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Landslide susceptibility assessment of the high range areas in Thiruvananthapuram district (Southwest India) using the MCDA-AHP model and geospatial techniques

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Abstract

Landslides are one of the most frequent hazards occurring in the mountainous terrain of the Western Ghats. The purpose of this study is to use the analytical hierarchy process approach to identify landslide-susceptible zones in the Western Ghats region of Thiruvananthapuram district. A total of 11 conditioning factors were evaluated in the susceptibility modelling. A landslide susceptibility map was created using satellite data and geographic information systems (GIS), and the study area was segmented into five susceptible zones using the natural breaks method. The AHP method of landslide susceptibility modelling identified 14.76% of the area as a very high-susceptible zone. The receiver operating characteristic (ROC) technique was used to validate the created landslide susceptibility map. The landslide susceptibility map produced using the AHP model is confirmed as having excellent and outstanding prediction capability for the training and validation datasets, based on the area under the ROC curve (AUC) value. When it comes to implementing landslide mitigation techniques, decision-makers and land-use planners will find the map quite valuable.

1. Introduction

Landslides are one of the most common and frequent natural hazards in India's Western Ghats, resulting in significant property loss and causalities (Akshaya et al. 2021). As a result, a susceptibility map with enhanced prediction capabilities is required for the execution of appropriate mitigation measures (Thomas et al. 2021).

The purpose of this study is to use the MCDA-AHP model to determine the susceptibility of the Western Ghats region of Thiruvananthapuram district. The study area has a history of disastrous landslide disasters, the most catastrophic of which was the Amboori landslide disaster, which occurred on November 9, 2001 and killed 39 people (Kuriakose et al. 2009). Slope angle, land use/land cover (LULC), lithology, soil texture, road buffer, lineament buffer, normalized difference road landslide index (NDRLI), normalized burnt ratio (NBR), modified normalized difference water index (MNDWI), normalized difference built-up index (NDBI), and advanced vegetation index (AVI) were among the 11 conditioning factors used in the modelling.

2. Method

2.1. Study area

The study area encompasses 647.12 km^2 and is located between 8°25' and 8°52' N latitudes and 77°0' and 77°18' E longitudes (Fig. 1). The elevation varies between 21 and 1828 m, with the highest values along the eastern boundary. This area encompasses nine villages in the Thiruvananthapuram district, namely Amboori, Keezharoor, Mannoorkara, Ottasekharamangalam, Peringamala, Thennoor, Vazhichal, Vellarada, and Vithura.

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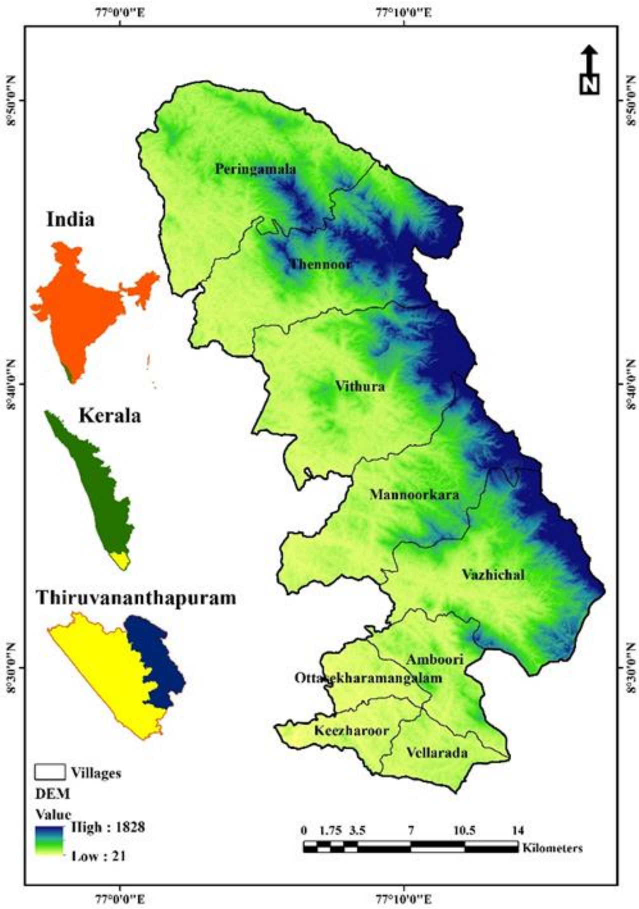

Figure 1. Location of the study area

2.2. Conditioning factors

The slope was computed from the ASTER GDEM using the ArcGIS 10.8 spatial analyst (surface) tools. The LULC types were extracted from the Landsat 8 OLI satellite images using the ERDAS Imagine 9.2 software. Various LULC types were classified using the maximum likelihood classification method (Thomas et al. 2021). The lithology was extracted from the lithology map published by the Geological Survey of India (GSI) using ArcGIS tools. The soil data was extracted from the soil map published by the National Bureau of Soil Science and Land Use Planning (NBSS&LUP) using ArcGIS tools. The road networks were extracted from the Survey of India topographic maps and updated using Google Earth Pro data, and the buffer distance of 100 m was derived using spatial analyst tools. The lineaments were derived from the Bhukosh portal (https://bhukosh.gsi.gov.in/Bhukosh/Public) of GSI, and the buffer distance of 100 m was derived using spatial analyst tools. NDRLI, NBR, MNDWI, NDBI, and AVI were calculated from the Landsat 8 OLI image using ArcGIS raster calculator tools. NDRLI, NBR, MNDWI, NDBI, and AVI were computed using Eq. 1 (Zhao et al. 2018), Eq. 2 (Delcourt et al. 2021, Roy et al. 2006), Eq. 3 (Xu 2006), Eq. 4 (Zha et al. 2003), and Eq. 5 (Bera et al. 2020), respectively. The thematic layers of the continuous factors and output map were classified using the natural breaks (Thomas et al. 2021) method.

$$\text{NDRLI} = \frac{(\text{SWIR1} - \text{Blue})}{(\text{SWIR1} + \text{Blue})} \quad (1)$$

$$\text{NBR} = \frac{(\text{NIR} - \text{SWIR})}{(\text{NIR} + \text{SWIR})} \quad (2)$$

$$\text{MNDWI} = \frac{(\text{Green} - \text{MIR})}{(\text{Green} + \text{MIR})} \quad (3)$$

$$\text{WRI} = \frac{(\text{SWIR1} - \text{NIR})}{(\text{SWIR1} + \text{NIR})} \quad (4)$$

$$\text{AVI} = [\text{NIR} + 1(1 - \text{Red})\text{x}(\text{NIR} - \text{Red})]^{1/3} \quad (5)$$

where SWIR, Blue, NIR, Green, MIR and Red stand for spectral reflectance in short wave infrared, blue, near-infrared, green, mid infrared and red bands, respectively.

2.3. AHP modelling

The AHP method for multi-criteria decision analysis was developed by Thomas L. Saaty (Saaty 1980). This approach is used to organize complex problems into a hierarchy and determine the best solution (Qazi and Abushammala 2020). The AHP method's ability to detect pairwise rating inconsistency is another noteworthy feature (Mondal and Maiti 2013). The most significant steps in AHP modelling are to generate a matrix for pair-wise comparisons and to compute the eigen vector, weighting coefficient (Table 1), and consistency ratio (Table 2) (as in Akshaya et al. 2021; Thomas et al. 2021).

2.4. Validation of the susceptibility map

ROC curve method (Thomas et al. 2021) was used to validate the susceptibility map. SPSS software was used to compute the AUC value. The validation was performed using landslide incidence data from the National Remote Sensing Centre and GSI. The total number of landslides, 100, was split into training datasets (70%) and validation datasets (30%).

3. Results

According to the AHP modelling, the key causal factors include LULC, NDRLI, road buffer, slope angle, and soil. Moderate slopes, gravelly clay and loamy soil, agricultural land, higher NDRLI values, and more road cuttings characterize the high and very-high susceptible zones. The susceptibility map developed using the MCDA-AHP method has AUC scores of 0.896 (training dataset) and 0.931 (validation dataset), confirming that the results have excellent and outstanding prediction capabilities for these datasets (Fig. 2). The high and very-highly susceptible zones together constitute 47.5% of the study area, according to the map developed using the AHP approach. The landslide susceptibility map is depicted in Figure 3.

Table 1. Pairwise comparison matrix

	Slp.	LULC	NDRLI	RB	Litho.	Soil	NBR	MNDWI	NDBI	LB	AVI	Vp	Cp
Slp.	1	2	3	4	5	6	7	8	9	10	11	3.202	0.187
LULC	1/2	1	2	3	4	5	6	7	8	9	10	2.462	0.144
NDRLI	1/3	1/2	1	2	3	4	5	6	7	8	9	1.848	0.108
RB	1/4	1/3	1/2	1	2	3	4	5	6	7	8	1.413	0.082
Litho.	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	1.271	0.074
Soil	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	1.244	0.073
NBR	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	1.221	0.071
MNDWI	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	1.194	0.070
NDBI	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	1.158	0.067
LB	1/10	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	1.105	0.064
AVI	1/11	1/10	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	1.038	0.060
∑	3.02	4.93	7.83	11.72	16.59	22.45	29.28	37.08	45.83	55.50	66.00	17.16	1.00

where Slp. = slope, RB = road buffer, Litho. = lithology, and LB = lineament buffer

Table 2. Normalized matrix

	∑ rank	[C]	[D] = [A]*[C]	[E] = [D]/[C]	λmax	CI	CR
Slp.	3.03	0.275	3.368	12.236			
LULC	2.23	0.202	2.506	12.386			
NDRLI	1.63	0.149	1.737	11.689			
RB	1.20	0.109	1.332	12.173			
Litho.	0.89	0.080	0.957	11.897			
Soil	0.65	0.059	0.683	11.594	**11.648**	**0.065**	**0.045 (4.47%)**
NBR	0.47	0.043	0.486	11.324			
MNDWI	0.34	0.031	0.345	11.143			
NDBI	0.25	0.022	0.248	11.096			
LB	0.18	0.016	0.183	11.198			
AVI	0.14	0.012	0.141	11.388			
∑	**11.00**	**1.00**		**128.124**			

4. Conclusion

Moderate slopes, gravelly clay and loamy soil, agricultural land, greater NDRLI values, and more road cuttings are found in the high and very-highly susceptible zones. The AUC values proved that the created map and AHP approach are effective in demarcating landslide susceptibility and can be used in locations with similar physiographic settings. The map is very useful for land-use planners to determine which villages are most susceptible to landslides. The susceptibility map can be used by decision-makers to detect landslide-prone roads and settlements. This will allow them to take the appropriate mitigation measures to protect people, infrastructure, and property; save money on relief and building efforts; and stop development activities in these areas.

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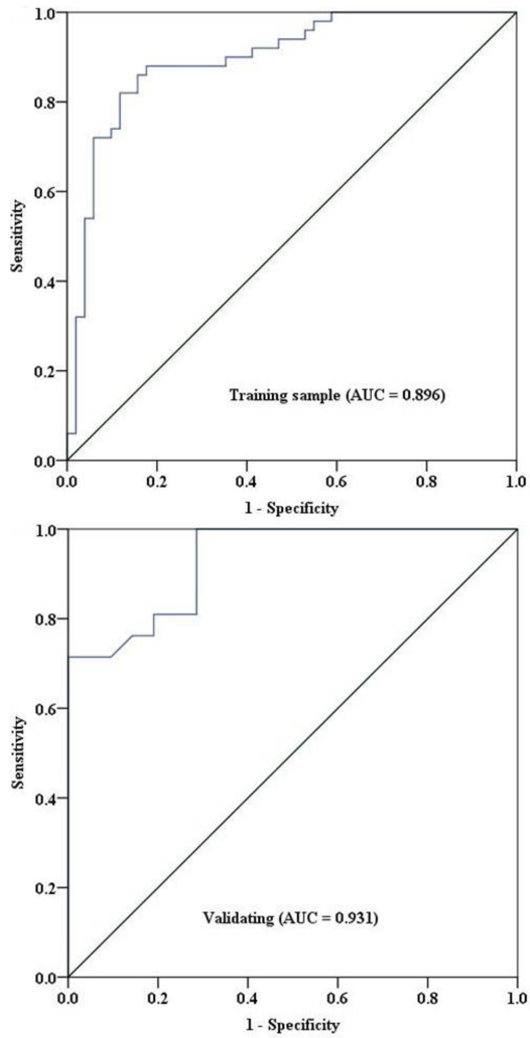

Figure 2. The ROC curves

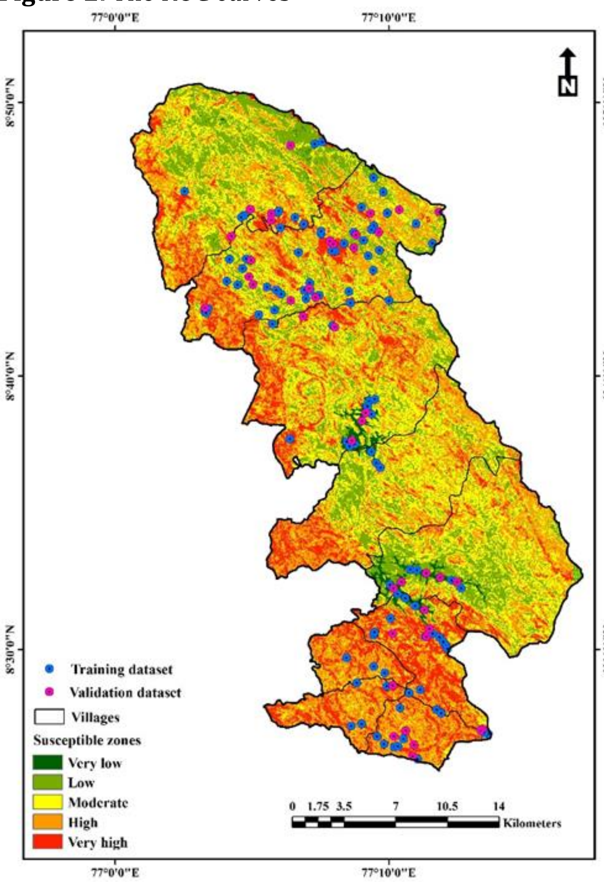

Figure 3. Landslide susceptible zones