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A Comparison of Landslide Susceptibility Zonation of Poonjar Sub-watershed, Kerala by Certainty Factor and Physically Based Methods

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ABSTRACT— ***Landslides are one of the most devastating natural disasters which may lead to loss of life and property. Western Ghats region of Southern India is identified to be one of the main landslide susceptible area by many researchers in the past. After identifying the slope angle, soil thickness, and the geotechnical properties cohesion, friction, density and permeability as the major causative factors, this study presents the popular physically based tool namely Stability Index and Mapping (SINMAP) and a bi-variate statistical method namely Certainty Factor (CF) for the Landslide Susceptibility Zonation (LSZ) of Poonjar sub-watershed in Western Ghats. Single calibration mode is invoked in SINMAP by considering land use type as the theme in the present study to prepare the LSZ map. The thematic layers of different causative factors are prepared and subsequently the landslide inventory map is overlaid upon them to get the landslide density of the whole area and that of each layer and the associated classes. Then the weights for each class are calculated by CF method and addition of weighted layers is made in ArcGIS platform to get the final landslide susceptibility map for the study area. Finally the map is reclassified and divided to get the LSZ map of the study area. A comparison of zonation maps shows that both the methods are successful in capturing the landslide information in moderately susceptible areas of Poonjar sub-watershed.***

Keywords— landslide, certainty factor SINMAP, Zonation , GIS

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1. INTRODUCTION

Western Ghats in Kerala is a landslide prone area which resulted in significant damage to property and agriculture many times in the past. Assessment of landslide susceptible areas based on scientific analysis can help to predict where landslides are most likely to occur, and thus decrease landslide damage by taking proper precautions. Landslide susceptibility assessment in a given area is based on the analysis of slope behavior and landslide occurrence in the past [1]. The analysis of landslides is complex, involving a multitude of factors and it needs to be studied systematically in order to locate the areas prone to landslides.

A good number of methodologies for landslide susceptibility zonation on regional scale has been attempted in the last few decades using direct (geomorphological) and indirect (quantitative & semi quantitative) methods. A Geographic Information System (GIS) model with statistical and spatial analysis approach ensures an interactive relationship between debris flows and their causative factors and facilitates the validation of maps thus obtained [2-8]. The area selected for present study is Poonjar sub-watershed of Meenachil river, which has suffered a lot of damage due to landslides, following heavy rains in the past.

The main objective of the current study is to prepare the landslide susceptibility zonation (LSZ) maps for Poonjar sub-watershed in Western Ghats Kerala, by using two different indirect mapping methods namely, Certainty factor (CF) method and physically based modeling by Stability INdex MAPping (SINMAP). The CF proposed by Shortliffe and Buchanan [9] is helpful to identify the potential factors of landslides. SINMAP being a combination of a deterministic stability model with a hydrological model it can also give information on the potential hazard areas where landslide may occur under future precipitation conditions. It may eventually help citizens, planners and engineers to reduce losses caused by existing and future landslides by means of prevention and mitigation.

2. STUDY AREA

The Poonjar sub-watershed is located in the eastern side of Kottayam district and covers an area of about 63.26 km2 in the western flanks of Western Ghats ,south central Kerala, India (Fig. 1).The Geographical positioning of the area is given by 76046’40’’E to 76054’36’’E and 9036’41’’N to 9041’08’’N and forms one of the upland sub-watershed of the river Meenachil. The terrain area is highly rugged with elevations ranging from 20 m to 1195m above sea level. Geologically the region comprises of Precambrian age [10]. The Location map of the study area is given in Fig.1.

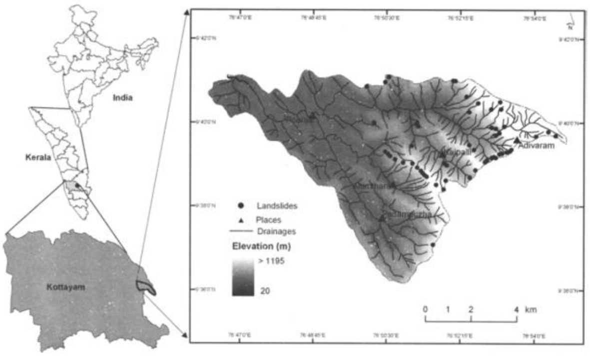

Figure 1 Location Map of Study area [10]

3. CERTAINTY FACTOR METHOD AND ITS IMPLEMENTATION

Certainty factor method is a bi-variate statistical analysis method in which, each individual thematic data layer is compared to the existing landslide distribution layer. The weight value of each category of causative factors is assigned based on landslide density. This involves the overlay of landslide distribution layer on each of the thematic data layers, and calculation of respective landslide density values. The CF, defined as a function of probability, was originally proposed by [9] and it was later modified by [11]. The CF Can be computed as per the following equation :

$$
\begin{aligned}
CF &= \frac{PP_a - PP_s}{PP_a(1-PP_s)} \quad if \quad PP_a > PP_s, \\
&= \frac{PP_a - PP_s}{PP_s(1-PP_a)} \quad if \quad PP_a < PP
\end{aligned}
\tag{1}
$$

where PP_a is the conditional probability of having a number of landslide event occurring in class a and PP_s is the prior probability of having the total number of landslide events occurring in the study area. The CF values varies in the range [-.1,-1], positive value means an increasing certainty in landslide occurrence, while negative value corresponds to a decreasing certainty in landslide occurrence. A value close to 0 means that the prior probability is very similar to the conditional one, so it is difficult to give any indication about the certainty of the landslide occurrence.

The favorability values (PP_a, PP_s) are derived from overlaying each data layer with the landslide inventory layer in ArcGIS and calculating the landslide occurrence frequency. And CF values are then calculated for each layer. After calculating the CF value of each class for all layers, the layers were then combined pair wise according to the integration rules. The detailed steps of CF calculating and integrating are provided by [12, 13].
Certainty factor method utilizes the advantage of statistical approach of assigning weightage to causative factors, integrated in a GIS environment to obtain the LSZ map. The causative factors identified are slope angle, soil thickness, and the geotechnical properties (such as cohesion, friction, density and permeability. The CF values of different layers are given in Table 1. The statistics of slides at different categories (high, low, medium susceptibility are given in Table 2. The final LSZ map of the area is given in Fig.2 in which the landslide inventory is also overlaid.

Table 1: Certainty Factor Values for Different Layers

Layer	Class	CF	Layer	Class	CF
Slope			Friction		
	(6-10)	-0.355		18.9	0.481
	(11-15)	0.205		33.1	-0.915
	(16-20)	0.399		36	0.100
	(21-25)	-0.635	Density		
	(26-30)	0.075		13	0.481
	(31-35)	0.476		14.7	-0.915
	>35	0.512		16.4	0.100
Cohesion			Soil Thickness		
	1.3	0.100		0-1	0.358
	1.6	0.481		2.5-4	-0.665
	2.3	-0.915		>4	0.209
Permeability					
	0.478	-0.915			
	0.656	0.481			
	0.68	0.100			

Table 2 Statistics of Landslide occurrences in Poonjar by CF Method (A For Area, H For High Susceptibility, M For Moderate Susceptibility And L For Low Susceptibility)

No. of slides in highly susceptible area	15
% slides	29.41
AH	6.61
AM	42.12
AL	14.53
Total Area (Sq Km)	63.26
%AH	10.44
%AM	66.59
%AL	22.97

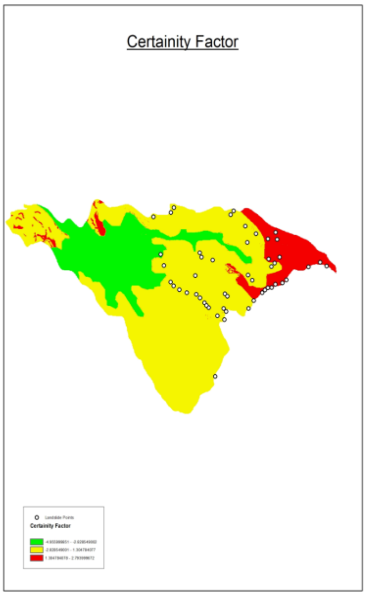

Figure 2 LSZ map of Poonjar area by CF Method

4. SINMAP IMPLEMENTATION FOR LANDSLIDE SUSCEPTIBILITY ESTIMATION

The deterministic slope stability model namely Stability INdex MAPping (SINMAP), developed by Pack et al., [14] is used in this study to assess the instability conditions and to establish a landslide hazard zonation map. SINMAP is a raster based slope stability predictive tool based on coupled hydrological-infinite slope stability model implemented in ArcView 8.3 platform. This approach applies to shallow translational land sliding phenomena controlled by shallow ground water convergence and more details on SINMAP can be found in [14]. The data requirement include inventory of past landslides, digital elevation model (DEM), geotechnical data such as soils strength properties, thickness of soil above the failure plane, and hydrological data such as soils hydraulic conductivity and the rainfall. All spatial data had a resolution of 20 m by 20 m. Then a calibration regions to be created in single or multi calibration framework by supplying lower bound and upper bound calibration parameter values of wetness index (T/R) where, T is the transmissibility, R is the recharge, cohesion index (C), and friction angle (φ). In this study, a single calibration theme involving eight calibration regions based on land use type, was applied. For all land use type, T/R ratio ranges between 2000-3000, cohesion ranges between 0-0.25 while, φ ranges between 30-45 are adopted in this study. The primary output of the model is a stability index, which is the probability that a location is stable assuming uniform distribution of the parameters over their uncertainty, is used to classify the terrain stability for each grid cell of the study area. This SI value ranges between 0 (most unstable) and 1 (least unstable) (Table 3). The LSZ map of Poonjar area is provided in Fig. 3.

4.1 Slope-Area (SA) Plot

A slope area chart (SA plot) of the area is prepared and a statistical summary of landslides in region is prepared. The SA plot provides a view of study data in slope area space. The resulted SA plot is shown in Fig. 4. Statistical results obtained from the SINMAP analysis are shown in Table 4.Major headings are to be column centered in a bold font without underline. They need be numbered. "2. Headings and Footnotes" at the top of this paragraph is a major heading.

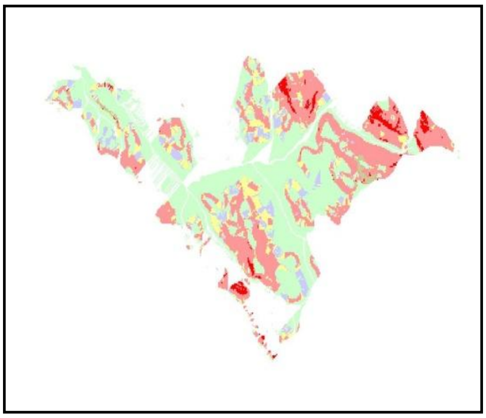

Figure 3. LSI Map of Poonjar by SINMAP

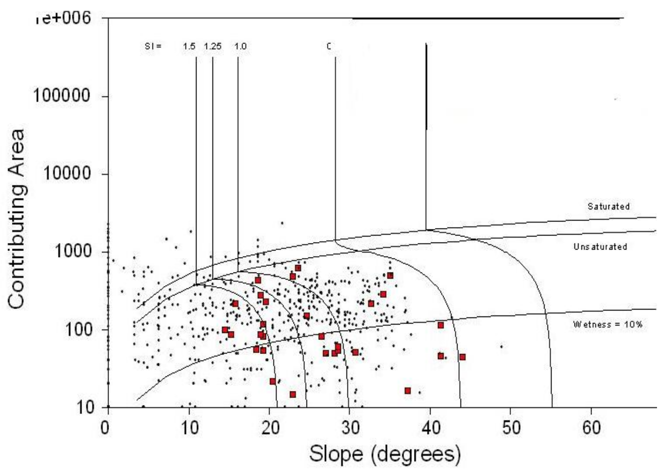

Figure 4. Graphical Representation of The Prediction of Susceptibility To Failure By Sinmap (S-A Plot)(Squares Are Landslide Locations In The Parameter Space)

Table 3 Stability Index Values for Different Layers

Classification	Stability index values(SI)
Stable (S)	$SI > 1.5$
Moderately stable (MS)	$1.25 < SI \leq 1.5$
Quasi-Stable (QS)	$1.0 < SI \leq 1.25$
Lower Threshold (LT)	$0.5 < SI \leq 1.0$
Upper Threshold (UT)	$0 < SI \leq 0.5$
Defended (D)	SI=0.0

Table 4 Statistics of SINMAP Analysis

Item	S	MS	QS	LT	UT	D	Total
Area (km^2)	12.8	8.4	16.1	21.91	3.76	0.3	63.3
% of region	20.2	13.28	26.51	33.64	5.9	0.4	100
No. of landslides	12	7	9	17	6	0	51
% of slides	23.5	13.7	17.6	33.3	11.76	0	100

The SINMAP implementation located the most potential susceptible areas under lower threshold (of susceptibility Index 0.5-1) (33.3 % slides). Considering together MS, QS and LT, it located 64 % (33 out of 51), which falls in 73.4 % of total area. By the CF method, the area of medium susceptibility is nearly 66 % (Table 2), which show fairly good matching. However, it located only 6 slides that also in UT instead of 'defended (D)' class. This may be because of the differences in defining the susceptibility inherent in the methodology. The SINMAP may be able to predict the landslide in the defended class by appropriate choice of a theme other than land use, analysis in multi calibration mode or by incorporating actual hydrologic information.

5. CONCLUSIONS

The present study applied CF method and SINMAP for landslide hazard zonation of Poonjar sub-watershed. It is found that both CF and SINMAP are successful in capturing landslides in moderately susceptible areas of Poonjar sub watershed. The CF could detect the occurrences in highly susceptible regions while SINMAP failed to do so. This shortcoming could be improved by choosing a different theme or by incorporating actual hydrologic information in the modeling process

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