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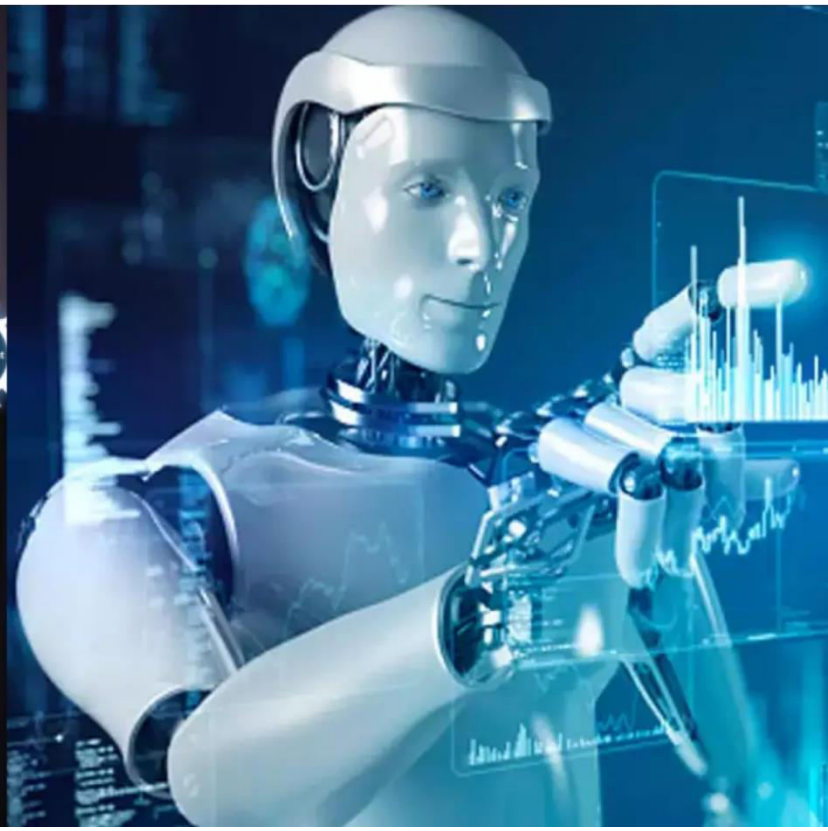

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Review Paper on Landslide Hazard Analysis and Risk Management in Karnataka's Western Ghats Region

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ABSTRACT: Landslides are major natural hazards in Karnataka's Western Ghats, caused by steep slopes, heavy rainfall, weak geology, and human activities like deforestation and construction. They involve the movement of soil, rock, or debris and are classified as falls, slides, flows, and creep. Rainfall is the primary trigger, increasing soil saturation and reducing stability. Landslides cause severe impacts, including loss of life, infrastructure damage, environmental degradation, and economic losses. Effective management involves landslide hazard zonation, GIS and machine learning techniques, slope stabilization, drainage control, afforestation, and early warning systems to reduce risks and improve disaster preparedness in vulnerable regions.

KEYWORDS: Landslides, Western Ghats, Karnataka, GIS, Machine Learning, Susceptibility Mapping, Rainfall, Slope Stability, Hazard Zonation, Risk Management.

I. INTRODUCTION

Landslides Landslides are among the most destructive natural hazards, particularly in mountainous and hilly regions such as the Western Ghats of Karnataka. This ecologically sensitive region is highly vulnerable to landslides due to its steep slopes, fragile geological formations, deeply weathered soils, and intense monsoonal rainfall. Districts including Kodagu, Uttara Kannada, Chikmagalur, Shivamogga, Dakshina Kannada, and Udupi frequently experience landslide events, especially during the southwest monsoon season.

Landslides occur due to a combination of natural and human-induced factors. Natural causes include heavy rainfall, erosion, and geological weaknesses, while anthropogenic activities such as deforestation, road construction, mining, and unplanned urbanization significantly increase slope instability. These factors disturb the natural equilibrium of slopes, making them more prone to failure. In recent years, the frequency and intensity of landslides in Karnataka have increased, leading to severe consequences such as loss of life, damage to infrastructure, environmental degradation, and economic losses.

Understanding landslide processes, causes, and impacts is essential for effective hazard assessment and risk management. Modern approaches such as Geographic Information Systems (GIS), remote sensing, and machine learning techniques have improved landslide susceptibility mapping and prediction accuracy. These tools help identify

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high-risk zones and support better planning and mitigation strategies. Therefore, a comprehensive and integrated approach is necessary to reduce landslide risks and ensure sustainable development in vulnerable regions.

II. LITERATURE SURVEY

The literature on landslide hazard analysis in Karnataka's Western Ghats reflects a progressive shift from traditional approaches to advanced data-driven techniques. Early studies primarily focused on identifying key triggering and conditioning factors such as rainfall intensity, slope gradient, geological structure, and soil characteristics. These studies commonly employed statistical and heuristic methods like Frequency Ratio (FR), Weight of Evidence (WoE), Information Value (IV), Shannon Entropy (SE), and Analytic Hierarchy Process (AHP). While these methods were relatively simple and cost-effective, they often assumed linear relationships between variables and had limitations in capturing the complex interactions influencing landslides.

With the advancement of geospatial technologies, Geographic Information Systems (GIS) and remote sensing have become essential tools in landslide research. These technologies enable efficient spatial analysis and integration of multiple environmental datasets, improving the accuracy of landslide susceptibility mapping. Satellite imagery and Digital Elevation Models (DEM) have been widely used to derive terrain parameters and monitor land-use changes.

In recent years, machine learning techniques have gained prominence due to their ability to model nonlinear relationships and handle large datasets. Models such as Logistic Regression, Support Vector Machine (SVM), Decision Trees, K-Nearest Neighbors (KNN), and Artificial Neural Networks (ANN) have shown improved predictive performance compared to traditional methods. Furthermore, ensemble models like Random Forest, Gradient Boosting, XGBoost, and LightGBM have demonstrated superior accuracy by reducing overfitting and combining multiple learning algorithms.

Despite these advancements, existing studies still face limitations such as restricted spatial coverage, limited use of conditioning factors, and reliance on static historical data. Additionally, the gap between research findings and practical implementation remains a challenge. Therefore, future research should focus on integrating real-time monitoring, advanced machine learning models, and comprehensive datasets to enhance landslide prediction and risk management strategies.

III. METHODOLOGY

The The methodology for landslide susceptibility assessment in Karnataka's Western Ghats follows a systematic, data-driven approach integrating geospatial techniques and machine learning models. The first step involves data collection, where landslide inventory data and multiple conditioning factors are gathered from reliable sources such as satellite imagery, government databases, and field observations. These factors include topographic parameters (slope, elevation, aspect), geological features (lithology, soil type), hydrological variables (rainfall, drainage density), and anthropogenic influences (land use, distance to roads).

The collected datasets are then processed within a Geographic Information System (GIS) environment. All data layers are standardized to a common spatial resolution and coordinate system to ensure consistency. Data preprocessing includes handling missing values, normalization of variables, and conversion of categorical data into numerical formats. This step is crucial for improving model performance and ensuring accurate analysis.

Next, feature selection is performed to identify the most significant factors influencing landslides. Statistical techniques such as correlation analysis and significance testing are used to eliminate redundant or highly correlated variables, thereby enhancing model efficiency. The prepared dataset is then divided into training and testing subsets, typically in a 75:25 ratio, to evaluate model performance.

Various machine learning models are applied, including Logistic Regression, Support Vector Machine (SVM), Random Forest, and Gradient Boosting. Ensemble techniques are also considered to improve predictive accuracy. Hyperparameter tuning methods such as Grid Search and Random Search are used to optimize model parameters and achieve better results.

Model performance is evaluated using metrics such as accuracy, precision, recall, F1-score, and AUC-ROC. The best-performing model is selected to generate landslide susceptibility maps, which classify the study area into different risk

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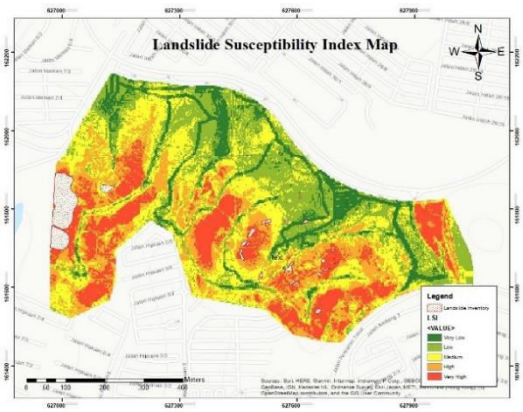
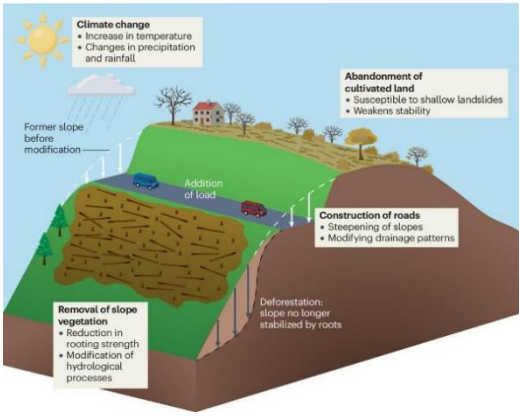
zones ranging from very low to very high susceptibility. These maps are validated using historical landslide data and are used to support decision-making for hazard mitigation and sustainable land-use planning.

IV. RESEARCH GAP





Despite significant advancements in landslide hazard analysis and risk management, several critical research gaps remain in studies related to Karnataka's Western Ghats. One major limitation is the **restricted spatial coverage** of existing studies. Most research focuses on small regions such as individual districts or watersheds, limiting the applicability of findings to broader regional planning and decision-making.

Another important gap is the **limited use of comprehensive conditioning factors**. Many studies rely on basic parameters such as slope, rainfall, and soil type, while neglecting key variables like land-use changes, anthropogenic activities, hydrological indices, and climate variability. Since landslides are complex phenomena influenced by multiple interacting factors, excluding these variables reduces model accuracy and reliability.

A significant challenge is the **dependence on static and historical data** rather than real-time monitoring. Landslides are dynamic events influenced by continuously changing conditions such as rainfall intensity, soil moisture, and groundwater levels. The lack of integration of real-time data limits the predictive capability of existing models and reduces the effectiveness of early warning systems.

Although machine learning techniques have been introduced, there is still **limited use of advanced and ensemble models**, such as deep learning and hybrid approaches. Additionally, many high-performing models act as "black boxes," lacking interpretability, which makes it difficult for decision-makers to understand and trust the results.

Furthermore, **data scarcity and inconsistency** in remote regions hinder accurate modeling. There is also a gap between research outcomes and practical implementation, as many studies are not effectively translated into policies or mitigation strategies. Lastly, **climate change impacts** are often overlooked, despite their significant role in altering rainfall patterns and increasing landslide frequency.

Addressing these gaps requires integrated, large-scale, and real-time data-driven approaches combining GIS, machine learning, and sustainable planning strategies.

V. DATA SOURCE

Accurate landslide susceptibility assessment in Karnataka's Western Ghats depends on the integration of diverse and high-quality datasets representing environmental, geological, hydrological, and human-related factors. The primary dataset is the Landslide Inventory Map (LIM), which records past landslide occurrences, including their location, type, and timing. This data is typically obtained from the Geological Survey of India (GSI) and forms the foundation for model training and validation.

Topographic data is derived from Digital Elevation Models (DEM), available from platforms such as USGS Earth Explorer. DEM data is used to generate terrain parameters like slope, elevation, aspect, curvature, and terrain ruggedness, which are critical in understanding slope stability. Geological and geomorphological datasets, including

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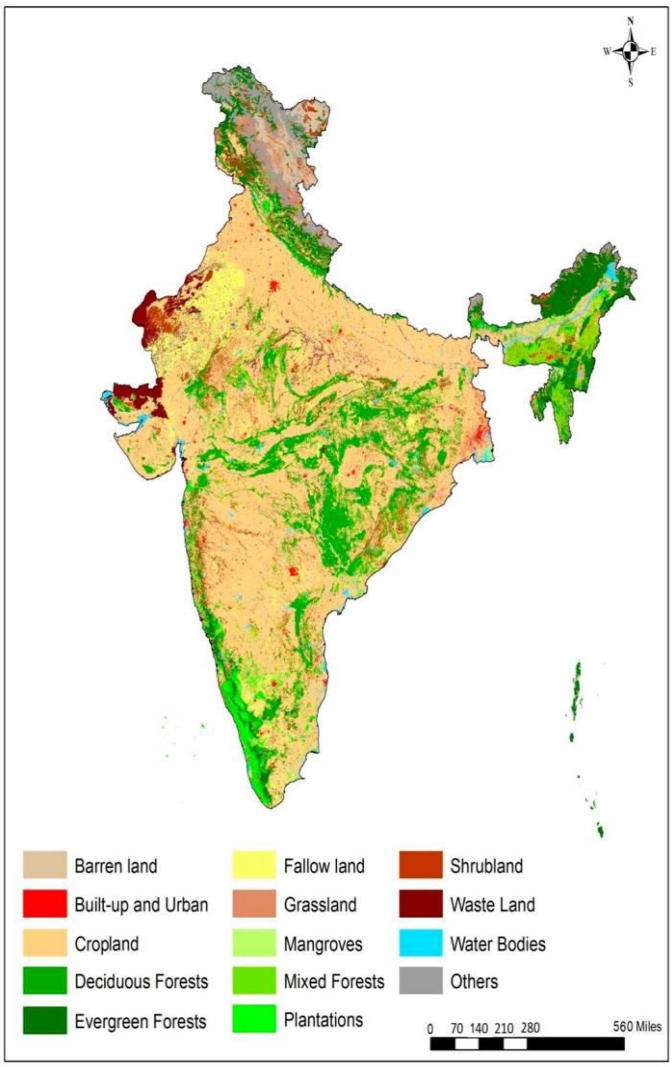
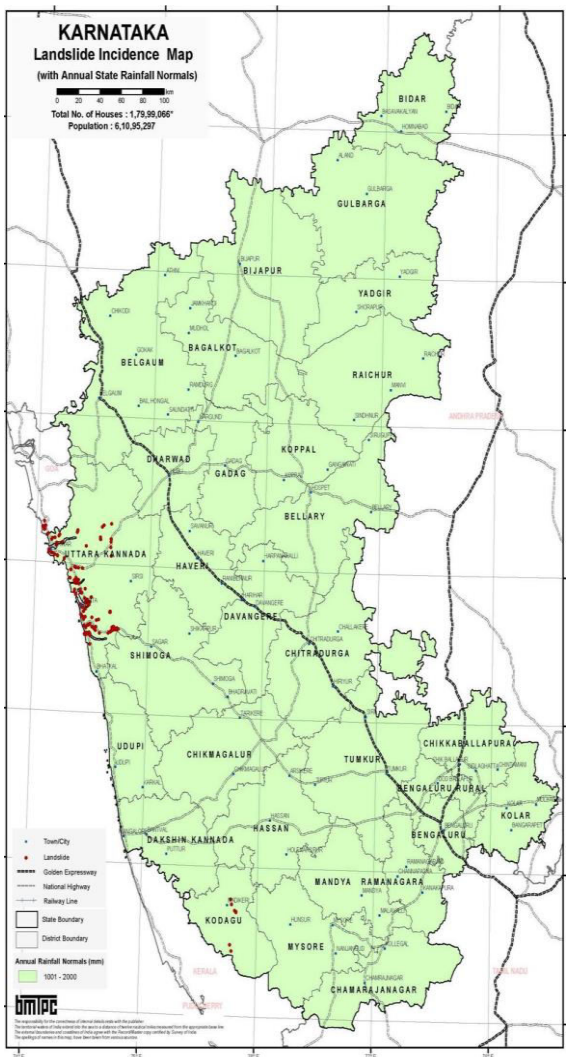
lithology, soil type, and structural features like faults and lineaments, are obtained from national geological databases and satellite interpretations.





Hydrological and climatic data play a vital role, as rainfall is a major triggering factor. Rainfall data is collected from sources such as CHIRPS and CHRS, providing high-resolution temporal and spatial rainfall information. Additional indices like the Topographic Wetness Index (TWI) are derived from DEM data to assess water accumulation and soil saturation.

Land Use/Land Cover (LULC) data is obtained from Landsat imagery and ArcGIS Living Atlas, enabling analysis of vegetation, urbanization, and human activities. Indices such as NDVI and NDBI are used to quantify vegetation health and built-up areas. Anthropogenic datasets, including road networks and distance to roads, are sourced from OpenStreetMap and DIVA-GIS.

All datasets are integrated within a GIS environment, standardized to a common resolution, and preprocessed through normalization and encoding techniques to ensure consistency and accuracy in modeling.

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Table1: Key Data Sources for Landslide Analysis

Data Type	Source	Purpose
Landslide Inventory	Geological Survey of India (GSI)	Model training & validation
DEM (Topography)	USGS Earth Explorer	Slope, elevation, terrain analysis
Geological Data	GSI, national databases	Lithology, faults, soil type
Rainfall Data	CHIRPS, CHRS	Trigger analysis
LULC Data	Landsat, ArcGIS Living Atlas	Vegetation & urbanization
Road/Infrastructure Data	OpenStreetMap, DIVA-GIS	Human impact analysis

VI. CONCLUSION

The study of landslide hazard analysis and risk management in Karnataka's Western Ghats highlights the increasing vulnerability of this region to slope failures due to a combination of natural and human-induced factors. Intense monsoonal rainfall, steep terrain, fragile geological formations, and weathered soils create highly unstable slope conditions. At the same time, anthropogenic activities such as deforestation, unplanned urbanization, road construction, and mining further aggravate slope instability and increase the frequency and severity of landslides.

The research emphasizes that traditional methods of landslide assessment, while useful, are limited in their ability to capture complex relationships among multiple influencing factors. The integration of Geographic Information Systems (GIS), remote sensing, and machine learning techniques has significantly enhanced the accuracy and efficiency of landslide susceptibility mapping. Advanced models such as Random Forest, Support Vector Machine, and Gradient Boosting have demonstrated strong predictive capabilities by analyzing nonlinear interactions between environmental variables. These approaches provide reliable tools for identifying high-risk zones and supporting informed decision-making.

However, the study also identifies key challenges, including limited availability of high-quality data, lack of real-time monitoring systems, and insufficient integration of research findings into practical policies. The absence of comprehensive large-scale studies and the underutilization of advanced analytical methods further limit effective landslide risk management. Additionally, the impacts of climate change, particularly changes in rainfall patterns and extreme weather events, add complexity to future landslide prediction and require greater attention.

To address these challenges, a comprehensive and integrated approach is essential. This includes the use of advanced technologies, real-time monitoring, early warning systems, and sustainable land-use planning. Strengthening institutional coordination, improving data quality, and enhancing community awareness are equally important. Overall, adopting a technology-driven and multidisciplinary strategy will be crucial in minimizing landslide risks, protecting lives and infrastructure, and ensuring sustainable development in the Western Ghats region.

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