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# LANDSLIDE RISK ASSESSMENT IN RAIGAD DISTRICT USING AHP AND GIS: A MULTI-CRITERIA DECISION-MAKING APPROACH

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## ABSTRACT

*This study presents an in-depth analysis of landslide susceptibility within Raigad district, Maharashtra, through a GIS-based multi-criteria decision-making approach. The research considers slope, aspect, land use, distance from roads, and streams for making a comprehensive map of the landslide susceptibility. The critical zones are the western and central parts of Raigad, characterized by steep slope and a dense drainage network. Pre-existing data on landslides in the paper area is used for validation of the susceptibility map. With the results from the validation, most of the landslides are inside very high or high danger zones projected by the model; hence the model can be said to be accurate and reliable. The present strong validation enables further aid in the enhancement of the credibility of the findings and augments the use of the susceptibility map.*

*The study also looked into the built-up area within proximity of high-risk areas. The proximity of built-up to the very high-risk zones was assessed through buffer analysis, where built-up within 1 km radius of the very high-risk zones was identified. The results explains the potential threat to this region and brings attention to for urgent mitigation measures. Other important causes that have made landslides highly vulnerable include deforestation, agricultural cultivation, and construction activities conducted by human beings. Such studies signal the areas describing the need for sustainable land uses and impositions of strict laws to reduce such threats magnificently. The landslide susceptibility map, along with its validation and proximity analysis, will be useful in providing key information to the planners and administrators of Raigad district. Therefore, the findings stand as a means to protect communities at risk from landslides.*

**Keywords:** Landslide susceptibility, Multi-Criteria Decision-Making (MCDM), Analytic Hierarchy Process (AHP), Geographic Information System (GIS), Site Suitability Analysis.

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## 1. INTRODUCTION

Landslides are one of the most frequent but very damaging natural disasters in India, particularly in areas where hilly and mountainous terrain dominates. large areas prone to landslides include the Western Ghats and the Himalayas in Northeastern hill states, featuring steep slopes and complex geology coupled with high values of rainfall. Add to this the recent increase in climate change, combined with unchecked human activities like deforestation and infrastructure development that further intensifies these incidents, also contributes to increase the frequency and intensity of these occurrences across the country.

Landslides are quite a frequent and disabling natural hazard in India, particularly in the hilly and mountainous regions of the country. **[2]** The history of landslides has been characterized by a plethora of incidents, which have resulted in huge loss of life and property damage, besides disrupting infrastructure. An appreciation of the history of landslides in India can be understood and placed in its geographic context only when this topic is dealt with in the same way. Landslides evidence has been found in Indian history dating back to ancient times, but proper records have been maintained only during the British period.**[12]** During that time, a number of landslides were reported in the Himalayas, more specifically related to some of the road and railway constructions done by the British. In the 19th and early 20th centuries, there have been many reported landslides in the Darjeeling Himalayas, Nilgiris, and other hill stations, causing serious disruptions. For example, critical infrastructure was damaged by the 1899 Darjeeling landslide.**[13]** During the post-independence period, there was the 1950 Assam earthquake, of Magnitude 8.6. The massive earthquake triggered many landslides throughout the Northeastern region, with primary concentration in Assam and Arunachal Pradesh. This process of catastrophe widely affected human life. Since then, there are multiple landslides across India like 1968 Darjeeling Landslides and 1970 Alaknanda Floods and Landslides. 2013 Uttarakhand Floods and Landslides was one of the worst natural disasters ever, and in excess of 5,000 people lost their lives in the 2013 floods and landslides in Uttarakhand. The Kedarnath area was seriously affected, and the landslides swept away entire villages.**[14]**

## 2. FACTORS INFLUENCING LANDSLIDES IN INDIA.

The geographic diversity of India plays an important role in the occurrence and distribution of landslides within the country.**[15]** The topography of the country comprises several regions that are relatively more prone to landslides due to geological, climatic, and human-induced characteristics. The most prominent and landslide-prone region in India is the Himalayan belt, stretching through the northern states from Jammu and Kashmir in the west to Arunachal Pradesh in the east.**[16]** The Himalayas are an example of a young, tectonically active mountain chain still undergoing geological processes thus giving rise to landslides very commonly. **[17]** Moreover, the steep slopes combined with the loose and fragmented geological structure of rock masses forms a critical setting of this region for slope failures. During the monsoons, when heavy downpours dampen the soil," saturation reduces to the stability of the slope which as a result frequently forms catastrophic landslides in the region.". Moreover, the seismic activity in the Himalayas, which continued to collide Indian and Eurasian tectonic plates, creates the potential for a landslide, particularly where there are pre-existing geological weaknesses.**[17]**

The other main mountain range of India—the Western Ghats, running up and down along the west coast—is also susceptible to landslides, particularly in the states of Kerala, Karnataka, and Maharashtra.**[19]** The Western Ghats generally consist of steep mountains with heavy torrential rains throughout the monsoon season; this often causes landslides.**[19]** Therefore, in this hilly region covered with dense vegetation and having torrential rainfall, landslides are a common feature, and its activity is more pronounced in the regions where haphazard deforestation and unplanned development have disturbed the natural stability of the slopes.**[20]**

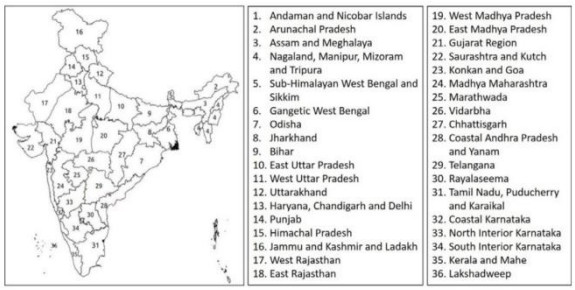


**Fig. 1** Meteorological sub-divisions of India (2020) (Source : IMD web site **https://mausam.imd.gov.in)** [18]

Mainland states that are prone to landslides are Assam, Meghalaya, and Arunachal Pradesh, which belong to the Northeastern part of the country. This region is a part of the Eastern Himalayas, Patkai, and Naga hills, supporting their very unstable geological configuration, coupled with heavy rainfall. The intense rain amount, coupled with seismic activity during the monsoons, causes frequent landsliding on the subcontinent's mainland. Moreover, the thick vegetation and complexed topography complicate the scenario, making landslides a major threat in this part of the country.

Other hill stations that have highlighted landslides are the Nilgiris of Tamil Nadu, and Odisha and Andhra Pradesh of the Eastern Ghats, though on a relatively much smaller scale compared to the Himalayas and the Western Ghats. In particular, the Nilgiris has a very long history of landslides, which are mostly generated by very intense monsoon rainfall.**[21]** The deeply weathered soil can easily get saturated within very quick short durations, thus causing landslides on steep slopes.

Other than these natural factors, different human activities have increased the potential landslide hazard in the country, particularly in many areas of India. Deforestation, construction of roads, mining, and unplanned urbanization are responsible for destabilizing slopes, making them prone to landslides.**[22]** Besides, the removal of vegetation that would normally bind the soil leads to increased chances of landslides, especially during heavy rainfall.In general, landslide-prone regions in India are shaped by both geological and climatic factors, as well as human-induced ones; therefore, landslides consistently form one of the important natural hazards occurring time and again in different parts of the country.

## 3. LANDSLIDE SUSCEPTIBILITY ANALYSIS

Landslide Susceptibility Analysis is one of the most important process of defining the areas prone to landslides and assessing the potential-related risk. This susceptibility analysis becomes very important in land use planning, disaster management, and interventional. This helps in order to mitigate the impacts of landslides on human lives, infrastructure, and the environment. The GIS incorporation into Multi-Criteria Decision Making (MCDM) has enhanced the capability and provided faster and more accurate results for the susceptibility analysis of landslides.**[1]** It seeks to identify and assess factors causing considerable potential susceptibility.

Broadly, these can be factors that are either intrinsic, in relation to the physical and geological characteristics of the area, or extrinsic, in relation to external influences like rainfall or human activities. The following are some of the key factors considered while undertaking landslide susceptibility analysis: Slope Gradient, Geology and Soil Type, Land Use and Vegetation Cover, Hydrological Conditions, Seismic Activity, and Human Activities**.[4]** The susceptibility analysis for landslides attempts to demarcate areas into different susceptibility zones based on the combination of these factors, running from low to high risk. Such information is crucial to decision-makers in the implementation of proper policies of land use and mitigation measures. **[3]**

## 4. STUDY AREA

Raigad district is located in Maharashtra's Konkan division, India. It is a region located within Western Ghat prone to landslides due to its geographic and climatic conditions.**[18]** The typical features of the area, steep slopes, dense forests, and heavy monsoon rainfall, make it prone to landslides. The area has a history of landslides, which are often caused by the heavy rainfall during the monsoon season. More recently, in 2014, a massive landslide took place in Malin village in the neighboring Pune district.**[23]** The landslide history, combined with the district's challenging topography, warrants a detailed landslide susceptibility analysis. It is imperative to understand the contributory factors to landslides in this region with regard to effective land-use planning and disaster risk management.

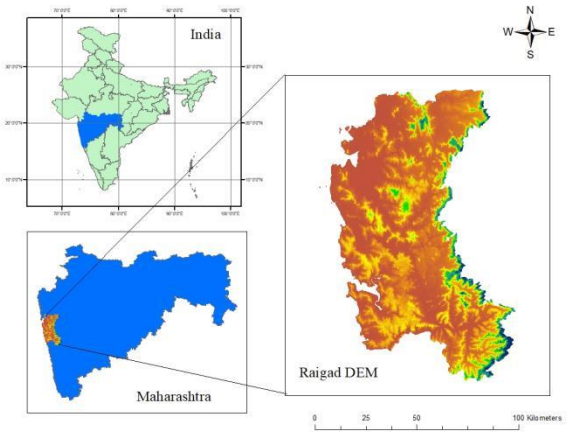


**Fig. 2** Study area map showing location of Raigad in India

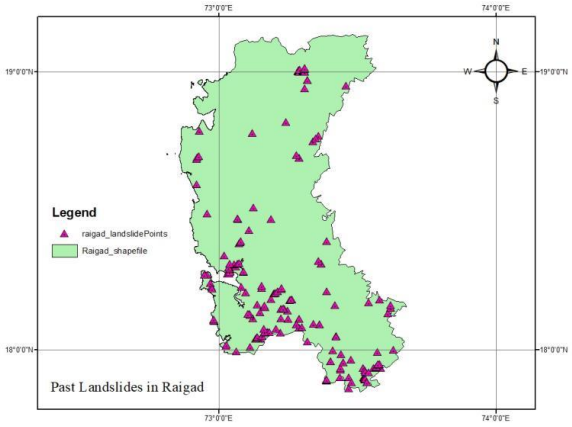


**Fig. 3** Past Land slides in Raigad (Source GSI, GoI 2023 [6])

## 1. METHODS AND METHODOLOGY

The methodology for landslide susceptibility analysis in Raigad district combines Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) techniques. The study begins by identifying the factors influencing landslides in the region, such as slope, rainfall, soil type, land use/land cover, distance from rivers, and proximity to fault lines.

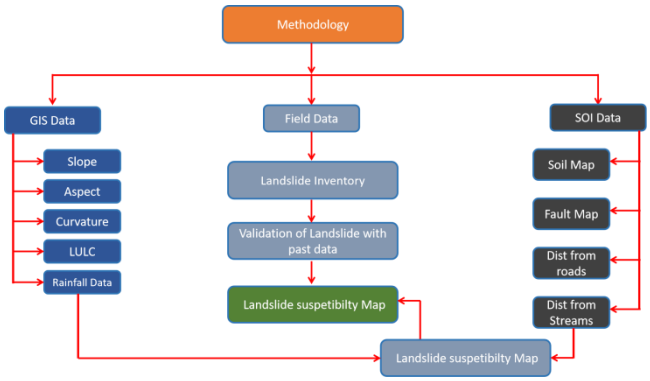


**Fig. 4** Methodology of landslide suspetibility analysis combining MCDM and AHP

GIS is employed to collect, process, and analyze spatial data related to these factors, creating various thematic layers that represent the landslide-contributing parameters. AHP is then used to assign weights to these factors based on their relative importance in triggering landslides. The pairwise comparison method within AHP helps in determining these weights, which are subsequently integrated into the GIS environment. By overlaying the weighted layers, a landslide susceptibility map is generated, categorizing the district into zones of varying landslide risk—ranging from very low to very high susceptibility. The results are validated using historical landslide data, ensuring the accuracy and reliability of the susceptibility model. This integrated approach of GIS and AHP provides a comprehensive and systematic method for assessing landslide risk, facilitating better land-use planning and disaster management in Raigad district.

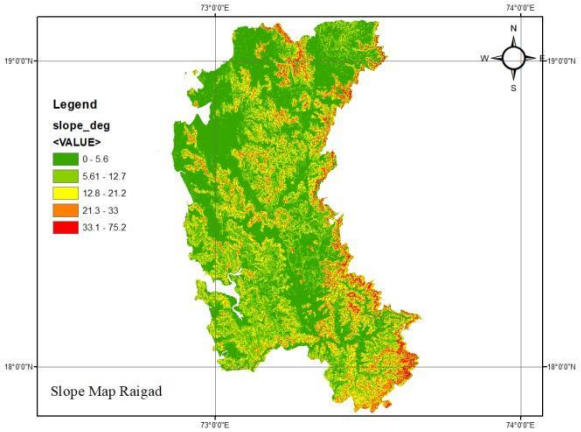


**Fig. 5** Slope of Raigad in Degrees (United States Geological Survey-2014) [9]

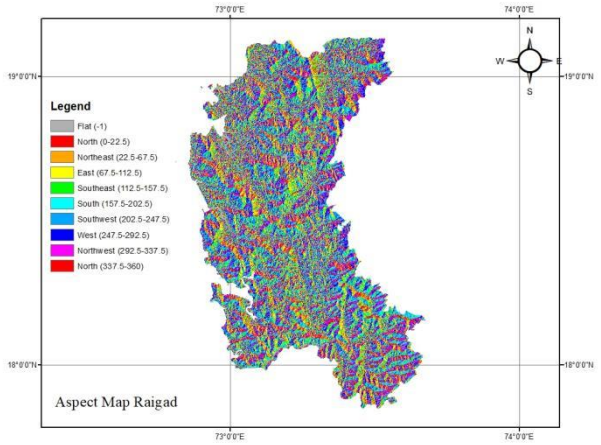


**Fig. 6** Generated aspect map of Raigad

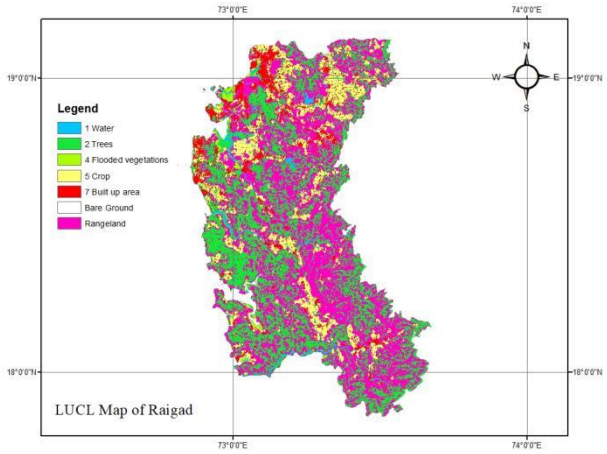


**Fig. 7** Land Use Land cover map of Raigad (As of 2023) [8]

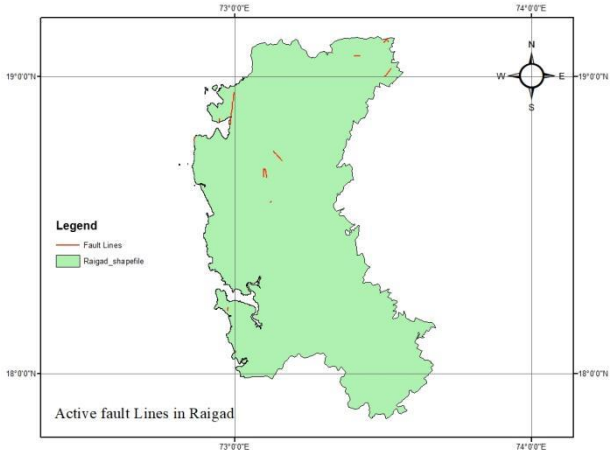


**Fig. 8** Active fault Lines in Raigad (Source GSI, GoI 2023 [6])

The validation stage of this methodology is done where the inventory of the landslides is cross-checked with the past data of landslides. Accuracy of the model becomes perfect. It has to check whether the area, which was shown susceptible according to the model, has had the landslide actually occurred in the past. This would be used to demonstrate the confidence of a model, and one can, therefore, know the future landslide events from the same. In this light, this validation step has to be done to ascertain and guarantee the credibility and robustness of the final sensory susceptibility map.

# 6. RESULTS

## 6.1. Distribution of Landslide Susceptibility:

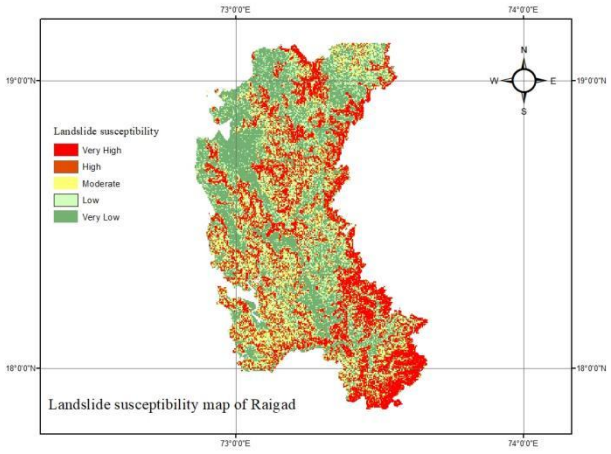


**Fig.9** Generated Landslide susceptibility map of Raigad

The above map is showing analysis of the susceptibility to landslide in Raigad district revealed tremendous variation across the area, which spreads from very high and high susceptible that are highly located along steep slopes, more precisely on the western and central parts of the district. Further, as the key purpose for this susceptibility map is considered for planning with mitigation purposes, it can be seen that a major portion of the district is considered prone to landslides, and hence efforts need to be put in place in such zones.

## 6.2 Classification of Area:

**i.Very High Susceptibility Zone:** This zone forms very important concern zones, since they take up quite a large area of the district, with very high slopes and very dense drainage networks. The analysis thus indicates these areas to emerge as the most susceptible to landslides, so improvement measures are urgently taken along with perpetual monitoring.

**ii.High Susceptibility Zone:** Zones of high risk deserve very high attention, as these are the most susceptible to landslides. These are mainly found adjacent to very-high-susceptibility areas and seem to be governed by similar geomorphologic factors.

**iii.Moderate, Low and Very Low Susceptibility Zones:** These are moderate and low susceptibility enclaves that include areas which are less sensitive, mainly in the flatter sections of the district. Even though the areas are relatively safer, they are not risk-free and as such not given enclose monitoring as a matter of priority but instead should have closer vigil during highly sensitive weather conditions.

## 6.2 The distance of built-up area to the High-Risk zone:

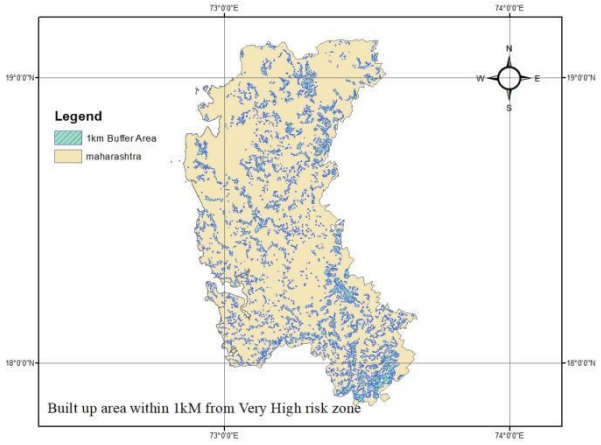


**Fig. 10** Build up area that are within 1 km from very high risk zones

The study also found that these constructed areas came within a 1 km radius from the highly hazardous landslide area. In this context, the settlement raises questions about the safety and sustainability of the dwellers. Hence development planning in these areas has to emphasize landslide mitigation with suitable structural measures to minimize risks to human life and property.

## 6.3 Validation of results

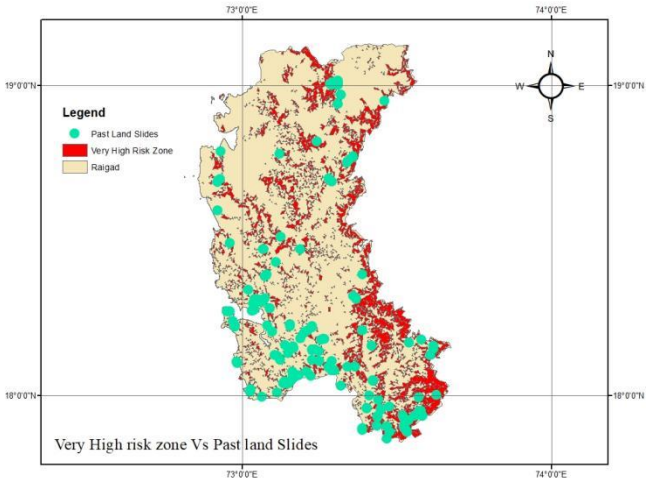


**Fig. 11** Past Land slides in Raigad (Source GSI, GoI 2023 [6])

This model recovered good evidence of the accuracy because the landslide susceptibility map was validated against historical landslide data. Nearly all historical landslides which are listed by Geographic Survey of India study as mentioned in [6] fit between the very high and high susceptibility zones defined by the model. This might be as very good correlation and that based on GIS information, it has effectively managed to capture important factors that contribute to landslide occurrence in the region. A successful validation process would raise confidence in the model prediction, and this would promote its application in future mitigations of landslide risks.

## CONCLUSION

The analysis revealed many parts of the Raigad district to be very highly prone to landslides. A multicriteria decision-making approach, based on the GIS, had been impacted to use the factors slope, aspect, land use, proximity to road and proximate to stream for incorporation in the analysis, intending to yield a complete landslide susceptibility map. These results indicate that the western and central parts of the district occur as the most pronounced areas of landslides with the help of steep slopes and dense drainage networks. This part of the district is in dire need of working-on mitigating measures and continuous monitoring.

It was also validated through historical landslide events listed by Geographic survey of India, proving once again modeling accuracy in terms of prediction since most of the landslide occurred in high and very high-risk zones. This is an additional evidence regarding the model's robustness and possible advantages in guiding future rehabilitative efforts associated with landslide management. On the other hand, their proximity to built-up areas presents an additional reason for adequate urban planning and establishment of structural measures that provide the required safety.

It is the established fact that landslide-prone areas very much have become susceptible with the process of deforestation, agricultural expansion, and recently with the construction. The urgent requirement of sustainable land use and stringent regulations are major findings of the study that can minimize these human-induced risks.

### Key Points:

**High Risk Zones:** The highest landslide incidence are in the western and central Raigad, which has steep slopes and dense drainage.From the historical landslide data, the inference is that the high and very high-risk zones are conforming to the model.

**Built-Up Areas:** Settlements need to be at a safe distance from the zones in high risks. It also required for adequate urban and structural safety.

**Human Impact:** Deforestation, agriculture construction places human life at greater risk by landslides- hence sustainable practices.

**Use for Planners:** The model shall be a useful tool for urban land utilities planners, disaster preparedness, and infrastructure.

This shall act as a key input to the Raigad administration and planners for risk reduction associated with landslides and overall improvement of safety of important zone areas.

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