EARTHQUAKE INDUCED LANDSLIDE HAZARD ZONATION

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of degree

of

MASTER OF TECHNOLOGY

in

EARTHQUAKE ENGINEERING

(With Specialization in Soil Dynamics)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation entitled, "**EARTHQUAKE INDUCED LANDSLIDE HAZARD ZONATION**", in the partial fulfillment of the requirements for the award of the degree of Master of Technology in Earthquake Engineering, with specialization in Soil dynamics, submitted in the Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out for a period from June 2015 to April 2016 under the supervision of **Dr. Ravi S. Jakka**, Associate Professor, Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Roorkee.

Date: ____________________________

Place: Roorkee (HIMANSHU RANA)

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

____

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ACKNOWELEDGEMENT

While bringing out this report to its final form, I came across a number of people, whose contributions in various ways helped me and they deserve a special thanks. It is a pleasure to convey my gratitude to all of them.

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I specially acknowledge him for his advice, supervision and vital contribution as and when required. His involvement with originality has triggered and nourished my intellectual maturity that will help me for along time to come. I am proud to record that I have the opportunity to work with exceptionally experienced professor like him.

Finally, I am deeply indebted to my parents and my family members for their moral support and continuous encouragement while carrying out this study.

Date:

Place: Roorkee HIMANSHU RANA

ABSTRACT

Landslide is very catastrophic natural hazard in the Himalayan region. There are highly destructive effects on environment, wealth, life, and landscape due to landslide. These effects make it necessary to study the landslide and development of landslide hazard zonation map.

Sikkim is considered for this study. This area is very prone to landslide due to steep slope and geological conditions. Landslide hazard zonation has conducted for Sikkim region in this study. Further as Sikkim is situated in the lesser Himalaya, seismically induced landslide are also common in this region. Hence earthquake induced landslide hazard zonation is conducted for the study region Sikkim. The landslide hazard zonation is carried out using different causative factors. Probabilistic seismic hazard has been carried out to evaluate variation of seismicity in this region. Peak ground acceleration (PGA) is considered as an indicator of severity of earthquake shaking for landslide.

For probabilistic seismic hazard analysis Earthquake catalogue for the region is obtained from USGS. These catalogues were homogenized and de-clustered to compile an appropriate seismicity database. The compiled catalogue includes earthquake of magnitude Mw>=3.5 for period between 1934 and 2015. For getting earthquake parameters like M_c, a, b value and λ_m by ZMAP software which is based on MATLAB software is used. For probabilistic seismic hazard analysis CRISIS software is used. For this analysis different earthquake sources like faults, thrusts, lineaments etc. are considered. By processing these data in CRISIS 2012 PGA values for Sikkim region are obtained. These PGA values are used in earthquake induced landslide hazard zonation.

ARCGIS 10.2.2 has been used for preparation of landslide hazard zonation map of the study region. Different maps like lithology, slope etc. are obtained from geological survey of India (GSI) and ISRO website www.bhuvan.nrsc.gov.in. These maps are processed to generate hazard map in ARCGIS. The final map of the landslide hazard represents the different categories of hazard namely very low hazard (VLH), low hazard (LH), moderate hazard (MH), high hazard (HH) and very high hazard (VHH) which represent the relative degree of susceptibility to landslide occurrence. This landslide hazard zonation map is very useful for future planning of construction, landslide hazard mitigation etc.

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1 INTRODUCTION

1.1 General

Landslide is very common in hilly regions. It causes damage to life, environment and property almost every year. To reduce the risk due to potential landslide there is a requirement of landslide hazard zonation map for the proper disaster mitigation and sustainable planning. Landslide hazard zonation map is very useful for future planning of disaster mitigation. Many landslides in hilly areas are caused due to improper planning of disaster mitigation and construction. Landslide hazard zonation is a macro zonation technique which can be defined as classification of an area into zones of different degrees of potential of landslide occurrence. In Himalayan mountains there are many landslides every year due to fragile geological settings, hydrogeological conditions, and steep slope. Now a day for sustainable development, it is necessary that the development of landslide analysis should be planned in a more systematic way. Landslide hazard zonation technique involves different causative factors like lithology, slope, relative relief, hydrogeological condition, land use and land cover and seismic factor. These factors have been assigned ratings according to their effect on landslide. These ratings are known as Landslide hazard evaluation factor (LHEF) ratings.

A Landslide Hazard Zonation Map serves as a basic tool for perspective project planning like development of township, defense colony, planning of layout of hill cut roads, railway tract or any other civil engineering structures on the landslide prone hilly terrain of our country. There are various methodologies available for Landslide Hazard Zonation mapping (more precisely Landslide Susceptibility Zonation) in our country and elsewhere in the world. These methodologies may be broadly grouped under two categories namely (i) LHZ mapping without considering landslide incidences and (ii) LHZ mapping considering landslide incidences.

However, the procedure of preparation of Landslide Hazard Zonation Map on Macro Scale (1:25,000/50,000) following BIS Code is furnished in brief. This is predominantly a numerical superimposition technique.

In hilly regions slope are very prone to landslides. If hilly region is situated near the seismically active zone then landslide susceptibility increases due to these seismic activities and in our BIS code of landslide hazard zonation there is no consideration of seismic activity. So we need to include seismic coefficient to BIS code to improve the landslide zonation method. By improving the method the zonation map would be more accurate. It will help in our important construction project to design. It will also useful for our economy on the long term basis.

The Landslide Hazard Zonation/ Landslide Risk Zonation Maps are prepared by integrating spatial, temporal and magnitude probability of landslides. For development of landslide hazard zonation map software ARCGIS 10.2.2 has been used. Based on TEHD five categories of potential landslide hazard are determined and represented in the final map. This landslide hazard zonation map can be used for sustainable planning of occurrence.

1.2 Objective and Scope of the Study

The objective of the dissertation is to prepare a most reliable and scientific earthquake induced landslide hazard zonation map of the study region. This has been achieved by following tasks:

1. Considering Sikkim state as the study region.
2. Study of the seismic and tectonic settings and preparation of earthquake catalogue of the Sikkim.
3. Processing of this catalogue using ZMAP to obtain seismic hazard parameters.
4. Using CRISIS software processing of seismic hazard parameter to determine probable PGA value for the study region.
5. Compilation of the maps useful for the landslide hazard zonation including seismic hazard map.
6. Preparation and integration of the GIS based maps of the influencing factors to obtain landslide hazard zonation map.
7. Checking whether the method is suitable to determine landslide hazard zonation map.

1.3 Organization of Dissertation

The study carried out is presented in the following chapters:

- Chapter 1 contains brief introduction, objective and scope of the study, and organization of this report.

- Chapter 2 deals with general information about landslide, landslide hazard zonation and probabilistic seismic hazard assessment. It also includes the information about the methods which are generally adopted for landslide hazard zonation and seismic hazard analysis.
- Chapter 3 is devoted to the details of the study area, procedure and methodology for landslide hazard zonation followed by probabilistic seismic hazard assessment.
- Chapter 4 includes the conclusion and discussions derived from all the content written in the report.

2 LITERATURE REVIEW

2.1 Landslide

A landslide is a result of many processes like weathering, erosion etc. Generally the important inherent factors are geology, geomorphology, soil, vegetation condition and hydrologic conditions.

Causes of landslide

The occurrence of landslides is the consequence of a complex field of forces which is active on a mass of rock or soil on the slope. Basically, the two main causes are

(1) An increment of shear force per unit area

(2) A decrement of strength

There are many reasons for increment in shear force like-

- Erosion or road cuts
- Due to weight of forest or snow
- Due to hydraulic pressure
- Seismic activity, blasting, artificial vibrations

There may be many reasons for decrement of strength-

- Change in the structure of formation
- Due to off loading

2.2 Landslide Hazard Zonation

a. Landslide susceptibility

Possibility of landslide in considered area on the basis of relation between influencing factors and areal distribution of landslide.

b. Landslide susceptibility mapping

In this mapping time is specified. It describes the distance and intensity of existing and possible lansliding to analyze the potential landslide in the considered area.

c. Landslide hazard

Probability of landslide of certain size at a certain location within a specified interval.

d. Landslide hazard zonation mapping

Classification of an area into zones of different degree of potential of landslide occurrence.

There are three methods to prepare the LHZ map which are as follows-

Empirical methods

This approach utilizes the past experience of landslide and correlate to the existing conditions. It is the most common approach used for the preparation of LHZ map. This is a macro zonation technique which divides an area into five categories- very unstable, unstable, moderately stable, stable and very stable. This approach is economical and used for preliminary investigation usually done on the scale of 1:25000 to 1:50000.

Analytical methods

These are micro zonation technique usually done on scale 1:1000 to 1:2000.this is for the precise investigation. This technique can be performed in laboratory as well as in field. This method needs information about the material strength.

Observational method

In this method there is requirement of equipment like inclinometer, piezometers and extensometers which are placed at the necessary points on the slope. This instrument can also assess the nature of landslide with time and hydrological conditions. This technique is also known as statistically technique. This method is mainly used for precise engineering projects and important projects.

General procedure for LHZ

For LHZ, empirical method is most commonly used because it is cost effective and less time taking. This method utilize past experience to determine future and existing potential landslide occurrence. In our IS CODE for LHZ empirical method is used. For this method the knowledge of influencing factor for landslide is very important. Some ratings are assigned to each influencing factor. LHZ map is prepared by combing these ratings. Maximum combined rating is 10 assigned to the area having maximum possibility of landslide occurrence. These ratings are also known as factor of landslide hazard evaluation (LHEF) rating. The combined rating is also known as total estimated hazard (TEHD).The influencing factor which are included in this method are as follows-

Table 1: Proposed maximum LHEF rating for different contributory factors for macro-zonation (IS 14496-Part 2):

Influencing factor	Maximum Assigned Rating
Geomorphology	2.0
Relationship of structural discontinuities with slope	2.0
Slope	2.0
Relative relief	1.0
Vegetation	2.0
Groundwater conditions	1.0
Total	10.0

a. Lithology

This factor includes the effect of environment on the rocks e.g. weathering, erosion etc. some rocks like igneous rock can resist the weathering action. But some rocks like tertiary sedimentary rocks cannot resist the weathering action and disintegrate easily. Those rocks which cannot resist the weathering or erosion have given the higher rating as compared to igneous rocks in our IS CODE 14496.

For soil, some soils are very old and well compacted so they have some shear strength. And some soil is loose and cannot support any pressure. So for soils rating is given according to the shearing strength of the soil.

b. Structure

This factor includes the geological features present in the rocks (thrust, bedding, joint, foliation and fault) and their direction with respect to the slope

c. Slope

In this category the ratings are given to slope categories depending upon the frequency of occurrence of specific slope angle. Slope is divided into five classes- very gentle slope (<15°), gentle slope (15°-25°), intermediate steep slope (25°-35°), steep slope (35°-45°) and very steep slope(>45°).

d. Relative relief

The relative relief maps represent the local relief of the greatest height between the top of the ridge and the valley floor within a single facet. This is divided into three classes- low (<100), medium (101-300), high (>300).

e. Land use and land cover

The susceptibility of a slope very much depends on its vegetation. Barren land shows higher erosion and weathering so more prone to landslide. The land which is thickly vegetated is less prone to landslide.

f. Hydrogeological conditions

The hydrological condition and drainage pattern also influence the landslide in any area.

Table 2: Description of zone based on TEHD rating (IS 14496-PART-2)

ZONE	TEHD VALUE	DISCRIPTION OF ZONE
1	<3.5	Very low hazard zone
2	3.5-5	low hazard zone
3	5.1-6.0	moderate hazard zone
4	6.1-7.5	high hazard zone
5	>7.5	Very high hazard zone

2.3 Seismic Hazard Assessment

Seismic hazard assessment is necessary for construction design in earthquake prone regions. Seismic hazard of a region can be computed by two methods namely deterministic approach and probabilistic approach. The deterministic approach includes the calculation of seismic hazard based on a particular earthquake scenario. In probabilistic approach includes the uncertainties which are involved in location, size and earthquake occurrence. The probabilistic approach is considered better and accurate as compared to deterministic approach because deterministic approach overestimates the value of hazard parameter. In probabilistic approach all earthquake incidents, its frequency, size and location are considered and integrated to determine the earthquake hazard parameter.

There are many methods which are available for PSHA. But PSHA is mostly conducted based on Ristau and Reiter (1996) method. The procedure of PSHA include four steps as described below-

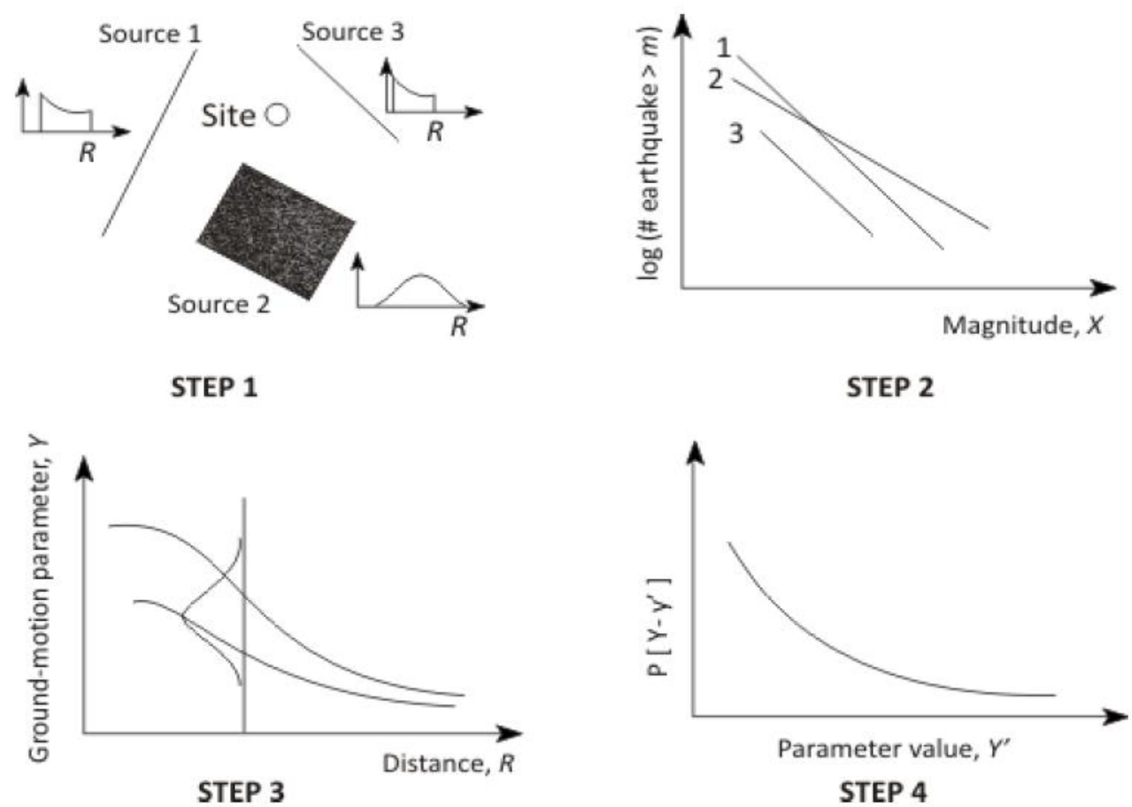

Figure 1: Four steps of probabilistic seismic hazard analysis (Kramer 2009)

- Determination of geological and tectonic setting and demarcation of earthquake sources,
- Determination of seismicity recurrence i.e. determination of recurrence relationship which is used to determine or characterize the seismicity of that region.

- Selection of appropriate ground motion model for the region
- A probable value of ground motion parameter is obtained which will be exceeded during a certain time interval.

3 SEISMIC HAZARD ASSESSMENT

3.1 Probabilistic Seismic Hazard Assessment

Sikkim, a small state of India, is not very much inhabitant and it is located in the northeast of the country. It is situated between 27°04' to 28° 07' North latitudes and 88° 01'to 88° 55' East longitudes. It is very near to the main central thrust (MCT) formed by interplate collision of Indian plate and Eurasian plate. The state has also experienced many high magnitude and devastating earthquakes like Assam earthquake, Shillong earthquake, Latur earthquake, Chamoli earthquake etc. Due to existence of collision zone the seismicity of the state is very high. The state lies in the seismic zone lV as per IS Code 1893.

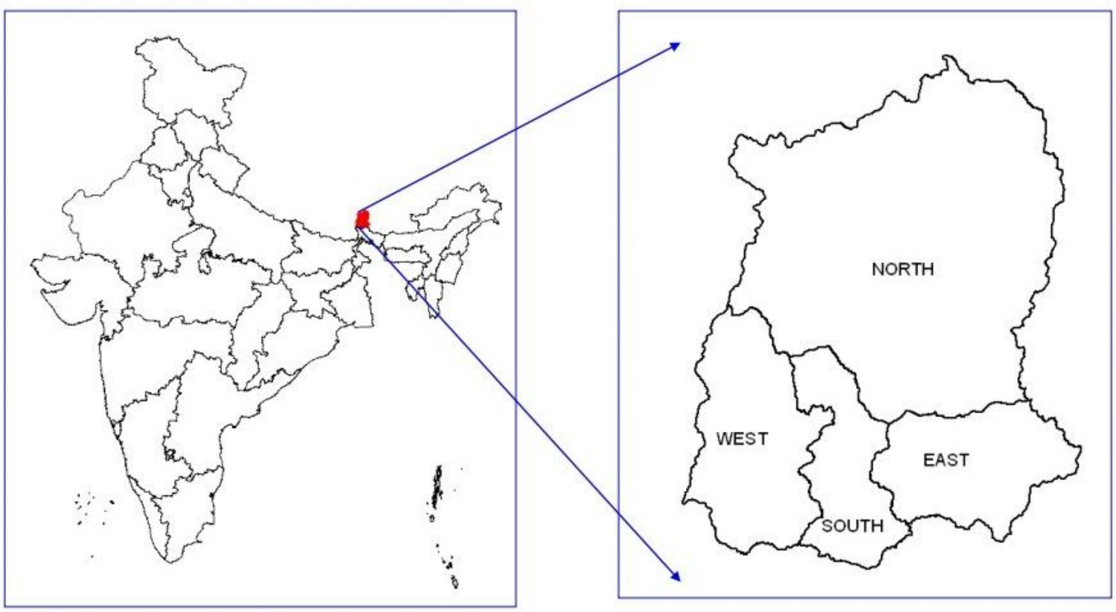

Figure 2: Location map of Sikkim

3.2 Geological and Tectonic Setting

Sikkim has major tectonic features like main central thrust (MCT) formed by interplate collision of Indian and Eurasian plate and main boundary thrust (MBT). Some researchers say that MCT is not active and MBT is active. Some researchers consider that MCT and MBT both are active. Sikkim is a part of active Himalayan thrust fold belt. There are other important features which influence the tectonic and seismicity of region are like Teesta and Gangtok lineament , Goalpara lineament, Kanchanjanga fault , Purnea fault lineament, Arun lineament, Dhubri fault in Sikkim. The MCT present across the Sikkim is not like sharp boundary. It is actually a ductile zone lies in several kilometers. This MCT separates two belts which are metamorphosed central crystalline and comparatively lower grade rocks of lesser Himalaya. Mostly present rocks in Sikkim are Precambrian rocks which consist of Phyllite and Schist. Phyllite and Schist are high susceptible to weathering and erosion and leads to production of poor brown clay soil.

The Sikkim state lies in the seismic zone IV according to seismic zonation map of India (BIS 1893-2002). The zone factor assigned to zone IV is 0.24. Zone IV is associated to the intensity VIII on the MMI scale. Most earthquake occurred in this region are due to strain accumulation and subduction of Indian plate against Eurasian plate. The earthquake occurred on 18 sept 2011 is very disastrous earthquake having magnitude 6.9. The epicenter of this earthquake is located near the TEESTA and Kanchanjanga lineament. The IMD reports many aftershocks of this earthquake.

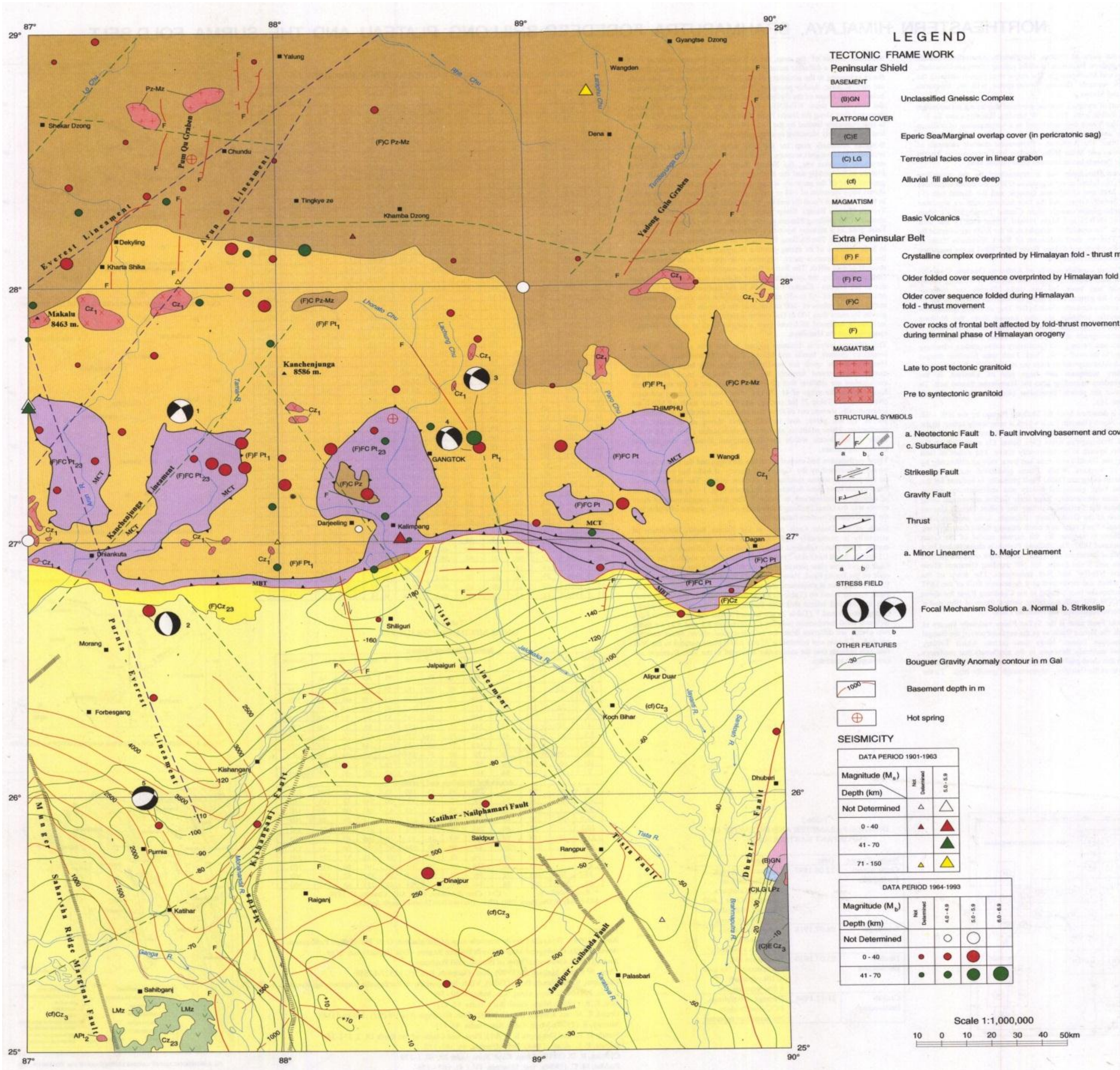

Figure 3: Sesmotectonic map of Sikkim (GSI)

3.3 Catalogue Preparation

PSHA is mostly conducted on the basis of Ristau and Reiter (1996), methodologies by which we determine the magnitude dependent seismicity rate of any region. PSHA is conducted using Gutenberg Richter relationship (1944) which is $\log\lambda_m = a - bm$ also known as Gutenberg Richter recurrence law. where λ_m is the mean annual rate of exceedence of magnitudes m, a is overall rate of earthquake in a region and b is relative ratio of small and large earthquake.

From engineering point of view very small magnitude earthquakes are eliminated because those earthquakes are not responsible for any damage in structures. If earthquake of magnitude less than a minimum magnitude m0 can be eliminated then G R relation is modified as $\lambda_m = \exp(\alpha-\beta m)$

$$\alpha = 2.303a \quad \text{--------------------(1)}$$

$$\beta = 2.303b \quad \text{---------------------(2)}$$

The earthquake catalogue for the analysis has been collected from two agencies: United States geological society (USGS) and international seismological center (ISC). This data is required for as long period as possible i.e. from the earliest time to the present time. The data obtained from different agencies include some parameters like location of epicenter, time of occurrence, magnitude of earthquake etc.

Magnitude of earthquake may be of different types i.e. m_s, m_b, m_w etc. the catalogue homogenization is an important step for the hazard analysis moment Magnitude does not depend on ground shaking level for describing the size of very large earthquake. But moment magnitude depends on released energy. For assessment of seismic hazard, all magnitudes are converted to moment magnitude because it depends on released energy and there is no saturation inn moment magnitude scale. Different empirical relationships are used for conversion of different magnitude scale. General orthogonal relationship given by Wason et. al. (2012) have been use to convert m_b, m_s, to m_w .

$$M_w = 0.646m_s+2.197 \quad (3.1<m_s<6.1) \quad \text{------------(3)}$$

$$M_w = 1.005m_s-0.0062 \quad (6.2<m_s<8.4) \quad \text{------------(4)}$$

According to Das et al. (2013) conversion of body wave magnitude m_b to moment magnitude m_w is

$$M_w = 1.17m_b+0.74 \quad \text{-----------------(5)}$$

After homogenization, declustering of catalogue is a necessary step which involves removal of aftershocks from main shocks. Main shocks are independent events and aftershocks are dependent on main shocks. For declustering the Gardner and Knop off (1974) procedure is used. It is also known as time window method of separation for each earthquake of magnitude mw. Those earthquakes which occurred in a particular time interval and within a distance are considered as aftershock.

3.4 Calculation of Hazard Parameters, M_C, A, B Value and λ_m

Magnitude of completeness M_c is known as minimum magnitude of earthquake which is exceeded by 100% seismic events. The value of M_c depends on the data available for that site and method of analysis. If analytical method is good and number of events is increasing then the value of M_c will decrease. Magnitude of completeness is also computed by plotting curve between earthquake magnitude and log of cumulative number of earthquake divided by number of years.

In this study M_c is computed by using Entire Magnitude Range method (EMR) given by Woessner and Wiemer (2005) because it is stable under most of the conditions and provide a comprehensive seismicity model. This model involves two parts (1) for the complete part, Guterberg Richter law, (2) for incomplete part, cumulative normal distribution. When we plot the curve between earthquake magnitude and log of cumulative number of earthquake divided by number of years, for determination of a value the best fit line is extended to intersect the ordinate. a represents seismic activities. Slope of best fit line indicate b value representing relative likelihood of occurrence of high magnitude earthquake.

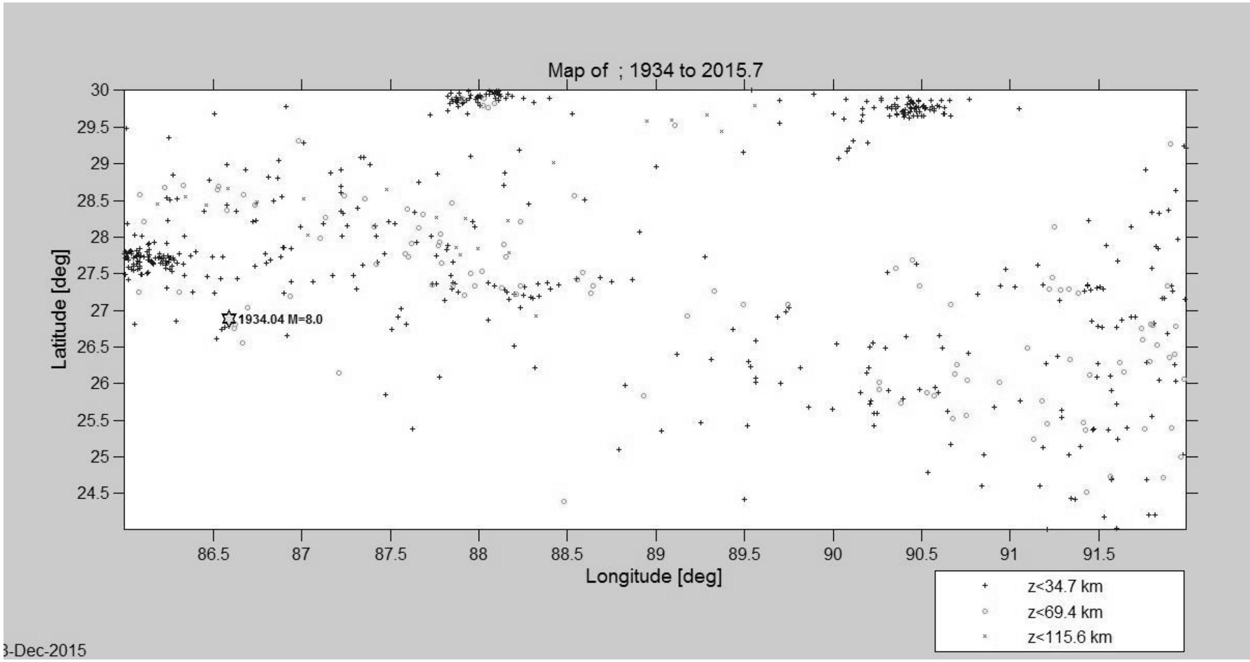

Figure 4: Seismicity map of area between longitude 85° to 92° E and latitude 24° to 30° N

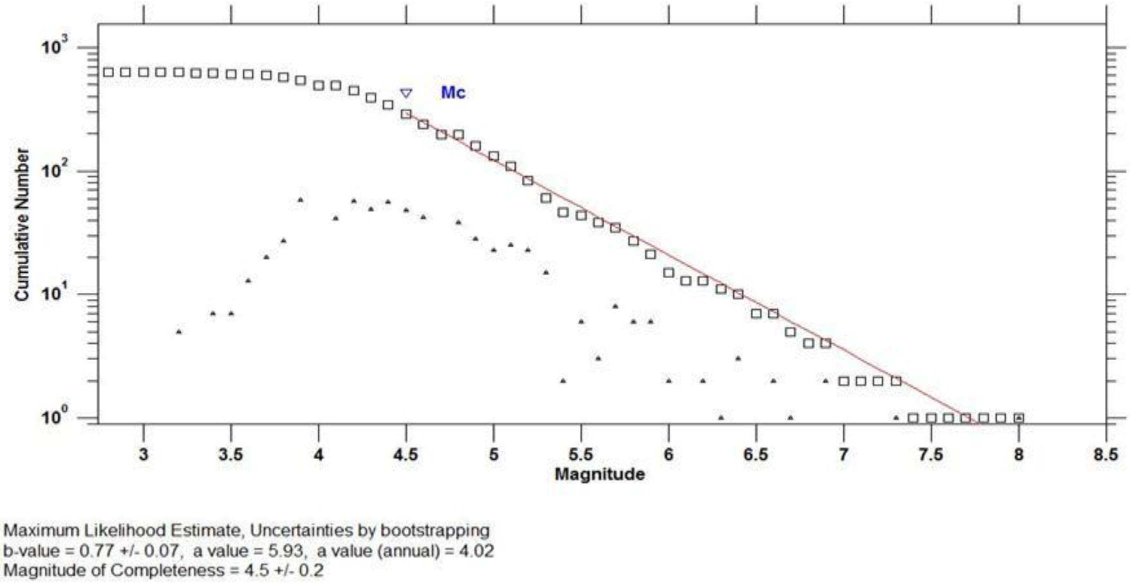

Figure 5: Frequency magnitude relation for the region

3.5 Attenuation Relationship

For computing hazard PGA, proper attenuation model is important. attenuation model given by Boore and Atkinson (2008) was used. This attenuation model requires earthquake magnitude, average wave velocity, fault type, and distance from source to site to give horizontal ground motion at this site. this model is applicable for magnitude range 5 to 8 with R_{JB} less than 200km and V_{S30}=180 to 1300 m/s. general attenuation model as per Boore and Atkinson can be written as

$$\ln Y = F_M(M)+F_D(R_{JB},M)+ F(V_{S30}, R_{JB}, M)+\varepsilon\sigma_T \qquad \text{----------------(4)}$$

where F_M is the magnitude scaling function; F_D is the distance function; R_{jB} is the closest distance to surface projection of rupture, M is moment magnitude, F_S is site amplification function; V_{S30} is shear-wave velocity in m/s in the top 30 M. ε = standard deviation of a single predicted value of InY from the mean value of lnY.

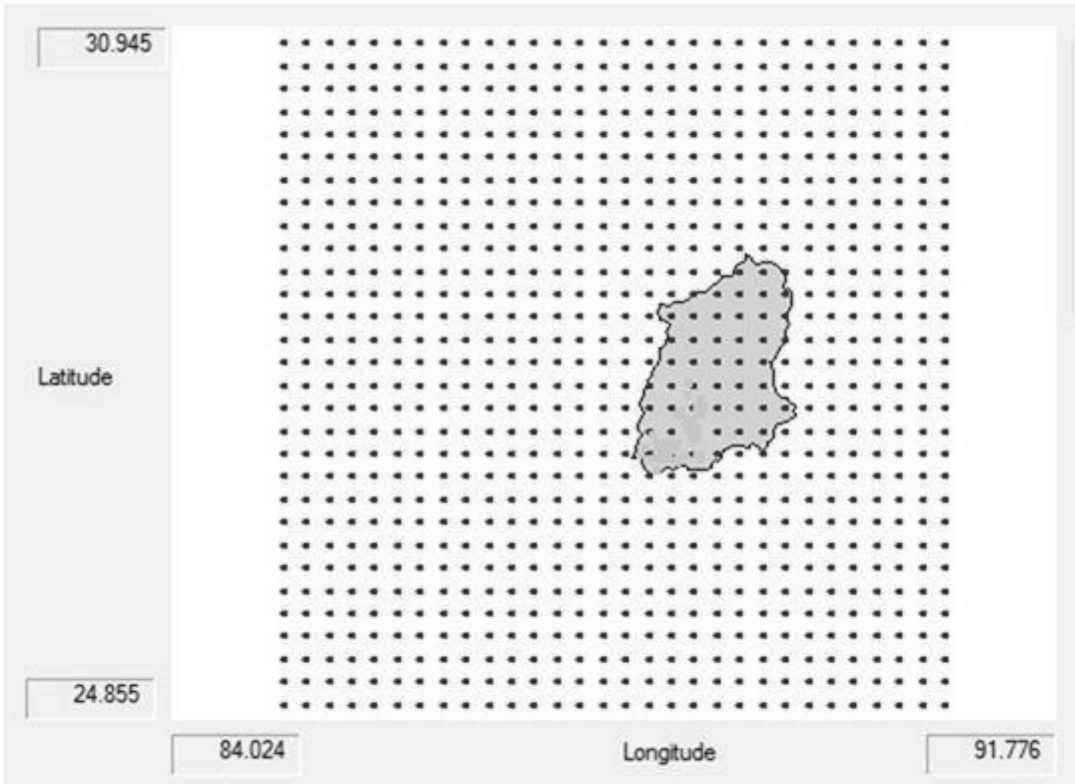

Figure 6: $0.2^o * 0.2^o$ size grid of the considered region

For the purpose of estimating PSHA, the state of SIKKIM and surrounding area between latitude 25^O 0'– 30˚0' N and longitude 85˚0'–90˚0E is considered. It is divided into small grids of size 0.2*0.2 as shown in figure-7. PGA is computed for 10% probability of exceedence in 50 years and 2% probability of exceedence. Ground motion distribution is shown in the form of zones considering constant b-value for the whole region

For the state of Sikkim, on considering constant b value, maximum PGA has been obtained for central south part in Sikkim and having maximum value of 0.22g for 10% probability of exceedence in Lachen city. In north western part of Sikkim PGA varies from 0.02g to 0.08g for 10% probability of exceedence.

For 2% probability of exceedence minimum PGA is 0.03g for northern part of Sikkim and maximum PGA found is 0.4g for central part of Sikkim.

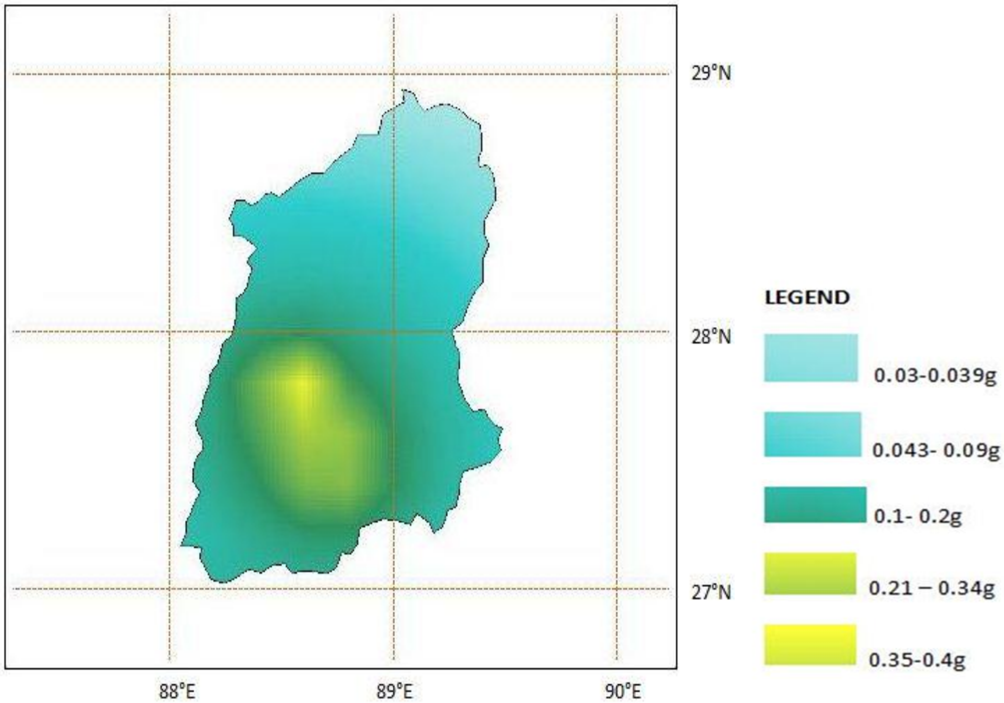

Figure 7: Peak ground acceleration for 2% probability of exceedence in 50 years

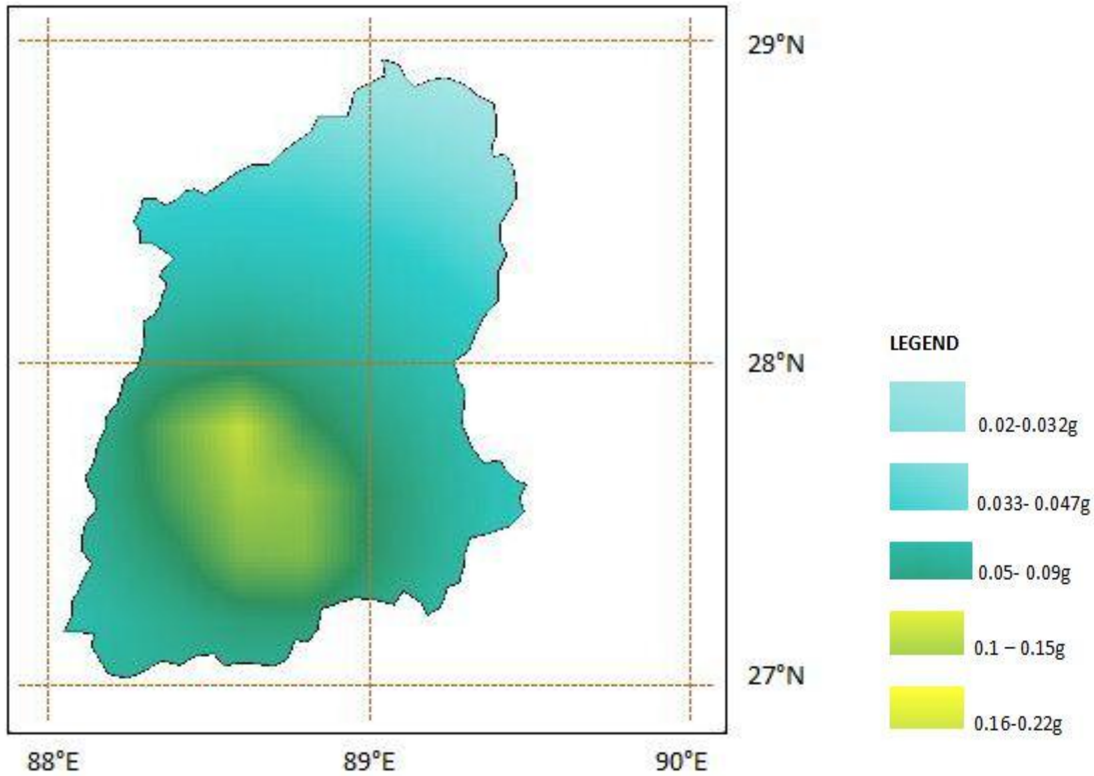

Figure 8: Peak ground acceleration for 10% probability of exceedence in 50 years

4 LANDSLIDE HAZARD ZONATION

4.1 Introduction

Sikkim is situated between 27° 04' to 28° 07’ North latitudes and 88° 01’to 88° 55’ East longitudes. It is hilly area consist of steep slopes, cliffs, tectonic features etc. in this area landslide occurrence is common due to which there is large amount of damage to the life and property every year. More than thirty thousand people were killed in landslide in 1968 (Chaubey 1992). Landslide occurs along one or more discrete surfaces in which earth and rock are involved. Preventive measures are taken in this area which is based on landslide investigation. In landslide investigation the knowledge of the factor which influence the landslide occurrence. Landslide hazard zonation based on IS 14496 involves these causative factors in investigation and combine these factor to zonation of hazard.

For landslide hazard zonation of our study region Sikkim different maps are obtained from different sources like lithology map is taken from Geological Survey of India (GSI) And slope map, land use and land cover and hydrogeological map is obtained from ISRO website www.bhuvan.nrsc.nic.in. For landslide hazard zonation ARCGIS10.2.2 software is used. These maps are processed in the ARCGIS software and LHEF ratings are given as mentioned in the IS CODE 14496. After giving ratings to all causative factors these ratings are integrated which is known as Total Estimated Hazard (TEHD). According to this TEHD factor the study region Sikkim is divided into different zones which are very low hazard zone, low hazard zone, moderate hazard zone, high hazard zone and very high hazard zone.

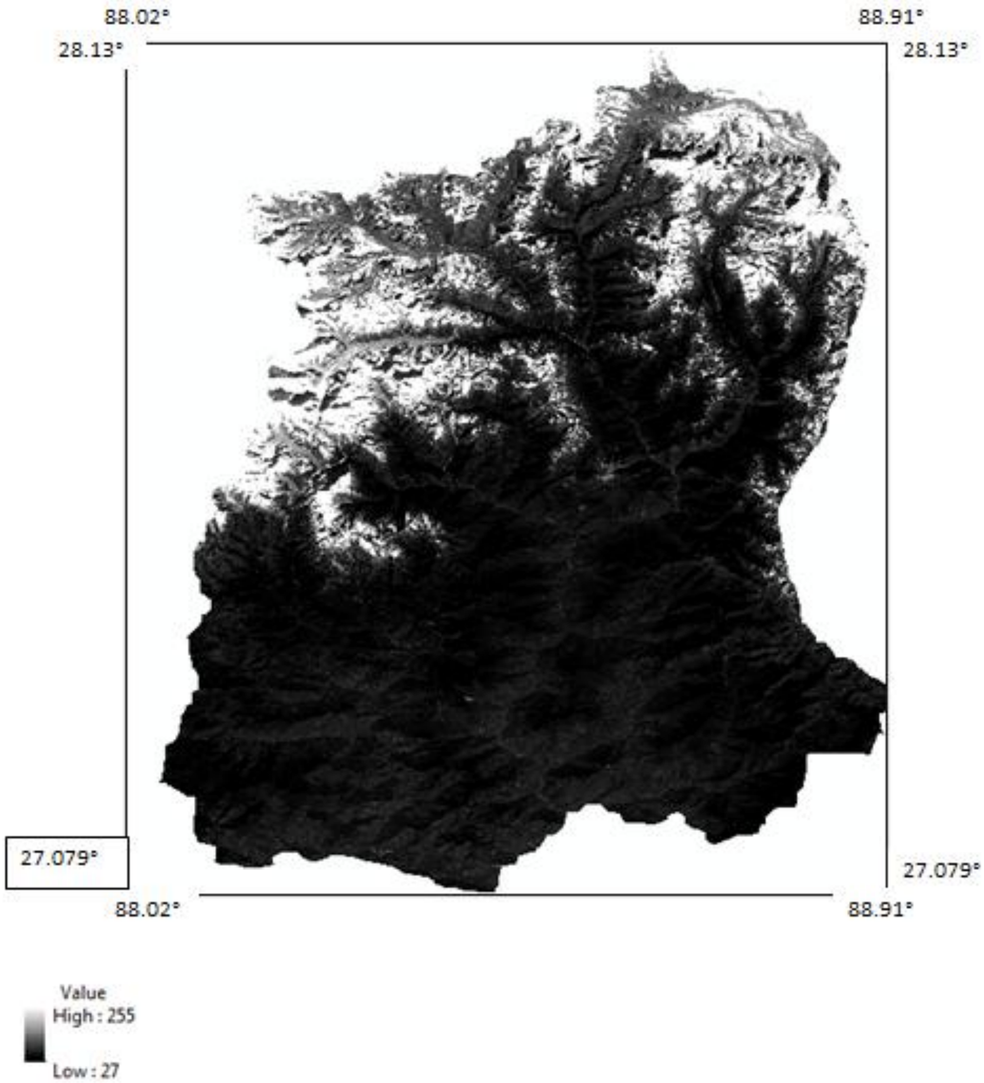

Figure 9: Digital Elevation map of Sikkim

4.2 Lithology

This lithological map of Sikkim is used for rating assignment based on geology and mineral present over there. This map is obtained from GSI.

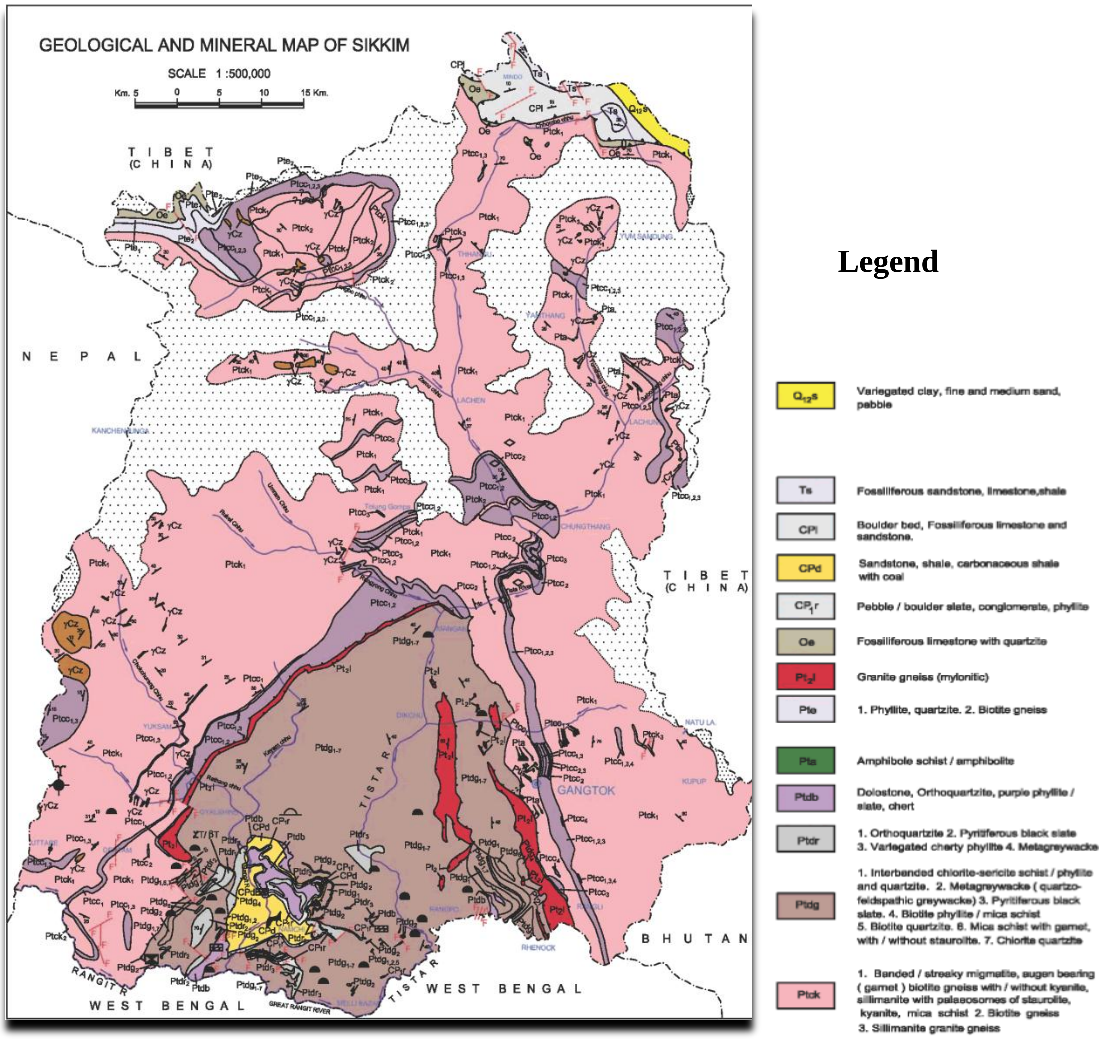

Figure 10: Lithological map of Sikkim (GSI)

In the study area 8 types of rock have been found. The rating given to them as per IS CODE have been shown in table

Table 3: Ratings of lithology

LITHOLOGY	RATING
sandstone	1
slate, phyllite	1.2
quartzite, lime stone, gabbro	0.2
schist, sand	1.3
Granite	0.3

After assigning the above rating, we get weighed lithology map as below-

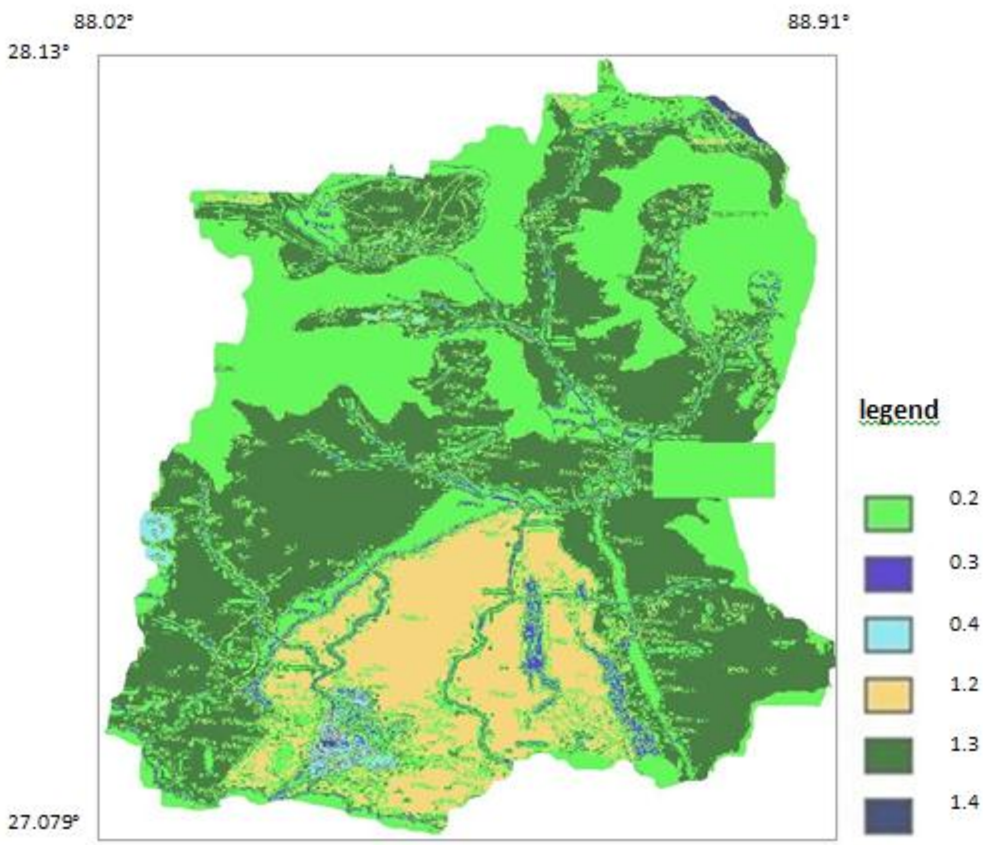

Figure 11: Weighed lithology map of the study region

4.3 Aspect

Aspect map defines the slope directions with respect to north between 0° to 360°. It represents local slope conditions.

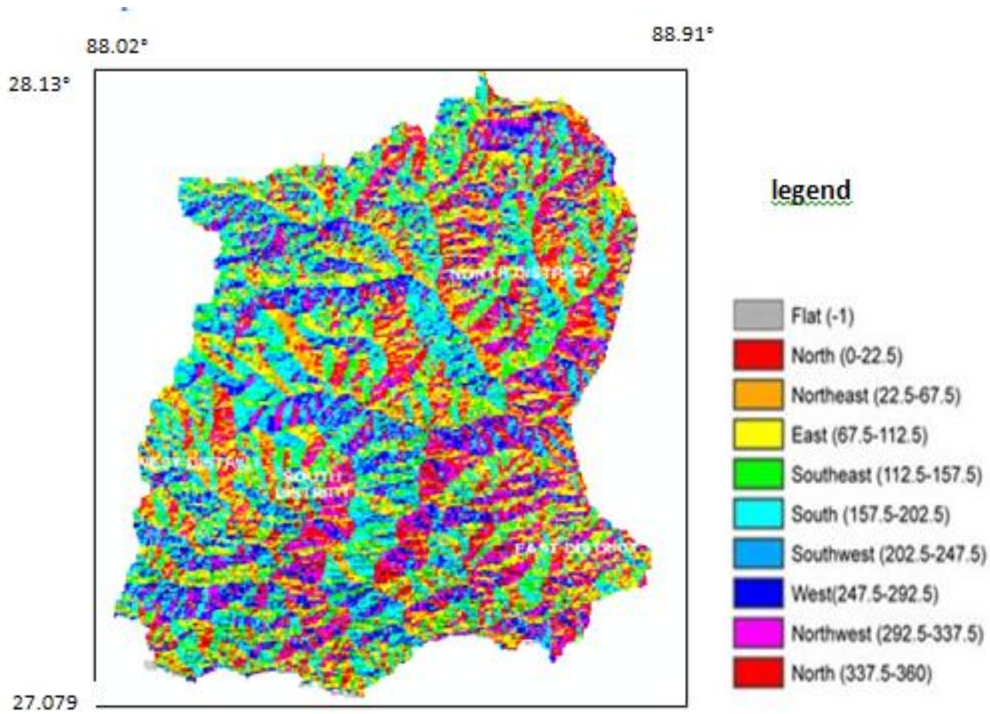

Figure 12: Aspect map of Sikkim

Table 4- assigned ratings to the slope (pixel wise)

Aspect	count(pixels)	ratings	count*rating
FLAT	6863	0	0
N	7443	0.1	744.3
NE	4724	0.2	944.8
E	8538	0.3	2561.4
SE	5145	0.4	2058
S	12167	0.5	6083.5
SW	4490	0.6	2694
W	5341	0.7	3738.7
NW	9874	0.8	7899.2
N	5561	0.9	5004.9
	£=70146		£=31728.8

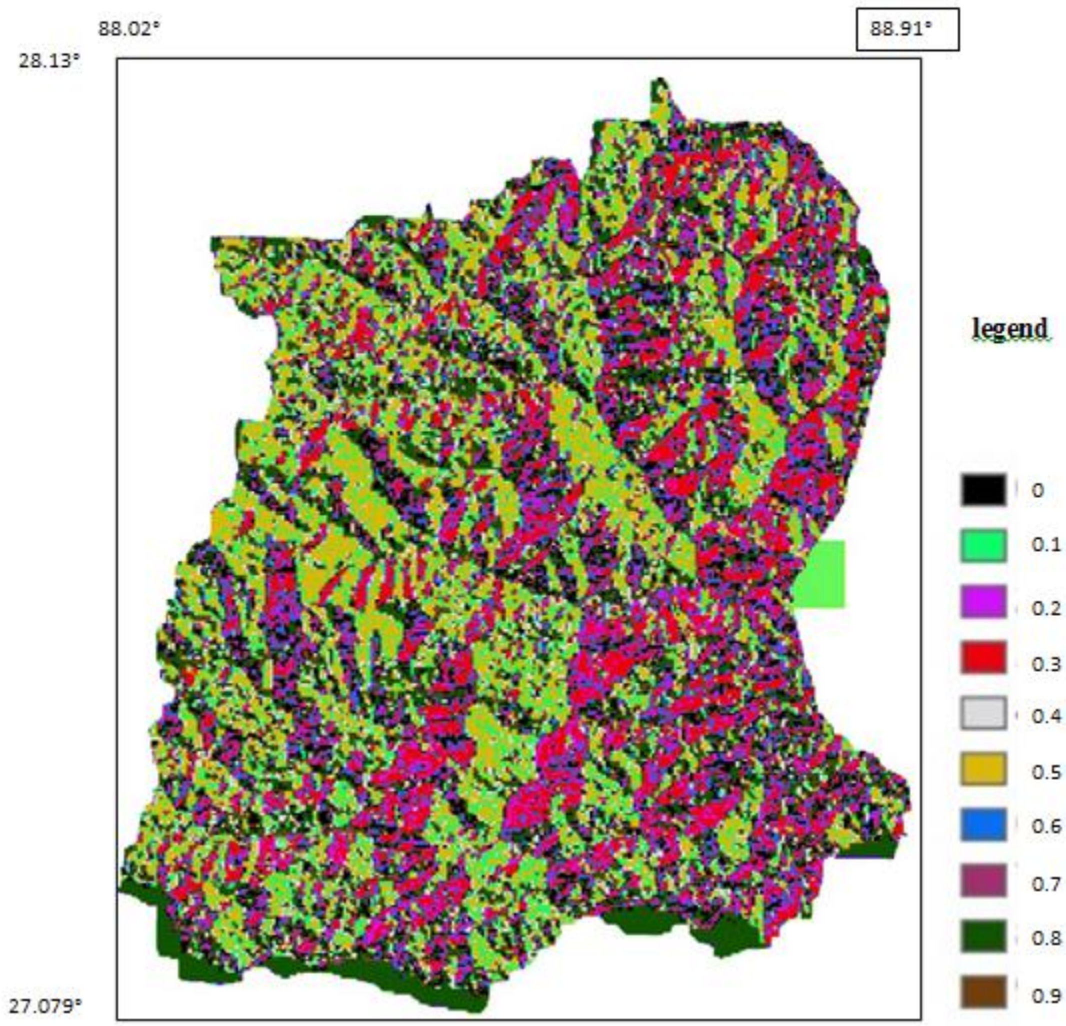

Figure 13: Weighed aspect map of study area

4.4 Relative relief

It is also a causative factor. This map is also used for the rating assignment.

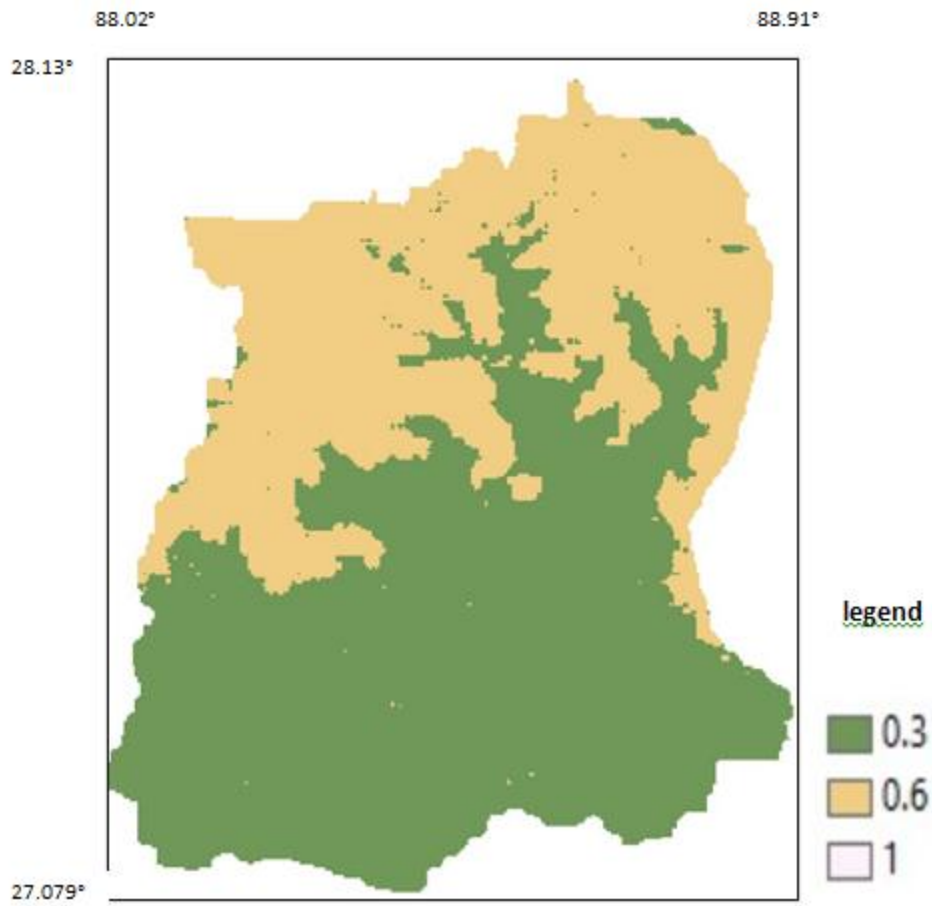

Figure 14: Weighed relative relief map of study region for 2008 before sikkim earthquake

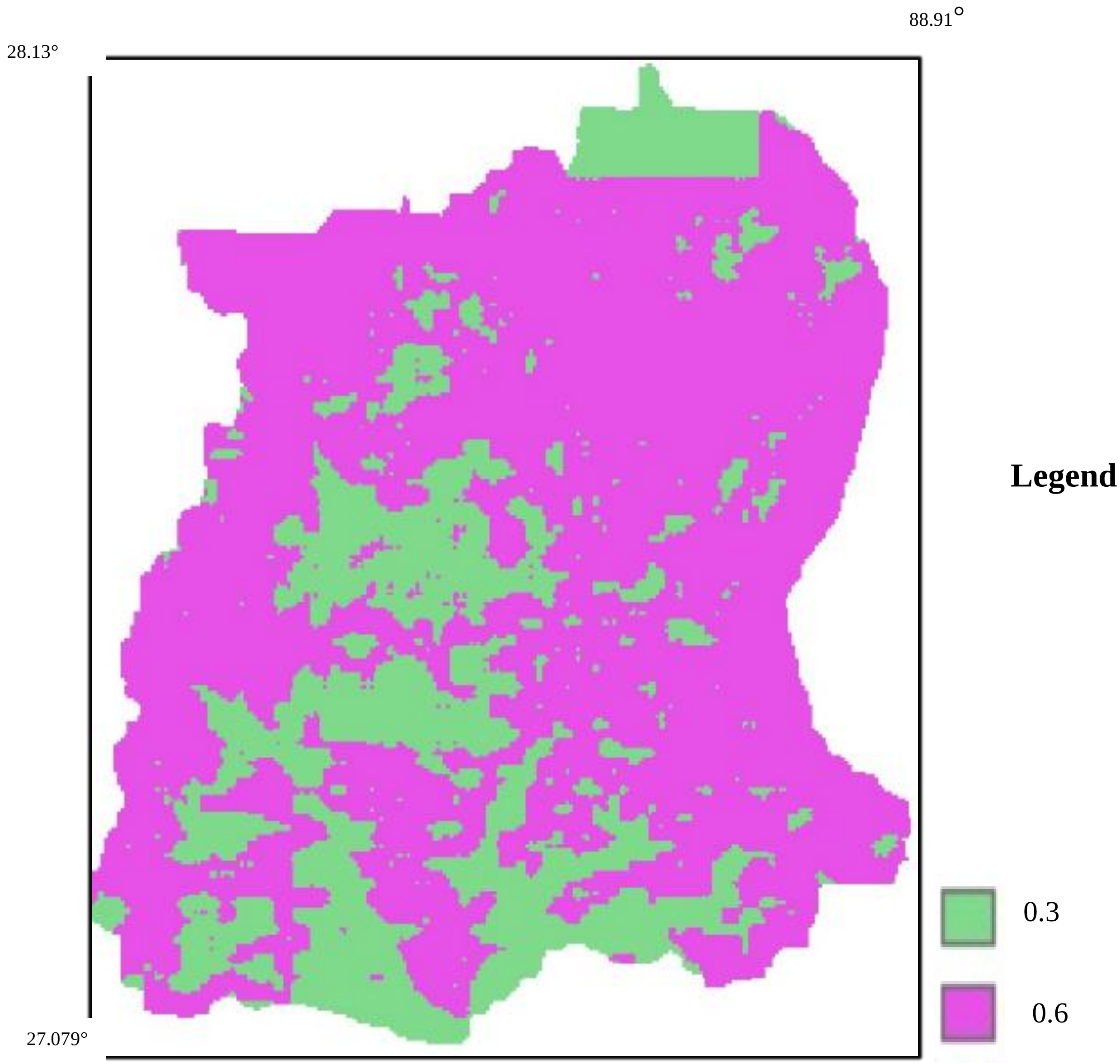

Figure 15: Weighted relative relief map of the study area for 2012 after sikkim earthquake

4.5 Vegetation map

This map of land cover is obtained from www.bhuvan.nrsc.gov.in . It is classified into different categories. We have processed this map into another map which is classified into five categories.

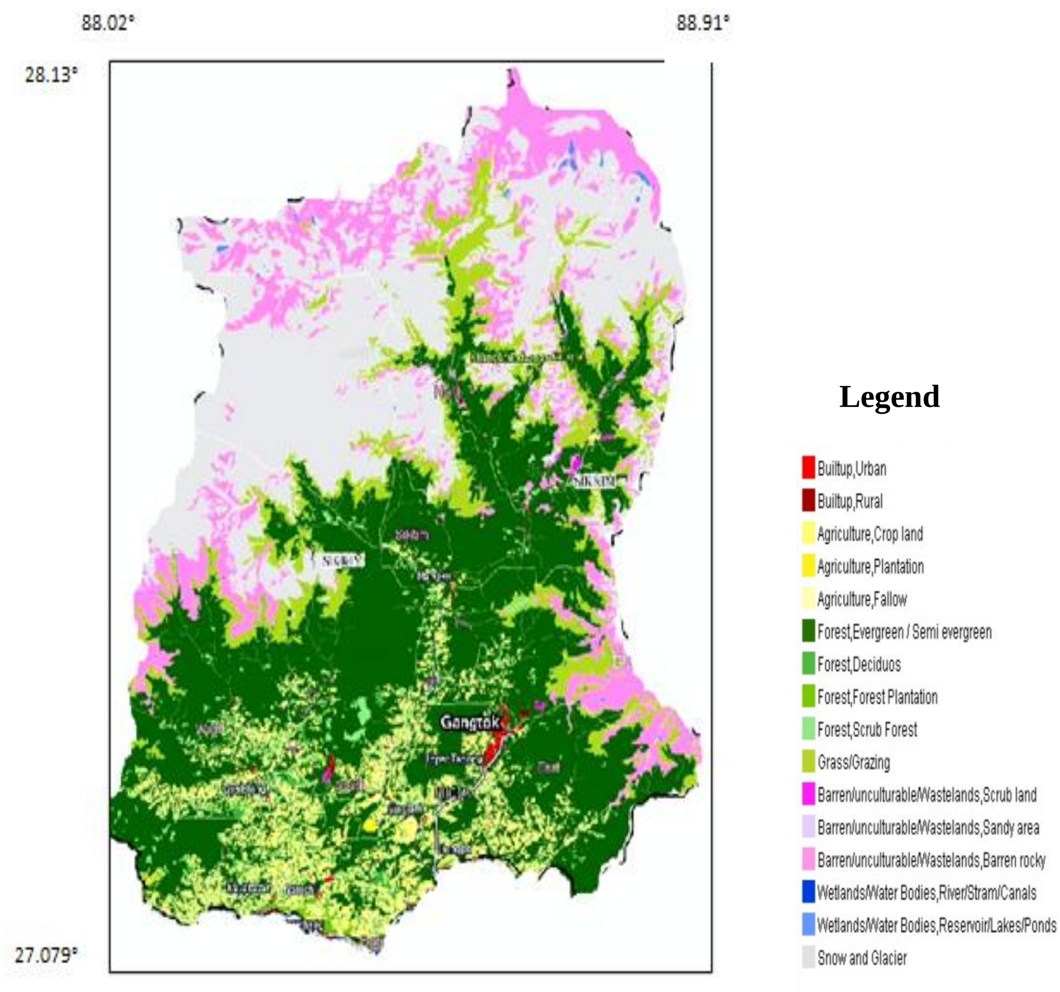

Figure 16: Vegetation map of Sikkim before Sikkim earthquake of 2011 (www.bhuvan.nrsc.gov.in)

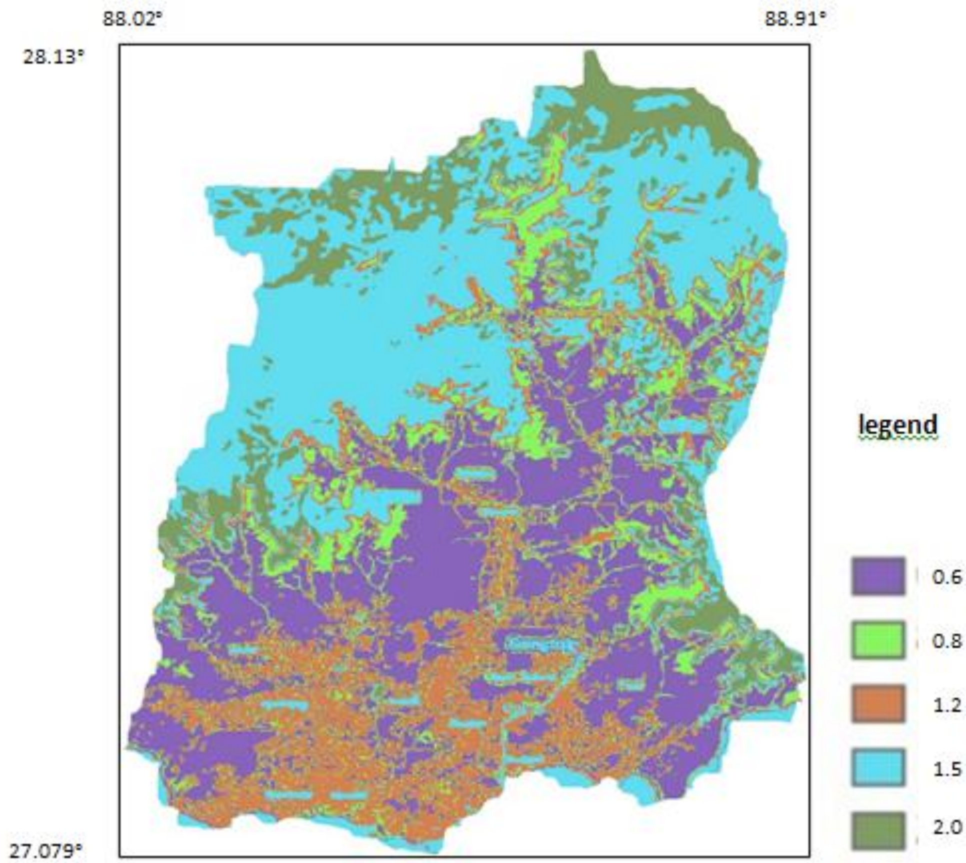

Figure 17: Weighed vegetation map of Sikkim before sikkim earthquake of 2011

Table 5: Ratings given to the vegetated area according to IS CODE 14496

Class	rating
agricultural land	0.6
thickly vegetated forest area	0.8
moderately vegetated area	1.2
sparsele vegetated area	1.5
barren land	2

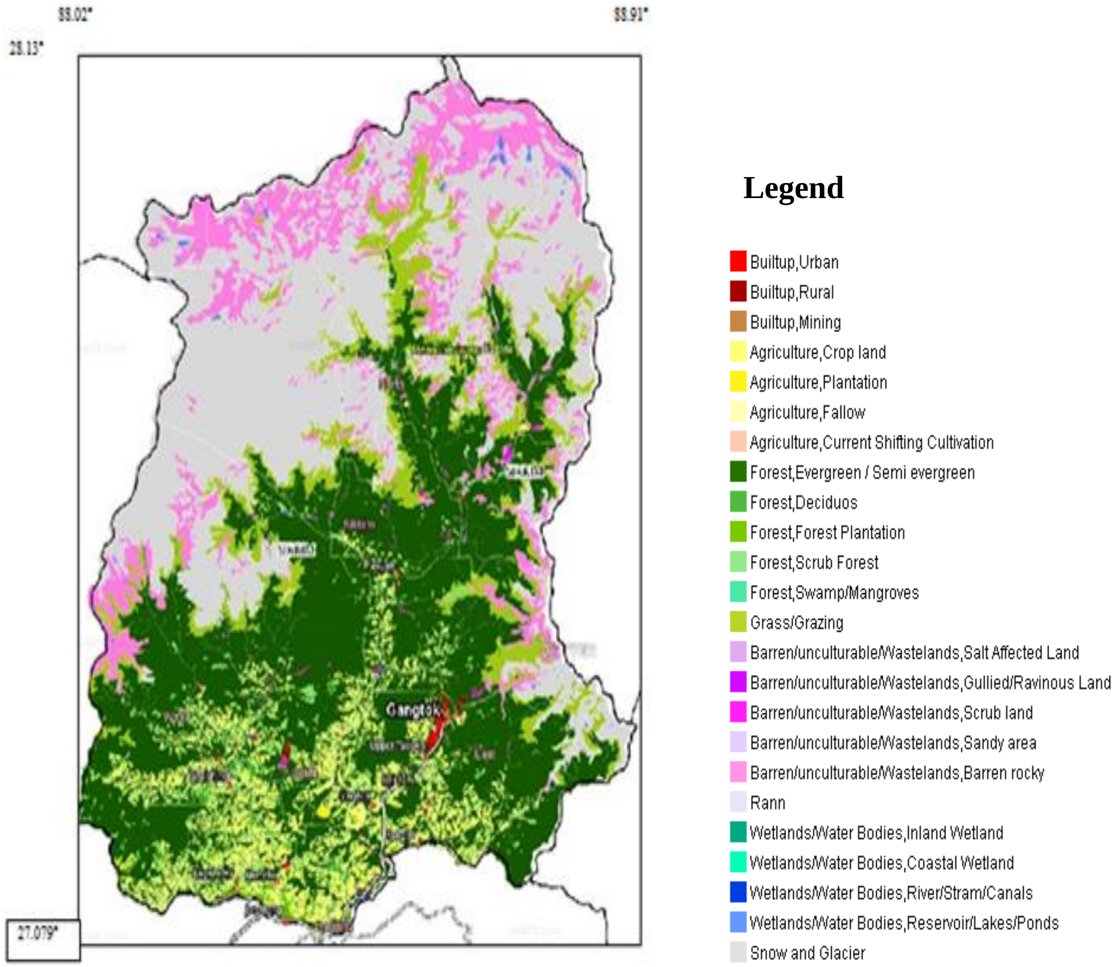

Figure 18: Vegetation map of Sikkim after Sikkim earthquake of 2011 (www.bhuvan.nrsc.gov.in)

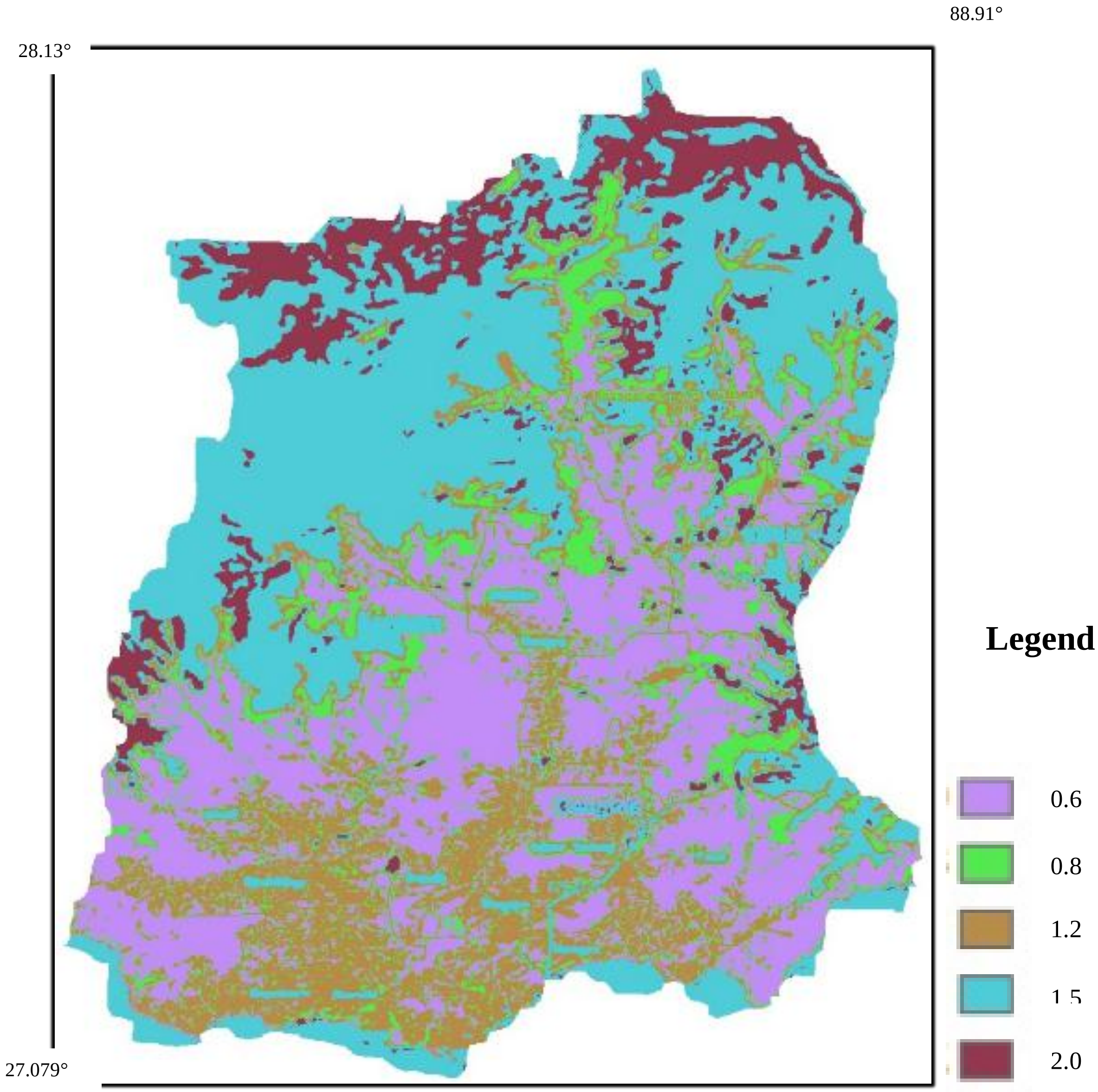

Figure 19: Weighed vegetation map of Sikim after sikkim earthquake of 2011

4.6 Slope

Following slope is used to calculate the rating based on pixels.

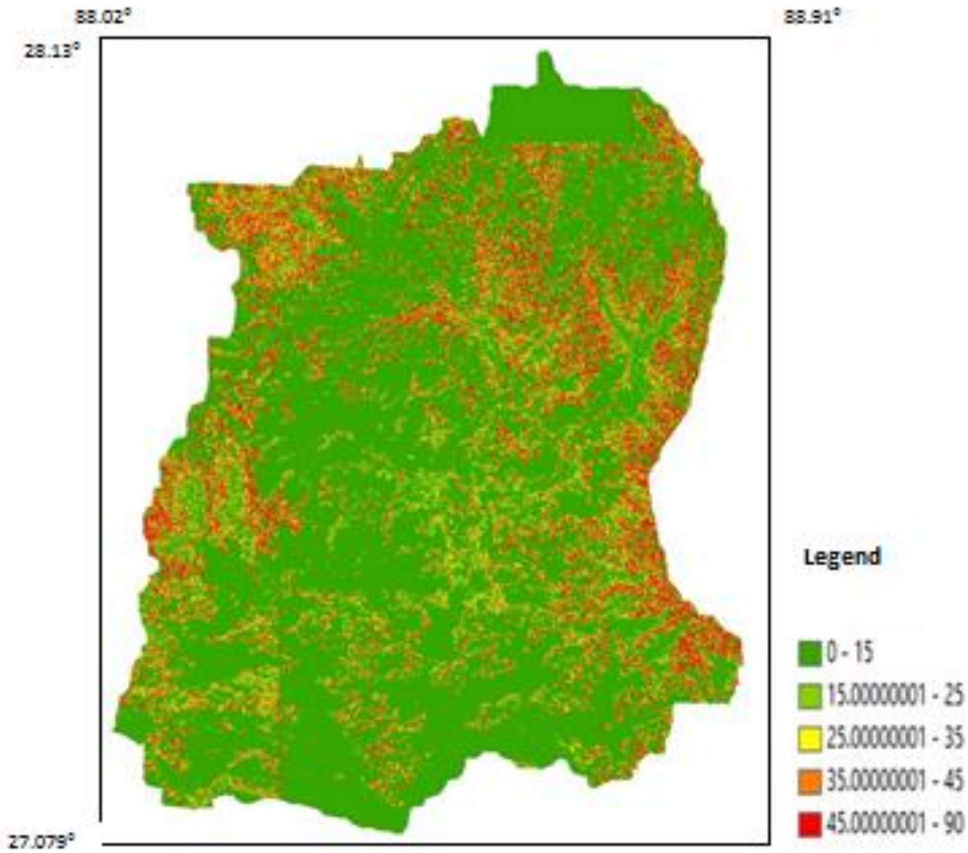

Figure 20: Slope map of Sikkim after Sikkim earthquake of 2011

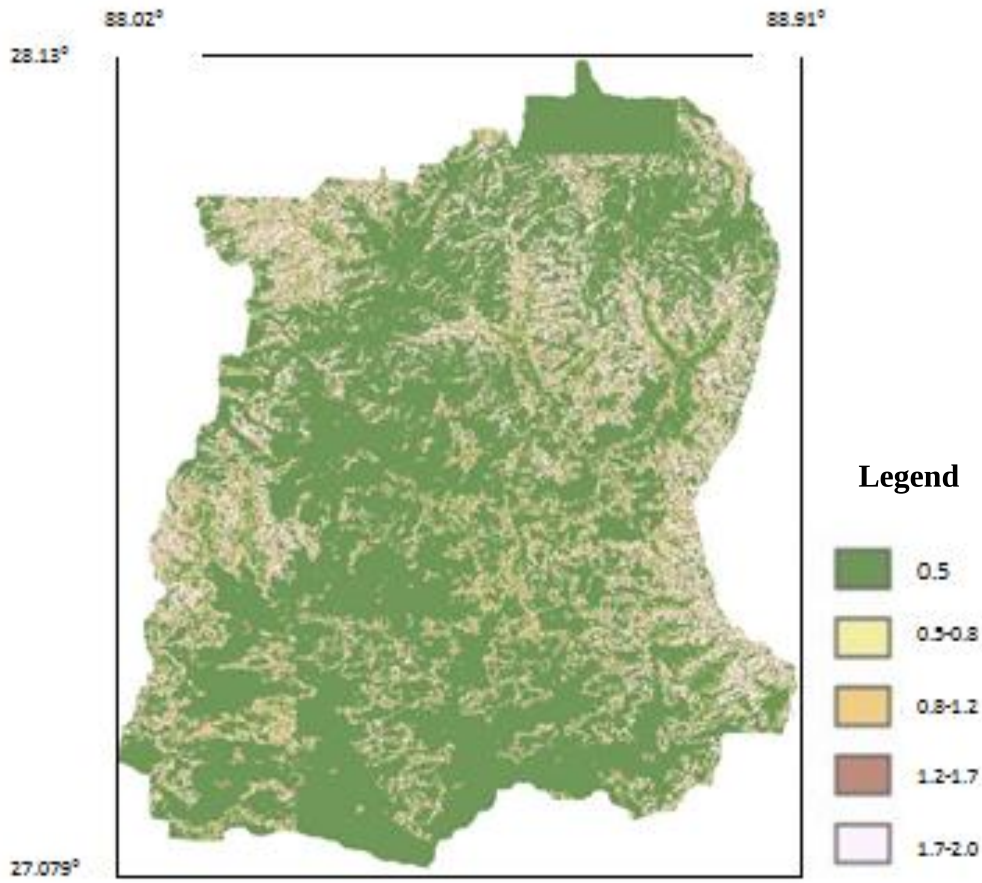

Figure 21: Weighed slope map of Sikkim after Sikkim earthquake

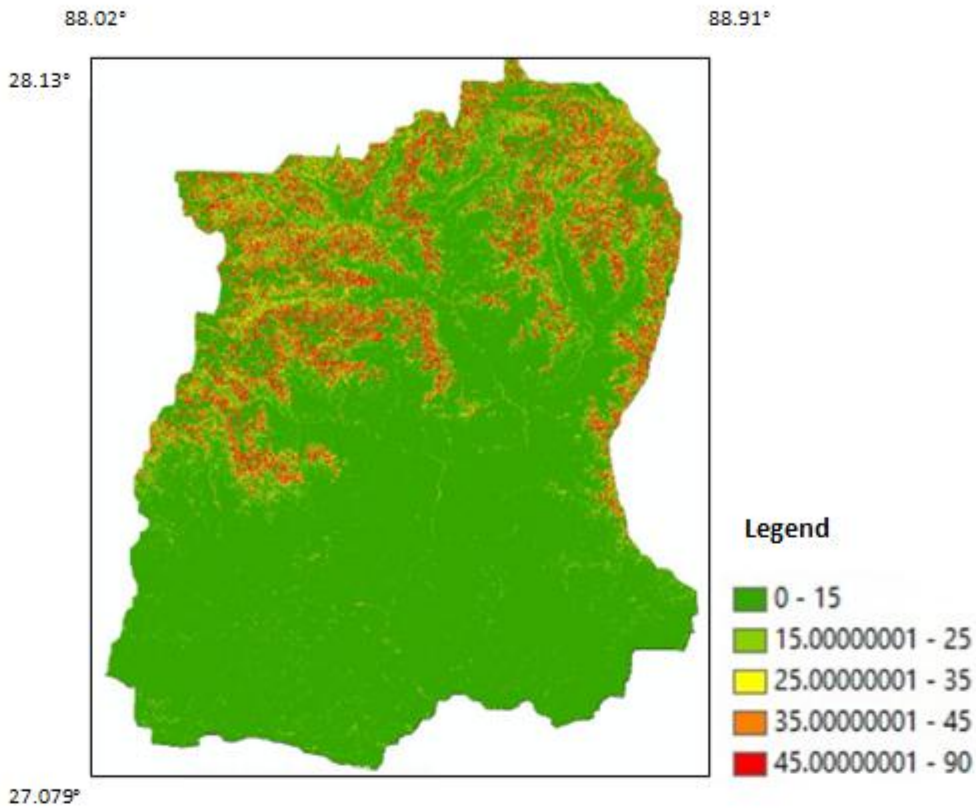

Figure 22: Slope map of Sikkim before Sikkim earthquake of 2011

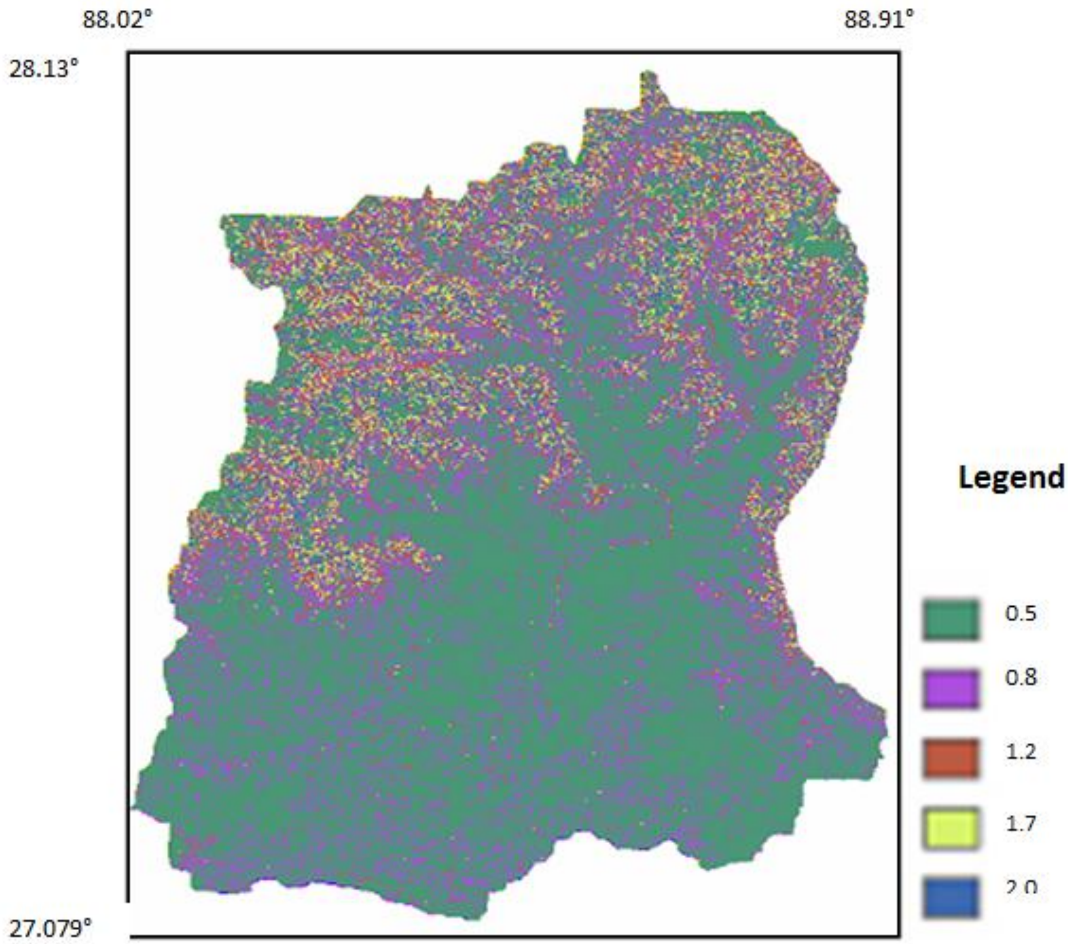

Figure 23: Weighed slope map of Sikkim before Sikkim earthquake

4.7 Hydrogeological factor

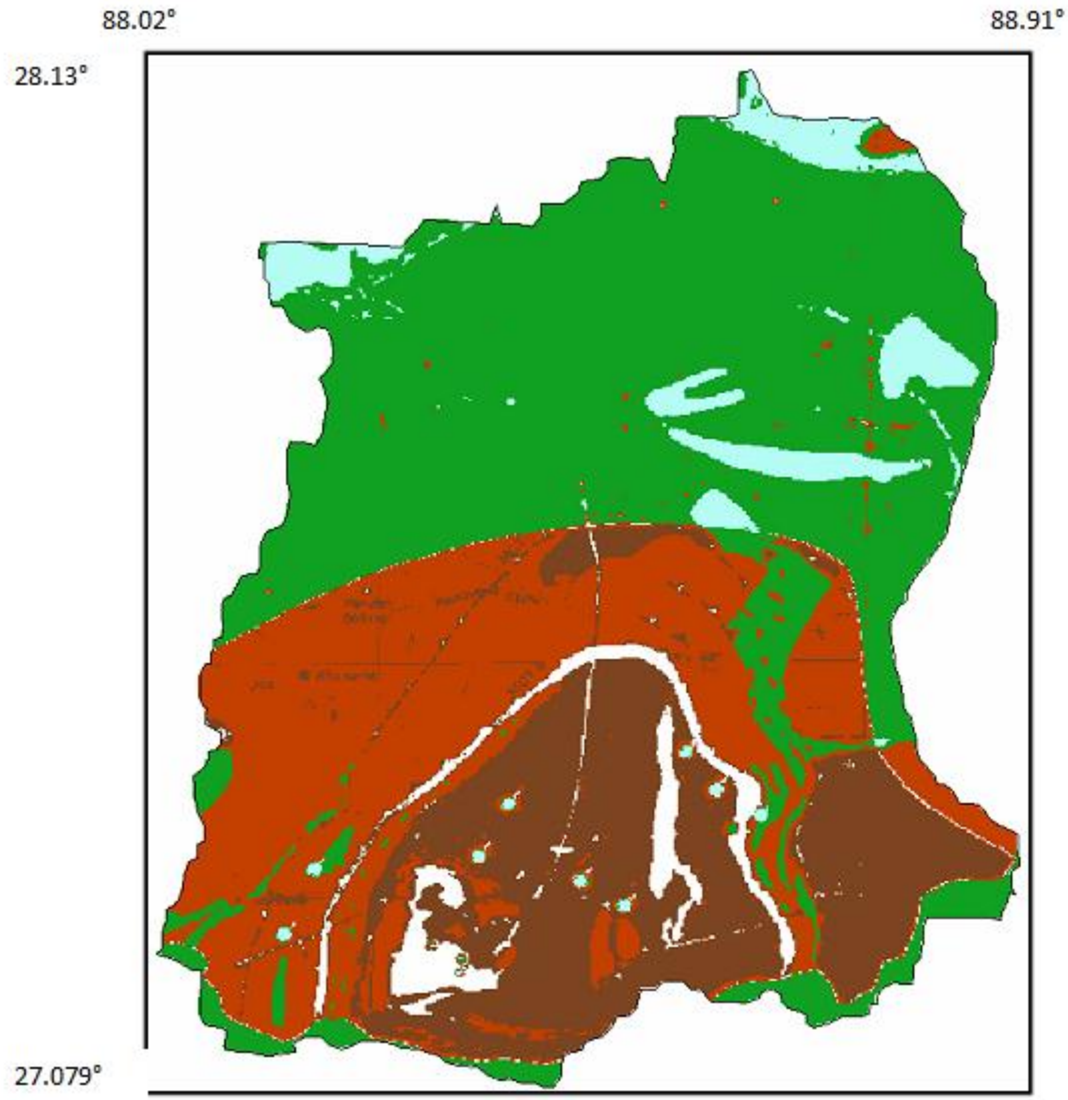

Figure 24: Hydrogeological map of Sikkim (central ground water board)

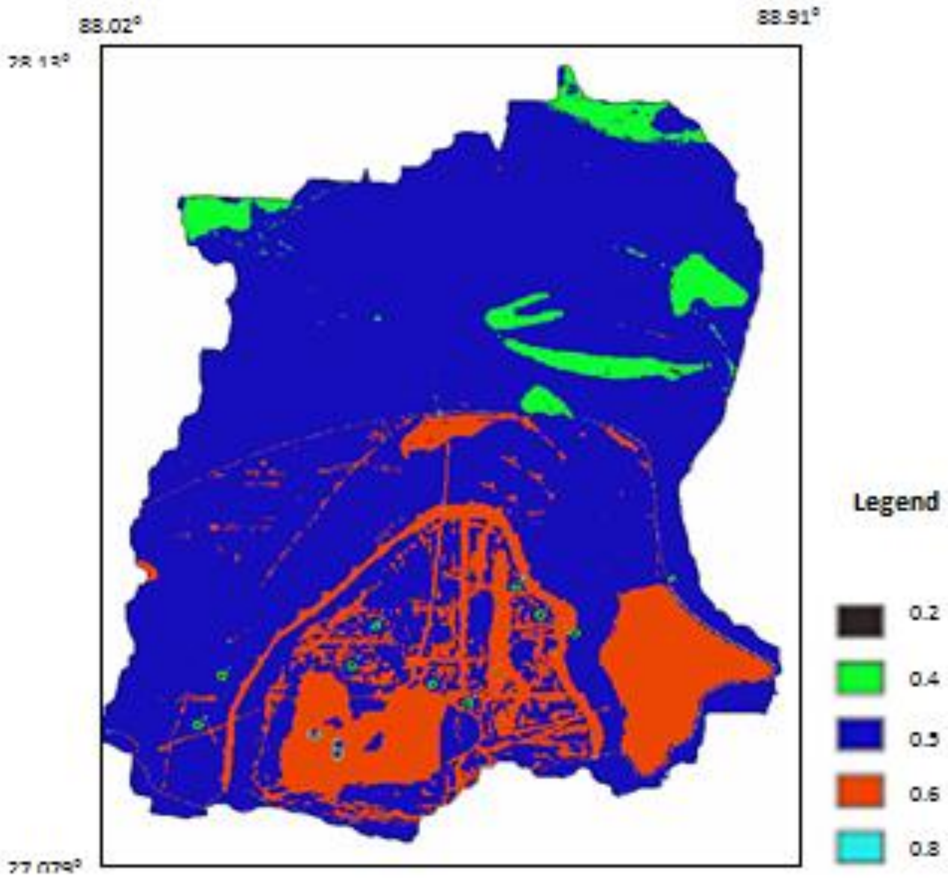

Figure 25: Weighed hydrogeological map of Sikkim

4.8 Seismic factor

Seismic factor is an important causative factor for landslide occurrence. This is not involved as a causative factor in landslide in our IS CODE 14496.

Table 6: Classification of PGA values

PGA(g)	Rating
<0.001	0
0.001-0.02	0.2
0.02-0.05	0.4
0.05-0.1	0.6
0.1-0.5	0.8
>0.5	1

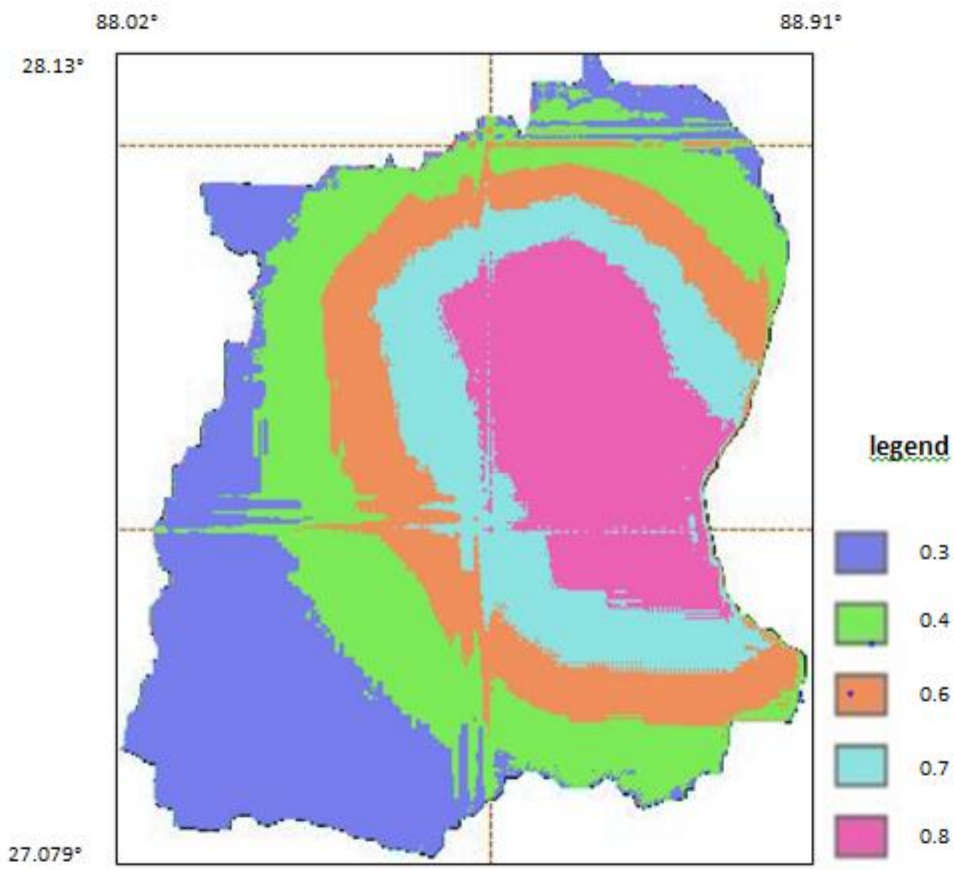

Figure 26: Weighed PGA map of Sikkim

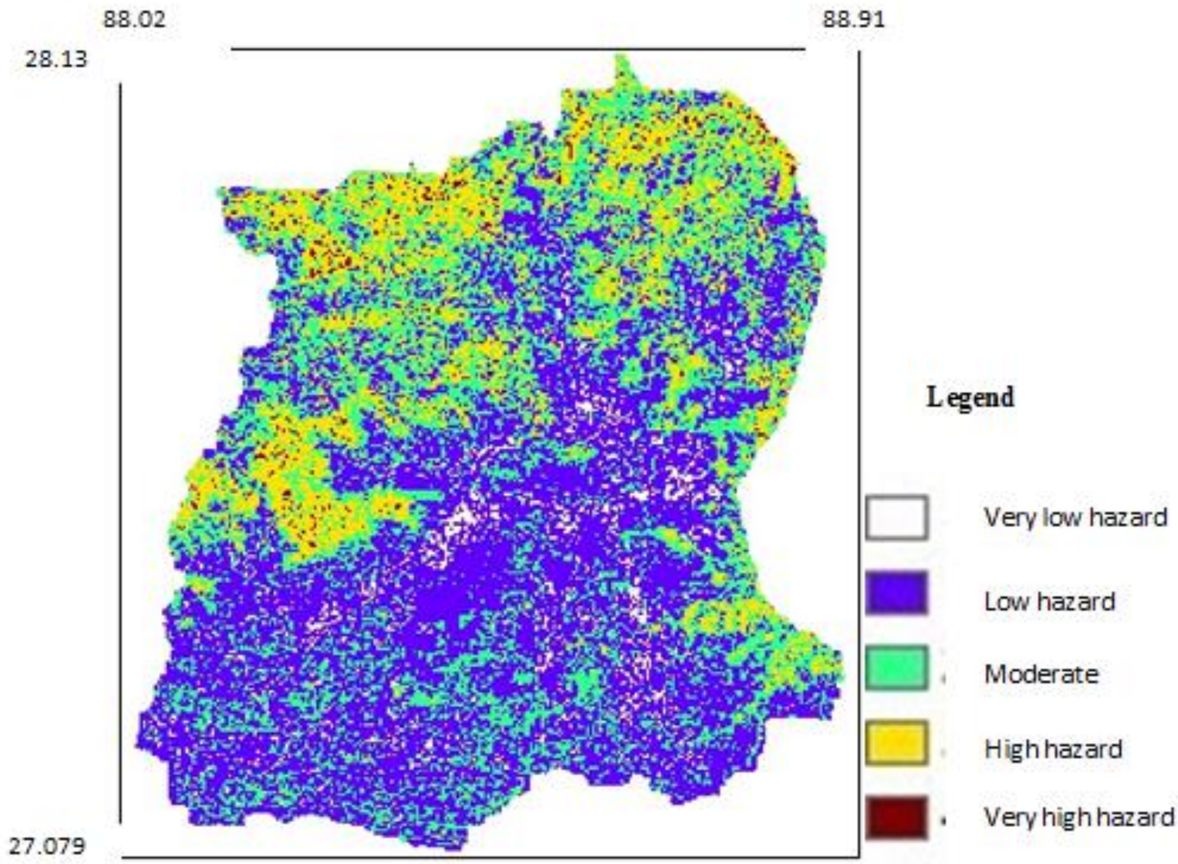

Figure 27: LHZ map of Sikkim before Sikkim earthquake of 2011 without seismicity

Table 7: Distribution of different zones before earthquake without seismicity (Pixel wise)

ZONE	PERCENTAGE AREA
very low hazard zone	3.75%
low hazard zone	47.8%
moderate hazard zone	32.4%
high hazard zone	15.02%
very high hazard zone	1.009%

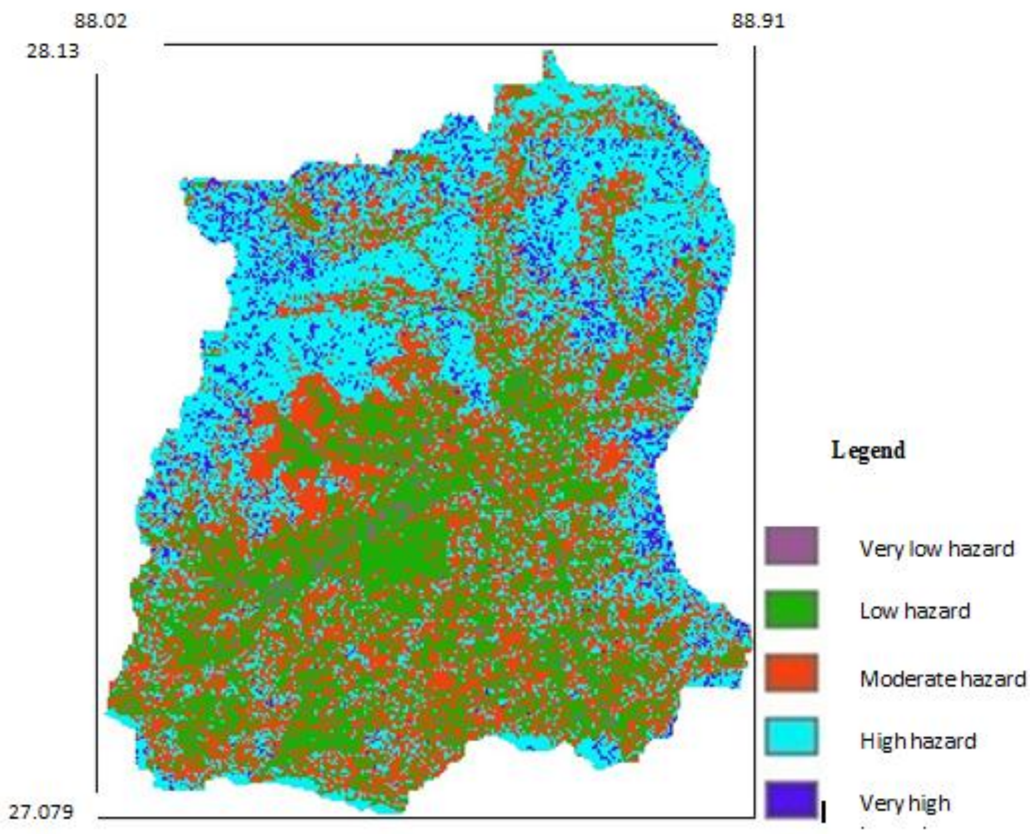

Figure 28: LHZ map of Sikkim before Sikkim earthquake of 2011 without seismicity

Table 8: Distribution of different zones after earthquake without seismicity (Pixel wise)

ZONE	PERCENTAGE AREA
very low hazard zone	0.9%
low hazard zone	24.9%
moderate hazard zone	32.69%
high hazard zone	35.59%
very high hazard zone	5.8%

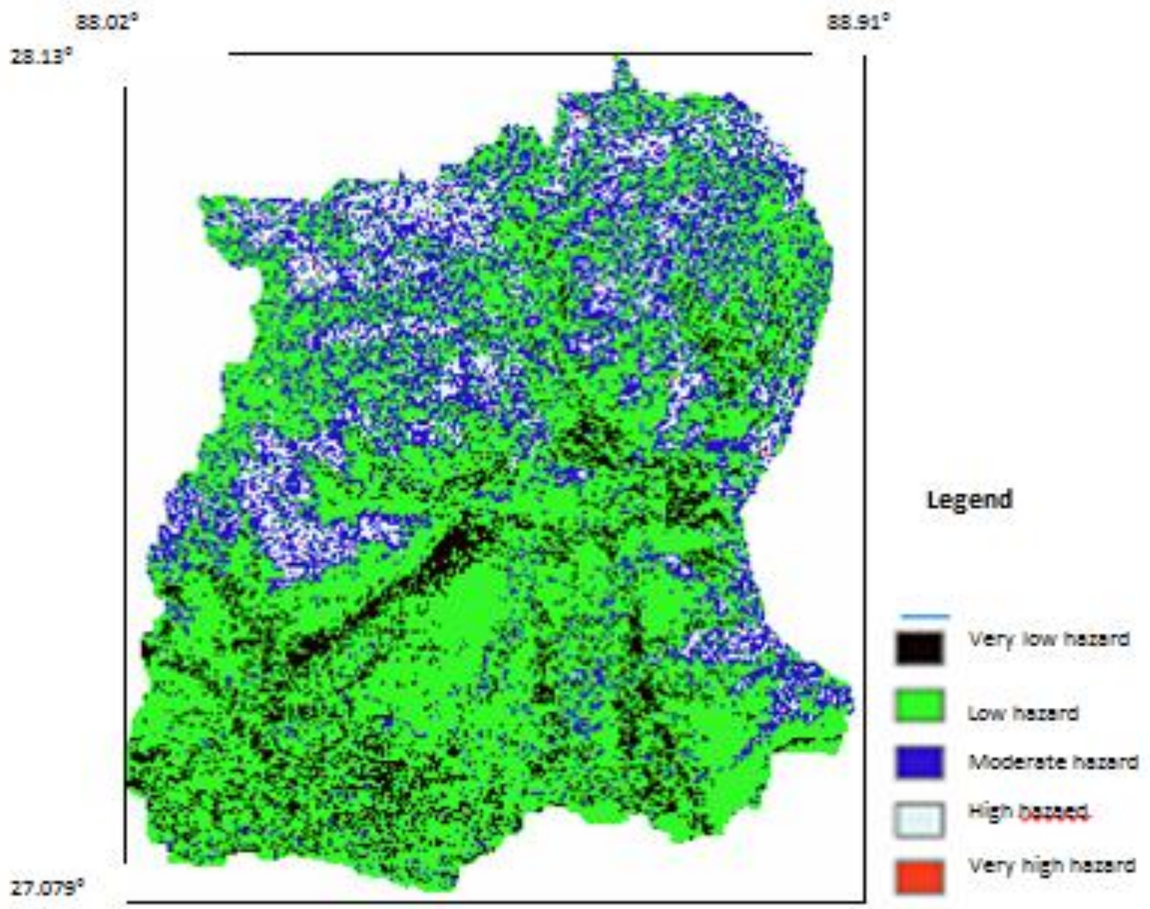

Figure 29: LHZ map of Sikkim before Sikkim earthquake of 2011 with seismicity

Above map represents the landslide hazard zonation map of study region before Sikkim earthquake of 2011. The distribution can be written percentage wise as below

Table 9: Distribution of different zones before earthquake (Pixel wise)

ZONE	PERCENTAGE AREA
very low hazard zone	11.11%
low hazard zone	58.66%
moderate hazard zone	22.22%
high hazard zone	7.92%
very high hazard zone	0.01%

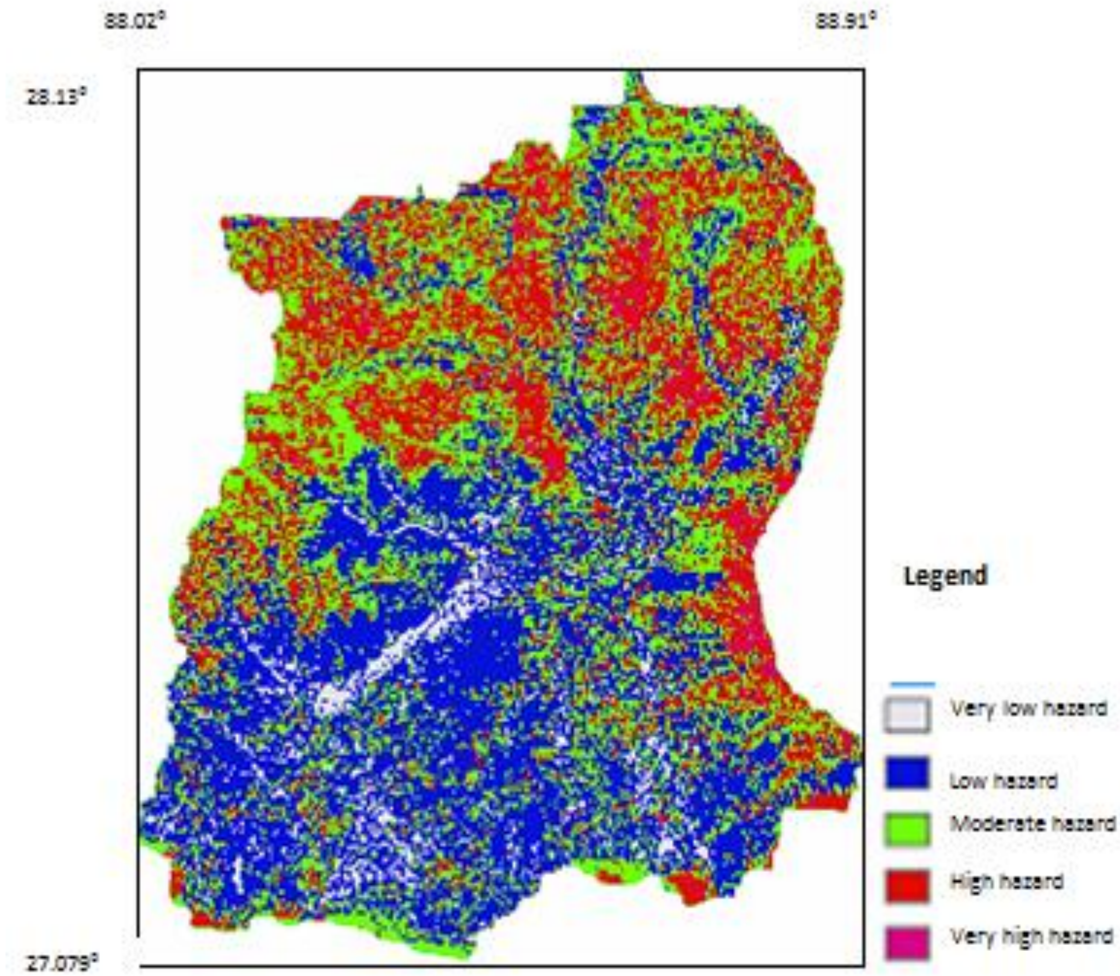

Figure 30: LHZ map of the considered area after Sikkim earthquake of 2011 with seismicity

The above map represents pixel wise distribution of landslide hazard after earthquake which is written percentage wise as below

Table 10: Distribution of different zones after earthquake (pixel wise)

ZONE	PERCENTAGE AREA
very low hazard zone	4.24%
low hazard zone	37%
moderate hazard zone	33.29%
high hazard zone	22.66%
very high hazard zone	2.40%

5 CONCLUSION

5.1 Summary And Conclusions

Occurrence of landslides is worldwide problem that results in thousands of deaths and tens of billions of dollars of damage every year. These losses can be avoided if the problem is recognized early through LHZ map. The geotechnical investigation of a landslide is carried out to establish the causative factors of landslide and to suggest most appropriate remedial measures.

To carry out earthquake induced landslide hazard zonation, we conducted the seismic hazard assessment of our study region, Sikkim. We used probabilistic approach to determine the seismic hazard of the study region. For probabilistic seismic hazard analysis Earthquake catalogue from USGS were studied for considering seismicity of the region. These catalogues were homogenized and de-clustered to compile an appropriate seismicity database. The compiled catalogue includes earthquake of magnitude M_w>=3.5 for period between 1934 and 2015. For getting earthquake parameters like M_c , a, b value and λ_m we used ZMAP software which is based on MATLAB software. For probabilistic seismic hazard analysis CRISIS software is used. For this analysis different earthquake sources like faults, thrusts etc. are considered. By processing these data the distribution of PGA map is obtained. Which is used in earthquake induced landslide hazard zonation as a causative factor.

PGA has been estimated by probabilistic method and b value is considered constant for the Sikkim. For 10% probability of exceedence maximum PGA in Sikkim region is found to be 0.22g, while minimum PGA is 0.02g. For 2% probability of exceedence maximum PGA is found to be 0.4g while minimum PGA found is 0.03g. A comparison of these PSHA results is made with respect to codal values. As per IS Code 1893, Sikkim falls in seismic zone IV, for which suggested PGA is 0.24g under design base earthquake. The maximum PGA values obtained in this study for 10% of probability of exceedence is in comparable range with the code suggested value for design base earthquake. Further, the PGA values estimated for 2% of probability of exceedence is also in comparable range with this code suggested values for maximum credible earthquake/maximum considered earthquake.

On considering constant b value, maximum PGA has been obtained for central south part in Sikkim and having maximum value of 0.22g to 0.08g for 10% probability of exceedence. For

2% probability of exceedence minimum PGA is 0.03g for northern part of Sikkim and maximum PGA found is 0.04g for central part of Sikkim. Considering constant b value, the region situated around MCT, MBT AND Tiesta lineament show higher PGA value for 10% and 2% probability of exceedence.

To carry out earthquake induced LHZ we used LHEF approach. We used different maps like lithology map, slope map, relative relief map, hydrogeological map, land cover map taken from Geological Survey Of India and ISRO website www.bhuvan.nic.in. We processed these maps and assigned ratings with the help of software ARCGIS 10.2.2 as mentioned in IS code 14496. Lastly the integration of all causative factors' rating was evaluated and fine LHZ map is prepared. In this study LHZ map are prepared for Sikkim before the Sikkim earthquake and after the Sikkim earthquake. Though, some authors have carried out landslide hazard zonation of some segments of Sikkim region(e.g. Anbalagan, 2014; Mehrotra, 1996), their studies are limited to landslide hazard zonation without considering earthquake effects. Our study results without considering earthquakes are well comparable with previous studies. Here, in our study, we considered earthquake induced landslides and come up with landslide zonation map.

Before Sikkim earthquake of 2011, the Very high hazard zone and high hazard zone lies in Northern Sikkim which was mostly in habitant and remain snow covered throughout the year. After Sikkim earthquake of 2011 , the area of very high hazard and high hazard has been increased and it mostly lies in North Eastern part of Sikkim and in eastern part there is a need of preventive measures.

5.2 Future Scope

The study has been conducted to prepare LHZ map which includes earthquake as a causative factor. One can use the following points for further studies in this area

a) The PSHA is carried out considering the whole region as a single seismgenic zone further detailed study can be carried out by considering the variability of b value.

b) The area lying in very high hazard zone and high hazard zone can be further studied at the scale of 1:1000 to 1:2000 to check the slope instability.

c) In LHEF rating system, we did not use actual field properties. For precise and accurate microzonation of critical points we can use actual field properties like strength of rock, joints of the rock, shear strength properties of soils, etc.
d) This study can be extended for other hilly regions to prepare the earthquake induced landslide hazard zonation map on the scale of 1:25000 to 1:50000.
e) To make more accurate and effective LHZ map, one can include some more additional influencing factors in LHEF rating system like actual rainfall intensity.

6 REFERENCES

Anbalagan R. (1992) “Landslide Hazard Evaluation and Zonation Mapping in Mountainous Terrain”, Eng. Geol., 32: 269-277.

Bhatia S C, Kumar R M and Gupta H K (1999) “A probabilistic seismic hazard map of India and adjoining regions”, Ann. Geofis. 42(6) 1153–1164.

BIS Code 1893-2002 “Earthquake hazard zoning map of India”, www.bis.org.in

Boore D M and Atkinson G M (2008) “Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s”, Earthq. Spectra 24;99–138.

Chander R (1988) “Interpretation of observed ground level changes due to the 1905 Kangra earthquak, Northwest Himalaya”, Tectonophys. 149 289–298.

Cornell C A (1968) “Engineering seismic risk analysis”, Bull. Seismol. Soc. Am. 58; 1583–1606.

Das R, Wason H R and Sharma M L (2012a) “Magnitude conversion to unified moment magnitude using orthogonal regression relation”, J. Asian Earth Sci. 50(2); 44–51.

Das R, Wason H R and Sharma M L (2012b) “Temporal and spatial variations in the magnitude of completeness for homogenized moment magnitude catalogue for Northeast India”, J. Earth Syst. Sci. 121(1); 19–28.

Das R, Wason H R and Sharma M L (2013) “General orthogonal regression relation between body and moment magnitudes”, Seismol. Res. Lett. 84(2); 219–224.

Development of probabilistic seismic hazard map of India 2011 Technical Report, National Disaster Management Authority (NDMA), Government of India, New Delhi.

Desai A, Shanker D and Jakka R S (2015) “Earthquake induced landslide hazard zonation of Nainital Region”, Journal of Nepal Geological Society 45

GSI (2000) Sesmotectonic Atlas of India and its Environs; Geological Survey of India.

Gansser A (1977) “The great Suture Zone between Himalaya and Tibet” A preliminary note; Sciences de la Terre: Himalayas CNRS 268; 181–192.

Gupta P., Uniyal S. (2013) “LHZ Mapping of the Area around Nainital using Bivairiate Statistical Analysis” International Journal of Advanced Technology and Engineering Research,3(1)

Gutenberg B and Richter C F (1944) “Frequency of earthquakes in California”, Bull. Seismol. Soc. Am. 34(4); 1985–1988.

Iyengar R N, Sharma D and Siddiqui J M (1999) “Earthquake history of India in medieval times”, Ind. J. Hist. Sci. 34(3); 181–237.

Joshi G C and Sharma M L (2008) “Uncertainties in the estimation of Mmax” J. Earth Syst. Sci. 117; 671–682.

Kijko A (2004) “Estimation of the maximum earthquake magnitude, Mmax” Pure Appl. Geophys. 161; 1655–1681.

Kramer S L (2003) “Geotechnical Earthquake Engineering” Prentice Hall International Series, Pearson Education, Delhi, Chapter 4.

Khattri K N, Rogers A M, Perkins D M and Algermissen S T (1984) “A seismic hazard map of India and adjacent area”, Tectonophys. 108; 93–134.

Mahajan A K, Thakur V C, Sharma M L and Chauhan M (2010) “Probabilistic seismic hazard map of NW Himalaya and its adjoining area, India”, Nat. Hazards 53; 443–457.

Middlemiss C S (1909) “Preliminary account of the Kangra earthquake of 4th April 1905”, Geol. Soc. India Memoir 32(4); 258–294.

Musson R (1999) “Probabilistic seismic hazard maps for the North Balkan region”, Ann. Geofis. 42(6); 1109–1124.

Oldham T (1883) “A catalog of Indian earthquakes from the earliest times to the end of 1869 AD”, Geol. Surv. India Memoir, XIX Part-3.

Ordaz M, Aguilar A and Arboleda J (2003) “Crisis 2003: Program for computing seismic hazard”, Ver. 3.01.

Reiter L (1990) “Earthquake hazard analysis: Issues and insights”, (Columbia, USA; Columbia University Press).

Ristau J (2009) “Comparison of magnitude estimates for New Zealand earthquakes: Moment magnitude, local magnitude, and teleseismic body-wave magnitude”, Bull. Seismol. Soc. Am. 99; 1841–1852.

Sharma M. L. (2000) “Attenuation Relationship for Estimation of Peak Ground Vertical Acceleration using Data from Strong Motion Arrays in India” 12th World Conference on Earthquake Engineering, Auckland, New Zealand.

Wason H R, Das R and Sharma M L (2012) “Magnitude conversion problem using General Orthogonal Regression”, Geophys. J. Int. 190(2);1091–1096.

Wiemer S and Wyss M (2001) “ZMAP: A Tool for Analyses of Seismicity Patterns”, A Cookbook, 57.

Woessner J and Wiemer S (2005) “Assessing the quality of earthquakes catalogues: Estimating the magnitude of completeness and its uncertainty”, Bull. Seismol. Soc. Am. 95(2); 684–698.