Proc. of the 9th International Symposium on Geotechnical Safety and Risk (ISGSR)
Edited by Zhongqiang Liu, Jian Dai and Kate Robinson
Published by Research Publishing, Singapore.
doi: 10.3850/GRF-25280825_isgsr-046-P157-cd

ISGSR2025

LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN THE WESTERN GHATS REGION OF INDIA USING A HYBRID ANALYTICAL APPROACH

Malay Pramanik

Civil & Infrastructure Engineering, Indian Institute of Technology Dharwad, India. E-mail: ce23dp005@iitdh.ac.in

Amarnath Hegde

Civil & Infrastructure Engineering, Indian Institute of Technology Dharwad, India. E-mail: ahegde@iitdh.ac.in

The Western Ghats region of India experiences frequent rainfall-induced landslides during the monsoon season, causing substantial socioeconomic losses. Mapping landslide susceptible areas is the first step towards establishing an effective landslide risk mitigation strategy. This study utilized a hybrid approach that integrates the Analytical Hierarchy Process (AHP) and Relative Frequency Ratio (RFR) to provide a comprehensive landslide susceptibility assessment of the region. By leveraging the benefits of both approaches, the hybrid model efficiently identified areas that are susceptible to landslides. A total of 680 landslide locations were extracted from the inventory of the Geological Survey of India. The landslide data were divided into training (70%) and testing (30%) datasets for analysis. Ten environmental and geological causative factors, including slope, rainfall, soil type, land use land cover, elevation, aspect, curvature, distance to roads, streams, and lineaments, were considered for analysis. The findings revealed that more than 25% of the study area was classified as having very high susceptibility to landslides. Among the seven districts in the study area, Uttara Kannada had the highest share of high to very high susceptible areas (18.23%). The accuracy of the model was evaluated using a Receiver Operating Characteristic (ROC) curve. The hybrid model displayed its superiority over the individual models by achieving a higher Area Under the Curve (AUC) value of 0.902. The findings of this study provide useful information, such as the locations of highly susceptible areas, which is required for effective landslide risk management and mitigation strategies.

Keywords: Landslide susceptibility; hybrid model; analytic hierarchy process; relative frequency ratio; Western ghats

1. Introduction

Landslides are common geohazards in regions with steep terrain, high rainfall, and complex geological conditions. The Western Ghats region of India is a hotspot for this type of hazard. Landslides in this region cause significant loss of life, property destruction, and economic disruption (Meena et al., 2021; Jain et al., 2024). However, comprehensive research on these geohazards in the Western Ghats region is limited. Landslide susceptibility mapping is the first step in establishing an effective landslide risk reduction strategy. Landslide susceptibility assessment techniques have evolved from traditional qualitative methods to advanced quantitative and hybrid approaches (Nguyen et al., 2019). Traditional qualitative methods are limited by subjectivity and a lack of reproducibility. Quantitative methods are data-driven approaches. Advancements in Geographic Information Systems (GIS) and remote sensing technology have made data-driven techniques more prevalent (Guzzetti et al., 2012; Shahabi and Hashim, 2015). This study adopts a hybrid approach, combining the Analytic Hierarchy Process (AHP) and Relative Frequency Ratio (RFR) methods. The AHP was adopted to incorporate expert judgment. The RFR method is popular for evaluating the spatial correlation between past landslides and causative factors (Lee and Pradhan, 2007). However, both methods have some limitations. AHP relies heavily on expert judgment, which can introduce subjectivity and inconsistency in landslide susceptibility assessments (Pourghasemi et al., 2012). The RFR method oversimplifies complex landslide causative factors by assuming independence among factors, potentially missing crucial interactions between them. The hybrid approach, which combines AHP and FR, aims to reduce the limitations of individual models and improve the overall precision of landslide susceptibility maps. This study assessed the landslide susceptibility of the Western Ghats in Karnataka, India.

2. Study Area

The Western Ghats region in Karnataka is located between latitudes 11°50' N and 15°40' N and longitudes 73°50' E to 76°50' E, spanning approximately 45,000 km^2. The study area stretches across seven districts including Uttara Kannada, Shimoga, Chikkamagaluru, Kodagu, Dakshina Kannada, Udupi, and Hassan. This region is recognized for its complex geological, hydrological, and topographical features. The region experiences intense monsoonal rainfall, with annual precipitation exceeding 3,000 mm in certain areas. The southwest monsoon, which occurs from June to September, accounts for most of the region's annual rainfall. The region is distinguished by steep slope gradients exceeding 45º in some areas. The elevation in this region ranges from 600 to over 2,600 m above mean sea level. The region predominantly has three types of soil: clay, loam, and clayey loam. The study area with previous landslide locations is shown in Figure 1.

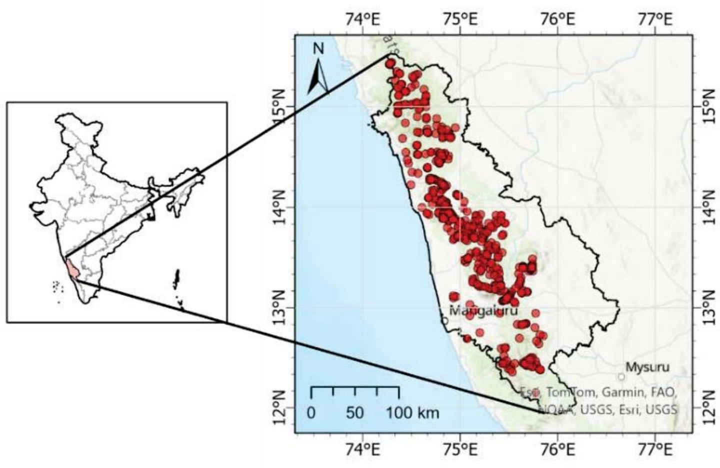

Figure 1 Study area with previous landslide locations

3. Data and Methodology

A comprehensive landslide susceptibility analysis requires various datasets, including previous landslide locations, topographical data, geological characteristics, rainfall history, road networks, and land cover. The previous landslide data were obtained from the Geological Survey of India (GSI), which contained 1,275 events at 680 locations. This dataset was divided into two parts, with 70% used for training and 30% for testing the susceptibility model. The sources of all the data used in this study are listed in Table 1.

This study adopted a consistent spatial resolution of 30 m for all landslide causative factors. To achieve this resolution for all datasets, the raw datasets were resampled using the bilinear interpolation technique. ArcGIS Pro 2.9.0 software was used for this purpose. To simplify the incorporation of causative factors into the landslide susceptibility model, they were systematically reclassified into sub-classes. For example, slope gradients were classified as gentle (0-15°), moderate (15-30°), steep (30-45°), and very steep (>45°). This reclassification process ensured that all datasets were in a compatible format, allowing for a reliable analysis of landslide susceptibility.

Table 1 Data and its sources

Purpose	Data	Source
Landslide training and testing dataset	Landslide locations	Bhukosh, Geological survey of India
Causative factors mapping	Soil	Food & Agriculture Organization, USA
	Topography	National Remote Sensing Centre, India
	Rainfall	Climatic Research Unit, University of East Anglia
	Lineaments & Road network	Bhukosh, Geological survey of India
	Landcover	Sentinel-2 satellite image

The Landslide Susceptibility Index (LSI) is a numerical metric that quantifies an area's susceptibility to landslides based on the presence of causative factors. The LSI classifies these areas into different susceptibility zones, ranging from very low to very highly susceptible. The adopted approach utilizes equation (1) to quantify the LSI of areas in the study area.

$$LSI = \sum NFR_{i,j} \times WF_j \tag{1}$$

where, $NFR_{i,j}$ is normalized frequency ratio of the i^{th} class of the causative factor evaluated using frequency ratio method and WF_j is the weighted factor of the j^{th} class of the causative factor evaluated using analytic hierarchy process. A detailed description of the methodology for the hybrid approach is available in the studies of Muavhi et al. (2022) and Tariq et al. (2022).

4. Results and Discussion

The influence of causative factors on landslide occurrence was analyzed. The analysis identified the slope gradient and rainfall as critical factors, with influence factors of 26.17% and 16.02%, respectively. It emphasizes the role of steep slopes and heavy rainy seasons in triggering landslides (Figure 2). Soil type (18%) and land cover (16%)

also had significant impacts, highlighting the importance of soil stability and vegetation cover in slope protection. Slope curvature (10%) moderately affected landslide susceptibility by influencing water accumulation on slopes. Factors such as distance to lineaments (5%) and distance to streams (3%) had lower impacts, whereas elevation (2%), distance to roads (1%), and slope aspect (0.5%) showed minimal influence. This distribution underscores the need to prioritize topographic and hydrological factors in landslide susceptibility assessments and highlights the importance of land-use planning and soil conservation efforts to mitigate landslide hazards effectively.

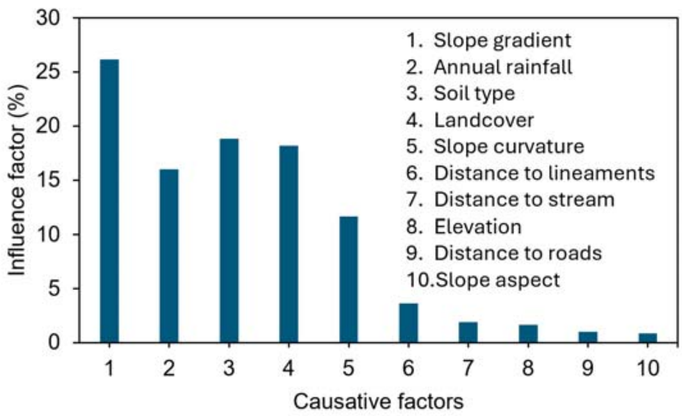

Figure 2 Influence of causative factors on landslide occurrence

The landslide susceptibility map (Figure 3. a) reveals that a substantial portion of the Western Ghats in Karnataka is susceptible to landslide occurrence. Approximately 25% of the study area fell within very high susceptibility zones, requiring careful monitoring. 35.62% of the area was classified as high susceptibility. The medium-susceptibility class covered 21.24% of the region, indicating areas where the risk was moderate. Meanwhile, low- and very-low-susceptibility zones accounted for 18.06% of the area, mostly representing more stable terrain (Figure 3. b).

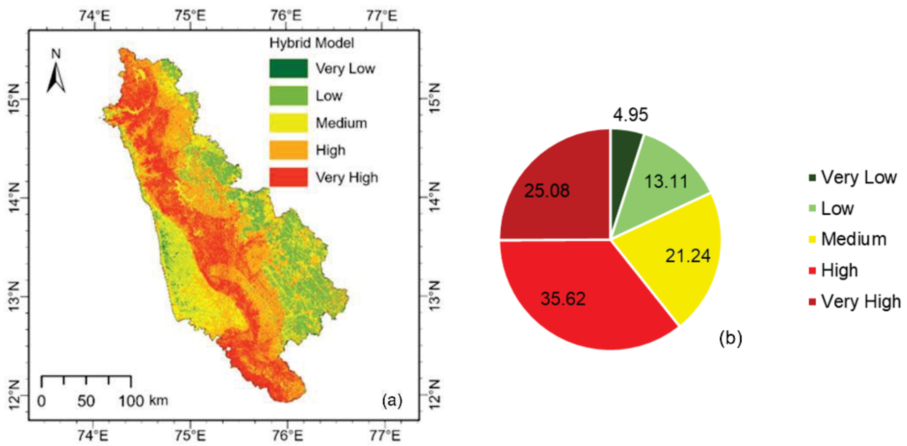

Figure 3. (a) Landslide susceptibility map and (b) landslide susceptible area

Among the seven districts in the study area, Uttara Kannada had the maximum share of highly susceptible areas (18.23%), followed by Shimoga (10.43%), Chikkamagaluru (10.32%), Kodagu (8.43%), Dakshina Kannada (5.85%), Hassan (5.02%), and Udupi (2.43%). The ROC curve analysis showed that the landslide susceptibility model effectively distinguished between highly susceptible and non-susceptible areas, with an AUC of 0.902 (Figure 4). The steep initial rise in the ROC curve reflects a high true positive rate with minimal false positives, making it suitable for practical applications.

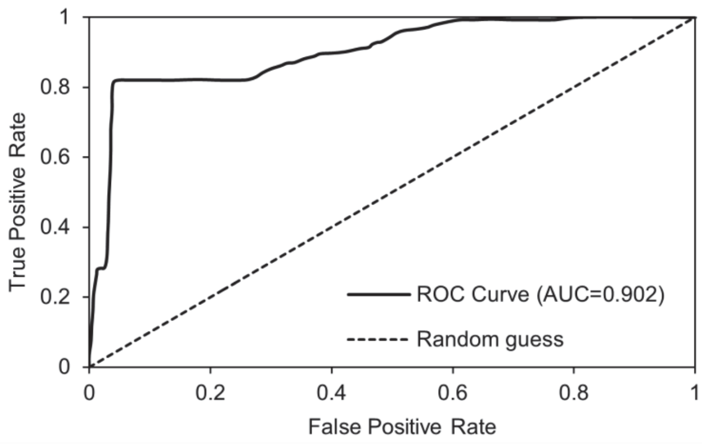

Figure 4 Receiver operating curve for the susceptibility model

5. Conclusions

The following conclusions can be drawn from the comprehensive analysis of the hybrid landslide susceptibility model:

- The slope gradient and rainfall are the most critical factors influencing landslide susceptibility in the Western Ghats of Karnataka, highlighting the importance of steep topography and intense monsoon rainfall.
- Soil type and land cover play crucial roles in slope stability, emphasizing the need for vegetation preservation and an understanding of soil properties to reduce landslide susceptibility.
- Over 25% of the region is classified as having very high susceptibility, underscoring the urgency of implementing monitoring systems and proactive risk management strategies. Among the seven districts in the study area, Uttara Kannada had the maximum share of highly susceptible areas (18.23%), followed by Shimoga (10.43%), Chikkamagaluru (10.32%), Kodagu (8.43%), Dakshina Kannada (5.85%), Hassan (5.02%), and Udupi (2.43%).
- The landslide susceptibility model, which exhibited an AUC of 0.902, demonstrated exceptional predictive performance, confirming its effectiveness in accurately identifying highly susceptible areas.

The model serves as a dependable resource for landslide risk reduction strategies, enhancing early warning systems, and guiding the prioritization of mitigation measures to safeguard communities and infrastructure. These findings underscore the necessity of implementing data-driven policies that emphasize sustainable land use, soil conservation, and comprehensive disaster preparedness to mitigate landslide impacts in the Western Ghats.

References

Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M., & Chang, K. T. (2012). Landslide inventory maps: New tools for an old problem. Earth-Science Reviews, 112(1-2), 42-66.

Jain, N., Roy, P., Martha, T. R., Sekhar, N. P., & Kumar, K. V. (2024). Causal analysis of unprecedented landslides during July 2021 in the Western Ghats of Maharashtra, India. Landslides, 21(1), 99-109.

Lee, S., & Pradhan, B. (2007). Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models. Landslides, 4(1), 33-41.

Meena, S. R., Ghorbanzadeh, O., van Westen, C. J., Nachappa, T. G., Blaschke, T., Singh, R. P., & Sarkar, R. (2021). Rapid mapping of landslides in the Western Ghats (India) triggered by 2018 extreme monsoon rainfall using a deep learning approach. Landslides, 18, 1937-1950.

Muavhi, N., Thamaga, K. H., & Mutoti, M. I. (2022). Mapping groundwater potential zones using relative frequency ratio, analytic hierarchy process and their hybrid models: case of Nzhelele-Makhado area in South Africa. Geocarto International, 37(21), 6311-6330.

Nguyen, H., Mehrabi, M., Kalantar, B., Moayedi, H., & Abdullahi, M. A. M. (2019). Potential of hybrid evolutionary approaches for assessment of geo-hazard landslide susceptibility mapping. Geomatics, Natural Hazards and Risk, 10(1), 1667-1693.

Pourghasemi, H. R., Pradhan, B., & Gokceoglu, C. (2012). Application of fuzzy logic and analytical hierarchy process (AHP) to landslide susceptibility mapping at Haraz watershed, Iran. Natural hazards, 63, 965-996.

Shahabi, H., & Hashim, M. (2015). Landslide susceptibility mapping using GIS-based statistical models and Remote sensing data in tropical environment. Scientific reports, 5(1), 9899.

Tariq, A., Yan, J., Ghaffar, B., Qin, S., Mousa, B. G., Sharifi, A., ... & Aslam, M. (2022). Flash flood susceptibility assessment and zonation by integrating analytic hierarchy process and frequency ratio model with diverse spatial data. Water, 14(19), 3069.