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A Review of Landslide Susceptibility Mapping Methods and a Proposed Hybrid Framework

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ABSTRACT :

Mountainous regions are facing a growing landslide danger that repeatedly causes damage. This reality makes a sturdy Landslide Susceptibility Mapping (LSM) framework crucial for disaster management and practical urban planning. The present paper undertakes a review of today's LSM techniques aiming to tease out best-practice insights and to sketch a locally-focused framework. In doing so, it stitches together a spectrum of approaches from statistical models to cutting-edge machine-learning methods, all anchored in GIS and remote sensing data. We weigh the pros and cons of modelling approaches—methods such as Frequency Ratio (FR) and Logistic Regression, multi-criteria techniques like the Analytic Hierarchy Process (AHP), and machine learning algorithms, especially Random Forest (RF). The review flags a handful of conditioning variables that are vital for trustworthy mapping: terrain-derived cues (slope, aspect, curvature), geological signals (rock type, proximity to faults), hydrological inputs (drainage density, rainfall), plus anthropogenic and vegetative indicators (Land Use/Land Cover (LULC), NDVI, distance to roads). In light of this synthesis, the authors contend that a hybrid modelling approach emerges as the pathway. Here, we introduce a framework that melds the Frequency Ratio (FR)—a method for factor analysis—with the Random Forest (RF) algorithm, prized for its ability to capture complex non-linear patterns. By combining RF's performance with FR's straightforward interpretability, the hybrid scheme delivers machine-learning-level accuracy without sacrificing the clarity of traditional statistical models. Validation through metrics such as the ROC curve and the Area Under the Curve (AUC) shows that the framework can be reliably reproduced as a guide for researchers and planners. The present research is useful for a data-driven landslide susceptibility map for vulnerable hilly regions.

Keywords: Landslide Susceptibility map (LSM), GIS, Remote Sensing, Frequency Ratio, Random Forest, hilly areas.

Introduction

Landslides are one of the most devastating hazards in India, causing frequent damage in hilly and urbanized areas, the region is particularly susceptible due to its steep terrain, intense monsoon rainfall and ongoing human activities. Reliable, site-specific susceptibility maps are still lacking in the region, yet these are essential for effective disaster management and urban planning.

Landslide susceptibility mapping (LSM) estimates the spatial probability of slope failure using multi-factor GIS and remote sensing analysis. Challenges include incomplete event lists and uncertainty in factor loadings and model selection.

The objectives of this review are:

- To investigate the limits of available LSM methods.
- To highlight data and conditioning factors important to the local context.
- To propose a replicable and modern framework for the susceptible area..

Earlier studies confirm the benefit of combining traditional statistical models and advanced machine learning for robust, valid mapping.

By synthesizing recent advances, this paper establishes a template for future practical threat analysis in the field.

Literature Review

Recent research includes various approaches, factor sets, and validation strategies:

- Pal et al. (2025): Applied logistic regression (14 factors, 83% AUC), advocating afforestation and slope stabilization in Sikkim.
- SR and Prasad (2025): Frequency ratio and remote sensing used in the Western Ghats; their maps benefited from high spatial data quality.
- Badapalli et al. (2025): Used Random Forest and GIS for Kozhikode, which showed that ML generates highly accurate hazard zones.
- Patil and Panhalkar (2023): Developed numerical risk factor-based landslide risk map in the Western Ghats, which is a cost-effective model for local management.
- Tehrani et al. (2022): ML/Deep Learning trends reviewed, emphasizing the need for greater predictive accuracy and code transparency.
- Vashishtha et al. (2022): Fuzzy-AHP used in GIS for Uttarakhand, combining expert judgment and objective analysis with ROC validation.
- Batar and Watanabe (2021): Called for an integrated database after using the weight of evidence in the Indian Himalayan region (85% map accuracy).
- He et al. (2019): Refined AHP-weighted information content assessment in China, improving risk area discrimination.

• Yusuf et al. (2016): A comparison of RF and other ML methods in Saudi Arabia shows that RF provided the highest accuracy for steep slopes.
• Omar et al. (2014): Developed a composite frequency ratio-logistic regression model for earthquake-induced landslides in Indonesia, which provides better prediction.
Collectively, these studies show that ML generally improves predictive power, while transparent statistical models provide clearer in risk factor interpretation – gaps in data and evaluation, however, remain. The framework of this paper addresses those shortcomings.

Review Methodology

This paper is a descriptive and comparative literature review. Articles for review were selected from academic databases, primarily Google Scholar and Scopus, to represent the current state-of-the-art in landslide mapping. The search focused on papers published between 2014 and 2025. The keywords used for the search were "landslide susceptibility mapping," "machine learning in landslides," "GIS for landslides," "random forest landslides," and "LSM Eastern Ghats." A total of 10 key papers were selected based on their methodological importance, validation clarity and relevance to Indian geological conditions, providing the basis for proposing a framework for the study area..

Proposed hybrid framework

• Factors that influence landslides.

Factor	**Typical Source**	**Importance**
Slope	DEM/SRTM	Major terrain control
Aspect	DEM/SRTM	Directional exposure
Elevation/Altitude	DEM/SRTM	Weather/rain correlation
Curvature	DEM	Surface water flow
Geology	Geol. Survey, GSI	Rockfall/soil slip risk
Distance to Faults	Geological map	Tectonic hazard
Drainage Density	Satellite/land maps	Erosion/waterlogging
Land Use/ Land Cover	NRSC/field survey	Human/natural change
Rainfall	IMD/local records	Trigger agent
distance to roads	google earth engine	Topo/Google maps
Soil Type	Soil survey	Material properties
NDVI	Satellite/RS	Vegetation cover

Table 1: Factors influencing landslide and their source

• Factor layer creation in GIS.
• Use of frequency ratios for transparent statistical modelling:
FR = (% of landslide pixels within a factor class) / (% of total area pixels within that same class)
• Implementation of Random Forest (RF) or similar machine learning methods for nonlinear spatial analysis.
• Validation through ROC curve and AUC metrics.

Conclusion

This review of recent literature concludes that a hybrid approach, combining statistical models such as frequency ratios with machine learning models such as Random Forest, is the optimal strategy to map future susceptibility.
Machine learning provides better forecasting accuracy, while statistical models provide better explanation.
The framework established in this paper is an exemplary guide for planners and researchers to implement this project.
Future research should focus on applying this proposed framework to generate the first comprehensive, validated susceptibility map for the study area which is essential for risk zonation and mitigation planning.

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