ASSESSMENT AND PREPARATION OF LANDSLIDE SUSCEPTIBILITY ZONATION MAP BY GEOSPATIAL METHOD USING REMOTE SENSING AND GIS

Abhik Saha (1), Vasanta Govind Kumar Villuri (1), Ashutosh Bhardwaj (2)

[1] Indian Institute of Technology (Indian School of Mines), Dhanbad, Jharkhand-826004, India.
[2] Indian Institute of Remote Sensing, 4, Kalidas Road, Dehradun- 248001, India.
Email: abhik.17dr000597@me.ism.ac.in ; vgkvilluri@iitism.ac.in ; ashutosh@iirs.gov.in

KEY WORDS: Landslide Susceptibility Zonation (LSZ); Landslide; Remote Sensing (RS); Geographic Information System (GIS).

ABSTRACT Landslide is the most affecting natural Hazard of any hilly region. It occurs due to changes in different aspects like slope, drainage, land use and land cover, lithology, geological conditions, etc. It is the disaster that directly affects the socio-economical condition of any region. Landslide Susceptibility Zonation (LSZ) Map is required to prevent landslide as well as the socio-economical losses of the hilly region. The availability of various Remote Sensing (RS) data and the advancement of the Geographic Information System (GIS) help to prepare the LHZ map. The integration of RS data and GIS application is adopted to generate the LHZ map of Darjeeling, India. Landsat 8, Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Data Elevation Model (DEM), and different Information maps are used to prepare six thematic layers for LHZ such as Slope, Drainage Density, Lineament, Geology, Land use & Land Cover, Soil. Thematic layers were assigned appropriate Numerical values as the weight for every factor and sub-factor in the GIS environment. The LHZ maps were produced by the weighted overlay technique. Resulted from it gives the LHZ map of the Darjeeling area. Further zoned into four classes as followed, Low, Moderate, High, and Very High. Later the map was validated by field data and geospatial analysis.

1. INTRODUCTION

Landslide is one of the common natural hazards in the hilly region which affects the socio-economical activities. 12.60 % of India's lands fall in the Landslide hazard zone (NDMA 2009). Qualitative and quantitative methods were implemented for categorizing Landslide Susceptibility Zone (LHZ) (Shano et al., 2020). For mitigating those losses, several new and hybrid approaches were introduced as well as implemented in worldwide (Pham et al., 2018; Yang et al., 2019). Urbanization, deforestation are triggering factors to increase the cases of landslides (Aleotti and Chowdhury, 1999, Chawla et al., 2019). Due to heavy rainfall and seismic activity, landslides happened every year in Darjeeling and Kalimpong district. These areas were severely affected in July to August 1993, May 2009, and September 2011(Roy et al., 2019). So, LHZ mapping of any hilly region helps to classify into different zones concerning their variability (Varnes, 1984). Nowadays, RS and GIS environment assistance to detect factors of landslides that may influence in particular areas (Gupta and Joshi, 1990; Van Westen, 1994; Nagarajan et al., 1998; Gupta, 2003; Budha and Bhardwaj, 2019). LHZ maps identity the vulnerable areas, that advice to not construct new things.

Current study evolves towards emerging a precise methodology for landslide susceptibility mapping which contains generating thematic layers and their analysis. The weighted overlay approach assigns numerical weight and rating to landslide affecting layers and classes

respectively (Bhasin et al., 2002). The weight and rating are determined to the layers and their respective classes on the basis of the literature review which was used by researchers in the past and accepted globally.

2. STUDY AREA

Our study area is lying in the Eastern Himalayan region, the northern part of state West Bengal, India i.e. part of district Darjeeling and Kalimpong (Figure 1). The study lies in between latitude 26°15′33″ N to 27°1′22″ N and longitudes 88°2′51″ E and 88°5′42.6″ E. The total area of Darjeeling Himalayas is 3,000 sq.km, and the highest peak of the region around 2,584 meters, that is Tiger Hill. Darjeeling, Ghum, Sonada, Kalimpong are the major cities in this area. Tea plantation and horticulture is the most land utilization feature.

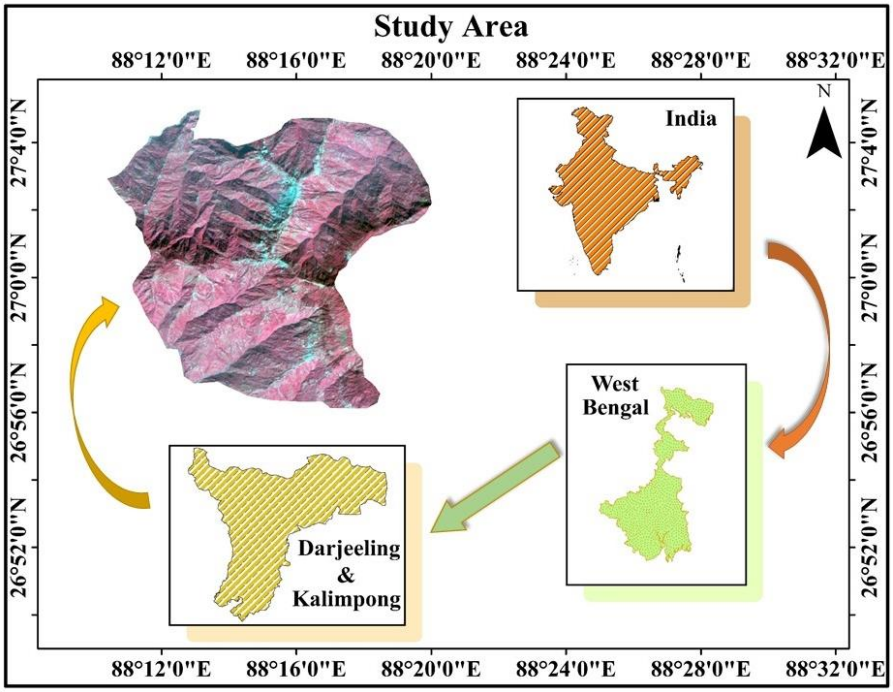

Figure 1: Study Area

Darjeeling is known for its tourism, mountains, and Darjeeling tea. Each year, nearly 500,000 visitors from India and 50,000 visitors from around the world came to visit Darjeeling and the surroundings. The population density is nearly 12000/sq.km. Due to the hilly region, the annual temperature of Darjeeling is approximately 14.9 °C, in winter the temperature falls nearly 1°C. The lowest temperature recorded till now is -5oC. Due to a low temperate climate, every year rainfall is happening from mid-April to the end of August. Annual rainfall is nearly 309 cm.

3. DATASET

Preparation of relevant thematic layers different remote sensing data were used which is mentions in Table-1. ArcGIS software was used to prepare required thematic layers i.e. slope, Land use & land cover (LULC), Lineament, Geology, Drainage Density, Soil from ASTER DEM, Landsat 8, LISS IV, and published data by the different organization (1 in 50,000 geology map by Geological Survey of India (GSI) and 1 in 5,00,000 soil map by National Bureau of Soil

Survey & Land use planning (NBSS & LUP)).

Table-1: Dataset Used

Sl. No.	Data Name	Purpose	Year	Spatial Resolution (m)
1	ASTER DEM	To study slope, drainage	2011	30
2	Landsat 8	To generate a LULC map	2016	30
3	LISS IV	To generate a lineament map	2011	5.8

4. METHODOLOGY

The basic methodology the LSZ mapping is shown in Figure 2. Landslides have occurred to different factors, but it is not always possible to collect all the data. The current study is obtained by six factors for LSZ mapping. They are slope, LULC, Lineament, Geology, Drainage Density, and Soil. Though rainfall and earthquake are one of the most initiating aspects of landslides hazard, those data layers are unable to add because the data are unable to collect. These data layers were produced through GIS software from remote sensing data, topographic maps, and published maps.

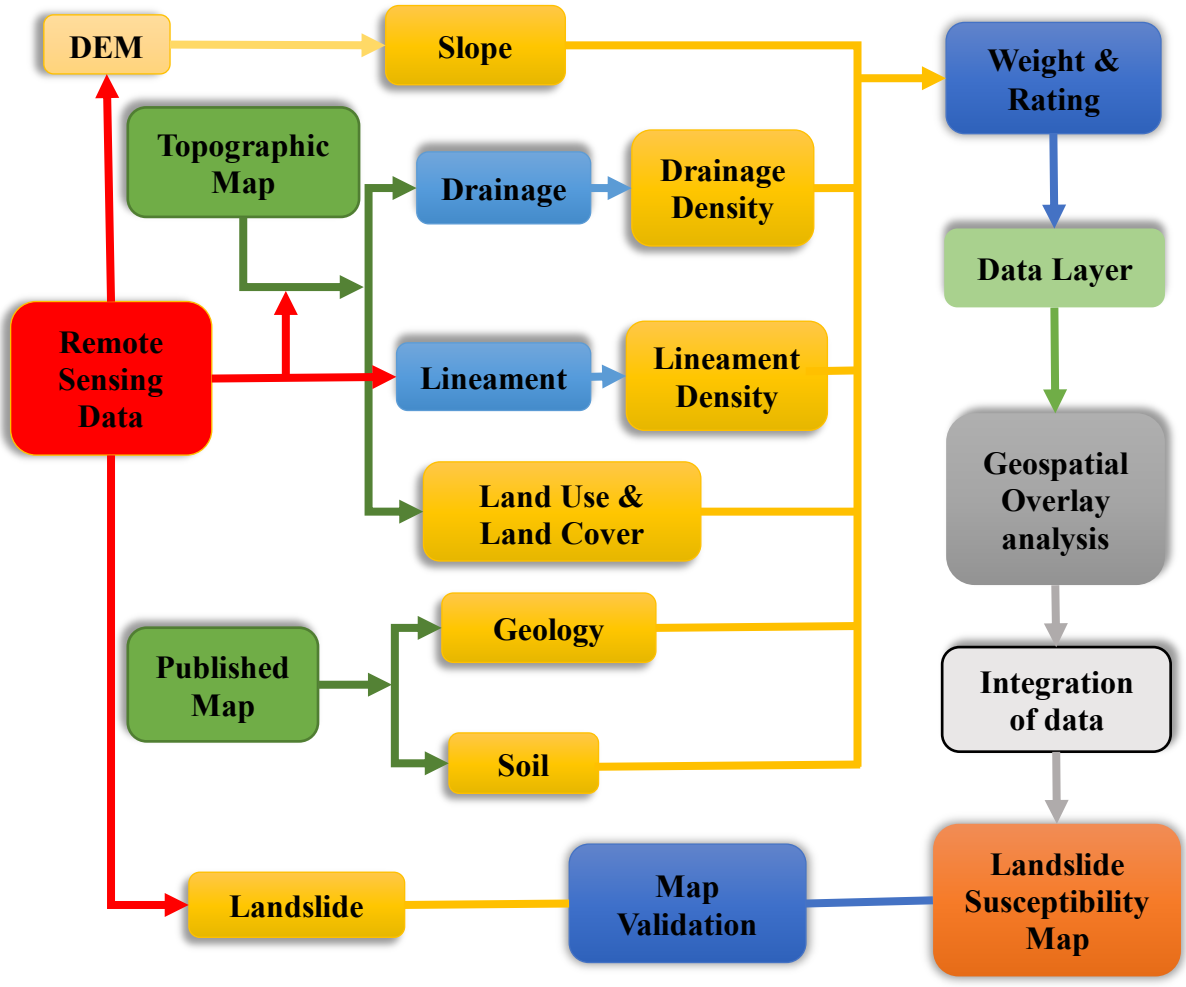

Figure 2: Methodology

In this study, the overlay analysis technique is used for the assessment of LHZ mapping. This study area, with the help of literature, field experiences, weights were allocated to the factor maps on the range of 1 to 10 based on slope stability, and rating values were assigned to each class of the factor maps on the numerical range of 1 to 9 (Lee et al., 2004, Chawla et al., 2017). Different factors and their classes were assigned their weight and rating. The thematic data layer was generated by arithmetically multiplying the rating of individual classes. The final LHZ map is created by the model builder tool. The output of LHZ is classified into different susceptibility zone namely low, moderate, high and very high. For validation of the LHZ map was done by a distribution map.

5. RESULT & DISCUSSION

5.1 Thematic Layer Generation

The required thematic layers were generated with the help of ArcGIS software from remote sensing data (ASTER DEM, LANDSAT- 8 and LISS- IV) and published data (1:50,000 geology map and 1:5,00,000 soil map).

5.1.1 Slope Map: The slope is one of the igniting factors for landslides. Steep slope is more vulnerable than a moderate or low slope. The slope map was made from ASTER DEM and divided into five classes concerning the slope angle. Figure 3 represents the slope map with different classes.

5.1.2 Drainage Density: In the past, landslide followed the drainage path to flow. Drainage of any area is associated with the topography and incline of any area (Sarkar and Kanungo 2004, Kanungo et al., 2006). The drainage density map (Figure 4) was created by the topographic map by Survey of India and the remaining part using Landsat-8 and LISS- IV.

5.1.3 Lineament: Faulted zones, joints, and fractured are more vulnerable to landslides. These zones allow water to enter those areas which increase the water pressure and helps to trigger sliding on these zones (Kanungo et al., 2006). The lineament map (Figure 5) was classified into very low, low, moderate, high, and very high as per their vulnerability.

5.1.4 Land Use & Land Cover: Various land use representation of that area is represented in the LULC map (Figure 6). Barren land or deforestation of an area increases the potential of landslides. The vegetation density is inversely connected with landslides (Kanungo et al., 2006). The area is classified into a water body, urban area, rural area, tea plantation, sparse forest, and barren land.

5.1.5 Geology: Strong rocks give more protection from landslide than loose and fragile rock and consequently are safe from occurring landslides and vice versa (Kanungo et al., 2006). The geology map (Figure 7) was prepared in ArcGIS software form the published data on a scale of 1 in 50,000 by GSI.

5.1.6 Soil: Soil that covers on the top of the slope has a good impact on the landslide (Sarkar and Kanungo, 2004). Soil map was made from 1:5,00,000, soil map (Figure 8) of West Bengal which was made by NBSS & LUP.

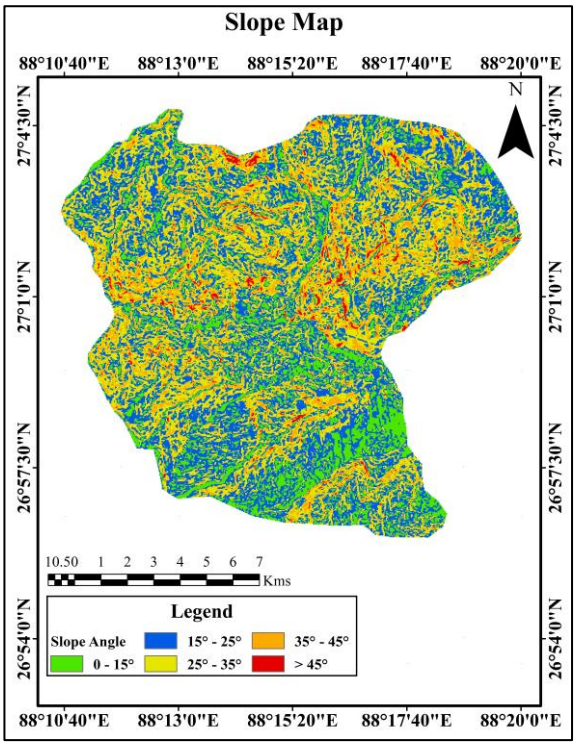

Figure 3: Slope Map

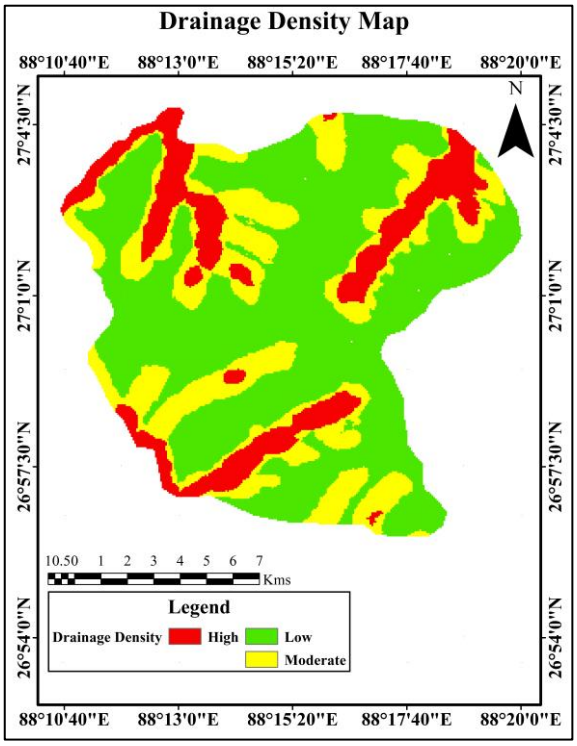

Figure 4: Drainage Density Map

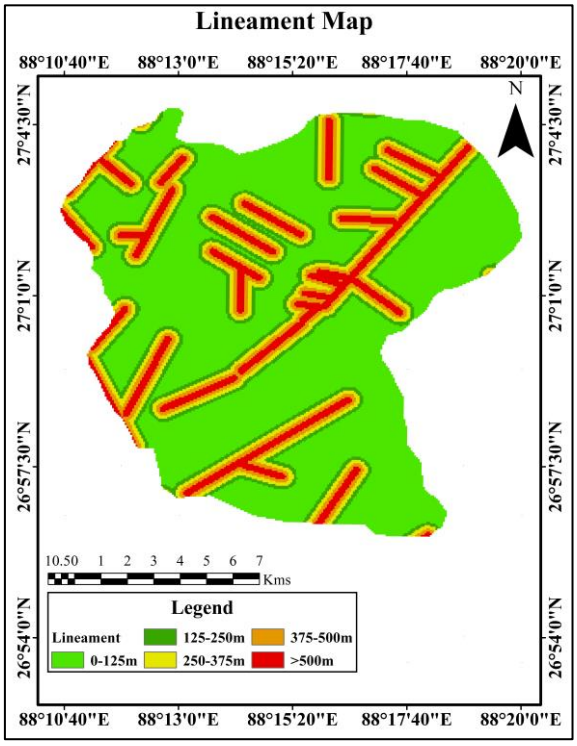

Figure 5: Lineament Map

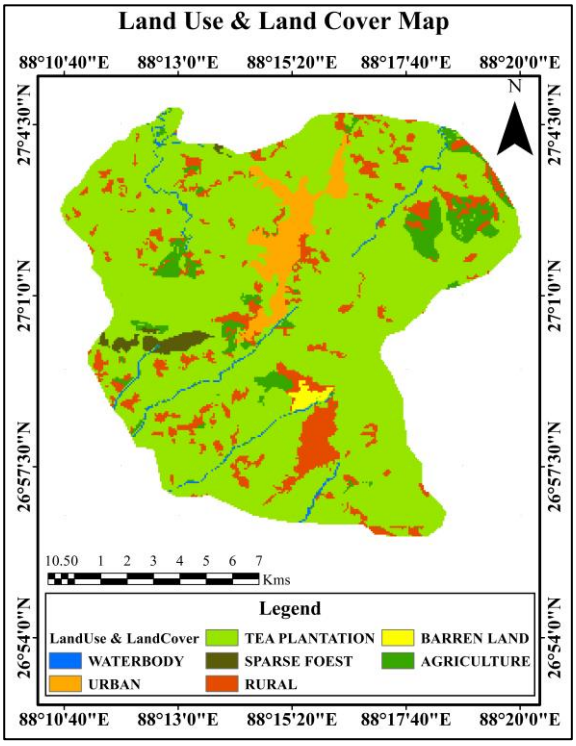

Figure 6: Land Use and Land Cover Map

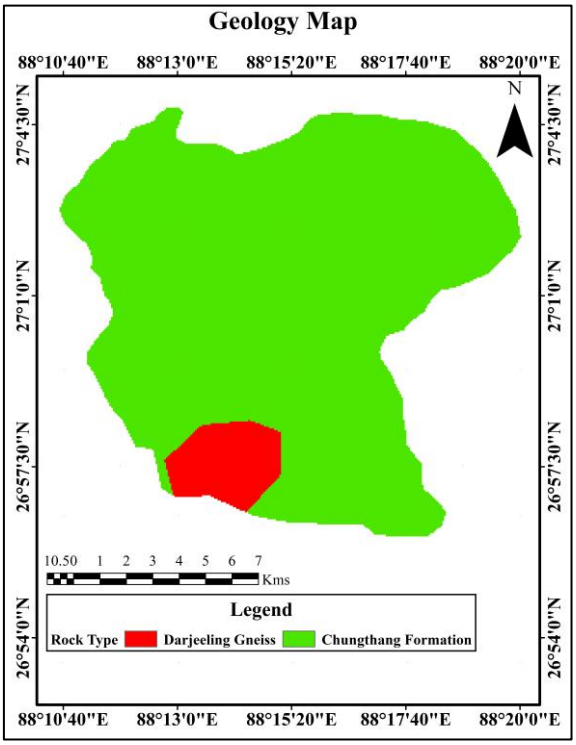

Figure 7: Geology Map

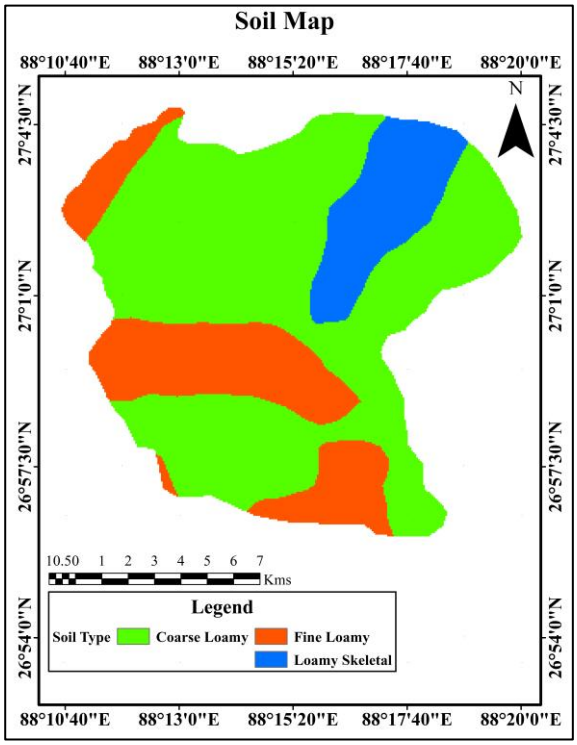

Figure 8: Soil Map

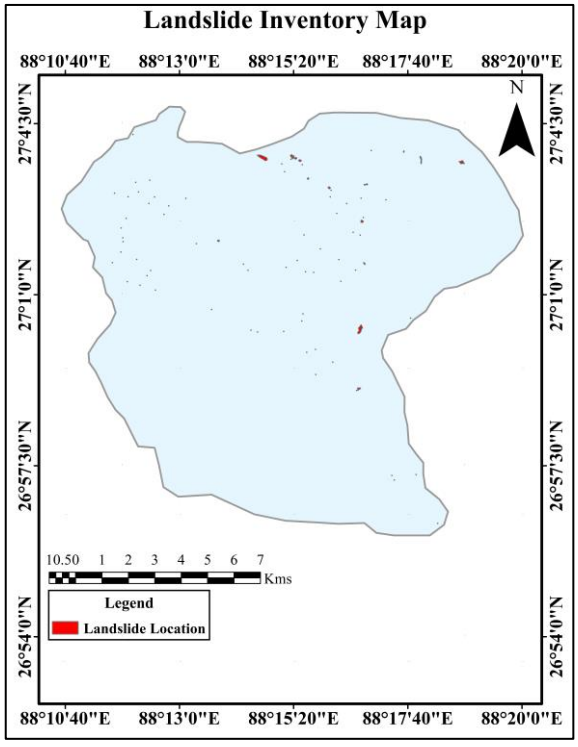

Figure 9: Landslide Inventory Map

5.1.7 Landslide Inventory Map: Drawing the relationship between past landslides and factors of those locations and final landslide susceptibility zone, inventory maps of the landslide are used. The landslide inventory map (Figure 9) was made after collecting data from google map and published data from GSI and a total of 93 landslide locations can be recognized, which helps to validate to the LHZ map.

5.2 Landslide Susceptibility Zonation Map

A knowledge-based approach was established from the past work by Sarkar et al., 2004, Kanungo et al., 2006, etc. for this study. The weight was assigned to the factor in the range of 1 to 10 and the rating of each factor classes was assigned in the range of 1 to 9.

Table-2: Details Weights & Ratings of Thematic Data Layers & Respective Classes

Sl.No.	Data Layer	Classes	Weight	Rating
1	Slope	0°-15°	10	1
		15°-25°		4
		25°-35°		6
		35°-45°		8
		>45°		10
2	Lineament	0-125	8	9
		126-250		7
		251-375		5
		376-500		3
		>500		1
3	Drainage Density	Low	7	3
		Moderate		5
		High		9
4	Geology	Chungthang Formation	5	3
		Darjeeling Gneiss		1
5	Soil	Coarse Loamy	2	3
		Fine Loamy		6
		Loamy Skeletal		9
6	Land Use & Land Cover	Water Body	4	1
		Urban area		2
		Rural area		3
		Tea plantation		4
		Agriculture land		
		Sparse forest		7
		barrel land		9

Table-2 represents the assigned value of factors and their respective classes. In the current study, six weighted thematic layers, slope, lineament, geology, land use & land Cover, drainage density, soil were used. These data layers were overlayed and mathematically multiplying by the below equation (Eq. 1) for generating Landslide Susceptibility Zone (LSZ) map in the GIS environment,

$$LSZ = Sl + DD + Li + LULC + Geo + So \quad \text{(Eq. 1)}$$

where, Sl = weighted slope, DD = weighted drainage density, Li = weighted lithology, LULC = weighted land use & land cover, Geo= weighted geology, So = weighted soil.

The LHZ map is distributed into four susceptibility classes, namely Very High Zone, High Zone, moderate Zone, and Low Zone. The range of Landslide Potential Index is 194 to 770 then the value is distributed into susceptibility classes. The range of Low susceptibility is 194 to 387, Moderate susceptibility is 388 to 468, High Susceptibility is 469 to 550 and Very High Susceptibility is 551 to 770. The classified was validated with the inventory map. Table-3 shows the distribution of the LHZ in the study area. In the inventory map, a total of 81 landslide locations fall under moderate to very susceptibility zone where 44 landslides in the High Zone, 30 landslides in the Moderate Zone, and 7 in the very High Zone. It was found in the study that, 12.61% of the area is in low zone, 40.73% is in the Moderate Zone, 35.47% is in high susceptibility zone and 11.19% is in the Very high zone.

Table-3: Distribution of LSZ with Landslides

Susceptibility Zone	Area (Sq.m)	Area percentage (%)	Number of Landslides	Frequency (per Sq.km)
Low	69863200	12.61	12	0.66
Moderate	67502900	40.73	30	0.426
High	25459200	35.47	44	0.72
Very high	4283560	11.19	7	0.37

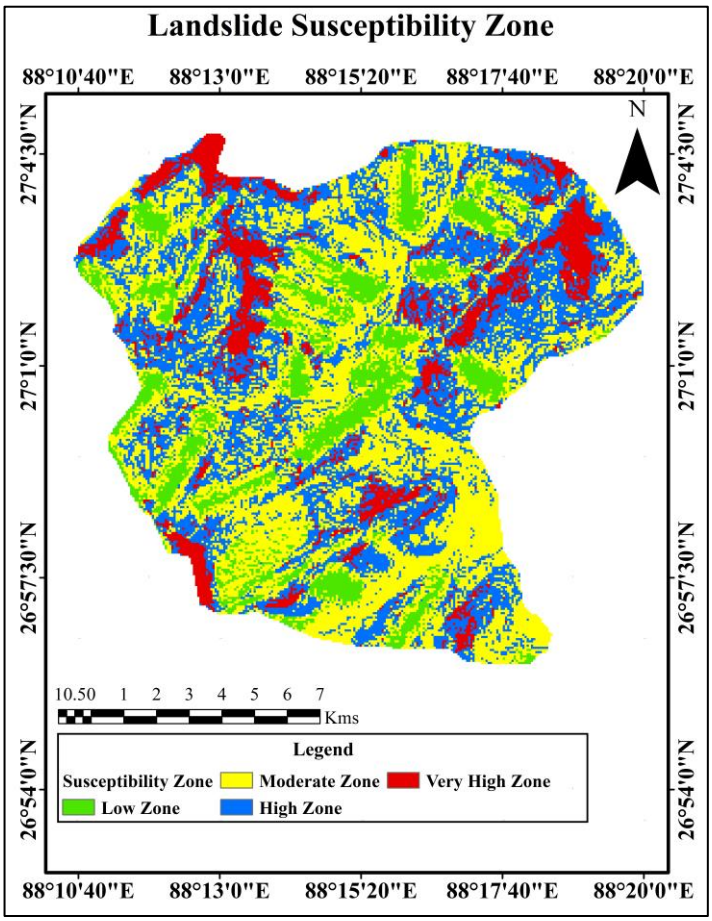

Figure 10: Landslide Susceptibility Zone

6. CONCLUSION

Darjeeling, the northern part of West Bengal is one of the active landslide affected zone in India. The current study produces an LHZ map with a weighted overlay technique in RS and GIS environment. As a result of the LHZ map, the whole map was distributed into four landslide susceptibility zone i.e., Low (12.61%), Moderate (40.73%), High (35.47%), Very High (11.19%) zone. We can future conclude that 87.39 % of the total area comes in moderate to very high landslide susceptibility zone. Frequency of Very High, High, Moderate and Low Landslide Susceptibility is 0.37, 0.72, 0.426 and 0.66 respectively.

The pattern of landslide locations, it shows that mostly highly dissected hills are the key location of landslide. Additionally, fewer vegetation areas with debris increase the potential of a landslide. Debris slide is the common landslide characterization of this area. So it can conclude that a highly dissected hill with debris and low to moderate vegetation especially sparse forest or barren land or tea plantation area is the most triggering factor for landslide in the above study area.

The final output was cross-checked with the filed survey, and it was observed that a major steep slope is observed in the very high and high zone. Therefore, we can say that the map relates well to the field. By adding more factors, the accuracy of the landslide susceptibility map can be increased. It is very much advisable to avoid those high and very high susceptibility zones.

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