Hazard Mapping of Landslide Vulnerable Zones in a Rainfed Region of Southern Peninsular India- A Geospatial Perspective

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Abstract - *Western Ghats of southern peninsular India with its high mountain forest ecosystem possess a rich biodiversity. They influence the Indian monsoon weather patterns and are recognized to be prone to frequent landslides. The present work is carried out in parts of Western Ghats, a rainfed region of southern peninsular India covering a geographical extent of 2131 Sq. Km. A weight index strategy is applied along with remote sensing and GIS for mapping landslide vulnerable zones. The factors such as slope, elevation, rainfall density, soil, land use land cover, geology, drainage density, road density and lineament density are selected to estimate the proneness of the landslides. Appropriate weights are assigned to these factors, overlayed and finally landslide vulnerable zone map is prepared using geographical information system (GIS). The landslide vulnerable zones are classified into five: stable zone (0.24%), moderately stable zone (70.8%), moderately unstable zone (28.48%), highly unstable zone (0.5%) and critical zone (0%). The results reveal that the predicted zones are in good agreement with the past landslide occurrences and hence can help in carrying out the risk assessment and better preparedness against the future landslide hazards.*

***Key Words*: Remote Sensing and GIS, Landslides, Thematic Maps, Weighted Overlay Analysis, Hazard mapping.**

1. Introduction

The geological phenomena, landslides are often catastrophic and well visible aftermath such as mass movements are widely recognized even by the non-geologists. These downward movements carry the rock, debris or earth down a slope. They result from the failure of the materials which make up the hill slope and are driven by the force of gravity. Although the action of gravity is the primary driving force for a landslide to occur, there are other contributing factors affecting the original slope stability. Pre-conditional factors build up specific sub-surface conditions that make the area/slope prone to failure, whereas the actual landslide often triggers before being released [1]. As remote sensing and GIS are widely used in spatial data analysis, the landslide vulnerable zones can be mapped and the probability of occurrence of landslide throughout an area can be estimated.

The qualitative and quantitative natures of landslides are studied using Remote Sensing and GIS and also by applying several statistical and computational models. A study by *Saha et al.* [2], used the methods information value (InfoVal) and landslide nominal susceptibility factor (LNSF) in mapping the statistical landslide susceptibility zonation. The comparison came with the output that most realistic map belong to LNSF method appears to conform the heterogeneity of the terrain. Another study by *Mathew et al.* [3], on landslide in Garhwal region of Himalayan was based on binary logistic regression (BLR) analysis and receiver operating curve method and it showed the accuracy of 91.7% over receiver operating curve method. Another research by *Antherjanam et al.* [4], incorporated geotechnical properties of soil as a factor and applied in stability index mapping (SINMAP). This was used to develop a regression model using support vector machine (SVM). The studies by *Vijith et al,* [5] [6], on landslides used the area under curve method (AUC) with a success rate of 84.46%. Another study by *Vijith and Madhu* [7] used bivariate statistical (BS) method known as weights of evidence modeling to estimate the potential landslide sites in the Western Ghats region. The BS model showed the accuracy of 89.2%.

In the present study, we use spatial analysis using remote sensing and GIS which serves as the best tool for mapping, monitoring and analysis with reasonable accuracy than that of extensive time requirement for field investigation and monitoring of landslide vulnerable zones. Products like digital elevation model (DEM) along with satellite imageries can be used together to generate surface features, geometry and physical conditions like slope, elevation...etc. The numerical weighting of these layer features are done in mapping the landslide vulnerable zones.

Western Ghats is one of the most important orographic features of the Indian peninsula fringing the west coast from Tapti estuary in the north to Cape-Comorin in the south. Our study area Wayanad (Fig. 1), a rainfed region of Kerala is prone to frequent landslides in the past. Several mass movements have been recorded in the Western Ghats region of Kerala [1], [6], [8], [9], [10], [11]. The rainfall over higher altitudes is considered as the triggering mechanism for the landslide activities [1]. These intense rainfalls in the steep slope region will cause heavy landmass movement. Thus the study in zonation of landslide regions has its importance.

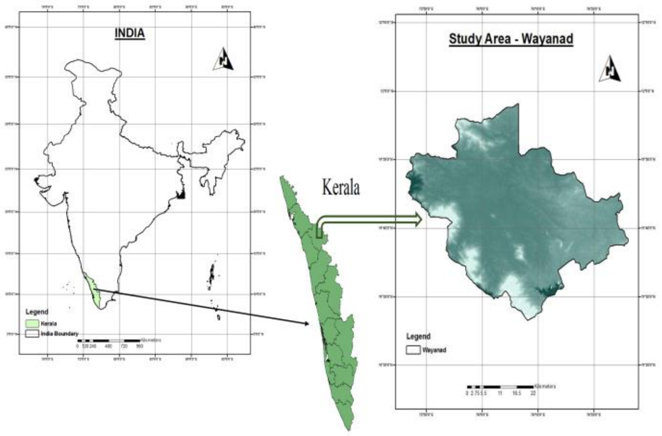

Fig - 1: Location Map of the Study Area.

2. Study Area

The study area Wayanad lies between latitude 11^{0}30’ N to 12^{0}3’ N and longitude of 76^{0}30’ E to 75^{0}39’ E with a geographical extent of 2131 Sq. Km. The area is rich with water resources. One of the major rivers is Kabani, a tributary of river Cauvery. Kabani has many tributaries including Thirunelli River, Panamaram River and Mananthavady River. All these rivulets help in forming a distinct landscape for the region. The important tourist spots are Kuruva Island with its naturally purified water resource, Chembra Peak with 2050m above mean sea level (MSL), Muthanga wildlife sanctuary, Tholpetty wildlife sanctuary, Pookode lake, Soochipara falls, Meenmutty falls..etc. The region has a salubrious climate with average rainfall of 3000mm. per year. However a decreasing trend in rainfall is seen in the area [12] over the last 100years. The maximum and minimum temperature for the last 5 years was 29^{o}C and 18^{o}C respectively. The study area has experienced several major and minor landslides before. The landslide of 2009 was reported with incidence of 14 mass movements with rainfall as a triggering factor.

3. Methodology

The spatial datasets used for the study are satellite imagery, open street map dataset, rainfall data from the Indian Meteorological Department, topographic sheets from Survey of India and the tools used for this study are digital elevation model (DEM) and ISRO Bhuvan web map services. The datasets thus obtained are used in the processing of the landslide hazard zonation map (Chart 1).

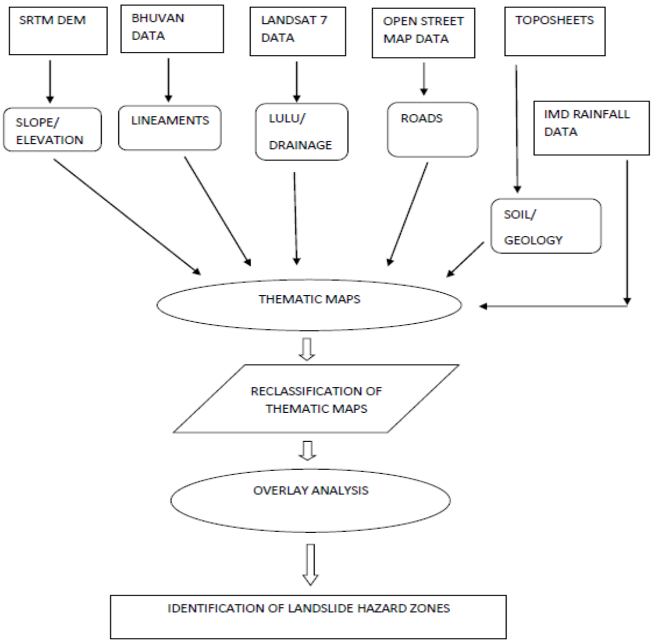

Chart - 1: Flowchart of the steps involved in the present study.

3.1. Data Preparation

a) Landsat 7 Dataset

The dataset of Landsat 7 is collected from the earth explorer.

Land Use Land Cover (LULC) is one of the important factors in mapping the landslide vulnerable zones. 19 land use land cover classes are identified from the Landsat 7 datasets and are retrieved by manual digitization (Fig. 2).

Drainage Density is the total length of stream lines per unit area. In this study, drainage dataset is retrieved from Landsat 7. Drainage density (Fig. 3) is processed using ArcGIS and classified into five classes with very low (<0.02 Km/Sq. Km.), low (0.02 – 0.04 Km/Sq. Km), moderate (0.04 –

0.07 Km/Sq. Km), high (0.07 – 0.15 Km/Sq. Km), Very high (0.15 – 0.3 Km/Sq. Km).

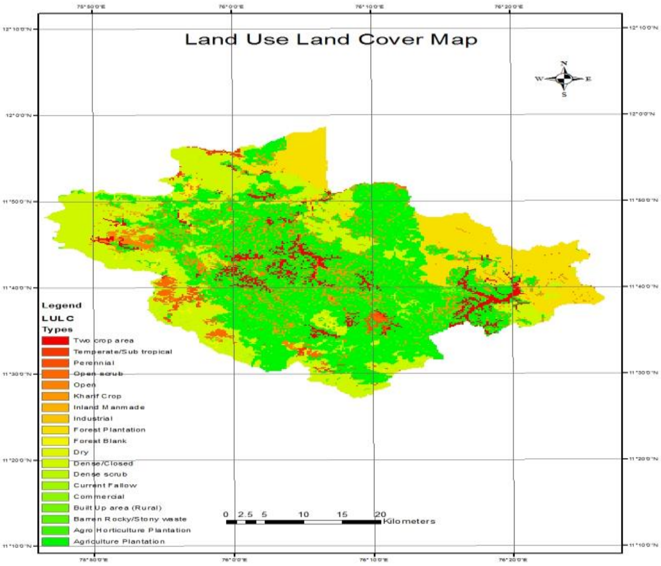

Fig – 2: Land Use Land Cover map of the study area.

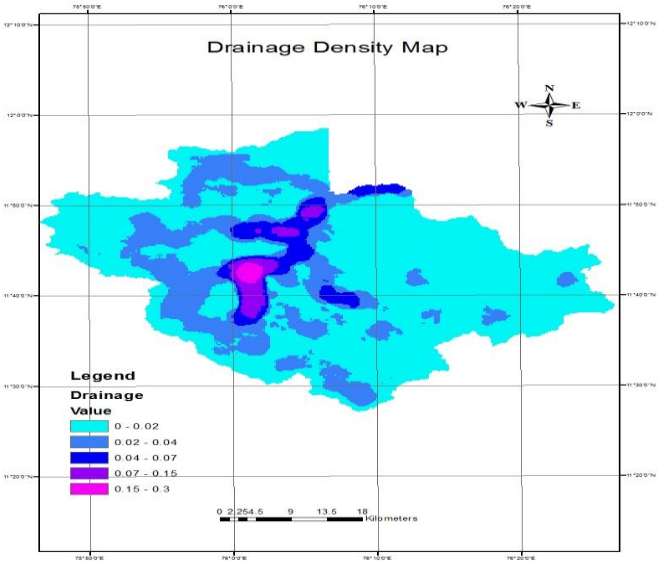

Fig – 3: Drainage Density map of the study area.

b) Digital Elevation Model (DEM)

The digital elevation model, a digital model or 3D representation of a terrain's surface is of SRTM- 1 Arc Second Global collected from earth explorer.

Slope is simply the inclination of a surface. The mass movement occurrence on a terrain is largely depends on its slope. Slope (Fig. 4) is generated from the DEM and reclassified into five classes: very low (< 5%), low (5 – 10 %), moderate (10 – 15%), high (15 – 30%), very high (30 – 70%).

Elevation is the height of terrain from the mean sea level. For our study, the elevation data (Fig. 5) is generated from the DEM using ArcGIS and classified into eight classes: (<500m), (500 – 750m), (750 – 1000m), (1000 – 1250m), (1250 – 1500m), (1500 – 1750m), (1750 – 2000m), (2000 – 2250m).

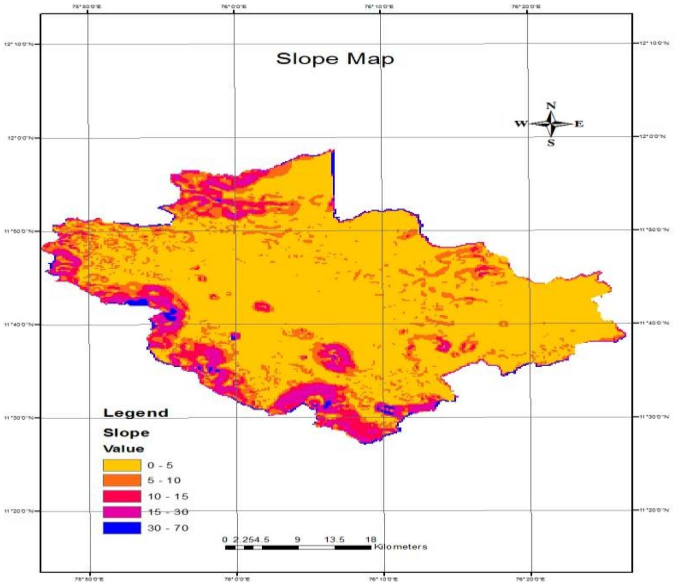

Fig – 4: Slope map of the study area.

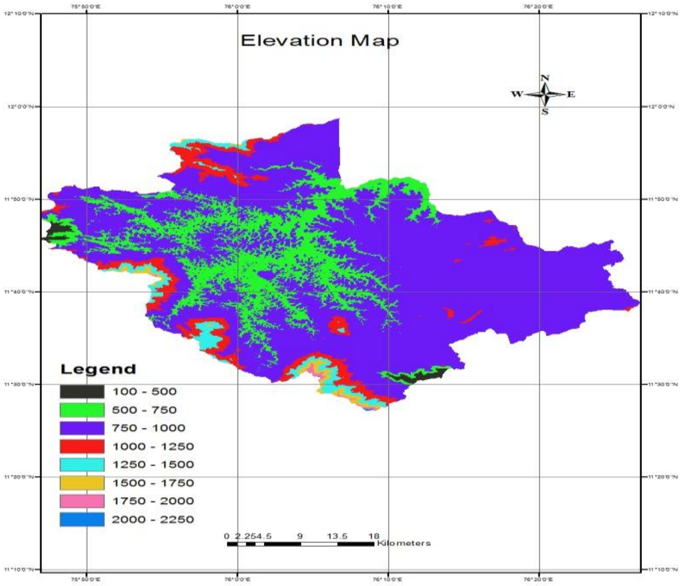

Fig – 5: Elevation map of the study area.

c) Bhuvan Dataset

Lineaments are linear topographic features of regional extent that is believed to reflect underlying crustal structure. These parameters are sometimes responsible for the slope failure. Thus the lineaments for the Wayanad are extracted from the bhuvan web map services (Fig. 6). (Web link: http://bhuvan.nrsc.gov.in/gis/thematic/index.php). The lineament density is generated and classified into six classes: very low (<0.05), very low (0.05 – 0.2), low (0.2 – 0.3), moderate (0.3 – 0.4), high (0.4 – 0.5), very high (0.5 – 0.7).

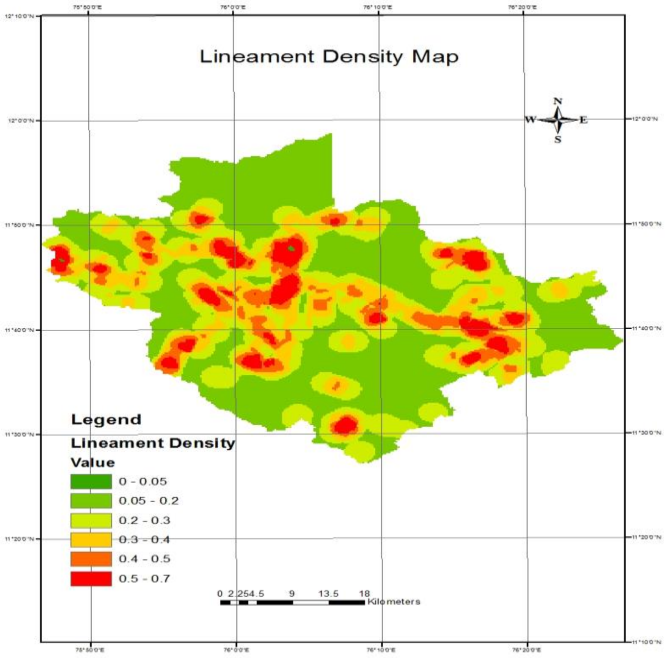

Fig – 6: Lineament Density map of the study area.

d) Open Street Map Dataset

Road dataset is collected from the open street map. Implementing of this parameter also helps us to identify the risky paths that falls in the slope instability region. Such roads can be avoided and even can take some mitigation measurements to protect the risky roads. The road density map is prepared and classified into five: very low (<0.2), low (0.2 – 0.6), moderate (0.6 – 1), high (1 – 1.7), very high (1.7 – 3) (Fig. 7).

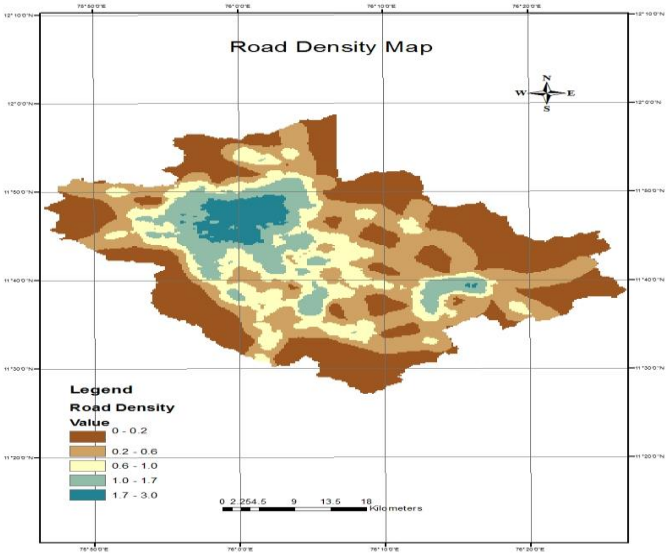

Fig – 7: Road Density map of the study area.

e) Survey of India Toposheets

Geology plays a vital role in slope stability. The data for our area is extracted from the Survey of India toposheet of scale 1:50,000. From the obtained data about 85% of area is covered with metamorphic rocks is vulnerable to landslides compared to the remaining plutonic rocks of 15% (Fig. 8). **Soil** data for the study area has been collected from Survey of India toposheet of scale 1: 250,000. The gravelly clay of region is vulnerable to landslides along with clay type. Hence the soil type of the study area is considered as unstable (Fig. 9).

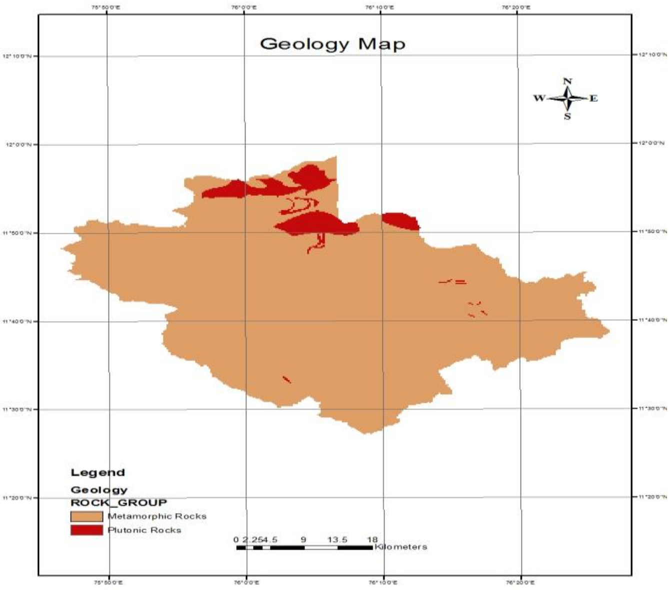

Fig – 8: Geology map of the study area.

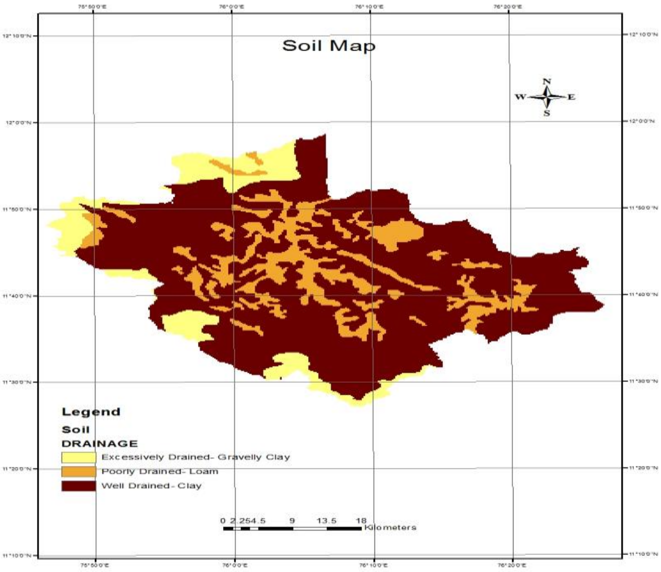

Fig – 9: Soil map of the study area.

f) IMD Rainfall Dataset

Rainfall is an important factor in predicting the landslide vulnerability map. The study area has intense rainfall and the landslides occurred during the past are associated with this heavy rainfall. Thus rainfall is considered as one of the triggering factors that is capable of producing a slope failure. The precipitation data for the region is collected from Indian Meteorological Department. Rainfall density map is prepared using ArcGIS and classified into seven classes: 1400mm, 1800mm, 1900mm, 2200mm, 2600mm, 3000mm, and 3600mm (Fig. 10).

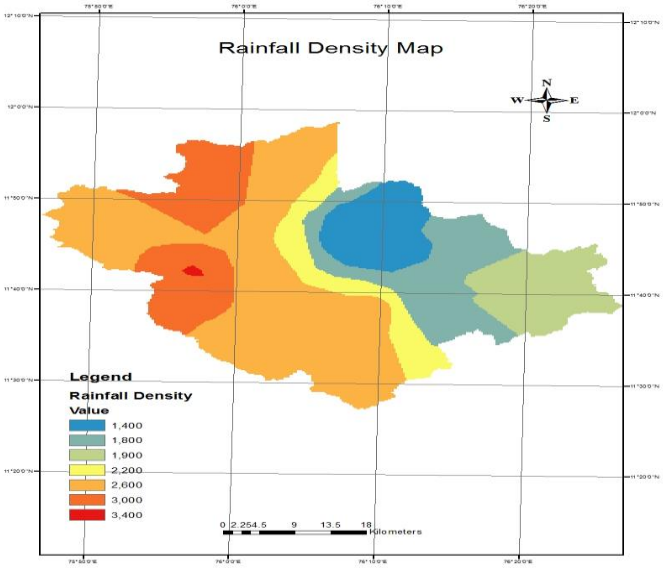

Fig – 10: Rainfall Density map of the study area.

3.2. Weighted Overlay Analysis

Weighted overlay analysis is the layer principle, one can easily extend the overlay by assigning levels of importance to each criterion. Thematic layers are processed for the nine landslide influencing factors with a ranking scale of 5 *Ajin et al.* [13] given as follows:

- Rank 1 – stable
- Rank 2 – moderately stable
- Rank 3 – moderately unstable
- Rank 4 – highly unstable
- Rank 5 – critical

Numerical weighting factors are assigned to each thematic layer according to its relative importance compared to all other layers. After that, the weighed layers are overlaid as before and ranks were assigned to each layer (Inverse Ranking Method). Hence the landslide vulnerable zones are mapped and analysed.

4. Mapped Landslide Vulnerable Zones

As overlay analysis is a multi-criteria analysis, wherein analysis can be carried out with complex things for finding out certain theme with the help of assignment of rank to the individual class of feature. Then by assigning weightage to the individual feature considering its influence over theme. All the thematic maps were converted into raster format and superimposed by weighted overlay analysis, which consists of rank and weightage wise thematic maps and integration of them through GIS (Table 1). Integration of thematic maps for carrying out multi-criteria or overlay analysis in GIS environment was done using ArcGIS software.

Table - 1: Ranks and Weightages of parameters given for Landslide Vulnerable Zonation Map

Sr. No.	Parameters	Classes	Rank	Weightage (%)
1	Slope	< 5 %	1	20
		5 to 10 %	2	
		10 to 15 %	3	
		15 to 30 %	4	
		30 to 70 %	5	
2	Elevation	< 500 m	1	10
		500 to 750 m	1	
		750 to 1000 m	2	
		1000 to 1250 m	2	
		1250 to 1500 m	3	
		1500 to 1750 m	4	
		1750 to 2000 m	5	
		2000 to 2250 m	5	
3	Rainfall Density	1400 mm	2	10
		1800 mm	2	
		1900 mm	3	
		2200 mm	4	
		2600 mm	4	
		3000 mm	5	
		3400 mm	5	
4	Lineament Density	< 0.05	1	10
		0.05 to 0.2	1	
		0.2 to 0.3	2	
		0.3 to 0.4	3	
		0.4 to 0.5	4	
		0.5 to 0.7	5	
5	LULC	Forest Plantation	1	18

		Agricultural Plantation	1	
		Current Fallow	4	
		Perennial	2	
		Kharif Crop	3	
		Dense/ Closed	2	
		Build up Area (rural)	5	
		Temperate/ sub-tropical	2	
		Dense Scrub	4	
		Open Scrub	5	
		Agro-Horticulture Plantation	4	
		Two Crop Area	3	
		Dry	4	
		Open	4	
		Forest Blank	5	
		Barren Rocky/ Stony Waste	1	
		Commercial	5	
		Inland Man-made	5	
		Industrial	5	
6	Drainage Density	< 0.02	1	5
		0.02 to 0.04	2	
		0.04 to 0.07	3	
		0.07 to 0.15	4	
		0.15 to 0.3	5	
7	Geology	Metamorphic Rocks	3	7
		Plutonic Rocks	2	
8	Soil	Gravelly Clay	5	15
		Clay	4	
		Loam	2	
9	Road Density	< 0.2	1	5
		0.2 to 0.6	2	
		0.6 to 1	3	
		1 to 1.7	4	
		1.7 to 3	5	

This study analyzed the landslide vulnerable regions and identified that eight factors influences the landslide phenomenon, viz. slope, LULC, rainfall, soil, geology, drainage, lineaments and elevation. The intense rainfall over the study area is considered as one of the triggering mechanisms for the landslide along with the regions of high altitude [1].

5. Results & Discussion

The use of satellite imageries and maps in hazard mapping studies are time preserving. The study area, Wayanad with its reserve forests is inaccessible and hence remote sensing, GIS techniques are used better for mapping. The same kind of study by *Ajin et al.* [13] uses the knowledge based weighing method with GIS overlay. As forest surveys for the estimation of landslide prone areas has its limitations, weighted overlay technique will act like a coming age tool in mapping. Though, the implementation of conventional techniques to this platform can increase the accuracy of the result that is being processed in GIS environment. A similar study was conducted by *Karthic Kumar et al.* [14] in Kothagiri region of Western Ghats, Tamil Nadu which fully operates in the GIS environment using weighted overlay. Another study by *Evany Nithya et al.* [15] studied in Nilgiris of Tamil Nadu was also by using the weighted overlay method.

The Landslide vulnerable map of Wayanad has been categorized into five zones: stable, moderately stable, moderately unstable, highly unstable and critical. The stable zone is about 0.24 percent (5 Sq. Km.) of the total area followed by moderately stable zone with 70.8 percent (1509 Sq. Km.). 28.48 percent (601 Sq. Km.) of the region is of moderately unstable zone and about 0.5 percent (10 Sq. Km.) falls on the highly unstable zone (Fig. 11, Chart 2). From the assessment of landslide vulnerable zones of hazard map, high altitude region with steeping slope is considered as prone to landslides. The vulnerable zones are in good agreement with the previous mass movements.

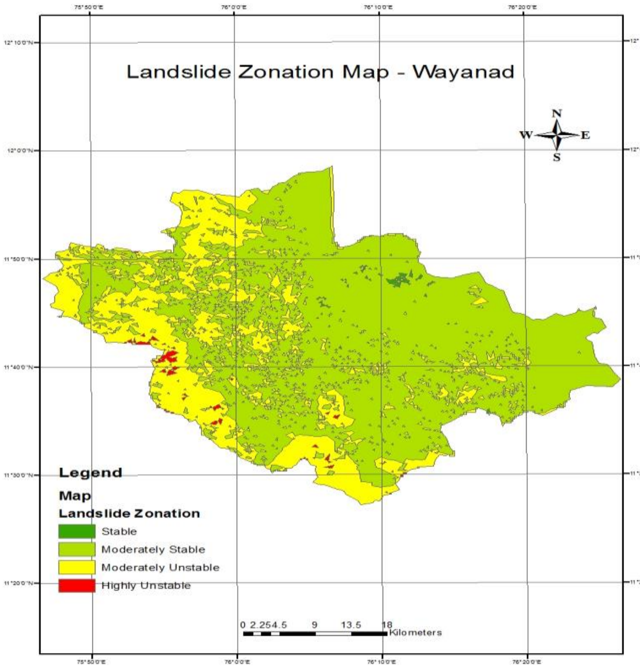

Fig – 11: Landslide Vulnerable Zonation Map- Wayanad

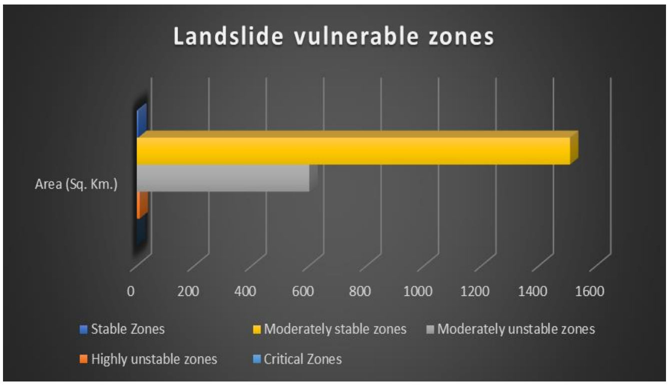

Chart 2 – Graphical representation of landslide vunerable regions in Sq. Km.

The parameters assigned with knowledge based weightage create a better way in order to predict the landslide vulnerable regions. The accuracy of the model depends on the ways that how the weights are assigned to each parameter which induces or triggers the mass movement.

The parameter, slope is the primary which can generate a landslide by its increase in the slope angle. The greater the slope angle, greater the occurrence of mass movement. Same as in the case of elevation too. The highest elevation along with a maximum slope angle can create a disastrous landfall. The rainfall as the triggering factor, the region does have a maximum rainfall of 3400mm. Without a proper drainage system, these kind of rainfall will lead to mass movements. The land use land cover plays as a control factor in mass movements. The denser the vegetation, null the mass movement, more or less a buildup area is more vulnerable than that of the vegetation's. Gravelly clay and clay of the region are more influential by landslide than loam soil. The metamorphic and plutonic rocks of the region are average influenced by the mass movement. Hence the parameters are well correlated with each other in all means and the failure in these parameters can trigger the mass movement.

6. Conclusions

The research was carried out in order to find the landslide vulnerable zones of rainfed region, Wayanad. The result shows high unstable zones are of the course of south to southwest. The moderately unstable region mostly falls over from south, southwest to northwest. It's seen that the steepness of the terrain over this region along with the triggering factor rain made the terrain unstable. From the assessment, it came to notice that certain anthropogenic activities are also responsible for the mass movement. The tampering with natural drainage system is one among them. Unauthorized quarry works for mineral exploration also makes the terrain unstable, cutting down of trees is of another kind. The tourist spots like Chembra Peak, Vythiri...etc. are in this southwest region. Hence, this study is relevant in implementing hazard management for the region.

From the hazard zonation map of landslide vulnerable zone in the study region of Wayanad, a typical rainfed region of southern peninsular India, it is identified that only less than 1% falls under the highly unstable and critical zone along with 28% falls under moderately unstable zone. However 71% lies in the moderately stable zone even if the region is under the influence of heavy rainfall.

With remote sensing and geographical information system (GIS) as a tool, the possibility of managing the hazardous situations along with monitoring can be possible. It can serve as a best practical tool in mapping, monitoring and analysis with reasonable accuracy within a short interval of time. Result from this case study shows that the remote sensing data and GIS application can be effectively use in the field of disaster management and weighted overlay analysis, a best option in mapping the hazardous regions. Ultimately it would help the planners and engineers to reduce losses of life and properties through prevention and mitigation measurements.

Acknowledgement

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