

COMPREHENSIVE LANDSLIDE SUSCEPTIBILITY MAPPING AND STABILITY ANALYSIS FOR SUSTAINABLE SLOPE MANAGEMENT IN THE MADIKERI REGION

Project Reference No.: 48S_BE_6090

College : *The National Institute Of Engineering, Mysuru*

Branch : *Department Of Civil Engineering*

Guide(S) : *Mrs. Shruthi A N*

Dr. Abhishek A Pathak

Student(S): *Ms. Yashaswini K H*

Mr. Vishwas M R

Mr. Pavan Kumar

Mr. Shankar Prasad P

Keywords:

Landslide, Geospatial analysis, Geotechnical investigations, Sensitivity analysis, Slope stability

Introduction/Background

Landslides, being one of the most destructive natural disasters, have become increasingly severe, particularly with the rapid urbanization occurring in the developing regions of hilly areas. Kodagu district, located in the Western Ghats of Karnataka, India, is an area highly vulnerable to landslides due to its sensitive topography, marked by ridges and steep slopes. This region has been frequently impacted by landslides, including mudslides, and floods, resulting in significant loss of life, such as the tragic events of 2018. The Madikeri region, in particular, is one of the most landslide-prone areas in Kodagu, where high and intense monsoonal rainfall exacerbates the risk. Despite the critical need for landslide susceptibility mapping to ensure safe infrastructure development, there remains a gap in comprehensive research that effectively integrates a range of parameters and advanced methodologies. Addressing this gap is essential to better understand and mitigate the risks posed by landslides, ultimately paving the way for more sustainable and resilient development in the region.

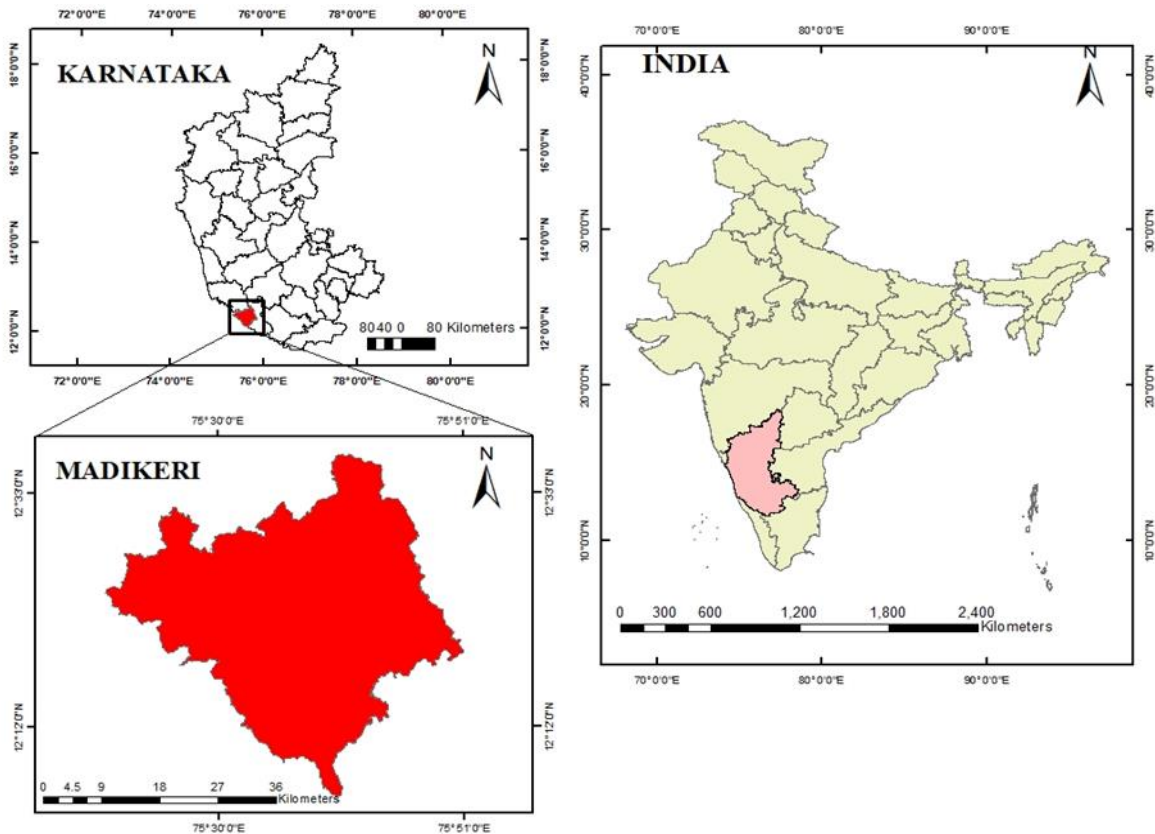


Fig.1: Location map of the study area

This study aims to address this gap by integrating geospatial and geotechnical evaluations to enhance the understanding of landslide dynamics and develop a precise risk assessment framework for the study area. Seventeen various parameters (thematic layers) and a mixture of spatial analysis techniques are considered to identify landslide risk prone zones and also a sensitivity analysis is performed to determine the key parameters influencing landslide.

The results from geospatial techniques identified high-risk regions, where in-situ and laboratory investigations are conducted on soil samples to determine their index and engineering properties. A numerical model is then developed to analyze slope stability, focusing on shear strength characteristics and their variations with water content and soil texture. The Factor of Safety (FoS) derived from numerical model along with geospatial analysis provides insights into the stability of different slopes in the region, enabling the identification of unstable areas in the region. The sensitivity analysis emphasized the crucial role of slope, Topographic Wetness Index, distance to road and rainfall among the various parameters in landslide risk assessment. The use of

geotechnical analysis combined with advanced geospatial techniques, offers a robust approach to landslide susceptibility mapping, which can be replicated in other regions seamlessly. The study offers a robust approach to landslide risk assessment for bureaucrats and policymakers, aiding informed decision-making in landslide disaster risk management, land-use planning, and mitigation strategies, while fostering sustainable development in mountainous areas.

Objectives:

- To develop a sophisticated comprehensive landslide susceptibility map for the Madikeri region by integrating geospatial techniques topographical, geological, vegetation, anthropogenic, hydrological, and hydrological parameters.
- Sensitivity analysis of various factors to identify the most influential parameter for landslides in the Madikeri region.
- Stability analysis of landslide susceptibility slopes for factor of safety using Geo-studio.

Methodology:

Despite the critical importance of landslide susceptibility mapping and geotechnical investigations in ensuring safe infrastructure development, there remains a gap in comprehensive studies that seamlessly integrate diverse parameters and advanced methods. This proposal seeks to bridge this gap by employing a multidisciplinary approach to landslide risk assessment, combining geospatial analyses and geotechnical evaluations(Fig.1).

The process begins with the collection of data sets related to landslide occurrences and various conditioning factors that influence landslide susceptibility. All the conditioning factors shown in Fig.2, Fig.3 and Fig.4 are then reclassified to standardize the different conditioning factors, making them suitable for analysis. The Analytic Hierarchy Process (AHP) is applied to prioritize the conditioning factors based on their relative importance in contributing to landslide susceptibility. Then frequency ratio is calculated for each conditioning factor, which helps in quantifying the relationship between the factors and the occurrence of landslides. Multi-Criteria Decision Making (MCDM) techniques and a Modified Frequency Ratio method, provide a thorough

assessment of landslide susceptibility. Sensitivity analysis will be done subsequently to identify the most influential parameters triggering landslides.

The final output is a landslide susceptibility map that visually represents areas at risk based on the analysed data and methodologies. The susceptibility map is validated using analytical method and then based on the results soil samples will be collected from high-risk areas to conduct geotechnical investigations and a numerical model using GeoStudio will be performed to analyze slope stability focusing on shear strength characteristics and their variations due to water content and soil texture.

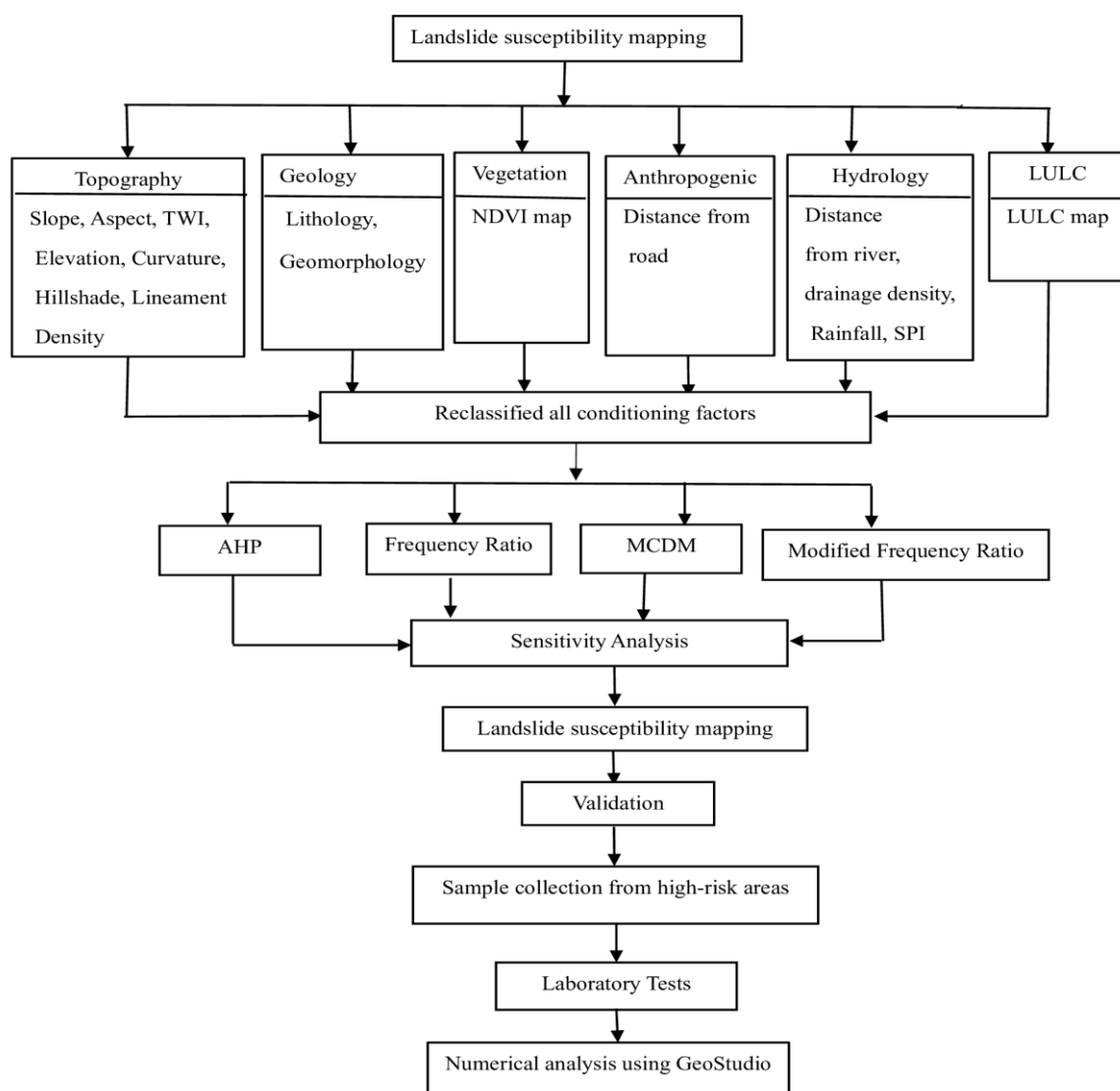


Fig 1: Methodology of the study

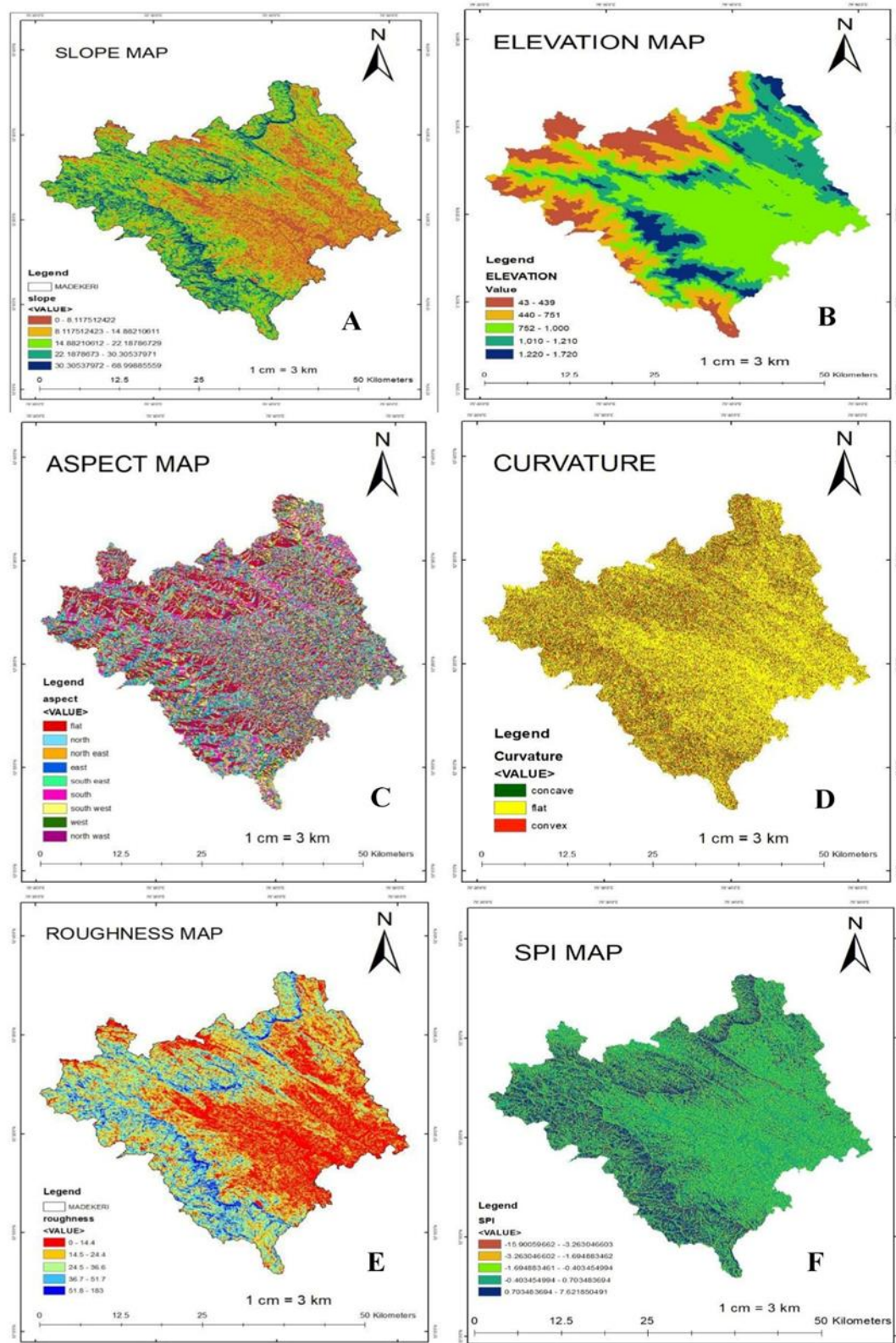


Fig 2: Maps of considered landslide conditioning factors

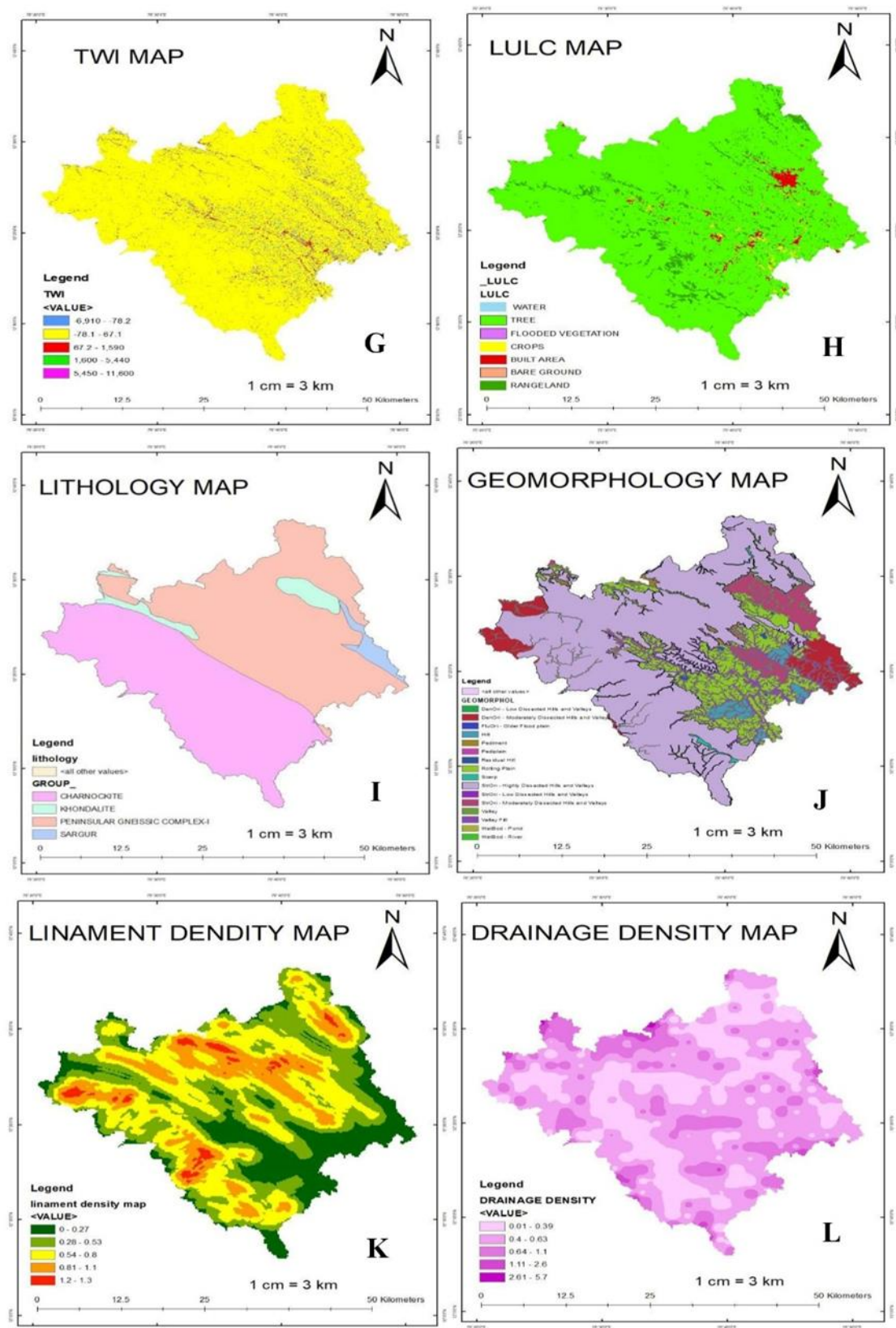


Fig 3: Maps of considered landslide conditioning factors

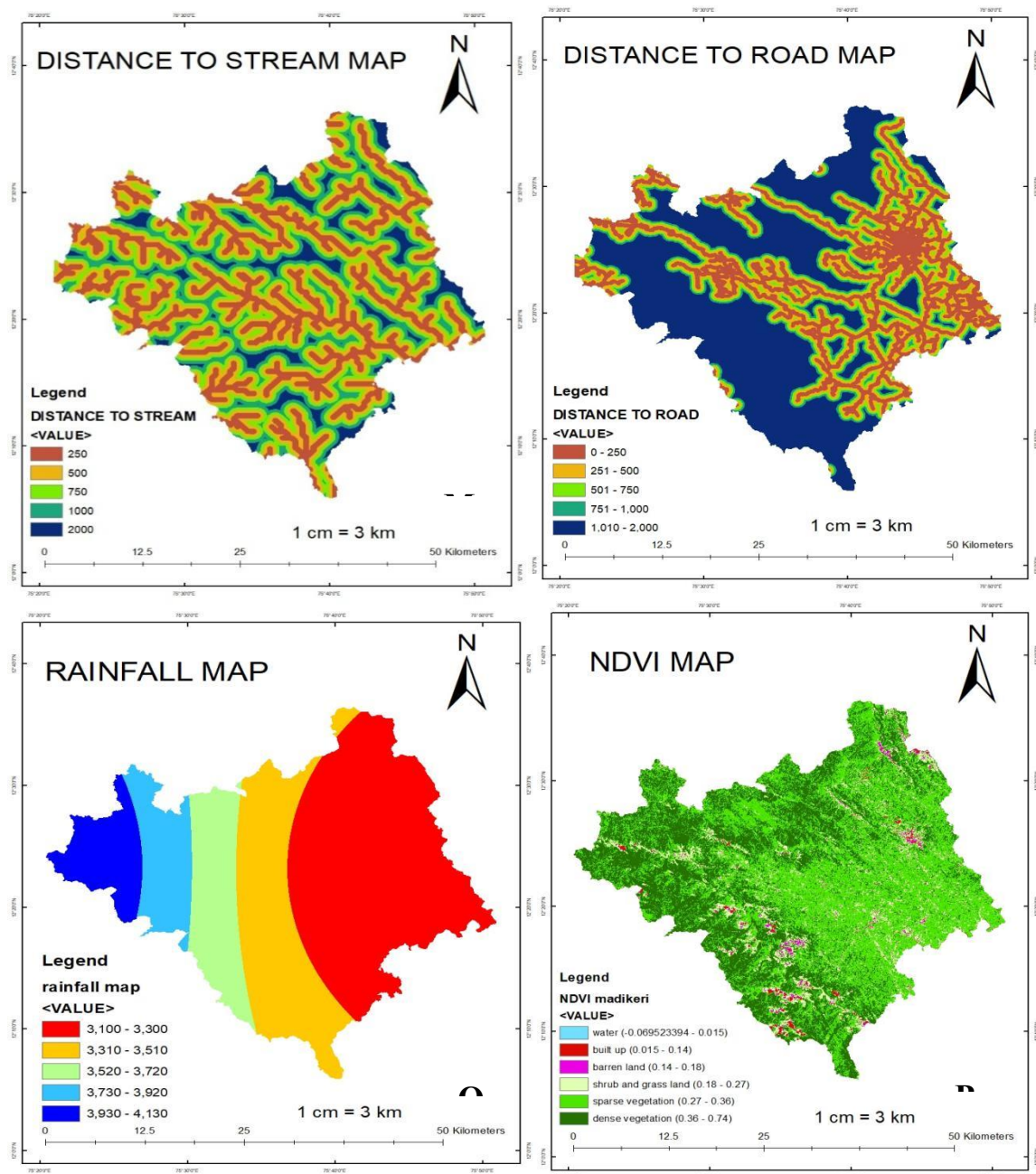


Fig 4: Maps of considered landslide conditioning factors

10. Results & Conclusions

10.1 Analytic Hierarchy Process (AHP)

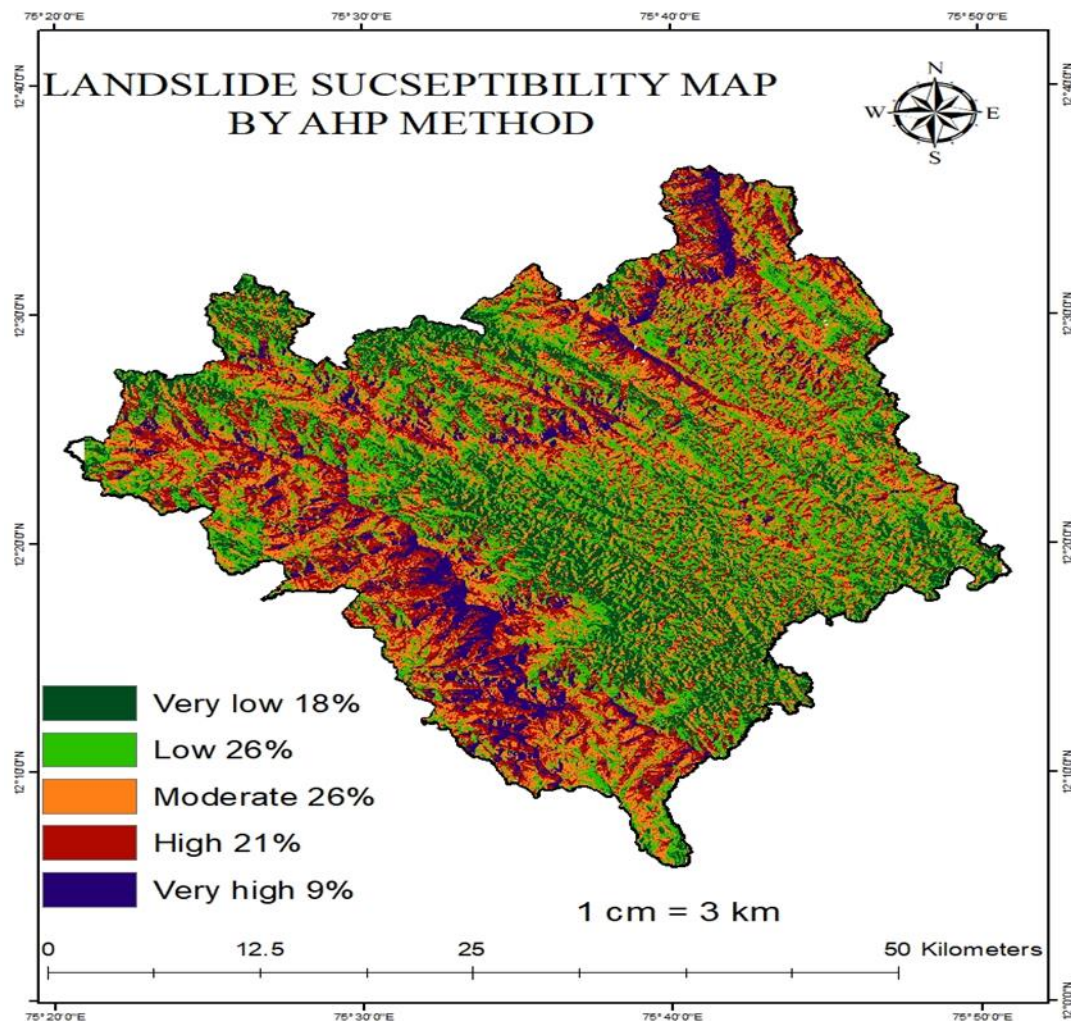


Fig 5: Landslide Susceptibility Map produced by AHP

Based on natural breaks, the resulting LSI map was classified into five classes. Accordingly, 18%, 26%, 26%, 21%, and 9% of the study area showed very low, low, moderate, high, and very high susceptibility area coverage respectively

10.2 Multi-Criteria Decision Making (MCDM)

Weighted Overlay Analysis under MCDM for Landslide Susceptibility Mapping

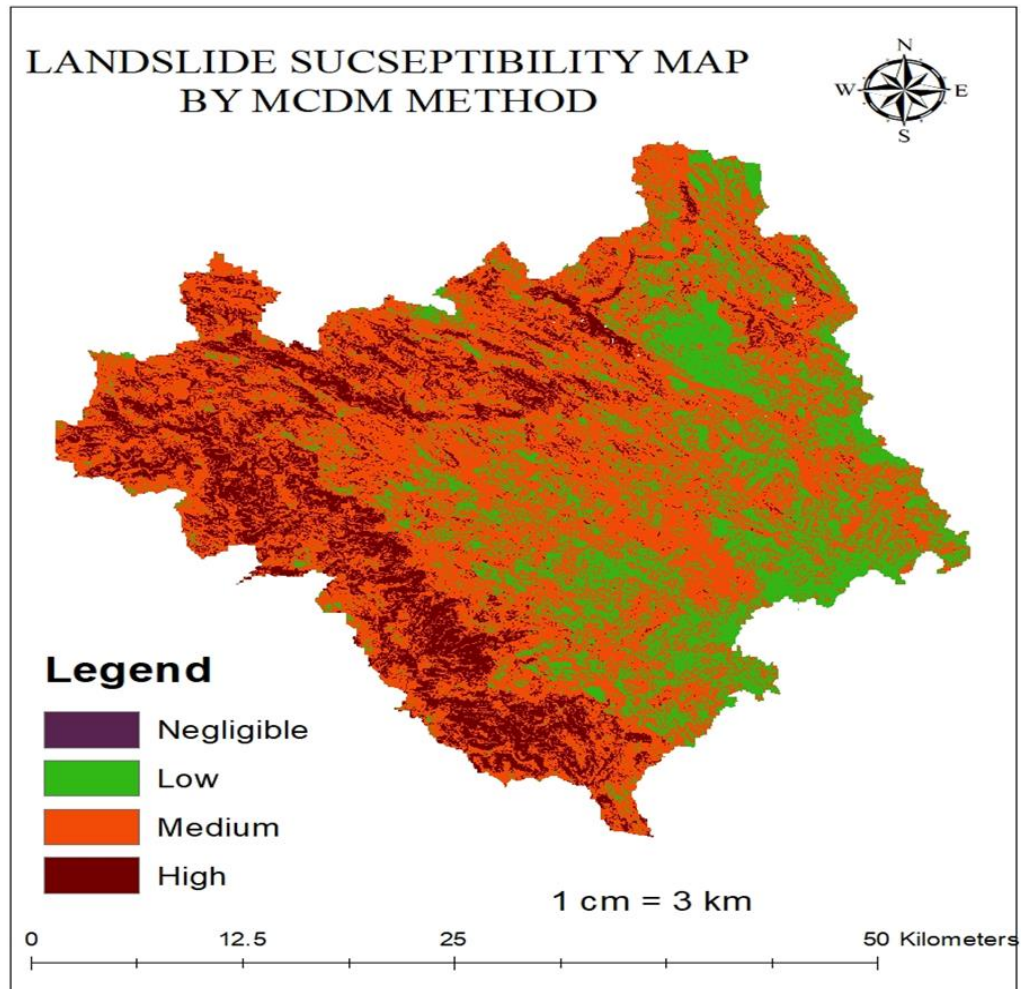


Fig 6 : Landslide Susceptibility Map produced by MCDM

Based on natural breaks, the resulting Landslide susceptibility map was classified into four classes namely negligible, low, medium and high.

10.4 Frequency Ratio

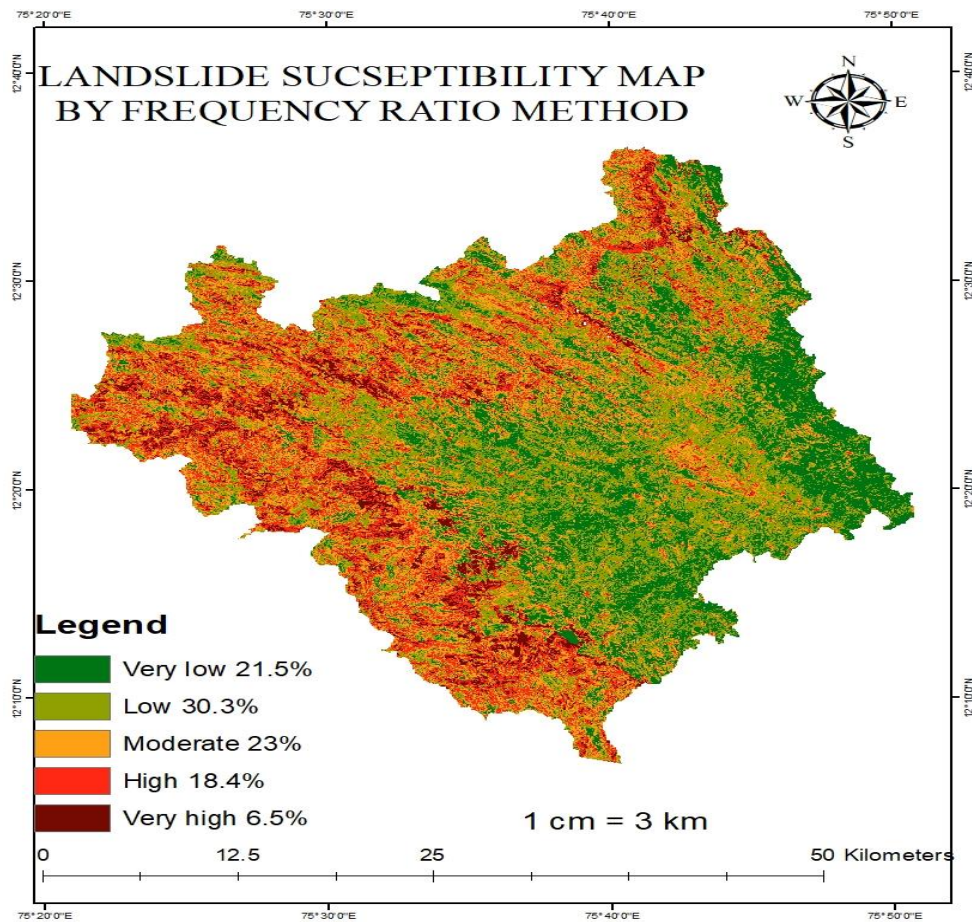


Fig 7: Landslide Susceptibility Map produced by Frequency ratio

10.5 Geotechnical characterization of soils

Based on the susceptibility mapping soil samples were collected from four distinct locations of Madikeri region. The laboratory tests focused on determining index properties, such as water content, specific gravity, unit weight, grain size analysis, and Atterberg limits. Additionally, shear strength parameters were determined using the direct shear test.

Index Properties	Location 1	Location 2	Location 3	Location 4
Sand	78%	77%	60%	68%
Clay	1%	1%	4%	2%
Silt	21%	22%	36%	30%
Liquid Limit	33%	32.7%	37%	38%
Shrinkage Limit	22.1%	33.37%	22.24%	22.28%
Free Swell Index	13%	20%	15%	30%

Table 1: Index Properties of collected soil samples

The susceptibility to landslides in the investigated locations, particularly Location 4, can be attributed to a combination of soil properties that reduce slope stability under certain conditions. Soils with higher silt and clay content, like those found in Locations 3 and 4, tend to retain water, and when saturated, their shear strength significantly decreases, making the slopes more prone to failure. Location 4 also exhibits a high Free Swell Index (30%), indicating the presence of expansive clays that swell when wet and shrink upon drying, leading to soil movement, cracks, and instability over time.

Additionally, the angle of internal friction across all locations is relatively low (18° – 19°), which means the soil particles offer less resistance to sliding. Combined with low cohesion values in some locations (as low as 3–4 kPa), these soils are more likely to fail under stress, especially when subjected to increased moisture from rainfall or irrigation. The variation in permeability, where water easily passes through upper sandy layers and accumulates in finer soils beneath, further increases pore water pressure and weakens the slope. Altogether, these factors create conditions that make these soils vulnerable to landslides, especially in sloping terrains or poorly drained areas.

Tests Conducted	Location 1	Location 2	Location 3	Location 4
Specific Gravity	2.51	2.63	2.57	2.56
OMC(%)	15.4	16.08	14.25	13
MDD(kN/m ³)	17.74	16.90	17.89	18.96
Direct Shear	C=3Kpa $\Phi = 19^{\circ}$	C=4Kpa $\Phi = 19.29^{\circ}$	C= 7 Kpa $\Phi = 19^{\circ}$	C=6 Kpa, $\Phi = 18^{\circ}$
Coefficient of Permeability (mm/sec)	0.083224	0.101473	0.05	0.0168
In Situ Density(kN/m ³)	14.71	15.637	15.16	15.33

Table 2: Engineering Properties of collected soil samples

Work to be Completed:

1. Modified Frequency ratio method
2. Sensitivity Analysis
3. Stability Analysis of Slope.



Fig 10: Sample collection from high-risk regions, Madikeri

Project Outcome & Industry Relevance

Practical Implications of the Project

The integration of scientific data such as pore water pressure, flux vectors, and factor of safety enhances the accuracy of slope stability analysis. This data is crucial for civil engineers and geologists when designing safer infrastructure, particularly in hilly or unstable terrains. It also supports the development of early warning systems and emergency response strategies, improving community preparedness and resilience.

From an academic and research perspective, the project contributes to the field of geospatial hazard modelling by refining methods like Frequency Ratio (FR) and Modified Frequency Ratio (MFR), which are widely used in landslide prediction. The

approach and results can be replicated or expanded for other regions facing similar geological challenges.

In terms of industry applications, sectors such as transportation, construction, hydropower, tourism, and mining can use these insights to avoid risky locations, reduce economic losses, and ensure the safety of assets and people. Overall, the project strengthens the link between data-driven research and practical decision-making in disaster management and land use planning.

Real-World Applications of the Project

Projects on landslide susceptibility mapping and stability analysis are essential for society, as they provide critical information for mitigating landslide risks, protecting infrastructure and the environment, and enhancing community resilience. The study can help in reducing the impact of landslides and create safer, more sustainable communities. The landslide susceptibility mapping and stability analysis are crucial for the **Karnataka State Natural Disaster Monitoring Center (KSNDMC)** in mitigating landslide risks and ensuring public safety. By providing critical data on landslide-prone areas, these projects enable KSNDMC to develop targeted risk reduction strategies, improve emergency preparedness and response, and enhance community resilience.

It is also helpful for the **National Highways Authority of India (NHAI)** to proactively identify high-risk zones and prioritize safer alignments for road projects. This approach not only minimizes potential hazards but also reduces construction and maintenance costs, ensuring the safety and sustainability of infrastructure development in vulnerable areas.

Working Model vs. Simulation/Study:

"The project was primarily a simulation-based and theoretical study, and did not involve the development of a physical working model."

Project Outcomes and Learnings:

Outcomes

1. Detailed maps identifying areas prone to landslides in the Madikeri region, using advanced geospatial techniques by considering 16 distinct parameters. These maps assist in risk assessment and planning for disaster preparedness.
2. The sensitivity analysis identifies the most influential factors contributing to landslides in the Madikeri region. This analysis provides critical insights into the dominant triggers of landslides, enabling targeted mitigation strategies and more accurate risk assessments for safer infrastructure development.
3. Data regarding pore water pressure, flux vector, and Factor of safety against slope failure in Madikeri region. This provides critical data for designing effective mitigation strategies and ensuring slope stability.

Learnings

Through this project, we learned how to use advanced geospatial tools to create detailed maps that show which areas in the Madikeri region are most at risk of landslides. By analysing 16 different parameters — like slope, soil type, rainfall, land use, and more we understood how different environmental and physical factors interact to cause landslides.

Overall, the project gave us a deeper understanding of how geospatial analysis supports disaster risk management, and how data-driven insights can help protect communities from landslide hazards.

Future Scope:

The present study establishes a strong foundation for landslide susceptibility analysis in the Madikeri region using geospatial and geotechnical methods. However, there exists considerable potential to expand and enhance the scope of this research.

Integration with Real-Time Monitoring Systems: The study can be extended by incorporating real-time monitoring tools such as inclinometers, piezometers, and remote sensing data (e.g., from Sentinel-1 SAR) to detect ground deformation and

rainfall-induced saturation, enabling dynamic landslide forecasting and early warning systems.

Machine Learning and AI-Based Modelling: Future studies can leverage advanced machine learning algorithms (e.g., Random Forest, Support Vector Machines, Neural Networks) to increase the predictive accuracy of landslide susceptibility maps. AI-based models can handle larger datasets and capture non-linear relationships between parameters.

Expansion to Larger and Adjacent Areas: The methodology developed for the Madikeri region can be applied and scaled to cover the entire Kodagu district or other landslide-prone districts in the Western Ghats, thereby creating a regional landslide risk atlas.

Policy Integration and Decision Support Tools: The results can be developed into a GIS-based decision support system (DSS) that can be used by local authorities for land-use planning, zoning regulations, and disaster management.

Community-Level Risk Communication: Future efforts can focus on translating the technical results into community-friendly formats (like mobile apps or visual dashboards) to increase public awareness and participation in landslide risk reduction.

Collaboration with Government and Industry Bodies: Partnering with agencies like KSNDMC, NHAI, and municipal planning bodies can help in applying the study findings to real-world projects like road design, housing development, and water catchment planning in hazard-prone areas.