# Landslide Susceptible Zone Mapping Using ARS and GIS Techniques in Selected Taluks of Kottayam District, Kerala, India



Ajin R S
University of Madras



Ana-Maria Loghin
Gheorghe Asachi Technical University of Iasi



Vinod P G
GeoVin Solutions (P) Ltd.

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# Landslide Susceptible Zone Mapping Using ARS and GIS Techniques in Selected Taluks of Kottayam District, Kerala, India

R. S. Ajin[1], Ana-Maria Loghin[2], P. G. Vinod[1], Mathew K. Jacob[3] & R. R. Krishnamurthy[4]

**Abstract**

A landslide is a geological phenomenon that describes a wide variety of ground movement processes, like rock falls or debris flows. Landslides, also known as landslips, slumps, or slope failures are the most common geo-hazards occurring in highland regions, especially mountainous regions. This phenomenon can be caused by natural factors or by human activities, resulting in environmental degradation, damage to buildings, roads, railways, pipelines, communication networks, and agricultural land. The present study area, Meenachil and Kanjirapally taluks in Kottayam district is prone to landslides, and have been severely affected by landslides during the past several years. In this study, an attempt has been made to prepare the landslide susceptible zone map based on Applied Remote Sensing (ARS) and Geographic Information System (GIS) techniques. In the present study, only eight influencing factors are selected viz. slope, elevation, soil, lithology, drainage density, land use/land cover, road density, and lineament density. In order to prepare the landslide susceptible zone map of Meenachil and Kanjirapally taluks, an Index or heuristic method is used. The prepared map shows the areas affected by landslides, as very low, low, moderate, high, and very high susceptible zones. The susceptible zone map is validated using the landslide incidence points of the study area. The landslide susceptible zone map is of great benefit for the geoscientists, engineers and experts in planning and development.



**Keywords**: *Landslide, geo-hazards, incidence points, susceptible zones.*

## 1. Introduction

Landslide is the movement of a mass of rock, debris, or earth down a slope, under the influence of gravity (Cruden and Varnes, 1996). This natural geological phenomenon is also known by the names 'slope failure' and 'mass wasting'. Slope failures involve flowing, sliding, toppling, or falling movements, and most of the landslides exhibit a combination of these movements

[1] Geomatics Division, GeoVin Solutions Pvt. Ltd., Thiruvananthapuram-695010, Kerala, India. Email: ajinares@gmail.com (Corresponding author)
[2] Faculty of Hydrotechnical Engineering, Geodesy and Environmental Engineering, Gheorghe Asachi Technical University of Iasi, Romania.
[3] Post Graduate Department of Geology, Sree Narayana College, Sivagiri, Kerala, India.
[4] Department of Applied Geology and Centre for Environmental Sciences, University of Madras, Chennai, India

(Varnes, 1978). Landslides become a major threat due to human activities, because the frequency and the intensity of slope failures increase due to activities like deforestation, change in underground and surface water movement pattern and unscientific developmental activities. In terms of frequency of occurrence or extent of damage caused, landslides may not be as devastating as earthquakes, major floods, forest fires, and cyclones. However landslides, depending on its intensity can cause significant loss of property and infrastructure besides loss of life. Landslides can be induced by rainfall as well as earthquakes. In India, landslides pose serious threat especially along the slopes of the Western Ghats, Himalayan foothills and Northeast hill terrains, during peak monsoon rainy seasons. The highland regions of Kerala representing the westward slope of the Western Ghats also experience different types of landslides. The landslide in this region is the result of heavy rainfall in unstable hill slopes.

In recent years, the assessment of landslide hazard and risk has become an important subject of interest for geoscientists, engineers, and also for the community and local administration in many places in the world. Considerable research works have been done and are in progress on the subject of landslide hazards and their impacts. In the studies involving landslide hazard evaluation, many researchers have used Remote Sensing and GIS techniques to demarcate the landslide hazard or susceptible zones (Gupta and Joshi, 1990; Dai et al., 2001; Cevik and Topal, 2003; Lan et al., 2004; Tangestani, 2004; Ayalew and Yamagishi, 2005; Akgun and Bulut, 2007; Pantha et al., 2008; Yalcin, 2008; Shafri et al., 2010; Eshghabad et al., 2012; Onagh et al., 2012; Pareta et al., 2012; Quan and Lee, 2012; Chingkhei et al., 2013; Feizizadeh et al, 2013; Ajin et al., 2014; Chalkias et al., 2014; Kavzoglu et al., 2014). Dutta and Sarma (2013) prepared landslide susceptibility map of Kalapahar hill, Guwahati (India) using GIS based heuristic method. Factors such as slope, elevation, lithology, land use/land cover, and distance to road were selected. Lallianthanga and Laltanpuia (2013) prepared landslide hazard zone map of Lunglei town, Mizoram (India) using geospatial tools and the heuristic method. In the modelling process, factors viz. lithology, geological structures, slope morphometry, geomorphology, and land use/land cover were selected.

The objective of this study is to demarcate the landslide susceptible zones in Meenachil and Kanjirapally taluks in Kerala using ARS and GIS techniques. In order to prepare the landslide susceptible zone map of the study area, with the demarcation of different susceptible zones, a Landslide Susceptibility Index (LSI) method is used. In this study, eight geo-environmental factors, viz. slope, elevation, soil, lithology, drainage density, land use/land cover, road density, and lineament density are selected.

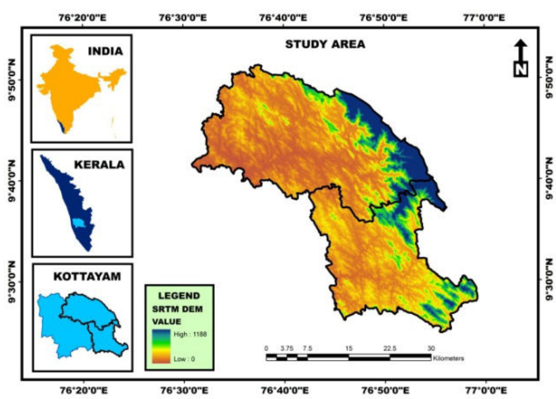


**Figure 1:** Study area map.

### 1.1. Study Area

The present study area, Meenachil and Kanjirapally taluks is located between 9°20′0″ and 9°55′0″ N latitudes and 76°30′0″ and

77°0′0″ E longitudes. With a total area of 1113.6 sq. km, this region is bordered by Vaikom, Kottayam, and Changanasserry taluks of Kottayam district to the west, Pathanamthitta district to the south, Idukki district to the east, and Ernakulam and Idukki districts to the north. The study area map, with the Meenachil taluk located in the north and the Kanjirapally taluk in the south is shown in Figure 1.

## 2. Materials and Methods

The study area falls over the Survey of India (SOI) toposheet nos: 58 C/9, 58 C/10, 58 C/11, 58 C/13, 58 C/14 and 58 C/15 of 1:50,000 scale. The thematic maps required for this study were prepared using ArcGIS 9.3 and ERDAS IMAGINE 9.2 software. The land use/land cover map was prepared from the IRS-P6 LISS-IV image of 5.8 m resolution. The supervised classification of the pre-processed LISS-IV image was carried out using ERDAS IMAGINE software tools. The drainage and road networks were digitized from the SOI toposheets and zones of lineament were digitized from the Geological Survey of India (GSI) Geological and Mineral map of Kerala at 1:500,000 scale. Google Earth was used to update the road networks in the study area. The drainage density, road density and lineament density maps were prepared from the digitized data using ArcGIS spatial analyst tools. The lithology map was also prepared from the GSI Geological and Mineral map. The soil map was prepared by digitizing NBSS&LUP (National Bureau of Soil Survey and Land use Planning) soil map of 1:250,000 scale. The contour data was derived from the SRTM DEM of 30 m resolution. ArcGIS spatial analyst and 3D analyst tools were used to prepare the slope and elevation maps, from the 20 m interval contour data. These thematic map layers were reclassified using the Natural breaks (Jenks) method. In order to prepare the susceptible zone map of the study area, a LSI method was used. To each class of the selected factors, there were assigned different ranks and also, weights were assigned to each factor according to its influence on landslide occurrence. The index was derived from the weight and rank (Index = Weight x Rank) and is shown in Table 1. The Landslide Susceptible Zone (LSZ) map was prepared by overlaying all the index map layers using ArcGIS tools. Finally, the susceptible zone map was validated using the landslide incidence points collected during the field survey.

Table 1: Rank, Weight, and Index assigned for different factors

| Sl. No. | Factor | Class | Rank | Wei-ght | Index |
|---|---|---|---|---|---|
| 1 | Slope (degree) | 0 – 3.69 | 1 | 20 | 20 |
| | | 3.69 – 8.40 | 2 | | 40 |
| | | 8.40 – 14.95 | 3 | | 60 |
| | | 14.95 – 22.85 | 4 | | 80 |
| | | 22.85 – 42.85 | 5 | | 100 |
| 2 | Elevation (m) | 0 – 96.76 | 1 | 16 | 16 |
| | | 96.76 – 223.02 | 2 | | 32 |
| | | 223.02 – 435.76 | 3 | | 48 |
| | | 435.76 – 726.51 | 4 | | 64 |
| | | 726.51 – 1180 | 5 | | 80 |
| 3 | Soil (depth) | Deep | 1 | 15 | 15 |
| | | Very deep | 2 | | 30 |
| 4 | Lithology | Acidic rocks | 1 | 14 | 14 |
| | | Basic rocks | 2 | | 28 |
| | | Migmatites | 3 | | 42 |
| | | Charnockites | 4 | | 56 |
| | | Khondalites | 5 | | 70 |

| | | | | | |
|---|---|---|---|---|---|
| 5 | Drainage density (km/ sq.km) | 0.21 – 1.53 | 1 | 12 | 12 |
| | | 1.53 – 2.13 | 2 | | 24 |
| | | 2.13 – 2.63 | 3 | | 36 |
| | | 2.63 – 3.17 | 4 | | 48 |
| | | 3.17 – 4.26 | 5 | | 60 |
| 6 | Land Use/Land Cover | Built-up area | 5 | 10 | 50 |
| | | Agricultural land | 4 | | 40 |
| | | Mixed vegetation | 3 | | 30 |
| | | Plantation | 2 | | 20 |
| | | Water body | 1 | | 10 |
| 7 | Road density (km/ sq.km) | 0 – 0.24 | 1 | 8 | 8 |
| | | 0.24 – 0.69 | 2 | | 16 |
| | | 0.69 – 1.13 | 3 | | 24 |
| | | 1.13 – 1.70 | 4 | | 32 |
| | | 1.70 – 2.92 | 5 | | 40 |
| 8 | Lineament density (km/ sq.km) | 0 – 0.07 | 1 | 5 | 5 |
| | | 0.07 – 0.20 | 2 | | 10 |
| | | 0.20 – 0.33 | 3 | | 15 |
| | | 0.33 – 0.53 | 4 | | 20 |
| | | 0.53 – 1.21 | 5 | | 25 |

Table 2: Area and Percentage of Landslide susceptible zones.

| Susceptible Zones | Area (Sq. Km) | Percentage of Area |
|---|---|---|
| Very Low | 265.48 | 23.84 |
| Low | 389.54 | 34.98 |
| Moderate | 239.42 | 21.50 |
| High | 140.65 | 12.63 |
| Very High | 78.51 | 7.05 |
| | Total=1113.6 | Total = 100 |

## 3. Results and Discussion

### 3.1. Slope

Slope is the most substantial natural factor triggering landslides. Expressed as a percentage or degree, this factor is directly proportional with the possibility of landslide occurrence. Thus, as the value of slope increases the likelihood of a landslide increases. This fact does not mean that gentler slopes are not prone to landslide. The influence of other factors can make even a gentle slope to be vulnerable to landslide. The slope of this study area is grouped into five classes viz., 0 – 3.69°, 3.69 – 8.40°, 8.40 – 14.95°, 14.95 – 22.85°, and 22.85 – 42.85°. The highest slopes are mostly confined to the east, northeast and southeast parts of the study area. The slope map is shown in Figure 2.

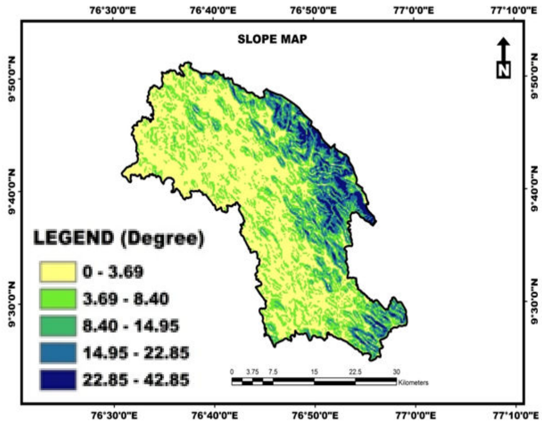


**Figure 2**: Slope map.

### 3.2. Elevation

Another important natural factor that causes the sliding of rocks or debris is the elevation of the area. This factor influences the landslide occurrence in a directly proportional manner: as the relative elevation of the area increases, the likelihood of a landslide increases. Thus, in areas with a higher elevation, there is a greater possibility of landslide occurrence, than in the lower ones. In areas of lower elevation, the frequency of landslides is low because the terrain itself is gentle, and is covered with thick colluviums or/and residual soils, and a higher water table will be required to initiate slope failure (Dai and Lee, 2002). The elevation of the area is grouped into five different classes viz., 0 – 96.76 m, 96.76 – 223.02 m, 223.02 – 435.76 m, 435.76 – 726.51 m, and 726.51 – 1180 m. The highest elevation areas are mainly seen towards the north and northeast parts. The elevation map is represented in Figure 3.

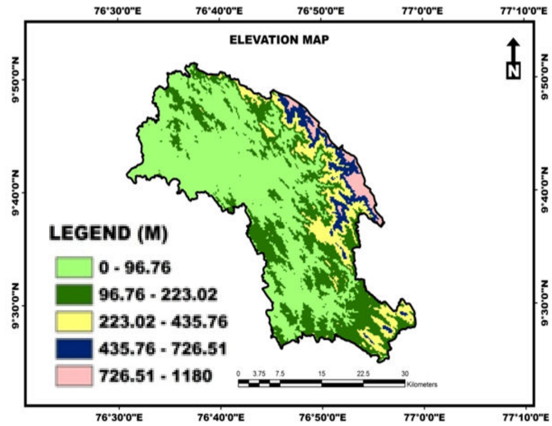


**Figure 3:** Elevation map.

### 3.3. Soil (depth)

The thickness of soil column is very sensitive and significant. The shear strength of the soil column due to downward gravity pull is critically important. Infiltrated pore water pressure when increased reduces the shear strength of the soil. Reduction in shear strength is a factor causing landslides. Increase in pore water pressure is caused directly by the percolating rain water and indirectly due to accumulation of water at depths due to soil permeability. The study area is composed of deep and very deep soils. The areas with very deep soil are more prone to landslides. The soil map is shown in Figure 4.

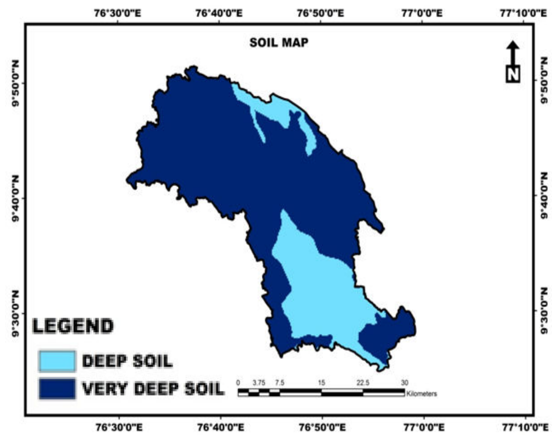


**Figure 4:** Soil map.

### 3.4. Lithology

Lithology influences landslide occurrence in several ways. Landslide occurs mainly in loose and poorly consolidated slope overlying the bedrocks. Weak, incompetent rock is more likely to fall than strong, competent rock. Generally rocks are more stable than the unconsolidated materials. The natural strength of rock is affected by several factors, including the genetic type of rock, the presence and nature of discontinuities like joints or other fractures, and the extent of weathering. These factors are critical for the rock strength. The more the discontinuities present in a rock type, the greater is the likelihood of rock instability. The igneous and metamorphic rocks are generally hard and massive, showing a greater resistance to erosion. On the contrary, sedimentary rocks are vulnerable to erosion and promote instability. The rock types present in this study area are acidic rocks, basic rocks, migmatites, khondalites, and charnockites. In this area, all the insitu rock types are stable and competent. The lithology map is shown in Figure 5.

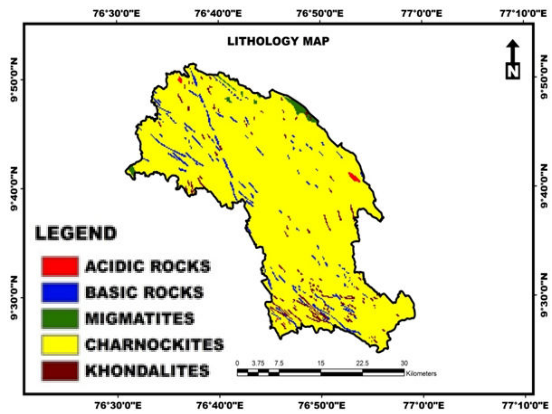


**Figure 5**: Lithology map.

### 3.5. Drainage density

Drainage density has a significant influence on landslide occurrence. Proximity to hydrological features such as streams or rivers can decrease slope stability. The stability of slopes may be adversely affected by streams due to erosion and undercutting at the foot of slopes. In this way, slopes become more susceptible to landslides, during periods of high precipitation or they can cause catastrophic failure along joints, bedding, and exfoliation plains. The drainage density of this area is grouped into five different classes, viz., 0.21 – 1.53 km/sq. km, 1.53 – 2.13 km/sq. km, 2.13 – 2.63 km/sq. km, 2.63 – 3.17 km/sq. km, and 3.17 – 4.26 km/sq. km. The drainage density map is shown in Figure 6.

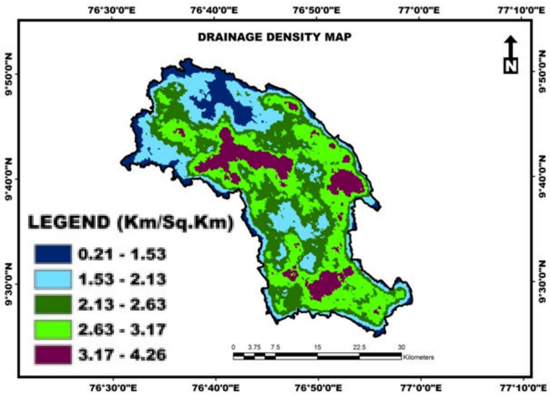


**Figure 6**: Drainage density map.

### 3.6. Land Use/Land Cover

Land cover is also one of the key factors responsible for the incidence of landslides. The areas with sparse vegetation are more prone to erosion and instability. In contrast, the densely vegetated areas are less prone, being more stable. Land cover pattern controls the action of climatic factor like rain, affecting the rate of erosion. If proper slope management techniques are adopted in the land use patterns, excess soil erosion can be prevented. Land use exerts a significant influence upon slope behaviour. Land use and the pattern of cultivation significantly affect the rate of infiltration of surface water during rainy season. Rate of infiltration of water is more when the top soil is loosened during cultivation. Natural barren (uncultivated) soil cover does not permit so much of infiltration. Chances of a landslide depend on the amount of water infiltrated in geomorphologically unstable slopes with loose soils and rocks. The land use/land cover types in this area are water body, plantation, mixed vegetation, agricultural land, and built-up area. In the study area, built-up area and agricultural land are more prone to landslides. The land use/land cover map is shown in Figure 7.

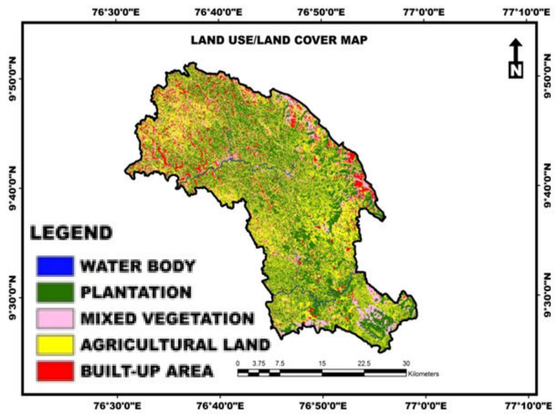


**Figure 7**: Land Use/Land Cover map.

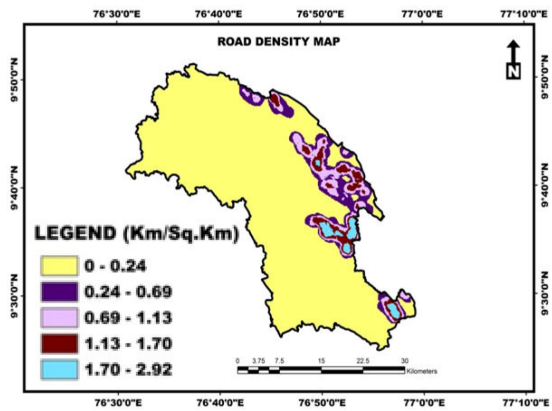


**Figure 8:** Road density map.

### 3.7. Road density

High elevation and sloppy terrains with high road density are more prone to landslides, as these areas are geomorphologically unstable. The removal of material from the lower portion of the slopes during road construction and widening of the roads can cause destabilization. In this study, the roads in the higher slopes only are selected, as those areas are more prone to slope failures.

The road density of this area is grouped into five classes, viz., 0 – 0.24 km/sq. km, 0.24 – 0.69 km/sq. km, 0.69 – 1.13 km/sq. km, 1.13 – 1.70 km/sq. km, and 1.70 – 2.92 km/sq. km. The road density map is shown in Figure 8.

### 3.8. Lineament density

The area with high lineament density is more prone to landslides. Lineament zones are generally tectonically potential segments of relative crustal movement. Hence release of fault or shear movements can result in landslides, especially in high slope areas. The faults, fractures and joints not only tend to destabilize the area through deterioration of the strength of the rocks, but also accelerate the weathering process (Mathew et al., 2007). The lineament density of this area is grouped into five classes viz., 0 – 0.07 km/sq. km, 0.07 – 0.20 km/sq. km, 0.20 – 0.33 km/sq. km, 0.33 – 0.53 km/sq. km, and 0.53 – 1.21 km/sq. km. The lineament density map is shown in Figure 9.

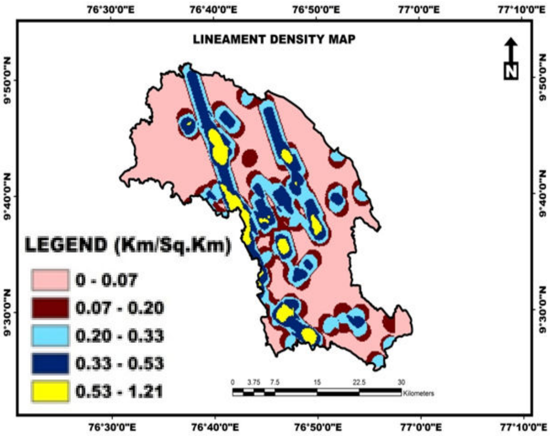


**Figure 9**: Lineament density map.

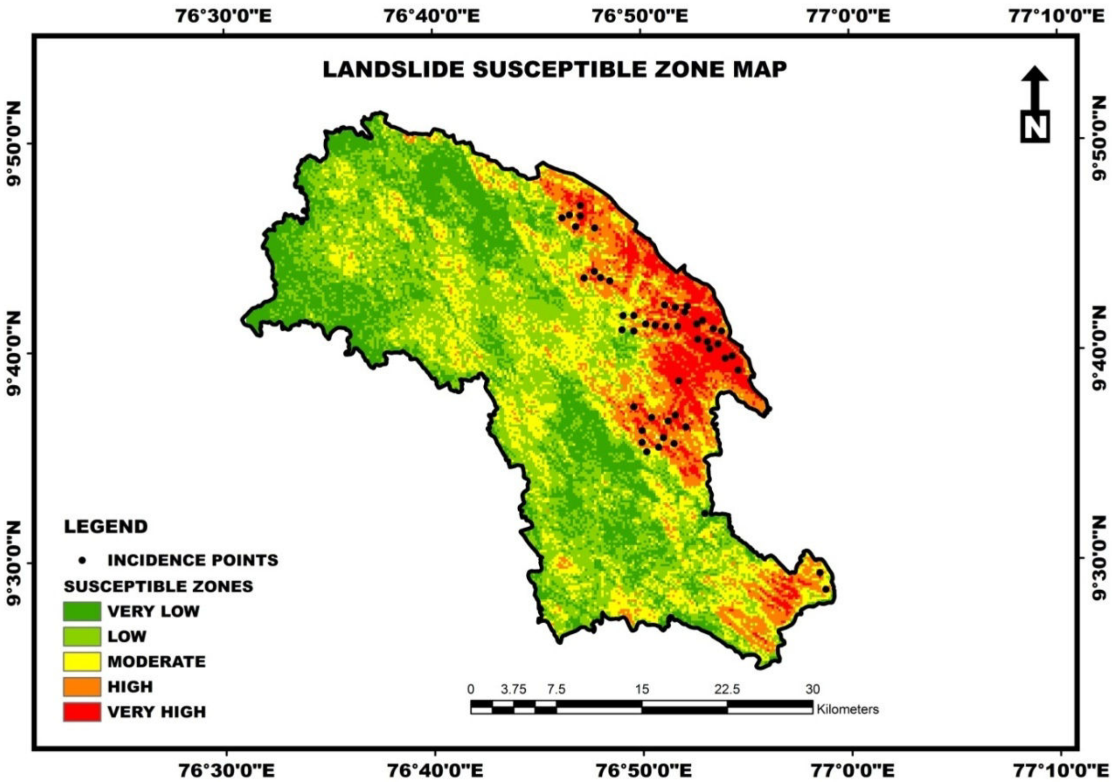


**Figure 10**: Landslide susceptible zone map.

### 3.9. Landslide Susceptible Zones

The LSZ map of the study area is prepared by taking into account eight important factors such as slope, elevation, soil, lithology, drainage density, land use/land cover, road density, and lineament density. The susceptible zone map is prepared by overlaying the index map layers of these factors using GIS tools. The area of the prepared map is grouped into five different susceptible zones viz. very low, low, moderate, high, and very high. In order to validate the results, the incidence points are overlaid on the landslide susceptible zones. In the study area, a total of 48 landslide incidences were recorded during the field survey. Out of the 48 landslide incidence points, 45 (93.75%) incidence points fall spatially over the high and very high susceptible zones. This shows the reliability of the methodology. The area and percentage of landslide susceptible zones is calculated and is shown in Table 2. The high and very high susceptible zones together constitute 19.68% (219.16 sq. km) of the study area. The study shows that slope, elevation, drainage density, road density and land use/land cover are the most influencing factors. The landslides are more frequent in areas with higher slopes and elevation; this is because of its direct relationship with the stability of a terrain. The areas with high drainage density are more prone to landslides; this is due to the erosional activities of streams. A significant number of landslides occurred in the road cuttings due to the instability created as a result of road widening and construction. Majority of the slope failures have occurred in built-up areas followed by agricultural land. The LSZ map is shown in Figure 10.

## 4. Conclusion

In many countries, the economic losses due to landslides are greater than those generated by any other natural disasters. RS and GIS are effective techniques used for the demarcation of landslide hazard or susceptible zones. India, due to its unique climatic conditions, and geotectonically and geodynamically active areas, has always been vulnerable to a large number of natural disasters, including landslides. Thus a proper management of landslide hazard is required. It is necessary to develop new methodologies which are more suitable to mitigate effectively the hazards related to landslides based on latest developments in geospatial technology. In the present study using ARS and GIS techniques, the area has been demarcated into five landslide susceptible zones, ranging from 'very low' to 'very high'. From this study, it is clear that slope, and elevation are the most important landslide causative factors, followed by drainage density, road density and land use/land cover. Therefore we can conclude that the landslides are caused by the combined action of natural and anthropogenic factors. The prepared susceptible zone map is validated and found that more than 90% of the failures have taken place in the high and very high susceptible zones; hence the methodology is reliable and can be used in other areas also. The LSZ map offers a significant help for geoscientists and engineers in the process of adopting appropriate mitigation measures in landslide prone areas. The prepared map could be of very useful to planners and developers for choosing suitable sites for future land use planning and developments, and also to locate constructions in the unstable zones.

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