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"Landslide Susceptibility Assessment of Kodagu District, India Using Geospatial Techniques and LHEF-Based Hazard Zonation"

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Abstract - Kodagu is smallest district in Karnataka which is located in south India and it's consist of three taluks namely Madikeri, Kushalnagar, Somwarpet. The district consists of pleasant climatic conditions and also becoming known for natural hazard. Majority of slopes in this district has significant risks from rainfall; hence chance of occurrence of landslide is more. There were so many effects due to landslide and flood in kodagu district on August 2018, 8 people has lost their life and about 4320 people have been rescued, hundreds of people got trapped in various parts of hilly, coffee growing area. 123 km of road have been damaged in Kodagu. Hence it is important to study the landslide. The study was started with preparation of maps for different factors that are reason for causing landslide. The main causative factors that are responsible for the landslide or slope failures are Topography , Lithology , Geological structure , Slope , Relief , Landuse and Land cover , etc and these maps are prepared using QGIS software version 2.8.1 and 3.4.7 . The study reveals that study area comprises three zones mainly high hazard zone, moderate hazard zone and low hazard zone

***Keywords* – Landslide, QGIS, Topography, Geological structure and hazard zone**

I. INTRODUCTION

Landslides are among the most destructive natural hazards affecting mountainous regions worldwide, resulting in significant loss of life, damage to infrastructure, and long-term socioeconomic impacts. They are triggered by a combination of geological, geomorphological, hydrological, and anthropogenic factors, with intense rainfall being the dominant initiating mechanism in tropical regions. In India, landslides are widespread across the Western Ghats, Himalayas, and Eastern Ghats, where steep slopes, fragile rock formations, and heavy monsoonal precipitation create highly unstable conditions.

Kodagu District, located in the Western Ghats of Karnataka, is particularly susceptible to recurrent landslides due to its rugged topography, high-intensity rainfall, deeply weathered lithology, and expanding land-use activities.

The catastrophic events during the August 2018 monsoon caused severe damage, including loss of lives, destruction of agricultural land, collapse of slopes, and disruption of transportation networks. These events highlighted the urgent need for scientific assessment and spatial mapping of landslide-prone areas to support disaster mitigation and decision-making.

Several studies have employed remote sensing, GIS-based statistical models, machine learning approaches, and LHEF-based hazard zonation to identify landslide-prone regions in India and across the world. While these studies demonstrate the importance of multi-criteria evaluation for landslide susceptibility mapping, limited research exists for the Kodagu region using standardized methodologies such as the Landslide Hazard Evaluation Factor (LHEF) approach recommended by IS 14496 (Part-2): 1998. Furthermore, previous works often lack integration of multiple terrain and environmental factors specific to the geomorphology of the Western Ghats.

In this context, the present study aims to evaluate landslide susceptibility in Kodagu District by integrating geospatial techniques with the LHEF method. Six major causative factors—topography, lithology, geological structure, slope morphometry, land use/land cover, and hydrogeological conditions—are quantitatively assessed to generate a Total Estimated Hazard (TEHD) zonation map. The results of this study provide spatial identification of high-, moderate-, and low-risk zones, contributing essential information for slope management, land-use planning, and disaster risk reduction in the Kodagu region. The findings also offer a valuable reference for future landslide susceptibility research in similar mountainous terrains of the Western Ghats.

II. STUDY AREA

Kodagu district is located in Karnataka state, the study area lies between North latitude 12º 9'17" and 12º 43'36" and East longitude 75°22' 29" and 76°19'15".

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It is bounded by Hassan district on the north, by Mysore district on the east, by Dakshin Kannada district on the west and Kasaragod district of Kerala state on the south There are many reason which caused landslides at various parts of Kodagu hence it is very much important to understand the science of landslide and their causes, characteristics, soil properties, geology of study area, etc. for assessment of landslide risk zones in the region to prevent disaster in the unkown future.

Figure 2.1: Location map

III. LITERATURE REVIEW

Landslide susceptibility mapping has become an essential component of hazard assessment in mountainous regions, and numerous studies have demonstrated the effectiveness of remote sensing and GIS-based multi-criteria analysis for evaluating slope stability. Early approaches focused on heuristic and qualitative methods, but recent research increasingly applies data-driven, statistical, and machine-learning techniques to improve prediction accuracy.

Pradhan (2010) and Pourghasemi et al. (2012) highlighted the importance of integrating geological, geomorphological, and hydrological factors using frequency ratio and weights-of-evidence models, demonstrating strong correlations between slope angle, lithology, and rainfall intensity. Similarly, Sitharam et al. (2012) and Shrivastava et al. (2015) employed GIS-based factor analysis for landslide hazard zonation in India and emphasized the significance of topographic variables and weathered soil formations in triggering failures.

Studies in the Eastern and Western Himalayas, such as those by Jaiswal et al. (2018), Das et al. (2016), Roy and Saha (2016), and Sarkar and Kanungo (2017), used statistical and logistic regression models, indicating that land-use changes and anthropogenic modification of slopes substantially increase vulnerability.

Machine learning techniques such as Random Forest (Bui et al., 2012), ANN and SVM models (Pradhan & Lee, 2010), ensemble approaches (Merghadi et al., 2020), and hybrid GIS frameworks (Chen et al., 2019) have shown higher predictive capability, demonstrating better handling of nonlinear relationships between landslide causative factors. However, many of these approaches require large training datasets, which are often unavailable for regions with limited landslide inventory, such as the Western Ghats.

In the Indian context, several researchers have applied LHEF-based hazard zonation following the IS 14496 (Part-2): 1998 guidelines. Anbalagan et al. (2018) and Martha et al. (2010, 2011) demonstrated the suitability of LHEF for regions with complex geology and limited field data through integration of lithology, slope morphometry, land cover, and hydrogeology. Their findings indicate that LHEF provides a reliable framework for identifying high-risk zones, especially where landslides are controlled by deeply weathered rock formations and steep escarpments.

Despite extensive global studies, limited research exists specifically for the Kodagu District in Karnataka, particularly using a standardized LHEF-GIS framework. Although the region has experienced severe landslides in recent years, especially during the 2018 monsoon event, only a few studies have explored the spatial distribution of susceptibility using detailed geospatial analysis. Furthermore, previous works have not fully incorporated multi-factor evaluation combining topographic, geological, hydrological, and land-use characteristics tailored to the geomorphology of the Western Ghats.

Therefore, this study addresses a significant research gap by applying the LHEF method integrated with geospatial techniques to develop a comprehensive landslide susceptibility zonation map for Kodagu District. By analyzing six major causative factors and comparing hazard classes, the study contributes to improved understanding of slope instability patterns and provides a valuable reference for regional planning and disaster management.

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IV. METHODOLOGY

In the present study methods mainly based on IS 14496(part 2) 1998 "preparation of landslide hazard zonation maps in mountainous terrain" – guidelines.

Following factors were considered for the study

- Topography
- Lithology.
- Geological structure.
- Slope morphology.
- Land use and land cover.
- Hydrogeological condition.

3.1. Topography.

The arrangement of the natural and artificial physical features of an area is generally called as topography. Topography of an area plays a major role for the landslide risk mapping. If the hill formations are more in the area then there are high chances of landslide risk. In the current study topography map is prepared using ASTERDEM as a base map and processed on QGIS and surfer 11GIS software. It is observed that the west part of the study area that lies under virajpet and madikeri contains more hills as compared to the central part of virajpet and entire sowmarpet. General 3D topography of the study area is shown in figure 3.1.

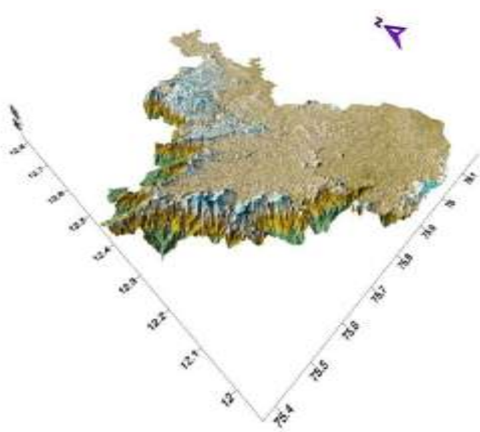

Figure 3.1: Topography Map

3.2 Lithology.

Lithology is defined as the study of different types of rocks of a particular area required for the research or any other purposes. The lithology of an area is a factor effecting landslide in such a way that if the rock or soil present is of soft material with weaker hardness, the landslide is lightly to occur where as if the rock is of hard, massive and compacted, then there is a less chance of landslide to occur in the particular area. Prepared by using the geological map of Karnataka that had been prepared by the GIS logical survey of India which is used as a base map. The Kodagu district map is then extracted using the QGIS software.

3.3 Slope.

Slope marpometry map defines slope categories on the basis of frequency of occurrence of particular angles of slope. The slope of an area is directly proportional to the landslide phenomenon. Steeper the slope higher is the danger of landslide. Similarly, if the ground surface is flat with slope less than 15degree, the chances of landslide occurrence is highly reduced. The map is prepared by using the ASTERDEM file which was downloaded from the USGS and processed using QGIS.

The type of slopes observed are

- Very gentle slope
- Gentle slope
- Moderately steep slope
- Steep slope
- Cliff

It is observed from the study area that the slope angle varies from 0degree to 60degree. The area dominating the steep slope that is virajpet and sowmarpet are less hazardous areas since their slope angle is very low and particularly flat land. Whereas some portion of these areas also contains moderately steep and gentle too where landslide risks is consistent. The areas on the western boundaries and some parts of Madikeri are hazardous and prone to landslides because they have moderately steep to steep slopes and receive heavy rainfall.

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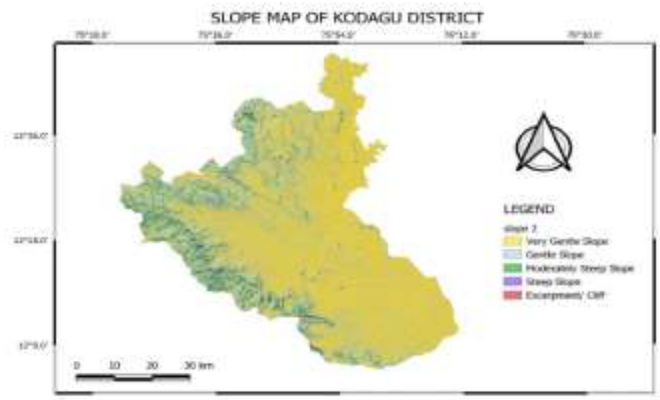

Figure 3.3 Slope Map

3.4 Landuse and Land Cover

The nature of land cover is an indirect indication of the stability of hill slopes. Forest covers in general smoothers the action of climatic agents on the slope and protects them from the effects of weathering and erosion. A well spread root system increases the shearing resistance of the slope material. The barren and sparsely vegetated areas show faster erosion and greater instability. Agriculture in general is practiced in low to very low slopes though moderately steep slopes are also used at some places. However, the agricultural lands represent areas of repeated artificial water stable. Based on the criteria of intensity of vegetation cover. The center portion of the study area i.e. Virajpet is observed to be agricultural land and extending with moderating vegetated area towards some part of madikeri and dominating most of the Somwarpet region. The boundaries of the district are covered densely with thick vegetated area. The north-east and south area consists of little bit of barren land which is indicated in the map with pink colour. Only a small amount of water bodies is situated in Somwarpet, as shown in the below map. It's observed in the map that Cream colour indicates that Agricultural land, Red colour shows Built-up land, Green colour indicates Forest land, Pink colour indicates Grassland land, Purple colour shows Wastelands, Blue colour indicates water bodies, and yellow colour indicates other land.

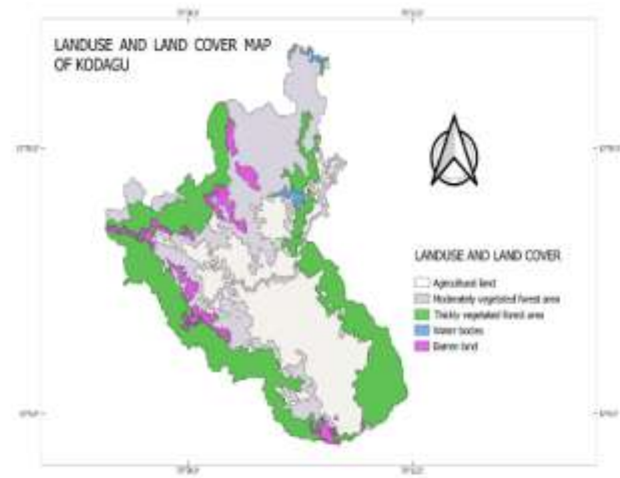

Figure 3.4 Land Use & Land Cover Map

3.5. Hydrogeological Condition

Since the groundwater in hilly terrain is generally channelized along structural discontinuities of rocks, it does not have uniform flow pattern. The observational evaluation of the groundwater on hill slopes is not possible over large areas. Due to time constraint and lack of facilities, field visit to almost all the places of district was very difficult. Therefore, in the present studies soil drainage maps prepared by NBSS & LUP, R.C., Bangalore/KSDA and CGWB have been used for the of purposes of quick appraisal the nature of surface indications of water such as damp, wet, dripping and flowing have been used for rating purposes. The studies usually have to carry out soon after the monsoon season, and the self-draining slope materials are likely to be dry. Based on the maps shown in the figure below, it is observed that study area falls under moderately to well drain hydrological conditions.

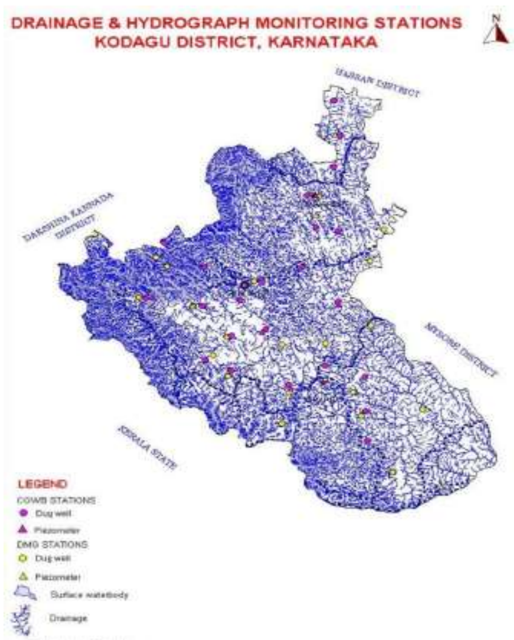

Figure 3.5 Hydrogeology Map

V. Result And Discussion

4.1 Landslide Hazard Evaluation Factor (Lhef) Rating Scheme

The LHEF rating scheme is a numerical system which is based on the major causative factors. The maximum LHEF ratings for different categories are determined on the basis of their estimated significance in causing liability. A detailed LHEF rating scheme showing the ratings for a variety of sub-categories of individual causative factors has been discussed below.

Table 4.1
LHEF Rating for Different Causative Factor

Causative factor	Maximum LHEF rating
Lithology	2
Structure	2
Slope morphometric	2
Relative relief	1
Land use and land cover	2
Hydrogeological Condition	1

4.2 Lithology

Based on the LHEF rating Guidelines table, following LHEF rating values are observed in the present study area.

Table 4.2.1
LHEF Rating Guidelines

Contributory factor.	Description.	Category.	Rating.
Lithology	Rock type	**Type I**	
		• Quartzite and limestone.	0.2
		• Granite and gabbro.	0.3
		• Gneiss.	0.4
		Type II	
		• Well cemented terrigenous sedimentary rocks dominantly sandstone with minor beds of clay stone.	1.0
		• Poorly cemented terrigenous sedimentary rocks dominantly sand rock with minor clay shale beds.	1.3
		Type III	
		• Slate and phyllite.	1.2
		• Schist	1.3
		• Shale with inter bedded clayey and non-clayey rocks	1.8
		• Highly weathered shale, phyllite and schist.	2.0

Table 4.2.2
LHEF Values Observed In Study Area

Type	Rocks / Soils	Rating	Correction factor	Total.
Type I	Charnockite Granitic gneiss.	0.2 0.4	3 3	0.6 1.2
Type II	Schist	1.3		1.3
Soil	• Clayey soil with naturally formed surface • Debris comprising mostly rock pieces with clayey Younger loose material • Older well compacted	1.0 2.0 1.2		1.0 2.0 1.2

From the map, it shows the presence of Schist, Charnockite and Granitic-Gneiss. According to LHEF rating scheme, certain categories are described for different types of rocks. Since the Charnockite and granitic-gneiss are very hard rocks, they have been categorized as Type 1 where the ratings for each are given as 0.2 and 0.4 respectively. The schist which is present in a very small amount is categorized as Type 3 and the rating determined is 1.3.

4.3 Slope

Based on the LHEF rating Guidelines table, following LHEF rating values are observed in the present study area.

Table 4.3
LHEF Ratings for Slope

Sl .No	Description	Category	Rating
1.	Escarpment / cliff	>45^0	2.0
2.	Steep slope	36^0 to 45^0	1.7
3.	Moderately Steep slope	26^0 to 35^0	1.2
4.	Gentle slope	$16^0$to 25^0	0.8
5.	Very gentle slope	<_15^0	0.5

Majority of study area i.e. parts of Virajpet and Somwarpet consists of very gentle slope where the slope angle is less than 15°. The boundaries in west part including Madikeri are governed by moderately steep slope as well as steep slope. The cliff which is having a slope angle more than 45° is observed in a very small portion in northern portion of the study area which lies under Somwarpet taluk.

4.4 Landuse And Landcover

Based on the LHEF rating Guidelines, following LHEF rating values are observed in the present study area:

Table 4.4
LHEF Rating for Land use and Land Cover

Sl. No	Description	Rating
1.	Agricultural land / populated flat land.	0.6
2.	Thickly vegetated area.	0.8
3.	Moderately vegetated forest area.	1.2
4.	Sparsely vegetated area.	1.5
5.	Barren land.	2.0

Based on all these observations the ratings are given to find out the land risk hazard zone. It has been observed that Agricultural land, Forest land, moderately vegetated area, sparsely vegetated area, Barren land are considered in the study area and hence the rating given is 0.6, 0.8, 1.2, 1.5 and 2.

4.5 Hydrogeological Conditions

According to LHEF, following ratings for the different hydrogeological conditions were given.

Table 4.5
LHEF Ratings for Hydrogeological Conditions

Sl.No	Description	Rating
1.	Flowing.	1.0
2.	Dripping.	0.8
3.	Wet.	0.5
4.	Damp.	0.2
5.	Dry.	0.0

Based on the maps shown, it is observed that study area falls under moderately to well drain hydrological conditions.

VI. CONCLUSION

This study applied geospatial techniques integrated with the Landslide Hazard Evaluation Factor (LHEF) method to assess landslide susceptibility in Kodagu District, Karnataka. The results demonstrate that landslide occurrence in the region is primarily controlled by a combination of steep slope morphometric**,** highly weathered lithological formations**,** and intense monsoon rainfall**,** particularly along the western margins influenced by the Western Ghats. The derived Total Estimated Hazard (TEHD) map effectively classifies the district into high**,** moderate, and low hazard zones, providing clear spatial differentiation of risk levels. The high-hazard zones predominantly occur in Madikeri and Virajpet, where steep slopes and weathered red gravelly clay soils are widespread. Moderate-hazard zones are concentrated in the northern parts of Somwarpe**t**, while low-hazard zon**es** correspond to gently sloping terrains with comparatively stable lithology and dense vegetation. The close agreement between the susceptibility pattern and documented 2018 landslide events indicates that the adopted methodology is reliable for regional-scale hazard assessment. Overall, the study highlights the significance of GIS-based multi-factor evaluation for identifying vulnerable areas in complex hilly terrains. The findings provide a scientific basis for land-use planning**,** slope-stabilization strategies, disaster preparedn**ess**, and the development of early-warning systems in Kodagu District. Future work may incorporate time-series rainfall, soil-moisture data, machine-learning models, and field-based geotechnical investigations to further improve predictive accuracy and support proactive landslide risk management.

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