces of plaster
Grade 2 (DG2)	Moderate damage	Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.	Small cracks in walls; fall of fairly large pieces of plaster, pan tiles slip off; cracks in chimneys; parts of chimney fall down
Grade 3 (DG3)	Heavy damage	Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roofline; failure of individual non-structural elements (partitions, gable walls).	Large and deep cracks in walls; fall of chimneys
Grade 4 (DG4)	Destruction	Serious failure of walls; partial structural failure of roofs and floors.	Gaps in walls; parts of buildings may collapse; separate parts of the building lose their cohesion; and inner wall
Grade 5 (DG5)	Total damage	Total or near total collapse.	Total collapse of buildings

(Source: EMS-98)

2.5. Building vulnerability assessment method

Seismic vulnerability of a building is the amount of expected damage induced to it by a particular level of earthquake intensity. It describes the probability of failure of buildings under different levels of ground shaking and is expressed as the percentage loss caused by a particular seismic hazard to the type of building under consideration (UNDP, 1994). Vulnerability analysis of building helps to identify strong and weak points inherent in the construction practice and the materials used in the construction.

There are mainly two methods used for analysing vulnerability of a building: qualitative and quantitative methods.

2.5.1. Qualitative assessment or observed vulnerability

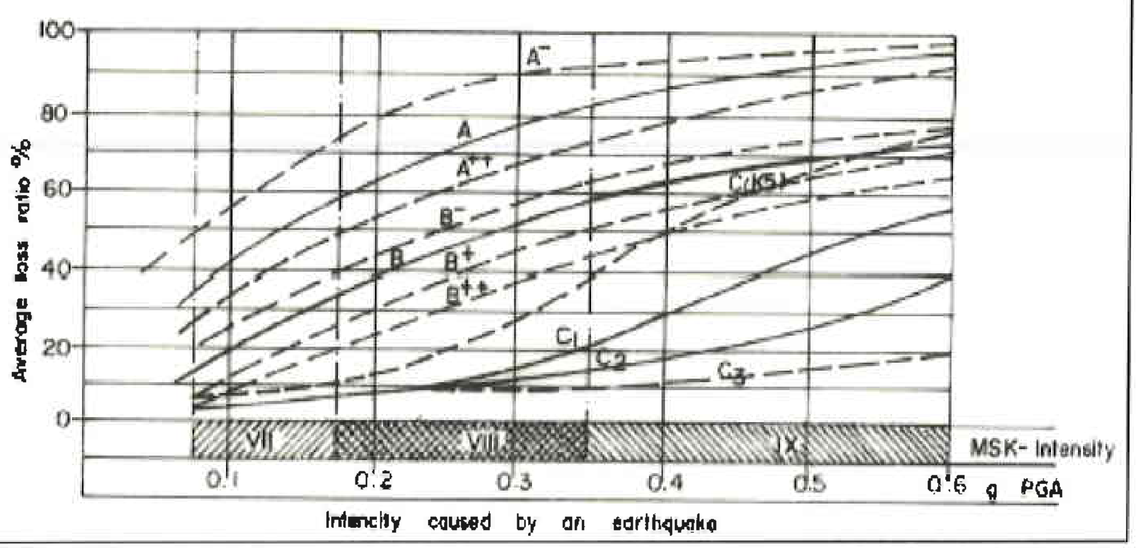
Qualitative analysis refers to the assessment of vulnerability based on the statistical evaluation of past earthquake damage. Vulnerability functions for different types of building are created based on the data collected in different past earthquake studies of the same or similar region. This type of vulnerability is valid for the area studied or the region having same types of buildings. For non-engineered buildings this method is suitable since it is not possible to get detailed data needed for quantitative analysis (UNDP, 1994). The fragility curve used in the RADIUS program and the recent fragility curve developed for European type RC structures are examples of vulnerability curves that have been designed based on statistical analysis of historic earthquake damage. The curve used in the RADIUS program was developed using the data from the study done for Bandung City in Indonesia and Antofagasta in Chile (RADIUS, 1999). The fragility curve for the European type RC structures was developed using a database of 99 post earthquake damage distributions observed in 19 earthquakes and concerning a total of 340 000 RC structures (Rossetto and Elnashai, 2002).

2.5.2. Quantitative assessment

This is based on numerical analysis of the structure. When there is no past earthquake observed building damage data, the vulnerability assessment of the building is carried out by structural calculation. In this method the buildings having same material and construction type are grouped into one class. From the design specification and construction detail of the building considered, the performance of it during an earthquake of an expected intensity is predicted using some calculations (UNDP, 1994). This method is more suitable for engineered buildings, which have detail drawing and design data needed for the calculation.

2.6. Vulnerability curves for Nepal

During the preparation of the National Building Code in 1994, the vulnerability assessment of building types in Nepal was first studied. The vulnerability functions for common types of buildings in Nepal were developed based on building damage data in the Manjil (Iran) earthquake (UNDP, 1994).



A = Buildings in fieldstone, rural buildings, adobe house, mud house (1 to 1.5 storeys).
A - = A-type building but with 3 storey height (2 storied in between A and A-).
A+ = A-type clay buildings but with horizontal and vertical timbers incorporated.
B = Buildings with mud mortar, ordinary bricks, large blocks, natural dressed stone or half-timbered buildings with height up to 1 to 1.5 storeys, or with cement mortar in brick masonry and height up to 3 storeys.
B- = B-type rural buildings with traditional materials and height up to three storeys, or brick masonry buildings in cement mortar with large openings with irregular plans and height up to five storeys.
B+ = B-type rural buildings with improved configurations in case of rural buildings, or brick masonry buildings in cement mortar with compact plans, permissible openings and height up to three storeys.
B++ = Strengthened initially, or retrofitted as for earthquake-resistant brick buildings of B, B-, B+
C1 = Strengthened good quality brick buildings in cement mortar (with seismic reinforcement, up to 3 storeys)
C2 = Normally designed Reinforced Concrete (RC) buildings (designed for normal load only) or mason-designed 3 storey RC buildings (Kathmandu Valley)
C3 = Specially designed RC buildings.
C (k5) = Mason-designed 5 storey RC buildings (Kathmandu Valley).

Figure 2.5: Fragility curves of building types in Nepal prepared during building code development project

During this project period a detailed survey of 54 representative buildings in Nepal was carried out and their strengths and weakness were analysed (Bothara et.al, 2000). The characteristics of these buildings were compared with the types of buildings in Manjil and the fragility curve was adjusted to form a new fragility curve of building types in Nepal. The fragility curve and the building mentioned on it are given in figure 2.5. The average loss ratio, given in this curve is the expected damage in terms of economic loss to a single building unit with respect to its reconstruction cost (UNDP, 1994)

During a recent study on earthquake vulnerability and loss estimation in Kathmandu, carried out by JICA , fragility curves for buildings in the Kathmandu valley were prepared by calibrating the above given curve and the existing curve of West Nepal prepared by another UNDP project. For the calibration, the damage observed and recorded in the 1988 earthquake in Nepal was used (JICA, 2002). In this study, two separate curves for damage rate and collapse rate were prepared and used (figure 2.6 and table 2.2). From the existing curves the two curves were calibrated in the following ways.

Table 2.2 : Calibrated curves in JICA studies

Type of building	Existing curve		Calibrated fragility curve	
	Curve from building code project	UNDP	Damage rate	Collapse rate
Stone (ST)	A		A++	B
Adobe (AD)	A to A+		A++	B
Brick with mud mortar (BM)	B- to B		B	B++
Brick with mud mortar well built (BMW)	B+		B++	C1
Brick with cement or lime mortar	B to C1		B++	C1
RC frame with masonry of 4 or more (RC5)	C1	K5	,1/2[K5+B++]	,1/4[K5+B++]
RC frame with masonry of 3 or less (RC3)	C2	K3	1/2[K3+B++]	,1/4[K3+B++]

The collapse rate curve was used for the estimation of death and injuries of the people in the scenario earthquakes.

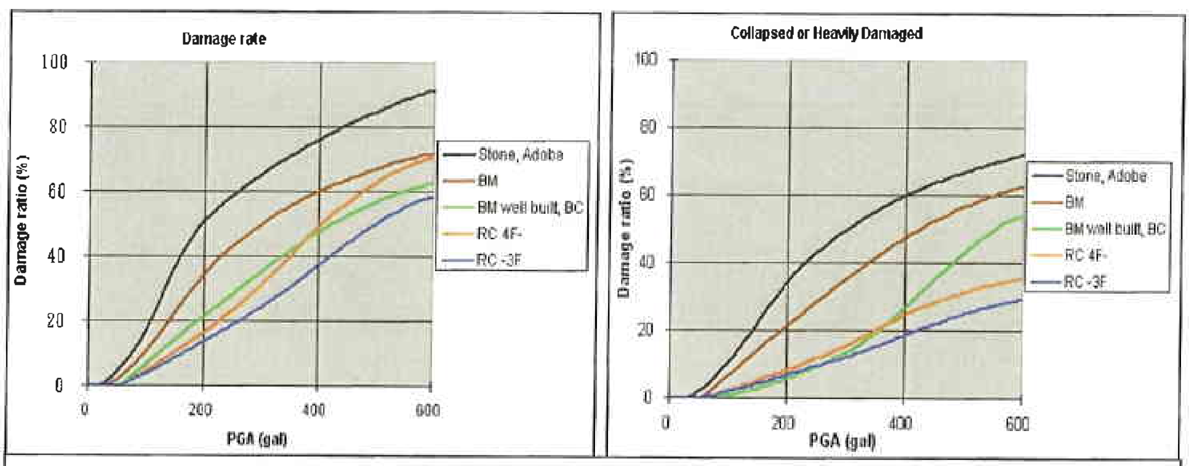


Figure 2.6: Fragility curves for buildings in Kathmandu valley used in JICA study (Left damage rate right collapse rate)

The classification of buildings in Kathmandu valley according to seismic vulnerability was done by NSET-Nepal during the Kathmandu Valley Earthquake Risk Management Project (KVERMP). In the JICA study buildings were classified into the following types

- **Stone, Adobe:** Building made by stone masonry or sun dried brick with mud mortar (Adobe)
- **BM:** Brick masonry building using mud mortar
- **BM well built, BC**: Brick masonry building well built using wooden bands in plinth and in lintel (BMW) or brick masonry building using cement sand mortar (BC)
- **RC 4F**: Reinforced framed structures with four stories or more
- **RC 3F**: Reinforced framed structures with three stories or less

2.7. Building inventories and generation of building database

Earthquake loss estimation using scenario earthquakes has been carried out in different seismic prone cities of the world. For damage estimation, the spatial distribution of buildings in the probable seismic hazard zone should be mapped. The best way is to locate the individual buildings on a map and to take all the information necessary for seismic vulnerability analysis. But the individual building mapping of a city area is not always practical because of the available time and resources. Using the remote sensing data and also performing the field survey, building database of an area can be generated.

2.7.1. Use of remote sensing data

The remote sensing data like aerial photos and high-resolution satellite images are used to observe and locate the built up areas. From the recently lunched high-resolution satellite images like IKONOS (1999) and QUICKBIRD (2001), it is possible to delineate the built-up area on the basis of textures, patterns, tones, size and shadows (Montoya, 2002). Analysing the different texture and pattern, the area can be delineated to form clusters of homogeneous units. Satellite images are also useful to locate the damaged areas and to carry out the rapid damage assessment after an earthquake. To find out the number casualties, in the Gujarat (India) earthquake in 2001, a fast damage assessment was carried out using the IKONOS image (Chiroiu, 2002). One day after the Bam Earthquake in Iran (in 26 Dec 2003), the one m resolution satellite image of the area was taken by Space Imaging's IKONOS satellite from which it was possible to locate the heavily damaged areas (http://www.parstimes.com/spaceimages/bam_ikonos.html). To create an individual building foot print layer and also to observe the building characteristics like height and type of the building large-scale aerial photographs are required.

2.7.2. Ground data capturing

By direct observing the buildings in the study area, building information required for damage assessment is obtained. Different case studies show that for seismic microzonation, the study area is divided into small elements or meshes of a certain size for which the analysis is carried out (JICA, 2002). Building and other lifeline systems are then mapped in each of these meshes. For the preliminary assessment of building damage due to a scenario earthquake in Metro Manila in Philippines, the area was divided into a grid with meshes of 300 by 300 m and buildings were classified into 6 classes according to the height of the buildings (Midorikawa et. al, 2002). During the JICA study for earthquake risk assessment in Kathmandu valley, the area was divided into a grid with meshes of 500 by 500 m and buildings were mapped from the aerial photos and field survey (JICA, 2002). In Yokohama City in Japan, the study was carried out in 250 by 250 m grids (Murakami & Sadohara, 2000). In Bandung municipality, in Indonesia, 100 building sample were taken randomly from each of 26 districts and analysis was done from these sample data (Surahman, 2000).

These case studies show that depending upon the objectives of the study and available time, building information could be taken in cluster or in individual basis. For individual building data collection, Rapid Visual Screening (RVS) method, prepared by FEMA, which utilizes a methodology based on a "sidewalk survey" of a building, is the recent method (Scawthorn et.al, 2002). Another method for individual data capturing is the video image method. Video image produced on the ground from a moving vehicle together with the use of GPS to position the building, can be used to capture the rode side buildings information (Montoya, 2002). Observing these video images, building database can be generated in the office after the fieldwork.

2.8. Earthquake loss estimation methods

To develop methodologies for seismic hazard and risk assessment, there are two approaches that have been used worldwide, because they have both been made available through the Internet, as ready-to-use computer programmes with a GIS component. These programmes are HAZUS (Hazard US) and RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters). Both of these programmes are integrated with GIS software and used for risk assessment, scenario modelling, vulnerability studies and microzonation of case studies city. In the following section these two methods will be discussed in more detail.

2.8.1. HAZUS

HAZUS is a loss estimation methodology integrated with GIS software program. It has been produced in the United States by the Federal Emergency Management Agency (FEMA) under a cooperative agreement with the National Institute of Building Science (HAZUS 99). HAZUS is used for earthquake-hazard mitigation, emergency preparedness, response and recovery planning, and disaster response operations. It is US-nationally applicable earthquake loss estimation methodology. To replicate this model in other cities outside US, similar type of detail and precise hazard and inventory data are required.

Ground shaking, liquefaction, and landslides are the earthquake hazard models used in this method. Ground Motions in terms of spectral acceleration (SA) and peak horizontal ground acceleration (PGA) are estimated based on the location, size and type of earthquake, and the local geology. Here the maximum acceleration experienced by a particle on the ground during the earthquake shaking is called the peak ground acceleration. The acceleration experienced by a building as modeled by a particle on a mass less vertical rod having the same natural period of vibration as the building is called the spectral acceleration (http://eqhazmaps.usgs.gov).

Four types of exposure databases have been prepared and used for damage estimation. These exposures are grouped as general building stock, essential and high potential loss facilities, transportation systems, and utilities.

Table 2.3: Building classification in HAZUS method

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1 2	W1 W2	**Wood, Light Frame (≤ 5,000 sq. ft.)** **Wood, Commercial and Industrial (> 5,000 sq. ft.)**		1 - 2 All	1 2	14 24
3 4 5	S1L S1M S1H	**Steel Moment Frame**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
6 7 8	S2L S2M S2H	**Steel Braced Frame**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
9	S3	**Steel Light Frame**		All	1	15
10 11 12	S4L S4M S4H	**Steel Frame with Cast-in-Place Concrete Shear Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
13 14 15	S5L S5M S5H	**Steel Frame with Unreinforced Masonry Infill Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 13	24 60 156
16 17 18	C1L C1M C1H	**Concrete Moment Frame**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
19 20 21	C2L C2M C2H	**Concrete Shear Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
22 23 24	C3L C3M C3H	**Concrete Frame with Unreinforced Masonry Infill Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
25	PC1	**Precast Concrete Tilt-Up Walls**		All	1	15
26 27 28	PC2L PC2M PC2H	**Precast Concrete Frames with Concrete Shear Walls**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
29 30	RM1L RM1M	**Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms**	Low-Rise Mid-Rise	1-3 4+	2 5	20 50
31 32 33	RM2L RM2M RM2H	**Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms**	Low-Rise Mid-Rise High-Rise	1 - 3 4 - 7 8+	2 5 12	20 50 120
34 35	URML URMM	**Unreinforced Masonry Bearing Walls**	Low-Rise Mid-Rise	1 - 2 3+	1 3	15 35
36	MH	**Mobile Homes**		All	1	10

In this method according to construction type, material type and height, buildings are classified into 36 different structural classes (see table 2.3). This classification is based on common building types in US. The building occupancy classes in this method are grouped as: Residential, Commercial, Industrial, Agricultural, Religious, Governmental, and Education.

The vulnerability function is based on two types of curves known as building capacity curve and demand spectrum. The building capacity curve represents the building characteristics, which is a plot of lateral resistance of a building as a function of characteristics lateral displacement. It is derived from a plot of shear force versus building displacement known as push over curve. In order to have same unit with the demand spectrum, the base shear of the capacity curve is converted to spectral acceleration and roof displacement is converted to spectral displacement.

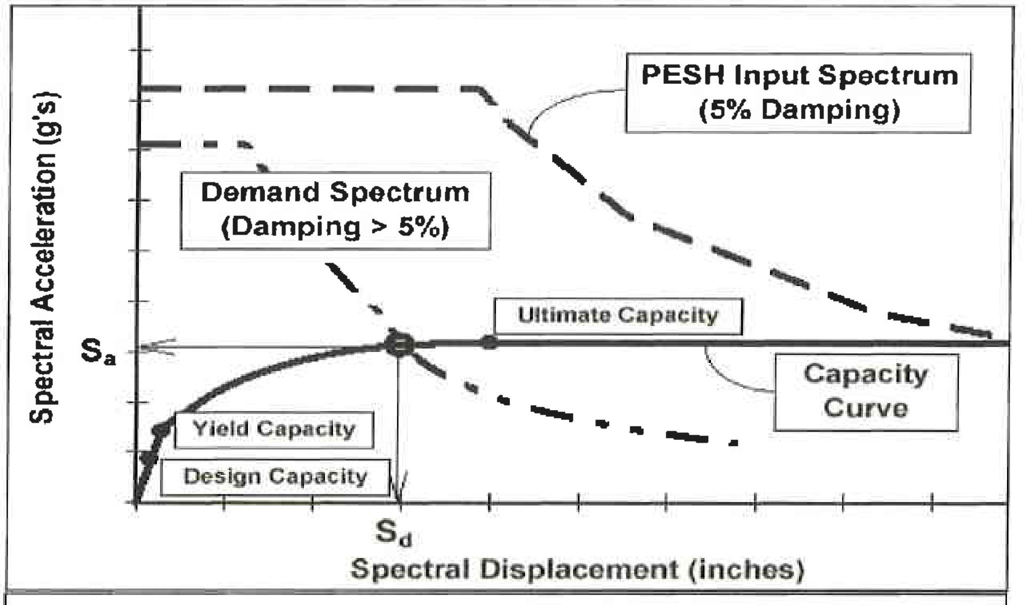


Figure 2.7: Example of capacity curve and demand spectrum (Source HAZUS 99)

The capacity curves of each types building are constructed with two control points, the yield capacity and ultimate capacity. The yield capacity represents the lateral strength of the building and accounts for design strength, redundancies in design, conversion in code requirement and expected strength of materials while the ultimate capacity represents the maximum strength of building when global structural strength reached the full mechanism. For each of the buildings types, these control points has been calculated and given in HAZUS manual.

The demand spectrum is the 5% damped PESH (Potential Earth Science Hazard). The peak building response is taken from the interaction of the building capacity curve and response spectrum of the PESH shaking demand at the building location. The peak building response, either spectral displacement or spectral acceleration at the point of interaction of the capacity curve and demand spectrum is parameter used with fragility curve to estimate the damage state probabilities.

According to the response to the earthquake, the building elements are classified into three types naming structural elements, non-structural drift sensitive elements and non-structural acceleration sensitive elements.
Building damage is estimated and expressed in terms of the probability of four types of damage states. These damage state are classified as Slight, Moderate, Extensive and Complete. For each of the above three building elements, these four types of damage state has been classified and defined separately.

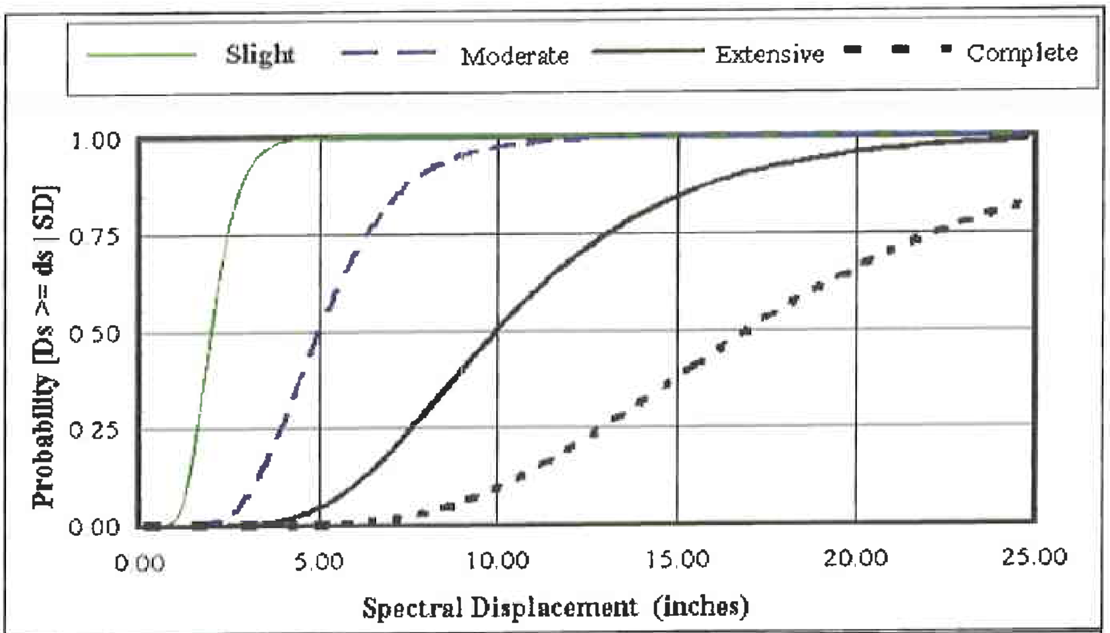


Figure 2.8: Example of fragility curve used in HAZUS (source HAZUS 99)

HAZUS is most recent and more accurate method for earthquake loss estimation, which is publicly available. Many other earthquake loss estimation models, have been developed by the (re)-insurance industry, and these are not available to the public. In the HAZUS method, Spectral displacement (Sd) of structural and non-structural element of a building to ground motion is used for building vulnerability assessment, instead of MMI which is derived from Peak Ground Acceleration (PGA).
To replicate the HAZUS model in other cities outside the US, a detailed inventory of exposure data, study on probable earthquake hazard and also the detailed study on fragility curves of building types in the locality according to pushover analysis is required. This needs more research in each of these fields.

HAZUS methodology has been designed for different scenarios and also for the post earthquake loss estimation. The HAZUS model has been used in many studies worldwide, for example in the Earthquake vulnerability and risk assessment for Newcastle, Australia (Stehle et.al, 2002), seismic damage assessment in Seoul, Korea (Baag et. al, 2002), seismic damage estimation in Victoria and Vancouver in south-western British Columbia, (Onur et. al, 2002), seismic loss estimation for the Turkish Catastrophe Insurance in Turkey (Robin Spence et. al, 2002) and preliminary assessment of building damage due to a scenario earthquake in Metro Manila Philippines (Midorikawa et. al, 2002). The HAZUS model has also been used for damage estimation after an earthquake. For rapid damage and casualty estimation after in the 2001 Bhuj earthquake in India, HAZUS methodology was applied (Chiroiu et. al 2002).

The building types as given in HAZUS are not common building types found in developing countries like Nepal. To adopt this method in a new area having buildings other than the 36 building types as mentioned in HAZUS, new fragility curves have to be derived from building capacity curve and demand spectrum analysis, which requires more research in this field. In the Bhuj earthquake, the losses, and casualties were estimated fast using the characteristics of un-reinforced masonry (URM) buildings, which were common building types in that area (Chiroiu et.al, 2002). For the seismic loss estimation for the Turkish Catastrophe Insurance, the spectral displacement approach of HAZUS was used with some modification to fit the 14 different types common in the Turkish building stock .The vulnerability parameters were calibrated using observation of damage to key types of Turkish building in the past (Spence et. al, 2002)

2.8.2. RADIUS

RADIUS is a program launched by the United Nations, as a contribution to the International Decade for Natural Disaster Reduction (IDNDR 1990-2000) aiming to reduce seismic disasters in urban areas (Okazaki & RADIUS team, 2000). Realising that, most of the cities in less developed countries have very limited resources and data needed for accurate seismic damage forecast and also for disaster mitigation planning, a simplified methodology has been proposed. The RADIUS method is more appropriate to prepare fast earthquake scenarios that better fits the needs of earthquake-threatened cities in developing countries (Villacis et.al 2000). The main purposes of the RADIUS project were to raise awareness and provide practical tools for earthquake risk reduction. The RADIUS has the following features as given in the methodology:

For scenario modelling, probable earthquake in the region is taken with Magnitude, Epicentre, Depth and Occurrence time. PGA and then MMI are calculated using empirical formulas.

Scenario earthquakes, ground conditions, demographic data and vulnerability functions are critical input data for the earthquake damage estimation. The ground is classified into four types of soil: Hard Rock, Soft Rock, Medium Soil, and Soft Soil and the corresponding fixed amplification factor is taken for probable amplification in that area.

The case study area is subdivided into zones of 1 to 5 Km using Excel based software and for each of the meshes the amount of houses, lifelines and probable population are mapped. The input and output in this grid cells can be visualised spatially as a simple raster maps.

Buildings in this program are classified into 10 different classes according to material type, construction type, applied code, uses and number of stories. This classification is based on the common building types in Latin American cities. The number of each type of building in each mesh is estimated by density of buildings with a weight called "Mesh weight".

Table 2.4 Building classification in Radius method

RES1	Informal construction - mainly slums, row housing etc. made from unburned bricks, mud mortar, loosely tied walls and roofs
RES2	URM-RC composite construction - sub-standard construction, not complying with the local codal provisions. Height up to 3 stories. URM is un-reinforced brick or stone masonry, while RC is steel reinforced cement concrete construction
RES3	URM-RC composite construction - old, deteriorated construction, not complying with the latest codal provisions. Height 4 - 6 stories
RES4	Engineered RC construction - newly constructed multi-storied buildings, for residential and commercial (shops and offices) purposes
EDU1	School buildings, up to 2 stories. Such buildings usually constitute a very small percentage of the total building counts
EDU2	School buildings, greater than 2 stories. Such buildings usually constitute a very small percentage of the total building counts
MED1	Low to medium rise hospitals. Such buildings usually constitute a very small percentage of the total building counts
MED2	High rise hospitals. Such buildings usually constitute a very small percentage of the total building counts
COM	Shopping Centres and Shopping Malls. Such buildings usually constitute a very small percentage of the total building counts
IND	Industrial facilities, both low and high risk

Vulnerability functions, which indicate the relation between seismic intensity and damage rate for structural types, are determined as the function of acceleration/MMI based on damage observed during past sample earthquakes. The damage levels considered in this method are collapse and heavy damage.

The RADIUS methodology is the outcome after the project had worked in selected nine case study cities around the world (Villacis, 2000). This method is simple and easy to implement. The building types and the fragility curve describe in RADIUS methodology are common buildings found in most developing countries. RADIUS method seems more appropriate for the study of preliminary earthquake hazard and vulnerability assessment.

3. Lalitpur Sub-Metropolitan City area

The case study city in this study was chosen the Lalitpur Sub-Metropolitan City area in Kathmandu Nepal. The overview of Lalitpur area, the geology and the main building types and their main vulnerability factors has been described in this chapter.

3.1. Study area: Lalitpur Sub-Metropolitan city

Lalitpur, also called Patan, is one of the municipalities in Kathmandu Valley, laying on south of Kathmandu metropolitan city, the capital of Nepal. It is situated in 85^0 18' E longitude and 27^0 40' N latitude. The city is located on relatively flat area with an elevation rising from about 1260 m to 1375 m. having 15.50 sq. km area .The total population and number of households in 2001 was 162991 and 34996 respectively (CBS, 2001). This municipality area has been divided into 22 administrative units called *Wards*. (See figure 3.2)

Figure 3.1: Lalitpur Sub-Metropolitan City area location map

Lalitpur is one of the oldest cities in Nepal famous crafts and artistic heritage. This city is also known as a city of craftsmen particularly renowned for metal workers and wood carvers. It is said that this city was founded by Veer Deva in 299 A.D. From that period to the present date, Lalitpur has been ruled by different kings and leaders of different dynasties. During the Malla dynasty (1200- 1768), Lalitpur was an independent Newar kingdom famous for art and architectures. This period is considered as the booming period of Nepalese architecture. It is estimated that there are more than 1200 Buddhist monuments and temples of various shapes and sizes scattered in and around this city, most of them built at that period. These monuments and temples have been constructed using local material like brick, stone, wood, tiles, and mud. During the early part of Shah period (1968 to date), European architecture was introduced in Kathmandu valley (Adhikari, 1998). During the Rana period (1846-1951), numbers of European style large sized buildings were built in Patan area, which are still in good condition and are typical buildings in this area. The present Ministry of General Administration building, Ministry of Local Development building, Ananda Niketan building (Pulchowk campus), Staff college buildings and some other residential buildings are from that period. Lime, stone, brick, wood and tiles were used as building materials in these buildings. For the last 35 years, cement was came in use and building construction using brick, cement and sand mortar, and reinforced concrete started in Lalitpur area. Almost all the buildings in present are built using these materials.

For many years, Lalitpur was limited to the core centre area. With the increase in population, and also being nearer to the capital city, the city started to expand gradually. After the construction of Ring road during 1980s rapid expansion of this city has been continuing.

According to the dominant building types, density and city growth, the Lalitpur area can be divided into, three zones: core, fringe and newly developing areas.

3.1.1. Core urban centre

This is the old religious and historical centre. This area is surrounded by four big *stupas* (monuments) one at each corner of its cardinal points which are said to have been built the Indian Emperor Ashoka when he came to Kathmandu Valley on his pilgrimage tour some 2250 years ago. Different temples and monuments, spring water taps, traditional private houses and narrow streets are the common characteristics of this area. Patan Durbar Square, the ancient Royal palace, is the most important monumental centre of this city, which has been recognized by UNESCO as a World Heritage Site.

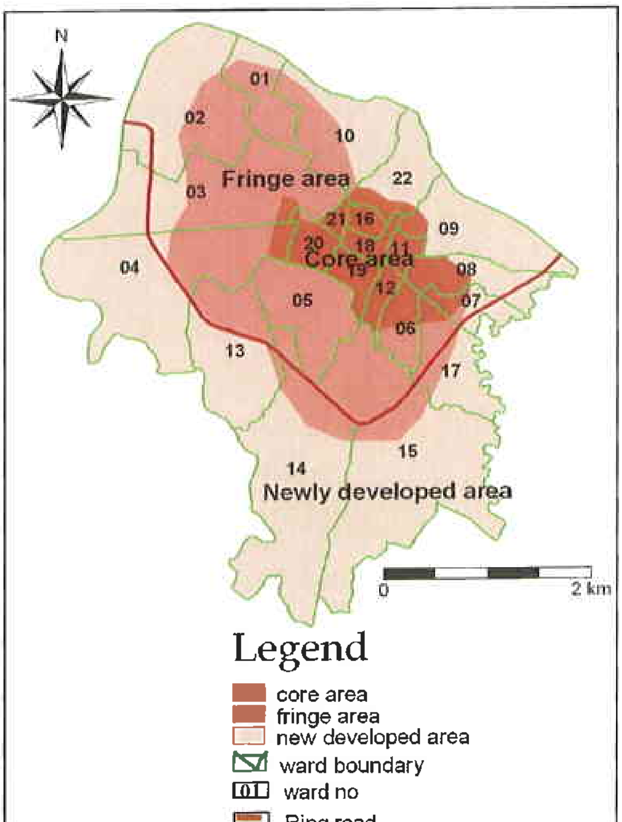


Figure 3.2: Lalitpur Sub-Metropolitan area showing ward number with the boundary and the *ring road*, the main road in this area.

The core area is the densest, having mixed types of buildings and land-use. The majority of buildings are load-bearing masonry with mud mortar and adobes. Replacement of these old buildings with new RCC building is quite common in recent years. Majorities of buildings are of four stories and almost all the buildings are found attached to each other. Two types of residential design pattern exist in these traditional buildings (Adhikari, 1998)

- Row house pattern. These are houses along the road some having common sidewalls. The ground floors of these buildings are commonly used for shops or for other commercial purposes and the stories above it are used for residential purposes.
- Courtyard pattern. In some part of the core area the buildings are joined forming a courtyard. In this system at least one house provides access to the street through a gateway on the ground floor. The courtyard provides common open space for all the houses around it

3.1.2. Fringe area

This is the outer periphery of core area but inside the ring road the main road in this area. This was the first area developed after the core centre area. Besides the residential houses, educational buildings like colleges and schools, government and private institutions, industrial-area and new commercial buildings are found in this area. The majority of buildings types are masonry buildings with brick in cement and RCC. The number of stories rises from two to five but most of them are three and four stories. Most of the buildings in this area are individual having their own compound wall, with some open space around it.

3.1.3. Newly developing areas

This is a rapidly urbanizing residential area where the majority of buildings are RCC. This is the area outside the ring road or near the river where vacant space is available for new buildings construction. Most of the buildings in this area are three and four stories. Phase-wise construction is quite common in the newly developed area where RCC buildings less three stories shows the building construction is in progress and more storeys will be added on in coming years.

3.1.4. Urbanization pattern

Lalitpur Sub-Metropolitan city is rapidly growing and every year hundreds of buildings has been constructed in the vacant and agricultural land. Almost all the residential houses are built by the house owner themselves according to their wish and capacity resulting in a heterogeneous building pattern. In figure 3.3 and table 3.1, the number of building permission given by the municipality in the past four years is indicated. It illustrates the increasing number of buildings constructed in

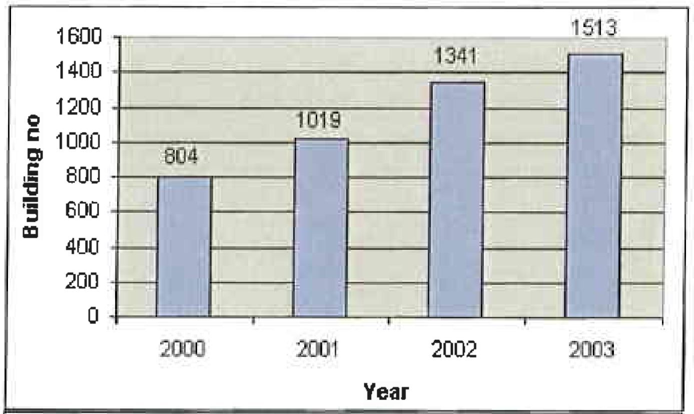


Figure 3.3: Building permission given by the Lalitpur Sub-metropolitan City Office in the past four years

this city. Ward no 11, 16, 18 and 21 are core city area where a lower number of building permissions is found as compared to other wards (Table 3.1)

Table 3.1: Population and number of houses permission given by Lalitpur Sub-Metropolitan City Office

Ward no	Population			No of houses get permitted to be built				
	Male	Female	Total	2000	2001	2002	2003 (July)	Total
1	3993	3097	7090	19	29	37	48	133
2	5491	4968	10459	77	104	150	150	481
3	5473	5164	10637	70	89	125	128	412
4	5511	5460	10971	85	100	137	142	464
5	3243	3330	6573	41	39	48	63	191
6	3322	3030	6352	15	19	39	24	97
7	3304	3104	6408	13	27	34	54	128
8	3798	3557	7355	28	48	31	53	160
9	4147	3988	8135	46	35	41	57	179
10	2974	2456	5430	28	49	75	67	219
11	2153	2085	4238	6	12	17	6	41
12	2930	2747	5677	17	19	17	30	83
13	3324	3229	6553	55	83	91	134	363
14	5745	5785	11530	118	112	190	213	633
15	6042	5310	11352	50	70	95	118	333
16	2630	2664	5294	5	13	15	17	50
17	3576	3117	6693	35	49	57	60	201
18	3503	3412	6915	14	15	20	20	69
19	3138	2910	6048	17	30	27	30	104
20	3383	3136	6519	15	26	31	38	110
21	2156	2093	4249	13	11	13	15	52
22	4666	3847	8513	37	40	51	46	174
Total	84502	78489	162991	804	1019	1341	1513	4677

The rapid urbanization in this area can be seen when images of different years is compared. In the figure 3.4, a part of Lalitpur city has been given in two images of two different years (CORONA-1967 and IKONOS-2001). It is observed that in the right image the area is almost saturated with buildings.

Figure 3.4: Buildings observed in CORONA image (Left) and IKONOS image (Right)

3.2. Geology of Lalitpur area

Kathmandu valley is underlain by soft soil lacustrine deposits. This thick and weak material is expected to produce high amplification during the earthquake. According to the geological map of Kathmandu valley, prepared by Department of Mines and Geology (DMG), Lalitpur sub-metropolitan area lies in two types of deposit layer named Chapagaon and Kalimati formation

Kalimati formation:

Kalimati formation consists of dark grey carbonaceous laminated clay and diatomaceous beds of open lacustrine facies. The formation name was given after a locality called Kalimati, situated in the south western part of Kathmandu city, where the so-called Kalimati (Black mud in Nepalese) is very well exposed. The Kalimati formation is also extensively distributed beneath Lalitpur sub-metropolitan area with an average thickness of 200 m and attains about 400 m at Harisiddhi (Southern part of Lalitpur Sub-Metropolitan area)(Fujii , 2001).

Chapagaon Terrace Deposit

It is named by Chapagaon village, which lies southern part of Lalitpur municipality. This is younger deposit that overlies the Kalimati formation (Fujii, 2001). It is fluvial in origin mainly composed of clean sub-rounded gravel to silty gravel with thin sand, silt or clay beds. This two types of formation is clearly observed in two bore hole data given in figure 3.5. The topmost layer of litholog at AG 88 shows silty layer where as the litholog at BHD 3 has only clay layer on the top.

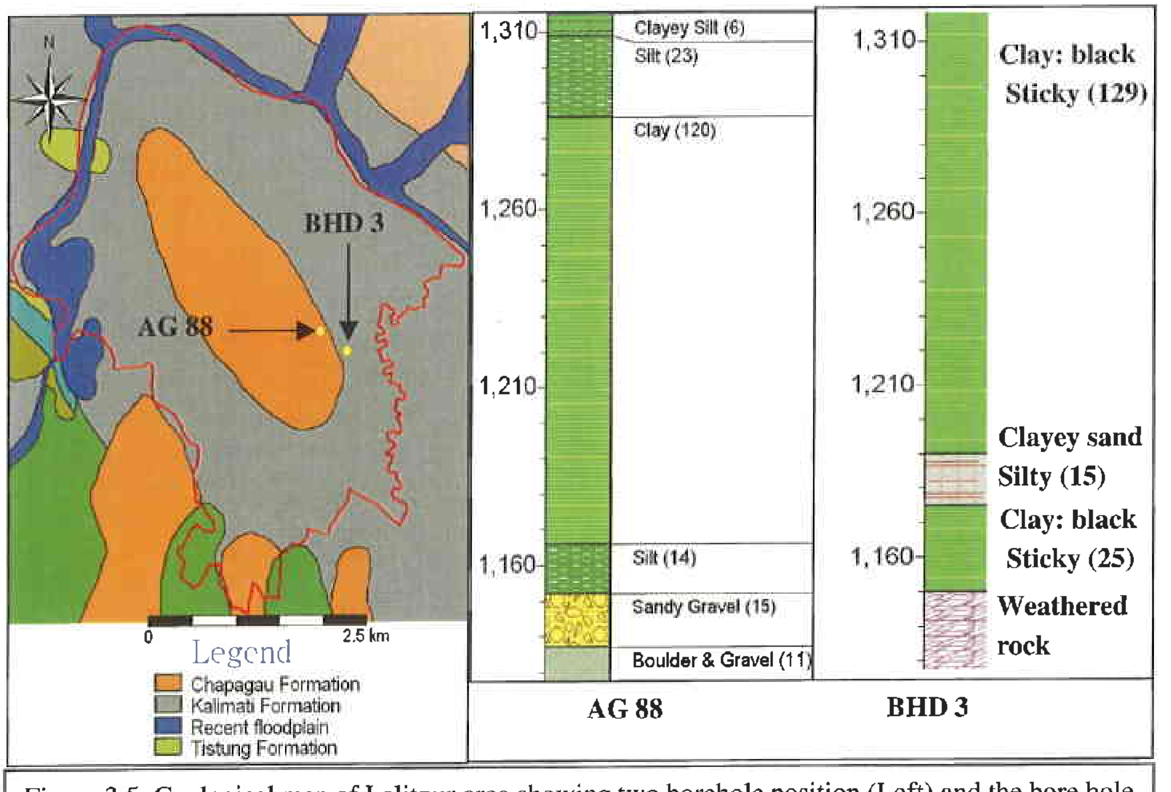


Figure 3.5: Geological map of Lalitpur area showing two borehole position (Left) and the bore hole log at the two location (Right) (Source: DMG, and Piya , 2004)

The total depth of bore holes and the depth of clay in different location of Lalitpur area is shown in table 3.2. These bore holes were drilled by different organisation for various purposes.

Table 3.2 Clay percentage contents in boreholes of Lalitpur area (Source: Piya 2004)

Well_ID	Location	Total depth	Clay thickness	Clay %	Others %
BHD3	B&B Hospital	195	154	79	21
B23	Patan Ind estate	304	234	77	23
AG88	Patan hospital	189	163	86	14
P32	Dhobighat	220	134	61	39
B24	Shanta Bhawan	60	41	68	32
B25	Surendra Bhawan	136	106	78	22
PR16	Nursing campus	74	45	60	40
PR21	Engg Campus	250	153	61	39
P29	Hotel Himalaya	218	174	80	20
DMG13	Balkumari	298	156	52	48
DMG14	Imadol	289	201	69	31
DMG9	Koteswor	300	178	59	41
DMG8	Sankhamul	455	200	44	56

3.3. Building occupancies and land use in Lalitpur area

Although, for the building construction purposes, Lalitpur area has been divided into different zones (see paragraph 3.5.2), proper land use planning lacks in this area. Most of the land in this area has been used for building construction for residential purposes and remaining vacant land has been reducing gradually. Most of the buildings are used for residential purposes. Commercial use in the ground floor and residential in the other upper floors is also quite common in roadside buildings. During the field work period only limited area was found distinctly used for institutional, educational, educational and commercial purposes. Building and land use as observed in the field has been grouped in the following classes.

- Residential area: The area where the predominate building use is for residential purposes
- Commercial area: The area where the building used for shops, hotels and other commercial purposes
- Industrial area: Building in industrial area
- Education area: School and college building area
- Institutional area: offices area
- Recreational area: The zoo, playground and other recreational areas
- Religious area: Temples, monuments and old palace area.
- Mixed use: The area where there are no distinct building use specially commercial and residential activities in the same building.
- Service area: The sewerage treatment plant area, bus station area and the electrical grid station area

- Agriculture: The area used for agriculture
- Water: River and pond area
- Vacant: vacant area
- Other: The hospital, prison and army camp area.

The predominant building occupancies and Land use observed during the fieldwork is given in the following figure.

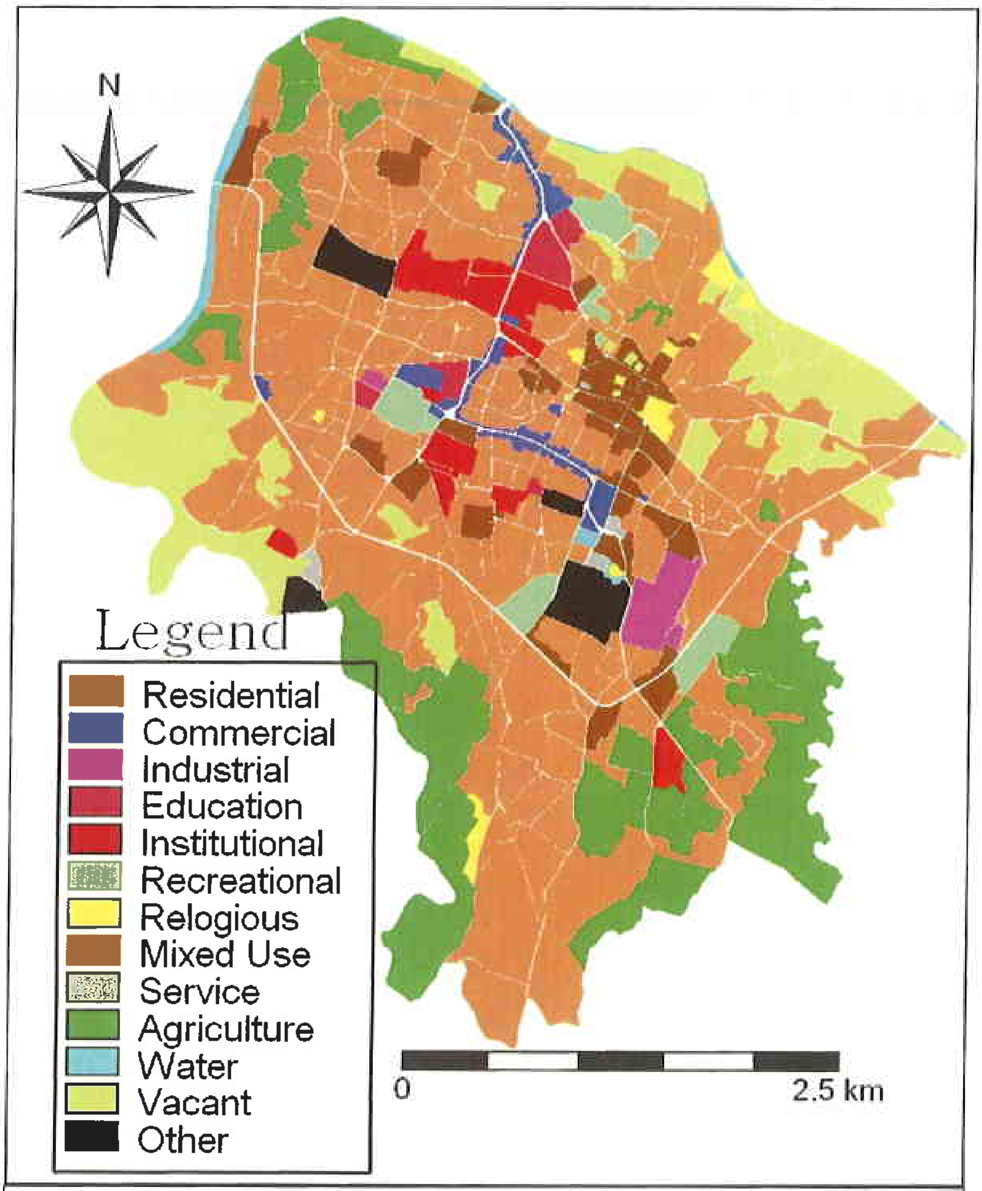


Figure 3.6: Land use map of Lalitpur area

3.4. Building types in Lalitpur area and their vulnerability

In the following sections the various building types in Lalitpur area will be presented and discussed. These buildings have been classified and described in KVERMP and also in JICA study. The same types were observed during the field visit of this study and data collection was done accordingly.

3.4.1. Adobe (AD) buildings

These are buildings constructed using sun-dried bricks with mud mortar for the construction of structural walls. These are old traditional buildings used for residential use. The roof of these buildings is made of tiles and the floors of timber and mud. Some one and two stories adobe buildings are found in Lalitpur area. These buildings possess very low bond strength and high damp observation (JICA, 2002). Adobe buildings may get cracked at earthquake Intensity VI and wide cracks and even partial collapse may occur at VII and collapses are widespread under an intensity of VIII (IAEE Manual, 1986).

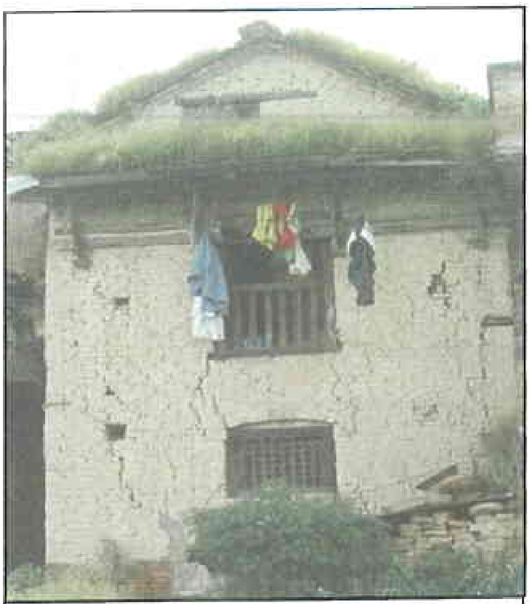


Figure 3.7: An old adobe building

3.4.2. Brick masonry buildings with mud joints (BM)

These are brick masonry buildings with fired bricks in mud mortar. The floor is made of wood or wood and mud. The roofs of these buildings are made of tiles and sometimes these are replaced by CGI (Corrugated Galvanized Iron) sheets. In the Lalitpur area these buildings are again classified into two classes, according to their seismic vulnerability (JICA, 2002)

- **Brick masonry building with mud mortar (BM)**
  These are ordinary brick buildings made using with mud mortar in the wall construction.
- **Brick masonry building with mud mortar well built (BMW)**

Some BM buildings like temples and old residential buildings in Lalitpur have been constructed using wooden joints for floor and roof and also with the use of wooden bands in plinths and in lintels. In the past earthquakes, these buildings showed better performance than simple BM buildings and thus their fragility is taken as the same as that of cement& sand mortar brick buildings (JICA, 2002). Before cement had come in use, BM buildings were a common type of construction in Lalitpur. In the core and the old residential pocket areas of the city, BM buildings are common. The number of stories of these buildings varies from 2 to 4 but the majority are of 4 stories. The storey height of most of these buildings is lower (1.8 m) than the modern buildings (2.7 m).

3.4.2.1. Vulnerability of AD and BM buildings

The vulnerability of these buildings is mainly due to low ductility and week bond between two orthogonal walls. The weak seismic performance of these buildings is due to the following reason (UNDP, 1994).

- **De-lamination of walls:** Vertical separation of internal and external leaves through the middle of wall thickness occurs when there is no proper bonding element connecting these two parts. Over stressing of the wall from the roof accelerates the process. Under shaking conditions, the wall becomes unstable and easily disturbed resulting in total collapse.

- **Weak corners and junctions:** Weak junctions are the result of improper bonds between cross walls. The wall perpendicular to the direction of earthquake force splits with the walls normal to them and may subsequently topple down.

Figure 3.8: BM buildings, ordinary built (Left), well built (Right)

- **Lack of integrity between load bearing elements:** If there is no proper connection between different components of a building like wall, roof, and floor, the system does not acts as a single load resisting system. In this case local deformation occurs causing partial or total collapse of the building.

- **Lack of diaphragm and lateral restraining members:** The main function of a horizontal element is to distribute and transfer horizontal seismic load to the vertical load-bearing element that is the wall below it. If there is no proper connection between different components of floor, it could not distribute the horizontal load to the wall resulting dislocation of wall.

- **Large and unsymmetrical openings:** Large openings weaken the masonry walls against vertical as well as create soft storey effect for horizontal seismic load.

- **Long unsupported wall length:** Long unsupported wall has greater slenderness ratio in horizontal plane, which reduces the compressive strength. Such wall is subjected to large bending moment at its mid span during face load. This leads to excessive bending stresses leading to plane deformation of the wall resulting in its failure.

3.4.3. Brick in cement buildings (BC)

These are load bearing brick masonry buildings with fired bricks in cement or lime mortar for the wall construction. Use of lime is found only in older historic building when there was no common use of cement. Foundation of these buildings is strip footing built up with stone masonry with mud mortar or brick work in cement sand mortar (UNDP, 1994). The floor and roof of these buildings is made up of RCC. Number of storey generally found is 3 and average storey height is 9ft (2.7 m). BC buildings in Kathmandu valley have been constructed for the last 30 years (JICA, 2002)

Figure 3.9: An example of BC building

3.4.3.1. Vulnerability of BC buildings:

The following are the main weaknesses in the materials and unreinforced masonry constructions and other reasons for the extensive damage of such buildings (IAEE manual, 1986)

- Heavy weight and very stiff buildings, attracting large seismic inertia forces.
- Very low tensile strength, particularly with poor mortars.
- Low shear strength, particularly with poor mortars.
- Brittle behaviour in tension as well as compression.
- Weak connection between wall and wall.
- Weak connection between roof and wall.
- Stress concentration at corners of windows and doors.
- Overall asymmetry in plan and elevation of building.
- Asymmetry due to imbalance in the sizes and positions of openings in the walls.
- Defects in construction such as use of substandard materials, unfilled joints between bricks, not-plumb walls, improper bonding between walls at right angles etc.

3.4.4. Reinforced Cement Concrete (RCC) Buildings

In the last 20-30 years, reinforced concrete framed structures have become a common construction features in Kathamdu and also in Lalitpur (JICA, 2000). In a RCC building, concrete columns, beams and slabs are the main load carrying elements. Foundation of RCC building is generally individual column footing with size 1.2m x 1.2m in plan and column and beam size 230 X 230 mm (9" x9") (UNDP, 1994). The average storey height is 2.7 m and the number of stories varies from 1 to 6, with a maximum of four to five floors in the core city area. In the newly developed areas most of the RCC buildings have three or four floors. Stage wise construction is common in RCC buildings in this area.

Figure 3.10: An example of RCC building

3.4.4.1. Vulnerability of RCC buildings

The main defect in RCC buildings in Kathamandu valley is the construction of up to five stories with a small size pillar and tendency to provide cantilever (JICA, 2002). The main seismic defects in RCC buildings are (UNDP, 1994):

- **Short Column effect:** when any or all of the beam-column portions are filled up with masonry brick wall only partially leaving wide opening e.g., for windows. This situation leads to excessive concentration of stresses during earthquakes, at the corners of the openings.
- **Soft-story effect:** Sudden decrease in wall area in plan and large openings in the lower floor as compared to the upper one are the main contributors to soft storey effect. This leads to excessive concentration of deformation in the soft storey floor resulting in its brittle failure. A weak story is one in which the story lateral strength is less than 80 percent of that in the story above (IBC, 2000).
- **Strong column-weak beam system not maintained:** The beam rests on columns. Hence, it is logical to have stronger columns in comparison to the strength of the beam. Many times the opposite is prevalent due to some unknown reason (UNDP, 1994).
- **Lack of ductile detailing:** These are the defects in using steel bars in RCC members. The main defects are anchorage problem, lack of confining bars, steel congestion problem and lack and deficiency in shear stirrups.

3.5. Building regulation and construction practices in Lalitpur area

3.5.1. Draft Nepal National Building Code (NBC)

In response to the 1988 earthquake in Nepal, a National Building Code Development Project was formulated under the Ministry of Physical Planning and Works. This project prepared a building code for the country in 1994. The code attempts to address the structural safety of all types of buildings in Nepal (Bothara, 2000). This code has been prepared following the two design philosophy objectives (UNDP, 1994).

1. Structures should be able to resist moderate earthquakes without significant damage; and
2. Structures should be able to resist major earthquakes without collapse

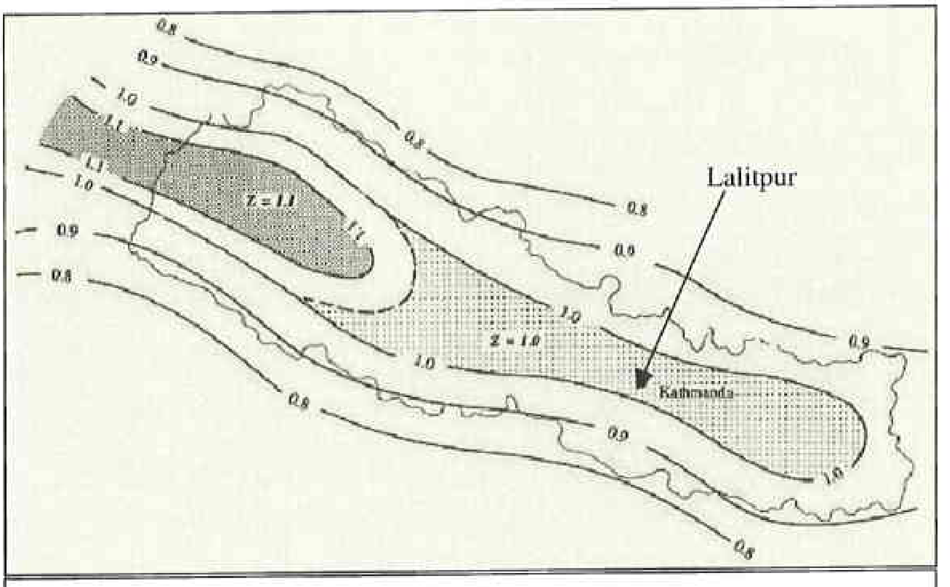


Figure3.11: Seismic hazard map of Nepal (Source: NBC, 1994)

In those objectives moderate earthquake means the strength of seismic ground motion of VI to VIII in MMI and major earthquake means VIII or more in MMI (JICA, 2002). The draft prescribes a method of designing buildings considering normal and lateral seismic load. During this project, a seismic hazard map of the whole country was prepared. In this map, for building design purposes, Nepal has been divided into different seismic zones with zone factor ranging from 0.8 to 1.1(higher value shows high hazard) in which Lalitpur Sub-Metropolitan area lies in a seismic zone of zone factor 1 (see figure 3.11)

3.5.2. Building Bylaw 1993

The "Building Bylaw 1993" was implemented by the Kathmandu Valley town Development Committee. The main purpose of this Bylaw (regulation) is to control and improve the building construction practices and is mandatory for all municipalities in the Kathmandu valley. This regulation is mainly focused on building planning which guides and restricts the building construction mentioning its size, height, maximum ground coverage, and floor area ratio for different building occupancies. In this regulation, for building construction purposes, Lalitpur Sub-Metropolitan area has been divided into the following zones.

- Old city zone
- Residential zone
- Institutional zone
- Industrial zone
- City expansion zone
- Recreational zone

For these different zones, according to the building occupancy class, the building dimension and ground coverage area has been limited and fixed. Table 3.2 shows the building construction criteria for different building occupancy classes in one of the zones (City expansion zone).

Table 3.3: Building permission criteria for different building types for different land area

S.N	Building type	Land area (sq. ft)	Maximum Ground Coverage Area	Maximum Floor Area Ratio	Maximum Height (m)
1	Residential	855 to 1369 sq. ft	80 %	1.75	H=2*Right of way + 2m (For light plane of 63.50)
2	Residential	1369 to 2738 sq. ft	70 %	1.75	
3	Residential	2738 to 4107 sq. ft	60 %	1.75	
4	Residential	>4107 sq. ft	50 %	1.75	
5	Educational	For all	40 %	1.50	
6	Institutional	For all	40 %	1.50	
7	Hotel	For all	40 %	3.00	
8	City centre, film hall, city centre	For all	40 %	2.00	
9	Small scale industry	For all	40 %	1.50	
10	Business complex	For all	40 %	2.00	

(Source: Building bylaw, 1993)

According to this regulation, each of the municipalities has been given the authority to control building construction practices within its boundary area. In the Lalitpur Sub-Metropolitan area, Lalitpur Sub-Metropolitan City Office is fully responsible to implement this regulation. There is a separate building permit section in this office, which takes application, drawing, design, and other necessary documents of the proposed building from the house owners or from the builders. After checking the documents and following some official procedure, this section gives permission for new building construction. Two years time period is given to construct the building and if not finished in the mentioned time, the builder has to reapply for further time period

Since the building code has not yet been made mandatory in Nepal, building construction following the code is carried out only at the initiative of the house owners'. In the past, only few new buildings were constructed following the seismic code. All the other buildings after 1993 till 2002 were constructed following the present bylaws.

After 2002, in the initiative of Lalitpur Sub-Metropolitan City Office, building construction following the seismic code has been started in Lalitpur Sub-Metropolitan area. At present, Lalitpur Sub-Metropolitan Office checks the building plans at the time of the commencement of the construction work in accordance of the building bylaws, and also checks the safety and structural design of the building from structural or seismic points of view.

4. Building database generation for Lalitpur Area

4.1. Data collection and preparation

The creation of the building database in this study was based on the interpretation of satellite images and aerial photos together with field survey. In the field, the study area was divided into small clusters of buildings and the building information was taken as percentages within the cluster. After preparing the building footprint layer, these percentage values were changed to numbers of buildings. This chapter describes the detailed procedure adopted to prepare the building database in the Lalitpur area.

4.2. Pre-field work

Before the fieldwork, the literature was reviewed about earthquakes, vulnerability of buildings, main building types and previous studies about earthquakes in the area. Available satellite images, aerial photos, topographical maps and other GIS maps of the study area were collected and studied. The data collection method was finalized, the data collection form was designed and a base map was prepared to map the information in the field. It was decided to take the IKONOS-Pan image of 2001 as a base map for delineation of building units. This base map was prepared by combining the ward boundary map, the road network and the river system. Hard copy maps of this image covering the whole Lalitpur Sub-Metropolitan city area were prepared in 1:5000 scales.

4.3. Field work

Around one month was spent for data collection in the field. Various building data from different related institutions and building information directly from the field were collected during this period

4.3.1. Homogeneous units area mapping

To find out the probable damage in the event of an earthquake and also to find out the optimal evacuation sites, it is always important to know the spatial distribution of buildings. The accuracy of the study is to a large part determined by the size of the basic mapping units defined for capturing the building data. Building data could be either collected for each individual building or for a group of buildings. Damage analysis based on surveying buildings individually is more accurate but it takes a lot more time. Besides, the resulting building damage estimation for every individual building might also be misleading, because the vulnerability assessment methods are designed for groups of buildings, and the behaviour of an individual building might seriously deviate from that based upon the specific characteristics of a single building. When existing administrative boundaries (like Ward boundaries in Lalitpur) are taken for defining the basic spatial unit for the loss estimation, the size becomes bigger, and vacant land and densely populated building area cannot be separated. Also the use of a grid system with a certain cell size, e.g. 500 by 500 meters as was used in the JICA (2001) study, is also not optimal for a building survey since the boundaries of the grid do not match the boundaries in the field like roads and ward boundaries. The grid system may even sometimes divide the buildings itself. Therefore, in this study it was decided to divide the Ward areas into smaller homogeneous units, and use these as basic mapping units for the building survey. In each homogeneous unit building data was collected using a survey sheet. See Table 4.1 for an example of this sheet, and the explanation of the classes used.

The main idea of homogeneous area mapping was to divide the municipality into smaller units, which are smaller than Wards but also, because of limited time, are not up to individual building level, to delineate these area in the map and to take building information surveying it in the field. Here the concept of the word *homogeneous* is used to mark those areas, which have the same building material type and building occupancy. But in the field, except for some parts, there was hardly any single area with buildings of exactly the same material type and height, but normally there was a mixture of different types of buildings. Most of the buildings in this city have been constructed by the building owners themselves following different construction practices and using different building materials. It is also quite common to use the same building for different building uses giving a heterogeneous building character. Hence it was decided to divide the area according to building uses and take the

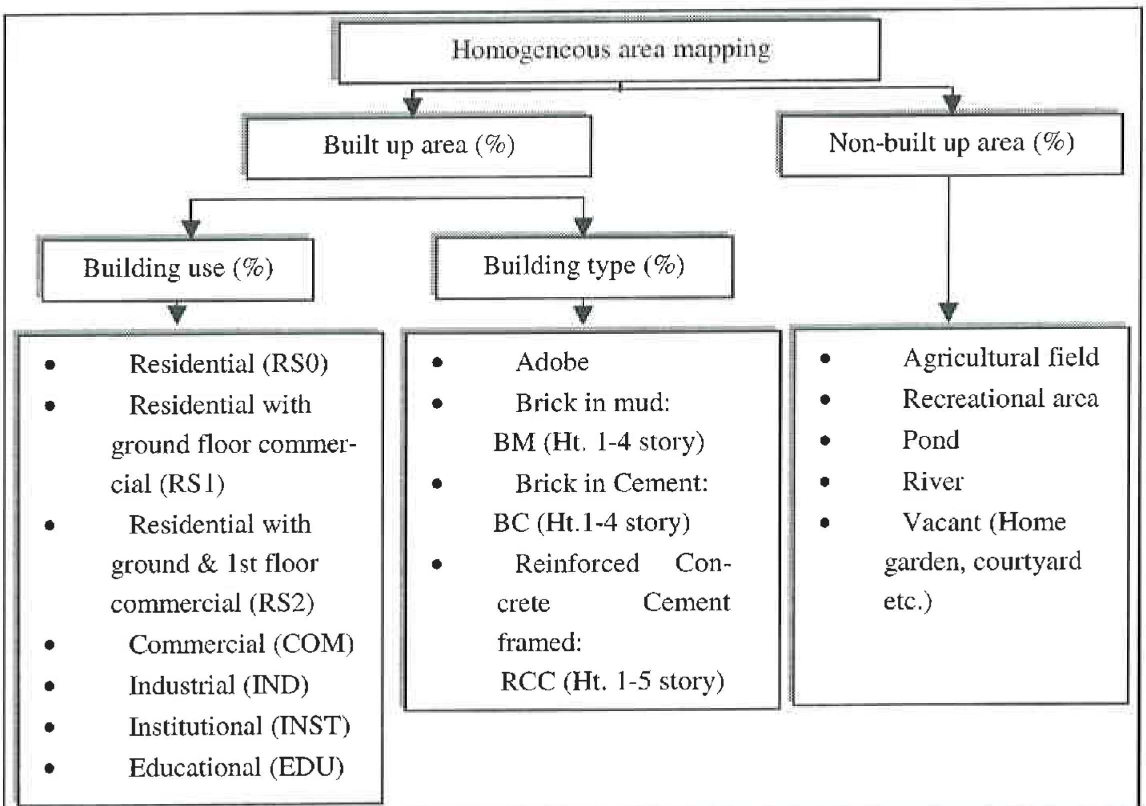


Figure 4.1: Homogeneous area mapping procedure

information in percentages as shown in the figure 4.1

The following methodology was adopted while mapping the homogeneous units:

- The map made from the IKONOS-pan image of 2001 was taken as base map for the area delineation and field survey
- Ward boundaries, roads, streets, and rivers were taken as boundary lines of the homogeneous units
- Areas with no buildings (Vacant land) like ponds, rivers, agricultural fields, recreational areas and also distinct building occupancy areas like industrial areas, military camp, zoo, institutional and educational areas were marked as separate units.
- The building occupancy was divided into the following class:
    - Residential (RS0)
    - Residential with ground floor commercial (RS1)
    - Residential with ground floor and first floor commercial (RS2)
    - Total commercial buildings (COM)
    - Industrial building (IND)
    - Institutional building (INST)
    - Educational (School and College) buildings (EDU) (School: SCH, College: COLG)
- From the same unit building type was estimated into following material types also considering the number of floors of the building, indicated with a number behind the code of the material type.
    - Adobe building (Adobe1, Adobe2)
    - BM building (BM1, BM2, BM3, BM4)
    - BC building (BC1, BC2, BC3, BC4)
    - RCC building (RCC1, RCC2, RCC3, RCC4, CC5)
- The size of the homogeneous units was determined considering density and uses of buildings. In the dense core area, having mixed occupancy, the information was taken in smaller units (up to 3 hectares) as compared to the outer fringe area (up to 5 hectares). For less dense newly developed residential areas having more vacant space the size of the homogeneous units was often quite large unto 10 hectare. All the vacant land including agricultural fields with few buildings were digitised separately.
- In each unit, built-up and non-built up area was estimated in percentage of homogeneous unit area. Building material type and occupancy class were estimated in the percentage of built up area. Wider roads and courtyard areas were excluded in estimating the built-up area but home gardens, boundary walls, and narrow streets were included.
- In each unit all the information of building types and uses was estimated in percentages (built-up and non built-up area by percentage of homogeneous unit and building material type and occupancy class from the total built up area)
- Each unit was assigned a unique unit identifier, which consisted of a combination of the Ward number, block number and sub-block number. In some cases, while observing the block, different building characteristics were found within it. In those cases the blocks were divided into sub-blocks.

Each unit was evaluated in the field using a sidewalk study by observing the building material and construction type and building use. Information of each unit was filled in the survey form (Table 4.1)

Table 4.1: Survey form used in the field

Ward No. ....Date.............................Survey by........................

Block No	Sub-block No	Built up Area (%)	Building use	%	Building type (material) and height	%	Cantiliver %	Soft story %	Remarks
1	2	3	4	5	6	7	8	9	10

1. Different numbers are assigned to the homogeneous unit.

2. Division of a block in sub block number if needed (During the field visit)

3. The percentage of the built-up area (buildings) was estimated walking around the delineated unit and also observing the satellite image [IKONOS-pan: scale 1:5000 map], wider Roads were considered as margins of separate units but the narrow streets were included in the homogeneous units.

4-5. The percentage of building use was observed in each unit and was divided into the following classes (a) Residential (RS0)(b) Residential with ground floor commercial (RS1)(c) Residential with ground and 1st floor commercial (RS2)(d) Commercial (COM) (e) Industrial (IND)(f) Institutional (Offices)(INST) (g) Educational (School and colleges) (EDU)

6-7. The percentages of the building types in the homogeneous unit were classified using the following classes.

- *a. Adobe1, Adobe 2: One, and Two story adobe type buildings.*
- *b. BM1, BM2, BM3, BM4: One, Two, Three and Four story brick building with mud mortar*
- *c. BC1, BC2, BC3, BC4: One, Two, Three, and Four story brick in cement mortar buildings.*
- *d. RC1, RC2, RC3, RC4, RC5: One, Two, Three, Four and Five story Reinforcement Concrete Cement framed buildings.*

8. The percentage of cantilever building in the unit was observed

9. The percentage of soft story building in the unit was observed and estimated.

10. Remarks

Figure 4.2 is an example of homogeneous unit area delineation and attribute information taken from one of the blocks in Ward number ten. The number 101802 on the top of the table shows the ID number of that polygon where the first two digits represents the Ward number (Ward number ten), the second two digits gives the polygon block number (18) and the last two digits shows the sub-block number (02).

	101802
buitl_up	70.0
non_built	30.0
LU	RS0
RS0	80.0
RS1	10.0
RS2	0.0
COM	0.0
INST	0.0
IND	0.0
SCH	10.0
COLG	0.0
AGRI	0.0
PLGR	0.0
RCC5	20.0
RCC4	30.0
RCC3	30.0
RCC2	0.0
RCC1	0.0
BC4	0.0
BC3	20.0

Figure 4.2: Example of homogeneous unit delineation

4.3.2. Secondary data collection

Different offices and institutions were visited during the field period to collect secondary data. Meetings were held with personnel from Lalitpur Sub-metropolitan offices, NSET-Nepal, ICIMOD and Kathmandu Metropolitan office to get a better idea of the study area and also to collect available data, maps, images and other literature about earthquakes and buildings in the study area. Aerial photos of different dates were collected from survey department and National Census data of 2001 was taken from Centre Bureau of Statistics office. The ward map and building permission data was taken from the Lalitpur Sub-metropolitan office. The large-scale topographic maps were collected from Kathmandu Metropolitan city office, NSET Nepal office and Lalitpur Sub-Metropolitan City office. An overview of the secondary data collected is given in Table 4.2.

Table 4.2: The secondary data collected from various sources

SN	Materials	Institution	Year of Publication
1	Aerial photos of the study area 1981 (1:8,000) 1992 (1:10,000) 1998 (1:10,000)	HMG/N/Ministry of Land reform and Management, Survey Department	1981, 1992, 1998
2	Large scale topographic map of the area, Including building footprints, contour lines, road network, temples and monuments, stream and river system, ward boundaries etc.)	NSET-Nepal, Lalitpur Sub-Metropolitan City Office	1998
3	Satellite images • Corona image (2.5 m resolution) • KVR image (2 m resolution) • IKONOS Pan (1 m resolution)	ITC, SLARIM project	1967 1991 2001
4	Census report, 2001	Central Bureau of Statistics	2001
6	Building sample data	NSET- Nepal, Lalitpur Sub-Metropolitan City Office	2001
5	Nepal National Building Code (NBC), Building bylaws, books, maps and other related documents.	NSET-Nepal, Lalitpur Sub-Metropolitan City Office, ICIMOD, Kathmandu Metropolitan Office	NBC in 1994 and other in different dates

4.3.3. Positioning of the individual buildings in the map

A building sample survey of the study area was carried out by NSET-Nepal in 2001. The objective of this survey was to collect information on representative building typologies in selected representative areas of Kathmandu Valley for the evaluation of the weakness of the prevalent building types (Building inventory report, 2001). These sample data sets have detailed building information like shape, size, height, age of the building, material type and construction practices adopted, main defects of the building from a seismic point of view; probability of people being in the building at different times of the day etc. A total of 127 building samples from NSET for the Lalitpur area were used from different representative parts of the city and from different building occupancies.

Another sample survey was done by the Lalitpur Sub-Metropolitan City Office (LSMCO). The purpose of this survey was to find out detailed building information in order to make a conservation plan for the old heritage area in the core city area. Except from the seismic defects and the number of people using the building, the data from LSMCO has the same detailed building information as the NSET samples. With the agreement of NSET-Nepal, and Lalitpur Sub-Metropolitan City Office, it was decided to use these sample data in this research. The overview and location of these data is given in table 4.3. and figure 4.3

Source	Type	Area	Number
NSET Sample data	Residential	Core	58
		Fringe	36
	Commercial	Along the commercial road/core	21
	Industrial	Industrial state/ fringe	10
	Educational	Colleges/ Core	2
City Office Data	Residential	Core	69
Total			**196**

Table 4.3: Sample data from NSET and Lalitpur Sub-Metropolitan City offices

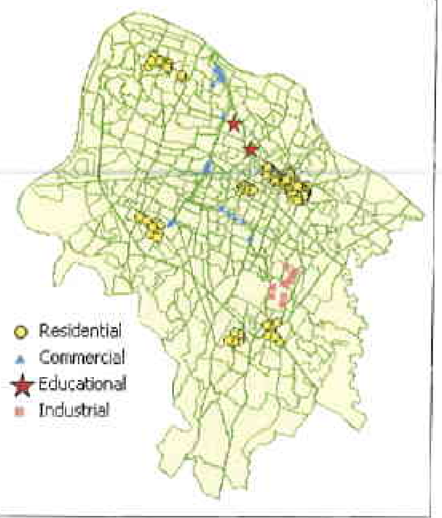


Figure 4.3: Positioning of sample data

The main problem of these data sets was the addressing difficulty, as houses do not have a proper addressing system in Lalitpur. The addressing problem of a building has been solved in the neighbouring Kathmandu Metropolitan City area, establishing an addressing system based on a metric system. The basic principle of this metric system is that each building along an access way is given a number that (nearly) equals the distance in meters from the access way's starting point to the entrance of the buildings (KVMP, 2001). Applying this system now every building in Kathmandu Metropolitan City area has a unique number and could be found easily from the given address.

This type of system still lacks for buildings in Lalitpur. Although the sample data sets have a lot of buildings information including the photographs, they don't possess coordinates or other information for the exact location in a map. Only the name of the street and settlement name from where these samples were taken have been mentioned in the survey form. From the address and with the help of people involved in the survey, these buildings were positioned and mapped in the homogeneous unit. A new

	11609
Address	Nagbahal
ID	11609
Wardno	16
Serial no	2-1-1-16-09
Tole	nagbahal
Bldtype	BM, RC
Settlement	Core
Const_year	2000
Story	6
Frht_m	2.50
Bld_use	Residential
Land_area	71.54
shape_inplan	RE
shpae_inelevation	SE
cantiliver	One
Locality	1
sattlement	1.0
Effect	2
Effect_1934	
Effect_1988	
Repaired	0
Designer	Self Tech
Supervisor	Self
Open_space	0.0
People_6_9am	2
people_8pm	6
people_6am	6
people_5pm	8

Figure 4.4: The attribute table of a sample building

identifier domain was assigned to each sample building and a point map of these buildings was digitised over the homogeneous units. An attribute table was created and the building information, which was in Microsoft Excel, was imported to an ILWIS table (see figure 4.4)

4.4. Post field work

All the information gathered in the fieldwork was tabulated, corrected and adjusted to form a building database of the study area. All these data were imported in ILWIS where all the GIS operations were carried out, such as interpolation, creation of attribute maps; overlaying, cross operation and other types of analysis. The following procedure was performed to prepare the GIS data for the analysis

4.4.1. Data preparation

The following procedure was adopted to create the building data sets of the study area.

4.4.1.1. Extraction and editing of data layers from Auto cad files

One of the most important maps for this study was a large-scale topographic map in digital form. From this map building footprints, the road network, rivers, ward boundaries and contour lines were extracted for the study area. This original map was in Auto Cad Dxf format, and consisted of segment map files of individual map sheets digitized in 1998 by the Kathmandu Urban Development Project (KUDP). Although it was a digital map, a lot of editing had to be done to make it into a useable GIS map:

Figure 4.5: The topographic map overlaid on IKONOS image, same coordinate but improper overlaying.

- There were all together 30 maps covering the whole Lalitpur area. All these segment maps were glued together in ILWIS to make a map covering the whole study area.
- The building footprint, the road network, rivers, ward boundaries and contour lines were then extracted to form separate layers.
- To make a building polygon map, the building segment map was cleaned and checked for dead end, self-overlap and intersections. Hundreds of errors were removed manually, before the polygon map could be generated.
- The contour lines were disjoined, without the altitude value and also often consisting of two or more superimposed lines. Extensive editing and assigning the contour value was performed

to form a GIS contour map. From the contour lines the Digital Elevation Model (DEM) of the area was created, with a pixel size of 1 meter.

4.4.1.2. Georeferencing the images and aerial photos

At least two types of coordinate systems are found in use in Nepal. The topographical map of the area is in one system and the images and other GIS maps were in the other system. Also when the IKONOS image and footprint layer were converted to the same coordinate system still they did not match properly giving shifting up to 25m (Figure 4.5).

One of the main problems was that there is no clear information about the two coordinate systems used in Nepal, like the datum and projection used which might have cause the problem (see Figure 4.6).

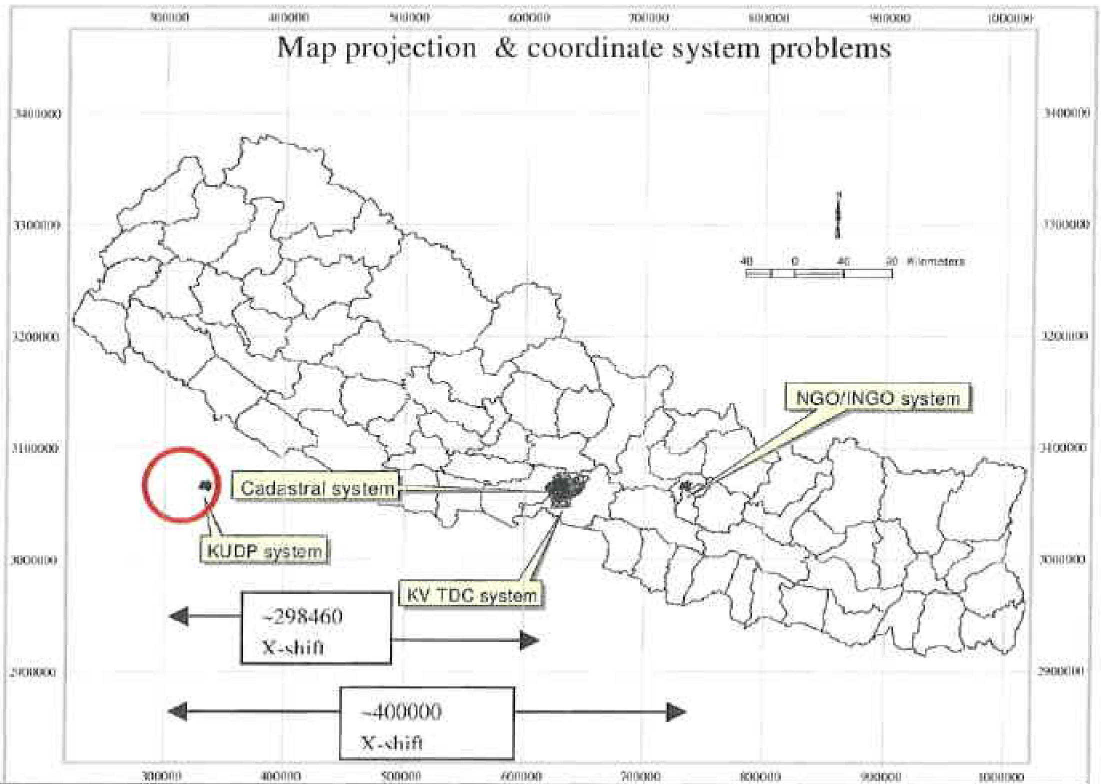


Figure 4.6: Projection and coordinate system problem in Nepal, different system followed by different organizations (Source: Kathmandu Metropolitan Office)

Since the 1:25,000 scale topographical map had a grid with coordinates, first it was tried to georeference all the maps, aerial photos and images taking the topographical map as a base map. But as it was a small-scale map, it was not possible to do a proper georeferencing for the large-scale building footprint map and the one-meter resolution IKONOS image. Again it was tried to georeference the images taking the building foot print as a base map. In this time also the foot print layer could not be overlaid exactly on the top of the IKONOS image. The reason might be because of digitising error in the foot pint layer or tilt and relief displacement in the images. To minimize this error, finally georeferencing of the image was done considering also elevation, using the direct linear method in ILWIS. In this method the large scale topographic map was used as a background map and the elevation value was taken from the DEM map (produced from the contour map with 2 m contour lines derived from the Auto Cad files). This method produced a significantly better-fit result (Figure 4.7).

Figure 4.7: The topographic map overlain on the IKONOS image after georeferencing and editing

The same procedure was applied for georeferencing all the other images, aerial photographs and maps. From the two coordinate systems, the following coordinate system is used in this research.
Projection: UTM zone 45 N
Ellipsoid : WGS 84
Datum : WGS 1984

The operation performed for georeferencing and homogeneous area digitising is shown in the following figure 4.8.

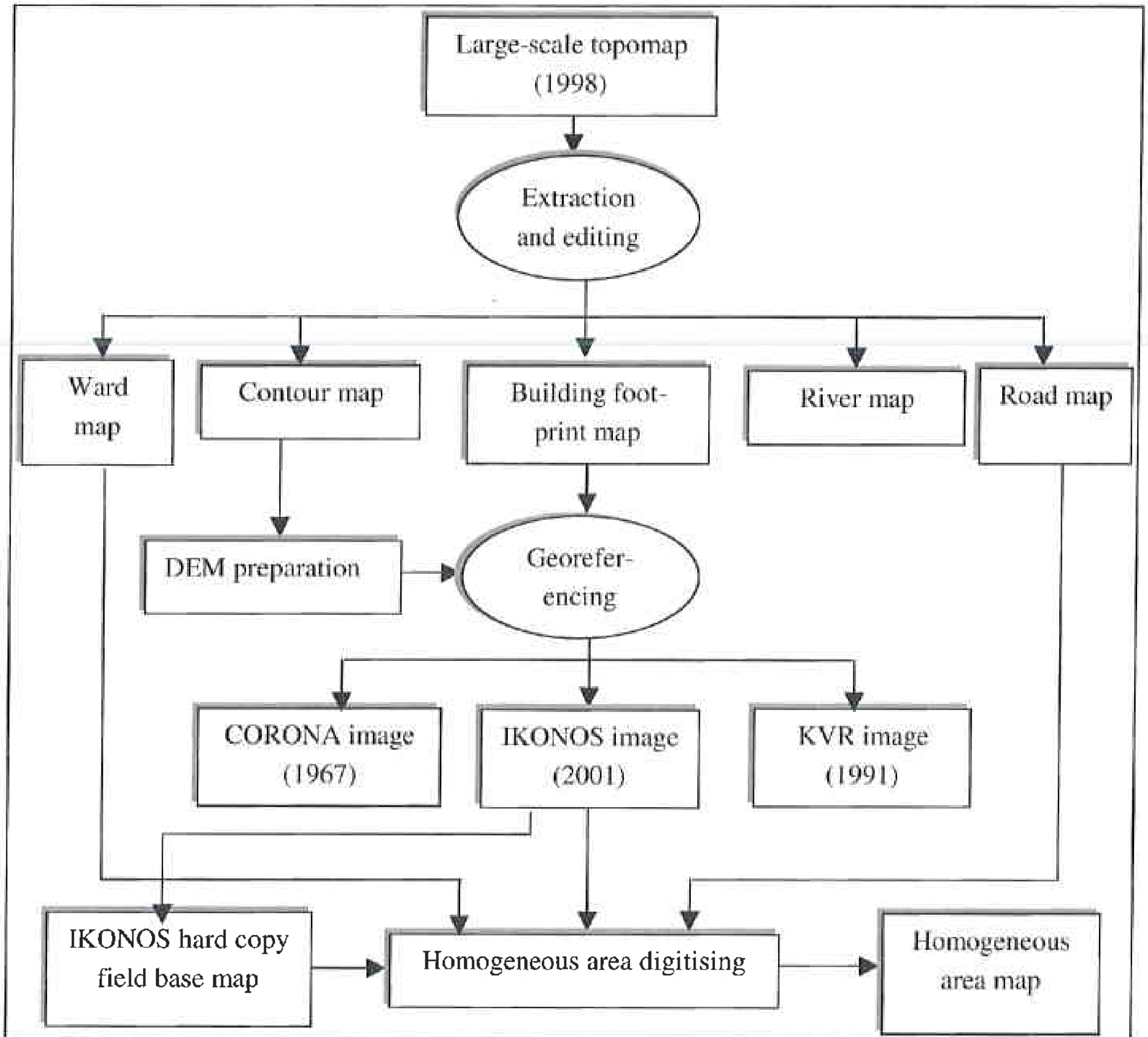


Figure 4.8: Procedure adopted for georeferencing and Homogeneous area digitising

4.4.1.3. Digitising the homogeneous units

The homogeneous units were marked in the field on the hard copy map of the IKONOS image. In digitising these units, instead of taking the IKONOS image as a base map, the building footprint map overlaying road networks and the ward boundary map was used. This was done in order to assure that the homogenous units would match exactly on the building footprint map. The roads boundaries were taken as the boundaries of the homogeneous units. Within each homogenous unit a point was digitised with the unique identifier of the unit, which was linked to an attribute table and all the information collected in the field was tabulated. Figure 4.9 is an example of the digitising of a homogeneous unit taking the roads as the boundary of the units. The point maps shows the ID number of the unit.

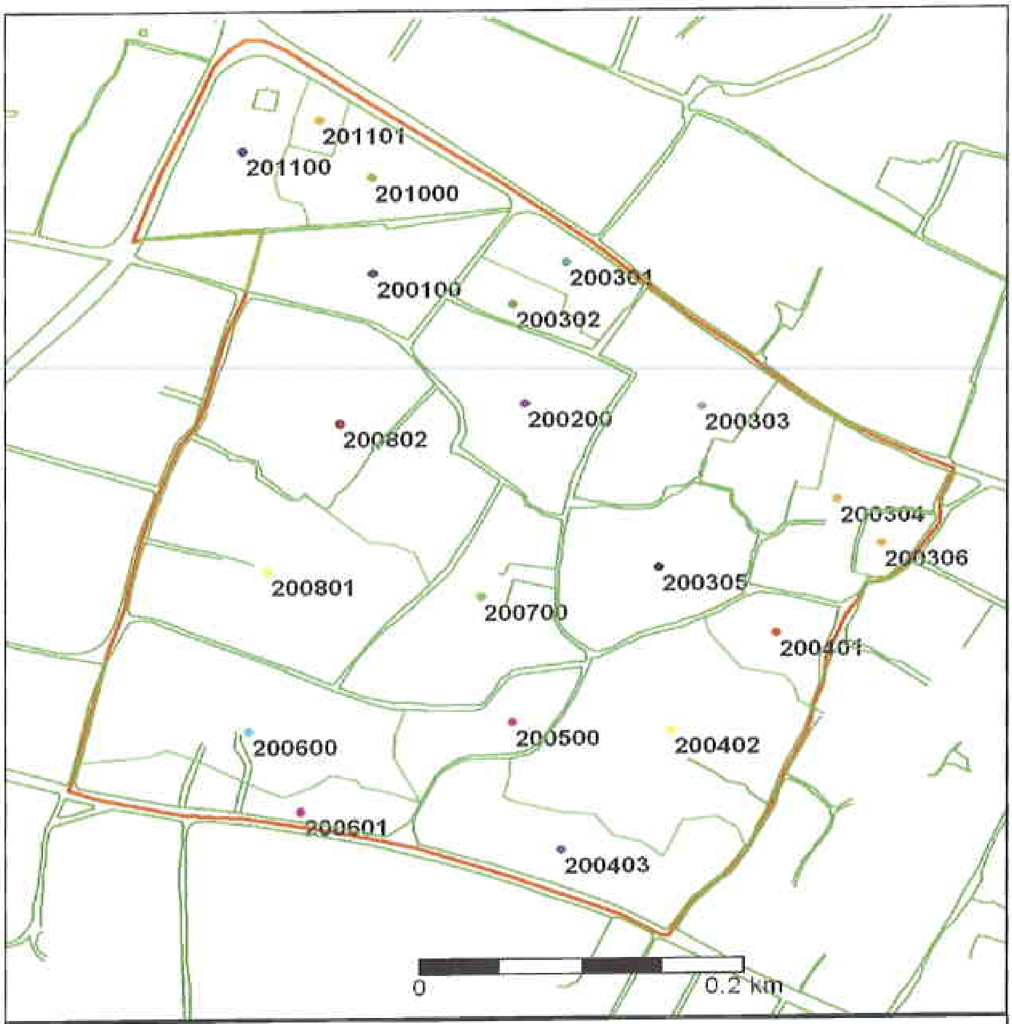
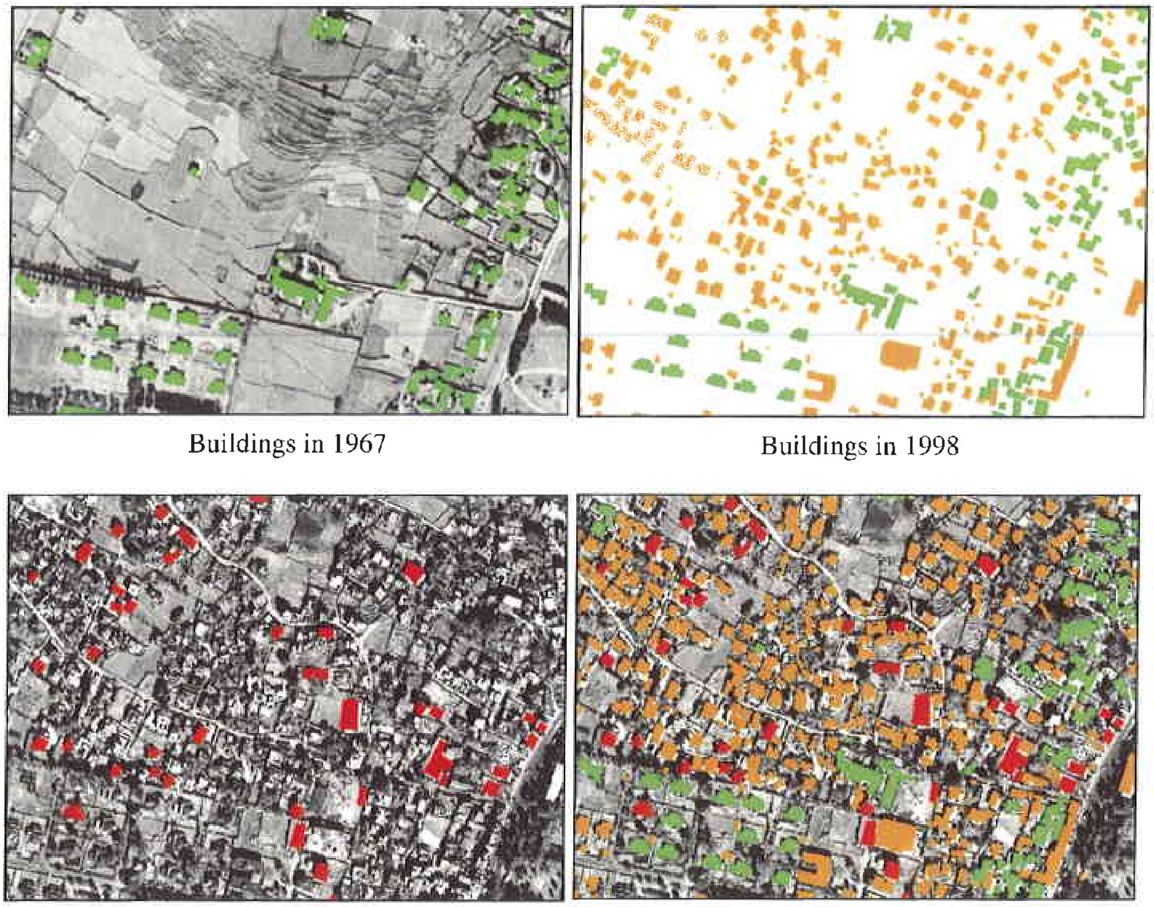


Figure 4.9: Homogeneous area digitising: an example from Ward no 20

4.4.1.4. Data set creation for individual buildings

The building footprint map was prepared based on aerial photos of 1981 and 1992 and was updated in 1998. All the buildings constructed after this year as observed in the IKONOS image (from 2001) were digitised on screen to create the building data set for the year 2001. A building footprint map was also prepared for the year 1967 by digitising and editing the buildings observed in the CORONA image in that year. Only the buildings observed in that image which are still there is in IKONOS image were taken to find out the pre 1967 buildings in current situation. The overview of buildings in different years in one part of Lalitpur city is shown in the figure 4.10



Buildings in 1967 | Buildings in 1998

Additional buildings (1998-2001) | Total buildings in 2001

Figure 4.10: Buildings in different years in one part of Lalitpur area

4.4.2. Buildings in Lalitpur Sub-Metropolitan area

From the individual digitised building layers from 1967, 1998 and 2001, the number of buildings and the corresponding size (area in plan) can be obtained. Since the building information was taken in the homogeneous unit all the calculations are based on these units.

4.4.2.1. Number & density of Buildings

In the core centre area, the buildings are very dense and attached to each other. In this area the existing building footprints have been digitised in blocks and from the existing image and aerial photographs, it was not possible to split the blocks into individual buildings. Therefore the number of buildings in this area was estimated by dividing the building footprint area by the average plinth area of a building. On observing the sample data set in this area, the plinth area is found ranging from 10 m^2 to 138 m^2 but most of the buildings were smaller than 50 m^2. In this study, the average plinth area is taken as 45 m^2. Every building polygon outside this core area is considered as a single building. A total number of 26873 buildings are estimated in 2001. These buildings are compared to the number of households from the census data (or number of families), which was taken in the same year. The ward wise distribution of number of households (from the census data) and the number of buildings obtained from this study is given in table 4.4 and shown in figure 4.11.

Table 4.4: Ward wise distribution of household, number of buildings and estimated and calculated built up areas

Ward No	No of household	Number of buildings (From this study)	Ward area (Ha.)	Homogeneous units		Built up area (Ha.)		Built up area (%)	
				No	Area (Ha.)	Calculated	Estimated in the field	Calculated	Estimated in the field
1	1691	848	42.36	16	41.30	8.75	23.68	21	57
2	2284	2085	129.88	39	125.49	17.95	55.92	14	45
3	2365	2409	150.98	42	145.61	23.54	70.57	16	48
4	2523	2069	180.99	62	175.79	16.99	56.11	10	32
5	1397	1541	70.35	33	67.24	15.47	41.12	23	61
6	1311	916	25.48	12	24.38	8.09	18.20	33	75
7	1299	451	23.80	8	23.07	3.16	8.05	14	35
8	1407	1546	44.40	18	42.94	8.73	18.71	20	44
9	1706	1225	74.93	22	73.25	7.20	18.80	10	26
10	1222	948	81.06	36	77.16	13.11	37.24	17	48
11	780	970	10.26	7	9.96	4.36	6.59	44	66
12	1129	902	13.10	11	12.20	4.79	7.52	39	62
13	1400	1053	95.34	24	92.39	9.88	34.11	11	37
14	2498	1791	184.65	26	180.30	15.01	55.29	8	31
15	2694	1705	243.35	42	237.56	20.18	60.24	8	25
16	989	1017	9.05	15	8.67	4.69	6.10	54	70
17	1509	743	56.67	9	55.11	4.98	16.26	9	30
18	1287	1258	12.70	17	12.02	6.15	8.80	51	73
19	1262	883	17.72	12	16.65	5.42	10.96	33	66
20	1447	821	19.92	20	18.58	5.51	10.73	30	58
21	906	630	6.23	5	5.94	2.84	4.40	48	74
22	1890	1062	46.89	23	45.97	7.10	18.80	15	41
Total	34996	26873	1540.11	499	1491.58	213.89	588.17	14	39

Source: CBS and from this study

Also the building density was calculated based on the footprint maps. In the core centre area the density of buildings is found highest as compared to the other areas. Buildings in this area are attached to each other having less vacant space as compared to the other areas. The building density map and also the building foot print layer in two part of Lalitpur area is shown in the figure 4.12.

The building density was also estimated in the field for each homogeneous unit. When this estimation is compared with the measured densities from the footprint map in all the cases the measured density was found high. During the field, the built up area was estimated in the percentage from the cluster of buildings including home garden, boundary wall and street, which resulted the high, built up area estimation. The area and number of homogeneous units taken in the field and the estimated and calculated built up area is given in the table 4.4

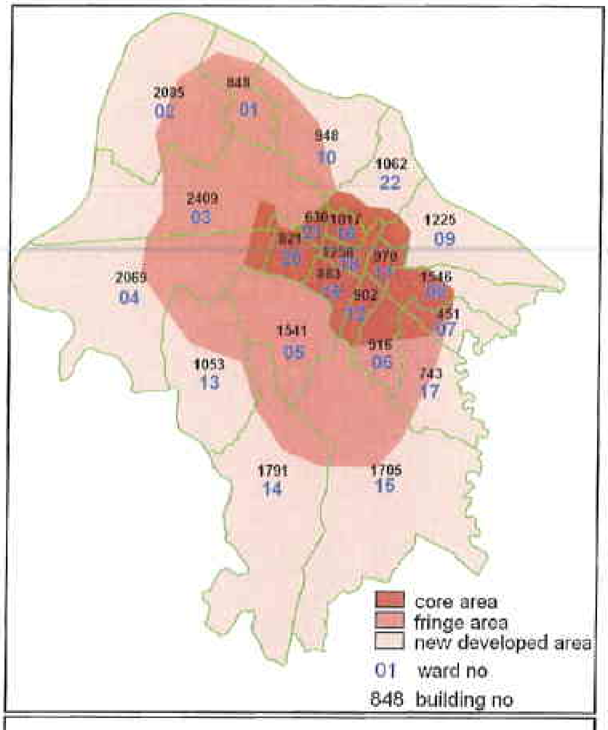


Figure 4.11: Ward-wise building distribution

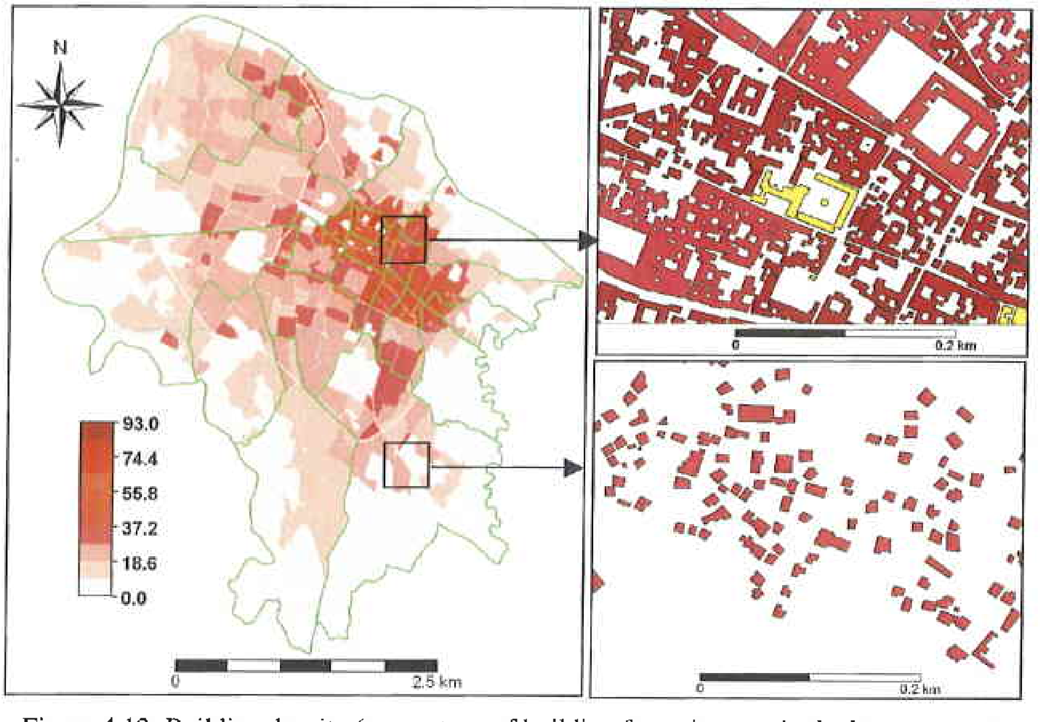


Figure 4.12: Building density (percentage of building footprint area in the homogeneous unit) in the left and building foot print in high and low density area in the right.

4.4.2.2. Types of buildings

As explained in chapter three, the main building types are Adobe; Brick in mud mortar (BM), Brick in cement sand mortar (BC) and Reinforced Cement Concrete (RCC) framed buildings in the study area. The most abundant types of buildings are the RCC ones that are found distributed in the entire city area (See figure 4.13). The current trend of construction is RCC types. Significant number of RCC buildings in the old core settlement area indicate the replacement of old buildings by these types of buildings. In total, 59 % of all buildings in Lalitpur are made of RCC. BC building and BM buildings are found nearly equally often, with a percentages constituting 20.7 % and 19.7 % respectively. Only 0.6 % adobe buildings are found in Lalitpur, only in the old core settlements. In the core centre and in some other old settlements, BM buildings are found. BC buildings are found mostly in the fringe area. The distribution of number of different types of buildings are given in next page (Figure 4.15)

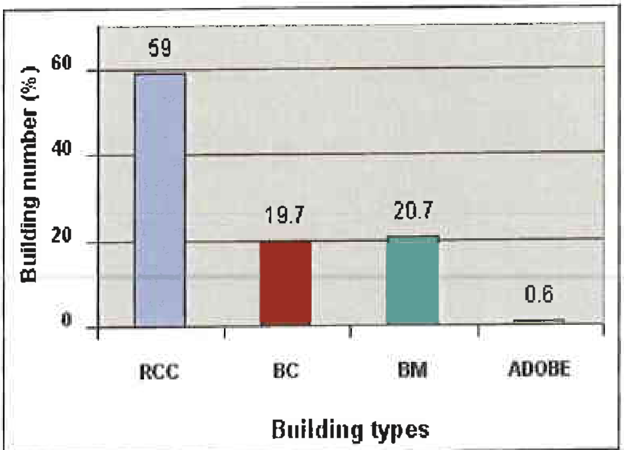


Figure 4.13: Number of buildings (in percentage) according to the type

4.4.2.3. Age of the buildings

Only 44 % of the present buildings are found in the time the CORONA image was taken (1967). These buildings from 1967 cover only 31% of the present building footprint area. By 1998, this building area increased to 85 % of the present area (See Table 4.5 and Figure 4.14). In the core centre area the old buildings have been replaced by modern RCC buildings. In this area buildings are still there CORONA images. In this calculation these buildings are also considered as old buildings . This shows that more than 56 percent of the present buildings are less than 35 years old.

Year/ buildings area and number	1967 (CORONA image)	1998 (Building foot print)	2001 (IKONOS image)
Built-up area (Hectare)	67.24	181.52	213.89
Number of buildings	11838	24528	26873

Table 4.5: Number of buildings and built-up area in three different periods

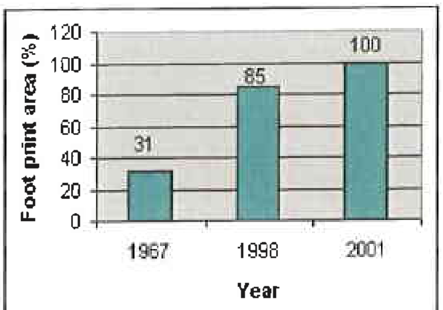


Figure 4.14: Trend of building construction

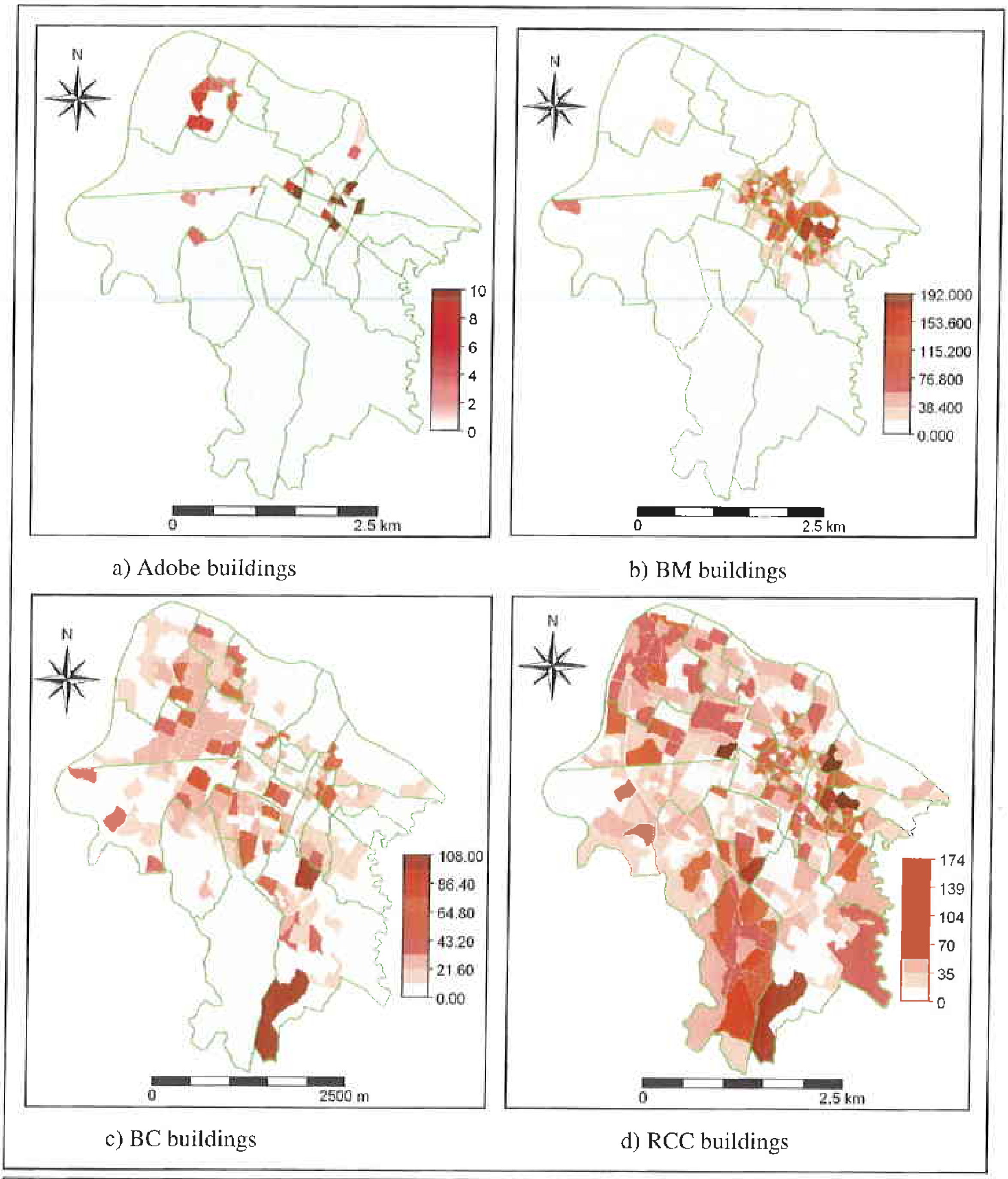


Figure 4.15: Distribution of types of buildings (numbers per homogeneous unit)

4.4.2.4. Story number and height of the buildings

In the Lalitpur area, different types of buildings are found with different story height. Although some official and commercial buildings have floor heights up to 12 ft, most of the modern BC and RCC buildings in residential areas have an average floor height of 9 ft (2.7 m.). In case of BM and Adobe buildings the floor height ranges from 6 ft to 8 ft (based on building sample data). The story numbers of these buildings are found ranging from one to five. Only a few six-story buildings were observed during the fieldwork; in this study these are included in five stories buildings. The majority of the buildings have three or four floors constituting 45 % and 34% of the total number of buildings respectively. Two and five stories buildings are found nearly equal in number with 10 % and 9.5 % respectively. The smallest number is with one story building having only 1.4 %. The distribution of buildings according to the story number is given in figure 4.16. The figure on the top shows the number of buildings (in %) according to story height and material type. The bottom figure is the total number of buildings in percentage according to the story height.

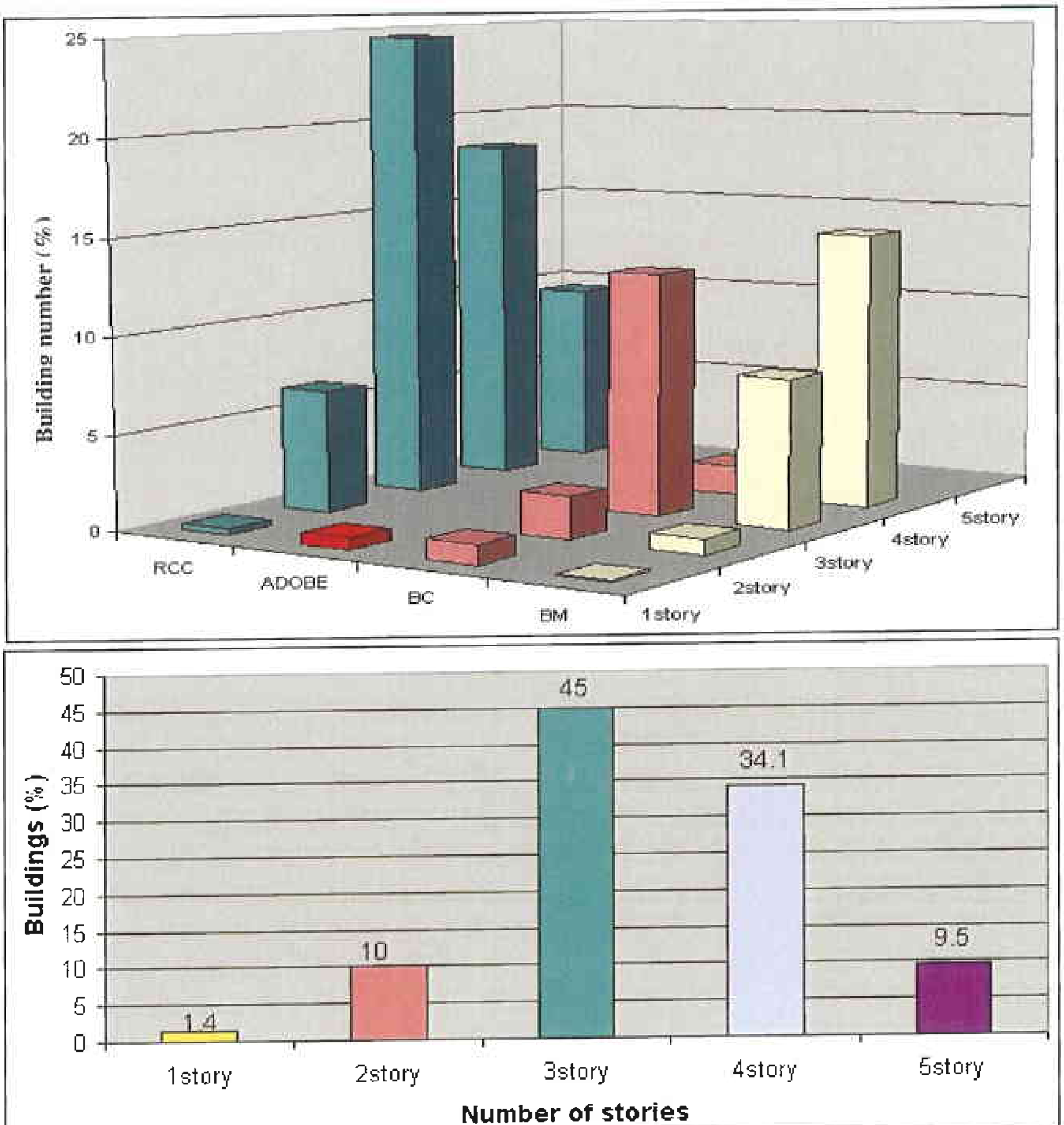


Figure 4.16: Building height given in story number (number in percentage)

4.5. Conclusion

Except for the individual building layer, all the calculation performed in this study is based on homogeneous unit. To find out the number of buildings, in attached building areas (in core) 45 m^2 plinth area was assumed. In other areas, the one polygon was assumed as a single building. In comparison of built up area estimated in the field and calculated taking the foot print layer, high difference was found between these two values (See the table 4.4). This over estimation is true because in the field the built up area considered was the cluster of buildings, which also included small vacant space like narrow-street, boundary wall, home garden etc. In the other hand the calculated built up area is only the building footprint area. The number of buildings and built up area in this study is based on buildings observed on IKONOS image of September 2001 and field survey was carried out two year later in September 2003. The new buildings constructed within this period have also aided to increase the built up areas.

It was also attempted to observe the two types of irregular building: soft stories and cantilever buildings. Significant number of cantilever and soft stories buildings were observed specially in RCC buildings (not included in this report). It was not allowed to inter the army camp to observe the types of the buildings. The buildings in the army camp and also in the zoo area are excluded in this study. Precise and exact digitising of individual building on observing IKONOS image was also difficult especially in core and dense areas. Only to know the approximate built up area and the number of buildings the digitising was completed.

5. Seismic building vulnerability assessment

5.1. Introduction

The procedure on the collection of the number of buildings of various types in each homogeneous unit was described in chapter 4. The results from this chapter are required, together with the vulnerability matrix prepared by NSET Nepal for the building types in Kathmandu Valley in order to find out the number of vulnerable buildings in Lalitpur area, and make a loss estimation for different scenario earthquakes and the corresponding expected intensities. The scenarios in the Lalitpur area were taken from the earlier research carried out by JICA (2002). Two other earthquake hazard zonation maps prepared by colleagues involved in microzonation and liquefaction assessment of the study area (Piya, 2004; Destegul, 2004) were also used to find out the damage scenarios in Lalitpur area. This chapter describes in detail the procedure followed and the results.

5.2. Building damage matrix

Depending upon the earthquake intensity and the building strength, a building may get damage during an earthquake ranging from fine cracks in plaster to the total collapse of the building. When the earthquake intensity is considered constant, the damage grade is then directly related to the strength of a building, which again is related to the material and construction type adopted in the construction (JICA, 2002). Considering the seismic vulnerability, the buildings in Kathmandu valley have been divided into the following classes (Building inventory report, 2001).

- Stone
- Adobe (AD)
- Brick with Mud Mortar, Poorly built (BM)
- Brick with Mud Mortar, Well built (BMW)
- Brick with Cement or Lime mortar (BC)
- Reinforced Concrete Frame with Masonry having four or more stories (RCC4)
- Reinforced Concrete Frame with Masonry having three or less stories (RCC3)

In the Lalitpur area, buildings made from stone were not observed during the fieldwork. The NSET classification has been adopted in this study.

In the table 5.1, the damage matrix, which is the percentage of building-damage-pattern for different earthquake intensities (in MMI) for common building types in Kathmandu valley, is given. This relation has been derived by NSET-Nepal and JICA considering the fragility curves prepared during the earlier building code project with some modification based on damage pattern observed in the 1988 earthquake in Nepal. In the table two types of damage grade patterns are given which were defined by JICA in the following way:

- Heavily Damage: Collapsed or un-repairable
- Partly Damage: Repairable (available for temporary evacuation)

Table 5.1: Damage matrixes for different types of building in Kathmandu (The values represent percentage of buildings with the same material type)

Building type: Adobe+ Field Stone Masonry Buildings

MMI		VI	VII	VIII	IX
PGA (% g)		5-10	10-20	20-35	>35
Damage Pattern (% of buildings)	Total Collapse	2-10	10-35	35-55	55-72
	Partial Damage	5-15	15-35	30	30

Building type: Brick in Mud (BM)

MMI		VI	VII	VIII	IX
PGA (% g)		5-10	10-20	20-35	>35
Damage Pattern (% of buildings)	Total Collapse	0-6	6-21	21-41	>41
	Partial Damage	3-8	8-25	25-28	<28

Building type: Brick in Mud (BMW) and Brick in Cement (BC)

MMI		VI	VII	VIII	IX
PGA (% g)		5-10	10-20	20-35	>35
Damage Pattern (% of buildings)	Total Collapse	0-1	1-5	5-18	>18
	Partial Damage	0-11	1-31	31-45	<45

Building type: R. C. Framed (≥4 storied)

MMI		VI	VII	VIII	IX
PGA (% g)		5-10	10-20	20-35	>35
Damage Pattern (% of buildings)	Total Collapse	0-2	2-8	8-19	19-35
	Partial Damage	0-4	4-16	16-38	38-65

Building type: R. C. Framed (≤3 storied)

MMI		VI	VII	VIII	IX
PGA (% g)		5-10	10-20	20-35	>35
Damage Pattern (% of buildings)	Total Collapse	0-2	2-7	7-15	15-30
	Partial Damage	0-4	4-14	14-30	30-60

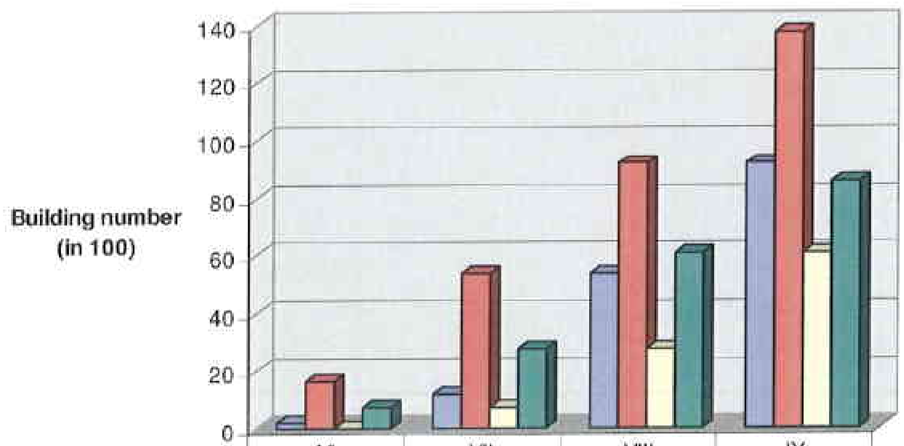
Source NSET Nepal

5.3. Vulnerable buildings in Lalitpur

The buildings with different heights and material types obtained as a result of this study were grouped into the above-mentioned classes. In the damage matrix table, the damage grades are given not with a single percentage value but a range showing minimum and maximum percentage of buildings in that building material class. This intensity-damage relationship was used to estimate the vulnerability of buildings types in Lalitpur area. The following four types of columns for each type of the intensity (from VI to IX) were created in GIS in order to calculate the number of vulnerable buildings in the homogeneous unit.

- Partial damage min (Minimum probable number of buildings having partial damage)
- Partial damage max (Maximum probable number of buildings having partial damage)
- Collapse min (Minimum probable number of buildings having total damage)
- Collapse max (maximum probable number of buildings having total damage)

The figure 5.1 is the result of the building vulnerability analysis in Lalitpur area. This table gives the total number of vulnerable buildings in different damage grades and in the four earthquake-intensities ranging from VI to IX. For example, if an earthquake of intensity IX occurred in the entire Lalitpur Sub-Metropolitan area, a number of buildings ranging from 9192 to 13710 will get partially damaged and 6104 to 8583 will collapse and in total, 15296 to 22293 buildings will be partially or completely damaged.



	VI	VII	VIII	IX
Partial damage min	185	1174	5380	9192
Partial damage max	1647	5388	9192	13710
Collapse min	0	737	2748	6104
Collapse max	737	2748	6104	8583

Intensity (MMI)

Figure 5.1: Total number of damaged buildings in different damage grades in four earthquake intensities

5.4. Scenario earthquakes

In this study, the scenario earthquakes and their corresponding expected intensities and also the liquefaction potential have been taken from earlier research that has been carried out in this area. Since Lalitpur is a flat area, the probability of earthquake-induced landslide is less. Hence landslide hazard has not been considered for the building damage estimation.

The expected earthquake intensities for different probable earthquake scenarios and also the liquefaction susceptibility map have been taken from three sources.

1. From the JICA study which was carried out in 2001-2002 under the project name *The Study on Earthquake Disaster Mitigation in the Kathmandu Valley(JICA, 2002)*
2. The research carried out by the ITC MSc. students who were engaged in the study on microzonation and liquefaction susceptibility mapping in Lalitpur area (Piya, 2004; Destegul, 2004).

In the JICA study, three probable earthquakes in this region were chosen and expected earthquake intensity maps in Modified Mercalli Intensity have been prepared for the whole Kathmandu valley. These model earthquakes have been defined in the following way (JICA, 2002).

- Mid Nepal Earthquake. This earthquake with a magnitude of 8 has been included, considering the seismic gap in the middle of Nepal. This is regarded as a huge earthquake in this region, comparable to the 1934 earthquake.
- North Bagmati Earthquake. Considering the fact that relatively smaller earthquakes occur frequently just north of Kathmandu valley, this earthquake has been chosen. This is regarded as middle scale earthquake
- Kathmandu Valley Local Earthquake (KV Earthquake). This earthquake model has been included based on a local earthquake caused by an active fault in the Southwest of Kathmandu valley.

The main characteristics and location of these earthquakes source are given in table 5.2 and figure 5.2.

Table 5.2: Characteristics of scenario model earthquakes chosen during JICA study

Item		Mid Nepal Earthquake	North Bagmati Earthquake	KV local Earthquake
Fault surface	Length (Km)	135	10	8
	Width (Km)	95	9	4
	Azimuth (Clockwise from north) (degree)	290	290	308
	Dip angle (Degree)	5	37	90
	Depth of upper edge (Km)	5	10	1
Surface wave magnitude (Ms)		8	6	5.7
Moment Magnitude (Mw)		8.03	5.99	5.73
Origin	N (degree)	27.25	27.65	27.65
	E (degree)	84.62	85.27	85.27
Type of Displacement		Reverse slip	Not specified	Not specified

(Source: JICA, 2002)

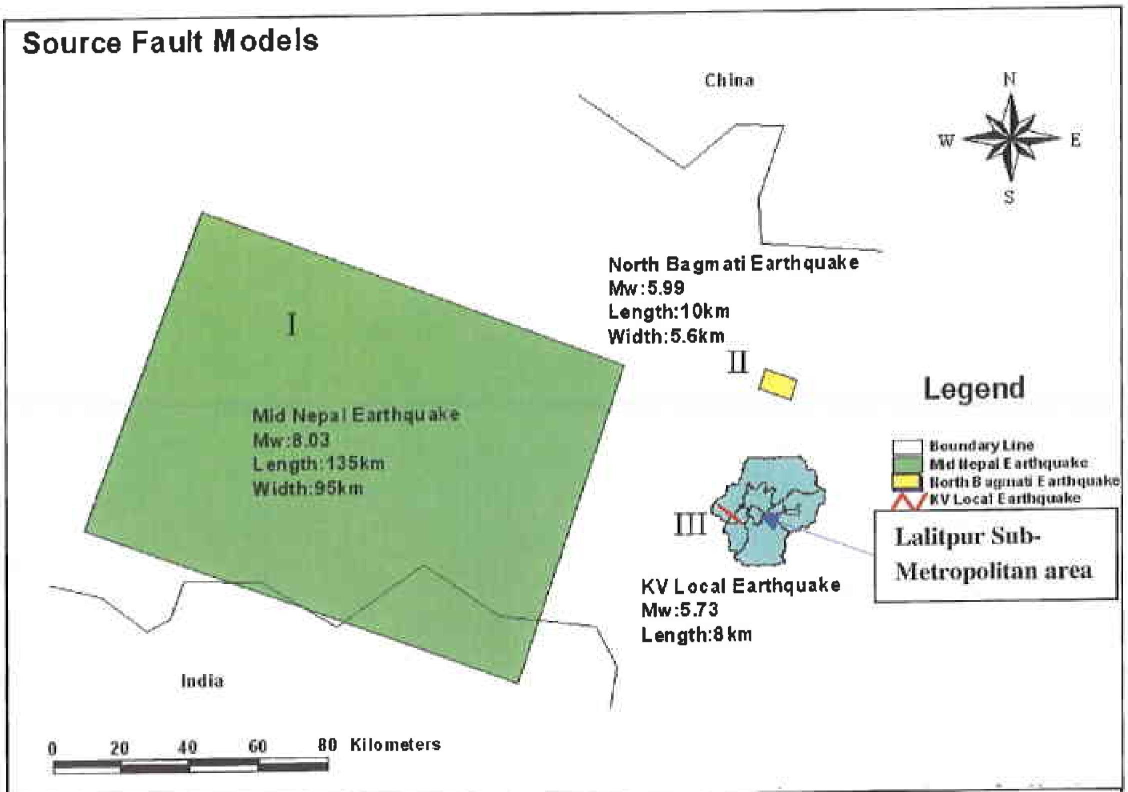
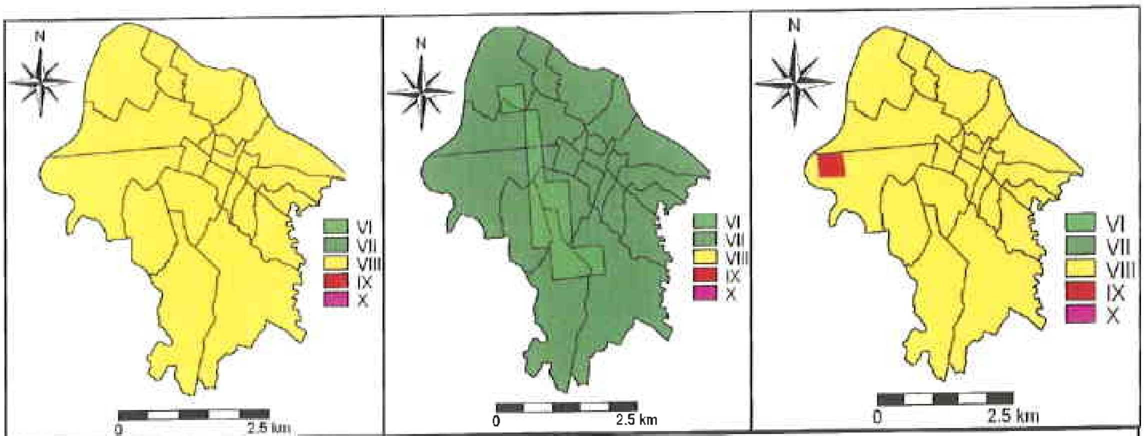


Figure 5.2: Location of the three earthquake-fault model used in JICA study (Source: JICA, 2002)

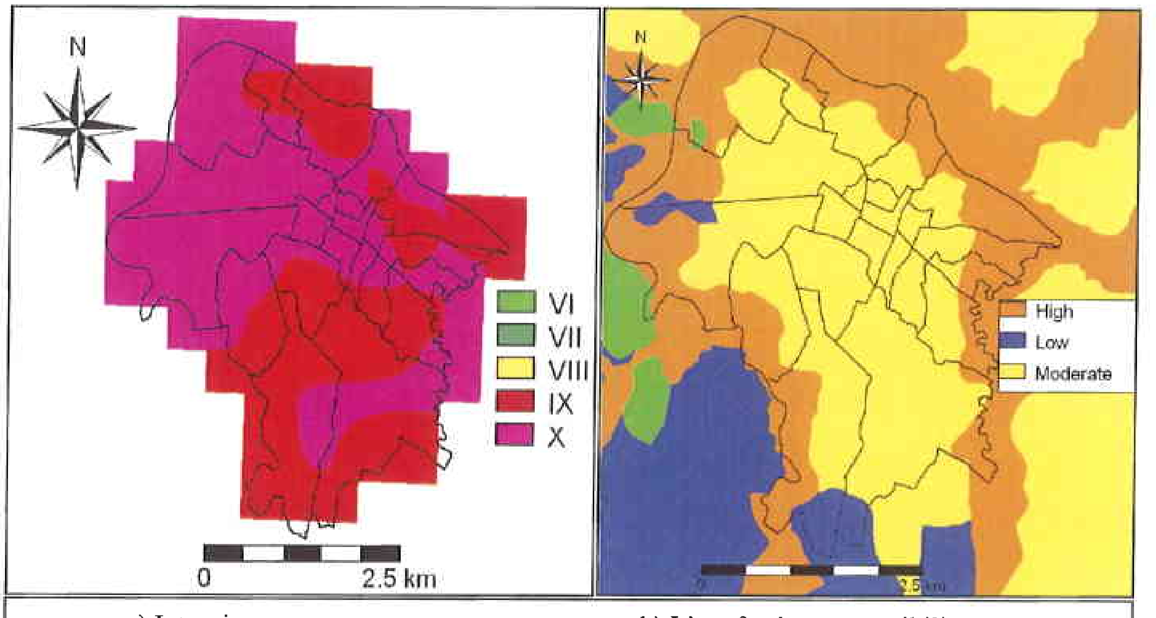
From the intensity maps of the whole Kathmandu valley, only the Lalitpur area was selected and observed. From these maps new intensity maps only covering the Lalitpur area were prepared. In these maps, for different earthquake models, the intensity was found varying from VI to IX (MMI scale (Figure: 5.3)



a) Mid Nepal earthquake b) North Bagmati earthquake c) KV local earthquake

Figure 5.3: Earthquake intensity maps of Lalitpur area for different scenario earthquakes (Source: JICA, 2002)

The ITC MSc colleagues involved in microzonation and liquefaction potential analysis have produced two earthquake hazard maps of this area. One is an intensity zonation map which was created by using a generalized soil profile model, considering an earthquake of magnitude 8 at 48 Km distance from the site (Destegul, 2004). Since this earthquake is a large earthquake, as compared to the expected intensities in JICA study, the intensities values in this case have been found very high with the value ranging from IX to X in MMI scale. The second hazard map of the area is the liquefaction susceptibility map. This map was produced after analysing the borehole data at different places in Kathmandu valley (Piya, 2004). According to this map most of the Lalitpur area lies in the moderate susceptibility class whereas some areas near the river floodplain, are located in the high susceptibility class. These two hazard maps are shown in figure 5.4



a) Intensity map b) Liquefaction susceptibility map

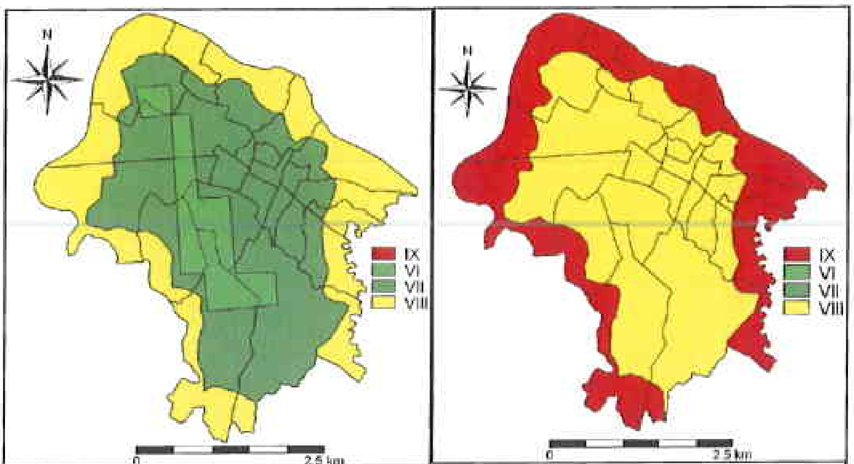
Figure 5.4: Earthquake intensity and Liquefaction susceptibility map of Lalitpur area. (Source: Destegul and Piya)

5.5. Damage estimation

Considering the different expected earthquake intensity values (in MMI) for different earthquake scenarios and applying the vulnerability relation given in chapter 5.3, the damage estimation of building types in the Lalitpur area was carried out. Comparative study was also carried out considering the liquefaction hazard in Lalitpur area. The liquefaction susceptibility was incorporated in the intensity maps of JICA to produce new intensity maps. In assigning new intensity value, it was assumed that the buildings in moderate and low liquefaction susceptible area would get lesser damage than the area with high liquefaction susceptible area. Thus in the high liquefaction area the existing intensity was increased by one. In moderate and low liquefaction area, the intensity was left as it is. The new intensity maps considering the liquefaction is given in figure 5.5

Since, in this study, the building information was aggregated in the homogeneous areas, there was a chance of having more than one intensity value in some of the units. In this case analysis was completed taking the predominant intensity value of the polygon.

Two types of building damages (partial damage and total damage) as given in the vulnerability matrix (table 5.1), were calculated for each scenario earthquake. The number of buildings for each type of damages ranges from the minimum probable number to the maximum probable number. The following sections describe the result of the calculation.



North Bagmati Earthquake | KV local and Mid Nepal Earthquakes

Figure 5.5: New intensity maps produced by considering the liquefaction susceptibility

5.5.1. Damage estimation without considering liquefaction susceptibility

a) Local Kathmandu valley earthquake:

In this scenario earthquake, most of the Lalitpur area lies in the VIII intensity zones. A small area was also observed in intensity IX but considering the predominant intensity value in the homogeneous unit, during calculation, it was also assigned intensity VIII. The total number of heavily damaged building in this earthquake was estimated from 2748 to 6104 and the partial damaged buildings were estimated from 5380 to 9192. In total 30 % to 56 % of buildings were estimated to be heavily or partly damaged. The estimated number of heavily damaged buildings was large in core area as compared to outer fringe area.

b) North Bagmati earthquake:

In this scenario earthquake, the predicted intensity in Lalitpur area is from VI to VII. In this intensity, the total number of partly damaged buildings in Lalitpur area was estimated from 1013 to 4673 and heavily damaged buildings were estimated from 641 to 2470. In total from 6% to 26% of all buildings were estimated to be partly or heavily damaged. The estimated number of damaged buildings was found more concentrated to the core area (Figure 5.6)

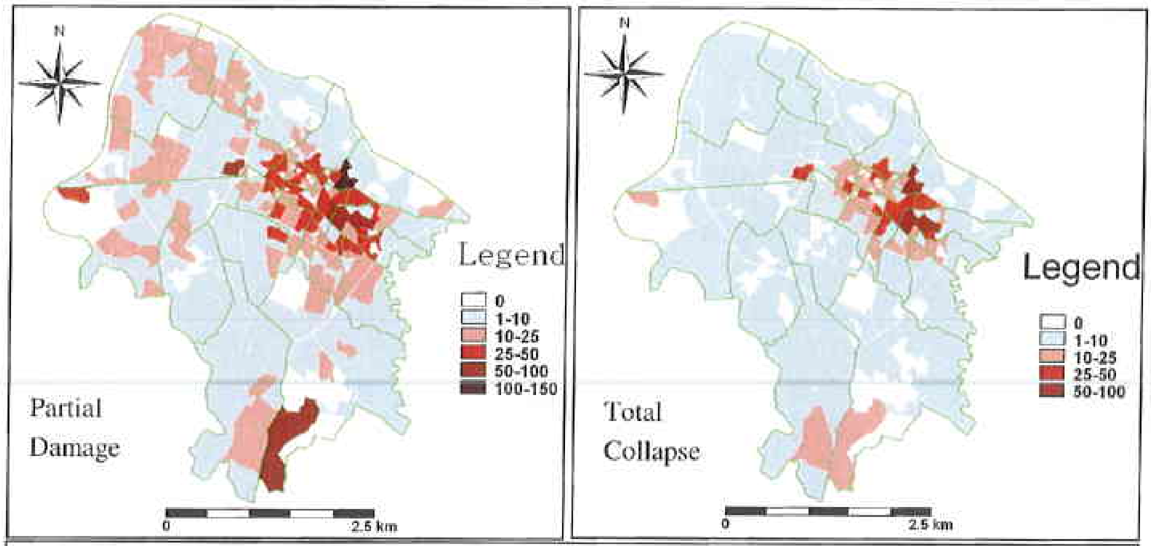


Figure 5.6: Maximum probable number of partially and heavily damaged building distribution in North Bagmati earthquake.

c) Mid Nepal earthquake:

From this earthquake scenario, the expected intensity in the Lalitpur area is similar to the Local Kathmandu Valley earthquake with all area having intensity VIII. The estimated number of damaged buildings is also similar to it.

d) Strong earthquake (with magnitude 8 at a 48 Km source distance)

For this scenario earthquake, the Lalitpur area lies in a zone with predicted intensities ranging from IX to X. Most of the area lies in intensity X as shown in figure 5.4. Since this earthquake is with large magnitude and the source is at a short distance, if occurred, the damage will be very high. This type of earthquake is considered as a very devastating earthquake. Although, for intensities more than IX, the vulnerability relation for building types in Lalitpur area has not been developed, if this type of earthquake occurred, it can be predicted that almost all the buildings will collapse. Since the maximum probable vulnerable building number in intensity IX is the minimum number for intensity X (from vulnerability damage matrix table), it is estimated that in this type of earthquake at least 13710 (51%) buildings will get partial damage, 8583 (32%) buildings will collapse. In total more than 83 % of all buildings will be damaged in this scenario earthquake. The ward wise damaged buildings in Mid Nepal earthquake and Kathmandu Valley Local earthquake is given in table 5.3. For other earthquake scenarios, the ward wise damaged buildings are given in Annex IV.

Table 5.3: Ward wise damaged buildings number in Mid Nepal and Kathmandu Valley Local earthquake scenarios

Mid-Nepal & Kathmandu Valley Local Earthquakes						
Ward No	Partial damage		Total collapse		Damage in total	
	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number
1	190	326	62	160	252	486
2	394	737	154	370	548	1107
3	470	835	185	447	655	1282
4	434	744	175	417	609	1161
5	333	578	99	257	432	835
6	193	313	107	234	300	547
7	83	150	51	111	134	261
8	326	507	215	452	541	959
9	243	392	153	319	396	711
10	161	324	68	162	229	486
11	224	314	158	322	382	636
12	183	298	122	256	305	554
13	187	364	78	187	265	551
14	271	572	126	284	397	856
15	344	592	125	303	469	895
16	219	330	154	316	373	646
17	143	252	82	179	225	431
18	269	405	200	405	469	810
19	191	311	106	234	297	545
20	172	288	94	209	266	497
21	134	210	96	194	230	404
22	216	350	138	286	354	636
Total	**5380**	**9192**	**2748**	**6104**	**8128**	**15296**

The maximum probable number of damaged buildings in Mid Nepal and Kathmandu valley Local earthquake is shown in figure 5.7

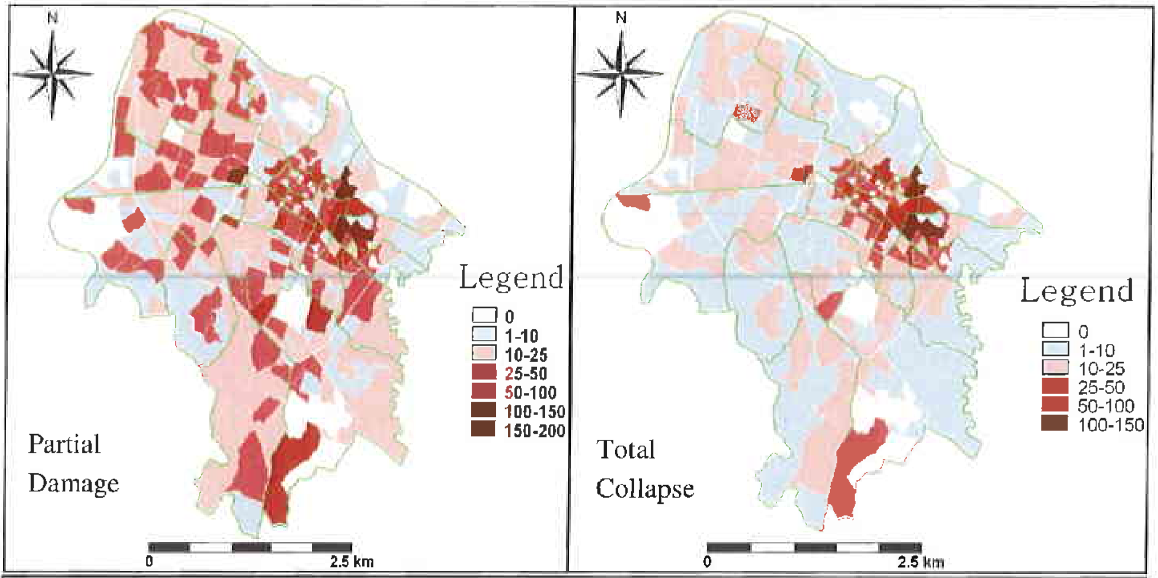


Figure 5.7: Maximum probable number of partially and heavily damaged building distribution in Mid Nepal and Kathmandu Valley Local earthquakes

The summary table of estimated building numbers for various damage grades and earthquake scenarios for whole Lalitpur area is given in Table 5.4

Table 5.4: Damage chart showing the number of buildings in different damage states for various earthquakes (without considering the Liquefaction susceptibility)

Scenario Earthquake/ Damage grade	Intensity	Partial Damage		Total Collapse		Damage in total	
		Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number
Kathmandu Valley Local Earthquake	VIII, IX	5380 (20 %)	9192 (34 %)	2748 (10 %)	6104 (22 %)	8128 (30 %)	15296 (56 %)
North Bagmati Earthquake	VI, VIII	1013 (4 %)	4673 (17 %)	641 (2 %)	2470 (9 %)	1654 (6 %)	7143 (26 %)
Mid-Nepal Earthquake	VIII	5380 (20 %)	9192 (34 %)	2748 (10 %)	6104 (22 %)	8128 (30 %)	15296 (56 %)
Strong earth-quake (M8, at 48 Km)	IX, X, XI	13710 (51 %)	–	8583 (32 %)	–	22293 (83 %)	–

5.5.2. Damage estimation considering effect of liquefaction

a) Local Kathmandu valley earthquake:

In this scenario earthquake, Lalitpur area lies in VIII and IX intensity zones. The intensity IX is in the low land area where liquefaction probability is high (Figure 5.5). In this case partially damaged buildings were estimated from 5804 to 9779 and heavily damaged buildings were estimated from 3034 to 6412 in numbers. In total, 32 % to 59 % of buildings were estimated to be partly or heavily damaged. In this earthquake, partially damaged buildings were found distributed in the whole city area where as heavily damaged buildings were concentrated in core centre area.

b) North Bagmati earthquake:

In this scenario earthquake, Lalitpur area lies in VI to VIII intensity zones. In this scenario earthquake partial damaged buildings were estimated from 1408 to 5102 and the probable number collapsed building were estimated from 798 to 2758 in numbers. In total from 8 % to 29 % buildings were estimated to be fully or partly damaged.

c) Mid Nepal earthquake:

Similar to Kathmandu Valley Local earthquake, the expected intensities in this case also range from VIII to IX. The estimated damaged buildings in this case are same to Kathmandu Valley Local earthquake.

d) Strong earthquake with magnitude 8 at 48 Km distance:

Already, it is such a strong earthquake that no further liquefaction susceptibility was considered in this scenario earthquake. The damage for this scenario is already very extensive.

The summary table for estimated damaged buildings in two damage states for different scenario earthquake considering the liquefaction susceptibility is given in table 5.5.

Table 5.5: Damage chart showing number of buildings in different damage states for various earthquake scenarios (Considering the Liquefaction susceptibility)

Scenario Earthquake/ Damage grade	Intensity	Partial Damage		Total Collapse		Damage in total	
		Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number
Kathmandu Valley Local Earthquake	VIII, IX	5804 (21 %)	9779 (36 %)	3034 (11 %)	6412 (23 %)	8838 (32 %)	16191 (59 %)
North Bagmati Earthquake	VI, VII, VIII	1408 (5 %)	5102 (19 %)	798 (3 %)	2758 (10 %)	2206 (8 %)	7860 (29 %)
Mid-Nepal Earthquake	VIII, IX	5804 (21 %)	9779 (36 %)	3034 (11 %)	6412 (23 %)	8838 (32 %)	16191 (59 %)

The partially and heavily damage distribution of buildings in various scenarios are shown in the following figures (Figure 5.8-5.10)

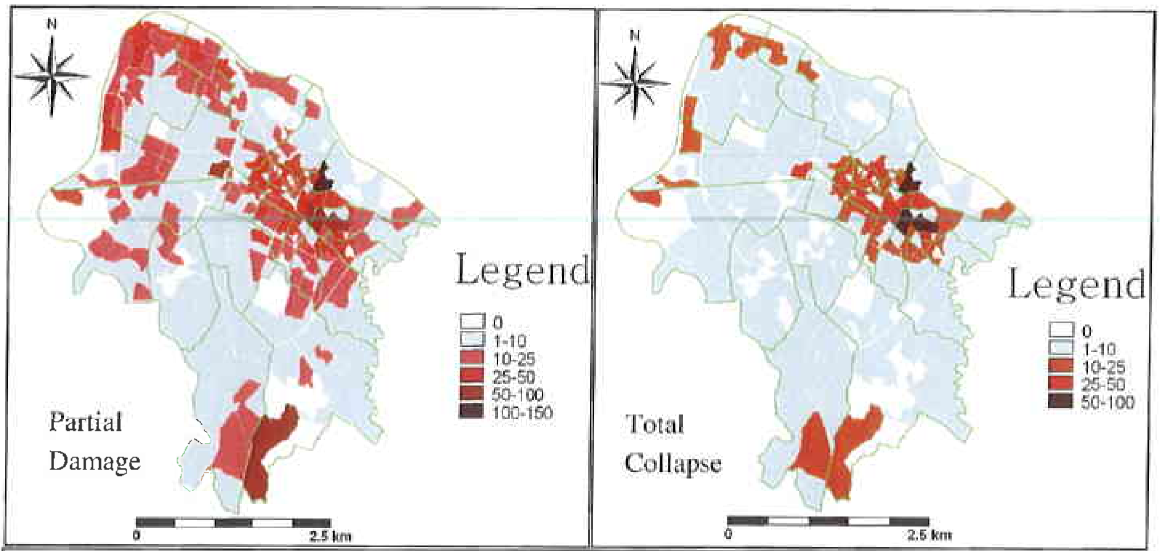


Figure 5.8: Maximum probable number of partially and heavily damaged building distribution in North Bagmati earthquake (Considering Liquefaction)

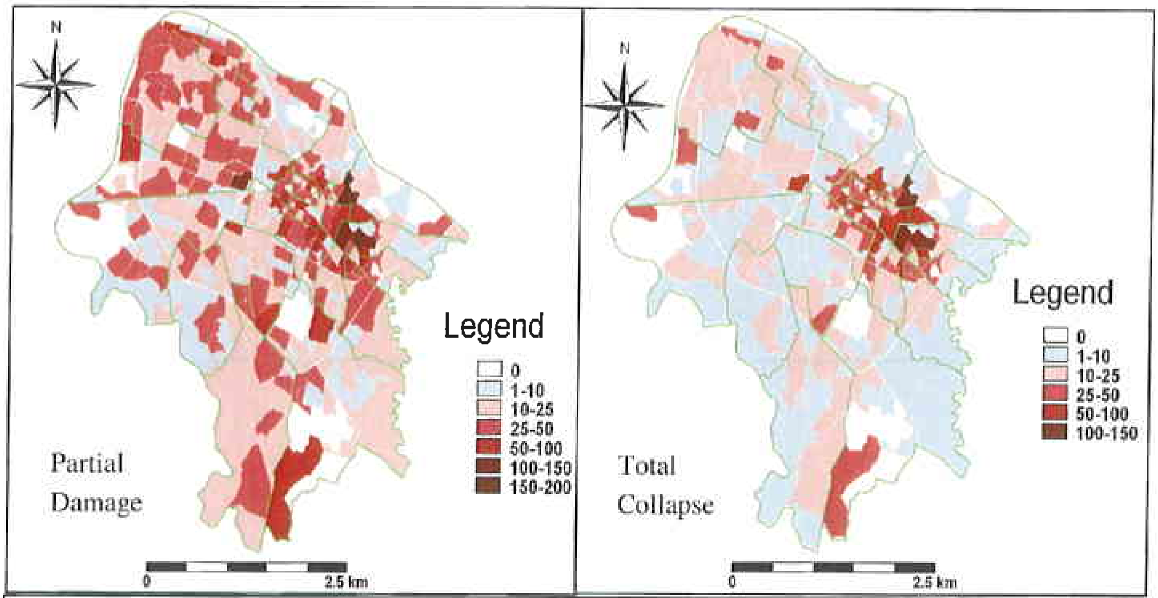


Figure 5.9: Maximum probable number of partially and heavily damages buildings distribution in Mid Nepal and Kathmandu Valley earthquakes (Considering liquefaction)

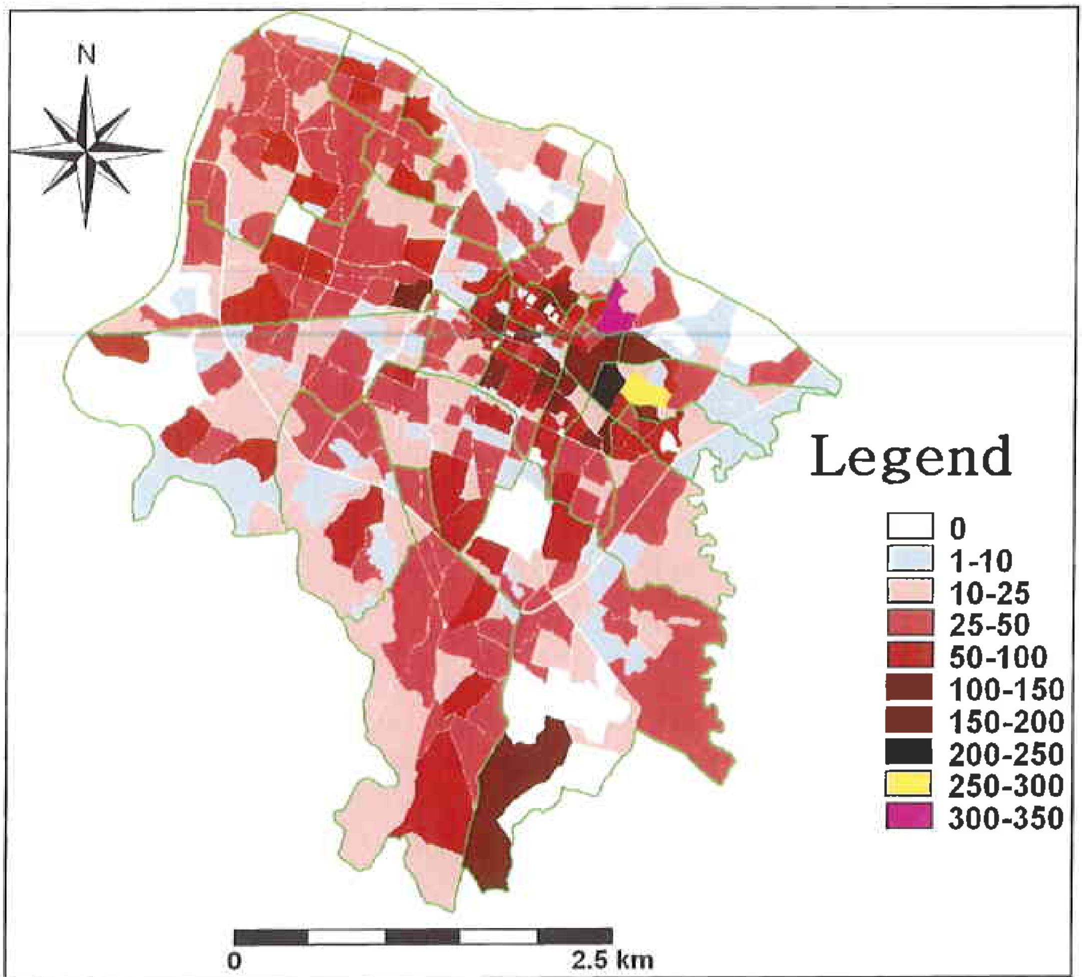


Figure 5.10: Total damaged buildings distribution in Mid Nepal and Kathmandu Valley earthquakes

5.5.3. Damage comparison:

For each scenario earthquake, a larger number of buildings are found damaged in the core centre area. This is due to the predominant old and vulnerable weak adobe and brick-in-mud wall buildings in this area. The expected damages for relatively smaller earthquake like North Bagmati earthquake, is smaller and focused in the core area whereas for large earthquakes like the Mid Nepal scenario earthquake, the building damage distribution was found in every part of Lalitpur area. For strong earthquakes like one with magnitude 8 and at a closer distance of 48 Km, the damage was found very heavy. Even considering the minimum probable value, 83% of the total buildings were found damaged partially or heavily. The damage distribution was also found related to the size of the homogeneous unit taken. In some units, in the new developing area, larger numbers of buildings were found damaged because of the bigger size of the unit having more buildings within it.

6. Conclusions and recommendations

6.1. Conclusions

The seismic building vulnerability assessment in the Lalitpur area was carried out considering the three objectives of this study: database preparation, evaluation of suitable vulnerability functions and damage estimation for different earthquake scenarios. With respect to the second objective it was decided to use the earthquake vulnerability functions for different building types from the earlier research carried out in this field by the National Society for Earthquake Technology (NSET). In achieving the third objective GIS maps and functions were created and linked to the building data in the Lalitpur area. Most of the time in this research was spent, however, in achieving the first objective, and preparing the building database for the Lalitpur area.

In order to carry out the seismic vulnerability assessment of buildings, information about the building occupancies, building types and possible seismic defects of the buildings is needed which was only possible to obtain from direct field observation. In this study a field survey was carried out in a limited period of 1 month, during which it was not possible to collect the building information at the individual building level, instead it was decided to describe groups of buildings within relatively small clusters. A total of 500 of such clusters, or homogeneous units, were delineated in the 15.5 sq Km municipal area of Lalitpur. The clustering was completed to make it more homogeneous in terms of building occupancies. A 1: 5000 scale base map, prepared from a 1m-resolution satellite image, was used for the positioning and delineation of these clusters.

Due to the mixed building character in terms of occupancies and types, the maximum available time was spent in the field to collect this type of information. Although it took more time, it was realized that the smaller the polygons were taken, the better was the information collection. The smaller polygons also gave the best result when GIS operations like crossing were performed with other GIS maps during the analysis. It was also realized that the fieldwork period was not sufficient for precise building observation in the whole Lalitpur area..

In the field it was also tried to take the data digitally using mobile GIS with a palmtop (Ipaq) and a GPS. The IKONOS image was loaded in the palmtop. In the field working with this system was slow because it took a long time to open and locate the position due to the large file size of the base image. So it was decided to take the building information in the traditional approach using survey forms. In this aspect, the digital data capturing technique is only appropriate if the base map is small enough, or the capacity of the palmtop large enough.

During the fieldwork also the available digital data was collected for the study area. By far the most important type of data, the digital topographical map containing the individual building footprints, was only available in Auto Cad DXF format, and in a series of map sheets with a different coordinate system. The conversion of this dataset to a useable GIS data layer that could be used in the building data collection could unfortunately only be done in the period after the fieldwork. If the digital building footprint data had been available at the start of the fieldwork period, it would have changed the data collection procedure considerably. It would have been possible to use the vector data layer in a mobile GIS, and to collect data on individual buildings. If the building information had been taken individually, the spatial location of individual building and also the attribute information would have been more accurate than the percentage information taken in the clusters of buildings

The missing building data in this study were digitised observing the changes on the IKONOS image with respect to the building footprint map, which was from 1998. It was also noticed that the proper digitizing of building footprint based on the IKONOS image is rather difficult, especially in the core city area, where many buildings are interconnected. In this study the building footprint area has been digitized only to find out the number of buildings and to calculate the approximate built up areas. Field verification and updating is necessary to these building layers.

For cities where there is no digital building information available and when it is not possible to collect the information for individual buildings, the cluster sampling method is appropriate for seismic hazard assessment. Clusters can be made homogeneous in terms of building types or occupancies according to the building characteristics in the study area.

The seismic building damage matrix for earthquake intensities ranging from VI to IX for the various building types in Kathmandu Valley, which was prepared by NSET Nepal, was used in this study. GIS operations were performed to link this relation to the building types in the Lalitpur area in order to find out the number of damaged buildings in different damage states.

The building damage estimation was carried out for different earthquake scenarios. Three earthquake scenarios form the JICA study in 2002 and two earthquake hazard scenarios prepared by ITC MSc. students were used to estimate the number of damaged and collapsed buildings in the Lalitpur area.

In this study, according to the earthquake type and expected intensities, partial damaged buildings were estimated ranging from 1013 (4%) to 13710 (51%). Similarly collapse buildings were estimated ranging from 641 (2%) to 8583 (32%).

In JICA study for whole Kathmandu valley the estimated damaged buildings were from 16.8% to 50.1 %. In this study for the same type of earthquakes in Lalitpur, 26% to 56% buildings were estimated to be damaged.

6.2. Recommendations

If there is no individual digital building foot print map or if the seismic building damage assessment has to be carried out in limited time, not enough to collect the building information individually, the homogeneous unit approach used in this study is appropriate to be applied in other cities. Obviously the more time given to observe the unit and the smaller the polygon taken the more accurate will be the information collection.

In this study, the new building layers in Lalitpur area were digitised from IKONOS image simply to know the number of buildings and footprint area. Field verification and updating of these buildings is necessary to find out the exact number of buildings. Besides, the foot print layer in the core area, which has been digitised in cluster form, needed to split to form individual building layer.

Since there is now a GIS building footprint map of Lalitpur area, it can be used for detailed vulnerability studies of individual buildings.

Significant number of seismic defects buildings like cantilever and soft stores RCC building were observed during the field visit which have not been incorporated in the damage matrix table prepared by NSET Nepal. Building construction following the seismic code has also been started in Lalitpur area. The structure analysis of these buildings is necessary to create damage matrix for these types of buildings.

More study should be carried out to find out the appropriate evacuation sites for post earthquake scenarios. It was realized that only limited vacant space is available in the Lalitpur area itself, and appropriate sites could only be found considering the available space in neighbouring Village Development Committees areas.

Some other aspects that might be incorporated in the recommendations:

- Best to work on individual buildings. Especially when there is a digital footprint map available.
- Lalitpur sub metropolitan office should start standardized building data collection system, to collect attributes related to the footprint data.
- The building database that will be generated on the buildings will be a multi-purpose database, and can be used for other municipal planning and management activities (e.g. cadastral, population registration etc).
- The database of buildings should play a key role in the design of a system for building permit registration and control, which is one of the most urgent activities in the framework of earthquake vulnerability reduction in the Lalitpur area.
- It is very important that Lalitpur works out a system of proper addressing, as has been done for Kathmandu.

References

Adhikari A.P. 1998. *Urban and Environmental Planning in Nepal, Analysis, Policies and Proposals*, IUCN Nepal, Kathmandu.

Ambrose J, Vergun D, 1999. Design for Earthquakes. John Willey & Sons, Inc. New York

ATC/SCAOC, 1993. *Training curriculum*, Applied Technology Council (ATC) and the Structural Engineers Association of California (SEAOC), (www.atcouncil.org)

Building by laws (Nepali) 1993. His Majesty's Government of Nepal, Kathmandu Valley Town Development committee. Kathmandu, Nepal

Baag C. E., Kim J. K., Yoon E. T., Kang T. S., Kim I. H., Lee I. K., 2002. *Seismic damage assessment in a model district of the Seoul, the capital city of Korea.* A paper presented in the 7th US National Conference on Earthquake Engineering (July21-25), Boston, Massachusetts

Bothara J.K. , Parajuli Y.K. , Arya A.S. , D Sharpe R., 2000. *Seismic safety in owner-built buildings.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

Building Inventory Survey Report, 2001, National Society for Earthquake Technology-Nepal (NSET-Nepal),

Chiroiu L., Eeri M., Andre G., Guillande R. and Bahoken F., 2002, *Earthquake damage assessment using high resolution satellite imagery.* A paper presented in the 7th US National Conference on Earthquake Engineering (July21-25), Boston, Massachusetts

CBS , 2001. *National Population Census*, Central Bureau of Statistics, Kathmandu Nepal

Destegul U.,2004. Sensitivity Analysis of soil site response Modelling in seismic microzonation for Lalitpur Nepal, ITC M.sc. Thesis

Dixit A. M., R D Welley Samant L., Nakarmi M., Pradhanang S. B., Tucker B. E. 2000. *The Kathmandu Valley Earthquake Risk Management.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

DMTP, 1994. *Disaster Management Training Programme.*Cambridge Architectural Research Limited, The Oast House, Malting Lane, Cambridge, United Kingdom

(EMS-98) *European Macroseismic Scale 1998*, Editor G. Grünthal Luxembourg,1998 (http://seismohazard.gfz-potsdam.de/projects/ems/eng/index_eng.html)

FEMA303, 1997. *Recommended Provisions for Seismic Regulations for new Buildings and other structures* ,Washington,

FEMA 310,1998. *Handbook for the Seismic Evaluation of Existing Buildings*, Washington.

Fujii R., Kuwahara Y. and Saki H.,2001. *Mineral composition changes recorded in the sediments from a 248-m-long drill-well in central part of the Kathmandu Basin, Nepal* Journal of Nepal Geological Society , vol. 25 pp 63-69.

Hazus 99, 1999. *Earthquake Loss Estimation Methodology User Manual* Federal Emergency Management Agency Washington, D.C (http://www.fema.gov/hazus/)

Hazirbaba K., Gullu H., Yildirim Y., Sari A., 2002. *Soil amplification and structural damage relationship during Dinar earthquake.* A paper presented in the 7th US National Conference on Earthquake Engineering (July21-25), Boston, Massachusetts.

IBC, 2000, *International Building Code*, International Code Council

IAEE Manual, 1986, National Information Centre of Earthquake Engineering at IIT Kanpur, India.(http://www.nicee.org/Manuals/iaee/iaee_manual.htm)

JICA, 2002, *The Study on Earthquake Disaster Mitigation in the Kathmandu valley Kingdom of Nepal. Final report, Vol - I, II, III &IV.* Japan International Cooperation agency (JICA) and Ministry of Home affairs, His Majesty's Government of Nepal

Montoya A. L. 2003. *Geo-data acquisition through mobile GIS and digital video: an urban disaster management perspective.* Environmental Modelling & Software 18 (10) 869–876

Montoya A. L., 2002. *Urban Disaster Management, A Case Study of Earthquake Risk Assessment in Cartago, Corta Rica.*ITC Publication Series No. 96

KVMP ,2001.*Manual on Metric Addressing System, Kathmandu Valley Mapping Programme*, His Majesty's Government of Nepal and Commission of the European Communities

Midorikawa S., Fujimoto K. and Arai J., 2002. *Preliminary Assessment of building damage due to a scenario earthquake in Metro Manila, Philippines.* A paper presented in the 7th US National Conference on Earthquake Engineering (July21-25), Boston, Massachusetts

Munich-Re, 2000. CD Rom: *World of Natural Hazard* (http://www.munichre.com)

Murakami S.And Sadohara S., 2000. *A study on scenario type seismic damage estimation by using GIS.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

NBC 1994. *Nepal National Building Code (NBC): NBC 105, NBC 109, NBC 201, NBC 202,NBC 203 NBC 204, NBC 205*, His Majesty's Government of Nepal, Ministry of Housing and Physical Planning, Department of Building.

O'Rourke and Jeon , 2000. *GIS Loss Estimation and Post Earthquake Assessment of residential building damage.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

Okazaki K. and RADIUS team, 2000. *RADIUS Initiative for IDNDR- How to reduce urban seismic Risk.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

Onur T., Ventura C. E., and Liam Finn W. D., 2002. *Seismic Damage estimation in southwestern British Columbia.* A paper presented in the 7th US National Conference on Earthquake Engineering (July21-25), Boston, Massachusetts

Piya, B.K. 2004, *Generation of Geological database for Liquefction hazard assessment in Kathmandu valley,* ITC M.sc. thesis

RADIUS, 1999, *Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters*, Launched by IDNDR, United Nations (http://geohaz.org/radius/)

Rossetto T. and Elnashai A., 2002. *Derivation of vulnerability functions for European-type RC structures based on observational data*, Engineering Structures 25 (2003) 1241–1263

Stehle J., Jones T., Schneider J., Stewart D., and Corby N., 2002. *Eartquake vulnerability and risk for new castle Australia.* A paper presented in the 7th US National Conference on Earthquake Engineering (July21-25), Boston, Massachusetts

Spence R., Peterken O., Booth E., Aydinoglu N., Bommer D.R.J., Tabuchi S., 2002. *Seismic loss estiamation for Turkish Catastrophe Insurance.* A paper presented in the 7th US National Conference on Earthquake Engineering (July21-25), Boston, Massachusetts

Scawthorn C., Rojahn C.and Shome N., 2002. *Rapid visual screening for potential seismic Hazards innovations to the methodology.* A paper presented in the 7th US National Conference on Earthquake Engineering (July21-25), Boston, Massachusetts

Surahman A., 2000. *Earthquake vulnerability evaluation of buildings in Bandung Municipality.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

UNDP, 1994,*1.Seismic Hazard Mapping and Risk Assessment for Nepal,*
2.Development of Alternative Building Materials and Technologies
3.Seismic vulnerability analysis, (Appendix c)
His Majesty's Govt. of Nepal, Ministry of Housing and Physical Planning, UNDP/UNCHS Habitat), Subproject NEP/88/054/21.03,1994.

Villacis C.A., Cardona C.N., Tucker B., 2000. *Implementation of fast earthquake scenario for risk Management in developing countries.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

VILLACIS C.A. Carlos A, 2000. *Radius an IDNDR project on urban earthquake risk management.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand.

Surahman A., 2000. *Earthquake vulnerability evaluation of buildings in Bandung Municipality.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

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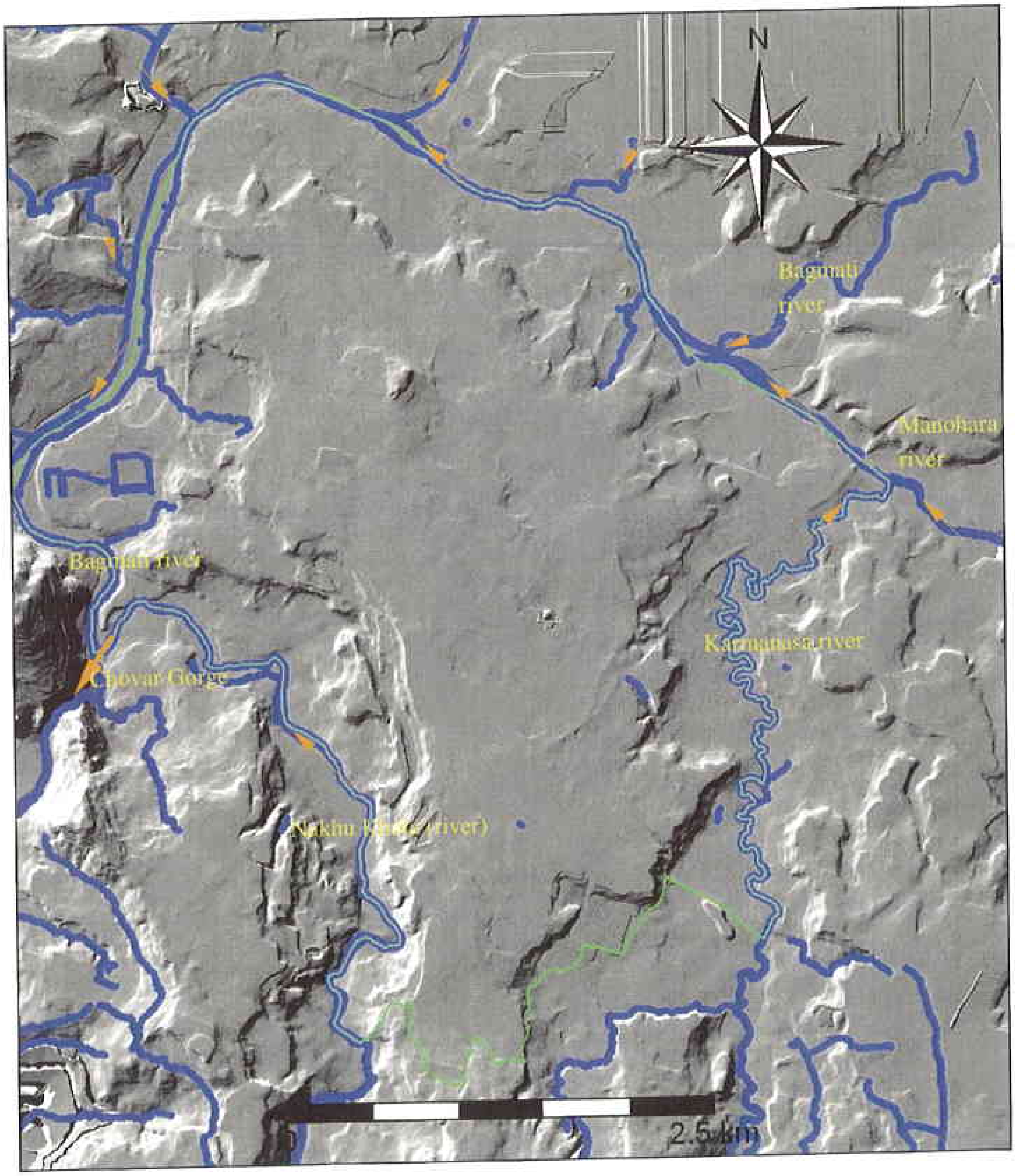
Villacis C.A., Cardona C.N., Tucker B., 2000. *Implementation of fast earthquake scenario for risk Management in developing countries.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand

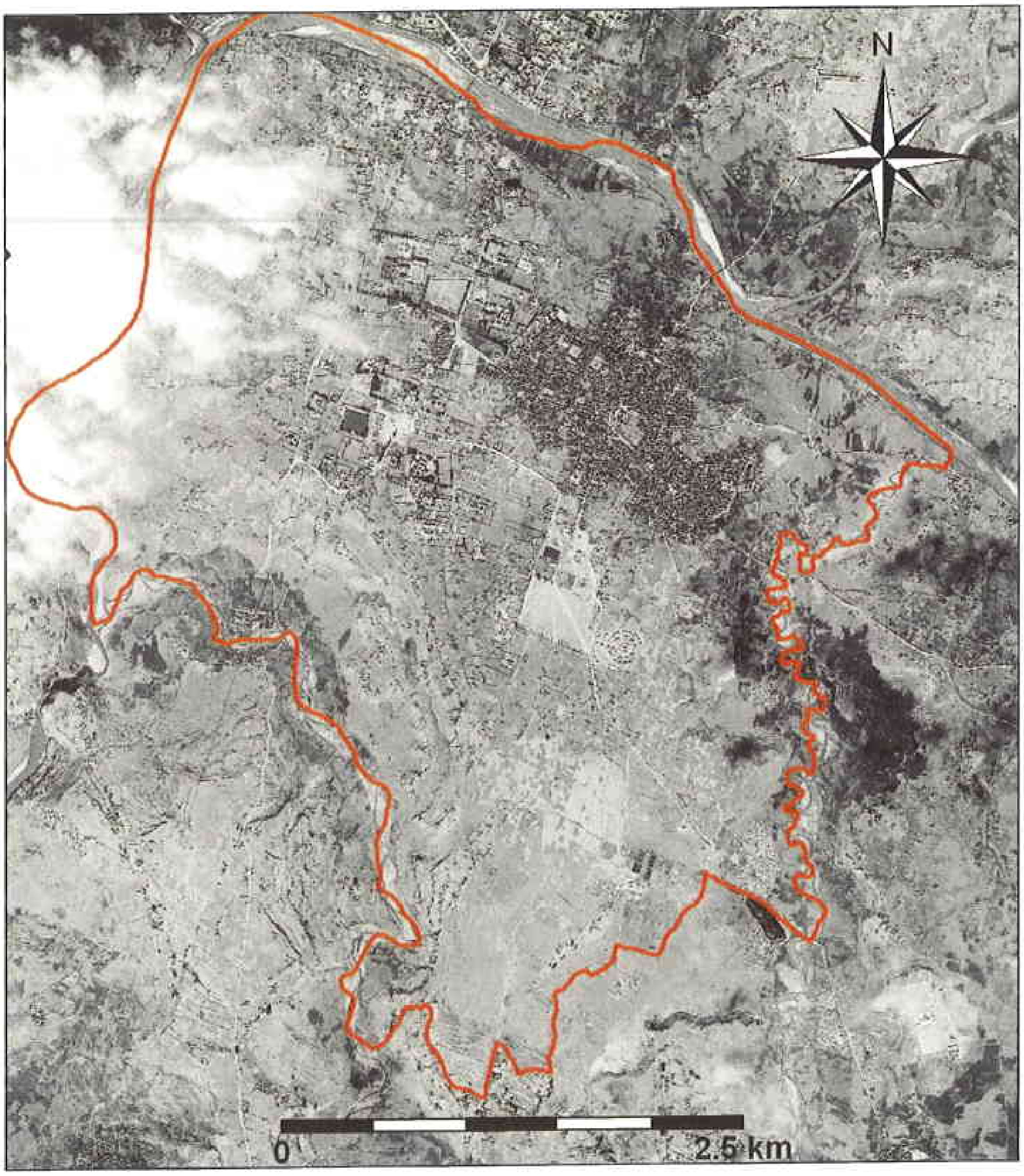
VILLACIS C.A. Carlos A, 2000. *Radius an IDNDR project on urban earthquake risk management.* A paper presented in the 12th World Conference on Earthquake Engineering (30 Jan-4 Feb), Auckland New Zealand.

Annex I: River system in Lalitpur area showing on the shadow map created from DEM

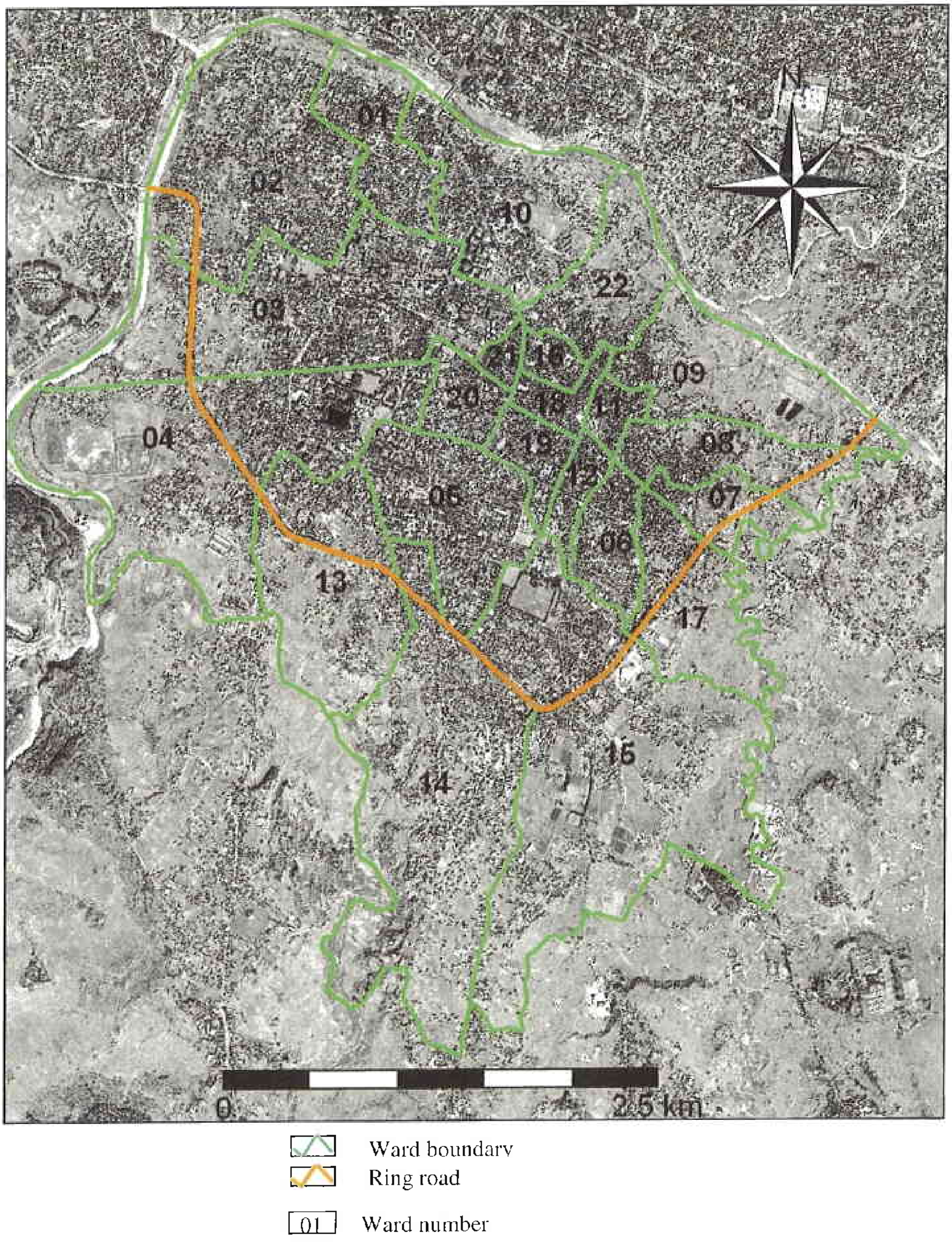


River system
Lalitpur Sub-Metropolitan area boundary
Flow direction

Annex II: Lalitpur in 1967 (CORONA image)



Annex III: Lalitpur in 2001 (IKONOS PAN)



Annex IV: Ward wise distribution of damaged buildings in different earthquake scenarios

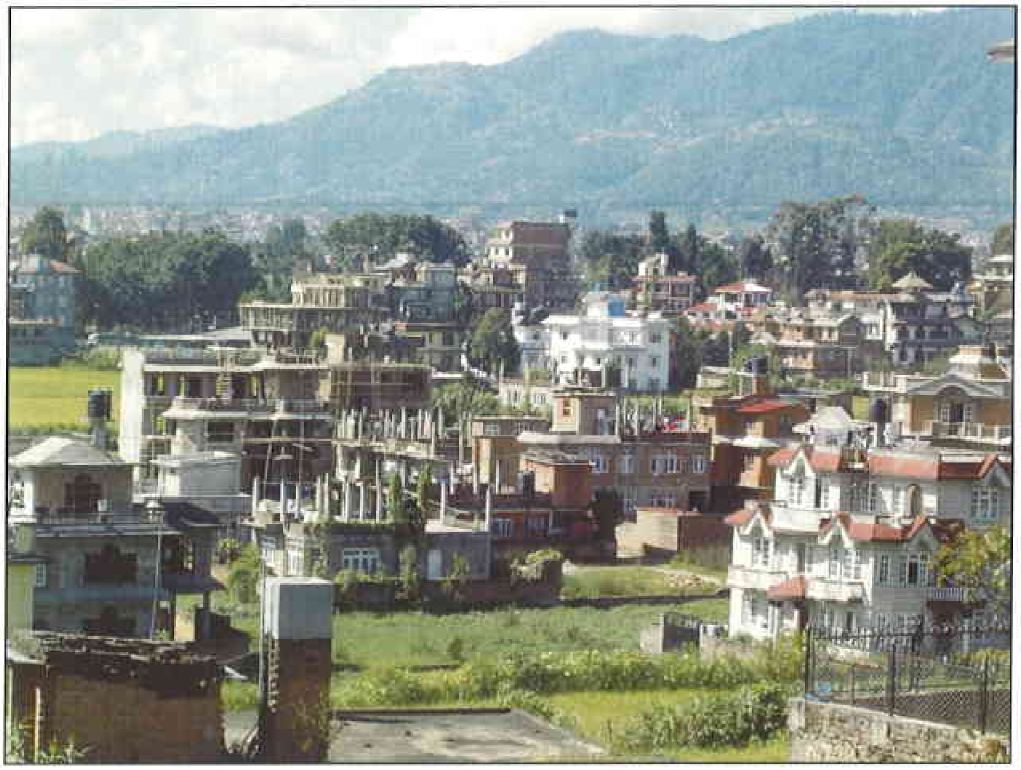
North-Bagmati Earthquake						
Ward No	Partial damage		Total collapse		Damage in total	
	Minimum probable number	Maximum probable number	Minimum probable number	Minimum probable number	Minimum probable number	Maximum Probable number
1	24	190	15	62	39	252
2	54	293	24	113	78	406
3	64	374	38	151	102	525
4	65	387	38	159	103	546
5	10	180	7	47	17	227
6	43	193	29	107	72	300
7	23	83	14	51	37	134
8	89	326	58	215	147	541
9	65	244	42	153	107	397
10	33	161	21	68	54	229
11	62	225	44	158	106	383
12	49	184	34	122	83	306
13	17	108	10	45	27	153
14	33	165	17	79	50	244
15	24	213	12	70	36	283
16	62	219	44	154	106	373
17	37	143	23	82	60	225
18	82	271	54	200	136	471
19	43	191	29	106	72	297
20	39	172	23	94	62	266
21	39	135	26	96	65	231
22	56	216	39	138	95	354
Total	**1013**	**4673**	**641**	**2470**	**1654**	**7143**

Mid-Nepal & Kathmandu Valley Local Earthquake (Considering liquefaction)						
Ward No	Partial damage		Total collapse		Damage in total	
	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number
1	257	399	107	199	364	598
2	529	937	226	476	755	1413
3	510	894	209	480	719	1374
4	461	758	211	426	672	1184
5	333	578	99	257	432	835
6	193	313	107	234	300	547
7	97	173	59	124	156	297
8	350	546	239	470	589	1016
9	269	432	172	340	441	772
10	224	409	108	206	332	615
11	224	314	158	322	382	636
12	183	298	122	256	305	554
13	194	377	82	193	276	570
14	276	582	129	289	405	871
15	344	592	125	303	469	895
16	219	330	154	316	373	646
17	143	252	82	179	225	431
18	269	405	200	405	469	810
19	191	311	106	234	297	545
20	172	288	94	209	266	497
21	134	210	96	194	230	404
22	232	381	149	300	381	681
Total	**5804**	**9779**	**3034**	**6412**	**8838**	**16191**

North Bagmati Earthquake (Considering liquefaction)						
Ward No	Partial damage		Total collapse		Damage in total	
	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number
1	97	257	36	107	133	364
2	154	428	65	185	219	613
3	92	414	51	175	143	589
4	110	412	59	193	169	605
5	10	180	7	47	17	227
6	43	193	29	107	72	300
7	33	97	18	59	51	156
8	119	350	71	239	190	589
9	91	270	54	172	145	442
10	93	231	42	112	135	343
11	62	225	44	158	106	383
12	49	184	34	122	83	306
13	22	115	12	49	34	164
14	37	170	18	82	55	252
15	24	213	12	70	36	283
16	62	219	44	154	106	373
17	37	143	23	82	60	225
18	82	271	54	200	136	471
19	43	191	29	106	72	297
20	39	172	23	94	62	266
21	39	135	26	96	65	231
22	70	232	47	149	117	381
Total	**1408**	**5102**	**798**	**2758**	**2206**	**7860**

Strong Earthquake (M8 at 48 Km)						
Ward No	Partial damage		Total collapse		Damage in total	
	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number	Minimum probable number	Maximum probable number
1	455	-	231	-	686	-
2	1176	-	607	-	1783	-
3	1268	-	678	-	1946	-
4	1080	-	601	-	1681	-
5	833	-	388	-	1221	-
6	440	-	305	-	745	-
7	238	-	160	-	398	-
8	709	-	565	-	1274	-
9	582	-	424	-	1006	-
10	553	-	285	-	838	-
11	388	-	371	-	759	-
12	426	-	333	-	759	-
13	607	-	317	-	924	-
14	1082	-	547	-	1629	-
15	868	-	449	-	1317	-
16	443	-	384	-	827	-
17	386	-	252	-	638	-
18	544	-	493	-	1037	-
19	423	-	298	-	721	-
20	412	-	275	-	687	-
21	289	-	246	-	535	-
22	508	-	374	-	882	-
Total	**13710**	-	**8583**	-	**22293**	-

Annex V: Some examples of buildings in Lalitpur area

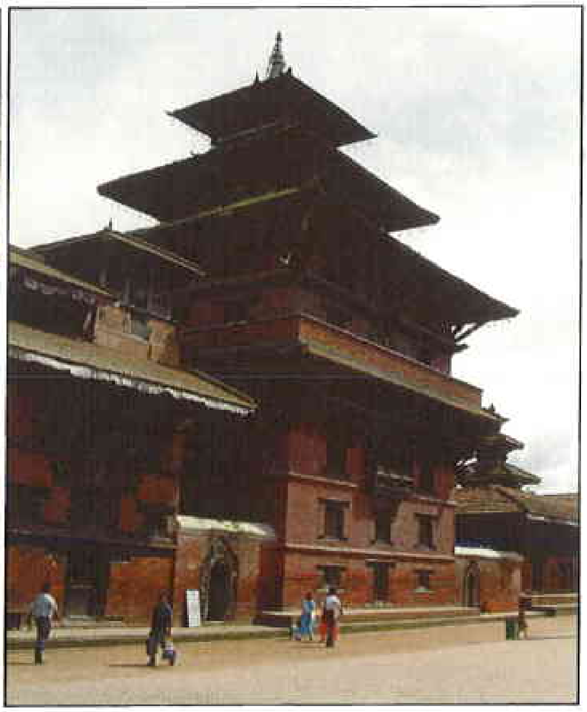


a) Buildings in new developing area, RCC buildings

b) A courtyard area ,RCC and BM buildings

c) Buildings in core centre area RCC and BM buildings

d) A temple only made by stone



e) Historical Palace (an example of BMW)