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Investigation of the Dynamics of Landslides Alongside the Risk and Vulnerable Factors Using Remote Sensing and Geographical Information System

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ABSTRACT: Landslide is one of the most damaging natural hazards in the mountainous region. These landslides are triggered mainly by rainfall or earthquakes. The growing population and expansion of settlements over these hazardous areas increased the impact of natural disasters in most of these areas. The aim of such study is to use a "working methodology" in which Geo-environmental parameters are analyzed to predict landslide prone areas using remotely sensed data products and geographic information system (GIS) and to investigate the dynamics of landslides alongside the risk and vulnerable factors. Population pressures & increasing urbanization along with the local zoning laws have been forcing man from flat lying areas & flood plains onto the adjacent hill-slopes. The hill-slope as an environmental setting can help us to avoid the severe flooding but can be equally hazardous because of potentially unstable earth materials. The high susceptibility to landslides of the study area is mainly due to complex geological setting with contemporary adjustments in slope and relief, rainfall and anthropogenic effects. Therefore, recognition of landslide prone topography is becoming increasingly important in land use decisions and in understanding the risks and vulnerable factors. The landslides hazards, in general, cannot be completely prevented. However, the intensity and severity of the impacts of the hazards can be minimized if the problem is recognized before the development activity and hence the need for the study.

KEYWORDS: Landslide, Natural hazard, Vulnerable factors, Environmental parameters.

I. INTRODUCTION

A landslide is a downslope movement of rock or soil, or both, occurring on the surface of rupture—either curved (rotational slide) or planar (translational slide) rupture—in which much of the material often moves as a coherent or a semicoherent mass with little internal deformation. Professionals like Engineers and Geologists define landslides in a unique and different way. Landslide phenomenon is associated with many disciplines it is associated with. Therefore, landslide can be described as the downslope movement of soil, rock and organic materials under the effects of gravity and also the landform that results from such movements. Landslides can otherwise used interchangeably with mass movements, slope failure and so on. Landslides are mostly triggered by events of heavy rainfall and seismicity, which is followed by flooding in the plains, the local population experiences the impact of the landslides caused in the location. It is one of the most destructive geological processes which causes enormous damages to the roads, bridges and houses and even loss of lives(1).

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II. RELATED WORK

Rapid Landuse and Land cover dynamics were investigated in the Nilgiris district of Tamilnadu State during the periods 1973-2009 by the combined use of Remote Sensing and Geographic Information Systems (GIS) techniques. Landsat-MSS, Landsat-TM and IRS-P6-LISS III satellite imageries were used to assess the Landuse and Land cover changes through visual interpretation techniques. The detailed analysis by Lakshumanan (2013) had revealed that the area under forest and settlement increased 9.35 km² and 1.02 km² every year for the past 36 years respectively. The forest plantation, tea plantation, barren rocky land and agro-horticulture showed a considerable decline for the period of 36 years. Encouragement of tourism and industrial development has altered the natural system of Nilgiris environment. The Nilgiris today is the most industrialized and commercialized hill area in the state. The rapid commercialization without corresponding improvements in infrastructures and amenities has long begun to strain the carrying capacity of the hills.

Landslide is the most frequently occurring natural hazard in the tectonically active region of the Himalaya. The immature geology with high degree of slope coupled with high rainfall are the natural causes of landslide in this region. In addition, the unplanned human activities also cause landslides. The present study by Lallianthanga et.al. (2013) investigated the Landslide Hazard Zonation (LHZ) of Aizawl district, Mizoram that consists of four urban settlements and ninety seven rural villages. Using Remote Sensing and Geographic Information System (GIS) techniques, thematic layers like slope morphometry, geological structures like faults and lineaments, lithology, relative relief and land use / land cover were generated. The weightage rating system was used for different classes of thematic layers which are based on relative importance of various causative factors. The classes were assigned corresponding rating value as attribute information in the GIS environment.

Landslides are one of the critical geological processes, which cause not only enormous damage to civil engineering structures i.e. roads, railways, bridges, dams, bio-engineering structures, and houses but also lead to loss of life. Hence, there is a need for landslide hazard zonation for identification of potential landslide areas. Kuldeep Pareta et.al. (2014) attempted the present study towards development of a landslide model by using multi-criteria decision analysis in GIS and remote sensing techniques for landslide hazard zonation.

Landslide is one of the major disasters causing damages to man and his properties. Though this phenomenon was restricted to the selected mountain regions around the world in the past, now it is occurring in almost all the mountains. The Indian subcontinent too is not an exception to it. But, though the rainfall and the improper interaction of the man remained the major tutoring factors for landslides, the vulnerability of the terrain to landslides depends upon the various geosystems which only assign landslide vulnerability grades. This stimulated many Geoscient-ists and the technocrats to study the geological parameters not only for landslide vulnerability mapping but also for mitigation and management. Various methods are being adopted for Landslide Vulnerability Mapping (LVM) resulting into differing types of outputs. So a new method was attempted by Muthukumar (2013) for Nilgiri mountains, Western Ghats, South India by assigning weightages to various geosystem parameters viz: Lithology, Lineament / fracture density, geomorphology, Slope, Land use / Land cover and their sub classes or subvariables, on the basis of their responses to landslides and integrated such weighted five geosystems to arrive finally at a landslide vulnerability map.

III. MATERIALS AND METHODS

STUDY AREA

The study area is Nilgiris district, which is located in Tamilnadu state and lies between the latitudes 11° 10' and 11° 43' N and longitudes 76° 15' and 77° 00' E and it covers 2541 km². The study area falls under the Survey of India toposheets No: 58 A/6, 58 A/7, 58 A/8, 58 A/10, 58 A/11, 58 A/12, 58 A/14 and 58 A/15. The Nilgiris is situated at an elevation of 2636 meters above Mean Sea Level (MSL). The geographical area consists of six taluks namely Udhagamandalam, Coonoor, Kotagiri, Gudalur, Kundah and Pandalur. The upper plateau at an altitude of 6,500 feet consists of three Taluks namely Udhagamandalam, Coonoor and Kotagiri while Gudalur Taluk is the oldest plateau at an altitude of 3,000 feet.

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The Nilgiris district usually receives rainfall from both during the southwest (June, July) and northeast (October, November) monsoons. The Southwest monsoon contributes to the entire Gudalur, Pandalur, Kundah Taluks and a part of Ooty Taluks. The North East monsoon contributes to some parts of Ooty Taluk, entire portion of Coonoor and Kotagiri Taluks. The normal average annual rainfall of the district varies from place to place and is somewhere between 1500 to 3000 mm. The daily rainfall data of the Nilgiris district from 29 rain-gauge stations for 29 years were collected from the Indian Meteorological Department, Chennai.

The base Map was prepared for the visual interpretation of the toposheet and watershed map. The land use/land cover pattern of a region is an outcome of natural and socioeconomic factors and their utilization by man in time and space(2).

The Land use / Land cover plays an important role in LHZ as it controls the rate of weathering and erosion of the underlying rock formations (3). Satellite imagery of 2014 was visually interpreted and analyzed for the variation on the image characteristics using the standard methods of visual interpretation techniques employed for the interpretation, classification and delineation of the categories based on tone, texture, pattern etc. It is used to identify various land use and land cover classes. The methodology consisted of preparing land use/land cover resource map from the LISS 8 data coupled with ground truth data. The Land use / land cover of the watershed was classified using the Maximum Likelihood Classifier of the Supervised Classification method. The signature files were prepared as shape files and used for the classification.

The drainage density map shows the flow of water throughout the area. Drainage density is defined as total stream length per basin area (4). The drainage density is an important factor as rain water percolates in areas with low drainage density. The drainage density of the study area has been calculated and has been classified as very low, low, medium, high and very high and is given in the map.

The rainfall analysis for all the available rainfall data was carried out to understand the variations in the (total/mean) rainfall. The rainfall data were interpolated using Krigging method to predict the values at unmeasured locations from the surrounding measured locations. A continuous surface or maps of the rainfall phenomenon were created for predictions using the spatial arrangement of the measured values in the nearby locations. The coefficient of variability of the annual rainfall and seasonal rainfall were calculated. The coefficient of variability may be defined as the deviation from the mean and is expressed as the percent of the mean annual. The precipitation ratio can be defined as the difference between the maximum and minimum rainfall of over the series of years expressed in the terms of mean. This ratio may give the stability of the rainfall with special relationship. Higher the ratio is higher in abnormality in rainfall and vice versa (5).

The Marcov Chain Model of dry and wet weeks for Agricultural planning was used by Reddy in 2008 at Bangalore. Marcov Chain process was carried out from the weekly rainfall data for the Nilgiris district to suggest the soil and water conservations measures to be carried out. The study has been carried out to determine the initial and conditional probabilities of occurrences of dry and wet weeks using threshold limits of 20 mm rainfall. The weekly rainfall values have been computed from the daily values and were used for the study. The dry and wet spell analysis was carried out using weekly rainfall based on Markov Chain Model considering less than 20 mm rainfall in a week as a dry week and 20 mm or more as a wet week.

The probabilities of main rainy season were calculated by using the following Weibull's formula. The mean, maximum, minimum, standard deviation and coefficient of variation of weekly rainfall were calculated manually. Reddy applied Markov chain model in Combolcha station, Ethiopia by choosing 10, 20, 40 and 80 mm/week as threshold limits(6). Marcov Chain model has been used with a threshold of 20 mm limit for estimating the weekly rainfall probability.

Aspect degree are classified according to the aspect class as flat, north, east, south and west (7). The aspect map was prepared using the DEM image using the ArcGIS Tool box windows. The direction of the slope was identified from the resulting raster. Slope is an important factor in the analysis of landslide. As the slope increases, the probability of the occurrences of landslide increases because as the slope angle increases the shear stress of the soil increases (8). The slope map of the study area was prepared using DEM and the slope percentage was calculated. The slope is classified as slope percentages ranging from 0-10%, 10-20%, 20-30%, 30-40% and >40%.

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The Lithology in the study area is charnokite group of bedrocks, covered by the ubiquitous red laterite or lateritic soil. Geomorphology is the scientific study of landforms and the processes that shape them. The erosional surfaces in Dodabetta, Ootacamund, Coonoor and Moyar are recorded in the district. All these erosional surfaces are capped by residual laterite(9). The geomorphology of the study area includes Denudated hill, Hill top weathered, piedmont slope, structural hill, structural valley and valley fill.

The topsoil cover on a slope has an influence on landslide occurrence as observed in the field (10). The soil map of the study area includes clay, clay loam, loam, loamy sand, sandy clay, sandy clay loam and sandy loam.

Relative relief represents the maximum height of a facet, from the bottom (valley floor) to top (ridge/spur) along the slope direction (11). The relative relief of the study area has been found from the Data Management Tool using the fishnet options and by Interpolation techniques.

IV. RESULTS AND DISCUSSION

Landslide risk is commonly defined as a function of landslide hazard, elements at risk with attributed damage potentials and given vulnerabilities of each element at risk to a landslide with a defined magnitude. Vulnerability is the degree of loss resulting from the occurrence of a phenomenon. Population, Number of houses and their types, population density, sewage disposal details etc., of the Nilgiris were obtained from the Census of India, 2011 and has been correlated with the landslide hazard zonation for the vulnerability study. The major step in hazard management is the preparation of landslide vulnerability zonation map. Using the degrees of loss from the disaster and the Landslide Hazard map, landslide vulnerability map was prepared using the classical raster calculation operations and is given in the Plate 1.

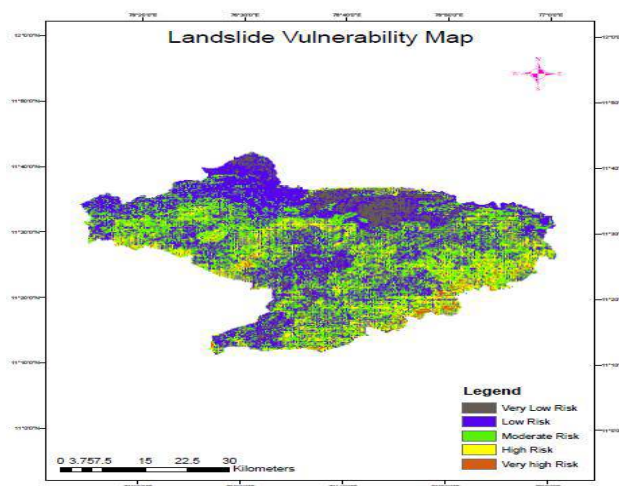


Plate 1: Landslide Vulnerability Map of the Study Area

From the landslide hazard map and landslide vulnerability map, the landslide risk map was prepared using the raster calculator and has been given in the Plate 2. Risk map is the assessment of the level of threat from landslides. The estimated risk level was categorized into five zones: very low risk, low risk, moderate risk, high risk and very high risk areas.

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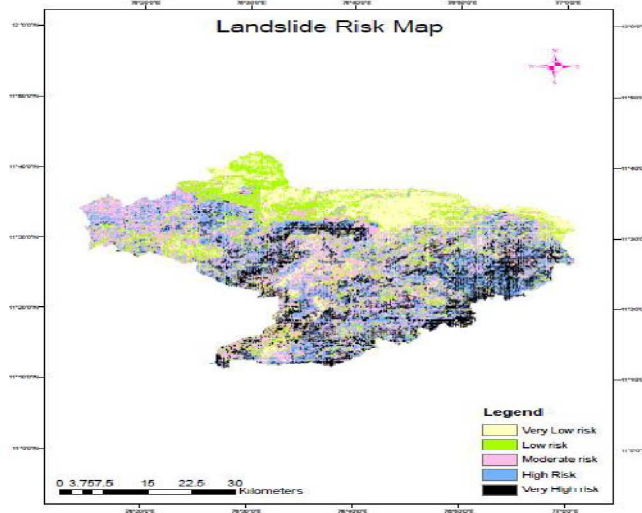


Plate 2 : Landslide Risk Map of the Study Area

The frequency ratio of the each of the risk factors slope, drainage density, soil, Lithology, geomorphology and land use/ land cover for landslide hazard zonation were calculated and has been given in the tables 1,2,3,4 and 5 respectively.

Table -1: Frequency ratio of Slope to landslide occurrences

Slope class	Landslide occurrence	Percentage of Landslide occurrence	Percentage of pixel domain	Ratio
0-10	3	1.50	34.87	0.04
10-20	39	11.54	26.00	0.44
20-30	66	32.70	20.42	1.60
30-40	75	37.68	12.68	2.97
>40	33	16.58	6.03	2.74
Total	199	100	100	

In the Table 1, the frequency ratio of the factors in the study area revealed that slope class of 30 to 40% was found to have more landslide frequency of 2.97, followed by more than 40% with a frequency ratio of 2.74, followed by 1.60 for 20-30%.

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Table -2: Frequency ratio of Drainage density to landslide occurrences

Drainage density class	Landslide occurrence	Percentage of Landslide occurrence	Percentage of pixel domain	Ratio
Very Low	28	14.07	20.32	0.69
Low	37	18.59	20.15	0.92
Moderate	40	20.11	19.87	1.01
High	53	26.63	19.89	1.33
Very high	41	20.63	19.74	1.04
Total	199	100	100	

In the Table 2, the frequency ratio of drainage density showed that high drainage density with high landslide frequency of 1.33, followed by very high drainage density with 1.04 landslide frequency, followed by 1.01, 0.92 for medium and low and very low drainage density with 0.69 landslide frequencies in the study area.

Table -3: Frequency ratio of Soil type to landslide occurrences

Soil type class	Landslide occurrence	Percentage of Landslide occurrence	Percentage of pixel domain	Ratio
Clay	9	4.52	26.45	0.17
Clay loam	0	-	8.60	-
Loam	36	18.09	7.27	2.48
Sandyloam	64	32.16	27.82	1.15
Sandy clay	61	30.65	13.09	2.32
Sandy Clay loam	14	7.03	10.06	0.69
Sandy loam	15	7.55	15.21	0.49
Total	199	100	100	

In the Table 3., the frequency ratio of top soil texture showed that loam, sandyclay and loamy sand had higher frequencies of 2.48, 2.32 and 1.15 followed by sandyclayloam with 0.69, followed by sandyclay with 0.49 and clay texture with 0.17 respectively.

Table -4: Frequency ratio of Lithology to landslide occurrences

Lithology class	Landslide occurrence	Percentage of Landslide occurrence	Percentage of pixel domain	Ratio
Alkali	0	0	0.24	0
Charnokite	196	98.49	71.24	1.38
Migmatite	0	0	0.62	0
Peninsular gneiss	3	1.51	25.05	0.06
Sathyamangalam group	0	0	2.85	0
Total	199	100	100	

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In the Table 4, the frequency ratio of Lithology showed that the Charnockite had a higher landslide frequency with 1.38 whereas other classes had nil landslide events expect a lesser in Peninsular Gneiss.

Table -5: Frequency ratio of Geomorphology to landslide occurrences

Geomorphology class	Landslide occurrence	Percentage of Landslide occurrence	Percentage of pixel domain	Ratio
DH	1	0.50	1.15	0.43
HTW	12	5.02	5.05	0.75
PS	0	0	1.46	0
SH	186	93.46	91.56	1.02
SV	0	0	0.61	0
VF	0	0	2.07	0
Total	199	100	100	

.In the Table 5, the frequency ratio of the geomorphology was higher in denudated structured hill with 1.02 followed by HTW with 0.75 landslide frequency and 0.43 in DH.

Table - 6: Frequency ratio of Land use/land cover to landslide occurrences

LULC class	Landslide occurrence	Percentage of Landslide occurrence	Percentage of pixel domain	Ratio
Water bodies	0	0	2.95	0
Dense forest	31	15.59	16.13	0.71
AgroHorticulturalPlantations	35	17.50	17.19	0.96
Agriculture	58	28.93	20.78	1.39
Tea plantations	48	24.18	26.58	0.91
Settlements	20	10.05	13.29	0.80
Barren	5	3.67	2.19	1.67
Mixed plantations	2	0.19	0.89	0.20
Total	199	100	100	

The frequency ratio of 1.67 and 1.39 was found in Barren and Agricultural lands followed by Agro Horticultural plantations and Tea plantations with 0.96 and 0.91 respectively. Settlements showed that 0.80 landslide frequency followed by dense forest with 0.71 respectively.

V. CONCLUSION

The frequency ratio of the factors in the study area revealed that slope class of 30 to 40% was found to have more landslide frequency of 2.97. The Drainage density showed that high drainage density with high landslide frequency of

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1.33 and top soil texture showed that loam had higher frequencies of 2.48. Lithology showed that the Charnockite had a higher landslide frequency with 1.38. Denudated structured hill with 1.02. The frequency ratio of 1.67 was for Barren lands. These all inferred that these were the most risk factors which were most vulnerable causing landslides.

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