Evidential belief Function (EBF) model Integration with GIS for Landslide susceptibility analysis in Idukki District, Kerala.

ABSTRACT:

A Geo-statistical Dempster-Shafer theory Evidential Belief Function(EBF) model was selected for Landslide susceptibility evaluation. The objective of the study is to predict the susceptible zones of Landslide in the Idukki District, Kerala using the EBF model and Geographical Information System (GIS) Technique. Topographical, Anthropogenic, and Geological factors are considered Landslide Conditioning Factors (LCFs), and Landslide Inventory data are used to establish Landslide Suscebtle zones. Landslide inventory data is divided into Training(70%) and Testing (30%) data. The resultant Landslide Susceptibility map is categorized into five zones very low, low, medium, high, and very high respectively in the study area. The success rate and prediction rate were calculated using the AUC_ROC method and the EBF Model achieved the highest precision with a success rate of 0.935, and a prediction rate of 0.943 in the current study.

Keywords:Dempster- Shafer theory,Landslide susceptibility,Evidence Belief Function, AUC-ROC, GIS.

1. Introduction:

Landslides are the most happening natural geographical hazard in the western Ghat region, Kerala. Thus, as landslides can result in fatalities and significant damage to Human settlements, their systematic prediction and avoidance are crucial components of land use planning(Park, 2011).According to the Kerala State Disaster Management Plan 2016(Kerala State Emergency Operations Centre, 2016)(Solanki et al., 2019), Kerala is prone to recurring landslides, with debris flows being the most common occurrence.

2. **Materials and Methods**:

2.1 Study Area

The study area is Idukki district (Figure 1) in the Western Ghats region(Akshaya et al., 2021), Kerala, located between Longitude 76°.62′, and 77°.41′, Latitude 9°.27′, 10°.35′ covers a geographical area 5004.55 sqkm. The district shares boundaries with the districts of Pathanamthitta to the south, Thrissur to the north, Kottayam district to the west, and Tamilnadu to the east(Directorate of Census Operations, Kerala, 2011). The flowchart depicted in Figure 2illustrates the methodology utilized in the study and is briefly explained in the mentioned below sections.

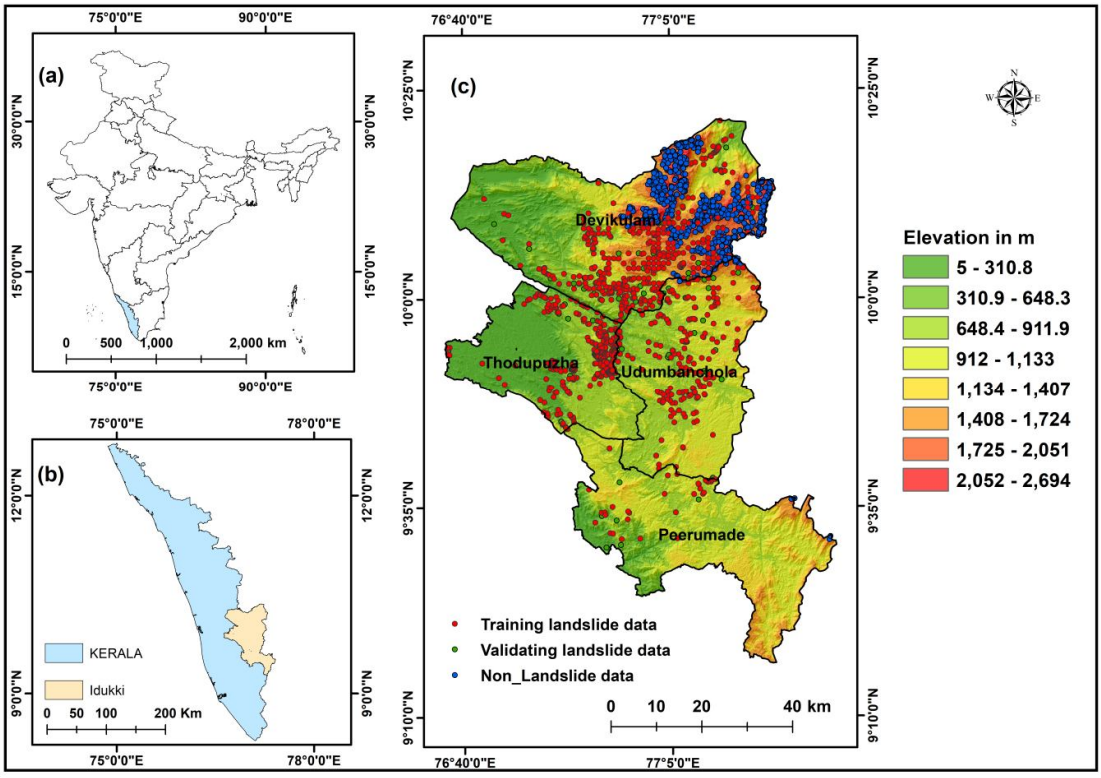

Figure 1 Location Map of the Study Area

2.2 Landslide Inventory Data:

It was prepared by 1,850 historical landslide points that were identified from historical records (NASA-Co-operative Open Online Landslide Repository(COOLR) (NASA) and Google Earth dataset(Ali et al., 2021).

2.3 Landslide conditioning factors:

The magnitude of the landslide depends on Topographical (Slope, Elevation, profile Curvature, Aspect, Relief amplitude, slope classes, Topographic Wetness Index(TWI), Topographic Position Index(TPI), Topographic Ruggedness Index(TRI), Sediment Transport Index(STI), Stream Power Index(SPI))(Poddar & Roy, 2024), Hydrological (Rainfall, Distance to Drainage(DTD)), geological (lithology, distance to lineament, and geomorphology), Environmental (Normalized Difference Vegetation Index(NDVI), Land use/Land cover(LU/LC)), and Anthropogenic factors (Distance to Road(DTR))**.**

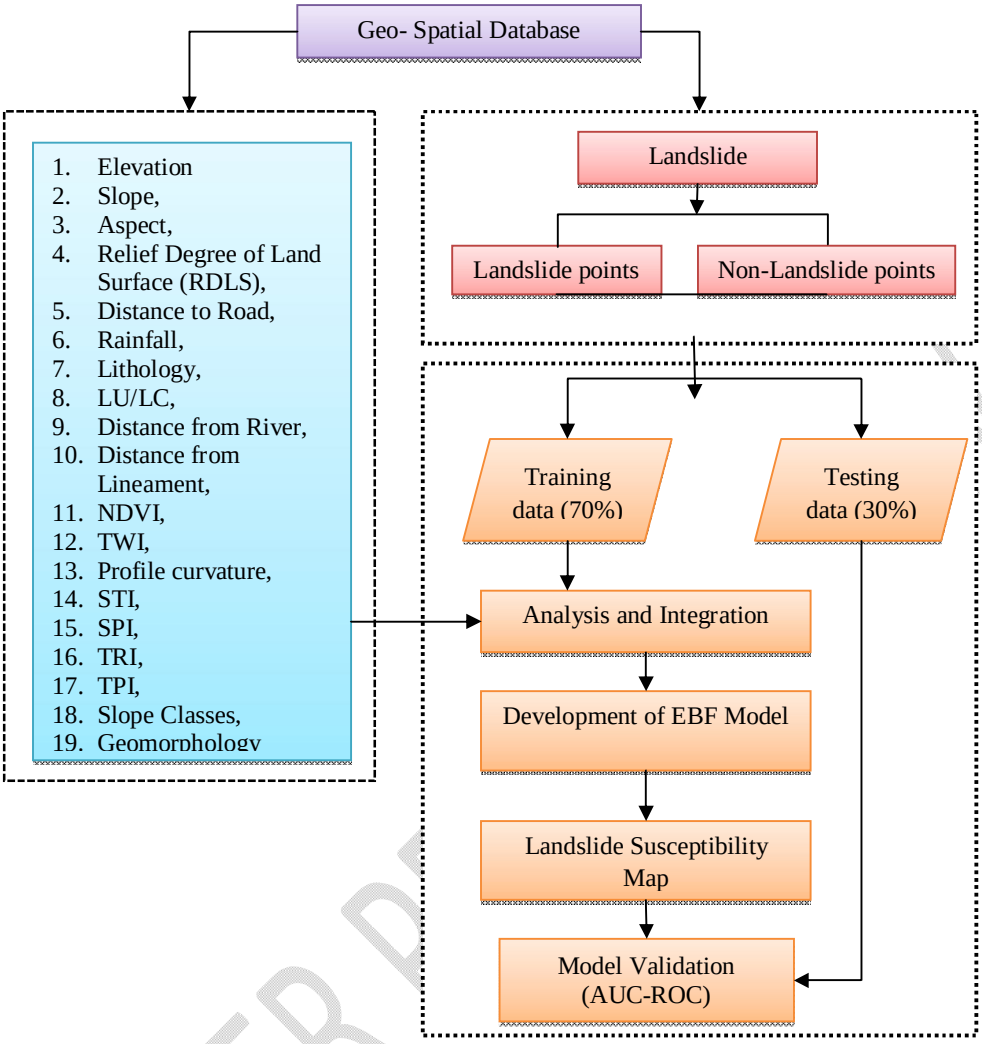

Figure 2 Workflow of the methodology

2.4 Application of the EBF model for Landslide susceptibility mapping(LSM)

In the present work, Landslide Inventory data and 19 landslide conditioning factors were used to generate LSM utilizing GIS-based EBF model. The EBF model is based on the "Dempster- Shafer theory"(Nampak et al., 2014), to use it, first all the thematic layers (landslide conditioning factors) (Althuwaynee et al., 2012)should be converted into layers of evidential data. In EBF model, four basic functions: Bel (degree of belief), Dis (degree of disbelief), Unc (degree of uncertainty), and Pls (degree of plausibility)(Lee et al., 2013)with a range of [0, 1].

The Dempster-Shafer theory of evidence is described by Equation (1)(Althuwaynee et al., 2012).

$$m: P(H) = \{0,1\}$$
$$m(\emptyset) = 0\ m(B) = 1$$
$$m(B) = 1: \sum_{H \subset P(H)} m(H) = 1 \qquad (1)$$

Based on mass function (m), belief functions can be expressed in equation (2)

$$Bel(B) = \sum_{H \subset B} m(H) \qquad (2)$$

The integrated EBF values of the LCFs will be implemented sequentially by using Equations (3) & (4). TheBel function (Figure 3) can be calculated by Equation (4)(Nampak et al., 2014), L is spatial layers of landslide conditioning factors, E_{ij} is evidence, Where 'i' is the amount of layers, 'j' is domain attribute individually to obtain certain accurate results(Park, 2011).

$$\lambda = (T_p)E_{ij}$$
$$= \left[N(L \cap E_{ij})/N(L)\right]/\left[N(E_{ij}) - N(L \cap E_{ij})/(N(A) - N(L))\right] \qquad (3)$$
$$= N/D$$

$$Bel = \frac{(T_p)E_{ij}}{\sum(T_p)E_{ij}} \qquad (4)$$

Where $T_p$is the class pixel involved by landslide occurrence,$N(L \cap E_{ij})$ is the number of landslide occurrence pixels in a domain, N(L) is the total number of landslide occurrences, $N(Eij)$is the number of pixels in a domain(Althuwaynee et al., 2012), and N(A) is the total number of pixels in a domain.

3. Result and discussion

3.1 Prediction Rate(PR) of Conditioning Factors:

The PR of every landslide conditioning factor was calculated using formula (5) (Meena et al., 2022), and the EBF model uses the Bel function as input data (Table 1).

$$PR = \frac{SA_{Max} - SA_{Min}}{Min\,[SA_{Max} - SA_{Min}]} \qquad (5)$$

WhereSA serves as Spatial Association indicator between conditioning factor and landslides. The maximum, minimum values, and prediction rate values for the EBF model are inTable 1. The LSM was produced utilizing 'Raster calculator' tool in the Spatial analyst toolbox in the ArcGIS Platform, the map was demonstrated inFigure 4**Error! Reference source not found.**. The percentage of area of the EBF model for landslide prediction was represented inTable 2.

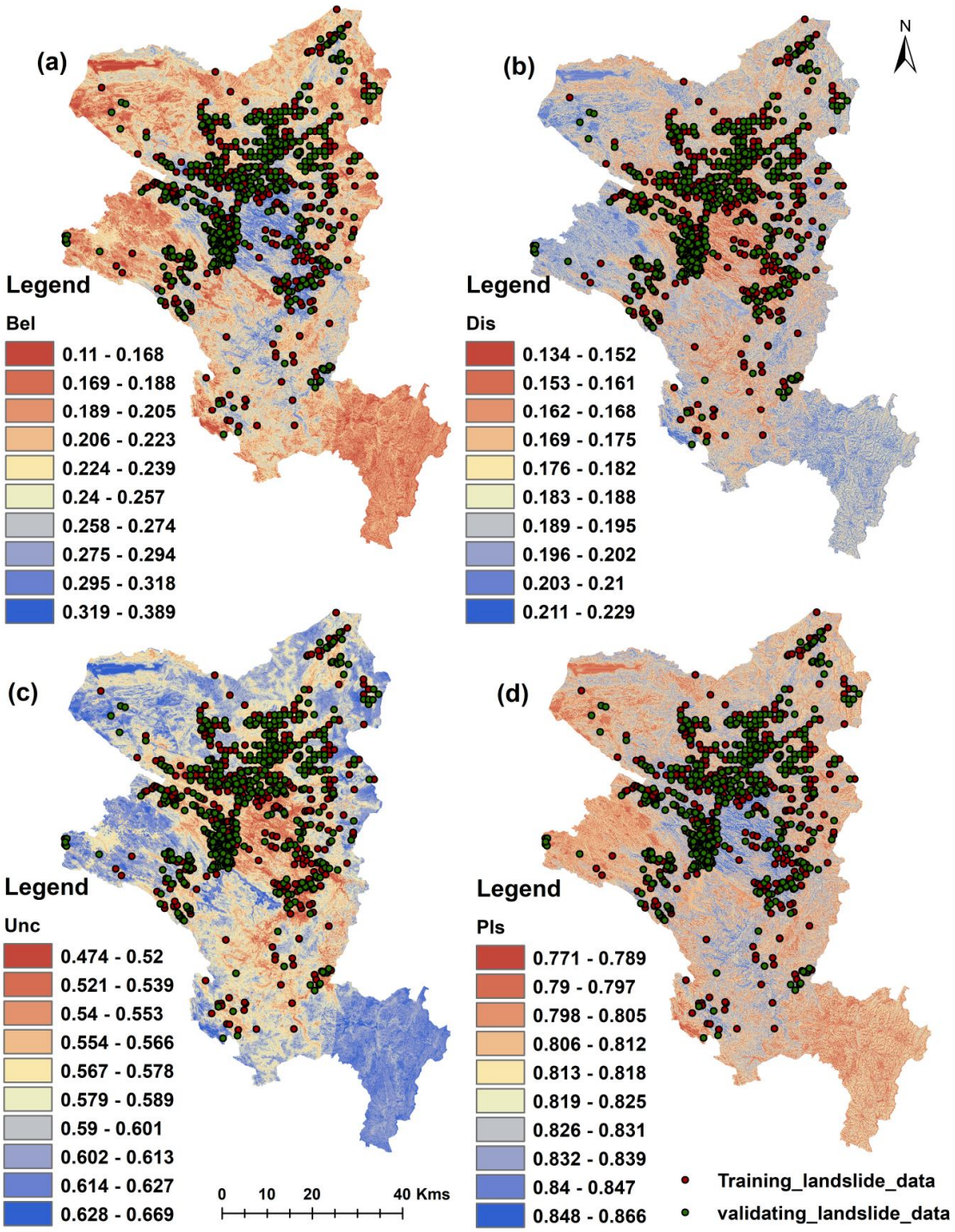

Figure 3 Integrated results of Evidence Belief Function (EBF) (a) Belief (bel), (b) Disbelief (Dis), (c) Uncertainty (Unc), and (d) Plausibility (Pls).

Table 1 Predictor Rate (PR) of EBF

Factors	EBF			
	SA_Max	SA_Min	l SA_Max -SA_Min l	PR_EBF
Elevation	0.528	0.069	0.458	7.289
Slope	0.339	0.074	0.266	4.228
Slope_Aspect	0.154	0.006	0.148	2.354
Profile_curvature	0.418	0.271	0.148	2.346
Relief Amplitude	0.339	0.100	0.239	3.799
NDVI	0.343	0.089	0.255	4.051
SPI	0.332	0.041	0.291	4.630
TWI	0.275	0.121	0.153	2.439
TRI	0.390	0.056	0.334	5.305
DTD	0.409	0.017	0.391	6.224
STI	0.482	0.065	0.417	6.627
TPI	0.476	0.238	0.238	3.777
Slope classes	0.291	0.050	0.241	3.836
DTR	0.709	0.004	0.706	11.224
DTL	0.236	0.173	0.063	1.000
LULC	0.793	0.000	0.793	12.608
RAINFALL	0.436	0.005	0.431	6.852
Lithology	0.237	0.000	0.237	3.777
Geomorphology	0.413	0.000	0.413	6.570

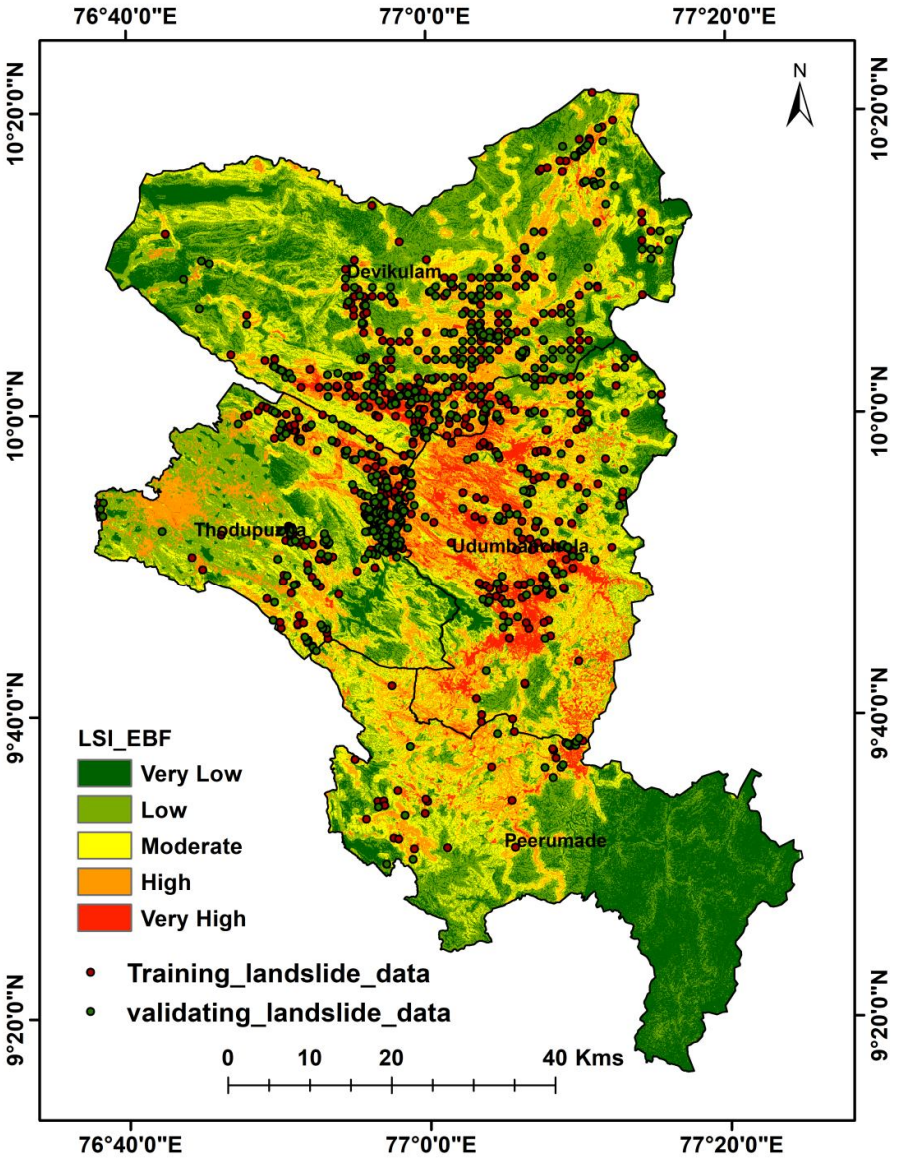

Figure 4 Landslide prediction map for EBF model

Table 2 Percentage of area of EBF model for landslide prediction

Susceptibility class	Area(Sqkm)	Area in %
Very low	1047.00	20.96
Low	1483.79	29.71
Medium	1223.51	24.50
High	930.47	18.63
Very high	309.79	6.20

3.2 Validation

The process's most important stage is confirming the locations that are prone to landslides. The susceptibility map in the current study was created using the EBF model and it was verified by contrasting it with the training data(70%) and tesing data(30%). The success rate and Prediction rate are assessed using AUC-ROC Apporoach(Figure 5).

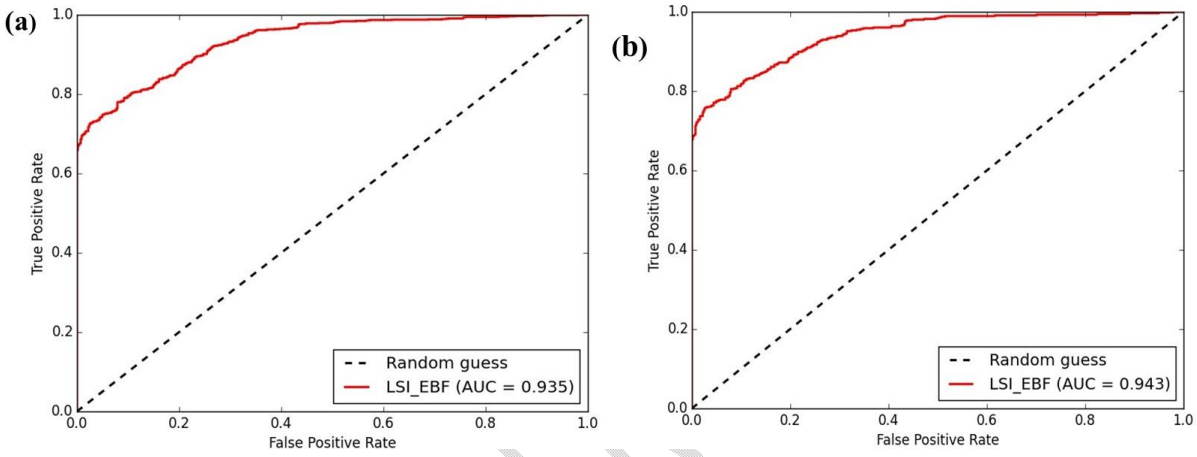

Figure 5 The success and prediction rate for Landslide susceptibility map; (a) Success rate (b) Prediction rate

4. **Conclusion**:

The landslide-prone areas in the Idukki are predicted by using the GIS-based EBF model. To produce susceptible zones, 19 conditioning factors and Landslide Inventory data (1850 points) are considered and prepared from various sources, 70% as training data to create the models and 30% as testing data to verify the model. The Landslide Susceptibility Models of EBF model are cross-validated by using the AUC-ROC method. EBF model exhibits higher accuracy in both the success rate and prediction rate in the study area. The LS maps of the study area are classified into five classes: Very low, Low, Moderate, High, and Very High through the natural break method each %area is 20.96%, 29.71%, 24.50%, 18.63%, and 6.20%. Based on the results, the high and very high-risk zones are

been found in the middle of the Idukki district,and implement mitigation actions to lessen the landslide event's effects in the study location.

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