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Landslide Susceptibility Mapping Using AHP Model in Nilgiri District

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Abstract

Landslides are common geological hazard taking place in the hilly areas. The Nilgiri district is vulnerable to landslide catastrophes, which is directly linked to the prosperity and development of the district. The main principle of the present study is to elucidate the landslide susceptible zones in the Nilgiri district so that it could be useful towards landslide disaster risk reduction.

In this study, the analytical hierarchy process (AHP) is used to create susceptibility maps. For this purpose, ten layers including landslide inventory, rainfall, lithology, lineament density, lineament buffer, aspect, slope, soil, soil depth, NDVI has been considered. Using this method each layer is split into smaller factors, then these factors are weighted based on their value, and to end with the last prepared layers are put together and the final map is generated. The mapping software ArcGIS is used to create the layer maps, which are used in the production of the landslide susceptibility maps.

KEY WORDS: *Landslide; Susceptibility map; GIS; Analytical hierarchy process*

Introduction

The term landslide is defined as the movement of soil, rock, and organic materials downslope under the influence of gravity (*Highland & Bobrowsky 2008*). Mass movement of landslides encompasses a wide range of failure modes including falls, topples, slides, spreads, and flows. Landslides are mainly controlled by geomorphological and geological factors (*Van Westen et al. 2011*) and can be activated by various factors such as precipitation, earthquakes, volcanic activity, changes in groundwater, and anthropogenic activities (*Highland & Bobrowsky 2008*). Basically, landslides are the down-slope movement of soil, rock and organic materials due to the power of gravity. These movements are short lived and suddenly arising phenomena that cause unexpected landscape changes and damage of life and property.

Landslide susceptibility is described as the possibility of the zone to form slope failures and susceptibility is generally expressed in a cartographic way (Yalcin, A. 2008). Landslide susceptibility zoning includes a degree of unpredictability and interpretation. Susceptibility zoning includes the spatial distribution and rating of the terrain units based on their potential to produce landslides *(Coromina, et al., 2008)*. Taking into account that landslides may occur in the future, due to the same conditions that created them in the past, we can use susceptibility assessments to predict the geographical position of future landslides (Guzzetti, et al., 1999) (Reichenbach, et al., 2005) (Ardizzone, et al.,2006). The events of landslide is associated to many factors which includes hydrology, lithology, climate, structure and geomorphic history; anyway, it is always not possible to add all factors of these parameters in susceptibility assessment (Moreiras, 2005). However, based on the conditions of the region, different factors are considered as layers affect landslide susceptibility zoning such as lithology-geology, seismic potential, slope and land cover.

In order to prepare landslide susceptibility maps several techniques can be used such as Analytic Hierarchy Process (AHP), fuzzy logic and statistical methods. Here, AHP model has been used for this study. The AHP model was first created and developed by Thomas L. Saaty in 1970. Analytical Hierarchy Process (AHP) is a multi-criteria decision analysis methodology. The AHP is a concept of measurement for dealing with quantifiable and intangible measures has been used in several areas, such as conflict resolution and decision theory *(10 Vargas, L.G., 1990).* Using the AHP method, multiple hazards (landslide, flood, seismic hazards, etc.) must justification for the uncertainty in the weighting coefficients *(Skilodimou, et al., 2019 - Bathrellos, et al., 2017).* The ratings are done on the basis of ordering of assessment indices. By the means of association weights are given to landslide-affecting factors, and on this basis the landslide is assessed. Methods based on expert experience methods and expert knowledge are, to a subjective, at certain level, and all methods required a rating based on experts' knowledge and experience. Ratings by different experts often lead to different assessment results.

The Nilgiris is one of the district in Tamil Nadu, India. It is mostly vulnerable to landslides as it experience heavy rainfall from South West as well as North East monsoons. This district falls under seismic zone the major natural catastrophes. From the year 1865 to 2009 several landslides and floods have been occurred all over the Nilgiri district. This has made a major negative impact on the fauna, flora and human settlements in this district. This paper is concerned with the use of Remote Sensing and GIS tools to identify the process of landslides in the Nilgiri hills.

Study area

The Nilgiris district is stretched over the area of 2,552.50 kilometers square. The entire region is mostly a hilly area, situated at an altitude of 1000 to 2,600 meters above the sea level. Almost the whole district is situated in the Western Ghats. The district's latitudinal and longitudinal dimensions are 130 kilometers (Latitude: 11°12 N to 11° 37 N) by 185 kilometers (Longitude: 76°30 E to 76°55 E).

The Nilgiris is surrounded by the Mysore district (Karnataka) and Wayanad, Malappuram and Palakkad districts (Kerala) in the West, Coimbatore district (Tamil Nadu) in the South and Erode district of Tamil Nadu and Chamarajanagar district (Karnataka) in the North (Fig:1). The Nilgiris district has rolling and steep topography. Around 60% of the cultivable land in Nilgiri district fall under 16° to 35° slopes.

According to 2011 census report the Nilgiris district had a population of 735394, out of which male population is 360143 and female population is 375251. The child sex ratio is 985 girls per 1000 boys and the population density of the Nilgiris district is 287 people per square kilometers.

The Nilgiris district has six taluks namely, Ooty, Coonoor, Kotagiri, Gudalur, Kundah and Pandalur. These taluks are divided into four Panchayat Unions; viz., Udhagamandalam, Coonoor, Kotagiri and Gudalur, besides two Municipalities, Wellington Cantonment and Aruvankadu Township. The District composed of 56 Revenue villages and 15 Revenue firkas. There are two revenues divisional in this district- Coonoor and Gudalur. For local concerns the Nilgiris also has 35 village panchayats and 13 town panchayats.

Nilgiri receives a high rainfall from South West monsoon (June to August). It also receives a heavy rain from North West monsoon (October to December). The district has the maximum average number of rainy days with 7 days per month, mean highest average

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Vol-8-Issue-12-Deecember-2019

temperature and mean minimum average temperature are 20.7^0 C and 9.6^0 C respectively and mean relative humidity is a maximum of 76.9% and minimum of 75.8%.

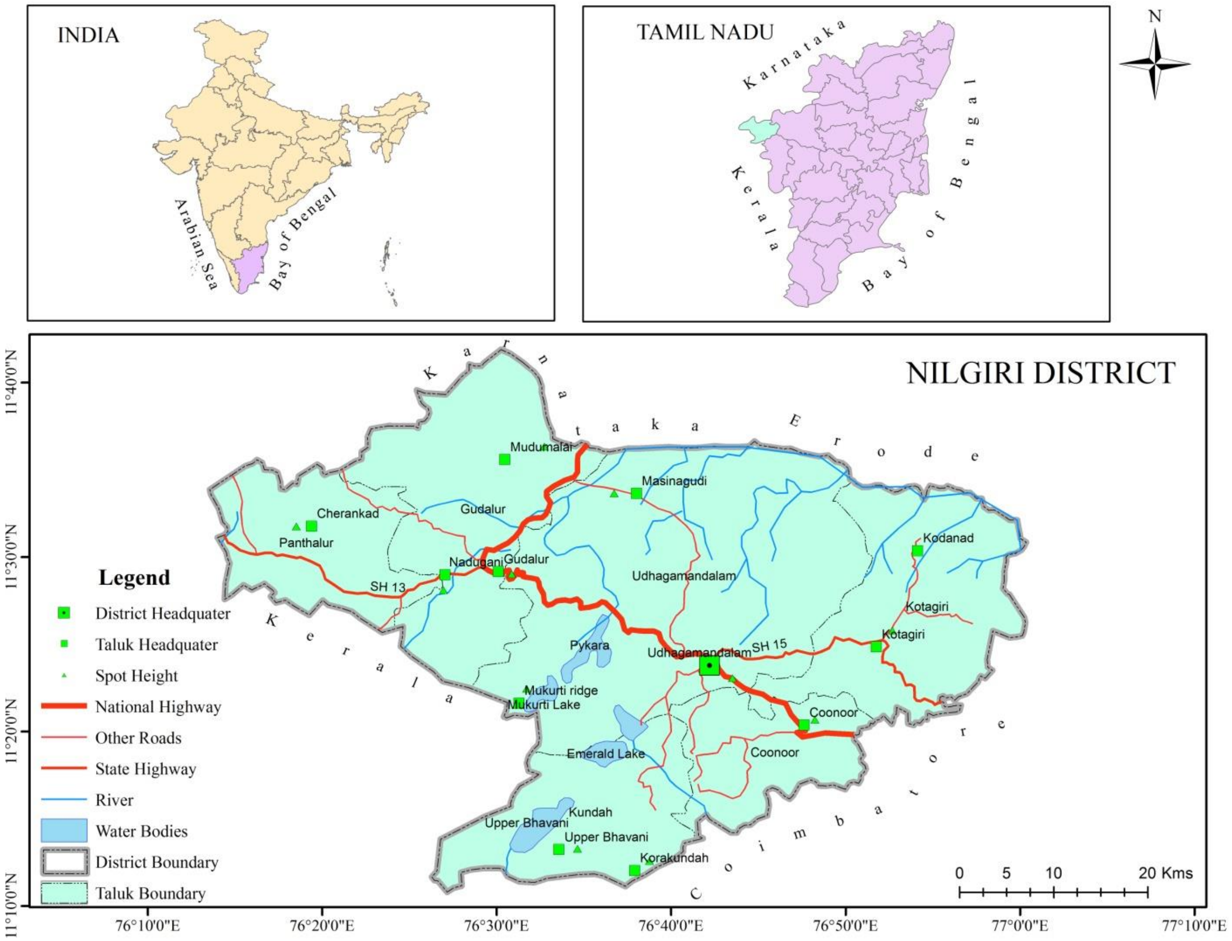

Fig 1: Study area base map

DATA

The satellite image of Landsat 8 OLI data has been acquired from USGS which is captured on March 2019. The month-wise rainfall data for different stations in Nilgiri district has been collected from State ground and surface water board, Taramani. Land use land cover for Niligiri district has been downloaded from EOSDIS. SRTM 30 m resolution data has been downloaded from USGS. Soil, soil depth and Lithology data has been collected from geological survey of India.

METHODOLOGY

The analytic hierarchy process (AHP), developed by Thomas Saaty in the late 1970s at the Wharton School of Business (Saaty 1980), is a decision-aiding tool for dealing with multi-criteria decisions making approach which permits the user to get into a scale of liking drawn from a set of alternatives. It allows to achieve priorities or weights as opposed to arbitrarily judgment *(Yalcin., 2008).* AHP method comprises a matrix-based pair-wise comparison of the consequence of all factor for landsliding. This method is generally used by most of the researchers. It is also a semi-qualitative method. AHP is composed of three principles, they are: decomposition, comparative judgment, and synthesis of priorities *(Malczewski 1999).* AHP has accomplished extensive application in site selection, suitability analysis, regional planning, and landslide susceptibility analysis. Using this method, each layer is parted into smaller factors, and then these factors are compared based on their importance. For comparison of significance of factors relative to each other, each factor is rated compared to every other factor by passing on a relative dominant value between 1 and 9. The dominant value and its description are shown in Table 1.

Table: 1-Fundamental scale for pair-wise comparisons (*Saaty and Vergas* 31)

Description	**Dominant value**
Equal importance	1
Moderate prevalence of one over another	3
Strong or essential prevalence	5
Very strong or demonstrated prevalence	7
Extremely high prevalence	9
Intermediate values	2,4,6,8

To create a pair-wise comparison matrix (A), factors of each level and their weights are shown as: $A_1, A_2, \dots, A_n$ and $w_1, w_2, \dots, w_n$. The relative significance of a_i and a_j is shown as a_{ij}. The pair-wise comparison matrix of factors $A_1, A_2, \dots, A_n$ as $A=[a_{ij}]$ is expressed as:

$$A = \{a_{ij}\}_{n\,x\,n} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \frac{W_1}{W_2} & \cdots & \frac{W_1}{W_{Nn}} \\ \frac{W_2}{W_1} & 1 & \cdots & \frac{W_2}{W_n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{W_n}{W_1} & \frac{W_n}{W_2} & \cdots & 1 \end{bmatrix}$$

In this matrix, the element, $a_{ij} = 1/a_{ji}$ and thus, when i=j, $a_{i\,j}= 1$. A matrix is normalized by using equation as:

$$a_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad i, j = 1,2, \ldots\ldots, n$$

And lastly, weights of factors are calculated by using following equation:

$$w_i = \left(\frac{1}{n}\right) \sum\nolimits_{j=1} n\ a_{ij} \qquad i \;=\; 1,2, \ldots\ldots, n$$

In matrix-based on pair-wise comparison, if the factors on the horizontal axis are more significant than the factors on the vertical axis, this value differs between 1 and 9. On the other hand, the value differs between the reciprocals ½ and 1/9 (Table: 3, 4). In AHP, for analyzing consistency of matrix, consistency ratio is used, depending on the number of parameters. The consistency ratio (CR) is acquired by comparing the consistency index (CI) with average random consistency index (RI).The consistency ratio is defined as:

$$CR = \frac{CR}{CI}$$

The consistency index of a matrix of comparisons is given by:

$$Consistency\ Index\ (CI) = \frac{\lambda max - n}{n - 1}$$

The average random consistency index (R.I.) is resultant from a sample of randomly produced reciprocal matrices using the scales 1/9, 1/8,…., 8 and 9 (Table 2).

Table 2: Average random consistency index (RI)

N (number of factor)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.5	1.40	1.45	1.49

For these matrices, the consistency ratio (CR) should be less than 0.1(*Saaty, T.L., 1977)*. After producing layers, the last created layers are gathered and the final map is generated. Table 3 shows the most important internal layers and their weightings. The creation of landslides is largely affected by geological structure, terrain and landform, as well as hydrometeorological circumstances. Thus, the landslide of the study area was evaluated by using 10 affecting factors (i.e aspect, lineament buffer, lineament density, lithology, LULC, NDVI, rainfall, slope, soil and soil depth). The weight of all assessment factor was determined by using AHP method. Based on the actual conditions in the study area combined with expert experience, a judgment matrix was created for the landslide affecting factors in the study area, as shown in Table 3, which summarizes the normalized weights. The matrix (consistency index (CI) = 0.1391; consistency index (RI) = 0.1391; consistency ratio (CR) = 0.94) passed the consistency check. Spatial distribution of annual average rainfall has been prepared using IDW interpolation in ArcGIS software. NDVI (Normalized Difference Vegetation Index) can be derived from satellite imagery by using the following association:

$$NDVI = \frac{NIR - R}{NIR + R}$$

Whereas, NIR symbolizes the near infra-red band and R represents the red band in a satellite image. Lineament has been extracted from landsat image using PCI geomatics and ArcGIS software. Lineament density has been prepared using density tools in ArcGIS software. Slope and Aspect has been prepared from the SRTM DEM data using ArcGIS software.

Table 3: AHP Judgment Matrix of the Landslide-Affecting Factors

Factors	**Sub-Factor**	**Criteria Weights**
Rainfall	Low	0.17121

	Moderate High	0.586374 2.517523
NDVI	Low Moderate High	2.48303 0.765847 0.147308
Lithology	Cenozoic Mesozoic Archean	2.307753 0.685342 0.214808
Soil	Clay loam Rock land Sandy Clay Sandy Clay loam/Sandy loam	0.501523 0.101214 1.292845 2.804305
Soil Depth	Deep VeryDeep Rock land	2.271874 0.587452 0.250409
Lineament Buffer	0 – 500 500 - 1000 1000-2000 > 2000	1.406967 1.406967 0.757888 0.435091
Slope	0 – 5 5-15 15 - 30 30 - 50 > 50	0.178172 0.341377 0.723471 2.557968 1.730182
LULC	Agriculture Forest Grass&Shrub Built up Water	1.642389 0.740241 0.698751 2.516152 0.153249

	BarrenLand	0.427149
Aspect	Flat	0.197752
	North	2.075432
	North East	1.472722
	East	0.631444
	South East	0.822073
	South	2.698293
	SouthWest	0.945569
	West	0.378475
	NorthWest	0.98992
Lineament Density	Low	0.197426
	Moderate	0.651219
	High	2.174251

RESULTS AND DISCUSSION

Soil:

The texture of soil signifies the comparative proportion of clay loam, rock land, sandy clay, and sandy clay loam / sandy loam content. A chain of rock land has been identified, which is starting from western part of Nilgiri followed by central towards the north-eastern side. Also it can be seen in some parts of south-eastern region. In Nilgiris soils has very few percentage of rock land form steady aggregates resistant to detachment. On the other hand, entire south-west, and most of the arts of south and east areas are covered with sandy clay loam soil. It is easy to cut off as they have low organic matter content, causing in their inability to form very stable aggregates *(Das and Agarwal 2002).* On extreme northern region sandy clayey soil is found. In fig: 2 we can see the most of the parts of Nilgiri districts has been covered with sandy clay loamy soil.

Soil Depth:

The soil depth forms one of the significant factors for calculating the stability of the soil and landslide susceptibility of the land. As the depth of the soil increases, the tendency of the absorption of the moisture in the soil also increased, resulting in reduced runoff rate. Therefore, shallow soil is considered to be more unstable and more likely to landslide than the deep soil. For the present study the depth of the soil has been categorized into four sub-factor (table: 3). Here in Nilgiris (fig: 2) most of the area contains very deep soil which is >150 cm. The entire central area, major parts of the western and southern region, also north-west and few areas of north depth of the soil can be seen around >150 cm. Whereas few areas of west, north towards east Rock land can be seen. It is also found in very few regions of south. The extreme northern region has the depth of 100-150 cm.

Slope:

Slope may be defined as an angular inclination between different elevations. The slope gradient defines the stage of development of a landscape. Slope steepness is also an important factor and the greater the height, steepness and concavity of slopes, the high the volumes of the landslides *(UNESCO/UNEP, 1988).* The angle of the slope directly affects landslide, so it is used in creating landslide susceptibility maps. The material (in the form of rocks or debris) can move down slope in reaction to gravity, it may be very slowly over many years or devastating quickly within seconds. Fig: 3 shows that in Nilgiri district most of the northern part has 0-5 degree slope. In western and central regions we can see 5-15 degree slope. 15-30 degree slope can be seen on the eastern and the southern regions, also in the edges of the west region along with few in central parts. Whereas in the rocky regions most of the slope ranges from 30-50 degree which is few on the west, covering much of the art of the north-eastern region and also towards the edges of south and south-eastern regions. In Nilgiri the area with slope >50 degree is very less. Such type of slope can be seen in rocky regions in south-western parts and south eastern region.

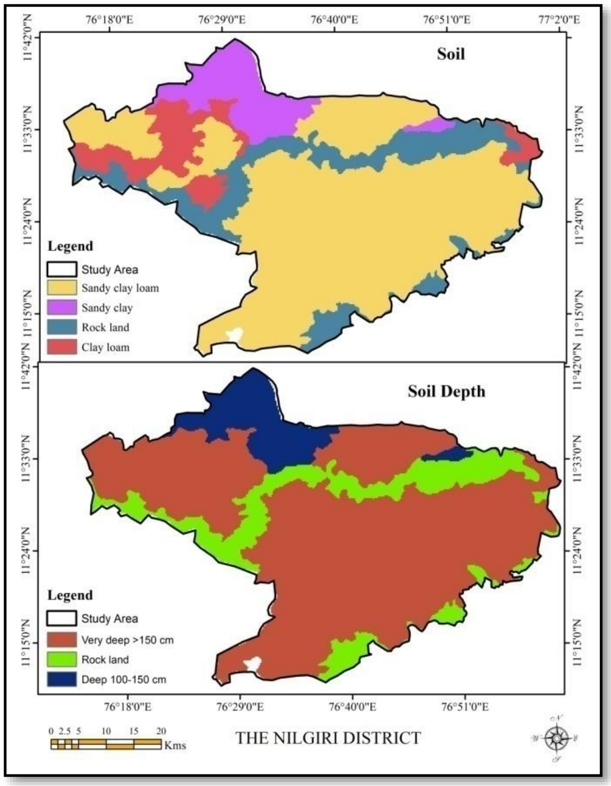

Fig 2: Soil and Soil Depth Map

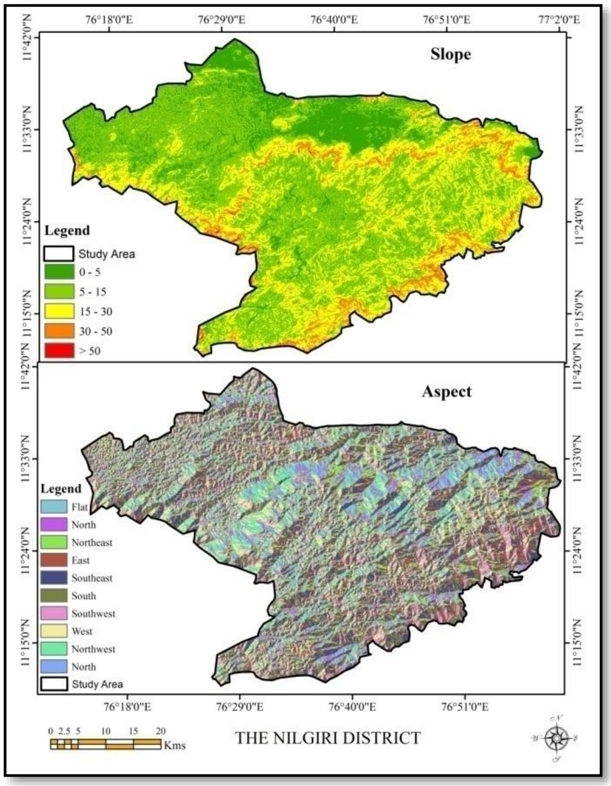

Fig 3: Slope and Aspect Map

Lithology

Lithology has a major part in landslide studies because different lithological units demonstrate different proceeding to active geomorphological processes like landslides (Carrara et al. 1991; Dai et al. 2001). For this study four sub-factors have been taken while creating AHP (Table: 3). Formation lithologies are classified into three types: genozoic, Mesozoic and archcan.In fig: 4, we can see that the north, north-western and majority of west is covered with genozoic rock. Mesozoic rocks are found very less in Nilgiri. Only west and few parts of northeast has Mesozoic rock. The entire east, south and southwest regions of Nilgiri is covered with archean rocks.

Land Use/ Land Cover

Land use is a significant factor that affects the landslides in the area under study. Generally, land use/land cover has influence on power of slope materials against sliding and control of water content of slope. Moreover, plant roots reinforce the slope and generally are considered as reinforcements. Land cover decreases the potential of landslide by absorbing the water of soil. For this study, land use/ land cover map is divided into 6 categories (table: 3). According to fig: 4, water bodies are found in central and southwestern regions. Agricultural lands have covered the largest part of west, also spread all over the central, eastern and southern regions. Grassland is mostly found in west and south-western regions of Nilgiri. The north, north-eastern regions and some parts in west and south-western regions are occupied with forest cover area. Barren land can be seen on one part of north and central region, also in the bottom of southern part. Built-up land is spread over the central, east, south-eastern regions. A small build-up region is also present in western part of the Nilgiri district.

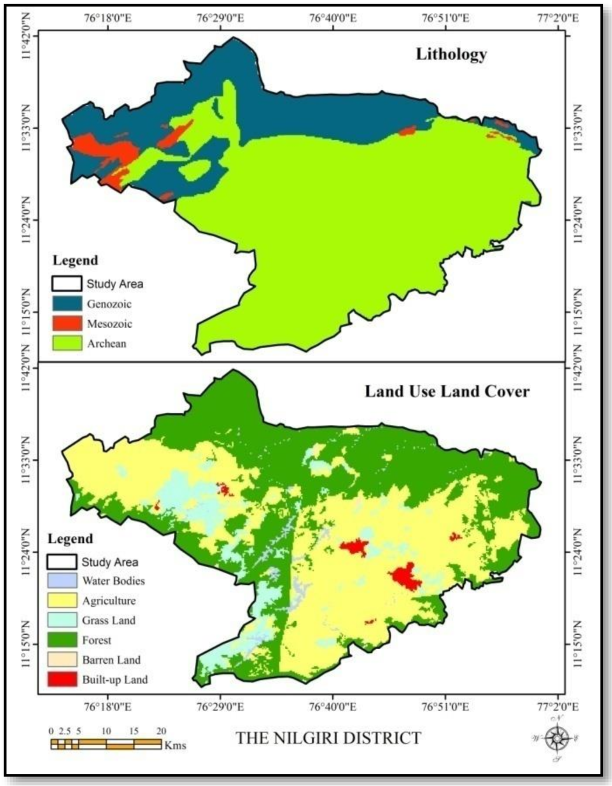

Fig 4: Lithology and Land Use/Land Cover

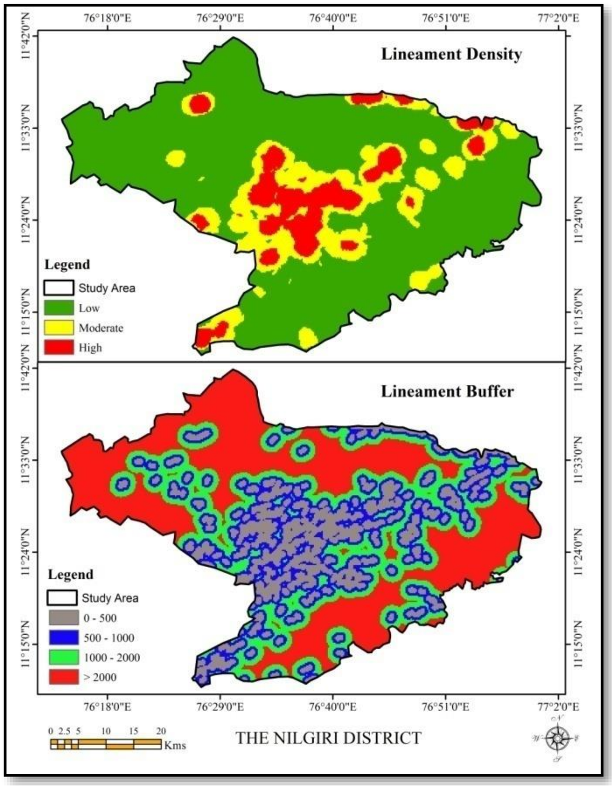

Fig 5: Lineament and Lineament Buffer

Lineament

Lineament states to the any linear feature present in the area, it can be a fault, shearing, fracture, and it can be in form of discontinuity and weaker zones in geological formation. Lineaments are also one of the essential geological features contributing to landslides because their existence and nonexistence make major changes in landslide vulnerability. In all over the study area lineament density is low (fig: 5), except the central, some parts of north, and southwest areas has moderate to high lineament density.

Rainfall

Rainfall, and the interception process, also seems to have a major impact as a 'trigger' on landslides *(Martelloni et al. 2011)*. Rainfall is one of the foremost and the easiest to correctly quantify using rain gauges. Thus, it is cost- effective means of an early warning system based on rainfall measurements and rainfall thresholds can be used to forecast the occurrences of landslide *(Keefer et al., 1987; Aleotti, 2004)*. Once the threshold values of rainfall at which landslides are initiated in a particular area are known, on the basis of same threshold value can be used for issuing early warnings, if the amount of rainfall in that particular area can be forecast *(NDMG 2009)*. If the predicted rainfall intensity exceeds the rainfall threshold, then alert warning can be sent to the regional administration, local community and rescue operation team. Therefore the accuracy and timely rainfall forecasting is very important. The map in fig: 6 shows that the most of the areas of south, east and north-eastern parts of the Nilgiris falls under low rainfall. The western and central areas receive moderate rainfall. Highest rainfall can be seen most in southern and few parts in the west of the Nilgiri.

NDVI (Normal Difference Vegetation Index)

NDVI is the significant parameter for the prediction of landslide *(Lee & Talib, 2005) (Pradhan & Lee, 2009*). Less in vegetation becomes the promoting factor for landslide occurrence in mountainous area (*Dahigamuwa et al., 2016)*. The high vegetation decrease the slope erodibility of the soil *(Gomez & Kavzoglu, 2005) (Weerasinghe et al., 2011*). In a region with high vegetation coverage, soil erosion does not occur easily, terrain erosion is slow and the damage to slopes is relatively insignificant. The higher NDVI, shows the higher vegetation growth. In the following prepared map (fig: 6) the north and south-western parts of Nilgiri is found with high NDVI and also moderate NDVI can be seen in extreme northern region. Low NDVI is deducted in the east, west and southern parts of Nilgiri.

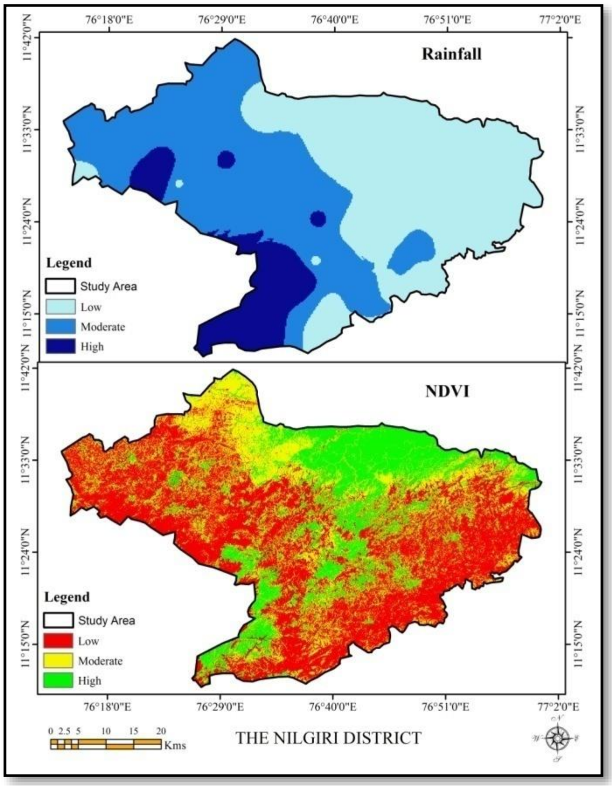

Fig 6: Rainfall and NDVI Map

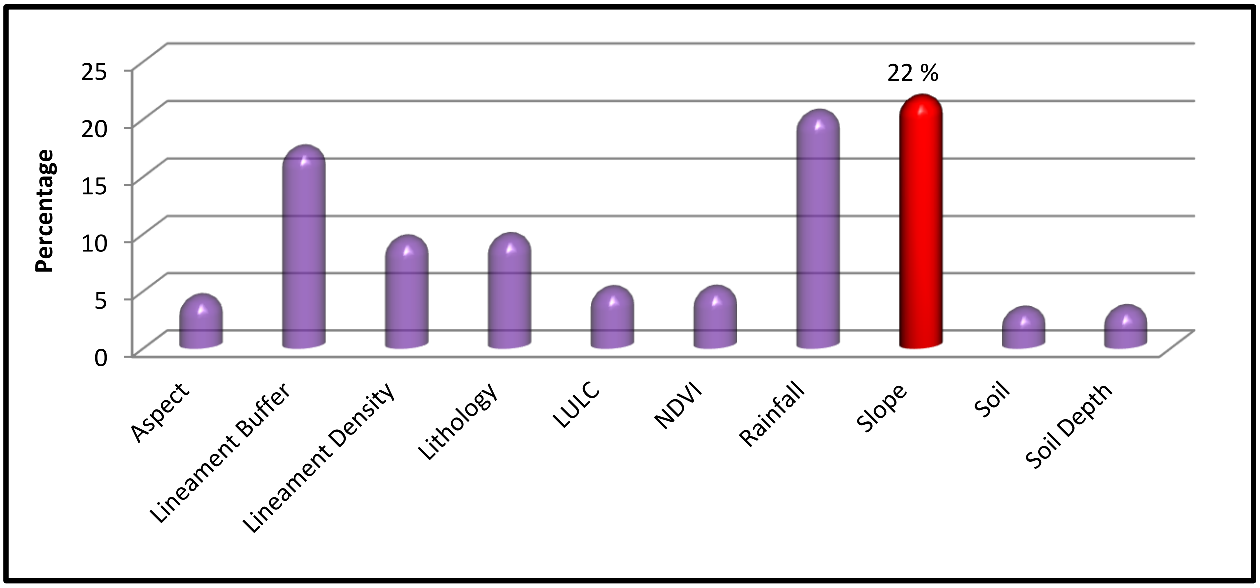

Fig: 7 Percentage Shares of Parameters

Here the following graph shows the comparison between all the factors used in AHP model to produce the susceptibility map. The graph (Fig: 7) shows the major factor which is more accountable for landslide in the study area. The result found from the comparison is that slope is also one of the main factors with 22% is responsible for the cause of landslide. Rainfall is also almost equally responsible for landslide which is 20% of all. 17% lineament buffer factor creates landslide venerable in Nilgiri district. The least responsible factor of landslide is soil and it has only 3%. According to the result high rainfall can stimulate landslides in the slope of 15-30 degree. Hence the regions with 15-30 degree slope are more venerable to landslide in study area.

Table: 4 Calculated AHP-weighted information contents of the landslide-affecting factors

Factor	Consistency Measure	Consistency Index	Consistency Ratio
Rainfall	3.1014	0.0507	0.0874
NDVI	3.1116	0.0558	0.0962
Lithology	3.0895	0.0447	0.0771
Soil	4.0748	0.0249	0.0277
Soil Depth	3.0636	0.0318	0.0548
Lineament Buffer	4.0050	0.0017	0.0018
Slope	5.3600	0.0900	0.0804
LULC	6.1085	0.0217	0.0175
Aspect	10.1241	0.1405	0.0969
Lineament Density	3.0867	0.0433	0.0747
Over all	11.2527	0.1391	0.0934

Source: Computed by Researcher

Landslide susceptibility

Landslide susceptibility maps gives an information of the region where landslides are most possible to happen in the coming future. The main purpose of landslide susceptibility mapping is to identify the locations where there is a possibility of occurrence of landslide events of an area. The phenomenon of landslide is associated to many influencing factors, which includes: climate, hydrology, lithology, structure and geomorphic history. However, all the aspects of all these parameters are not possible to include every time for the assessment of susceptibility mapping. In this study depending on the conditions of the region, different factors (such as soil, lithology, slope, land use/ land cover, etc) are considered as influencing layer for landslide susceptibility zoning. For this study, landslide vulnerable zones are analyzed and mapped by using the landslide occurring factors through Analytic Hierarchy Process (AHP). Previously in many studies this method of GIS based on AHP has been applied and which have been proved very effective technique to landslide susceptibility mapping (*Ercanoglu et al., 2008; Yalcin. 2008*).

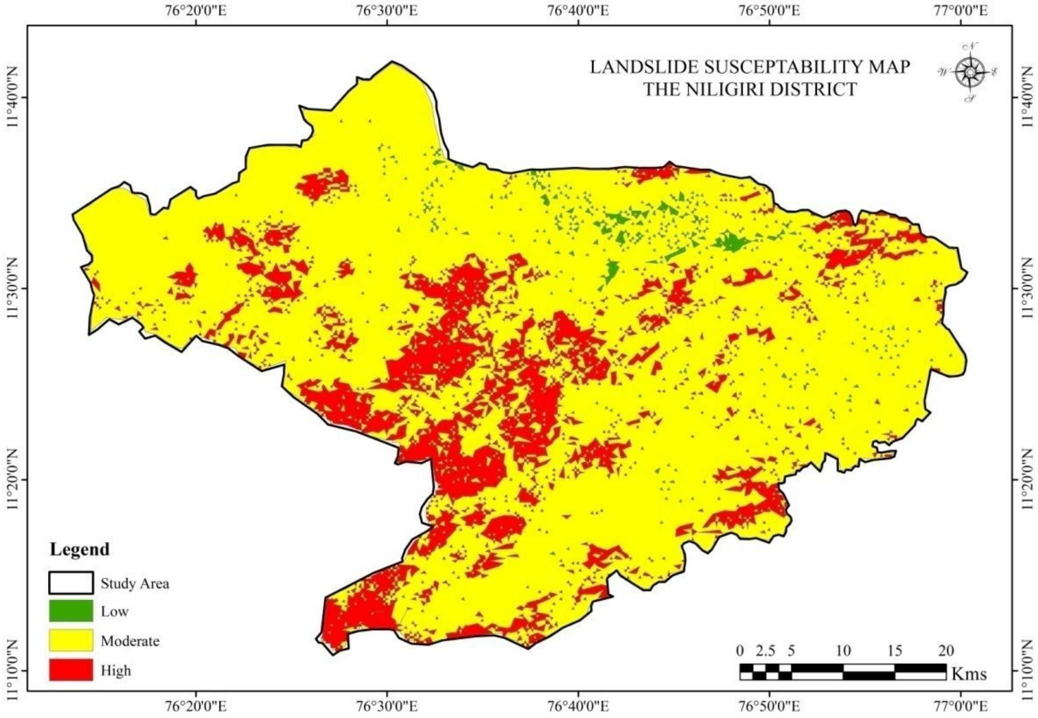

Fig 7: Landslide Susceptibility Map of Study Area

All the factors have the involvement on landslide occurrences out of which some are major and minor contributory factors. Here fig: 7 show the landslide susceptibility map of entire Nilgiri district. The susceptibility classes were classified into three, they are: the high, moderate and low landslide prone zone. Low susceptibility is found on the rear parts of northern and western areas of the Nilgiri district. Moderate susceptibility is widely spread all over the study area. High susceptibility areas mostly lie in the west, south-west and southern part of the Nligiris. We got the statistics of area or percentage of Landslide Susceptibility Classes, which was given in fig: 8. Results showed that the area of 460.11 km^2 (18.025%) located in the high hazard zone, a more considerable area of 2063.527 km^2 (80.843%) was assigned to moderate zone, whereas area of 28.863km^2 (1.130%) landslide susceptibility zone.

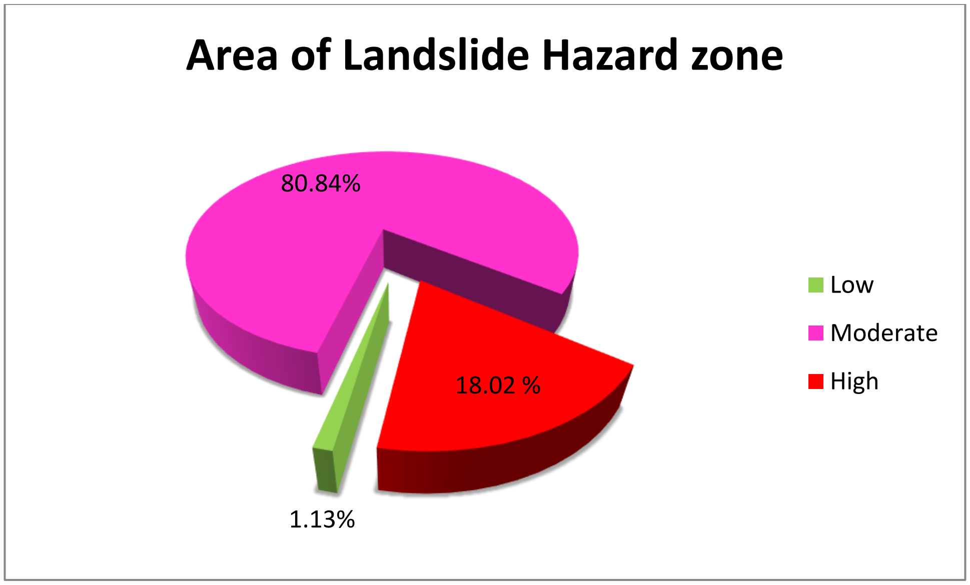

Figure: 8 Area of Landslide Hazard zone

Conclusion

Landslides are either natural or manmade. It constitutes one of the major natural calamities, which accounts for extensive loss of life and destruction of communication routes, human settlements, agricultural and forestland. For an effective disaster management planning it is essential to create and investigate the landslide zonation of the area, which can be beneficial for landslide hazard mitigation planning. This study has tried to find out the major factor which is most responsible for causes of landslide process in Nilgiris district and develop a landslide susceptibility map which is a major step for make an effort for extensive hazard management. This study has been conducted by using APH method of susceptibility mapping. This landslide map contains ten factors which are responsible for landslide. Therefore, we have found the most responsible and dominant factors of landslide in the Nilgiri district. Most of the terrain in Nilgiri district which comes under high venerable areas has been endangered to slope failures under the effect of extreme rainfall. In this susceptibility assessment, we have developed three vulnerable zones, and they are low, moderate and high. The landslide susceptibility map of Nilgiri district will be helpful for engineering works, regional development, tourism industry and tourists because now we know which areas which are highly vulnerable to landslide. These remedies can help to reduce the cause and effects of landslides. The improvement of surface drainage by the procedure of shifting small waterway from the landslide vulnerable area, and sediment should be dredged from the drainage to avoid landslide. The concrete wall or barriers should be constructed next to the roadside and the riverside in landslide-prone area. Plantation of trees is necessary in the landslide-triggering areas.

Reference

1. Barredo, J., Benavides, A., Hervás, J., & van Westen, C. J. (2000). Comparing heuristic landslide hazard assessment techniques using GIS in the Tirajana basin, Gran Canaria Island, Spain. *International journal of applied earth observation and geoinformation*, *2*(1), 9-23.
2. Bathrellos, G. D., Skilodimou, H. D., Chousianitis, K., Youssef, A. M., & Pradhan, B. (2017). Suitability estimation for urban development using multi-hazard assessment map. *Science of the Total Environment*, *575*, 119-134. (CrossRef)
3. Dahigamuwa, T., Yu, Q., & Gunaratne, M. (2016). Feasibility study of land cover classification based on normalized difference vegetation index for landslide risk assessment. *Geosciences*, *6*(4), 45.
4. Fell, R., Corominas, J., Bonnard, CH., Cascini, C., Leroi, E., Z. Savage, W., 2008b. Guidelines for landslide
5. Gomez, H., & Kavzoglu, T. (2005). Assessment of shallow landslide susceptibility using artificial neural networks in Jabonosa River Basin, Venezuela. *Engineering Geology*, *78*(1-2), 11-27.
6. Guzzetti, F., Carrara, A., Cardinali, M., & Reichenbach, P. (1999). Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. *Geomorphology*, *31*(1-4), 181-216.
7. Guzzetti, F., Reichenbach, P., Ardizzone, F., Cardinali, M., & Galli, M. (2006). Estimating the quality of landslide susceptibility models. *Geomorphology*, *81*(1-2), 166-184.

8. Guzzetti, F., Reichenbach, P., Cardinali, M., Galli, M., & Ardizzone, F. (2005). Probabilistic landslide hazard assessment at the basin scale. *Geomorphology*, *72*(1-4), 272-299.
9. Highland, L., & Bobrowsky, P. T. (2008). The landslide handbook: a guide to understanding landslides (p. 129). *Reston: US Geological Survey*.
10. Lee, S., & Talib, J. A. (2005). Probabilistic landslide susceptibility and factor effect analysis. *Environmental Geology*, *47*(7), 982-990.
11. Moreiras, S. M. (2005). Landslide susceptibility zonation in the Rio Mendoza valley, Argentina. *Geomorphology*, *66*(1-4), 345-357.
12. Pradhan, B., & Lee, S. (2009). Landslide risk analysis using artificial neural network model focussing on different training sites. *International Journal of Physical Sciences*, *4*(1), 1-15.
13. Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of mathematical psychology*, *15*(3), 234-281.
14. Saaty, T. L. (1980). The analytic hierarchy process McGraw-Hill. *New York*, *324*.
15. Skilodimou, H. D., Bathrellos, G. D., Chousianitis, K., Youssef, A. M., & Pradhan, B. (2019). Multi-hazard assessment modeling via multi-criteria analysis and GIS: a case study. *Environmental earth sciences*, *78*(2), 47.
16. Susceptibility, hazard and risk zoning for land use planning. Engineering Geology., 102, 99–111
17. Vargas, L. G. (1990). An overview of the analytic hierarchy process and its applications. *European journal of operational research*, *48*(1), 2-8.
18. Weerasinghe, K. M., Gunaratne, M., Ratnaweera, P., & Arambepola, N. M. S. I. (2011). Upgrading of the subjective landslide hazard evaluation scheme in Sri Lanka. *Civil Engineering and Environmental Systems*, *28*(2), 99-121.
19. Yalcin, A. (2008). GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): comparisons of results and confirmations. *Catena*, *72*(1), 1-12.

20. Roy, P. S., Meiyappan, P., Joshi, P. K., Kale, M. P., Srivastav, V. K., Srivasatava, S. K., ... & Bhavani, P. (2016). Decadal Land Use and Land Cover Classifications across India, 1985, 1995, 2005. *ORNL DAAC*.
21. Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V., & Reichenbach, P. (1991). GIS techniques and statistical models in evaluating landslide hazard. *Earth surface processes and landforms*, *16*(5), 427-445.
22. Dai, F. C., Lee, C. F., Li, J. X. Z. W., & Xu, Z. W. (2001). Assessment of landslide susceptibility on the natural terrain of Lantau Island, Hong Kong. *Environmental Geology*, *40*(3), 381-391.