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GIS Approach to Map the Levels of Earthquake Vulnerability of Buildings in Some Areas Effected by 2015 Earthquakes in Nepal

by

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the degree of
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Kathmandu, 20.11.2017

Science pledge

By my signature below, I certify that my project report is entirely the result of my own work. I have cited all sources of information and data that I have used in my project report and indicated their origin.

Kathmandu, Nepal

20-November-2017

Place and Date	Signature

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November, 2017

Abstract

Buildings are very important for people to live but when earthquake strikes many buildings can become very dangerous to people's lives. As Nepal is known to experience earthquakes periodically, the buildings need to be assessed so that proper action can be taken place to create an earthquake resilient environment. This study was conducted to apply GIS in order to analyze the earthquake vulnerability of buildings by considering multiple criteria of building structure and also to study the spatial distribution of buildings that are most likely to cause damage. The study region chosen for this research was Birendranagar Municipality (wards 5,6,7,8,9,10,16,17 and 18), Birtamod and Vyas.

The study focused on data from Building Inventory Data Survey (BIDS), a mobile based survey run by National Society for Earthquake Technology (NSET), to conduct the analysis. A Web-GIS application for validating the BIDS datasets was also developed. In order to assess the buildings, first the earthquake hazard in the three study regions were identified. Then the factors of buildings that contribute to the earthquake vulnerability were identified. Then, pairwise comparison method was used to find the factors' weights which was used to compute Earthquake Vulnerability Index (EVI) of those buildings. This was used to compute the probability of damage to the buildings. Highly damage prone building's collapse zone was also assessed to identify safe buildings and people that could be damaged due to nearby vulnerable buildings.

The result of this research shows that in all three study areas, there are less than 10% buildings that are built as well as they can be when it comes to building structure. The results also showed that EVI was similar among the three municipalities showing that there are similar construction practices in the three study regions. Furthermore, there were a lot of buildings with high collapse probability in Birendranagar and Vyas. Because of lower

earthquake hazard in Birtamod, even though the buildings had similar EVI, the buildings were found to be safer comparatively.

The results suggest that there is the need to spread awareness among various stakeholders such as house owners and masons. Various skill oriented training programs could be beneficial as well. Given the sheer number of buildings that are highly damage prone, governing bodies also should consider some sort of action plan to make these stronger. This is made possible as this study has identified and located highly vulnerable buildings.

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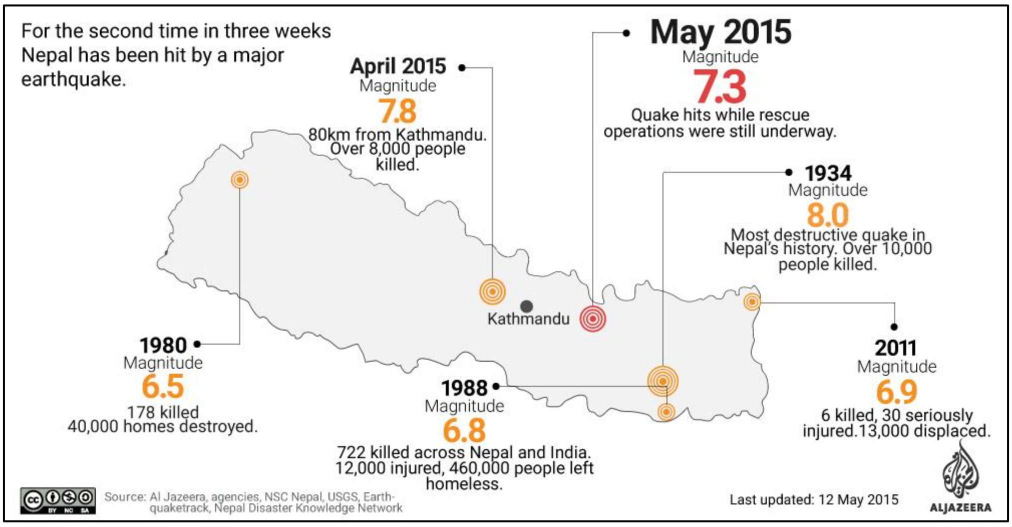
BIDS	Building Inventory Data Survey
CSV	Comma Separated Values
ESRI	Environmental System Research Institute
EVI	Earthquake Vulnerability Index
GIS	Geographic Information System
GPS	Global Positioning System
JICA	Japan International Cooperation Agency
KML	Keyhole Markup Language
MMI	Modified Mercalli Intensity
MoHA	Ministry of Home Affairs, Nepal
NSET	National Society for Earthquake Technology - Nepal
OCHA	Office for the Coordination of Humanitarian Affairs
PGA	Peak Ground Acceleration
ROAP	Regional Office for Asia and the Pacific
URL	Uniform Resource Locator
USGS	United States Geological Survey
VDC	Village Development Committee
WMTS	Web Map Tile Service

Chapter-1: Introduction

1.1 Background

Nepal is a landlocked country located in south eastern part of Asia. It shares borders with two countries namely, China on the north and India on the remaining three sides. It extends from 26.37° N to 30.45° N latitude and 80.07° E to 88.20° E longitude. It is divided into 7 provinces and 75 districts with the total area of approximately 147181 sq km. Nepal is a multi-ethnic, multi-lingual and multi-cultural nation with 125 ethnic groups being reported in the census of 2011. It houses more than 28 million people. The capital city Kathmandu itself has a population of more than 1 million.

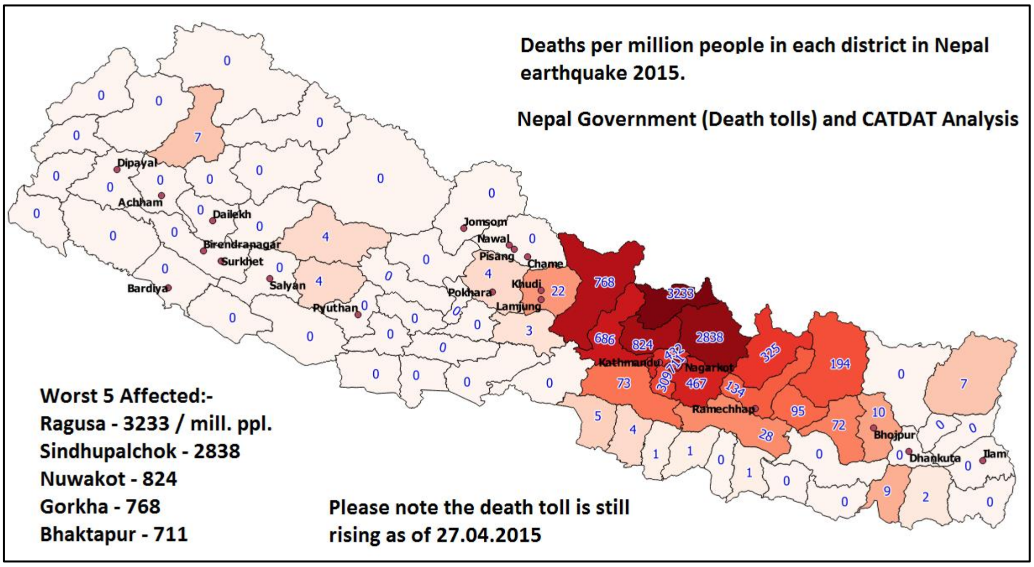
Nepal lies in a high seismic activity zone **(Bilham, Gaur, & Molnar, 2001; Merelli & Yanofsky, 2015)**. It has experienced multitude of big earthquakes in the past with the oldest recorded one dating back to June 7, 1255 AD **(DPNet-Nepal, n.d.)**. This can also be seen on Map 1 which shows the history of earthquakes in Nepal and was published by Ritzen Y.



Map 1 Earthquake history map of Nepal **(Ritzen, 2015)**

As it can be seen, while the intensities have varied, major earthquakes have occurred in the past throughout Nepal. Nepal has recently experienced such big earthquake on April 25, 2015 which was followed by hundreds of aftershocks of varying strength **(Ghose, 2015;**

Robertson & Koontz, 2015). In this earthquake, about 9000 people were killed, many thousands were injured and more than 600,000 structures in Kathmandu and other nearby town some degree of damage was observed **(Rafferty, 2015)**. This data can also be observed on Map 2 below which was prepared by Dr. James Daniell. And even though the data are lacking to accurately back the predictions, there are speculations of another "mega-earthquake" in near future **(Bilham, Mencin, Bendick, & Bürgmann, 2017)**.



Map 2 Deaths per million people, Nepal earthquake 2015 **(Daniell, 2015)**

In the wake of such a devastating event, countless individuals and organizations have been working towards minimizing disaster risks and increasing disaster resilience especially when it comes to earthquake. National Society for Earthquake Technology – Nepal (NSET) is one such organization which has been actively involved in post disaster activities. While its main focus is to minimize risks by giving trainings to various stakeholders with regards to making earthquake resistant structures, one of their aim is to prepare earthquake scenarios of municipalities of Nepal. In order to do this, they have been conducting a survey titled Building Inventory Data Survey (BIDS) where they collect various information on every building of the survey region including its location data **(Khanal, Bhattarai, Saud, & Pradhan, 2017)**. Their focus on monitoring and improving the construction practices in Nepal is due to the fact that, while earthquake itself is dangerous, during earthquakes most of the deaths are caused by either collapsing infrastructures or falling objects or other disasters such as fire that originate from failing structures **(Sarvis, 2015)**. In order to get the local people of the survey regions more involved in the process, local people are recruited as volunteers to act as surveyors. This makes them into stakeholders of the result that this survey produces and also makes them aware about earthquake resistant buildings.

It was seen during the last earthquake, the 2015 Gorkha Earthquake, that there were a lot of different data on building damages being distributed to the public. In this regard, application of GIS tools could be very reliable in showing the correct precise damage data. This could be further used in locating damaged buildings and also in decision making by local authorities.

1.1.1 Building Inventory Data Survey (BIDS)

As mentioned above the objective of this survey is to create an earthquake scenario of the survey region. USGS has defined earthquake scenario as “a realization of potential future earthquake by assuming a particular magnitude, location and fault” **(USGS, n.d.-a)**. The earthquake scenario created by NSET will use the data collected by BIDS and will display the state of buildings on municipalities of Nepal should an earthquake strike.

In order to conduct the survey, local volunteers sent to field so that local people feel comfortable to provide required data while also making the volunteers spread awareness throughout the survey region. However, recruiting local personnel comes with the issue that is their evident lack of knowledge in building structures and map literacy. In order to reduce the issues that arise, they are properly provided with trainings on how to identify building structural components and locate buildings on maps prior to sending them to field for survey. The surveyors take a smartphone with an Open Data Kit based KoboToolbox survey form in it and base maps to locate the houses by drawing over it. The outline of this form can be found in **Annex** I. Once the surveyors are deployed on field, they identify the building they are surveying and mark the building by outlining it in the paper map. They also give a unique ID to each building in the process. Then they use the smartphone to fill out the pre-installed form mentioned earlier which contains questions regarding the buildings. Since this still has the risk of having human errors in collected data, the surveyors are supervised closely. While the supervision for structural data collection is good, the supervision for validating collected building locations is still not optimal as it involves frequent communication and data transfer with off-site GIS experts.

The data collected by BIDS is divided into two parts. One, survey data collected from a smartphone which includes structural information of the building as well as GPS location of the survey and the other, digitization based on the markings on base maps by the surveyors **(Khanal et al., 2017)**. The survey data is stored as a spreadsheet as it is exported from KoboToolBox servers and the digitization are stored as KML file as they are digitized using Google Earth.

1.1.2 Need assessment

The first step towards building safer communities is proper earthquake centric planning on how to build safer communities. For that we have to know where we need to focus so that we can best prioritize areas that need most attention.

One of the essential part of this is to know which buildings are vulnerable. This showed us which types of buildings need more focus and which type of trainings should be developed in order to make future constructions less vulnerable earthquake. Another important aspect of this is the location data of the buildings. This tells us where the most vulnerable buildings are located which gives us an idea where the activities and plans need to be focused on.

In order to reach a safe community, we cannot just be focusing on building new safer buildings because the vulnerable buildings are not only exclusive to causing damage to themselves and what is contained. If a vulnerable building gets damaged or collapses, it can cause damage to safer buildings that fall within its proximity as well. Therefore, while keeping an eye on setting earthquake safe construction trends in the future, we should also be working towards strengthening the vulnerable buildings. For this as well, we need to be able to identify the vulnerable buildings.

Although programs such as Building Inventory Data Surveys have already taken such initiative by collecting data on buildings in multiple municipalities, the intended results i.e. earthquake scenarios and identification of vulnerable buildings have yet to be developed. The collected data is very detailed and provides us with a strong base for identifying vulnerable buildings. Since location data is essential in this sort of analysis, GIS tools and approaches can be effectively utilized to generate results.

This project is essential as it provides a basis of identifying vulnerable buildings and locating them. It also gives us means to utilize third party datasets as well so that other datasets can be modelled accordingly to obtain similar results.

1.1.3 Research approach

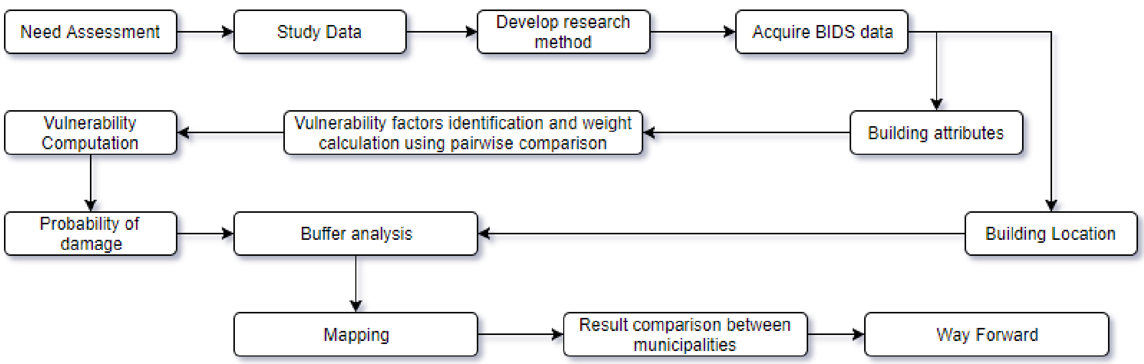


Figure 1 Research approach

The research begins with the need assessment of the research. The availability of data is an important factor to consider for any reference. Therefore, we need to study the available datasets so that a research method can be modelled after it. The next step is to acquire the required data. For this research, BIDS data of target municipalities and administrative boundary data obtained from the Survey Department of Nepal was used. Hazard maps of Nepal will also be used to find earthquake hazard of Vyas municipality. The building attributes that contribute to vulnerability were identified. Then, the vulnerability of each building was computed. After that, probability of damage of each building was calculated as well. Buffer analysis was carried out in order to determine the collapse zones of highly vulnerable buildings which in turn gave us the number of people who would be affected by building collapse. Using all the results, maps were prepared for each of the three study areas. The results between municipalities were compared and conclusions were drawn.

1.2 Objectives of the project

The aim of this project is to use GIS to analyze earthquake vulnerability of buildings in different parts of Nepal. The project also aims to use secondary data to analyze the ability of buildings to withstand earthquakes.

The main objective of the research is to use GIS and BIDS data to compute earthquake vulnerability of buildings in Birendranagar, Birtamod and Vyas municipalities and compare the results.

The sub-objectives of the project are:

a. To develop a Web-GIS application to help in validation of digitization of buildings during the survey (section **2.2**)
b. To calculate earthquake vulnerability of buildings in Birendranagar, Birtamod and Vyas municipalities (section **2.8**).

c. To find probability of damage for each building in case of an earthquake (section **2.9**)

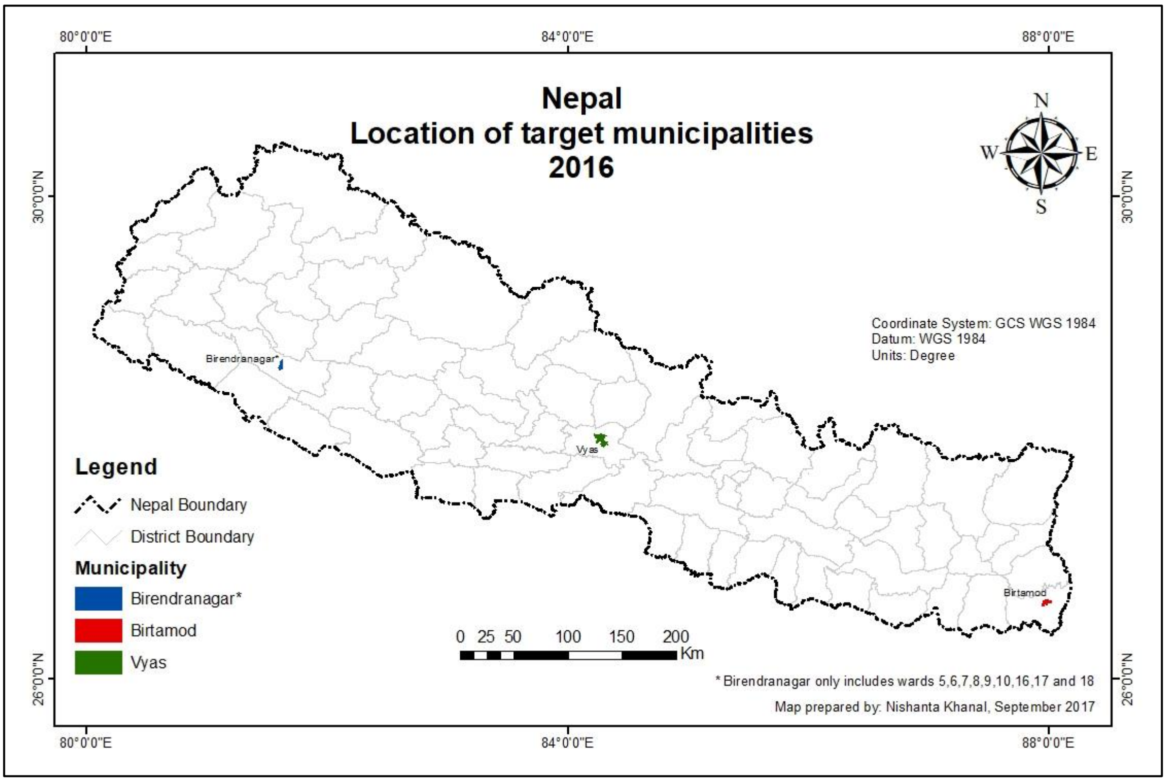
d. To prepare maps of probability of total collapse, partial damage and overall damage of the buildings (section **3.3**)

e. To find the number of people affected by building collapse (section **3.4**)

f. To compare the results among the three target municipalities

1.3 Introduction of the study area

For this project, three municipalities of Nepal were selected namely Birendranagar, Birtamod and Vyas. These three municipality were selected as they are spread throughout the country with Birendranagar being located in the western part, Birtamod being located in the eastern part and Vyas being located towards the central part of the country. Their location in Nepal can be seen on Map 3.



Map 3 Location of target municipalities

1.3.1 Birendranagar municipality

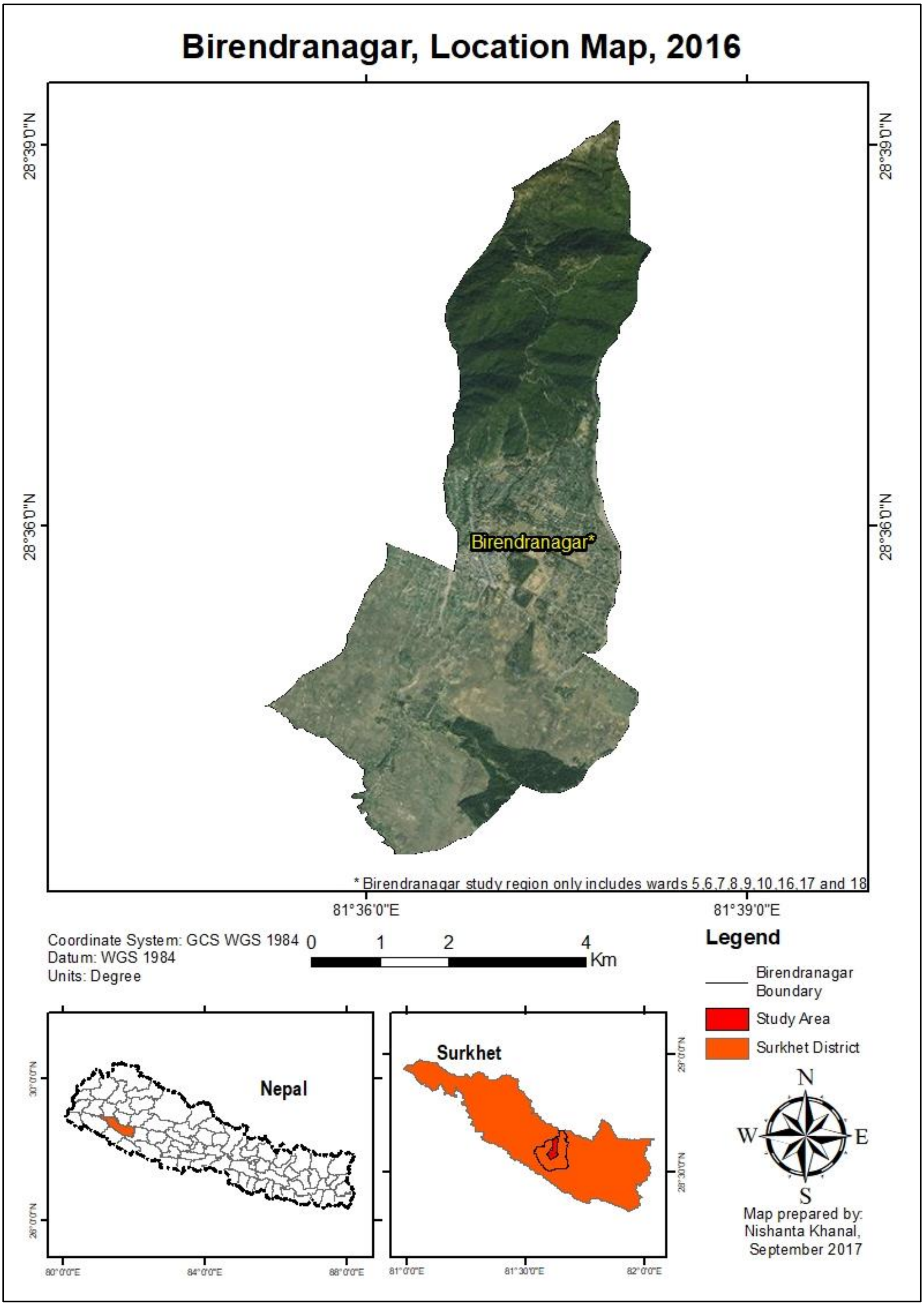
Birendranagar municipality is located between 28.5055° N to 28.6921° N latitude and 81.5349° E to 81.7781° E longitude. It is located in Surkhet district of Nepal. It is approximately 580 km road travel distance to the west of the capital city Kathmandu. It covers an area of around 244 sq km. According to the 2011 Nepal census, the municipality had a population of 52137 and 12045 number of households. Due to availability of data, the study region in Birendranagar municipality was limited to wards 5,6,7,8,9,10,16,17 and 18. The location of this study area is presented on Map 4.

1.3.2 Birtamod municipality

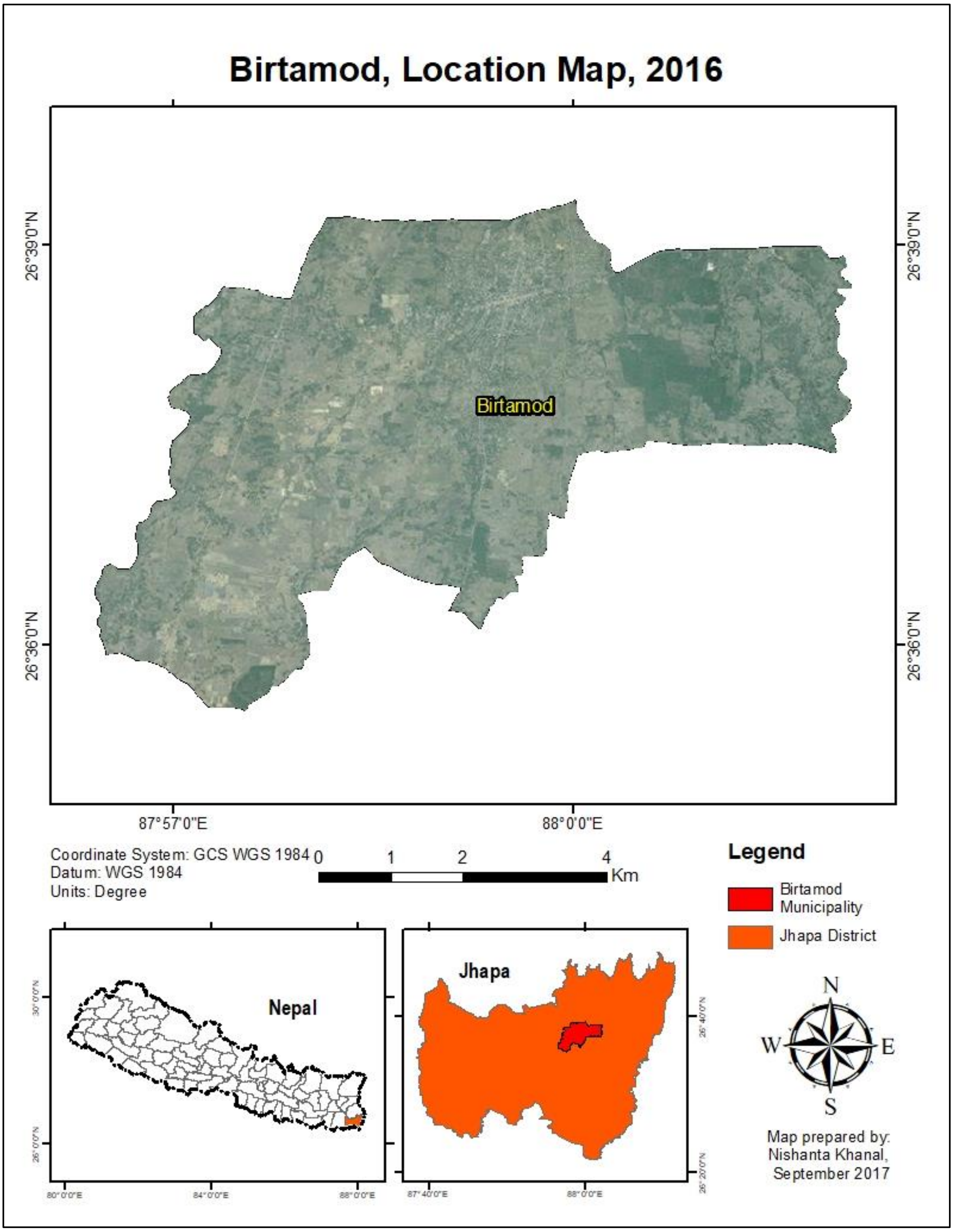
Birtamod municipality is located between 26.5916° N to 26.6557° N latitude and 87.9401° E to 88.0347° E longitude. It is situated about 440 km road travel distance to the east of Kathmandu and about 100 km east of Biratnagar. It covered an area of 36 sq km at the time of survey, however the municipality has since been expanded to include nearby VDCs taking its total area coverage to 78 sq km. According to 2011 Nepal census, the municipality had 60,177 population and 10,235 households **(CBS, 2011)**. The location of Birtamod municipality can be seen on Map 5.

1.3.3 Vyas municipality

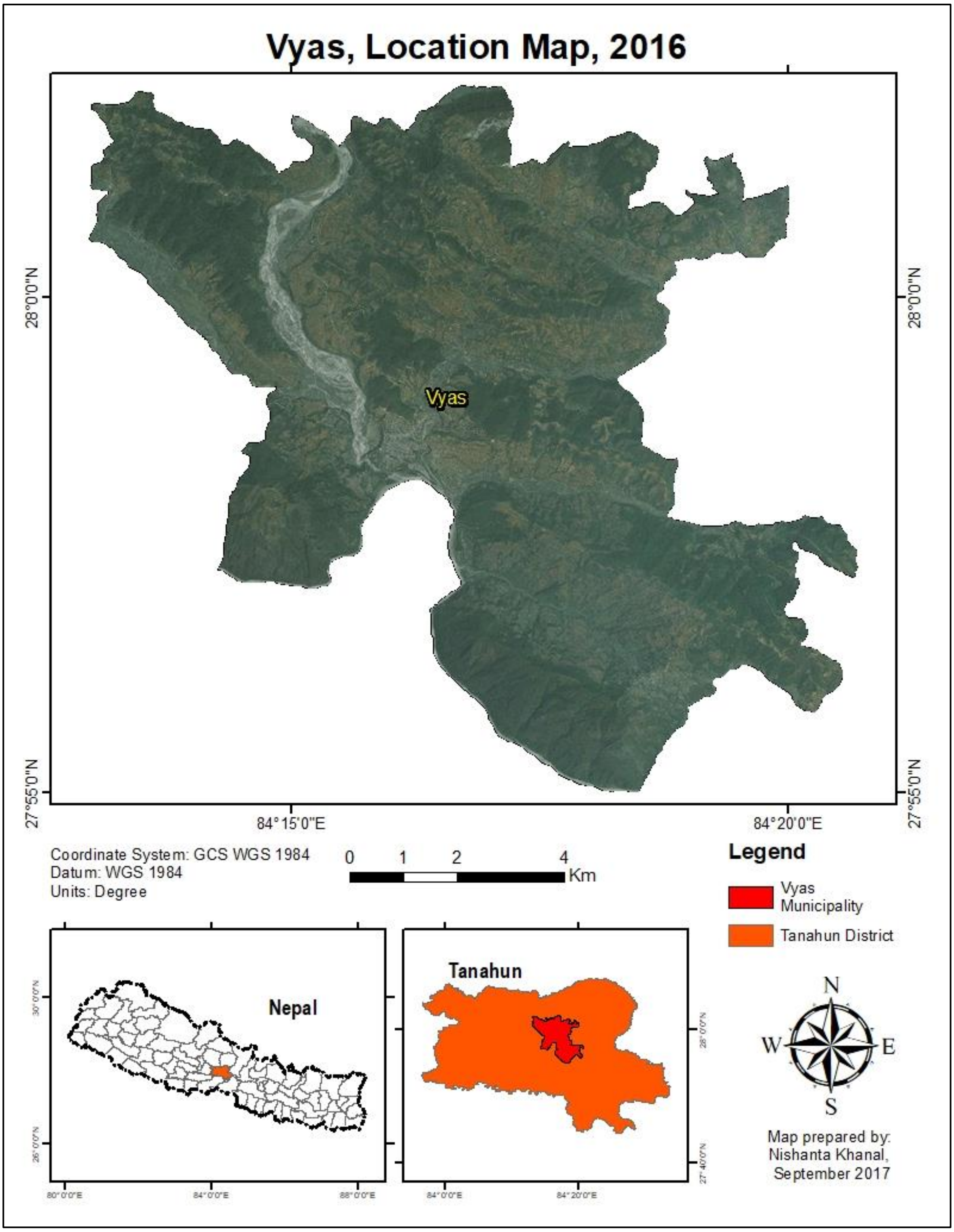
Vyas municipality is located between 27.9160° N to 28.0363° N latitude and 84.2152° E to 84.345809° E longitude. It is situated about 150 km west of Kathmandu and about 50 km east of Pokhara along the Prithvi Highway. It covered an area of 86 sq km at the time of survey, however the municipality has since been expanded to include nearby VDCs taking its total area coverage to 248 sq km. According to 2011 Nepal census, the municipality had 42,899 population and 11,321 households **(CBS, 2011)**. The location map of the Vyas municipality can be seen on Map 6.



Map 4 Birendranagar, Location Map, 2016



Map 5 Birtamod, Location Map, 2016



Map 6 Location map of Vyas municipality

1.4 Literature Review

1.4.1 Seismic hazard in Nepal

As mentioned in the introduction, Nepal lies in a high seismic activity zone. This includes all parts of Nepal. This has been portrayed in various documents and maps prepared by various people and organizations.

Mike Sandiford, CP Rajendran and Kristin Morell have put together an article on why Nepal is prone to earthquakes. In this article they mention that these earthquakes are due to “a dramatic manifestation of the ongoing convergence between the Indo-Australian and Asian tectonic plates that has progressively built the Himalayas over the last 50 million years.” As the Indo-Australian and Asian Plates are converging, strain builds between them. When there is enough strain, the Earth’s crust finally gives away and earthquakes occur. **(Sandiford, Rajendran, & Morell, 2015)**

This prevalence of earthquake in Nepal is a well-known fact. It can be clearly seen on records of earthquakes that have occurred in past in Nepal. Ritzen Y published a map showing history of major earthquakes in Nepal. This map can be found in section **1.1** (Map 1). It can be seen in this map that major earthquakes have occurred in Nepal since a long time ago. The oldest quake shown in this map is 1934. There have been numerous quakes since and they have occurred from the east to the west of the country. **(Ritzen, 2015)**

United Nations Office for the Coordination of Humanitarian Affairs - Regional Office for Asia and the Pacific (OCHA ROAP) prepared a map portraying Nepal’s exposure to seismic volcanic and tropical storm hazard. It shows that Nepal lies in a very high seismic hazard zone with high intensity earthquake being probable throughout the country. Almost all part of the country lies in the hazard zone of earthquake of intensity VIII or higher in the modified Mercalli intensity scale. **(PreventionWeb, 2011)**.

Amateur Seismic Center also had prepared a map in 2006 showing the seismic hazard on Nepal. It also shows that the entirety of Nepal lies above the high seismic hazard zone. They used data from the Global Seismic Hazard Assessment Program to prepare the map **(ASC, 2006)**.

While Nepal has recently endured a major earthquake, the possibility of another similar or larger earthquake in the near future is still there according to multiple researchers. Murphy, Taylor, et. al. in 2014 identified a rupture of more than 60 km length in western Nepal. This could mean that another large earthquake originating in western part could be imminent on Nepal **(Murphy et al., 2014)**.

Furthermore, a study was conducted after 2015 Gorkha earthquake by Wesnousky et. al. where their findings suggest that there could be a 124-mile long fault building up. This could be further evidence that there could potentially be an even stronger earthquake **(Wesnousky et al., 2017)**.

1.4.2 The Modified Mercalli Intensity (MMI) Scale

Earthquake intensity is generally regarded as the effect of an earthquake on the Earth's surface. The Modified Mercalli Intensity (MMI) scale was developed by American seismologists Harry Wood and Frank Neumann in 1931. The scale uses roman numerals to represent intensity and extends from I to X with I being the weakest. Generally, intensities above VIII are based on observed structural damage so structural engineers contribute information to determine the intensity on ground **(USGS, n.d.-b)**.

Wald, Quitoriano, et al. in 1999 studied the relationship between peak ground acceleration, peak ground velocity and Modified Mercalli Intensity and found that higher accelerations and velocities were consistent with higher damages and hence higher MMI **(Wald, Quitoriano, Heaton, & Kanamori, 1999)**.

1.4.3 Earthquake vulnerability assessment of buildings

Earthquake is a common phenomenon throughout the world. There have been numerous researches conducted on assessment of capacity of buildings to withstand earthquakes. Delavar, Moradi et. al. in 2015 assessed the earthquake vulnerability of hospital buildings in Tehran, Iran. In this research they used multi criteria decision based approach as they believe that there is more than one factor that comes into play when talking about vulnerability of buildings. They asked 5 experts to evaluate vulnerability of hospital buildings and then aggregated the evaluations and used particle swarm optimization (PSO) method to extract optimum values **(Delavar, Moradi, & Moshiri, 2015)**.

Panahi, Rezaie et. al. in 2014 assessed earthquake vulnerability of School buildings in Tehran city. They used analytic hierarchy process to give weights to factors and also used GIS in their research. Furthermore, they even used peak ground acceleration, slope and soil liquefaction layers to develop a geotechnical map for the study. For their research they considered building attributes such as construction materials, age, quality and seismic resonance as well. They identified 3% of schools among their total study sample as highly vulnerable buildings **(Panahi, Rezaie, & Meshkani, 2014)**.

Shah and Pujol in 2015 assessed 146 low rise reinforced concrete buildings in Kathmandu, Nepal. They found that the results that they computed in this assessment were comparable to that from similar surveys that took place in Haiti and Turkey. They also found that in case of most of damaged buildings, the relation of wall index to column index was similar. They also stated that if this trend was used as a threshold for identifying the vulnerable buildings, 91% of the buildings that they surveyed in Kathmandu would be classified as vulnerable buildings.**(Shah & Pujol, 2015)**

Thapaliya, 2006 assessed the buildings in Lalitpur, Nepal. For this he used pairwise comparison method to calculate vulnerability of buildings. He prepared maps displaying probable damage and also compared results from field data to the data from building permit records. The field data was collected as a part of his study and was governed by the requirement for his research. His study concluded that building permit records lacked data on building condition and also suggested some measures to improve it. He also concluded that to properly assess building vulnerability one would require earthquake hazard data, site characteristics and building characteristics **(Thapaliya, 2006)**

1.4.4 Factors affecting seismic vulnerability assessment of buildings

There are various factors affecting seismic vulnerability of buildings. Generally, the biggest factor is peak ground acceleration (PGA) however, since most studies focus on local vulnerability assessments, PGA tends to remain constant throughout the study region. However, the factors used for assessments are largely governed by the availability of data. Therefore, different researches tend to use different factors based on what data is available to them.

Thapaliya, 2006, while assessing buildings of Lalitpur, used many factors for his research. They are as follows

a. Construction type:

   The construction type of a building refers to the load resisting system of the building. For example, a building can be load bearing type for example with brick and cement or brick and mud, etc. without pillars or reinforced concrete frame with masonry infill for example. pillar based buildings with walls in between

b. Construction material:

   This refers to the material that was predominantly used to construct the buildings for example bricks, stones, concrete blocks, reinforced concretes, etc.

c. Structural bands:

   According to Thapaliya, 2006, these are one of the most important things in buildings that can reduce the possibility of failure mechanisms. Various structural bands were considered such as lintel band and roof band.

d. Building configuration:

   The configuration of a building can also be loosely regarded to the plan of the building and deals with proper symmetry of the building as well. It entails things like length to width ratio, height to width ratio, irregularity in plan, irregularity in elevation, etc.

e. Building uses:

   While the use of building does not directly influence the building's vulnerability, construction practices with the intended use could make major difference. Thapaliya, 2006 found that about 12% of the surveyed buildings were commercial on ground floor and residential on upper floors. Due to this, the buildings were created with large percentage of openings in façade in ground floor. This resulted in weak ground floors being "soft storeys" which made the building vulnerable.

f. Building condition:

   The visual way is also one of the good way to assess the vulnerability of buildings. Visual indicators such as wall cracks, floor cracks, wall and floor dampness were selected for his study.

g. Building height:

   One of the more obvious factors is the building height. However, unlike popular belief, tall is not necessarily more vulnerable. The natural period of building and frequency of seismic wave greatly determine which building height is more vulnerable.

h. Attachment and floor coincidence:

   Many buildings are attached either on one side or more. This can be disastrous especially when the floor levels of attached buildings do not coincide as it can create a pounding effect on the buildings.

i. Partial floor:

   Partial floors can cause the center of mass of buildings to shift which creates torsion when earthquake occurs. This will cause building structure to fail.

j. Age of buildings

   Each building has a lifetime. The older the building, the more likely it is to be damaged during earthquake.

Thapaliya, 2006 used pairwise comparison method (PCP) to give weight to the factors.

(Thapaliya, 2006)

Amatya,2013 identified vulnerable buildings in her study area as a part of identifying emergency roads during earthquake. For this she used different to compute building vulnerability. They are:

a. Plan Irregularity:

   Regular structures such as square, circular and rectangular are relatively safer than other shaped structures in case of an earthquake. Building shaped like L shape, T shape and other unconventional shapes are generally regarded as relatively unsafe.

b. Vertical Irregularity:

   Vertical irregularity can be observed in buildings by examining storey-to-storey variation.

c. Opening:

   Large openings in buildings can result to wall failure in buildings due to the difference in stiffness among sections of the structure.

d. Poor Condition:

   Poor condition of a building can generally be correlated to dampness and damage to the building structure. This can increase the building vulnerability.

e. Number of stories:

   According to Amatya, damage percentage increases linearly with the number of storeys.

f. Column Size:

   Column size is very important in case of Reinforced Concrete Cement (RCC) structures.

g. Building code or guidelines:

   Nepal Building Code has provided guidelines for building earthquake resistant buildings. This factor checks if the building code has been adhered to or not.

She has given weights to these factors using perspective analysis.

(Amatya, 2013)

Cochrane and Schaad had used material types of buildings to assess their vulnerabilities and compare them. They categorized the buildings into a total of ten categories

1. Wooden frame
   A. With light exterior wall
   B. With brick veneer finish
2. Steel frame
   A. With steel bracing or reinforced concrete shear walls or with light weight cladding systems
   B. Without bracing or shear walls and with non-load bearing walls of reinforced concrete, brick, glass, etc.
3. Reinforced concrete frame
   A. With reinforced concrete or brick shear walls

B. Without shear walls and with load or non-load bearing walls of precast concrete, brick, glass etc.
C. Precast concrete frame and lift slab buildings

4. Others
    A. Reinforced concrete, pre-cast tilt-up, reinforced masonry or reinforced hollow block
    B. Unreinforced brick or solid block earing walls
    C. Unreinforced hollow block bearing walls

They found that, buildings with frames generally performed better than those without.

(Cochrane & Schaad, 1992)

NSET conducts a building permit drawing assessment where it computes vulnerability of buildings. Some of the factor that it uses that can be relevant to this research are

a. Size of columns:

    The size of columns (pillars) in a frame based buildings is an important factor for building strength. The required size of columns, according to the building code of Nepal, has changed over the years so there are still constructions being done in outdated mandates.

b. Soft storey:

    When a floor is very light with very few loads but the floor above it is heavy with high load, the lower floor will have lower stiffness with respect to the upper floor. This is known as a soft storey. This can be generally found in houses designed to be used as commercial buildings in ground floor but still houses a residence upstairs.

c. Dimension ratio:

    The ratio of length to breadth of a building is another important factor. If the length of building is more than three times its breadth, it is considered to be vulnerable. This is due to the relative difference in stiffness in different axes of the building.

d. Setbacks:

   Symmetry is important in both horizontal and vertical axis for a building to be ideal when it comes to resisting earthquakes. If a building has multiple levels but the upper level is significantly smaller than the lower level, it can make the building vulnerable during earthquakes as well.

e. Vertical discontinuity:

   Vertical discontinuity can occur in a building in various forms. Heavy overhangs, soft storey, partial floors, setbacks, are some examples of it. The presence of such discontinuity can contribute to the building's vulnerability.

f. Short column:

   Short column, as the name suggests, occurs when two columns are of unequal length. This causes the shorter column to receive more force which makes it vulnerable.

g. Torsion:

   The torsion on a building can rise due to various factors such as partial storey, unsymmetrical design, etc.

h. Adjacent buildings

   When an earthquake strikes, adjacent buildings especially the one with different floor levels shake and collide. This phenomenon is known as the pounding effect. This directly causes damage to the buildings.

The form for this survey can be found in **Annex II**. **(NSET, 2017)**

1.4.5 Collapse zone

The collapse zone of a structure is defined as the area around the structure that could contain debris if the building collapsed. This area is often defined by establishing a perimeter at a distance from the building that is equal to 1.5 times the height of the structure **(NAUM, 2015)**. It means that if a building collapses, people or structures within that area could get hit by the falling debris.

In 2014, Loflin and co. outlined the importance of demarking the collapse zone while going in on fire rescue missions. He gave two cases where rescuers were harmed due to falling debris within the collapse zone **(Loflin, Tarley, & Lutz, 2014)**. This tells us that it would be better if future plans such as rescue plans and even construction plans could take collapse zone into account.

1.5 Assumptions

The assumptions were made in order to successfully carry out this study

a. While the impact of earthquake is largely governed by the seismic waves and point of origin of the earthquake, as far as today's technology allows, we cannot accurately predict these parameters. Therefore, it is assumed that earthquake intensity over the study areas will be uniform.

b. From literature review, it can be seen that most studies consider similar set of factors while assessing vulnerability of the buildings. Therefore, it is assumed that these sources, along with the expert consultation received are credible and hold true while determining factors and their weights.

c. It is also assumed that the BIDS dataset obtained from NSET is accurate, as these were collected by volunteers trained for this very purpose who worked under tight expert supervision.

d. The dataset being used, or any dataset that can be used, does not have every detail of building that contributes to its vulnerability. So, it is assumed that apart from the factors considered, building attributes are uniform throughout the buildings.

Using these objectives, procedures and processes based on literature review and assumptions, a suitable methodology for the research was formulated.

Chapter-2: Methodology

On the basis of literature review, prospect of data availability and attainability, the given study time frame and resources on hand, the most plausible methodology was formulated as follows

Figure 2 Methodology of the study

2.1 Building Inventory Data Survey (BIDS) data collection

Even though the BIDS survey was not conducted specifically for this research and was carried out by a third party i.e. National Society for Earthquake Technology, Nepal (NSET), it is one of the most important part of this study as it is the source of data for this study. In case of BIDS survey, the preparation and data processing spans from before the survey starts to the final data archiving after the survey ends. Hence, the tasks involved in this survey can be broken down into two parts Pre-survey and Post-Survey.

2.1.1 Pre-Survey

Pre-survey includes the tasks carried out before the survey starts. As the local people are recruited as surveyors, they need to be first trained on data collection for the survey since their knowledge might be lacking regarding building structures, mobile data collection or map literacy. Other than that, materials required for the survey itself are prepared as well.

Surveyors collect structural data on mobile device while they collect location data on the same mobile device as GPS coordinates and also on paper base maps by drawing the building outline on the satellite image of the area. In order to prepare these base maps, the area is divided into grids. The division of survey area into grids also help to properly manage the survey and assign grids to surveyors for the survey. The surveyors are assigned to grids and they take respective base maps with them to the field.

The steps followed to create survey grids and prepare base maps using ArcGIS are as follows

a. Obtain boundary of the survey region
b. Create fishnet over the survey region extent
c. Delete the grids that do not contain survey region at all

d. Add google images to ArcMap using WMTS from Portable Basemap Server **(CodeplexUsername-diligentpig, 2014)**

e. Create data driven pages using grid features and prepare base maps using it

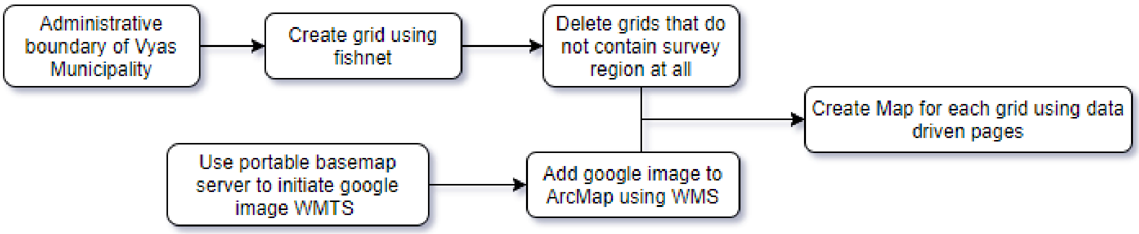


Figure 3 Methodology to prepare a base map to be taken on field

A sample of the resulting maps can be seen below on Map 7.

Map 7 A sample base map for BIDS survey

Since, the building outlines drawn on satellite images are digitized by survey supervisors using Google Earth, the satellite image displayed in the survey base maps are google images. Note that according to their polity the google images are not to be used for commercial, distribution or storage purposes. In this procedure as well, the images are used to assist the survey and not stored or supplied to other people/organizations.

2.1.2 Post-Survey

Once a survey is done, the data collected on the smartphone is uploaded to the server. The building outlines that the surveyors drew on paper base maps are collected and digitized on Google Earth by in-field supervisors as well. The two data is sent for validation to GIS expert who examines the distance between the GPS coordinate collected during survey and digitized buildings and tells if there could be an error in data collection. Since, the procedure of collecting data runs throughout the survey by uploading data to the servers, the dataset for building attributes is complete when the overall survey ends. However, once the survey is complete, all the surveyed data are compiled into two different formats Microsoft Excel Spreadsheet for the data from mobile device and Google Earth KML for the digitization of buildings.

2.2 Data validation using Web-GIS application

When it comes to structural attribute data of the buildings, the data collection is closely supervised in-field so as to minimize the errors in data. However, the same does not hold true for the location data of buildings. Since the location data of buildings can be found in two forms, they can be tallied against each other to validate the data. In order to facilitate this, a Web-GIS application was developed with the intention of making it applicable in future surveys as well. The requirements of this web application were that

1. it should be able to visualize the GPS coordinates of the survey and the digitized building outlines

2. it should be able to match the ID of GPS survey and digitization, and also show the distance between them for validation
3. it should be able to be used offline so that it could be used in scenarios where there is limited connectivity
4. it should be able to be used as a digitization platform removing the need to work with Google Earth as using two applications back and forth would not be ideal

2.2.1 Web-GIS application development

A Web-GIS application was developed according to the requirements mentioned above. The application was developed as a client-side application. This means that all the processing was done on the client side and not any server. This removed the need to be connected to the internet once the application was loaded. It makes the application highly useable since the files that we work with are of very high size and continuously uploading/downloading the files could make the process very slow especially in remote areas where the internet connection is very slow.

All the plugins required for the application were also made available locally. So, the application can be carried on a portable drive to be used on absence of internet connection. The plugins/external resources used for this application are as follows:

a. Leaflet – It is one of the most popular open source JavaScript libraries for creating web maps. The application was built on top of it. It can be downloaded freely from http://leafletjs.com/download.html .
b. Leaflet.EasyButton – It is a library for leaflet that lets users easily create a control for the leaflet based web maps. It was used to create the file select button. The library can be accessed on https://github.com/CliffCloud/Leaflet.EasyButton .
c. Leaflet.draw – It is a library for leaflet that enables creating, editing and deleting geographic features (point, line and polygon) on the map. It was modified and

extended to create various controls and features for the application such as adding building ID on digitization, editing building ID and feature shape, deleting feature and exporting the existing polygon to KML. It is shared openly on GitHub on the page https://github.com/Leaflet/Leaflet.draw .

d. togeojson – It is an open library that converts features on leaflet to geojson format. It was used to convert the polygon layer of digitization into geojson format. It can be obtained from https://github.com/mapbox/togeojson .
e. tokml – It is a library for Mapbox (another library built on top of leaflet) that converts GeoJSON to KML format. It was used to convert polygon layer which contains digitization to KML format. It is also shared openly on GitHub on the following page. https://github.com/mapbox/tokml
f. FileSaver.js – A JavaScript library to save files on the client side. It was used to export the converted data to KML file. It is openly available on the following URL. https://github.com/eligrey/FileSaver.js/

The interface of this application was designed to be easy for digitizers. Therefore, the application contains a full screen map view with small controls on the sides. This allows unobstructed view to edit and create polygons as required. The interface can be seen on the Figure 4.

The application can load two datasets. First, GPS coordinates from a csv file and second, digitization of buildings from KML file. As soon as the two datasets are loaded, it matches the id of the points and polygons and creates a line joining the point and the centroid of the polygon. The application also calculates the distance between them. This also happens as soon as a new polygon is created. Therefore, this application can be used by in-field supervisors to validate the surveys as they digitize making the procedure real-time. The interface after the two datasets are loaded can be seen on Figure 5. In Figure 5, the blue polygon is the polygon that was newly created i.e. not loaded from the existing dataset while the orange polygons are the ones loaded from the KML file containing digitization. The application also provides users with interactivity as we can click on either points or polygons to see their IDs on popups. Clicking on lines would give us the ID of the features that it is joining as well as the distance between them.

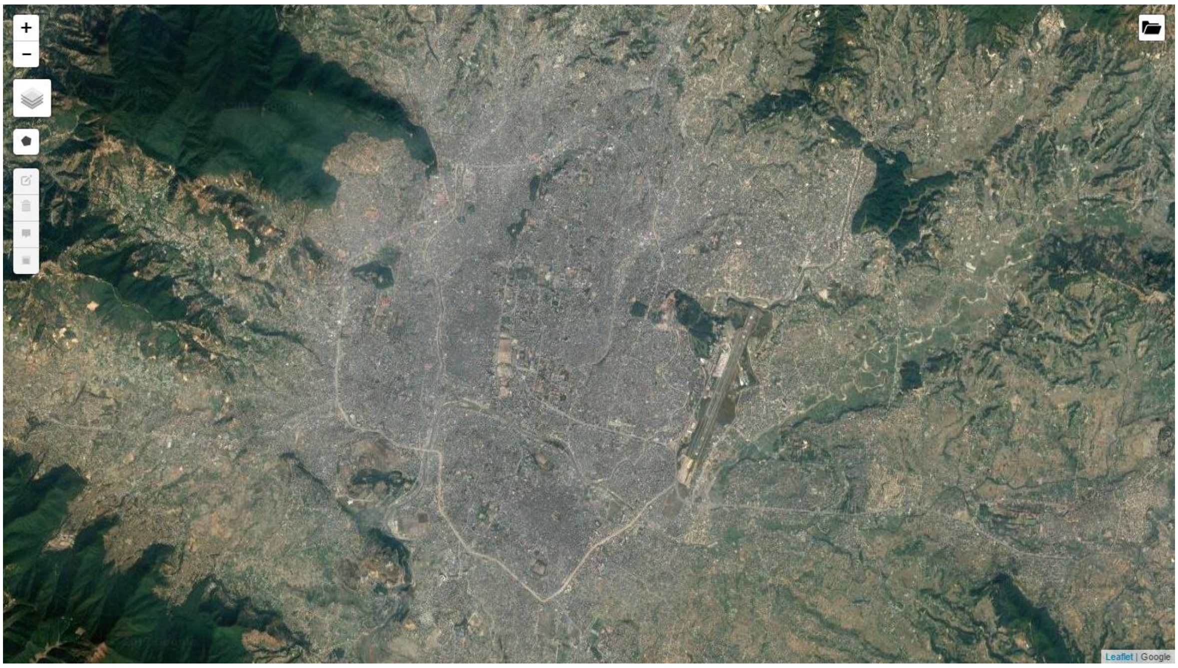


Figure 4 Web-GIS application interface

Figure 5 Web-GIS application interface (data-loaded)

This application is capable of performing following actions

1. Load CSV file containing, at least, GPS coordinate of surveys and an ID
2. Load KML file containing digitization of buildings with ID
3. Match points (GPS co-ordinates) to the polygons (digitization of buildings) using ID
4. Create a line between matched features and calculate the distance between them
5. Turn satellite image layer on or off
6. Create, delete, edit boundary or Rename ID of polygons
7. Save the edited KML file

The completed application was named “Leaflet Digitizer” and made open source. It can be found on GitHub using the URL https://github.com/banmedo/LeafletDigitizer

2.2.2 Data validation and correction

The first step in validating and correcting the data is to identify possible errors. Using this application, we can easily visually examine for errors. Considering accuracy and precision of GPS and the fact that surveyors can record data from varying distance from the building itself, it was not possible to set a specific threshold to identify data with errors. Therefore, the way to find error in data is to see if there are possible mismatch in the data and that the distance between the survey point and the centroid of the building is too long, which is represented by a long line. As in Figure 6, the building digitization towards north was matched with GPS coordinate that is further from another point that is not matched with any other polygon. This can be a case of human error in giving ID to the digitized building.

Figure 6 Identifying errors using Web-GIS application

These possible errors are then confirmed with the help of in-field supervisor from NSET and are addressed. After the dataset is freed of such inconsistencies, Other required application as well as datasets are collected and prepared for performing analysis.

2.3 Software used

In order to successfully complete the research, Environmental System Research Institute's (ESRI) ArcGIS 10.3 was used. All the data used for this analysis was first converted into ArcGIS 10.3 compatible formats such as shapefiles and geodatabase tables. ArcGIS 10.3 was used to perform calculations by using field calculator and also to overlay the datasets. A software named Portable Basemap Server by a user on the platform Codeplex by the username of diligentpig was used in order to emulate a web map tile service (WMTS) server for google images **(CodeplexUsername-diligentpig, 2014)**. This was used by NSET to prepare base maps for the survey. Microsoft's Excel 13 was also used to conduct pairwise comparison on factors to assign them weights. These weights were used to calculate the earthquake vulnerability index (EVI) of the buildings.

2.4 GIS data collection and data preparation

2.4.1 Data collection

The data collected and used for the successful completion of this project can be seen on the Table 1 below.

Table 1 Datasets used in the study

Data Description	Source	Format/Type
BIDS spreadsheet data contains building attributes and GPS of survey in spreadsheet	National Society for Earthquake Technology Nepal (NSET)	Microsoft Excel Spreadsheet (xlsx) GPS coordinates – Points Vector type
BIDS digitization data contains digitization in KML format	National Society for Earthquake Technology Nepal (NSET)	Google Earth KML (KML) KML Polygon Vector type
Administrative boundaries 2016 contains administrative boundaries up to ward level of entire country	Survey Department of Nepal	ESRI shapefile polygon Vector type
Nepal: Natural Hazards Risk map.	OCHA Regional office for Asia Pacific **(PreventionWeb, 2011)**	Map image (png) Raster type

1. **BIDS spreadsheet data**

   This dataset contained various information on the surveyed buildings. It was collected from NSET. This was one of the resulting datasets of the BIDS program. This dataset was collected for each municipality. The data was in Microsoft Excel Spreadsheet (xlsx) format. This spreadsheet contained the data that surveyors collected on mobile handheld devices on field. Therefore, the data present in the spreadsheet was governed by the BIDS survey form which can be seen on **Annex I**.

   This dataset primarily contains structural information on buildings such as building type, building material, number of floors, etc. It also contained the GPS coordinates collected by the mobile handheld device on field. While this dataset also contained information on house owner's name and contact number, those data were not shared so as not to breach privacy of the house owners. There was a unique building ID for each building as well that was used to link it to its digitization as well.

Since this data was collected on a partnership with the municipal administrative bodies and contain pre-mentioned information on house owners, the sharing of this data was restricted and was provided solely for research purposes. This data was also coded so a dictionary of the dataset containing codes and their meanings was used to decode and then interpret the data. The coordinate system for this dataset was as follows.

GCS_WGS_1984

WKID: 4326 Authority: EPSG

Angular Unit: Degree (0.0174532925199433)

Prime Meridian: Greenwich (0.0)

Datum: D_WGS_1984

Spheroid: WGS_1984

Semimajor Axis: 6378137.0

Semiminor Axis: 6356752.314245179

Inverse Flattening: 298.257223563

2. BIDS KML data

This dataset contained the digitized outlines of the surveyed buildings. This data was also collected from NSET and was one of the resulting datasets of the BIDS program as well. This dataset was collected for each municipality. This data was in the Google Earth Keyhole Markup Language (.kml) format. The data in this KML was the one that was digitized from the outline that surveyors drew on their paper base maps on field. Since this dataset contained digitization of buildings, it is of polygon type. The polygons in KML were each given a name which is the building ID used while collecting data on mobile device. This ID was used to match each building's digitization to its corresponding survey. The coordinate for this dataset was as follows.

GCS_WGS_1984

WKID: 4326 Authority: EPSG

Angular Unit: Degree (0.0174532925199433)

Prime Meridian: Greenwich (0.0)

Datum: D_WGS_1984

Spheroid: WGS_1984

Semimajor Axis: 6378137.0

Semiminor Axis: 6356752.314245179

Inverse Flattening: 298.257223563

3. Administrative boundaries

Administrative boundaries of Nepal were collected as well. This data was collected to visualize the region of study and the results of this study on maps. This data was collected from the Survey Department of Nepal. Since Nepal is undergoing changes in administrative level in 2017 A.D. with village development committees (VDCs) and municipalities merging and forming new administrative units, the administrative boundaries used for this research were of when the data collection took place by NSET i.e. 2016 A.D. The data obtained was of ward level data and was of polygon type. It contained information on ward number, VDC/municipality and district of each ward in Nepal. This information was used to create higher level datasets such as country boundary, municipal boundary and district boundary. The coordinate system of this dataset was as follows.

Projected Coordinate System: MUTM_84

Projection: Transverse_Mercator

False_Easting: 500000.00000000

False_Northing: 0.00000000

Central_Meridian: 84.00000000

Scale_Factor: 0.99990000

Latitude_Of_Origin: 0.00000000

Linear Unit: Meter

Geographic Coordinate System: GCS_Nepal_Nagarkot

Datum: D_Nepal_Nagarkot

Prime Meridian: Greenwich

Angular Unit: Degree

4. **Nepal: Natural Hazards Risk**

In order to find the earthquake hazard in the study regions of Nepal for this research, the map prepared by United Nations Office for the Coordination of Humanitarian Affairs - Regional Office for Asia and the Pacific (OCHA ROAP) titled "Nepal: Natural Hazards Risk" was used. In this map they have intended to show various natural hazards in Nepal such as seismic, volcanic and tropical storm risk. However, according to the map the map, Nepal does not have a high risk for hazards other than earthquakes. This map was used as a base map where the municipal boundaries were overlaid to interpret possible earthquake hazard. The coordinate system of the map as stated on the map itself was "Lat/Lon WGS84" which refers to

GCS_WGS_1984

WKID: 4326 Authority: EPSG

Angular Unit: Degree (0.0174532925199433)

Prime Meridian: Greenwich (0.0)

Datum: D_WGS_1984

Spheroid: WGS_1984

Semimajor Axis: 6378137.0

Semiminor Axis: 6356752.314245179

Inverse Flattening: 298.257223563

2.4.2 Data preparation

Since, a lot of the data used in this research is not from ArcGIS environment, which is the software of our choice, we need to prepare the data to make it ready to work with on ArcGIS. In order to do this, a geodatabase was created for each municipality which would contain all GIS files and layers required for the analysis and mapping.

1. **Preparing BIDS spreadsheet data**

   The BIDS spreadsheet data was prepared to be used with ArcGIS. Since some column headers, which would be used as fieldnames in GIS, started with an underscore '_' symbols, they would not work with GIS, So, they were fixed by removing the symbol at the start of field names. Some field names conflicted with the reserved words of ArcGIS which were appropriately changed as well. Then the data was loaded into ArcGIS 10.3 using the AddData button. The imported table was then exported into the geodatabase from its right click context menu on ArcGIS 10.3 layer pane.

2. **Preparing BIDS digitization data**

   Since the digitization was done in Google Earth and was in KML format, it was easily converted into a format supported by ArcGIS. To do this, the FromKML tool from Conversion Tools was used. However, since KML can store multiple types of geometries in the same file unlike shapefiles which can only store one type of geometry in one file, the tool creates a separate database as an export. This new geodatabase separates all included geometries in KML into separate feature classes according to their geometry type. So, once the KML import was complete, the polygon feature classes were moved from the generated geodatabase to the required geodatabase.

3. **Joining the BIDS datasets**

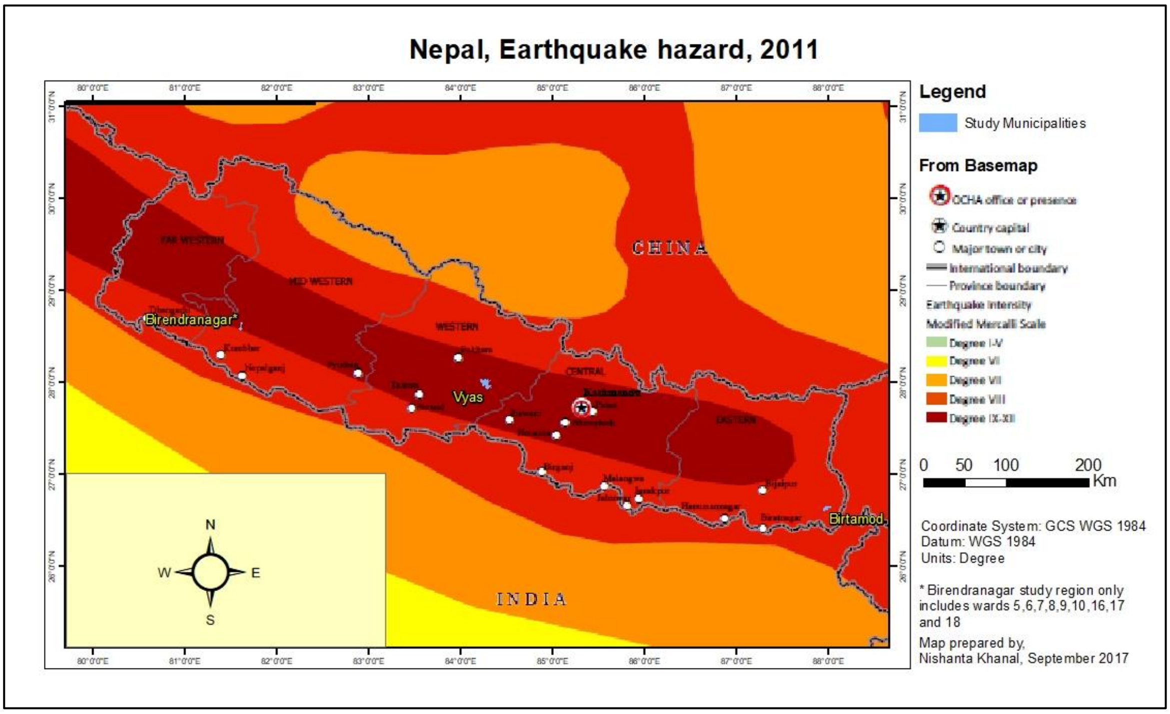
   After importing the BIDS datasets to a geodatabase, they needed to be linked so we could use the polygons in the digitization with the survey data. There was a common field in both the datasets which was the unique ID given to each individual during the survey. Using this ID field, the survey data was joined to the polygon feature class containing digitization of buildings.

4. **Preparing administrative boundaries**

   The collected administrative boundary data was ward level data. This data also had information on the VDC/municipality and district it belonged to. Therefore, the dataset was dissolved using the Dissolve tool inside Data Management tools in ArcGIS. The dissolve was done according to the respective fields to create new feature classes of VDC/municipality and district level polygon data. Similarly, the layer as a whole was dissolved to create a single polygon feature class of Nepal. All these feature classes were also converted to line feature class using the Feature to Line tool under Data Management Tools.

2.5 Identifying seismic hazard in target municipalities

In order to find if the buildings in a region is vulnerable to earthquakes, we first need to find if the area lies in an area with seismic hazard. Since the probability of building to collapse is highly dependent on the intensity of earthquake experienced by the building, it is essential to identify the probable intensity of earthquake for the area. In order to do this, a hazard map of Nepal titled “Nepal: Natural Hazard Risks” prepared by OCHA Regional Office for Asia Pacific was used **(PreventionWeb, 2011)**. First, the map and boundary of Nepal obtained from Survey Department of Nepal was loaded in ArcGIS 10.3. Since it lacked any sort of grids, it was georeferenced using feature shape of Nepal boundary. After Georeferencing the map, it was used as base map and the study regions were overlaid over it. The resulting map, Map 8 was prepared.



Map 8 Nepal, Earthquake Hazard, 2011

(basemap source PreventionHub, 2011)

As it can be seen, Nepal almost exclusively falls inside the red zone which is the high hazard zone. According to the base map, most of the areas in Nepal have 20% probability of experiencing an earthquake of said or more magnitude in 50 years. Although the central part of Nepal recently experienced a major earthquake on 25th of April 2015, the fault lines still exist there so there can be even more earthquakes of similar or more magnitude in the future. This is supported by the fact that experts believe that another “mega-earthquake” could soon hit Nepal **(Bilham et al., 2017)**.

As for our study areas, two of the three municipalities namely, Birendranagar and Vyas fall within the most hazardous zone where they are likely to experience an earthquake of more than IX intensity. While Birtamod falls out of the most dangerous zone, it still falls under the zone that is likely to experience an earthquake of more than VIII intensity. While all these locations could experience an earthquake of same magnitude, for this study, we will use this probable intensity as base and proceed with the assumption that Birendranagar and Vyas are likely to experience an earthquake of intensity IX while Birtamod is likely to experience an earthquake of intensity VIII.

2.6 Identifying building vulnerability factors

There are a lot of factors that determine the vulnerability of building when it comes to earthquake. This was explained in section **1.4.4**. However, the selection of the factors to be used for the project is largely governed by the availability of the data. Therefore, considering the availably of data in the BIDS dataset and from literature review, a set of factors were selected for calculating earthquake vulnerability index for this research. Since, the building inventory data survey was created to be used to assess earthquake vulnerabilities of buildings, a lot of experts have been involved in the process. These BIDS experts were consulted as well. The factors to be used in this study are as follows:

a. Size of the support system

The support system of a building is the component of the building that bears the load of the building and keeps the superstructure standing. The size of the support system is the measure of size of the load resisting system of the building. It plays a vital role in determining the earthquake vulnerability of a building as it is the component that gives strength to the building. Since the support system is different for different type of buildings, in case of column (pillar) based buildings, the size of support system is the size of the column while, in case of masonry buildings it is the size of walls. A smaller than adequate size of support system greatly weakens the buildings.

b. Soft Storey

Soft storey in buildings is the case where a floor of the building is not rigid enough compared to the floors above. It occurs especially in buildings where the first floor is built for commercial purposes with shutters rather than walls and the floors above are built for residential purposes with complete walls. After 2015 Gorkha earthquake, it was observed that soft storey was one of the most common causes of collapse. **(Gautam, Rodrigues, Bhetwal, Neupane, & Sanada, 2016)**. Therefore, the presence of soft storey is taken as a major contributor to the earthquake vulnerability of the building.

c. Slope of the foundation

Slope of the foundation refers to whether the foundations of the building are standing on the same level or not. Houses that are built on high sloping grounds generally have foundation on different levels due to the shape of the ground itself. This can be avoided by excavating land to a plane surface. If a building has foundation in different levels, there will be longer and shorter foundations which can create short column effect on the shorter foundation making the building vulnerable.

d. Shape of the building

The shape of building refers to the geometry of building as seen on the plan of the building. A building can be of a square, rectangular, L-shape, U-shape, etc. A regular shaped building i.e. square, circular and rectangular (not narrow rectangular) are generally regarded as safe structures while other irregular and unconventionally shaped structures are regarded to be relatively vulnerable **(Amatya, 2013)**.

e. Narrow and tall

A building can be considered narrow and tall if its height exceeds 3 times its width. These types of buildings can be seen on urban areas and shopping districts where the cost of land is very high and people tend to build buildings to commercialize them. A narrow and tall building is considered to be highly vulnerable in terms of earthquake. This is because of the center of mass being very high in such buildings.

f. Number of floors

The number of floors/storeys in a building. This is attributed to the height of the building as more floors mean more height. The height of the building has linear relationship with damage percentage. Similar to a narrow and tall building, the building's center of mass will be higher the taller it is.

g. Setback

Setback is basically a step-like recession in exterior wall **(Wikipedia, n. d.)**. In the BIDS data, a setback is present if a floor's superstructure covers less than half of the floor below. Since setbacks result in abrupt change in floor levels in terms of geometry, mass and stiffness, they can make the building vulnerable to earthquakes **(Ramin & Mehrabpour, 2014).**

h. Floor level difference

In areas where there are narrow lots such as urban areas and commercial areas, we can find a lot of buildings that are attached to another building. In some cases, we can even find buildings that are attached to other buildings on three sides. Floor level difference in a building exists if the building that it is attached to has different floor level than it. Due to this, when earthquake strikes and the buildings shake, the floor of a building strikes the columns (pillars) of another building. This causes a pounding effect in the two buildings which causes damage. Therefore, the presence of floor level difference makes a building more vulnerable.

i. Large Overhangs

In order to save ground space or just for architectural purposes, people expand the area of upper floor by extending the floors beyond the area of lower floors. In such cases the structure above the extension is not directly supported by any structure under it. When a building has superstructure built on top of such cantilevers, it is considered to have a large overhang. Building damages due to this has been observed in 2015 Gorkha earthquake. **(Gautam et al., 2016)**

j. Age of building

A building has its lifetime as well and it grows weaker as it ages. Therefore, older buildings are considered more vulnerable than newer ones.

k. Visual condition of building

Visual condition of the building can often be misleading as a building that looks unappealing and ill maintained from the outside could be strong. However, the poor visual condition of a building can be attributed to the dampness of the building. If dampness exists in building material, molds can grow on the walls which can mean that the building has poor visual condition and also are more vulnerable.

Now that the factors to be used to calculate earthquake vulnerability factors are determined, the next thing we need to do is to assign each factor their individual weight in order to calculate earthquake vulnerability index (EVI).

2.7 Assigning weight to factors using pairwise comparison method

The factors that are expected to contribute towards the strength or vulnerability of a building were determined. However, not all the factors affect the building's performance during earthquake to the same degree. Therefore, in order to compute EVI of each building, the factors that contribute towards a building's earthquake vulnerability need to be assigned a weight depending on how much they contribute towards it. To find weights of individual factors, the pairwise comparison method was adopted. Pairwise comparison method is an adoption of Analytic Hierarchy Process (AHP) where weights are given based on comparison between two objects at a time on a ratio scale.

This method takes two parameters at a time and compares their relative significance. This relative importance is then measured on a scale which is then quantified. The weights are then derived from it. The scale for this comparison for this research is as follows

Table 2 Pairwise comparison scale

1 Equal Importance	2 Equal to moderate importance
3 Moderate importance	4 Moderate to strong importance
5 Strong importance	6 Strong to very strong importance
7 Very strong importance	8 Very strong to extreme importance
9 Extreme importance	

This comparison is qualitative. In order to turn it into quantitative measure, the Geometric mean method was used as it has been tested to give better results than other methods. In this method, the individual row elements are multiplied and their n^{th} root is taken where n is the number of factors. In order to reduce the value to 1, the resulting values are normalized using their sum.

Table 3 Pairwise comparison of factors

Rank	Factors	Size of support system	Soft Storey	Slope of foundation	Shape of building plan	Narrow and tall	Number of floors	Setback	Floor level difference	Large Overhangs	Age of building	Visual Condition of building	RMV	Geometric Mean	Normalized Value
1	**Size of support system**	1	2	2	3	3	4	5	6	6	8	9	1866240	3.716	0.243
2	**Soft Storey**	0.500	1	1	2	2	3	4	5	5	7	8	33600	2.579	0.169
3	**Slope of foundation**	0.500	1	1	2	2	3	3	4	4	6	8	13824	2.379	0.156
4	**Shape of building plan**	0.333	0.500	0.500	1	1	2	3	3	4	5	7	210	1.626	0.107
5	**Narrow and tall**	0.333	0.500	0.500	1	1	2	2	3	3	5	6	90	1.505	0.099
6	**Number of floors**	0.250	0.333	0.333	0.500	0.500	1	2	2	3	4	5	1.667	1.048	0.069
7	**Setback**	0.200	0.250	0.333	0.333	0.500	0.500	1	2	2	3	4	0.067	0.782	0.051
8	**Floor level difference**	0.167	0.200	0.250	0.333	0.333	0.500	0.500	1	1	2	3	0.001	0.550	0.036
9	**Large Overhangs**	0.167	0.200	0.250	0.250	0.333	0.333	0.500	1	1	2	3	0.001	0.516	0.034
10	**Age of building**	0.125	0.143	0.167	0.200	0.200	0.250	0.333	0.500	0.500	1	2	0.000	0.329	0.022
11	**Visual Condition of building**	0.111	0.125	0.125	0.143	0.167	0.200	0.250	0.333	0.333	0.500	1	0.000	0.234	0.015
													Sum	15.265	

An example computation shows how the calculation is being done for the first row of the table. The similar applies for all other rows.

Row multiplied value (RMV) = 1 x 2 x 2 x 3 x 3 x 4 x 5 x 6 x 6 x 8 x 9

= 1866240

Geometric mean = $RMV^{(1 / \text{number of factors})}$

= $1866240^{1/11}$

= 3.716

Normalized Value = Geometric mean / Sum of geometric mean

= 3.716 / 15.265

= 0.243

In this way all the weights for all the factors are computed. These weights are then used to compute EVI of the buildings. However, even though size of support system is important factor, sufficient data is not available for some types of buildings so the factor was omitted for such buildings and instead the following weights were used for them.

Table 4 Pairwise comparison of factors without size of support system

Rank	Factors	Soft Storey	Slope of foundation	Shape of building plan	Narrow and tall	Number of floors	Setback	Floor level difference	Large Overhangs	Age of building	Visual Condition of building	RMV	Geometric Mean	Normalized Value
1	**Soft Storey**	1	1	2	2	3	4	5	5	7	8	67200	3.039	0.227
2	**Slope of foundation**	1	1	2	2	3	3	4	4	6	8	27648	2.781	0.208
3	**Shape of building plan**	0.500	0.500	1	1	2	3	3	4	5	7	630	1.905	0.142
4	**Narrow and tall**	0.500	0.500	1	1	2	2	3	3	5	6	270	1.750	0.131
5	**Number of floors**	0.333	0.333	0.500	0.500	1	2	2	3	4	5	6.667	1.209	0.090
6	**Setback**	0.250	0.333	0.333	0.500	0.500	1	2	2	3	4	0.333	0.896	0.067
7	**Floor level difference**	0.200	0.250	0.333	0.333	0.500	0.500	1	1	2	3	0.008	0.620	0.046
8	**Large Overhangs**	0.200	0.250	0.250	0.333	0.333	0.500	1	1	2	3	0.004	0.578	0.043
9	**Age of building**	0.143	0.167	0.200	0.200	0.250	0.333	0.500	0.500	1	2	0.000	0.363	0.027
10	**Visual Condition of building**	0.125	0.125	0.143	0.167	0.200	0.250	0.333	0.333	0.500	1	0.000	0.252	0.019
												Sum	13.393	

In doing so, it is assumed that for the buildings that do not have sufficient data on size of support system, they have adequate size of support system that do not contribute towards the building’s vulnerability and that the factor is constant throughout the buildings.

In case of some of these factors, they are more than just “exists” and “does not exist” scenario. Therefore, they have intermediate level values which can indicate partial contribution to building vulnerability. For such cases, weight modifiers are introduced so that we can have higher accuracy in the computation of EVI. These weight modifiers are obtained by looking into different categories of prevalent configurations within each factor. The resulting modifiers are used by multiplying the respective weight of a factor before adding total for the EVI.

In case if size of support material, it differs between types of buildings, therefore the weight modifiers are also defined according the building type. In case of buildings with columns, the modifiers were declared according to the dimensions of its columns as follows

Table 5 Weight modifiers for size of support system - columns

Size of support system	**Modifier**
>= 12 inches by 12 inches	0
9 by 12 to 12 by 12	0.5
< 9 by 12	1

These modifiers have been select based on the building code of Nepal and also from Assessment of Building Permit Drawing conducted by NSET/BCIPN mentioned in section **1.4.3**. The survey form for this assessment can be found in **Annex II**.

Similarly, for wall system buildings the weight modifiers were given by referring to the building code. Since there are different types of buildings within the load bearing wall category, the weight modifiers were calculated based on these various types as seen on Table 5.

Table 6 Weight modifiers for size of support system - walls

Material	Size of support system	Modifier
Bricks	>= 14 inches	0
	9 to 14 inches	0.7
	< 9 inches	1
Blocks	>= 12 inches	0
	< 12 inches	1
Stone or Earthen or Others	>= 18 inches	0
	14 to 18 inches	0.7
	<14 inches	1

Since there was no sufficient information on other types of building's size of support system, this factor was omitted for other types of buildings. Other factors that needed weight modifiers were Slope of foundation, Shape of building plan, Number of floors, Floor level difference, age of building and visual condition of building. The weight modifiers for these factors can be seen on Table 6.

Table 7 Weight modifiers for other factors

Factor	Values	Modifiers
Slope of foundation	Flat	0
	Moderate	0.5
	Steep	1
Shape of building plan	Square/ Rectangular	0
	Narrow Rectangular	0.7
	Others	1
Number of floors	1-2	0
	3-5	0.7
	>5	1
Floor level difference	No or building not attached	0
	Yes, and building attached on one side	0.5
	Yes, and building attached on multiple sides	1
Age of building	0-10	0
	11-30	0.3

	30-50	0.7
	>50	1
Visual condition of the building	Good	0
	Average	0.5
	Poor	1

2.8 Calculating earthquake vulnerability indices of every building

After the weights of the factors and their modifiers were defined, EVI of the buildings were calculated. the fields in the attribute table were filtered so that only the columns with the data required remained. To do this, the other fields were deleted using the delete fields tool in the toolbox Data Management Tools of ArcGIS 10.3.

A new field named EVI of datatype double was created to store EVI of the buildings. Field calculator was opened for the new field to calculate EVI. In the field calculator, the parser was selected as Python and the Show Codeblock checkbox was checked. This revealed the code area where a script incorporating all the prementioned weights and modifiers was written as seen on Figure 8. The script checked the factors in each building and calculated its EVI based on the defined modifiers. The script can be found in the **Annex III.**

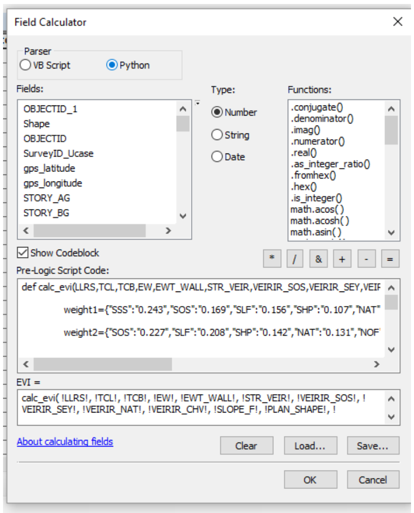


Figure 7 Calculating EVI

2.9 Calculating probability of damage

Now that the vulnerability of each building was calculated, the probability of damage to the buildings needs to be calculated. From section 2.5, it was determined that the probable earthquakes in Birendranagar and Vyas were of intensity IX while that of Birtamod was of intensity VIII.

JICA and NSET have collectively conducted a research on the fragility of buildings in Kathmandu **(NSET, JICA, & MoHA, 2001)** from which **Thapaliya, 2006** has adopted a damage probability matrix for his research. This matrix can be found on **Annex IV**. This matrix divides provides a range of probability of damage for different types of building under different earthquake intensities. In order to narrow down the range, each building type was further divided into its subcategories based on the EVI calculated earlier. Each category had three subcategories of buildings which included buildings with certain EVI values as mentioned in Table 7.

Table 8 Basis for building type subcategories

EVI	Vulnerability level	Code
0 to 0.2	low	3
>0.2 to 0.5	medium	2
>0.5	high	1

Another thing to note is that, using conservative estimate, any building type not mentioned is estimated to sustain damage as much as seen on adobe/stone masonry buildings as they are seen to be most susceptible to damage. Therefore, the buildings will be divided into 5 types according to the damage probability matrix in **Annex IV** and then into 3 sub categories each using the EVI calculated earlier. Then, the range for a type of building was broken down to the min value, median value and max value of the range according to low, medium and high vulnerability respectively. In doing so, following matrix was obtained. The probabilities were computed for scenario intensity of VIII and IX because two of our three municipality has a probable intensity of IX while the third municipality has a probable intensity of VIII.

Table 9 Damage probability for different categories of buildings

Building Category	Scenario Intensity VIII		Scenario Intensity IX	
	Total collapse Probability	Partial damage Probability	Total collapse Probability	Partial damage Probability
AD1	55	28	72	28
AD2	45	30	63	30
AD3	35	31	55	31
BM1	41	28	62	19
BM2	31	27	51	25
BM3	21	25	41	29
BC1	18	45	54	17
BC2	12	38	35	32
BC3	5	31	19	45
RCC3_1	15	30	30	60
RCC3_2	11	22	23	45
RCC3_3	7	14	15	30
RCC4_1	19	38	35	65
RCC4_2	14	27	27	52
RCC4_3	8	16	19	38

In order to insert these values to the feature class, two new fields were added to the feature class of each municipality namely total and partial. Then scripts for each field were written in field calculator similar to when calculating EVI. This gave us the probability of damage in different scenario for each building. This script looked at the number of storeys, load resisting system, construction material, external wall material and EVI of a building to first classify the building and then assign it a respective probability according to the Table 9. This python script for this can be found in **Annex V**.

After the probability of damage and probability of collapse was calculated, the probability of overall damage was calculated. As used by JICA in 2002, the overall probability of damage was defined as the sum of total collapse probability and half of the probability of partial damage. To calculate this, a new field named overall was created and the following formula was used

overall = total + partial / 2

After computing the probabilities of different damages to the buildings, the number of people affected by collapsing buildings was determined.

2.10 Buffer analysis

In an earthquake, the biggest danger is from failing structures and falling objects. However, they are not limited to one's own house or the building that they are currently in. One of the biggest danger comes from the falling debris from nearby structures. These debris can not only damage other structures but also claim lives. There is an area around a structure where these debris of failed structure are likely to fall. This area is known as collapse zone. The collapse zone for a structure extends up to one and half times the height of the structure. In order to identify the collapse zone of buildings with high probability of collapse, buildings a buffer was created around buildings with collapse probability of more than or equal to 25%. The buffer created for each building would not be same as the collapse zone is dependent on the height on the building.

First the floor height of structures was assumed to be 9 feet (2.743 meters) as it is the standard practice of construction. Then, a new field was created to store the range of buffer for buffer analysis. It was named buffer_range and field calculator was used to compute the value as follows

buffer_range = 1.5 x (number of floors x 2.743)

The value was stored in meters. Then, a new layer was created will all buildings that had 50% or more collapse probability. Using this layer as input, the tool Buffer of Analysis Tools in ArcGIS. The field buffer_range was supplied as a parameter for distance so that the buffer around each feature would be created according to the field. After the creation of buffer was complete, the buildings that fall within or intersect the newly created buffer layer were selected, inspected and summarized.

2.11 Mapping and comparison of results

After the fields were computed, the data was mapped. Maps showing building locations, EVI, probability of collapse and probability of partial damage were prepared for all three municipalities. The maps were visually compared between all three municipalities. The number of buildings within collapse zone and consecutively the number of people who were affected by the collapse zone was also compared.

Chapter-3: Results

3.1 Distribution of buildings

The building location of the surveyed buildings in each of the three regions were mapped using ArcGIS 10.3.

3.1.1 Birendranagar municipality

Building Inventory Data Survey (BIDS), in Birendranagar, did not cover the whole municipality and instead only covered the wards 5,6,7,8,9,10,16,17 and 18 which are the most populated wards of the municipality. Therefore, our dataset contains only the location of building in those wards. From Map 9, it can be seen that most of the buildings are concentrated at the central part of the North-South stretch of the municipality while the buildings are spread out along the East-West stretch.

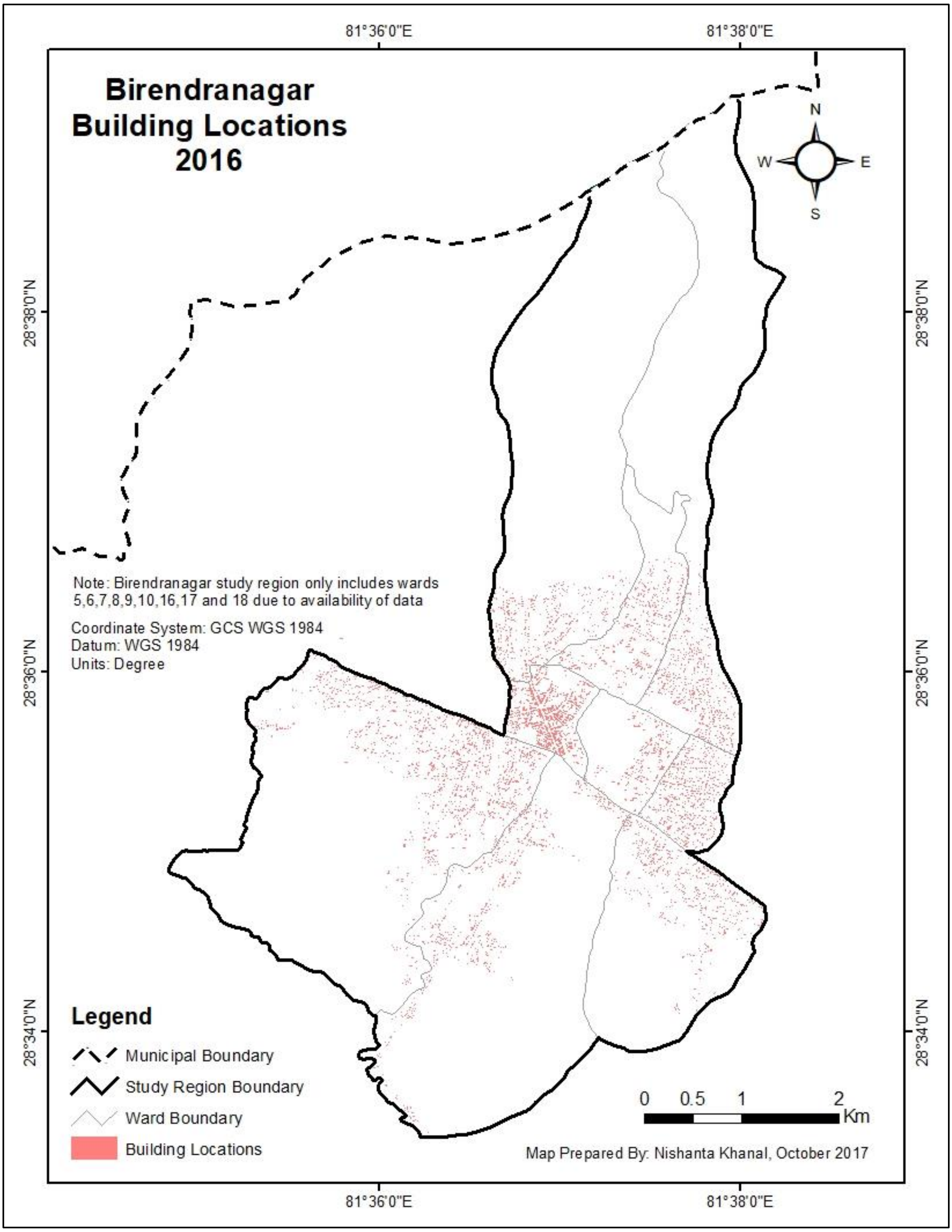
3.1.2 Birtamod municipality

Buildings throughout the Birtamod municipality were surveyed in BIDS. Therefore, the dataset contains building location of all the buildings in the Birtamod municipality. From Map 10, it can be seen that buildings are spread throughout the municipality. However, the distribution of buildings is most dense at the center of municipality and it gets thinner along East-West direction. Along the North-South direction as well, the distribution of building is high at the northern parts of the municipality.

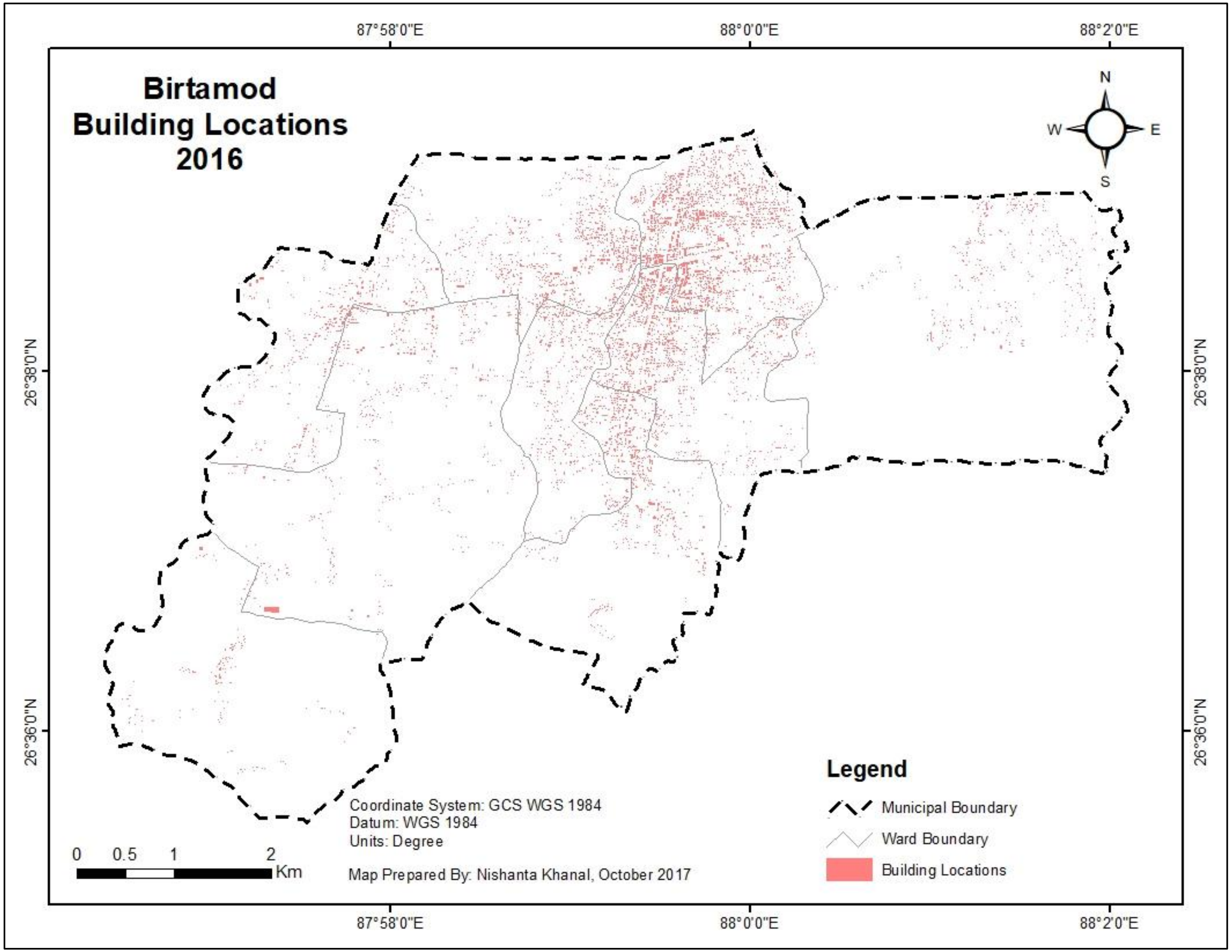
3.1.3 Vyas municipality

The data collected during BIDS had some data outside of the government supplied municipality boundaries which were removed from the dataset in order to limit the mapping within the target municipality. This left us with 10883 buildings within the official Vyas

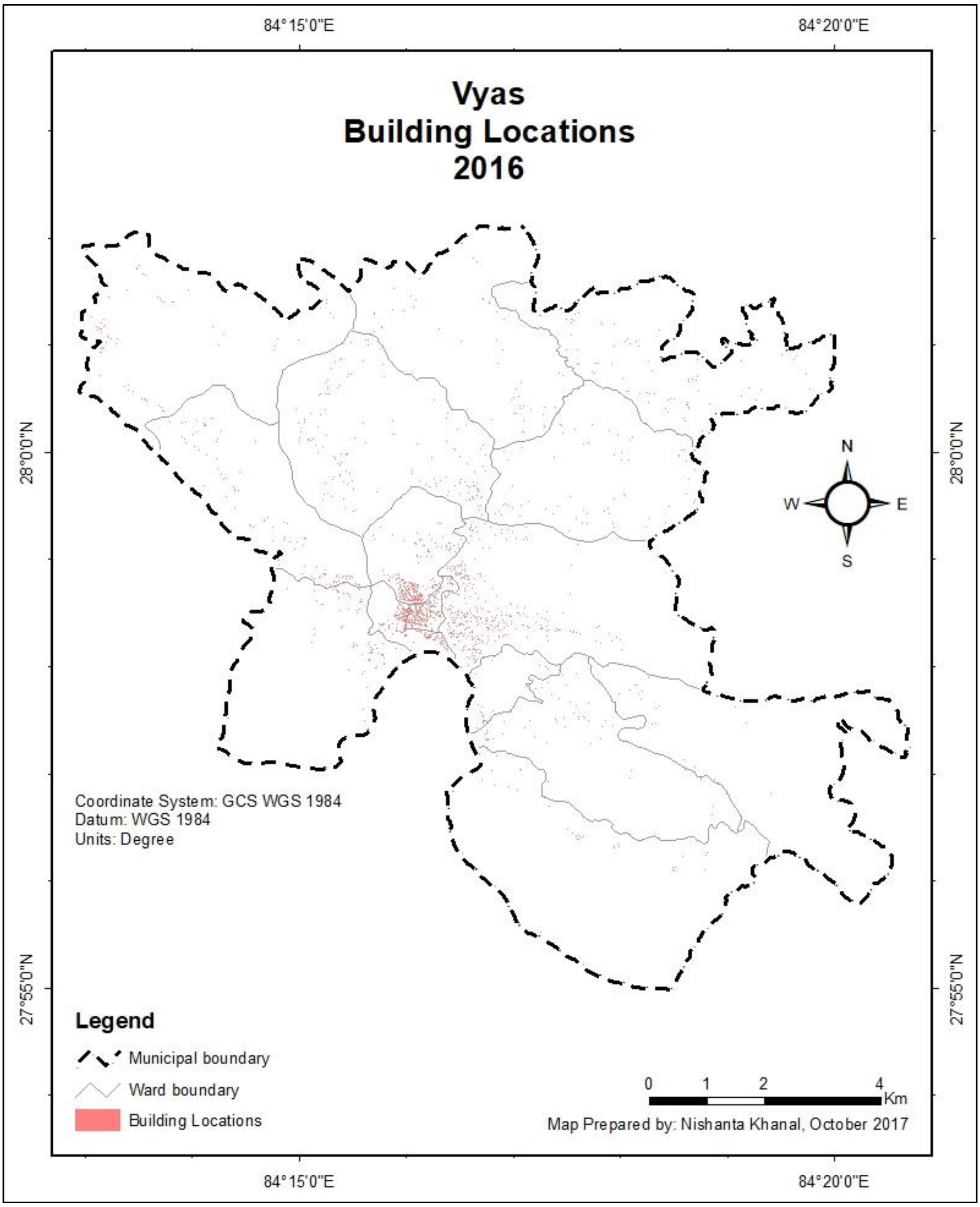
Municipality bounds. The buildings seem to be concentrated towards the central part of the municipality with buildings spread throughout. This can be seen on Map 11.



Map 9 Birendranagar, Building Locations, 2016



Map 10 Birtamod, Building Locations 2016



Map 11 Vyas, Building Locations, 2016

Since the building polygons were too small to be properly identifiable, they were symbolized with a border size of 1 on ArcGIS 10.3. While this made it easy to identify the buildings, it should be noted that these new symbols do not represent actual dimensions.

3.2 Earthquake vulnerability index

The earthquake vulnerability indices of all the surveyed buildings in the study region Birendranagar Municipality (wards 5,6,7,8,9,10,16,17 and 18), Birtamod municipality and Vyas municipality of Nepal were calculated.

3.2.1 Birendranagar municipality

Since, in case of Birendranagar Municipality, the analysis was done only on wards 5,6,7,8,9,10,17 and 18 due to limitation of data so the result obtained is only indicative of those wards. The calculation of EVI resulted in numbers as seen on Table 10. It can be seen that majority of the buildings fall under the medium vulnerable category i.e. between 0.2 and 0.5 EVI with around 56.94% of buildings. After that, almost 42.87% of buildings in the study area of Birendranagar Municipality fall in the low vulnerable category. This represents that most of the building in the study area have followed earthquake safe construction practices to certain extent but are still introducing building components and designs that introduce vulnerabilities.

A surprising low number of buildings 21 which amounts to 0.19% of the total buildings fell under the highly vulnerable category. However, only two of these buildings exceeded 30 years of age with zero buildings exceeding the age of 35. This shows that there are still signs of earthquake vulnerable construction practices in the municipality.

Table 10 Building proportion according to EVI, Birendranagar

EVI	Number of buildings	Percentage
0 to 0.2	4639	42.87%
>0.2 to 0.5	6161	56.94%
+>0.5	21	0.19%
Total	**10821**	**100%**

The minimum EVI observed for this study region was 0. There were 407 buildings (3.76%) with EVI value equal to 0. This means that with regards to the factors that were selected for this study, 407 of the surveyed buildings were constructed as strong as they possibly could and without most of the attributes that contribute to making the building vulnerable to earthquakes.

The maximum EVI observed was 0.6928 and the mean EVI was 0.2052. Therefore, on average, buildings in this area fall slightly within the moderately vulnerable category. This statistic can be further explored in Figure 8 below. It can be seen that the graph is slightly skewed towards left with more buildings towards the low vulnerability size. However, a spike can be observed as we near 0.3 EVI. This maximum frequency slightly exceeds the 3000 buildings mark. The second highest value lies around 1500 which is around half of the maximum value. This means that although different types of buildings can be found in the municipality, a lot of buildings tend to follow the same construction practices. The lower frequency towards the high vulnerability region is expected as it is unlikely that buildings would implement all the vulnerable elements in buildings.

However, one thing to note from the figure is that even though there are 42.87% of buildings classified as low vulnerability i.e. less than 0.2 EVI, the frequency graph tells us that statistic could be misleading. It can be seen on the graph that the number of buildings that are close to 0 EVI is not high as most of the buildings that fall in that range seem to have a value closer to 0.2 EVI. In fact, after a certain number of buildings with EVI towards the lower end of 0 - 0.2 range, there are very few buildings that are in lower or mid sections of that range. It shows that most of the buildings that have been classified under low vulnerability actually are edging towards the category medium vulnerability.

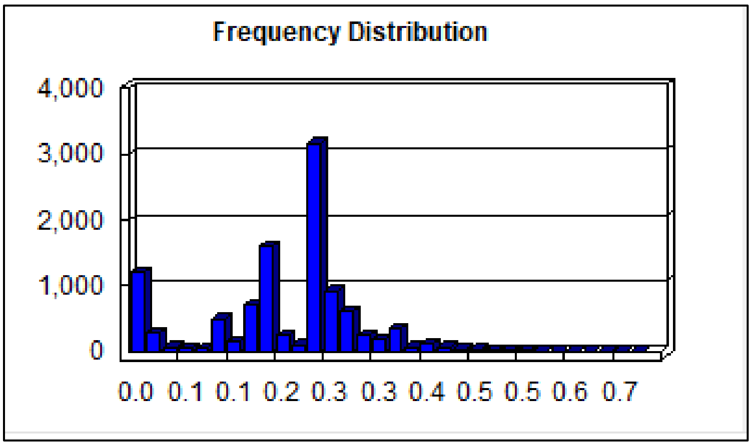


Figure 8 EVI frequency distribution, Birendranagar

While the low number of buildings in high value region for all three municipalities is normal, it can be attributed to lack of consideration of certain attributes deemed important in multiple sources such as bands **(Cochrane & Schaad, 1992; Thapaliya, 2006)**. The same can be said for the low values. While having these data would not change the shape of the graph drastically, it would definitely contribute to some change.

On Map 12, the distribution of buildings according to their EVI can be seen. As seen on map, the yellow buildings, which are of medium vulnerability category are dominant throughout the municipality. The low vulnerable buildings are spread throughout the built-up areas of the municipality as well. However, they can be seen more in the north-eastern part of the municipality. While the few highly vulnerable buildings are not clustered together in one spot, most of them are present in the western part of the municipality.

This shows that while the construction practice throughout the municipality is not the best, they seem to be better towards the eastern parts of the municipality. On the other hand, the western part of the municipality seems to house relatively worse construction practices in the municipality.

3.2.2 Birtamod municipality

EVI for each surveyed building throughout the Birtamod municipality was calculated. The calculation of EVI resulted in numbers as seen on Table 11. It can be observed that most of the buildings are under the medium vulnerable category i.e. between 0.2 and 0.5 EVI with around 68.11% of buildings. Other than that, 30.79% of buildings in the Birtamod Municipality fall in the low vulnerable category. This indicates that the building in the municipality have followed guidelines for earthquake safe construction while constructing buildings but also are still introducing building components and designs that introduce vulnerabilities.

131 buildings (1.10%) among all the buildings fell under the highly vulnerable category. These buildings had mean age of 11.25 years with minimum value being 1 year and maximum value being 30 years. This shows that there are still signs of earthquake vulnerable construction practices in the municipality as even some new buildings that are being constructed are not complying to earthquake safe standards.

Table 11 Building proportion according to EVI, Birtamod

EVI	**Number of buildings**	**Percentage**
0 to 0.2	3656	30.79%
>0.2 to 0.5	8088	68.11%
>0.5	131	1.10%
Total	**11875**	**100%**

The minimum EVI observed for this study region was 0 as well. There were 662 buildings (5.57%) with EVI value equal to 0. This means that with regards to the factors that were selected for this study, 662 of the surveyed buildings were constructed as earthquake resistant as they possibly could and the attributes that contribute to making the building vulnerable to earthquakes.

The maximum EVI observed was 0.7363 and the mean EVI was 0.2156. Therefore, on average, buildings in this area fall within the moderately vulnerable category. This can be observed in Figure 9 below as well. It can be seen in the graph that despite only having 131 buildings at 0 EVI, a lot of buildings are really close to the value as the frequency bar slightly exceeds 2000. However, a steep rise can be observed as we approach 0.3 EVI as well. This frequency bar slightly exceeds the 3000 buildings count. In this case however, the second is the one at least vulnerability. This means that houses that are constructed in this municipality are more likely to follow earthquake resistant construction practices. In this case as well, the lower frequency towards the high vulnerability region is expected as it is unlikely that buildings would implement all the vulnerable elements in buildings.

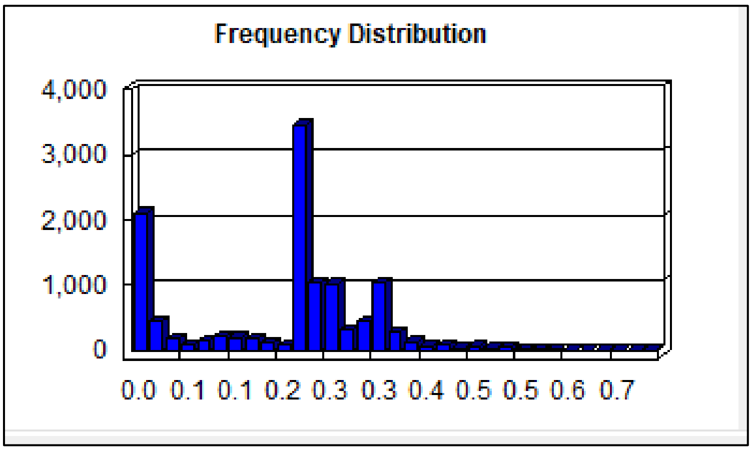


Figure 9 EVI frequency distribution, Birtamod

On Map 13, the distribution of buildings in Birtamod according to their EVI can be seen. As seen on map, the yellow buildings, which are of medium vulnerability category are dominant throughout the municipality in this case as well. The low vulnerable buildings are spread throughout the built-up areas of the municipality as well. While they can be clearly observed towards south of the central part of the municipality, such buildings can be seen throughout the municipality on other areas as well. The highly vulnerable buildings are predominantly found in the densely populated part of the municipality. This shows that the construction practice in the municipality is lagging in terms of earthquake resistant designs. It also looks like the good and the bad practices are mixed in the areas could mean that there is awareness regarding earthquake vulnerability but has not been widespread enough.

3.2.3 Vyas municipality

EVI for each surveyed building throughout the Birtamod municipality was calculated. The calculation of EVI resulted in numbers as seen on Table 12. It can be seen that majority of the buildings fall under the medium vulnerable category i.e. between 0.2 and 0.5 EVI with around 58.23% of buildings. After that, almost 41.35% of buildings in Vyas Municipality fall in the low vulnerable category. This represents that most of the building in the municipality have followed earthquake safe construction practices to certain extent but are still not fully adopting practices to make their buildings as earthquake safe as they can be.

46 buildings, which amounts to 0.42% of the total buildings fell under the highly vulnerable category. Out of these 46, only 14 buildings were below the age of 10 years and the average age was 14.73 years. This shows that while there are still some instances of vulnerable buildings being built, it is starting to decrease in number.

Table 12 Building proportion according to EVI, Vyas

EVI	Number of buildings	Percentage
0 to 0.2	4500	41.35%
>0.2 to 0.5	6337	58.23%
>0.5	46	0.42%
Total	**10883**	**100%**

After the calculation of EVI it was observed that the maximum EVI was 0.6526 and the minimum was 0 in 299 buildings (2.75%). The mean EVI was found to be 0.2052 with a standard deviation of 0.1297. The distribution of EVI can be seen in the Figure 10. The graph shows that a large number of buildings (more than 1500) have the best configuration possible, with regards to earthquake safety, for their respective building typology as represented by the high number of 0 value in the graph. The high number of buildings in the mid-range of the graph suggest that there is substantial amount of buildings that are not safe and are at risk. Moreover, unlike other municipalities, the large number of houses in mid-range of the graph is more spread out. This means that people are opting for different design choices and are still creating buildings that are vulnerable to earthquake.

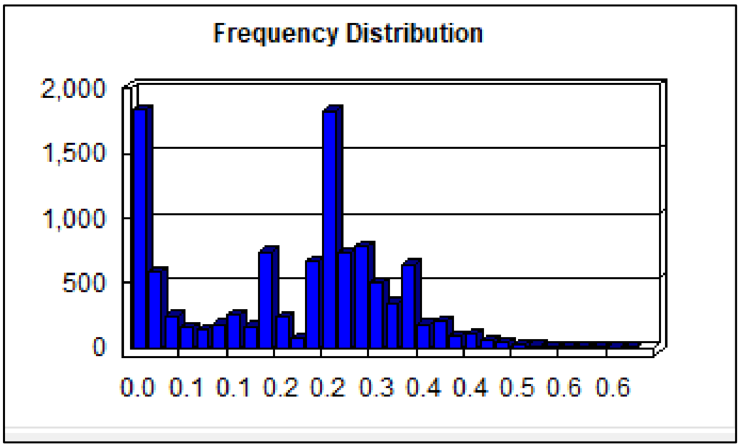
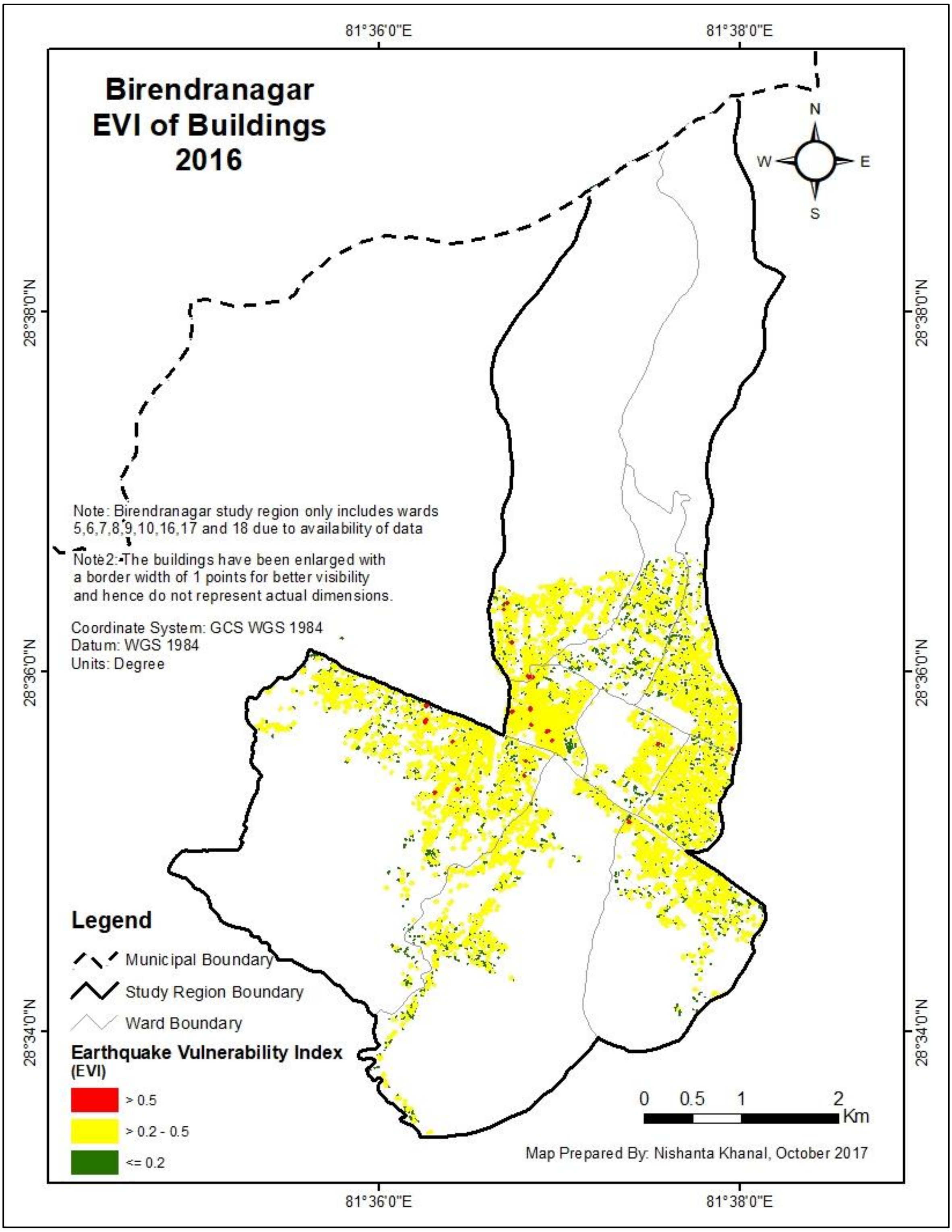


Figure 10 EVI frequency distribution, Vyas

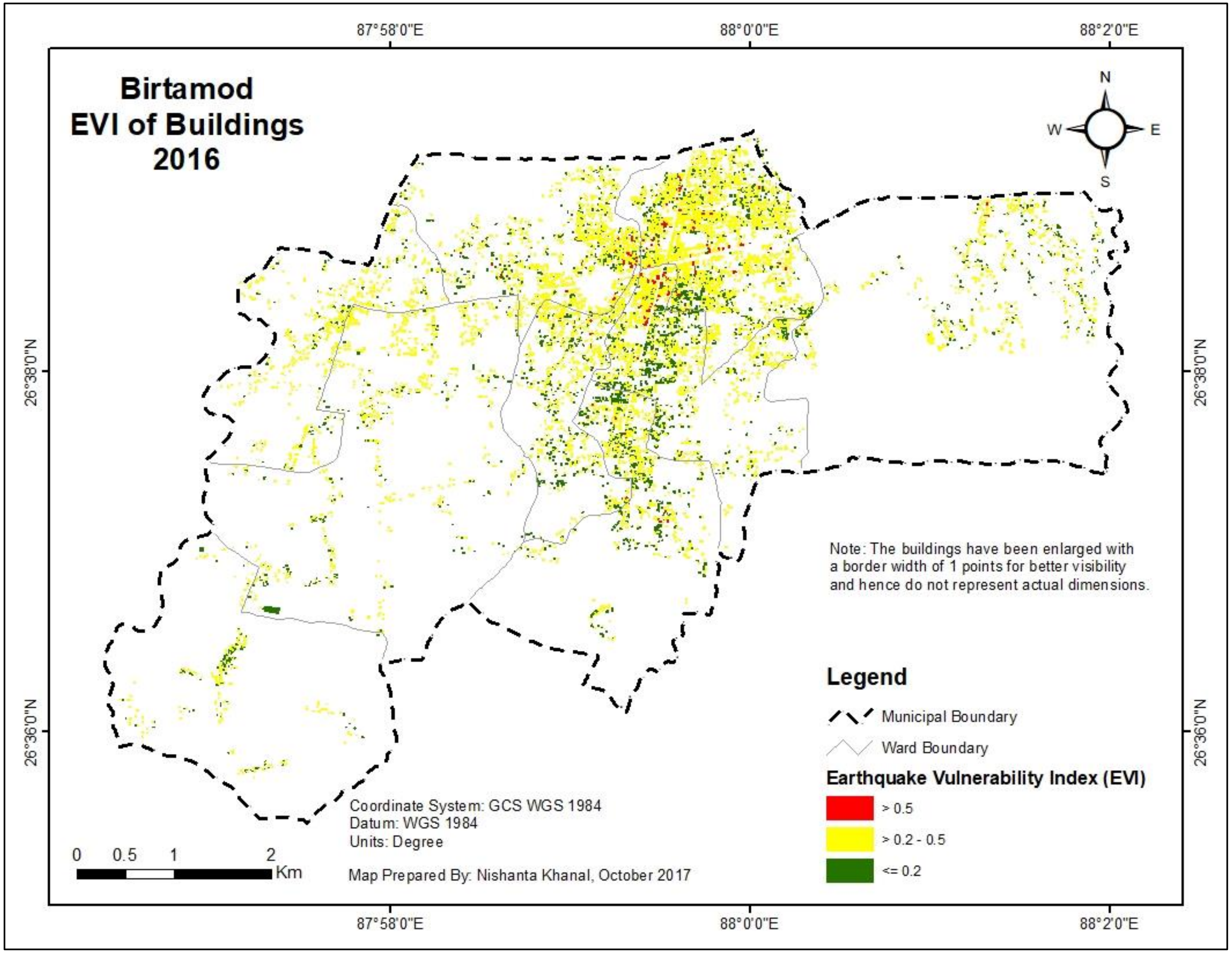
3.2.4 Comparing EVIs between study regions

On comparing the three municipalities based on their buildings' EVI, it can be seen that they are similar in a lot of ways. In all of the areas there is a high point in frequency around 0.2 – 0.3 EVI. Furthermore, they all have very low frequency at the tail end of the graph with higher EVI. Even taking a look at the maps of the tree study regions, it can be seen that the buildings that are of very high EVI i.e. greater than 0.5 lie on the core densely populated part of the respective municipalities.

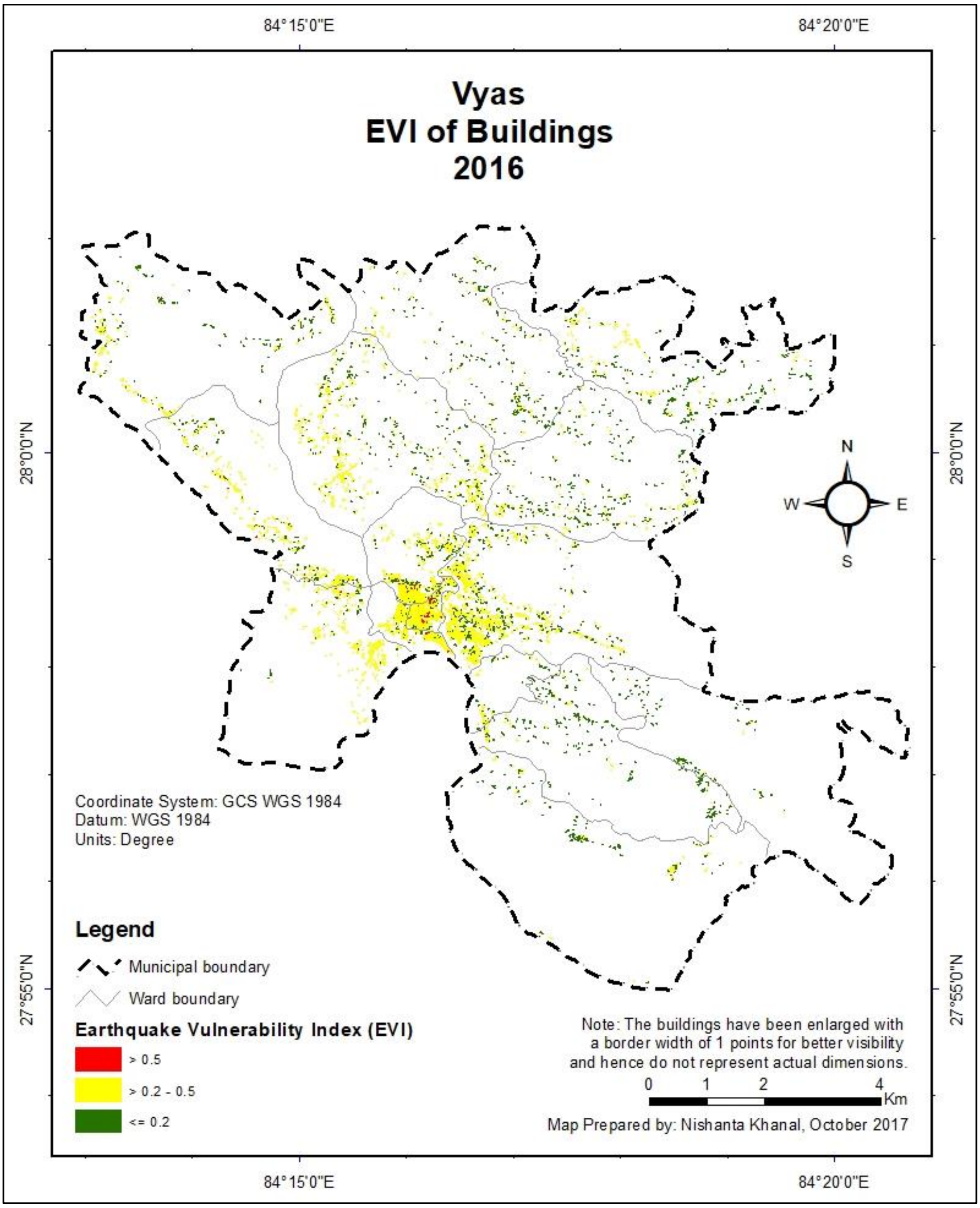
However, there are certain differences as well. While Birtamod and Vyas both have a high number of buildings that have very small EVI and thus are safe, this number is lower in case of Birendranagar. Although Birendranagar has 42.87% of buildings in the low vulnerability range which is higher compared to Birtamod's 30.79% and Vyas's 41.35%, most of the buildings in low vulnerability category of Birendranagar have EVI closer to 0.2. Meanwhile, Birtamod has the highest ratio of buildings that are vulnerable compared to the other two municipalities. It is shown by the 68.11% of building in medium vulnerability range compared to 56.94% and 58.23% of Birendranagar and Vyas respectively.



Map 12 Birendranagar, EVI of Buildings, 2016



Map 13 Birtamod, EVI of buildings, 2016



Map 14 Vyas, EVI of buildings 2016

3.3 Probability of damage

The probability of partial damage, total collapse and overall probability of damage was calculated for all the surveyed building in the study regions using the damage matrix at **Annex IV** and Table 9.

3.3.1 Birendranagar municipality

In Birendranagar municipality, the probable earthquake scenario was considered to be of Modified Mercalli Intensity (MMI) IX. The maximum probability of partial damage observed here was 65% while the minimum was 17%. The average partial damage probability of buildings in this region was 38.64%. The frequency distribution in Figure 11 shows that most of the buildings have partial damage probability of around 47%. From Map 15, it can be seen that the building with more than 50% probability of partial damage are located in the core part of the study region which has high density. The buildings that can be considered relatively safe are spread throughout the study region while the buildings that are moderately prone to partial damage are predominant throughout the study region.

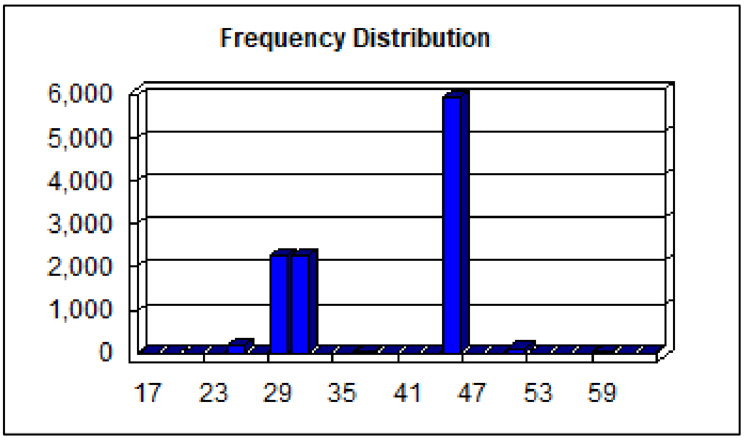


Figure 11 Partial damage probability frequency distribution, Birendranagar

In case of building collapse probability of buildings in Birendranagar, it was found that on average the buildings had 31.62% probability to fail. While a majority of buildings were on relatively safer side with around 25% probability of collapse, the second highest frequency was seen at a probability of slightly less than 57%. The maximum probability of collapse was 63% while the minimum was 15%. This information can be obtained from Figure 12 below. The distribution of buildings according to collapse probability can be seen on Map 16. It can be observed that a lot of buildings are relatively safe from collapse as they have less than 25% probability. While the buildings at medium range with 25% to 50% probability are mostly seen on eastern part of the study area, the buildings with very high probability of collapse i.e. greater than 50% seem to be spread across the municipality.

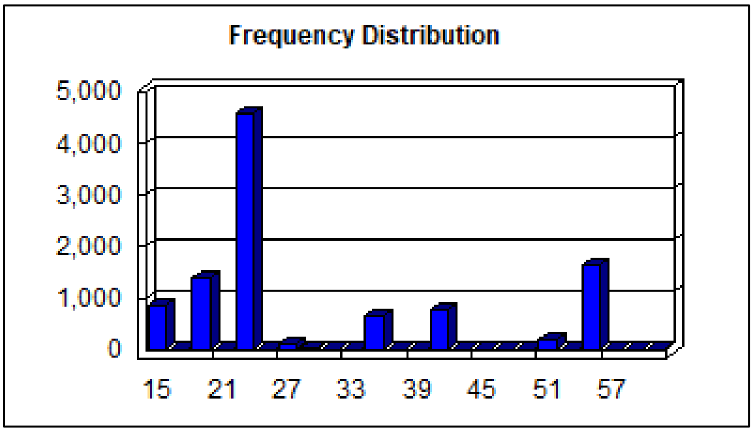


Figure 12 Building collapse probability frequency distribution, Birendranagar

The probability of overall damage is basically a combination of partial damage probability and collapse probability. On average, the buildings in Birendranagar had a probability of 50.94% of sustaining some form of damage. The maximum probability seen in this case was 78% while the minimum was 30%.

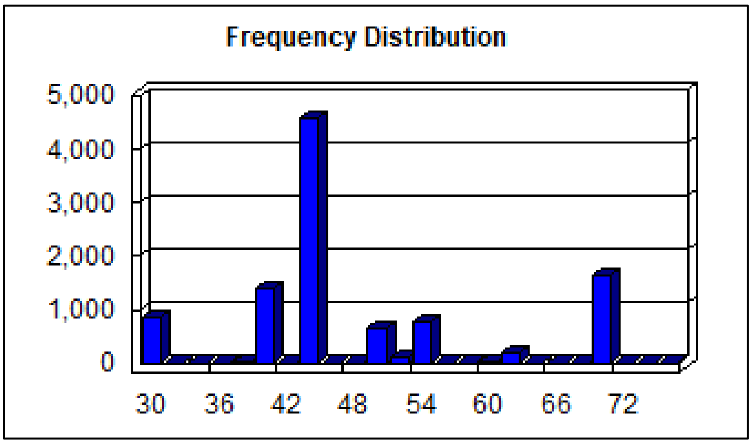
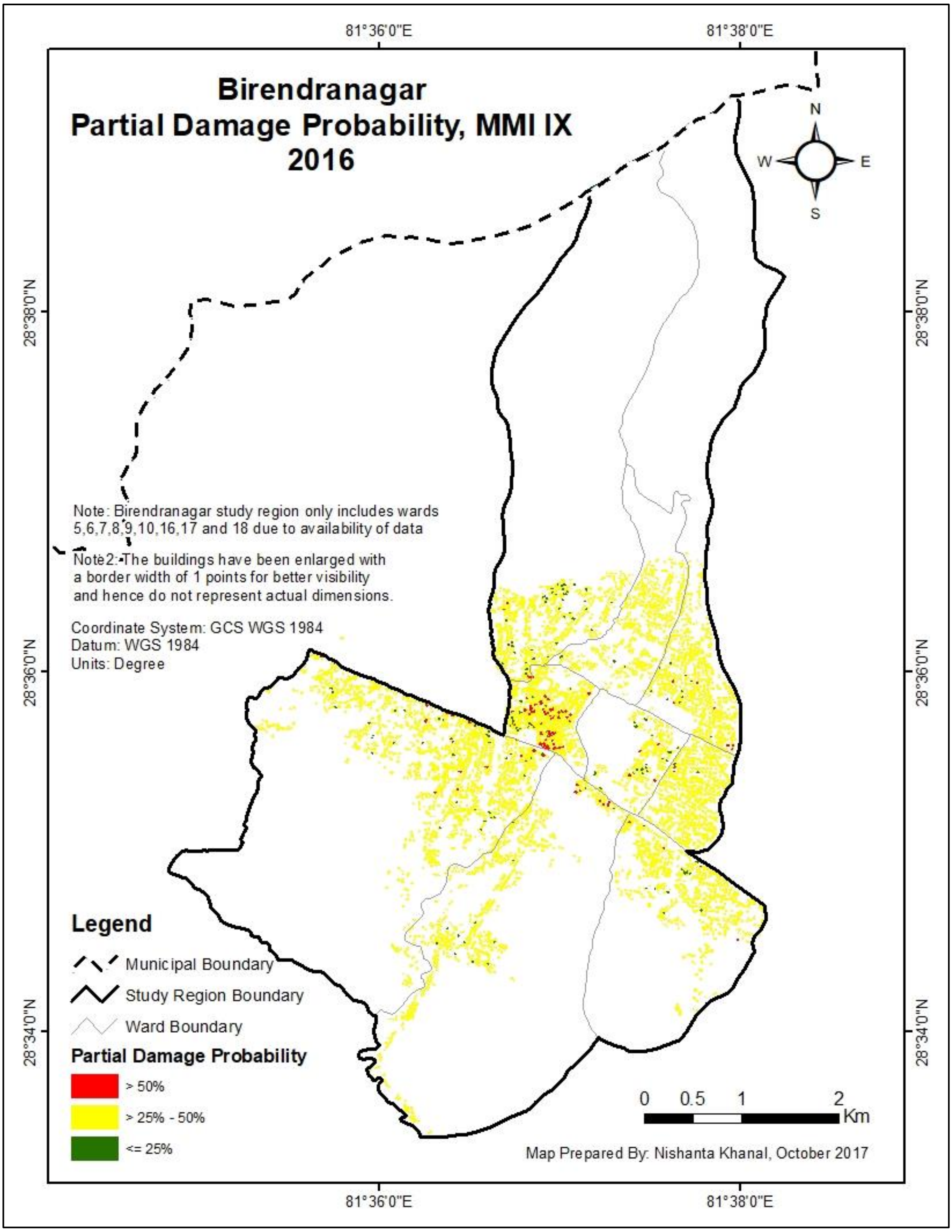
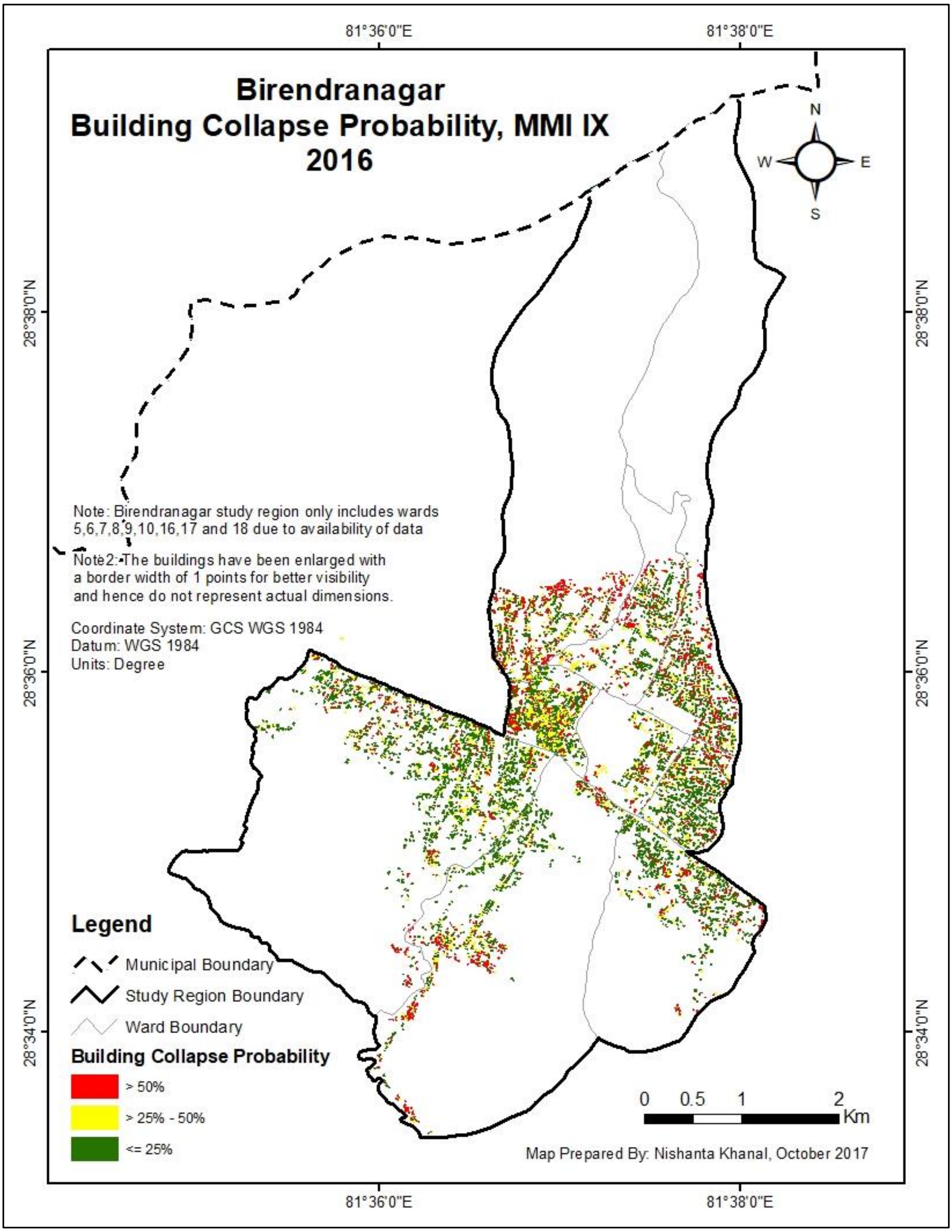


Figure 13 Overall damage probability, Birendranagar

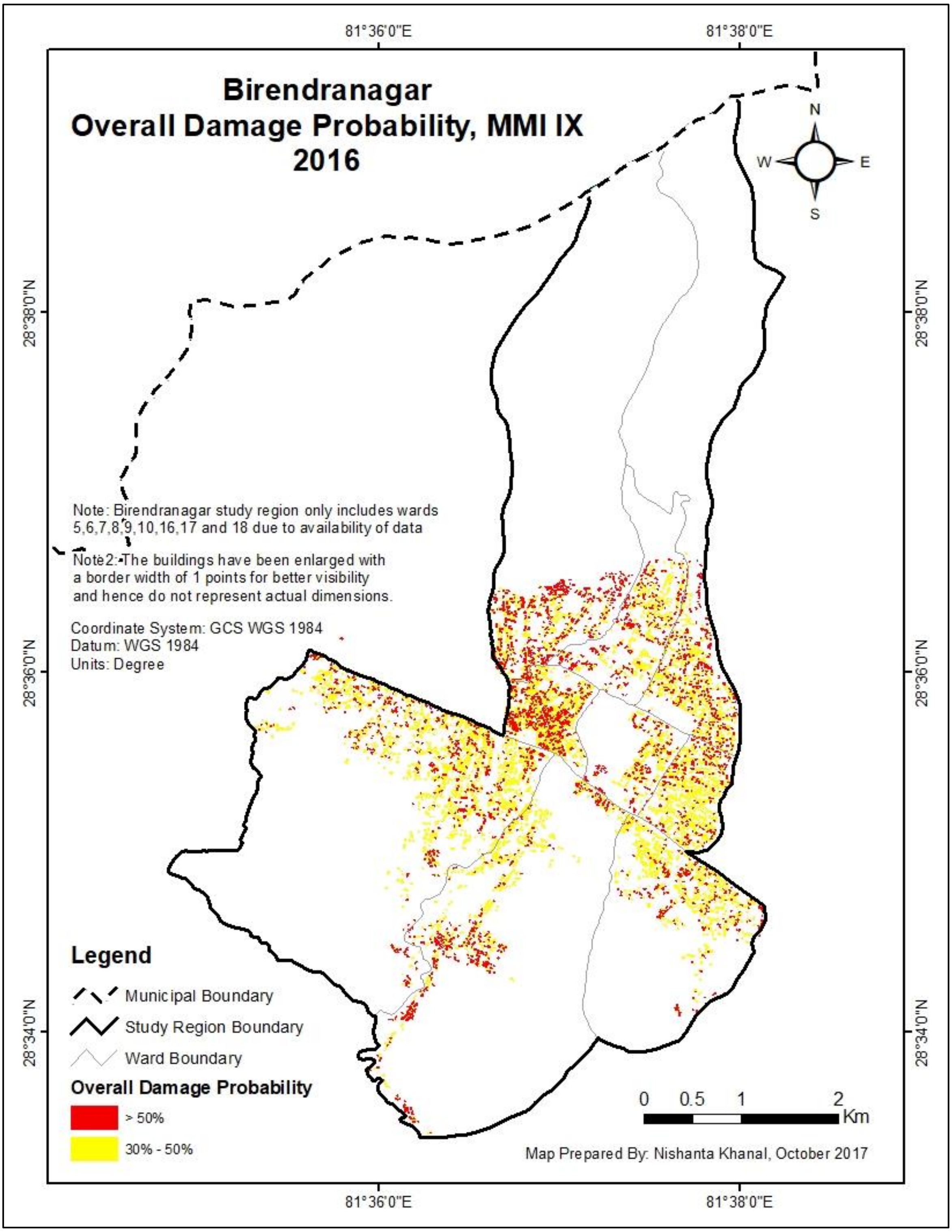
From Map 17, it can be observed that buildings on the northern half of the study region have higher probability of being damaged one way or the other by an earthquake of MMI IX. This can also be observed towards the far southern part of the study region.



Map 15 Birendranagar, Partial Damage Probability, MMI IX, 2016



Map 16 Birendranagar, Building Collapse Probability, MMI IX, 2016



Map 17 Birendranagar, Overall Damage Probability, MMI IX, 2016

3.3.2 Birtamod municipality

For Birtamod municipality, the probable earthquake scenario was considered to be of Modified Mercalli Intensity (MMI) VIII. The extreme probabilities of partial damage observed here was the maximum 45% and the minimum 17%. The average partial damage probability of buildings in this region was 23.46%. The frequency distribution in Figure 14 shows that most of the buildings have partial damage probability of around 22%. It can also be seen that the second highest group of probability is around 31%.

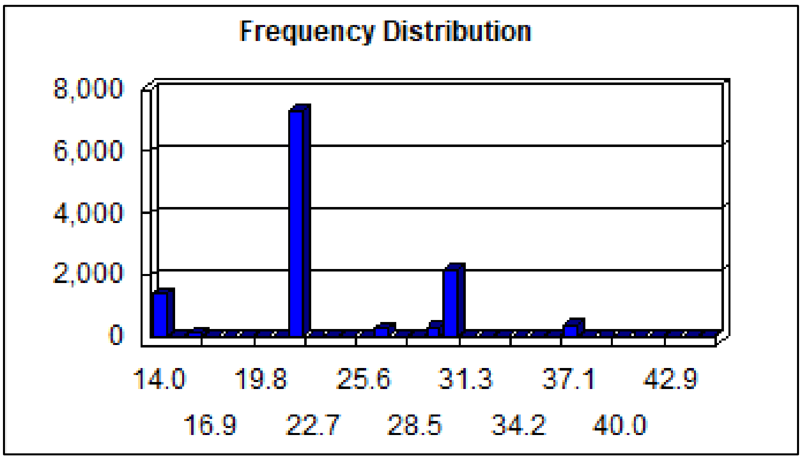


Figure 14 Partial damage probability frequency distribution, Birtamod

Since Birtamod municipality has lower hazard, the probability of partial damage is low as well which is shown by the lack of buildings with high partial damage probability on Map 18. The buildings that have high probability are found spread throughout the municipality and mixed in with the safe buildings.

In case of building collapse probability of buildings in Birtamod, it was found that on average the buildings had 15.32% probability to fail. While a majority of buildings were on relatively safer side with around 11% probability of collapse, the second highest frequency was seen at a probability of slightly more than 35%. The maximum probability of collapse for this municipality was 45% while the minimum was 5% as well. This information can be obtained from Figure 15 below. Similar to partial damage probability, collapse probability of buildings in Birtamod is also spread around the municipality as represented by Map 19. However, it can be seen that most of the buildings with moderate probability of collapse lie on the outskirts of densely populated area with some mixed in as well.

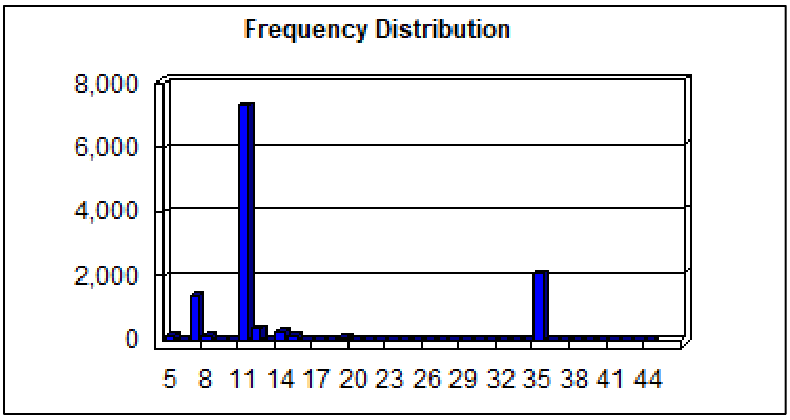


Figure 15 Building collapse probability frequency distribution, Birtamod

On average, the buildings in Birtamod had a probability of 27.05% of acquiring some form of damage. The maximum probability seen in this case was 60% while the minimum was 14%. The frequency distribution of overall damage probability can be seen on Figure 16.

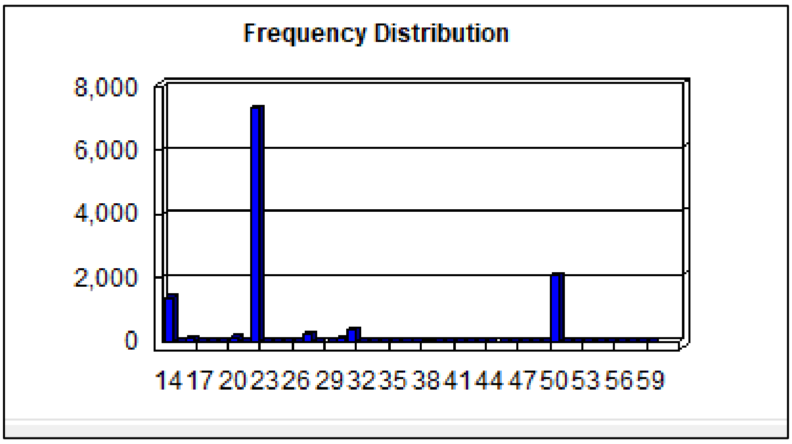
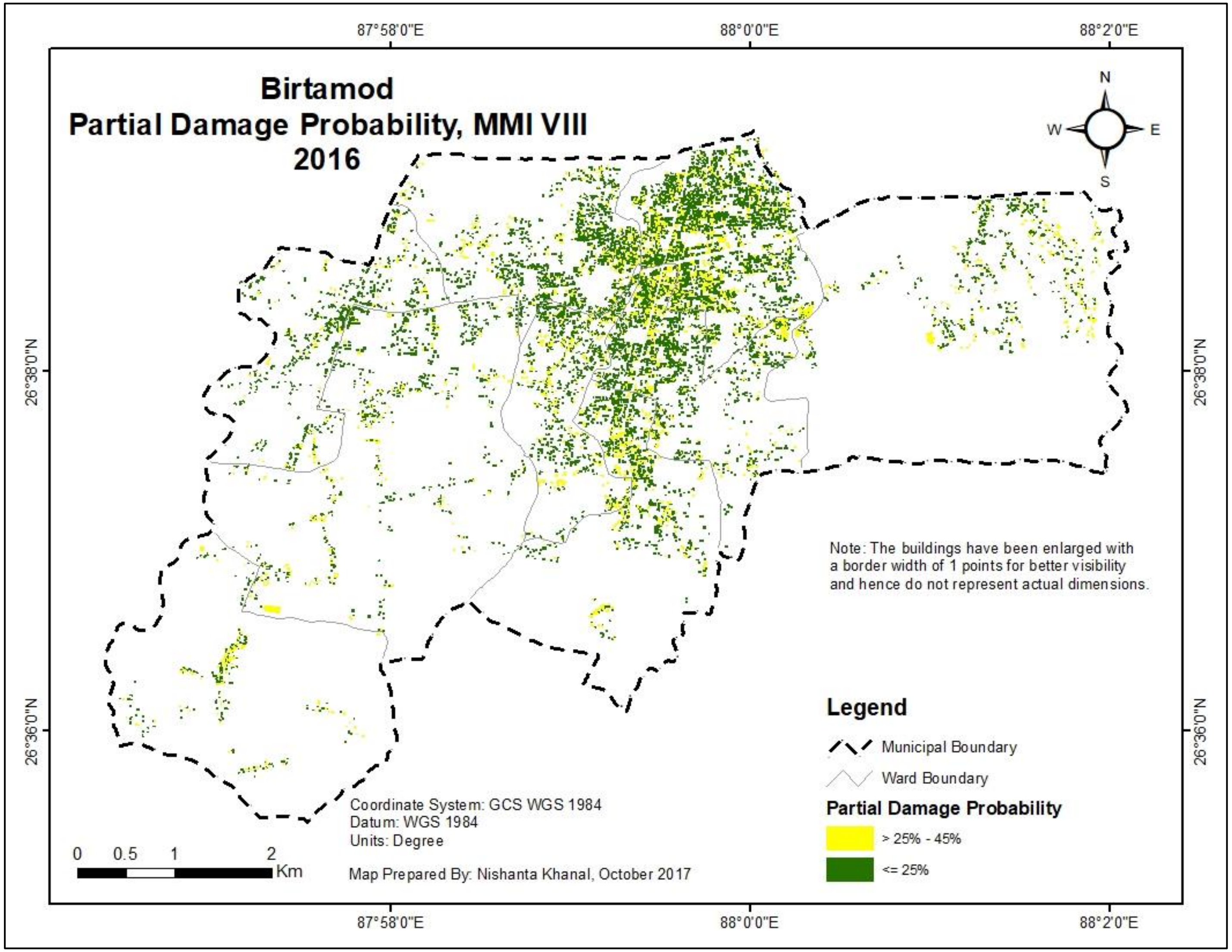
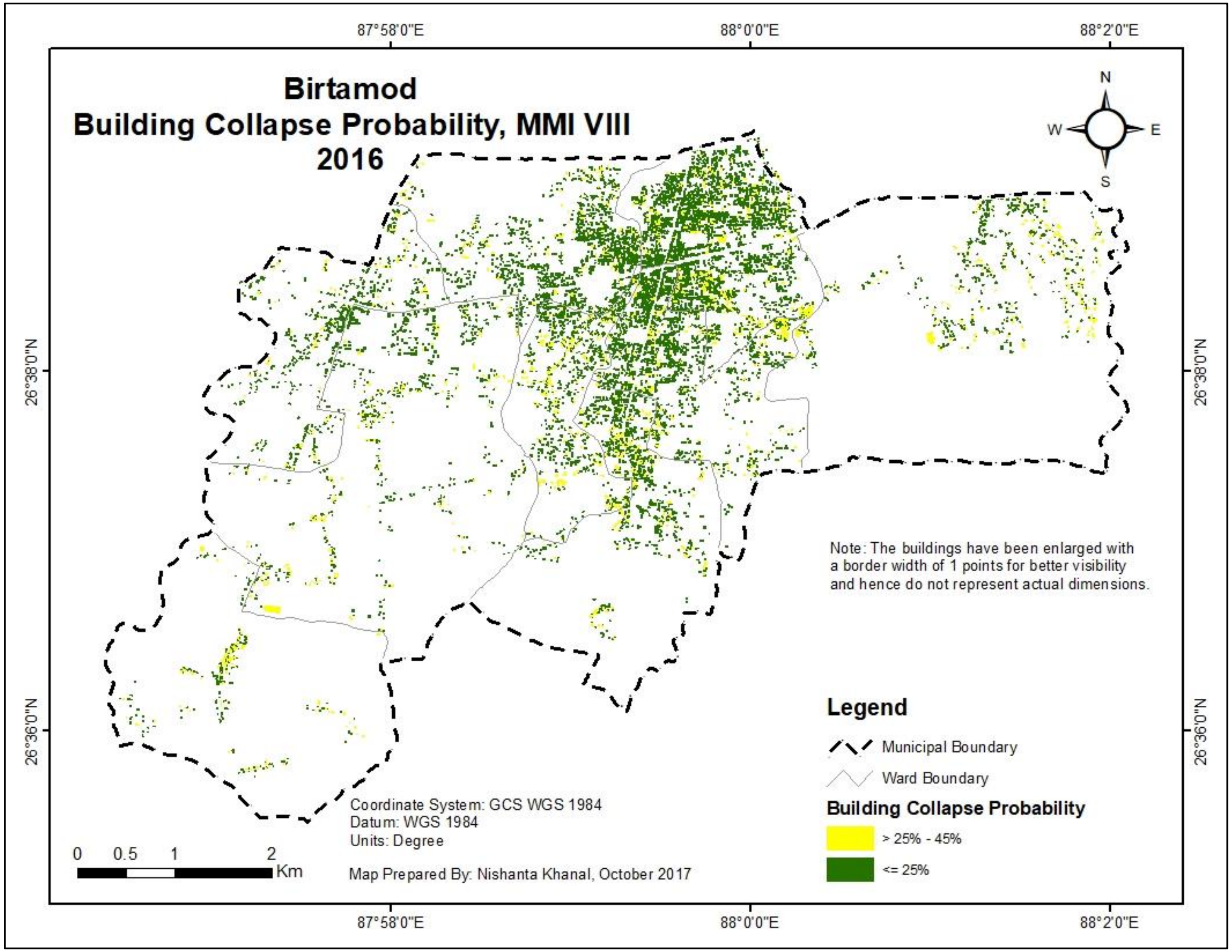


Figure 16 Overall damage probability frequency distribution, Vyas

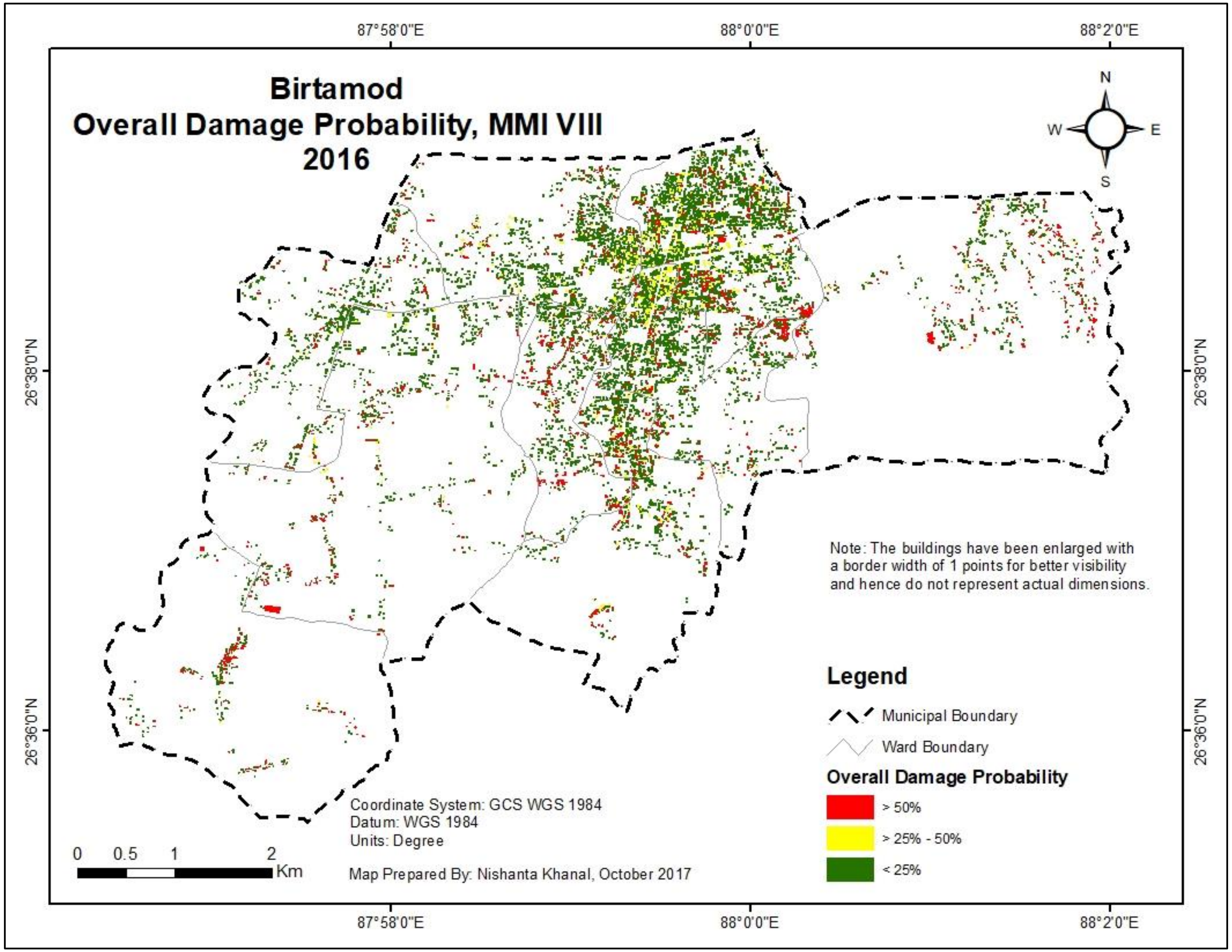
Map 20 reinforces the idea of distribution of damage prone buildings around the outskirts of densely populated area with a few mixed within it as represented by the polygons symbolized in red. In general, the safe buildings and the buildings that are moderately or highly damage prone seem to be mixed throughout the municipality.



Map 18 Birtamod, Partial Damage Probability, MMI VIII, 2016



Map 19 Birtamod, Building Collapse Probability, MMI VIII, 2016



Map 20 Birtamod, Overall Damage Probability, MMI VIII, 2016

3.3.3 Vyas municipality

For Vyas municipality, the probable earthquake scenario was considered to be of Modified Mercalli Intensity (MMI) IX. The extreme probabilities of partial damage observed here was the maximum 65% and the minimum 19%. The average partial damage probability of buildings in this region was 35.92%. The frequency distribution in Figure 17 shows that most of the buildings have partial damage probability of around 46%. It can also be seen that the second highest group of probability is around 31%.

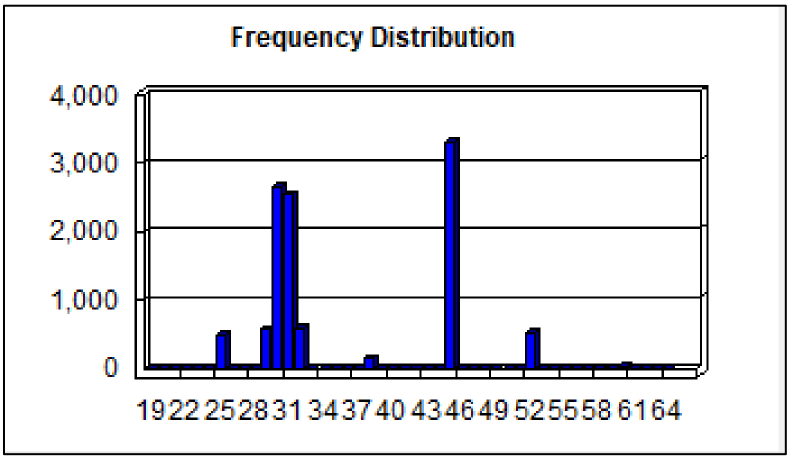


Figure 17 Partial damage probability frequency distribution, Vyas

It can be seen on Map 21 that the few buildings that have low probability of sustaining partial damage are spread throughout the municipality and can be found even in the remote areas of the municipality. However, the buildings with very high probability of partial damage seem to be in abundance in the core residential area of the building. This can be correlated to the Map 22 which shows building collapse probability. In Map 22, there are very few buildings in densely populated area that have high probability of collapse as they are mostly found in remote areas. This means that there are buildings in core area that are designed well to prevent from collapse but will get partially damaged once high intensity earthquake strikes.

In case of building collapse probability of buildings in Birtamod, it was found that on average the buildings had 38.83% probability to fail. While a majority of buildings were on around

21% probability of collapse, the second highest frequency was seen at a probability of slightly less than 57% which is quite a high number. The maximum probability of collapse for this municipality was 72% while the minimum was 15% as well. This information can be obtained from Figure 18 below.

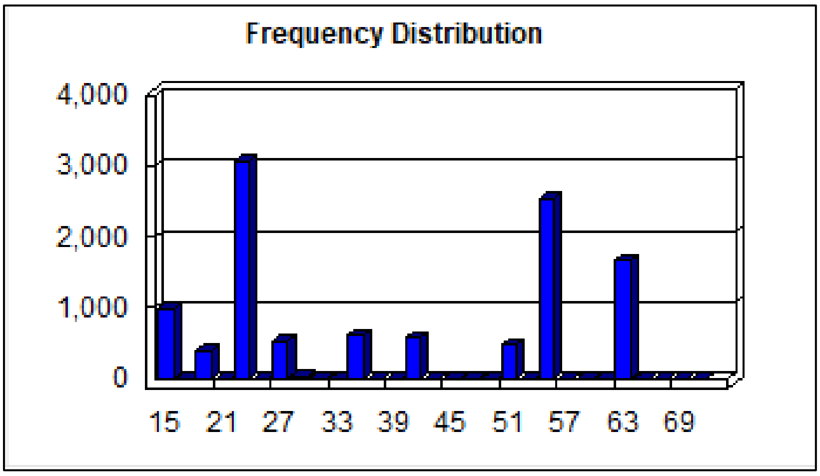


Figure 18 Building Collapse probability frequency distribution, Vyas

On average, the buildings in Birtamod had a probability of 64.73% of acquiring some form of damage. The maximum probability seen in this case was 86% while the minimum was 30%. The frequency distribution of overall damage probability can be seen on Figure 16.

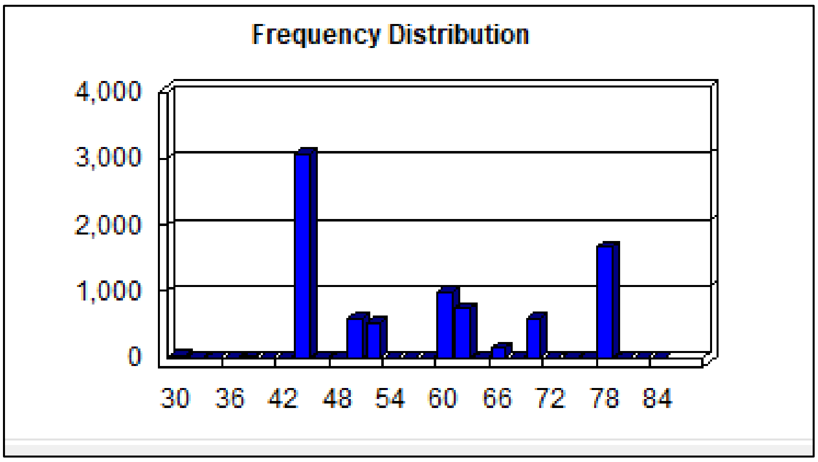
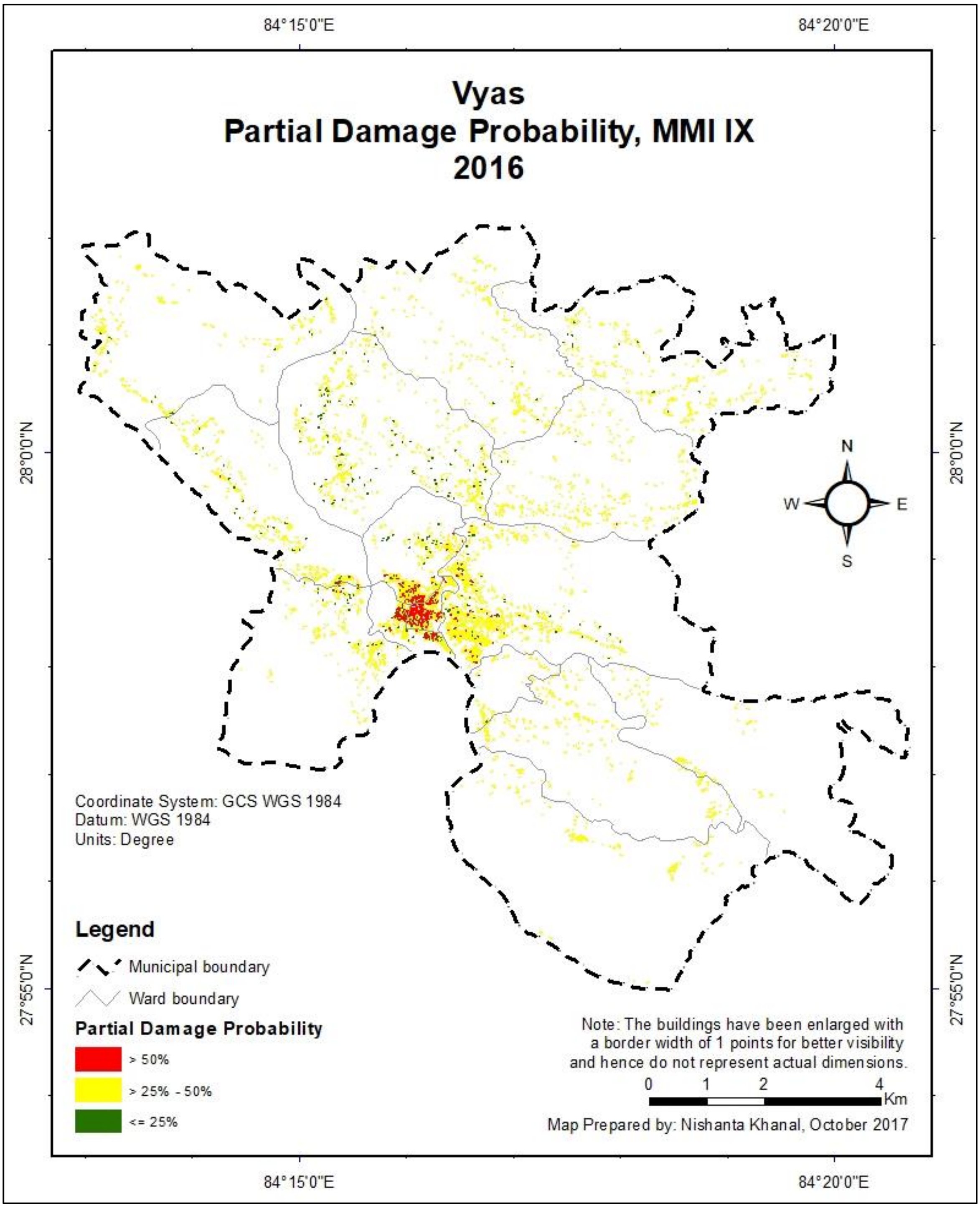
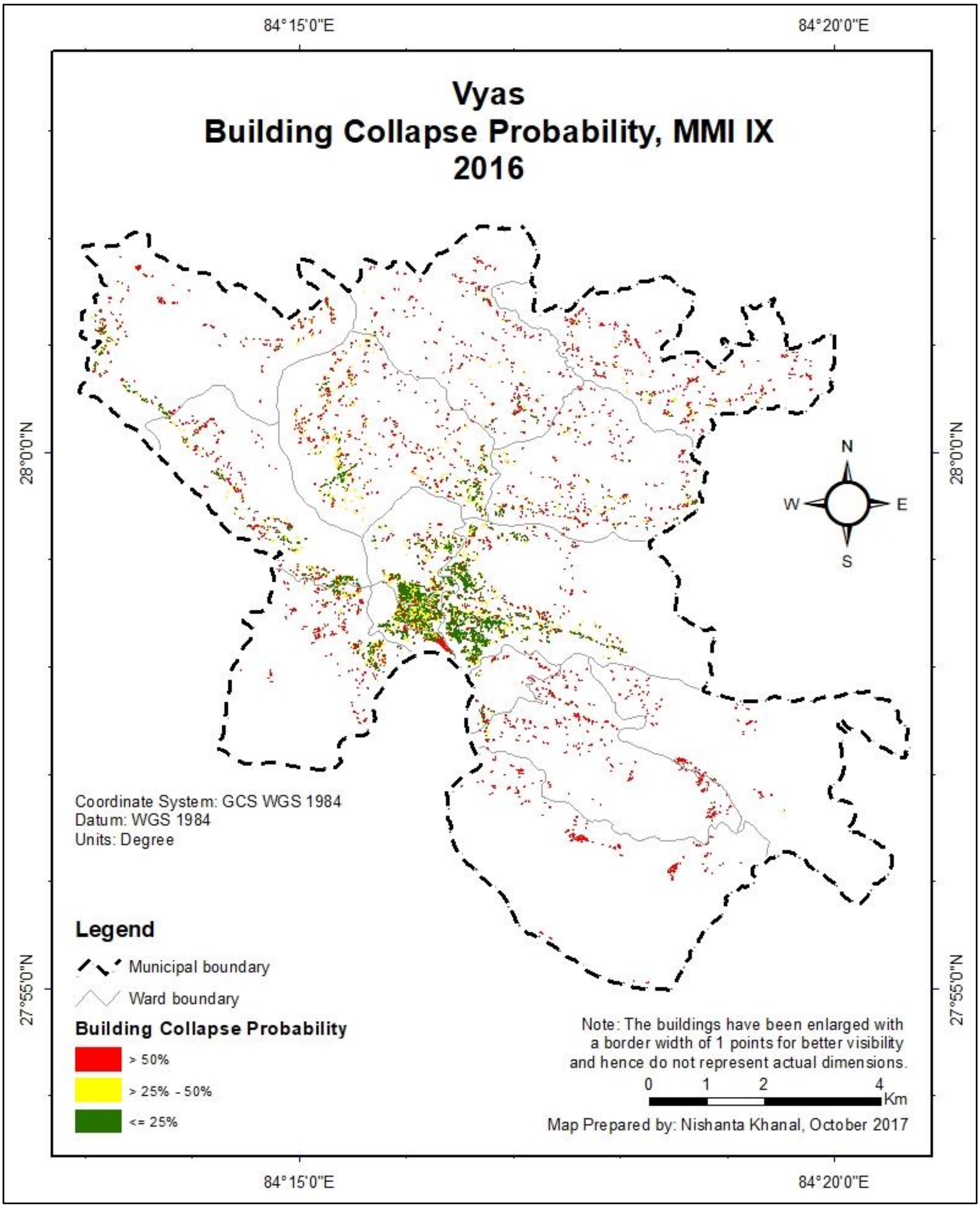


Figure 19 Overall Damage probability frequency distribution, Vyas

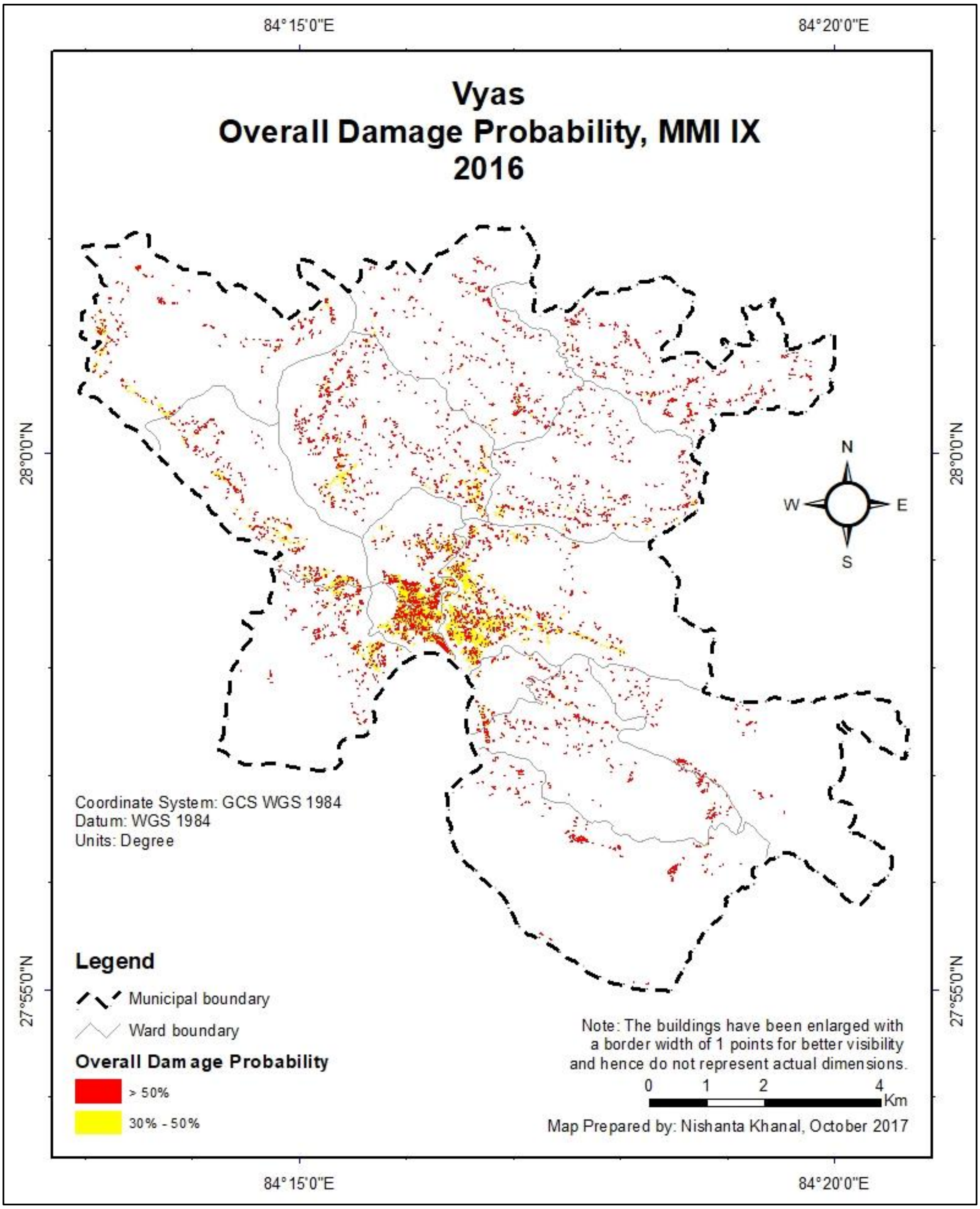
Map 23, which shows overall damage probability of buildings in Vyas municipality, gives an interesting picture. It can be seen that most of the buildings that have medium probability of sustaining some form of damage are mostly located within the highly populated area. Also, as the distance increases from this core area, such buildings become hard to find. This can be due to the fact that more traditional homes are found in those outer regions of the municipality.



Map 21 Vyas, Partial Damage Probability, MMI IX, 2016



Map 22 Vyas, Building Collapse Probability, MMI IX, 2016



Map 23 Vyas, Overall Damage Probability, MMI IX, 2016

3.3.4 Comparing probability of damages between study regions

While comparing the probability of damages for the three municipalities there was a clear difference. It was due to the considered scenario earthquake intensity. Since, it was estimated that Birtamod had an earthquake hazard of MMI VIII while the other two had an earthquake hazard of IX, there was a clear indication that the buildings in Birtamod has very small values compared to the probability of damages in buildings in the other two municipalities. This high reduction in probability can be attributed to the considered earthquake scenario for this study for the Birtamod municipality. Even though the EVI of buildings were fairly similar to the other two municipalities as seen on section **3.2**, The probabilities of damages are very different. This tells us that earthquake hazard is a very important factor when it comes to how well a building can withstand earthquakes.

While in Birendranagar and Birtamod, it was seen that the safe and highly vulnerable houses were more or less blended in residential areas, it was different in the case of Vyas municipality. Unlike other two, in Vyas buildings with high probability of collapse were few in the densely populated area while they were mostly found in numbers in the outer parts of the municipality. This shows that while the construction practices in Birendranagar and Birtamod are not much separated geographically, for Vyas it can be said that the earthquake safe construction practices are limited to the core parts of the municipality.

3.4 Buffer analysis for collapse zone

Since the collapse zone is about debris of failed building falling to endanger and/or cause harm to other structure and/or lives, the collapse zone of buildings with moderate to high probability of collapse were considered for this analysis. The following Table 13 shows the results of the analysis. In the table, the header names mean as follows

NoB = Total Number of Buildings

BCP = Buildings with moderate and high collapse probability (> 25%)

PCP = People living in HCP

BCZ = Buildings in the collapse zone

PCZ = Number of people in the collapse zone

SBCZ = Number of Safe buildings in the collapse zone

SPCZ = Number of people in collapse zone that live in safe buildings

Table 13 Buildings and people within the collapse zone

Municipality	**NoB**	**BCP**	**PCP**	**BCZ**	**PCZ**	**SBCZ**	**SPCZ**
Birendranagar	10821	3998	25694	6235	39311	2237	13617
Birtamod	11875	2258	8085	3322	14379	1064	6294
Vyas	10883	6435	24558	8444	39643	2009	15085

The buffer analysis for collapse zone returned shockingly high numbers. In case of Birendranagar municipality, there were 3998 buildings (36.95%) buildings that had more than 25% probability of collapse. However, there were 2237 buildings (20.67%) that were within the collapse zone of those buildings that had less than 25% collapse probability. The number of people that would be affected by these collapsing buildings had increased by 13617 as well. Since the scenario for Birtamod was considered with lesser intensity of earthquake, it had relatively smaller numbers as well. The number of safe buildings that fell into the collapse zone of other buildings with high likelihood of collapse was 1064 which 8.96% of the total buildings. What was the number of people affected by collapsed buildings increased from 8085 to 14379 as well. On the other hand, Vyas municipality resulted in the biggest numbers. There were 6435 buildings (59.13%) that had a collapse probability higher than 25%. Furthermore, on considering the collapse zone, 2009 buildings (18.46%) that were relatively safe with less than 25% probability of collapse were expected to be affected too. The number of affected people increased by 15085 as well.

This tells us that there could be serious damages caused by failing buildings to even the buildings that are expected to stand firm when earthquake strikes. Therefore, the vulnerability of nearby buildings could also be an important factor when identifying vulnerable buildings. Municipal plans need to incorporate these ideas while making construction plans as well.

Chapter-4: Discussion and Conclusions

4.1 Discussion

From the results, it can be seen that a lot of buildings in the municipalities require attention. This is shown by the large number of buildings that fell under the medium category on classification based on EVI. In each of the three municipalities, majority of buildings fell under this category. There were even some buildings that fell under the highly vulnerable category for each of the buildings. However, it is also a positive thing that there were many buildings with low EVI which signifies that there are construction practices in place that result in safer houses.

Despite having similar distributions for the EVI, the probability of damage in case of Birtamod municipality was significantly low. This is due to the fact that the earthquake hazard for Birtamod is lower than that of other municipalities. However, an earthquake of MMI VIII is still considered very high which was shown by the probability of damage on buildings which, even though were lower compared to other two study regions, were still significant. Furthermore, since earthquakes cannot yet be accurately predicted with existing human knowledge and technologies, the scenario earthquakes can very well be exceeded. In such cases the probability of damage in buildings of Birtamod would significantly rise as well.

The results of buffer analysis for the collapse zone gave us expected yet interesting results. It was seen that there were a significant number of relatively safe buildings that fell within the collapse zone of buildings with high probability of damage. In each case, this number exceeded 1000 buildings. Even the safest municipality among the three, Birtamod, had more than 6000 people affected by collapsing building who did not reside in those buildings. Therefore, it can be inferred that in order to construct earthquake safe houses, people need to check if the houses in the surrounding area are not vulnerable to earthquake as well.

With regards these results, there seems to be an obvious lack of awareness and skills regarding safe construction practices. While elements of it can be seen in bits and pieces, there are very few buildings that have successfully adopted such practices. None of the three municipalities had even 10% buildings with EVI 0. This shows that there needs to be awareness and training programs regarding safer construction practices.

This result obtained complies with expected result. The use of earthquake centric construction technology such as seal and lintel bands were not that common in construction of buildings and have gained momentum after the earthquake. So, a lot of buildings were expected to be vulnerable. Therefore, the results reaffirm the widespread belief and provides a basis for further actions. It also shows that the focus of future actions needs to be spread throughout the municipality instead of focusing on just the core part.

There have been some similar studies done on computing earthquake vulnerability of buildings. One such implementation was seen for assessing vulnerability of buildings in Lalitpur, Nepal in 2006 by Thapaliya **(Thapaliya, 2006)**. Another example can be seen in Dhaka, Bangladesh in 2015 by Rahman et. al. who worked on mapping earthquake and fire vulnerability using GIS **(Rahman, Ansary, & Islam, 2015)**.

These projects collect data themselves to suit their assessments which does not make use of existing datasets. While this does provide a strong basis for research with possibly more accurate measure of the building vulnerability as all the required data are collected by self, it limits the scope of the research to a small area as seen in those research. From this project, we could see that secondary data can be used to model the computations which means that the large volume of data collected by third party organizations can be used to produce meaningful results. This can be used to study and visualize the spatial patterns of vulnerable buildings in a wide area.

4.2 Conclusion

Nepal lies in a high seismic zone and it has been well documented over the years. It is also inevitable that it experiences major quakes in future as well. Since buildings are the major components that cause disaster during earthquake, it is essential to study the state of buildings in the country. For this GIS can massively help as it can be used to not only identify the buildings that needs to be addressed but locate them as well. This research was conducted with the objective of analyzing buildings and their performance during a scenario earthquake in different reaches of Nepal.

In this study, the earthquake vulnerability and probability of each building for earthquake scenarios of Birendranagar, Birtamod and Vyas according to their respective earthquake hazards were mapped. Buffer analysis on collapse zone of vulnerable buildings was also conducted in order to identify the safer buildings that were in danger due to nearby vulnerable buildings. To do this the data from BIDS program of NSET were used. The factors for earthquake vulnerability were identified from among the available dataset and pairwise comparison method was used to give weights to them. This method of ranking serves the purpose of the research and can provide us with a weight system based on expert opinion and other studies.

The dataset, while it had lot of data, was lacking some data used in other research which had high weights such as presence of bands in buildings. If these data were present in the dataset and were used for the study, it is believed that the result would have been more accurate. The availability of data in the dataset directly contributes to the accuracy of this assessment therefore it would be better to either use a more complete dataset. It is also recommended to revise the survey so as to research and include what data needs to be collected.

After analyzing the surveyed buildings, it was found that a few of buildings are as safe as they can be, which amounted to less than 10% of the total buildings in each of the three municipalities. All other buildings had at least one or more attributes that contributed to earthquake vulnerability. This indicated that even though the buildings can be built optimally, a lot of masons as well as house owners were not completely aware about earthquake resilient construction practices. Furthermore, it also indicated that special attention should be given to existing houses to promote activities such as retrofit for giving them a better chance to withstand earthquakes. For this as well, house owners should be made aware of possible solutions of making their houses more earthquake resilient.

Even though there are certain parts of the country, like Birtamod municipality, where the earthquake hazard is less than in other parts, these areas should follow earthquake safe practices as well. From this study we found out that the construction practices were pretty similar in all three municipality. While this means that none of the three municipalities are creating buildings the best way possible, it also means that same construction practices are widespread throughout the country and it can be improved using the same format of activities.

A way forward for this project can be to thoroughly study the spatial distribution of vulnerable buildings and estimate the number people living in high risk. This can further be used to develop plans for activities such as awareness programs and trainings on construction practices. This can even be used to create an emergency rescue plan for the municipality. The results and maps created can prove to be important for various activities such as emergency operation planning, awareness program planning, risk assessment etc. This study has helped identify the exact location of buildings which can be used by municipality and concerned bodies to notify the house owners of various actions such as retrofit so that they can make their building better equipped to withstand a major earthquake.

Chapter 5: Limitations and Recommendation

5.1 Limitation

The study was done based on the data collected by NSET during one of its program named BIDS at the three municipalities. As new buildings are constantly being built, any buildings that were constructed past the data collection date is not considered for this study. Also, the BIDS datasets had information on house owners such as their name and contact number, which were not disclosed as they were considered unethical for public sharing. Full credits of the datasets go to NSET which also means that they are liable for the said dataset. According to the agreement with NSET, the data was only used for research and has not been shared by me in any shape or form.

The research was not carried out from a structural engineering perspective. Therefore, all the structural details and information used for this study has purely been derived from literature review, expert consultation and other sources. No field verification has been done to validate the method calculation of EVI of buildings and consecutively the probability of damage.

5.2 Recommendations

On the basis of this study, following recommendations can be made for improving the earthquake resilience of buildings that are currently standing and will be built on future

1. The strength of existing buildings to withstand earthquakes can be improved. This study has located the vulnerable buildings and using the workflow one can replicate this in other areas as well. Since the results include identification of vulnerable buildings and mapping them as well, municipality offices can find out which buildings are vulnerable and take action accordingly. Since the dataset contains information on house owner they can be directly contacted as well. They can inform the house owner about how to

make their building better as well for example, if they need to retrofit their building or what sort of actions they would have to take to make their house stronger.

2. Since in a lot of cases house owners are unaware of practices that would make their houses better against earthquakes, especially in remote areas, there should be awareness programs targeting house owners.
3. Creating an earthquake safe community is more than just making existing houses stronger. As the saying goes “Prevention is better than cure” actions should be taken so that the houses being constructed in future are better as well. Masons are the ones that directly work on the construction of a house. Similar awareness programs and trainings should be targeted to masons as well.
4. This research has prepared maps of the municipalities showing where the most vulnerable buildings are present. Using the maps prepared, it can be inferred where the houses are most vulnerable. This can be used to conduct targeted actions in those selected areas.

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Annexures

Annex I – Building Inventory Data Survey form

भवन सर्भेक्षण फाराम

1	Name of surveyor सर्भेक्षकको नाम			
2	Ward number वडा नम्वर			
3	Tole टोल			
4	Road code रोड कोड			
5	Map sheet number नक्साको पाना नम्बर			
6	Building ID भवनको नम्बर			
7	GPS coordinates अक्षांश देशान्तर			
8	Number of storeys above ground level जमीन सतह माथीको तल्ला संख्या			
9	Number of storeys below ground level जमीन सतह मुनीको तल्ला संख्या			
10	Height of ground floor (feet) भूमि तलाको उचाइ (फिटमा)			
11	Slope of surrounding ground जमीनको भिरालोपना	○ Flat समतल ○ Moderate slope सामान्य भिरालो ○ Steep slope धेरै भिरालो		
12	Slope of footing/foundation जगको भिरालोपना	○ Flat समतल ○ Moderate slope सामान्य भिरालो ○ Steep slope धेरै भिरालो		
13	Occupancy भवनको प्रयोग	○ Residential आवासीय	○ Residence निवास ○ Informal housing अनौपचारिक आवास	
		○ Commercial and public व्यपारिक, सार्वजनिक	○ Retail trade खुद्रा व्यापार ○ Wholesale trade and storage (warehouse) थोक व्यापार र भण्डारण (गोदाम) ○ Offices, professional/technical service कार्यालय, व्यावसायिक / प्राविधिक सेवा गर्न ○ Hospital/medical clinic अस्पताल / चिकित्सा क्लिनिक ○ Entertainment मनोरंजन ○ Public building सार्वजनिक भवन ○ Recreational leisure मनोरंजनात्मक	
		○ Industrial औद्योगिक	○ Heavy industrial भारी औद्योगिक ○ Light industrial घरेलु औद्योगिक	
		○ Agriculture कृषी	○ Produce storage उत्पादन भण्डारण ○ Animal shelter गोठ ○ Agricultural processing कृषि प्रशोधन	
		○ Assembly जमघट	○ Religious gathering धार्मिक सभा ○ Arena रंगशाला ○ Cinema or concert hall सिनेमा वा कन्सर्ट हल ○ Other gatherings अन्य जमघट	
		○ Government सरकारी कार्यालय	○ Government, general services सरकारी कार्यालय, सामान्य सेवा ○ Government, emergency response सरकारी कार्यालय, आपतकालीन प्रतिक्रिया	
		○ Education शैक्षिक	○ Pre-school facility पूर्वप्राथमिक सुविधा ○ School विद्यालय ○ College/university, offices and/or classrooms कलेज / विश्वविद्यालय, कार्यालय र / वा कक्षाकोठाहरू ○ College/university, research facilities and/or lab कलेज / विश्वविद्यालय, अनुसन्धान सुविधा र / वा ल्याब	
		○ Mixed use मिश्रित	○ Mostly residential and commercial धेरै जसो आवासीय र थोरै व्यपारिक, सार्वजनिक ○ Mostly commercial and residential धेरै जसो व्यपारिक, सार्वजनिक र थोरै आवासीय ○ Mostly commercial and industrial धेरै जसो व्यपारिक, सार्वजनिक र थोरै औद्योगिक ○ Mostly residential and industrial धेरै जसो आवासीय र थोरै औद्योगिक ○ Mostly industrial and commercial धेरै जसो औद्योगिक र व्यपारिक, थोरै सार्वजनिक ○ Mostly industrial and residential धेरै जसो औद्योगिक र थोरै आवासीय ○ Mostly residential and agricultural धेरै जसो आवासीय र थोरै कृषी ○ Mostly education and residential धेरै जसो शैक्षिक र थोरै आवासीय	
		○ Other अन्य		
		Name of primary offices/organizations using this building भवनको उपयोग गरिरहेको कार्यालय वा संस्थाको नाम		
14	Building position भवनको अवस्था	Detached building नजोडिएको भवन		
		○ Attach at one side एकातिर जोडिएको ○ Attach at two sides दुईतिर जोडिएको ○ Attach at three sides तिन तिर बाट जोडिएको ○ Corner building कुनाको भवन	Is floor level of attached building is at same level के भवनको तलाहरु समान रुपमा जोडिएका छन?	○ Yes छ ○ No छैन
15	Shape of the building plan भवनको प्लानको आकार	○ Square/ Rectangular वर्गाकार/ आयाताकार	Length of building (feet) भवनको लम्बाइ (फिटमा)	
		○ Narrow rectangular साँघुरो आयाताकार	Breadth of building (feet) भवनको चौडाई (फिटमा)	
		○ T-Shape टी आकार ○ L-Shape एल आकार ○ U-Shape यु आकार ○ E-Shape ई आकार ○ H-Shaped एच आकार ○ Multi projected वहु-प्रोजेक्शन भएको ○ Building with central courtyard घरको विचमा आँगन भएको ○ Other अन्य	Max. Length of building (feet) भवनको अधिकतम लम्बाइ (फिटमा)	
16	Vertical structural irregularity तल्लाको संरचनात्मक अनियमितता	○ Regular structure नियमित संरचना		
		○ Irregular Structure अनियमित संरचना	○ Soft storey एउटा तल्ला खुल्ला भएको ○ Setbacks तलाको क्षेत्रफल घट्दै गएको ○ large overhangs भारी छज्जा ○ Narrow and tall साँघुरो र अग्लो	
17	Load resisting system भार प्रतिरोध प्रणाली	○ Infilled frame पीलर	Typical column length (Inch) पीलरको लम्बाई (ईन्चमा) Typical column breadth (Inch) पीलरको चौडाई (ईन्चमा)	Exterior wall material बाहिरी गारोको सामाग्री ○ Rubble or semi dressed stone नदीको गोलो ढुँगा ○ Dressed stone काटेर मिलाएको ढुँगा ○ Adobe bricks काचो ईटा ○ Fired clay bricks पकाएको ईटा ○ Concrete blocks कंक्रिट ब्लक ○ Reinforced masonry सिल/लिंटेल बैंड भएको गारो ○ Wooden काठ ○ Cement based boards सिमेन्ट बोर्ड ○ Other अन्य Exterior wall thickness (Inch) बाहिरि गारोको मोटाई (ईन्चमा)

		○ Wall गारो	Wall material गारोको सामाग्री ○ Rubble or semi dressed stone नदीको गोलो ढुँगा ○ Dressed stone काटेर मिलाएको ढुँगा ○ Adobe bricks काचो ईटा ○ Fired clay bricks पकाएको ईटा ○ Concrete blocks कंक्रिट ब्लक ○ Other अन्य	Mortar Type गारोको जोढाईको प्रकार ○ No mortar मोर्टार छैन ○ Mud mortar माटोको जोढाई ○ Lime mortar चूनाको जोढाई ○ Cement mortar सीमेंटको जोढाई External wall thickness (Inch) बाहिरी गारोको मोटाई (इन्चमा) Internal wall thickness (Inch) भित्री गारोको मोटाई (इन्चमा) Presence of sill/lintel bands सिल/लिंटेल बैंड छ ○ Yes छ ○ No छैन
		○ Post and beam पोस्ट र बीम	Post material पोस्ट सामग्री ○ Wood काठ ○ Bamboo बाँस ○ Steel स्टील	Post size पोस्ट आकार
		○ Hybrid मिश्रित	○ Infilled frame and wall पीलर र गारो ○ Wall and Post & beam गारो, पोस्ट र बीम ○ Wall with different system गारोहरु	
		○ Other अन्य		
18	Roof shape छतको आकार	○ Flat समतल ○ Pitched with gable ends चुली गारो सहितको धुर ○ Pitched and hipped चारैतिर धुर ○ Monopitch एकातिर भिरालो छान ○ Complex मिश्रित ○ Other अन्य		
19	Roof covering material छतको कवर सामग्री	○ Concrete roof without additional covering/ Cement sand mortar ढलान ○ Clay or concrete tile माटो , सिमेन्ट टायल ○ Fibre cement or metal tile फाइबर सिमेन्ट र धातुको टाइल ○ Slate स्लेट ○ Stone slab ढुँगाको छानो ○ Metal (CGI) धातु,टिन, जस्ता ○ Vegetative खर, फुसको छानो ○ Earthen माटोको ○ Other अन्य		
20	Roof system material छत प्रणालीको सामग्री	○ Concrete ढलान ○ Wooden काठ ○ Bamboo बाँस ○ Masonry ईटा सहितको ढलान ○ Jack Arch गुम्वज शैली ○ Metal धातु ○ Other अन्य		
21	Floor system material तल्ला प्रणालीको सामाग्री	○ Floor non existent तल्ला छैन ○ Concrete ढलान ○ Wooden काठ ○ Bamboo बाँस ○ Masonry ईटा सहितको ढलान ○ Jack Arch गुम्वज शैली ○ Metal धातु ○ Other अन्य		
22	Foundation system जग प्रणाली	○ No foundation जग नभएको ○ Stone foundation ढुँगाको जग ○ Brick foundation ईटाको जग ○ Isolated foundation हातिपाईला जग ○ Combined foundation संयुक्त जग ○ Mat or Raft foundation मेट फाउंडेशन ○ Other अन्य		
23	Visual physical condition of building भवनको दृश्यगत अवस्था	○ Poor कमजोर ○ Average सामान्य ○ Good राम्रो		
24	Presence of extended light roof shade माथिल्लो तल्लामा जस्ता पाताको छहारी निर्माण गरेको	○ Yes छ ○ No छैन		
25	Presence of different load resistance typology in top storey compare to ground floor भूमि तल्ला भन्दा माथि तलामा फरक भार प्रतिरोध प्रणाली निर्माण गरेको	○ Yes छ ○ No छैन		
26	Presence of horizontal extension of building भूमि तलमा पछि थप घर बनाएको	○ Yes छ ○ No छैन		
27	Age of building भवनको आयु			
28	Plan for floor addition on future तला थप्ने योजना	○ Yes छ ○ No छैन	If yes, specify additional numbers of storey in future यदि भए कति तला थप्ने योजना छ ?	
29	Number of night occupants रातिमा बस्ने जनसंख्या			
30	Number of day occupants दिनमा वस्ने जनसंख्या			
31	Number of transit occupants during day time दिनमा आवत-जावत गरिरहने संख्या			
32	Name of house owner घरधनीको नाम			
33	Are you house owner? तपाई घर मालिक हुनुहुन्छ?	○ Yes हो ○ No होइन	Name of responder प्रतिक्रियाकर्ता को नाम	
34	Contact number of responder प्रतिक्रियाकर्ता सम्पर्क नम्बर			
35	Front face with full height अगाडी मोहडाको तस्विर			
36	Side/back face with full height दाँया/पछाडी मोहडाको तस्विर			
37	Building damage level भवनको क्षति स्तर	○ None/Minor छैन/ कम ○ Moderate मध्यम ○ Severely असाध्यै		

Annex II – Assessment of building permit drawing NSET/ BCIPN

Building Code Implementation Program in Nepal (BCIPN)

Assessment of Building Permit Drawing

This checklist is developed to evaluate building design and drawings submitted in the Municipality according to the codal provisions. Additionally, it helps to prepare an inventory of building practices and analysis for Building Code Compliance. This assessment is being carried out by the National Society for Earthquake Technology-Nepal (NSET) together with Dhangadi sub-Metropolitan City.

A. GENERAL INFORMATION

File No:		Submitted Date:	
Municipality:		Ward No:	
Tole:		Land Plot No:	
House Owner Name:		Owner Contact No.:	
Land Area:		Building Typology:	
No. of Storey:		Ground Floor Area:	
Type of Construction:		Building Category:	
Drawn By:		Designed By:	

B. MANDATORY COMPLIANCE CHECKLIST

S.N	Mandatory Attributes	Descriptions	Specific Conditions	√	Recommendation
1	Grade of Concrete		Compliance		
			Non-Compliance		
2	Size of Column		Compliance		
			Non-Compliance		
3	Soft Story		Compliance		
			Non-Compliance		

C. CONFIGURATION RELATED CHECKLIST (Vulnerability Factor (v); Weightage (w); Vulnerability Score (v*w)

S.N	Attributes	Specific Conditions	v	w	v*w	Recommendation/Remarks
1	Overall Dimension Ratio	L/B≤3	0	3		
		3<L/B≤5	0.5			
		L/B>5	1			
2	Length of Wings	Ratio≤0.15	0	3		
		0.15<Ratio≤0.3	0.5			
		Ratio>0.3	1			
3	Setbacks	Compliance	0	4		
		Not Compliance	1			
4	Redundancy	Nos. of bays in both direction≥2	0	6		
		Nos. of bays in one direction is ≥2 and other direction is <2	0.75			
		Nos. of bays in both direction < 2	1			
5	Column Layout	All columns are in grid line	0	7		
		Up to 15 % of column out of grid line	0.25			
		16% to 50% of column out of grid line is between	0.5			
		more than 50% of column out of grid line	1			
6	Beam Discontinuity	All beams are continuous	0	7		
		Up to 15% of beams are discontinuous	0.25			
		16% to 50% of beams are discontinuous	0.5			
		More than 50%of beams are discontinuous	1			
7	Vertical Discontinuity	Compliance	0	4		
		Non-Compliance	1			
8	Cantilever Projection	Projection ≤1m and no walls in projection	0	2		
		Projection ≤1m and full brick wall in projection	0.5			
		Projection>1 and no walls in projection	0.25			
		Projection >1 and full brick wall in projection	1			
9	Short Column	None columns has short column effect	0	6		
		15% columns has short column effect	0.25			
		16%-50% internal column has short column effect OR upto 15% peripheral columns has short column effect	0.5			
		More than 50% column has short column effect	1			
10	Torsion	Eccentricity ≤ 10%	0	6		
		10% <Eccentricity ≤ 20%	0.5			
		20% <Eccentricity ≤ 30%	1			

S.N	Attributes	Specific Conditions	v	w	v*w	Recommendation/Remarks
11	Adjacent Building	The building have adequate seismic gap	0	2		
		One side is attached	0.25			
		Two adjacent side is attached	0.75			
		Two opposite sides are attached	0.5			
		Three Side is attached	1			
		Configuration Related Vulnerability Score (C) out of 50				
D. STRENGTH RELATED CHECKLIST						
12	Size of Beam	Compliance	0	4		
		Non-Compliance	1			
13	Strong Column Weak Beam	$\Sigma Mc \geq 1.1 \Sigma Mb$	0	6		
		$\Sigma Mc < 1.1 \Sigma Mb$	1			
14	Shear Stress In Column	Compliance	0	5		
		Non-Compliance	1			
		Strength Related Vulnerability Score (D) out of 15				
E. DUCTILITY RELATED CHECKLIST						
15	Minimum Number of Bars in Column	Compliance	0	4		
		Non-Compliance	1			
16	Stirrups in Column	Compliance	0	5		
		Non-Compliance	1			
17	Column Bar Splices	Compliance	0	3		
		Non-Compliance	1			
18	Column stirrups Spacing	Compliance	0	3		
		Non-Compliance	1			
19	Beam Column Joint	Compliance	0	3		
		Non-Compliance	1			
20	Beam Bar Splices	Compliance	0	3		
		Non-Compliance	1			
21	Beam Stirrup Spacing	Compliance	0	3		
		Non-Compliance	1			
22	Joint Reinforcement	Compliance	0	3		
		Non-Compliance	1			
23	Stirrup	Compliance	0	3		
		Non-Compliance	1			
		Ductility Related Vulnerability Score (E) out of 30				
F. CONNECTION RELATED ATTRIBUTES						
24	Wall Connection	Compliance	0	5		
		Non-Compliance	1			
		Connection Related Total Vulnerability Score (F) out of 5				
TOTAL VULNERABILITY SCORE OUT OF 100 (C+D+E+F):						

FINAL EVALUATION AND RECOMMENDATIONS

S.N	Description	Recommendation

Prepared By:

Name:____________________ Signature: …………………………… Date: ……………………………..

Annex III – Script for EVI calculation

```
def
calc_evi(LLRS,TCL,TCB,EW,EWT_WALL,STR_VEIR,VEIRIR_SOS,VEIRIR_SEY,VEIRIR_NAT,VEIRIR_CHV,SLOPE_F,PL
AN_SHAPE,STORY_AG,STORY_BG,BPFL,BLD_POSITION,Age_of_building,VIS_COND):
	weight1={"SSS":"0.243","SOS":"0.169","SLF":"0.156","SHP":"0.107","NAT":"0.099","NOF":"0.069","SEY":"0.051","
FLD":"0.036","CHV":"0.034","AGE":"0.022","VSC":"0.015"}
	weight2={"SOS":"0.227","SLF":"0.208","SHP":"0.142","NAT":"0.131","NOF":"0.090","SEY":"0.067","FLD":"0.046","
CHV":"0.043","AGE":"0.027","VSC":"0.019"}
	evi = 0
	if ((LLRS == "LRSW") or (LLRS == "LRSIF")):
		##set weight 1 as default
		weight=weight1
	else:
		##set weight 2 as default
		weight=weight2


	#FOR Size of Support System
	if (LLRS=="LRSIF"):
		#for column
		###check column width
		collen = int(TCL)
		colbre = int(TCB)
		if ((collen<12) and (colbre<12)):
			evi = evi + float(weight["SSS"])
		elif ((collen<12) or (colbre<12)):
			evi = evi + float(weight["SSS"])*0.5
	elif (LLRS=="LRSW"):
		#for wall
		#check external wall width
		if ((EW=="FCB") or (EW == "AB")):
			#condition for brick
			if (int(EWT_WALL)<9):
				evi = evi+float(weight["SSS"])
			elif (int(EWT_WALL)<14):
				evi = evi+float(weight["SSS"])*0.7
		elif(EW=="CB"):
			#condition for block
			if (int(EWT_WALL)<12):
				evi = evi+float(weight["SSS"])
		else:
			#condition for others
			if (int(EWT_WALL)<14):
				evi = evi+float(weight["SSS"])
			elif (int(EWT_WALL)<18):
				evi = evi+float(weight["SSS"])*0.7

	#FOR soft storey, setback, narrow and tall and overhangs
	if (STR_VEIR =="VEIRIR"):
		if (VEIRIR_SOS=="TRUE"):
			#if soft storey present
			evi=evi+float(weight["SOS"])
		if (VEIRIR_SEY=="TRUE"):
			#if setback present
			evi=evi+float(weight["SEY"])
		if (VEIRIR_NAT=="TRUE"):
			#if narrow and tall
			evi=evi+float(weight["NAT"])
		if (VEIRIR_CHV=="TRUE"):
			#if heavy overhang present
			evi=evi+float(weight["CHV"])

	#FOR slope of ground floor
	if (SLOPE_F=="SFS"):
		#for steep slope
		evi = evi + float(weight["SLF"])
	elif (SLOPE_F=="SFM"):
		#for moderate slope
		evi = evi + float(weight["SLF"])*0.7

	#FOR shape of building plan
	if (PLAN_SHAPE=="PSNR"):
		#for narrow rectangular
```

```
        evi = evi + float(weight["SHP"])*0.7
else:
        if (PLAN_SHAPE!="PSR"):
                #for any other shape
                evi = evi + float(weight["SHP"])

#for number of floors
if (str(STORY_BG)=="None"):
        #if story below ground is null, set it to 0
        STORY_BG = 0
no_of_floors = (int(STORY_AG)+int(STORY_BG))
if (no_of_floors>5):
        #for very tall buildings
        evi = evi + float(weight["NOF"])
elif (no_of_floors<=5 and no_of_floors>=3):
        #for moderately tall buildings
        evi = evi + float(weight["NOF"])*0.7

#for floor level difference
if (BPFL=="BPFLN"):
        if (BLD_POSITION=="BP1"):
                #if attached on one side
                evi = evi + float(weight["FLD"])*0.5
        else:
                #if attached on more sides
                evi = evi + float(weight["FLD"])

#for age of building
age = int(Age_of_building)
if (age>50):
        evi = evi + float(weight["AGE"])
elif (age<=50 and age>30):
        evi = evi + float(weight["AGE"])*0.7
elif (age<=30 and age>10):
        evi = evi + float(weight["AGE"])*0.3

#for visual building condition
if (VIS_COND=="PCP"):
        #if visual condition is poor
        evi = evi + float(weight["VSC"])
elif (VIS_COND=="PCA"):
        #if visual condition is poor
        evi = evi + float(weight["VSC"])*0.5
return evi
```

Annex IV – Damage matrices for different types of buildings

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 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 (less than or equal to 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

Building type: R.C. Framed (greater than 3 storeyed)

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

(NSET et al., 2001)

Annex V – Script to identify probability of damage

```
VIII_t = [55,45,35,41,31,21,18,12,5,15,11,7,19,14,8]
VIII_p = [28,30,31,28,27,25,45,38,31,30,22,14,38,27,16]
IX_t = [72,63,55,62,51,41,54,35,19,30,23,15,35,27,19]
IX_p = [28,30,31,19,25,29,17,32,45,60,45,30,65,52,38]

def calc_dmg(STORY_AG, STORY_BG, LLRS, EW, MT, EVI):
	#set which array to use dependng on intensity of earthquake
	matrix = IX_p

	if (str(STORY_BG) == "None"):
		STORY_BG = 0
	#check type of building
	if (LLRS=="LRSIF"):
		#check number of floors
		tot_story = int(STORY_BG)+int(STORY_AG)
		if (tot_story>3):
			#if its a tall column based building
			if (EVI > 0.5):
				return matrix[12]
			elif (EVI > 0.2):
				return matrix[13]
			else:
				return matrix[14]
		else:
			#if it is a short column based building
			if (EVI > 0.5):
				return matrix[9]
			elif (EVI > 0.2):
				return matrix[10]
			else:
				return matrix[11]
	elif (LLRS=="LRSW"):
		#if wall system ( includes brick in ud, brick in cement and adobe)
		if (EW=="FCB"):
			#if it is brick masonry home
			if (MT=="CM"):
				#if it has cement mortar
				if (EVI > 0.5):
					return matrix[6]
				elif (EVI > 0.2):
					return matrix[7]
				else:
					return matrix[8]
			elif (MT=="MM"):
				#if it has other mortar
				if (EVI > 0.5):
					return matrix[3]
				elif (EVI > 0.2):
					return matrix[4]
				else:
					return matrix[5]
			else:
				#if it is another type of masonry
				if (EVI > 0.5):
					return matrix[0]
				elif (EVI > 0.2):
					return matrix[1]
				else:
					return matrix[2]
		else:
			#if it is another type of masonry
			if (EVI > 0.5):
				return matrix[0]
			elif (EVI > 0.2):
				return matrix[1]
			else:
				return matrix[2]
	else:
		#if it is other type of building
		if (EVI > 0.5):
			return matrix[0]
		elif (EVI > 0.2):
```

```
        return matrix[1]
else:
        return matrix[2]
```