Comprehensive Landslide Vulnerability Zones in Ranni Taluk, Pathanamthitta District, Kerala, Using Remote Sensing & GIS Techniques

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Abstract

Landslide is known to be one of the most dangerous natural hazards. The present study aims to comprehend landslide vulnerability zones in Ranni Taluk, a small forest division, north of Pathanamthitta district, Kerala using Geo-Spatial techniques. The factors determining the landslide vulnerability such as rainfall, vegetation, slope & aspect, geology, geomorphology, soil, drainage density, lineament, land use/ land-cover, road density and elevation of the given area varies according to its geographic setting. These factors are interdependent and have major and minor effects upon other factors. Remote Sensing (RS) and Geographic Information System (GIS) techniques are adopted to prepare the base thematic layers of the above factors and the weightage was assigned to each factor based on its potential in triggering landslide. Based on assigned weights, a weighted overlay analysis was performed to demarcate the vulnerable areas. The study reveals that around 50% of the total study area possess moderate to very high landslide vulnerability and only 19% of the study region possess very low vulnerability. Thus, a vulnerability assessment stresses the importance of strengthening the participation of local body government towards developing better disaster management plans for the study area.

Keywords: *Landslide vulnerability, Influencing Factor, Weighted Overlay, GIS and Remote Sensing.*

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1. Introduction

The term landslide refers to the downward sliding movement of huge quantities of land masses and earth particles. The sliding movement of the rock masses occurs from a higher level to a lower level, mostly in steep sloping areas. Landslide, a type of mass wasting, are the most destructive event which is caused due to any down slope movement of soil and rocks under the direct influence of gravity. According to the United States Geological Survey, there are 5 modes of slope movements such as falls, topples, slides, spreads and flows. Based on the geological material and type of ground movements, it encompasses another classification as rock falls, mudflow, debris flow, earth subsidence and slope failures. Landslides can occur anywhere in the world. They are more widespread than any other extreme events. Landslides can be the result of both natural phenomenon and human activities. It results in an incalculable loss of life and property. Mud flow and Debris flow are the most common type of landslides identified in Kerala. According to World Health Organization, from the year 1998 to 2017, about 4.8 million people were affected by landslide hazards, including an estimated 18,000 deaths.

In Kerala, landslides are more common in the localized areas of the Western Ghats, where the region depicts steep slopes and over-saturated soil character due to the huge amount of rainfall received. The total area of the Kerala state is 38,863 square kilometers from which 40% of the land lies in the high lands regions forming the western slopes of the Western Ghats. Almost all districts except Alappuzha falls within this region making them landslide vulnerable areas. The topography of the region shows rugged hills with steep slopes with the rest of the soil and earth materials. The slope of the Western Ghats are generally steep to very steep with highly intended plateau edges, having more than 25 degree slope (Kerala State Disaster Management Authority). The most recent landslide events of Kerala includes Puthumala landslide in Wayanad and Kavalappara in Malappuram district during 2019. On the 6th of August 2020, another most destructive landslide occurred in Pettimudi, which is a hamlet in Rajamala ward under Munnar village in Idukki district of Kerala.

Vulnerability analysis is an important part of hazard analysis, which is confronted with complexity, uncertainty factors and other characteristics (Ting Liao et al., 2011). In the present study, a detailed description and analysis of landslide vulnerability assessment of Ranni taluk in Pathanamthitta district was performed by analyzing various geophysical parameters.

2. Study Area

Ranni is a small village in the Pathanamthitta district of Kerala, India. For this study, we have taken the entire taluk, which covers over an area of 1004.61 square kilometers from which 708 square kilometers comes under forest cover which is exactly the 70% of the total area (Census of India, 2011). It provides a complete green environment to Ranni. The word Ranni is derived from a similar Malayalam word called “Rani” which means the “Queen”, so the region is locally known as “Malanadinte Rani” which means the “Queen of the eastern hills”. The exact geographic location of the region is at 9° 22’ 0”N latitude and 76° 46’ 0”E longitude and the average elevation of the area is about 131m above the mean sea level and also even higher towards the east.

The river Pamba known for its sacredness related with Sabarimala temple flows through this region and the famous Hindu temple Sabarimala is situated in this taluk. It is one of the largest taluks in Kerala having great forests, hills and rivers. The total population of the region is identified to be 1,64,463 people from which 79,010 are the male population and 85,453 female population (District Census Handbook Pathanamthitta, 2011). The region exhibits a wet climate commonly. The area receives SW monsoon during June to August and NE monsoon during October to November exactly like the rest of the state. During the summer season, from March to May the area receives thundershowers occasionally. Other than this climatic condition, the region shows a cooler climate towards east, because of the higher elevation.

Pathanamthitta district is identified to be the 3rd most landslide prone district in Kerala after Idukki and Palakkad. About 6.41% of the district is vulnerable to the occurrence of landslides (Kerala State Management Plan Profile by KSDMA). According to Kerala State Disaster Management Authority, Ranni is one of the most landslide prone taluk in the state (Figure 1).

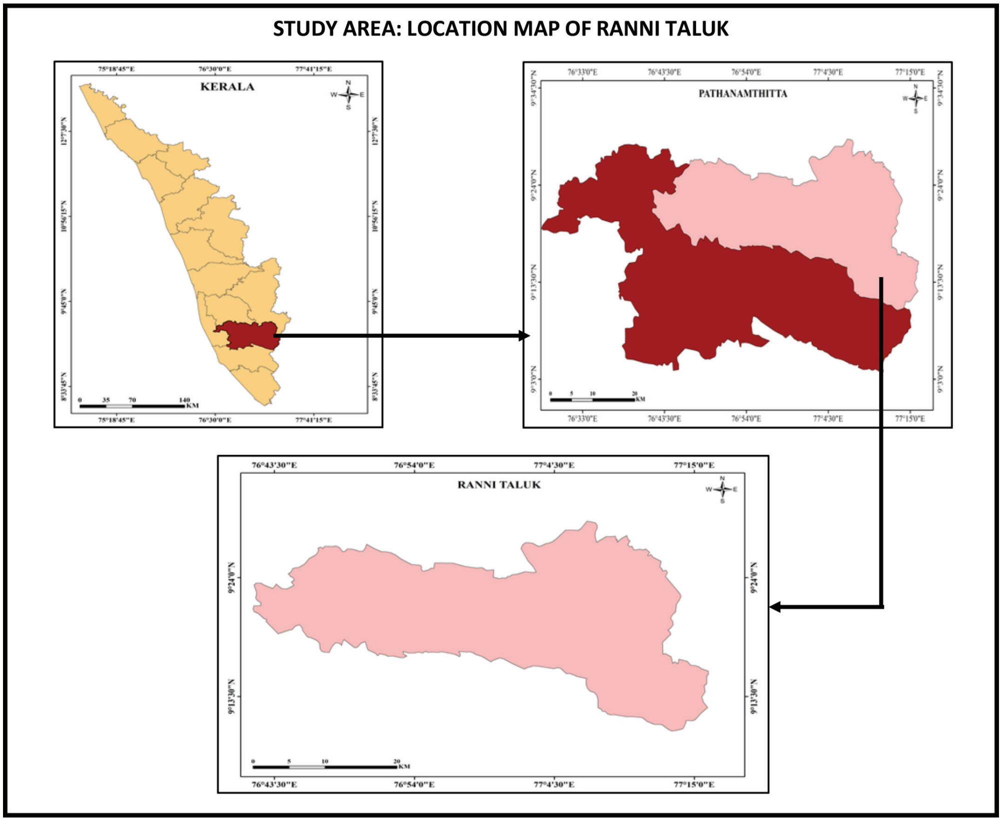

Figure 1: Location Map of Ranni Taluk

3. Methods and Methodology

Weighed overlay analysis was used to identify the potential landslide prone areas in Ranni Taluk. For the present study, the factors identified are Slope, Aspect, Elevation, Geology, Geomorphology, Rainfall, LULC, Lineament, Road density, Drainage density and Normalized Difference Vegetation Index. The spatial data sources were derived from Geological Survey of India maps; Satellite images (Landsat 8) and Tropical Rainfall Measuring Mission (TRMM). In the Arc GIS 10.3 setting, these thematic layers were converted to a raster format with a resolution of 30m and subjected to weighted overlay analysis. The Multi Influencing Factor Technique was used to assign weights to individual parameters. The weighted overlay method is a straight forward method for determining the evolution of landslide risk in a given region. This method is based on the premise that the conditions that resulted in the previous landslides would recur in the future in other locations, resulting in new landslide prone areas. The graphical representation of the methodology followed in the present study is represented in Figure 2.

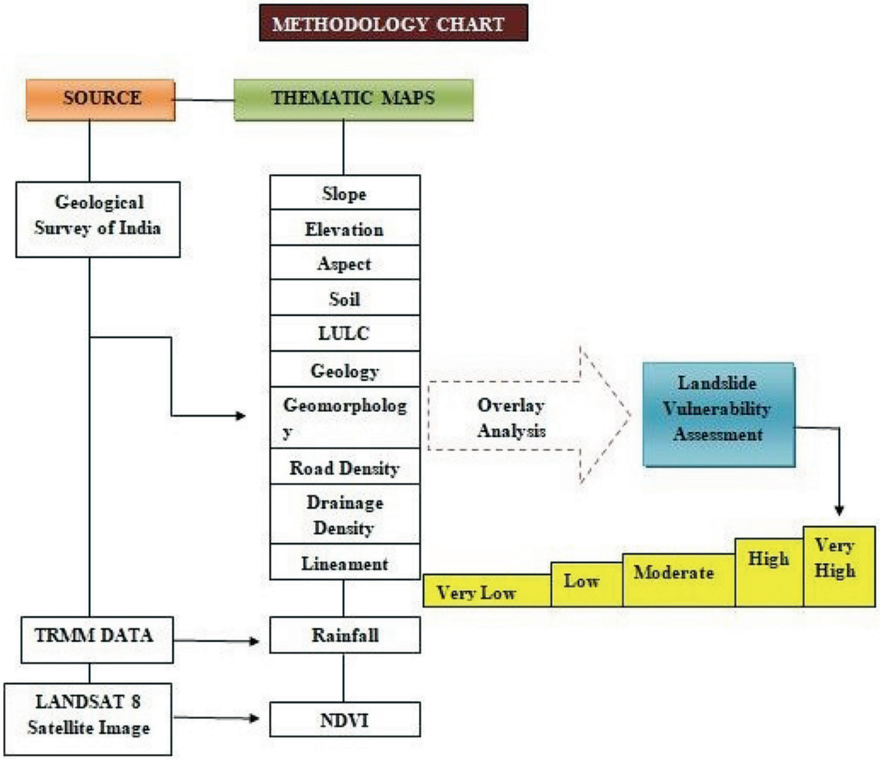

Figure 2: Methodology Chart

4. Result and Disscusion

4.1 Digital Elevation Model

DEM is a valuable tool for the topographic parameterization, especially for erosion and drainage analysis, hill-slope hydrology, watersheds, groundwater flow and contaminant transport studies (Walker and Willgoose, 1999; De Vantier and Feldman, 1993; Jenson and Domingue, 1988).

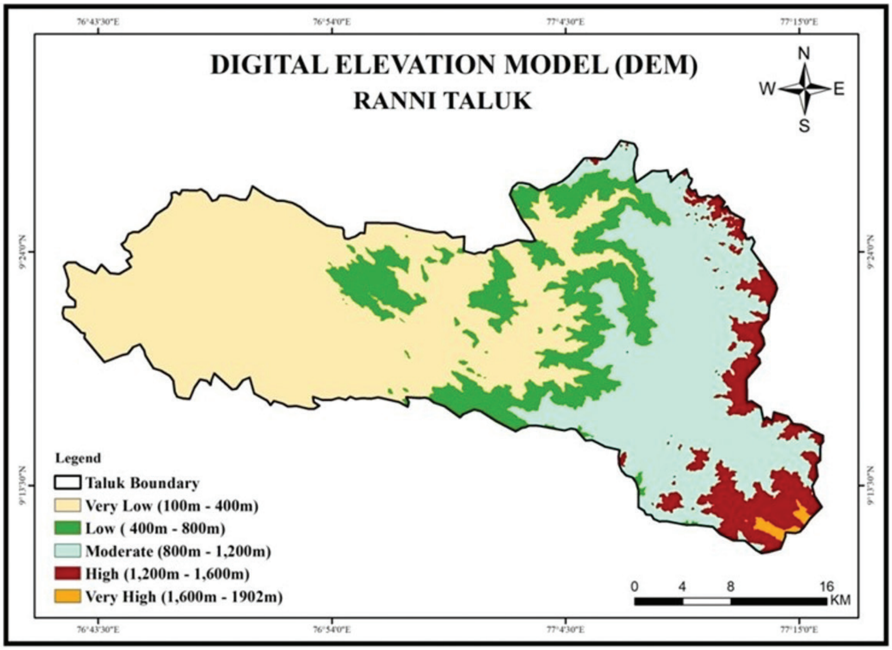

Figure 3: DEM of Ranni Taluk

The elevation trend of Ranni increases from east to west (Figure 3). The contour data of the study area is collected first from Open DEM that provide spatial data as vector layers. The extracted contours were processed in a GIS based software like ArcGIS, to get the output.

4.2 Slope & Aspect

Aspect identifies the downslope direction of the maximum rate of change in value from each pixel to its neighbors. Aspect can be thought of as the slope direction. The values of the output raster will be the compass direction of the aspect, represented by a hue (color). Slope represents the rate of change of elevation for each digital elevation model (DEM) pixel. Slope represents the steepness of the surface and is symbolized into three classes that are shown using color saturation (brightness) (pro.arcgis.com).

The rate of slope increases towards the west (Figure 4). The slope map was prepared using the DEM result in ArcGIS software. The aspect map shows the direction of the slope dip (Figure 5). It was prepared using the resulting slope map. Both the maps are a result of the raster processing in ArcGIS software.

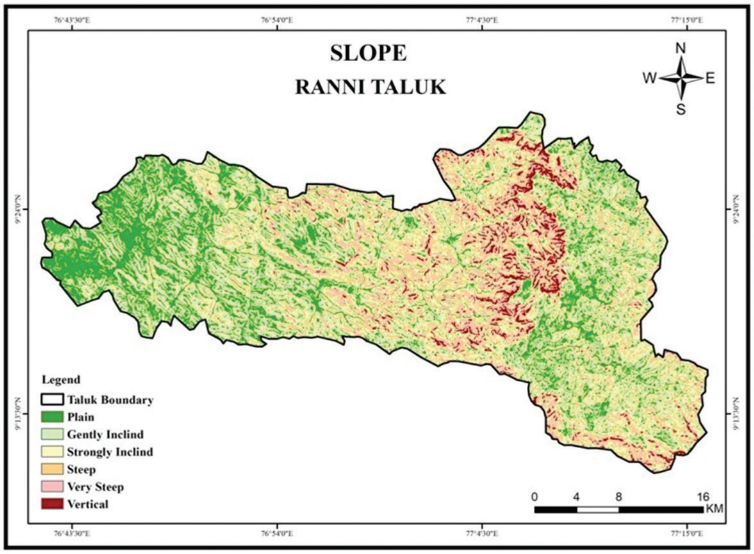

Figure 4: Slope of Ranni Taluk

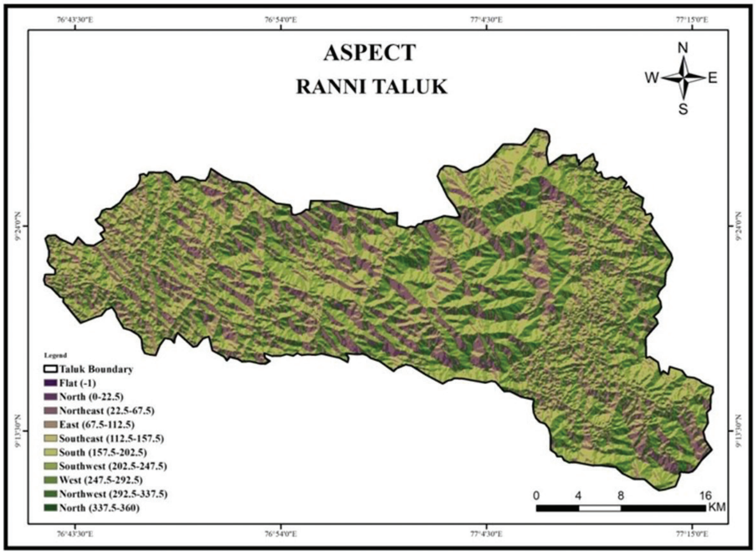

Figure 5: Aspect of Ranni Taluk

4.3 Drainage Density

Hortan (1932) first proposed drainage density as a useful measure of the linear scale of landform elements in stream eroded topography. Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed is drained by stream to length of overland flow. Rugged regions or those with high relief will also have a higher drainage density than other drainage basins if the other characteristics of the basin are the same. Drainage density can affect the shape of a river's hydrograph during a rain storm. Rivers that have a high drainage density will often have a more, flashy hydrograph with a steep falling limb. High densities can also indicate a greater flood risk. High drainage densities also mean a high bifurcation ratio. A high frequency ratio and high drainage density indicates a higher probability of landslide while, on the other hand, lower drainage density with a less frequency ratio exhibits a lower landslide probability (B Mandal & S Mandal, 2016).

The main rivers that drain this region are Achankovil, Manimala and Pamba. The vector data for the rivers that drains the Ranni area was extracted firstly from Bhukosh. Then using this layer, the drainage density of the area was determined. The drainage density trend of Ranni varies mostly from high to very high (Figure 6). This could be one among the other reasons for an increased landslide susceptibility in this place.

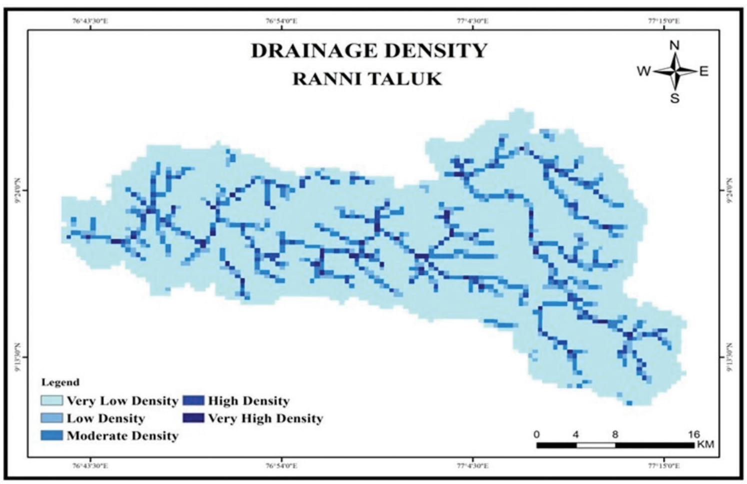

Figure 6: Drainage Density of Ranni Taluk

4.4 Lineaments

Geological structural features, such as the discontinuities that may be detected on satellite imagery as lineaments, in many cases control landslide occurrences. Lineament may represent the plane of weakness where the strength of the slope material has been reduced, eventually resulting in slope failure (Norhakim Yusof et al., 2011).

The lineament information about the study area was extracted from Bhukosh in the official site of Geological Survey of India. From the identified lineaments 4 proximity buffer was created for 250 meters, 500 meters, 750 meters and 1000 meters. The lineament trend of Ranni is high given the taluk being the southern part of the Western Ghats. The density of the lineaments and the possibility of landslides are directly proportional, thus making its study inevitable while analyzing the landslide trends of Ranni (Figure 7).

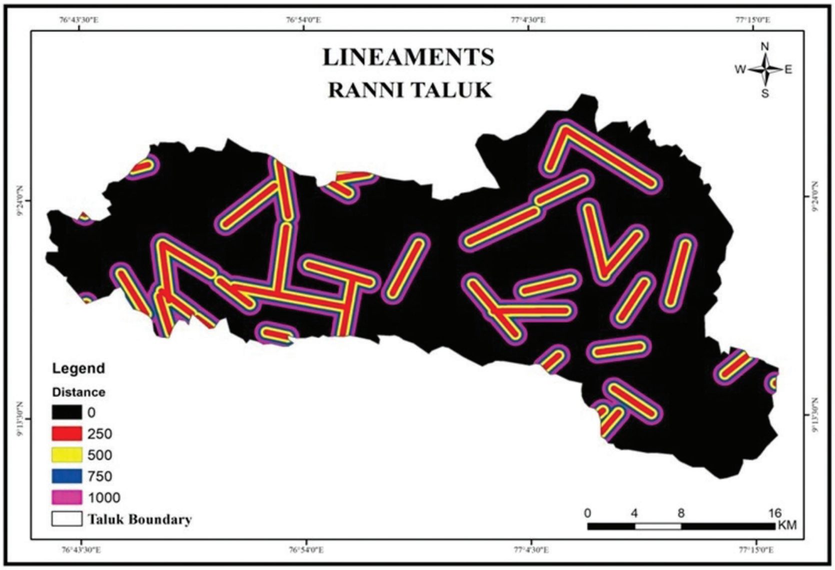

Figure 7: Lineament of Ranni Taluk

4.5 Normalized Difference Vegetation Index (NDVI)

The normalized difference vegetation index (NDVI) is a simple graphical indicator that can be used to analyze remote sensing measurements, often from a space platform, assessing whether or not the target being observed contains live green vegetation. The NDVI is calculated from these individual measurements as follows:

NDVI = (NIR-Red) / (NIR+Red)

Where, Red and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near infrared regions, respectively. These spectral reflectance are themselves ratios of the reflected over the incoming radiation in each spectral band individually, hence they take on values between 0.0 and 1.0.

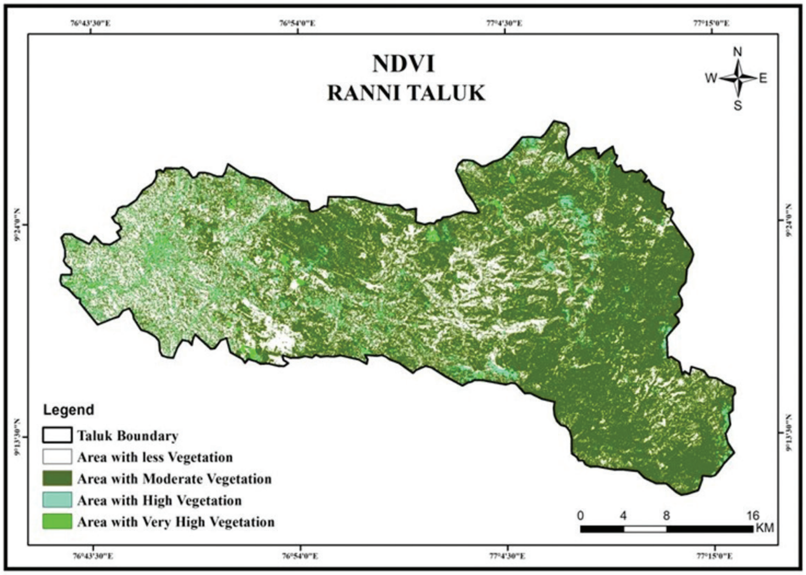

Figure 8: NDVI of Ranni Taluk

In general, the NDVI of Ranni (Figure 8) shows the presence of a very thick and healthy vegetation. This can be due to the presence of reserved forests in these regions, that is, towards the east and the large agricultural fields in the west. The use of NDVI in landslide studies will help us understand about the substantial loss that can occur to the greenery of an area. It will also help to get a clear picture of the agricultural conditions of the region before and after the event.

4.6 Soil

Landslides are primarily caused by changes in water content and stresses in the unsaturated region. Soil characteristics like clay content contributes to the stresses in the unsaturated region. Landslides are to be blamed for the landslide vulnerability in those areas that have a presence of clay, especially in the hilly area. Due to the complicated topography of the hilly area, clay plays a significant role in causing slope failure and landslides. The most prominent soil types found in this region are; Clay, Gravelly clay, Gravelly Loam and Loam (Figure 9). The highland regions are composed of clayey soils and the plains are composed of loamy soils.

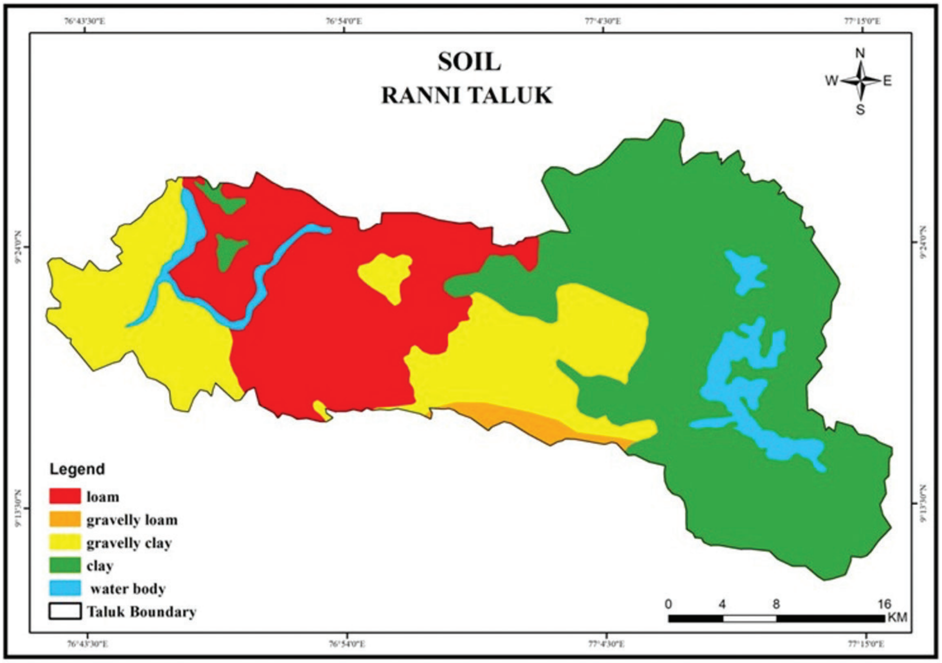

Figure 9: Soils of Ranni Taluk

4.7 Geology

The term "geology" refers to the physical characteristics of the material. Different layers of the earth or rock may have different strengths and hardness, or the earth or rock may be fragile or broken. Geology is the general characteristics of sediments, rocks, and rock types present in the stratigraphic divisions of the earth. Precisely, the study of rocks and their formation is called geology. It helps in understanding and describing the physical characteristics of rock units such as their color, grain size, texture or composition. Geology also helps in understanding porosity, permeability, water saturation, etc., and other petro physical properties of rocks. In this map (Figure 10), the major geological forms of Ranni comes under the Charnockite group.

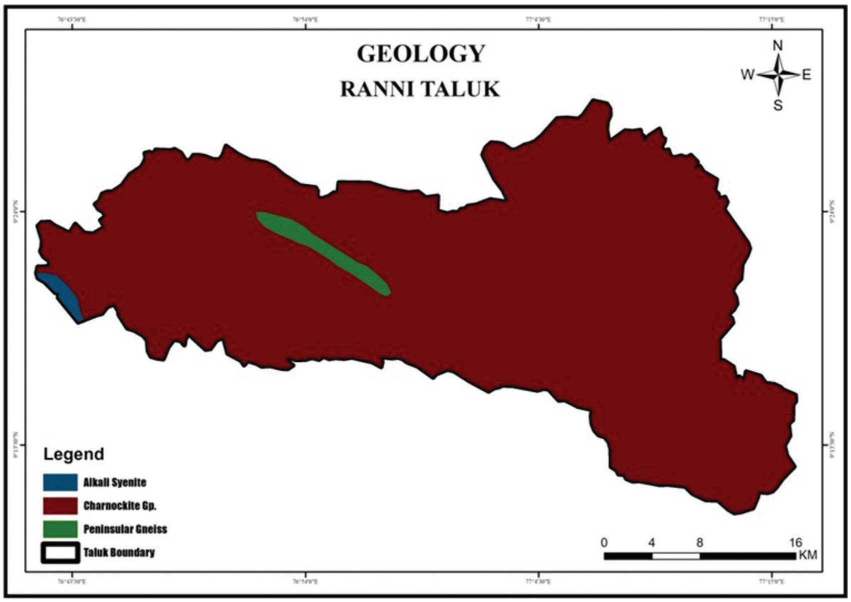

Figure 10: Geology of Ranni Taluk

4.8 Geomorphology

Geomorphology is the study of landforms, their processes, form and sediments at the surface of the Earth (and sometimes on other planets). Study includes looking at landscapes to work out how the earth surface processes, such as air, water and ice, can mold the landscape (www.geomorphology.org.uk). The landscape of Ranni is primarily composed of highly dissected hills and valleys followed by a flat Pedi plain to the west (Figure 11). The famous Pamba Basin Hydro Electric Project is located here.

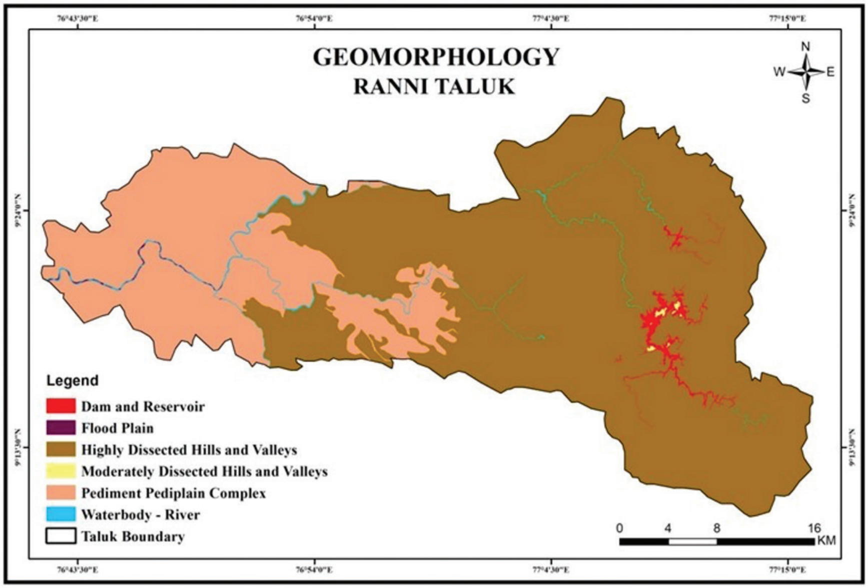

Figure 11: Geomorphology of Ranni Taluk

4.9 LULC

Land cover and land use changes are one among the four major global environmental issues, together with biodiversity, atmospheric composition and climate change (Walker and Steffen, 1997; Walker, 1998). Therefore, it is always important to monitor land use change within a certain period of time and predict patterns of future land use changes on a spatial basis (Nurmiaty, etal., 2014). Mapping is the most efficient method for projecting changing land use (Mani, 2012). Standard visual interpretation methods were applied to identify and interpret the land use pattern of the area and various land use classes delineated includes Agricultural lands, Built up, Forest, Natural/Semi natural grassland & grazing land, Wastelands, Water body and Wetlands (Figure 12). The dominant land use is of Forests and Agricultural lands. (Suresh S., etal., 2018). More than half of the area is covered by Forest. The prominent settlement areas are located towards the west of the taluk, mostly along the river banks. These settlements are surrounded by agricultural lands.

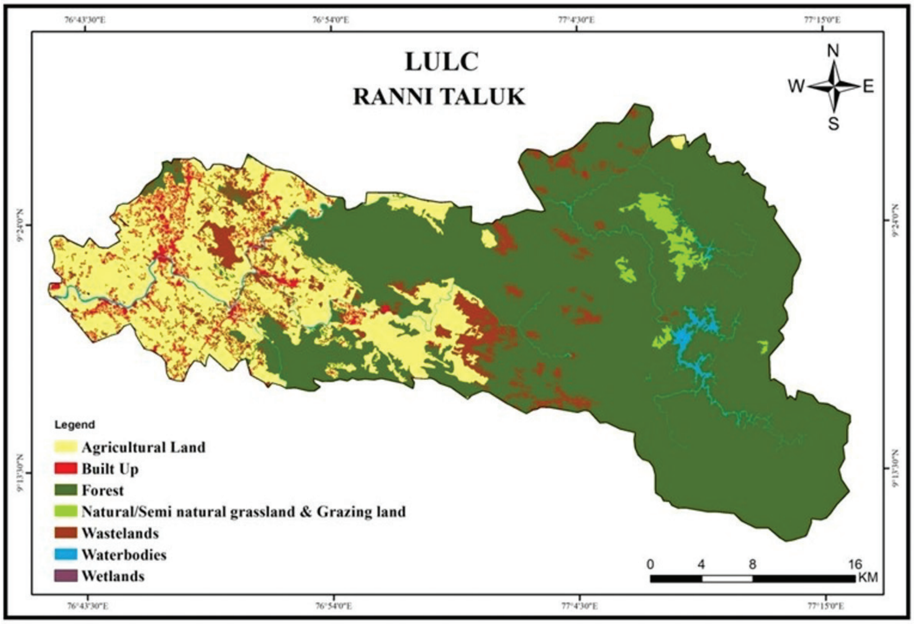

Figure 12: LULC of Ranni Taluk

4.10 Rainfall

Rainfall is the primary triggering agent for landslides and is often used for prediction of slope failures. However, the relationship between rainfall and landslide occurrences are very complex. Great efforts have been made on the study of regional rainfall-induced landslide forecasting models in recent years; still, there is no commonly accepted method for rainfall-induced landslide forecast (Shibiao Bai, et al., May 13). In this paper, rainfall data for the study area was obtained from the TRMM data and was analyzed using the IDW interpolation tool from ArcGIS (Figure 13).

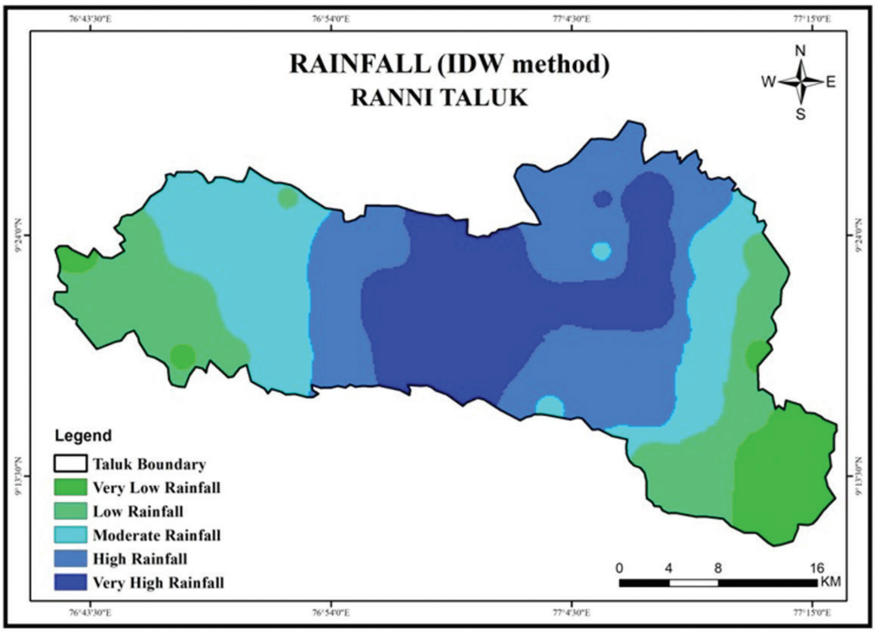

Figure 13: Rainfall Map of Ranni Taluk

4.11 Road Density

Road density is a simple indicator of the concentration of roads in an area. The road density can be determined for road segments that have characteristics that are attributed, like road segments within a 100 meter buffer of stream channels. The road network connectivity is high in the western side of Ranni taluk (Figure 14). This can be easily correlated with the location of built up areas and settlement sites on the same side. The road network ensures better connectivity of the human population.

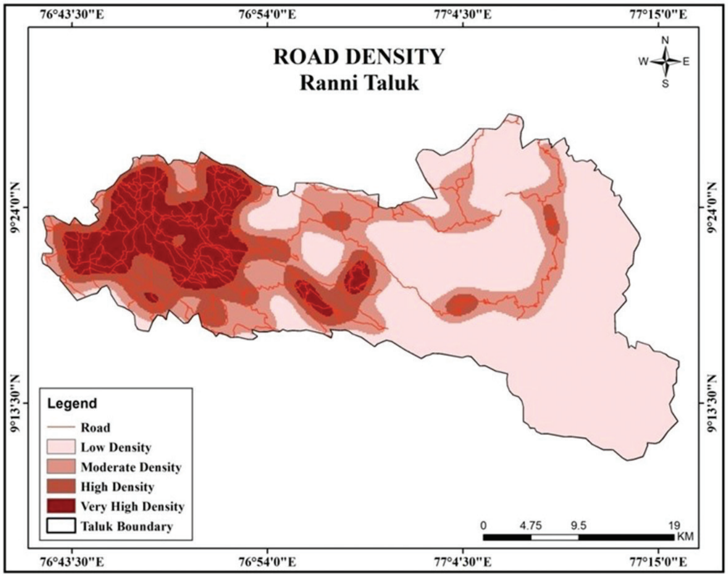

Figure 14: Road Density of Ranni Taluk

4.12 Weighted Overlay Analysis for Landslide Vulnerability Assessment

As mentioned in the methodology section, elevation, slope, aspect, geology, geomorphology, soil, drainage density, lineament, land-use/land-cover, road density and rainfall are the parameters considered for the present study. Based on how these parameters influence the landslide vulnerability, these parameters were given ranks accordingly.

4.12.1 Classification of Weighted Parameters Influencing the Vulnerable Zones:

The rank classification for the selected factors influencing landslide vulnerability ranges from 1 to 5. For the slope, elevation, rainfall, aspect and road density, the ranking is given in ascending order, from very low to very high, in which rank 1 show very low landslide vulnerability while rank 5 indicates very high vulnerability. Other factors like

NDVI, drainage density and lineament displays a descending ranking pattern. So the chances of occurrences of landslide is high in lower rank values and it becomes low towards higher rank. The parameters of landslide vulnerability assessment like geology, LULC, soil and geomorphology, the ranking is based on the specific characteristics of each parameters.

Table 1: Classification of Parameters used for Weighted Overlay Analysis

Sl. No.	Factor	Class	Rank	Weight
1	Slope	Very Low	1	10
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	
2	Elevation	Very Low	1	10
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	
3	Geology	Charnockite	5	8
		Peninsular Gneissic	4	
		Syenite	2	
4	LULC	Water Body	1	8
		Agriculture	1	
		Forest	3	
		Waste Land	4	
		Built Up	5	
		Natural/semi natural Vegetation	2	
5	Soil	Gravelly Clay	3	8
		Clay	2	
		Gravelly Loam	5	
		Loam	4	

6	Rainfall	Very Low	1	12
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	
7	Aspect	Very Low	1	5
		Low	2	
		Moderate	3	
		High	4	
		Very High	5	
8	Drainage Density	Low	4	5
		Moderate	3	
		High	2	
		Very High	1	
9	NDVI	Area with Less Vegetation	4	8
		Area with Moderate Vegetation	3	
		Area with High Vegetation	2	
		Area with Very High Vegetation	1	
10	Road Density	Low Density	1	8
		Moderate Density	4	
		High Density	3	
		Very High Density	2	
11	Geomorphololgy	Dam & Reservoir	5	10
		Flood Plain	4	
		Highly Dissected Hills and Valley	2	
		Moderately Dissected Hills and Valleys	1	
		Pediment pediplain	3	
12	Lineament	0	1	8
		250	5	
		500	4	
		750	3	
		1000	2	

4.13 Landslide Vulnerability Zones

The result of weighted overlay analysis was mapped and classified into five classes as Very low, Low, Moderate, High and Very high based on the vulnerability of landslide. The result (Table 2) shows that, 201.12 sq.km area comes under very low landslide vulnerability, 338.57 sq.km area comes under low vulnerability, 240.25 sq.km area comes under moderate vulnerability, 144.98 sq.km comes under highly vulnerability and 109.71 sq.km comes under very high vulnerability areas. The map given (Figure 15) shows the vulnerable areas. The villages to the west, such as, Ayroor, Angadi, Ranni, Cherukole, parts of Pazhavangady and also the highly sloping areas of the Chittar-Seethathode village in the east. The vulnerability reduces from the central region towards the north.

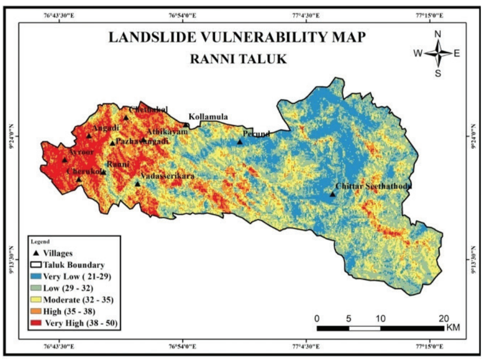

Figure 15: Village wise Landslide Vulnerability Map of Ranni Taluk

The given classifications were then converted using ArcGIS software and the area was calculated within these five classes. The areas of each class are tabulated below:

Table 2: Areas under each Vulnerability Class

Class	Area (in sq. km)	Area (in %)
Very Low	201.12	19.43
Low	338.57	32.72
Moderate	240.25	23.22
High	144.98	14.01
Very High	109.71	10.60

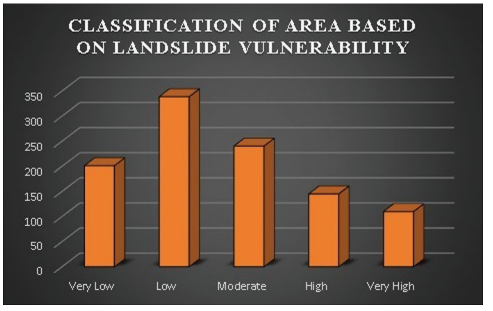

Figure 16: Areas under each Vulnerability Class

The graphical representation (Figure 16) implies the classification of areas based on landslide vulnerability. The graph clearly shows that 32.72% of area comes under lower chances of landslide vulnerability which comprises a large portion of the study area.

5. Conclusion

This paper attempts to conduct a landslide vulnerability assessment using the GIS and remote sensing tools effectively. According to a report released by the Kerala State Disaster Management Authority (KSDMA), Ranni taluk is a landslide prone area. Therefore, this study puts forward the Landslide vulnerability assessment and Micro zonation of Ranni taluk. Twelve parameters affecting landslides were analyzed using weighted overlay method. Slope failure in the eastern part of the Ranni increases the risk of landslides. However, in the western parts being relatively low sloping, yet are highly vulnerable due to the presence of anthropogenic factors. This is mainly due to changes in land use and the structural characteristics of the soil and geology. So it is more likely that there will be a soil piping phenomenon similar to landslides here. Studies by Center for Earth Science Studies (CESS) have identified Ranni as a highly prone area for soil piping in South Kerala. Therefore, this study indicates that more studies are intended towards this area in relation to future studies in soil piping and soil erodability.

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