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Delineation of potential landslide prone zones using Remote Sensing and GIS Techniques: A case study from north western part of Aizawl city, Mizoram, India

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ABSTRACT

A landslide susceptibility map depicts the areas that have potential for land sliding. The present study is carried out to predict the spatial distribution of future landslides within the study area. The satellite imagery of IRS LISS III of 23.5 meters spatial resolution, CARTOSAT DEM of 30 meters resolution along with topographical sheets of 1:50,000 scale prepared by Survey of India (SoI) has been used for deriving baseline information on various causative factors maps like slope, aspect, drainage density, structure, lithology and land use/land cover. The various causative factor maps, which may have influence on the landslide event are arranged and consolidated to set up the potential zone map.

The numerical values of 0 to 10 are allocated to different causative variables for instability of slope. It is observed that 10.83% of the study area is Low Hazard Zone, 84.84 % is Medium Hazard Zone and only 2.32 % show High Hazard Zone.

1. Introduction

Landslide is a general term used to depict the downslope movement of soil, rock, and organic materials under the impacts of gravity and furthermore the landform that outcomes from such development. Remote sensing images provide many useful land use and land cover information which are integrated in a GIS environment with other spatial components affecting the event of landslide that identifies a potential landslide prone zone. These probable sliding locations are controlled by relating a portion of the principal factors that contribute to arrive sliding with the past distribution of landslides. This data would then be able to be extrapolated to foresee different regions of potential land sliding. There are a several expert assessment systems accessible for landslides susceptibility mapping which incorporates procedures proposed by Pachauri and Pant, 1992; Anbalagan, 1992; Sarkar, et. al., 1995; Turrini and Visintainer, 1998; Guzzetti, et. al., 1999, and so forth. Mitigation of future landslide prone zones is of prime concern and through the present investigation endeavors are made to delineate the probable landslide zones in the study area. For this reason Landslide Hazard Zonation (LHZ) mapping utilizing incorporated Remote Sensing and GIS strategy has been completed in order to classify the land surface into zones of varying degree of hazard. Therefore, the landslide hazard zonation mapping generated through present investigation to the planners and engineers to know the potential zones which are vulnerable for landslide calamity and they may implement appropriate remedial measures for disaster risk reduction and management.

2. Objectives

The main objective of the present stud is to delineate the potential landslide hazard zones within the study area.

3. Study Area

The present study area has been selected in the north western part of Aizawl city with an intention to predict the probable landslide hazard zone along NH 54 which is the only one high way road connecting the capital city of Aizawl and Lengpui Airport. Geographically, the study area lies between longitudes 92°39'E - 92°42'E and latitudes 23°44'N - 23°48'N which falls in the pieces of Survey of India toposheet numbers 84A/9, 84A/10, covering an area of about 53.56 km^2.

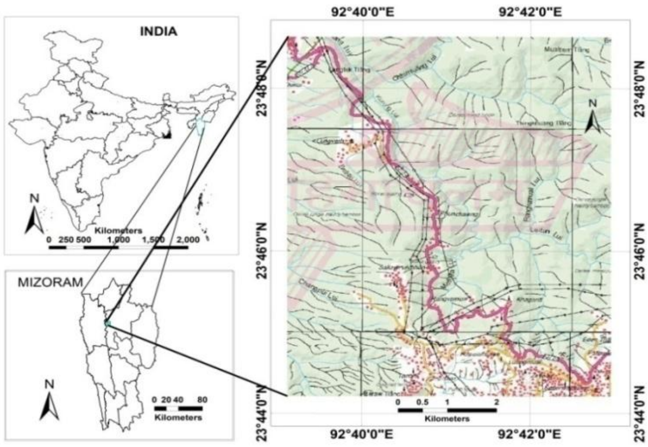
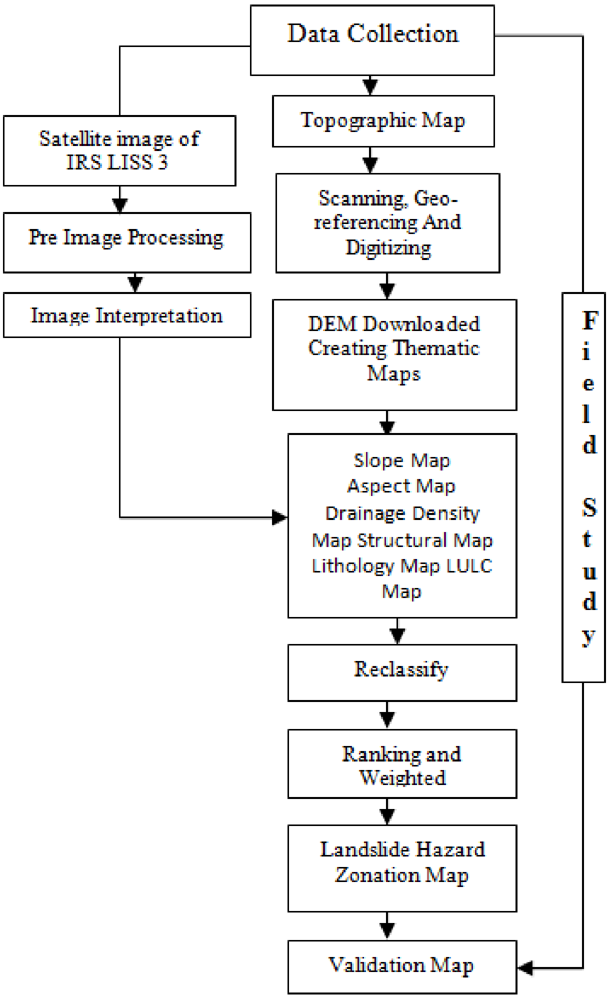


Figure 1. Location map of the study area.

4. Materials and Methods

The data that has been utilized for the present study incorporates satellite imagery of IRS LISS III acquired on 21st January, 2013 of 23.5 meters spatial resolution and CARTOSAT DEM of 30 meters resolution along with Survey of India (SoI) toposheets of 1:50,000 scale for inferring baseline data on different causative variable maps like slope, aspect, drainage density, structure, lithology and land use/land cover maps. These factor maps has been integrated in GIS environment using index overlay analysis that is combining layers of evidences in stages to generate the intermediate factor maps and then the final map. Assigned subjective weights to each class and also to each layer (Map Weight) of the evidences on a scale of 0-10 (Barman and Rao, 2019) as given in the table 7. ERDAS Imagine 9.2 and ArcGIS 10.3.1softwares has been used for image processing, lineament analysis and land use / land cover classification to get the final results.



The image processing is a significant technique in remote sensing and GIS for feature extraction from satellite data. Analysis of remote sensing imagery plays a significant role in mapping the sliding areas of a region to assess the impact associated with sliding. Generation of various thematic maps such as slope, aspect, drainage density, structure, lithology and land use/land cover has been prepared by using IRS LISS III satellite data, Cartosat Digital Elevation Model, topographic map on l : 50,000 scales and various other sources which are analyzed in the GIS environment. There are six thematic layers which are considered to be the causative factors for slope failure are discussed below.

4.1 Slope

Slope angle is an important causative factor for slope failure. Dai and Lee, (2002) revealed that landslides are maximum when the slant angle is between 35-40°. The slope in the study area have been divided into three broad classes of 0-18°, 18-30° and 30-55° named as Low angle, Moderate angle and High angle slopes, respectively. Generally, it is evident that higher the slope angle higher chances of slope failure (Sharma and Sanjeevi, 2015). The weightages are allocated as per steepness of the slope i.e. higher is the slope angle more weightage is assigned and lower weightage for gentler slope (Table 1 and Fig. 2).

In the study area, class one is the low angle slope of 0-18^0 which covers an area of 18.95 sq.km. The second class belongs to the moderate slope angle consists of 18^0 - 30^0 covers more than half of the area i.e. 27.36 sq.km. The last class is high angle slope belongs to the 30^0 - 55^0 which covers an area of 7.25 sq.km.

Table 1. Slope classification of the study area and its statistics.

Angle in Degree	Slope	Class	Class Weight	Area (km^2)	Area in %
0-18°	Low angle	1	0	18.95	35.38
18-30°	Moderate Angle	2	4	27.36	51.09
30-55°	High angle	3	8	7.25	13.53

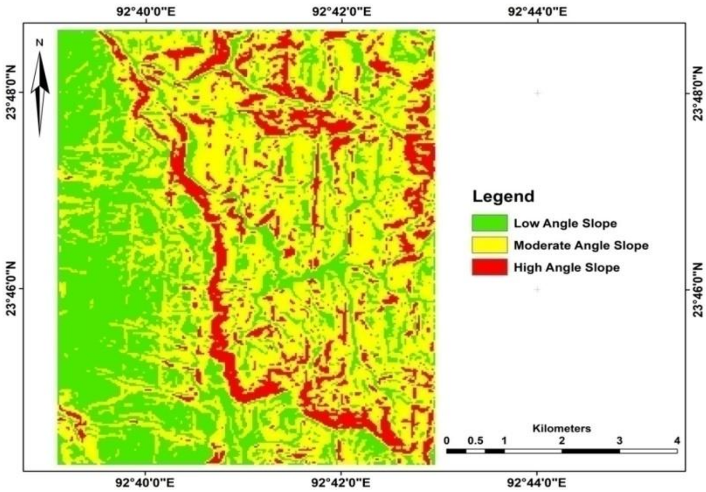


Figure 2. Slope map of the study area.

4.2 Structure

The structural map of the area has been prepared in GIS environment by merging lineament features interpreted from satellite imagery such as faults, channel networks and major roads (Fig. 3). Major road is also considered as linear feature because in hilly terrain streets are built along the inclines without considering the slope stability. These lineaments typically show textural, soil tonal, stream networks and vegetation as linear, curvilinear appearance in satellite imagery (Balachandar, et. al., 2010). It has been reported that fault structures and landslides show positive correlation between them as around 88 percent of the landslides were detected within 250 m distance from the major faults (Gokceoglu and Aksoyin, 1996).

The lineaments are the surface phenomena where weathering effect is faster as these areas are always exposed to climatic variations. Landslide event is commonly more in the regions where lineament density and linear intersections are more concentrated (Barman and Rao, 2019). Proximity analysis tool in Arc map has been used to buffer the structural parameters, buffering of 100 meters is considered as vulnerable zone along roads and stream networks and for the faults buffering of 200 meters is considered where chances of occurring landslide is more. However, higher weightage values are assigned to faults followed by roads and least value for streams (Table 2.)

Table 2. Buffer and class weight parameters

Structure	Buffer in meter	Class	Class Weight
Road	100	1	8
Stream	100	2	6
Fault	200	3	9

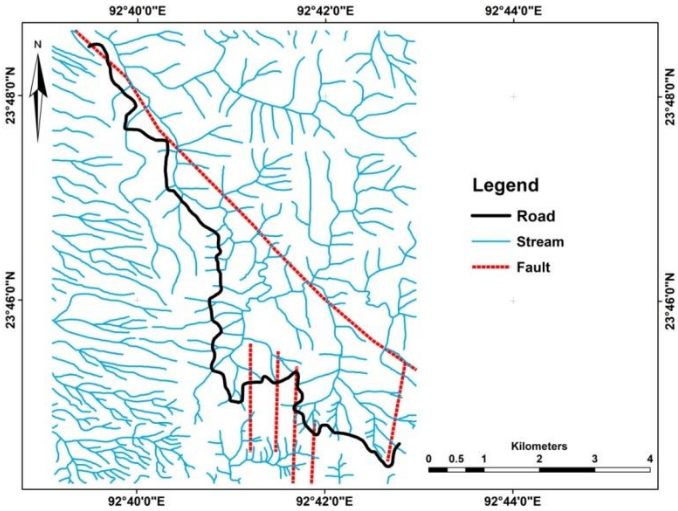


Figure 3. Structural map of the study area.

4.3 Land Use /Land Cover

Land Use/ Land Cover map is also an important criterion for landslide related study. *Vegetation* can provide a considerable contribution to the stability of slope through enhancing soil cohesion. It is thought that the fine *roots help* to keep the surface soil together and prevent surface erosion. The main effects of vegetation on slope stability are generally considered to be mechanical stabilisation due to the presence of roots (Nilaweera and Nutalaya, 1999). For the present study, land use map has been classified into four classes; these are thick forest, sparse vegetation, barren land and built up areas. The regions with denser vegetation are considered as less susceptible to land sliding as compare with less or no vegetation where susceptibility is more (Gokceoglu and Aksoy, 1996). Infrastructure developmental activities mainly constructions in the Himalayan regions have significantly increased the recurrence of landslides (Praveen, et. al., 2014). In this study, the built up and barren land areas are considered to be more susceptible to landslides. Onagh, et. al., (2012) revealed that land use is one of the key elements for the occurrence of landslides since slopes with barren are more prone to landslides. The weightages are assigned to different classes according to their severity which are shown in Table 3 and Figure 4.

Table 3. Land use land cover classification and its statistics.

Type	Class	Class Weight	Area (km^2)	Area %
Built-up area	1	8	5.60	10.456
Barren Land	2	7	3.10	5.788
Sparse Vegetation	3	6	17.56	32.786
Thick Forest	4	4	27.30	50.97

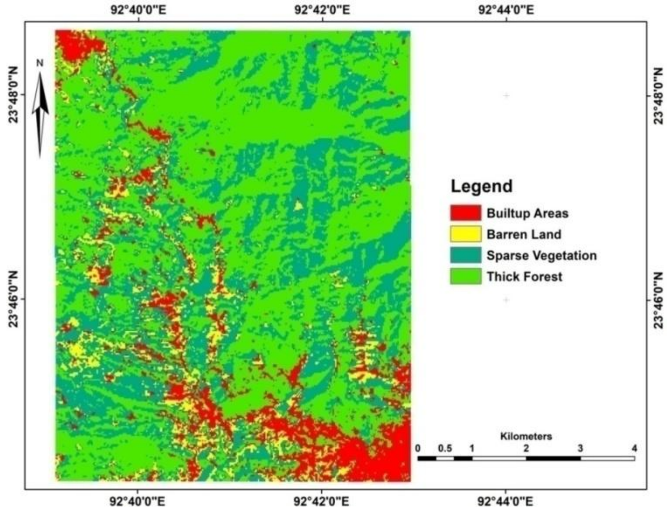


Figure 4. Land cover classification map of the study area.

4.4 Lithology

Lithological characteristics of the study area are categorized based on the classification proposed by Karunakaran, 1974 and Ganju, 1975, as middle Bhuban, upper Bhuban and Bokabil formations of Surma group (Fig. 5). The lithological composition of middle Bhuban formation is mainly argillaceous with shales and siltstones as the predominant rock type. It comprises of shale, siltstone, sandy shale and clayey groups with subordinate amount of sandstones. The upper Bhuban succession is essentially arenaceous part with sandstones, shales and siltstones as the prevailing rock type. The Bokabil formation includes shales with siltstones and sandstones. For the event of landslide, crumple and folded shale unit is the most vulnerable rock type, followed by shale-siltstone unit (Fig. 5). As per this, weightage values are assigned for each one of the rock types. The statistics of rock types is given in Table 4.

Table 4. The statistical information of different lithological units.

Formation	Class	Class Weight	Area (km^2)	Area in %
Upper Bbuban	1	7	39.81	74.33
Lower Bhuban	2	7	12.69	23.69
Bokabil	3	9	1.06	1.98

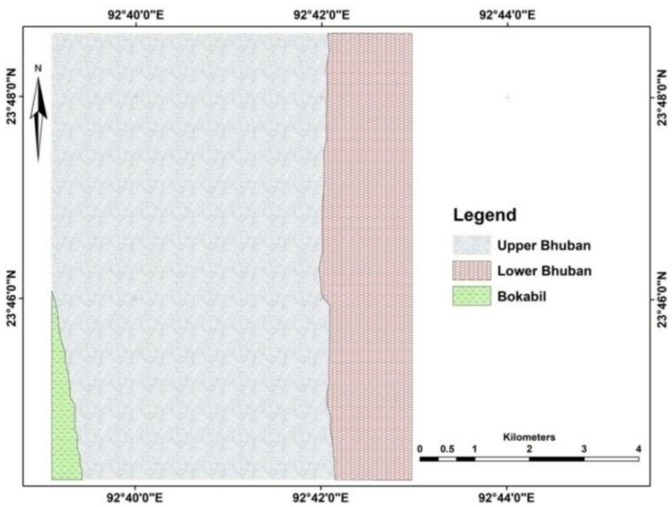


Figure 4.Lithology map of the study area.

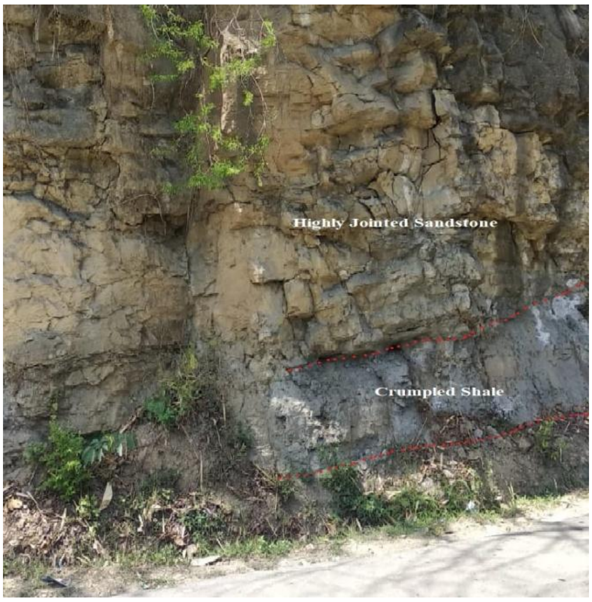


Figure 5. Field photograph showing crumpled shale and highly jointed sandstone along the road section.

4.5 Drainage Density

Drainage density is an important triggering factor for activating landslides. Areas of high drainage density indicate high moisture content which directly accelerate the weathering phenomena within that area and hence more vulnerable to landslides. Far from the drainages the landslide occurrences also decreases (Shiferaw, et. al., 2014). Accordingly high drainage density is assigned higher weightage compared to low drainage density (Table 5 and Fig. 6).

In the study area drainage density classes are demarcated as low and high and the weightages assigned as 6 and 8, respectively. The high drainage density class having an area of 31.85sq.km belongs to 59.47 percentage of the total area.

Table 5. The statistical information on drainage density in the study area.

Drainage Density	Class	Class Weight	Area (km^2).	Area in %
Low	1	6	21,71	41.53
High	2	8	31.85	59.47

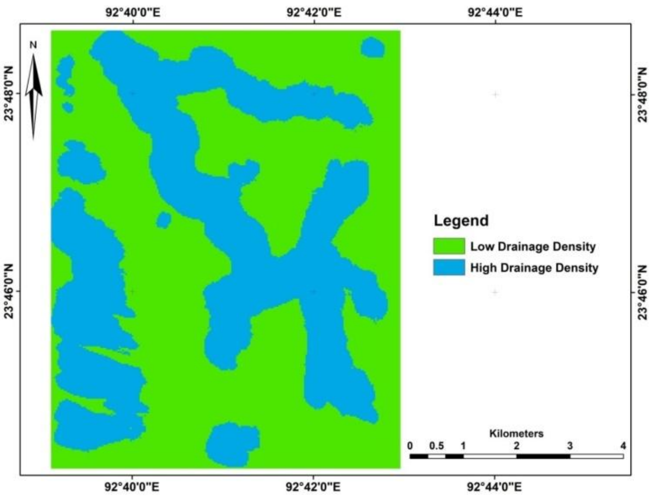


Figure 6. Drainage Density map of the study area.

4.6 Aspect

Aspect values indicate the direction of various slope faces with respect to north. In the present study, aspect map is generated from DEM and different ranks assigned to different directions. Dai and Lee, (2002) revealed that in north facing slopes, the landslide recurrence is moderately low, and it increases with the right orientation angle and reaches the maximum on south facing slopes. Due to higher amount of solar insulation in the south facing slopes, occurrence of landslide is also more in south facing aspect (Seshagiri, et. al., 1982). Accordingly values are incorporated in different aspect directions.

The entire study area has been demarcated ten classes based on the slope aspect (Fig. 7 and table 6). The first class of aspect is flat slope having the least area i.e. 0.25 sq.km. Further the slope aspect classes divided as North, NE, East, SE, South, SW, West and NE, the highest area occupied by the west slope aspect class having an area 11.39 sq.km followed by NW class.

Table 6. The calculated statistical information based on the aspect map of study area.

Aspect	Class	Class Score	Area (km^2)	Area %
Flat	1	0	0.25	0.47
North	2	3	3.32	6.2
North-East	3	4	5.50	10.27
East	4	5	4.68	8.74
South-East	5	6	3.06	5.71
South	6	7	2.92	5.45
South-West	7	6	7.65	14.28
West	8	5	11.39	21.27
North-West	9	4	11.04	20.61

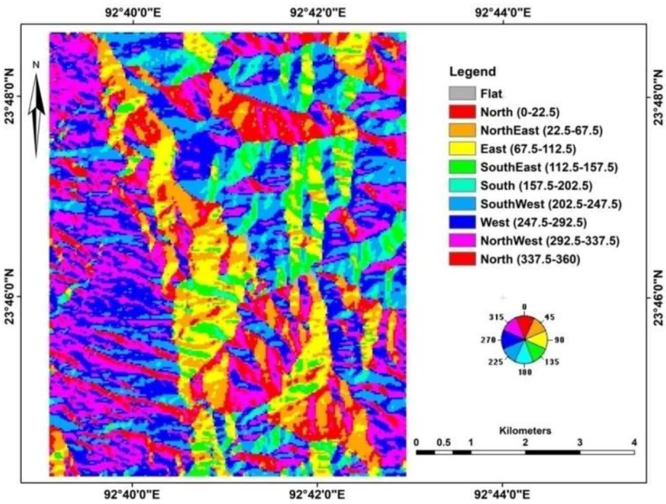


Figure 7. Aspect map of the study area

4.7 Landslide Hazard Index

Landslide hazard index (LHI) for each grid cell is determined in the attribute table as per the following formula proposed by Pandey, et. al., 2007.

$$LHI = \Sigma \text{ Class Score X Map weight}$$

Table 7. Ranks and weights of thematic layers

4.8 Landslide Hazard Zonation

All the thematic data layers has been integrated in GIS environment to find out the probable potential landslide prone zone map for the study area as Total Estimated Hazard (TEHD) value. These values ranges from 0-4 are categorized as Low Hazard Zones, 4-6.5 are categorized as Medium Hazard Zones and values ranges from 6.5-8.05 are categorized as High Hazard Zones. These TEHD values demonstrate the net likelihood of landslide event at those specific locations (Fig. 8 and Table 7).

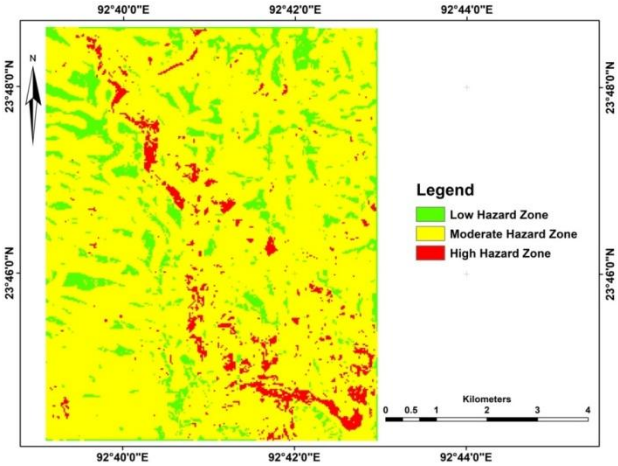


Figure 8. Landslide susceptibility map of the study area.

Table 7. Distribution of Landslide Hazard Zones in the study area.

Class	TEHD	Area (km^2)	Area in %
Low Hazard Zones	0-4	5.8	10.83
Medium Hazard Zones	4-6.5	45.44	84.84
High Hazard Zones	6.5-8.05	2.32	4.33

5. Validation

For validation of the prepared map, the active land sliding location data collected from the field has been superimposed in the present map and it has found that the active sliding zones are falling exactly on top of the High Hazard Zones (Figure 9).

Layers	Map Weight	Class	Class Score	LHI = ∑ Class Score X Map Weight
Slope	9	1	0	0
		2	4	36
		3	8	72
Structure	8	1	8	64
		2	6	48
		3	9	72
Land use & Land Cover	7	1	8	56
		2	7	49
		3	6	42
		4	4	28
Lithology	6	1	7	42
		2	7	42
		3	9	54
Drainage Density	5	1	6	30
		2	8	40
Aspect	4	1	0	0
		2	3	12
		3	4	16
		4	5	20
		5	6	24
		6	7	28
		7	6	24
		8	5	20
		9	4	16
		10	3	12

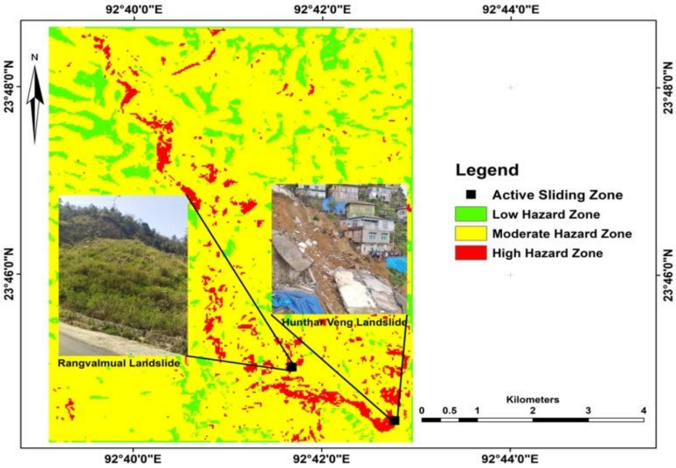


Figure 9. Validated map of the study area with active land slide zones

6. Conclusions

Based on the field observations and evaluating the different causative factors inferred that this model is perfectly predicting the probable potential landslide zones within the study area. The drainage density classes are demarcated as low and high and the class weight assigned as 6 and 8, respectively. The high drainage density class having an area of 31.85sq.km belongs to 59.47 percentage of the total area.

The entire study area has been demarcated ten classes based on the slope aspect. The first class of aspect is flat slope having the least area of 0.25 sq.km. Further, the slope aspect classes divided as North, NE, East, SE, South, SW, West and NE, the highest area occupied by the west slope aspect class having an area 11.39 sq.km followed by NW class

Thus, the landslide hazard zonation mapping produced through present study will be useful to the planners and engineers to know the zones which are prone for landslide disaster and they may plan suitable remedial measures for disaster risk reduction and management.

In terms of severity, the study reveals that 4.33 per cent of the study area is highly vulnerable to landslides 84.84 percent classified as medium/moderate hazard zone and 10.83 percent under low hazard zone.

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