

Research Article

Landslide Hazard Zonation using Remote Sensing, Ground Penetrating Radar surveys and Geographical Information System in Katteri Watershed, Nilgiri, Tamil Nadu, India

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Abstract

The aim of this study is to carry out a detailed GPR survey in conjunction with remote sensing techniques to prepare Landslide Hazard Zonation map of Katteri watershed in the Nilgiris-Tamil Nadu, India. The methodology involves satellite image interpretation and ground-penetrating radar (GPR) surveys, GPR surveys was used to determine the thickness of the weathered overburden that is likely to slide if triggered. Different thematic layer (Geomorphology, Lineament density, Drainage density, Land cover/Land use, lithomarge thickness and NDVI) were prepared from DEM and ETM images and from GPR data. Based on the susceptibility index the landslide susceptibility zones are classified into five classes. The susceptibility level increases with the increase in susceptibility index. It is seen that north eastern and north-western region of the watershed is high to moderately susceptible to landslide, the central portion is moderately susceptible whereas the south western portion is less susceptible.

Keywords: Landslide, GPR, lithomarge thickness, Remote Sensing, ranks and weights, GIS analysis, susceptibility

1. Introduction

Landslides play an important role in the evolution of landforms and represent a serious hazard in many areas of the world. In some places, fatalities and economic damage caused by landslides are larger than those caused by other natural hazards, including volcanic eruptions earthquakes, and floods. Due to the extraordinary breadth of the spectrum of landslide phenomena, no single method exists to identify and map landslides (Guzzeti, 2006), to ascertain landslide hazards, and to evaluate the associated risk (Guzzeti, 2006). This paper reports the work done to provide a scientific rationale and a set of remote sensing and ground based approach for the preparation of landslide hazard zonation map for the Katteri Watershed in Nilgiris.

There is a variation in the degree of landslide incidences in various hill ranges. Steep terrain and high frequency of rainfall make landslide occurrence frequent on natural terrain (Dai and Lee, 2002). Intense rainfall coupled with the increase in human activities associated with urban development has contributed to increase instability of slopes (Bhasin et al, 2001). Landslide is a frequently occurring phenomenon in the Nilgiri district, south India because

of high intensity rainfall. Landslides are one of the complex phenomena, involving multitudes of factors and need to be studied systematically in order to evaluate the hazard. Most of the landslides occur in places where deforestation, plantation, urbanization, shifting cultivation, infrastructure developmental activities etc. take place. In such places, infiltration is more and landslides occur because various soil layers, such as pervious and impervious are available, and also thickness of soil available is high. Normally, the causes of landslides are determined by carrying out sampling of factors such as soil, rock, slope inclination, land cover, ground water level and other related parameters at the site.

This paper is concerned with the use of Ground Penetrating Radar, remote sensing and Geographical Information System to understand the causative factors and map the spatial and temporal distribution of landslides in Katteri sub-watershed in a part of the Nilgiri Hills of Tamil Nadu, India.

2. Study area

The study area is a part of Ooty town in the Nilgiris district, in the north western part of Tamil Nadu, India, covering an area of 30 square km (4x7.5 sq km in east-west and north-south direction). It lies between 76°41' 30"E, 76° 45' 0"E and 11° 19' 30"N, 11° 24' 0" and falls

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under survey of India toposheet no. 58 A/11. The area falls in the tropical zone of weathering. Most part of it is deeply weathered and at some places thick soil cover of up to 13 m was found by GPR surveys. The exposed area reveals a humus zone of 0.50 to 1.0 m followed by red or brown or yellow silt and clay. The weathered zone between the clay and the fresh rock is normally about a meter thick. Intense rainstorm followed by dry period have helped formation of considerable depth of weathering, and at some places weathering extended up to 45 m in the study area. (Rajakumar, 2007).

The general elevation of the study area (Katteri Watershed) varies from 1940m to 2200m above msl, Alanji being the highest peak (2200m) and KatteriNaduhatti lowest (1940m). The greater part of the area is deeply weathered, as a result development of thick soil cover over the bed rock is common observation.

3. Methodology

The methodology involves the desk study, field survey, and the integration of both. The methodology adopted to arrive at landslide hazard zonation is outline below in the form of a flow chart.

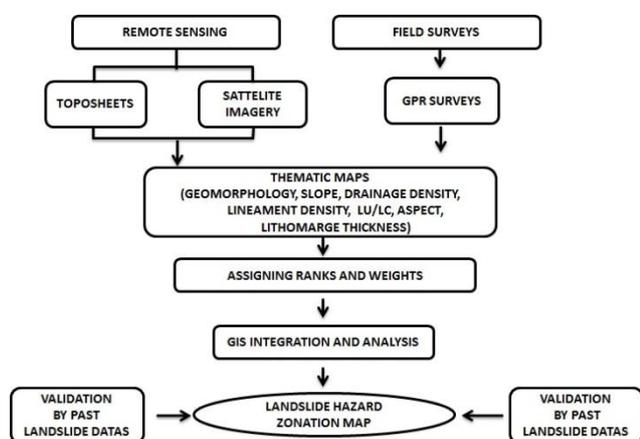


Fig.1 Flowchart depicting Methodology used in the study

3.1 Remote Sensing inputs

Thematic maps such as slope, land use, lineament density, drainage density, aspect, Geomorphology were prepared using LANDSAT, TM and ETM imagery, topographic map of 1: 50,000 scales, and various other sources and are analyzed in the GIS environment

3.2 Ground Penetrating Radar Surveys

Extensive field surveys were carried out to provide the information on the thickness of the weathered material overlying the bedrock. Twenty four (24) locations were identified and the position was recorded using Global Positioning System for GPR surveys. A common Mid-Point surveying technique is adopted in the present study, which is three person operation surveying

technique. Common mid- point (CMP) profiles of 50 MHz were collected from the identified location. The profiles were collected with initial antenna separation of 2 m. GPR data were processed using a band pass filter to remove low and high frequency noise. The final profile shows the distinct two layers lithology characters. The first layer is the weathered zone, in which the present study is concern about. The thickness of this layer is the total material that are likely to slide with the slope failure.

3.3 Integration and GIS Analysis

After carefully analysing the causative factors/ thematic maps, appropriate ranks and weights were assigned and the final landslide hazard zonation map was prepared. The legend was derived from the mean and standard deviation of the union map.

4. Result and discussion

Seven relevant factors in map format, responsible for the occurrence of landslide were identified from remote sensing techniques and GPR surveys in GIS environment. These thematic layers were integrated by union overlay analysis. The highlight of this study is the emphasis laid on ground based surveys to determine the thickness of the weathered overburden in the watershed. A discussion about the causative factors/ thematic layers is as follows:-

4.1 Slope

Slope is an important factor in the analysis of landslide. As the slope increases the probability of the occurrence of landslide increases because the shear stress of the soil increases. Dai and Lee (2002) reported that landslide is maximum when the slope angle is between 35° and 40° and it decreases when slope is greater than 40°

For the present study, slope map is derived from SRTM DEM imagery. The slope class was categorized as (0° - 10°)-very gentle slope, (11° - 25°)-gentle slope, (26° - 35°)-moderate slope and $>35^{\circ}$ as high slope. The moderate and high slope is found in the northern and north western region (fig.2). The maximum slope of the area is 42° . Generally it is evident that the slide occurs in slope within 60° . In other word, the amount of weathered material accumulates at slope less than 60° , which can slide by losing the friction by the action of altering its geotechnical properties. This is against with the slope greater than 60° , as the material tends to flow as soon as the weathering is initiated, leaving behind no material to slide. Hence it is clear that there is huge amount of weathered material present, as the slope of the area is such that, it does not allowed the material to flow as soon as it weathered. Very steep slope is found in northern region, steep slope is observed in the northern and north western region, where as moderate and gentle slope are widely scattered throughout the

study area. The area with very high slope is found to be highly susceptible to landslide and the susceptibility decreases with the decrease in slope.

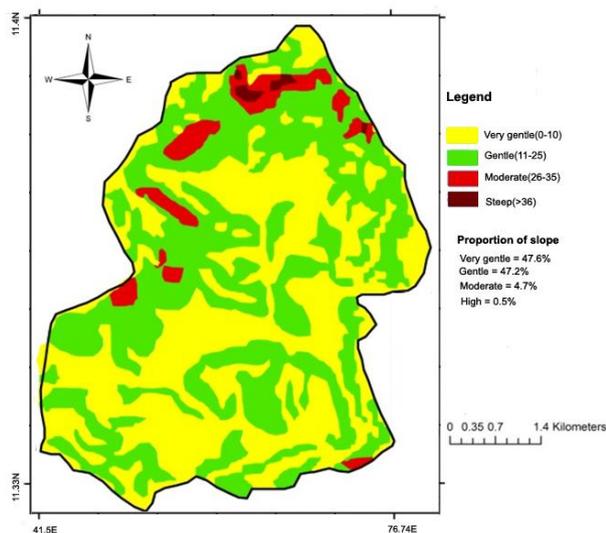


Fig.2 Slope map

3.1.2 Land use/Land cover

Changes in vegetation cover often results in modified landslide behaviour (Glade, 2003). From various investigations it is learnt that land use/vegetation cover of a woody type with strong and large root helps to improve the stability of slopes. The areas with denser vegetation were considered to be less susceptible to sliding with respect to the area with less or no vegetation (Gokceoglu and Aksoy, 1996).

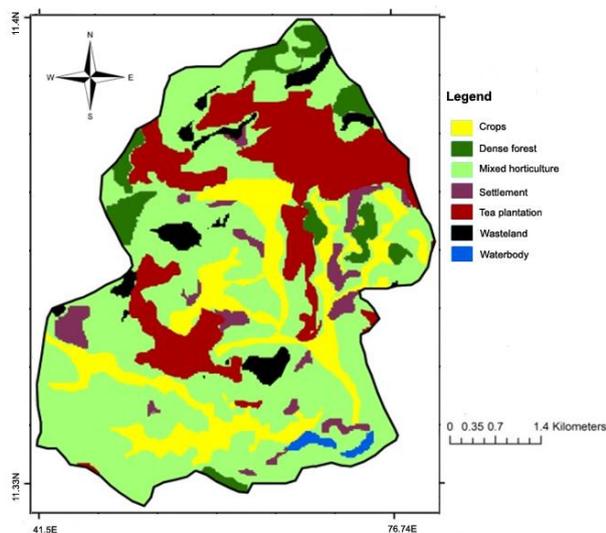


Fig.3 Lansuse landcover map

The land cover map was prepared from ETM imagery. The watershed area is characterised by the dense forest, crops, mixed horticultural land, tea plantation, settlement area and waste lands. The horticulture plantation is found as the major landuse in the

watershed. In this study, the tea plantation and mixed horticulture region (fig. 3) which falls under the central portion of the watershed is found to be having moderate susceptibility, whereas the dense forest region in the extreme north are less susceptible. The susceptible maps of the study area are shown in Figure 12. The areas which are very densely vegetated are found to be less susceptible.

3.1.3 Drainage

Drainage plays a vital role in weathering and hence in turn to landslide, the coarse drainage locations are more prone than that of finer drainage i.e, more the drainage density, less is the area susceptible to landslide. This is because, the region with high drainage density (fine density) represent the hard rock terrain, the water flows on the surface of the terrain, resulting in less weathering phenomenon, however it do contribute to weathering which should not be negligible, but it is not as effective as being contributed by less drainage density. In case of coarse drainage pattern, the water seeps into the formation than to flow on the surface depending on the nature of the rock below it. The rate of infiltration is more than the rate of runoff, as a result vertical weathering is pronounced resulting in turns in the accumulation of material that is responsible for the occurrence of landslide. The drainage map was extracted from DEM in 1:50000 scales, the nature of drainage are coarsely distributed in the region. The drainage density classification so obtained based on the frequency of drainage lines per 0.5sq km is shown in the table 1

As the distance from the drainage line increases the probability of occurrence of landslide also increase, as the surface runoff decreases and infiltration increases, the grade of weathering increases. To understand the role of drainage, a drainage map was prepared from SRTM imagery. The drainage map was overlaid on a grid cover of size 0.50 x 0.50 km. The number of drainage lines present in each grid is counted which will give the drainage frequency value. The frequency value is used for preparing drainage density map by thiessen polygon method. Accordingly the drainage density has been classified into 4 groups based on the number of drainage incidences (high, medium, low and very low). Majority of the watershed falls under low density category.

Table 1 Drairage density classification

No of lines per 0.5 sq km	Drainage classification
0 – 2	very low
2 – 4	low
4 – 6	medium
6 – 8	high

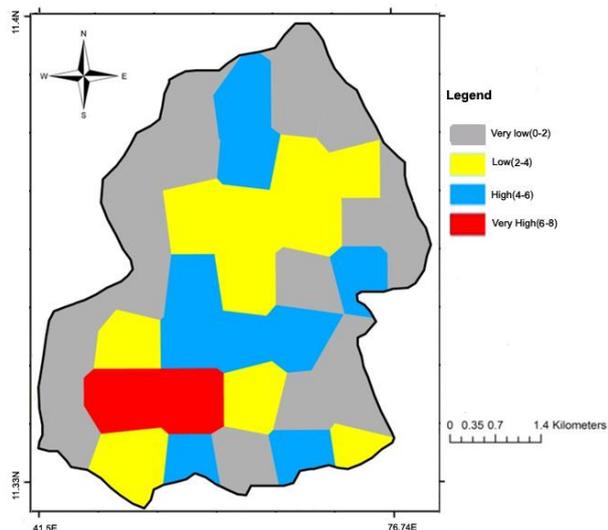
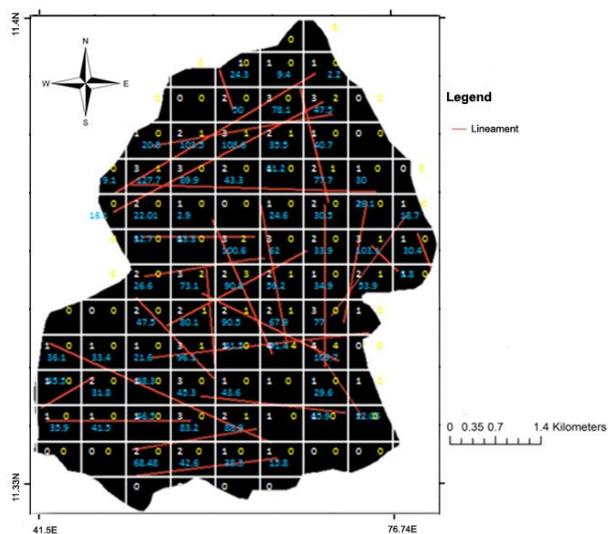


Fig.4 Drainage Density map of the study area

3.1.4 Lineament

Lineaments are the rectilinear, linear or curvilinear features of tectonic origin observed in satellite data. These lineaments normally show tonal, textural, soil tonal, drainage and vegetation linearity and curvilinearities in satellite data (D Balachandar et al, 2010). All these linear features were interpreted from the satellite data and the lineament map prepared for the Katteri Watershed.



intersection and lineament length. Lineaments are regions where weathering is prominent. The landslide occurrence is more in area of high lineament density and intersection. Taking this as one of the important factor lineament map is prepared from ETM imagery.

Lineament frequency value was obtained by dividing the lineament map into 0.5X0.5 km² grid and counting the no of lineament present in each grid. The number of lineament intersection present in each grid was counted which gives the lineament intersection value. Hence more the number of intersections, higher will be the probability of landslide occurrence.

Same grid is used for obtaining lineament length values. The total lineament length per grid is calculated which gives lineament length value. The length of the lineament is given importance in this study, considering the fact that longer the lineament, deeper it is and hence more prone to vertical downward weathering.

Fig.5 Values for lineament density; white=occurrence, yellow=intersection, blue=density

The influence of these structures is conducive to infiltration and development of hydrostatic pressure on the slope forming material (Nagarajan et al., 996). Faults and landslides have a close association; about 88% of the landslides were detected within an area closer than 250 m to major faults (Gokceoglu and Aksoy 1996). Lineament density map was prepared by combining the result of lineament frequency, lineament

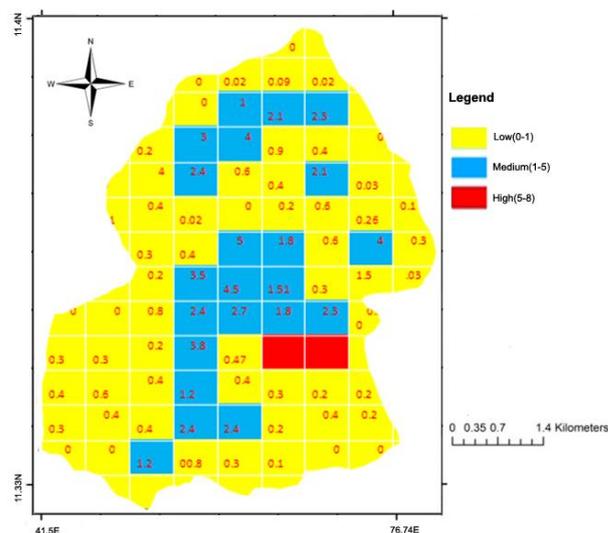


Fig.6 Lineament density map of the study area

3.1.5 Aspect

It has been reported that in north facing slopes the landslide frequency is relatively low, and it increases with the orientation angle, reaching the maximum on south facing slopes and then declines (Dai and Lee, 2002).

In the present study, aspect map is generated through GIS analysis from SRTM imagery and ranking is assigned to directions and formed as a theme

From the field investigation and the Geological Survey of India report by Seshagiri et al. (1982), most of the landslides occurred in south facing aspect was caused by a higher amount of solar insolation in these slopes. It is learned from reports that slope with higher insolation and associated higher temperatures have increased erosion. Areas where vegetation has been removed will receive direct sunlight, creating drier soil conditions, thus increasing the probability of landslide occurrences.

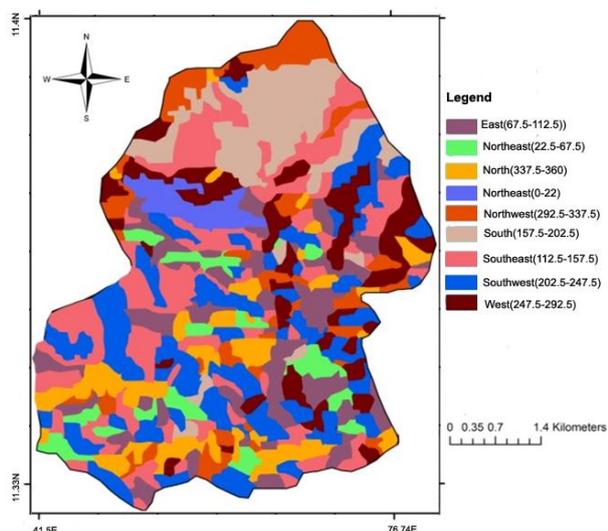


Fig.7 Aspect map of the study area

3.1.6 Geomorphology

The bedrock geology of the area consists mainly of Charnockite, hypersthene bearing bluish grey rock which forms the basement in high grade metamorphic terrain. A simplified geomorphology map of the area was prepared from the satellite imagery (landsat ETM+) and the major units identified are- Valley fills/ structural valley, Denudational hills and Mounds

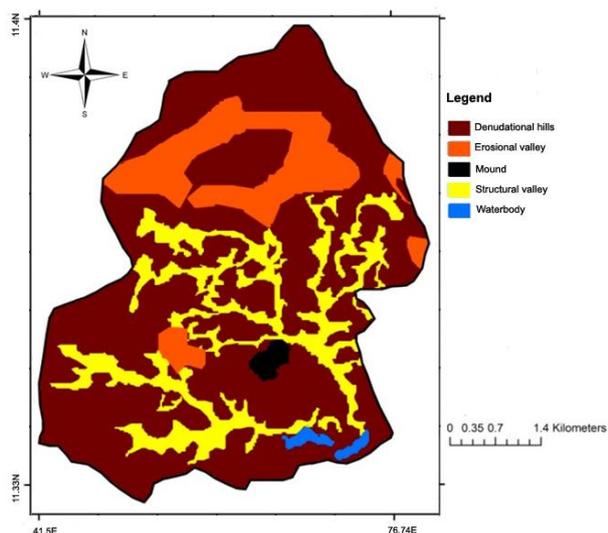


Fig.8 Geomorphology map of the study area

The major geomorphic unit covering the area is denudational hills. These are intensely weathered rock mass lying at higher altitude. The result is due to the continuous surface runoff and intense percolation of water through the rock mass which decorously weathers the overlying rock. Valley fills occurs at lower altitude along valley floor and is the accumulation of colluvial materials transported from the uplands into the valleys; hence they may not cause major slides. Mounds are the resistant, ridge like feature. The

weathered mantle is totally absent over mound and hence is considered as the safest portion from the landslide point of view

3.1.7 Thickness of Lithomarge

Ground Penetrating Radar survey is a geophysical technique that uses electromagnetic energy with central frequencies generally between 50 and 1200 MHz to image the sub-surface in a way very similar to seismic reflection. Ground Penetrating Radar (GPR) technology applications have become wider nowadays. They include utility mapping as important part of civil engineering applications, geological structure, soil analysis, applications in agriculture, etc. Characteristics of the technology make it suitable for structure analysis of shallow landslides (A Ristic, et all 2013) whose number and impact on environment is dominant in the study area. The results of GPR data analysis of the shallow landslide are represented in the present study.

One of the most important factors responsible for the occurrence of landslide is the thickness of the weathered overburden lying at a slope greater than angle of repose. Ground penetrating radar survey is used in present study to evaluate the thickness of these materials which are likely to slide.

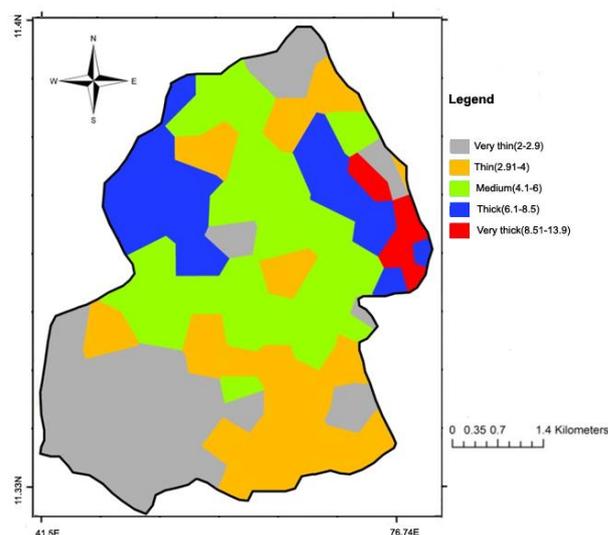


Fig.9 lithomarge thickness map derived from GPR Surveys

The CMPs surveys were used primarily to evaluate the thickness of the first layer, i.e., the weathered zone-lithomarge, which is presented in Table 2. The GPR profiles so obtained indicate wide variation in the thickness of the weathered zone across the study area which is responsible for the occurrence of landslide. Thicker the weathered material present above the parent rock, higher will be the area susceptible to landslide and vice versa. The spatial variation of the lithomarge as interpreted from GPR data is shown in figure 11. High to very high lithomarge thickness (fig

Table 2 thickness of weathered zone calculated from GPR survey profiles

Latitude	Longitude	Locations	Thickness
11.38114	76.70481	Lovedale	5.1
11.37272	76.71861	Sandur	7
11.37022	76.71889	Kammandu 1	7
11.38244	76.71678	Kammandu 2	2
11.37753	76.72614	Santhoor	4.6
11.38142	76.71428	Acchanakal	7.2
11.37908	76.73950	Ketti 1	7.9
11.37919	76.73958	Ketti 2	9.8
11.37992	76.74208	Yellanalli 1	2.2
11.37983	76.74247	Yellanalli 2	2.8
11.38860	76.73195	Yellanalli 3	3.4
11.37069	76.74528	Kekatti 1	3.3
11.36717	76.74628	Kekatti 2	11.1
11.34576	76.71284	Mutturadu	10
11.36247	76.74472	Mukatti 1	2
11.36206	76.74319	Mukatti 2	13.9
11.35647	76.73811	Mel udayahatti 1	8.5
11.36199	76.71927	Mel udayahatti 2	5.5
11.34381	76.73503	Thuratti 1	4.4
11.34519	76.73519	Thuratti 2	2.8
11.34136	76.72981	Katteri	3.1
11.35639	76.71003	Kollimalai	2.5
11.35883	76.70483	Thambatti	5.3
11.36658	76.70764	Gandhipettai	3.3

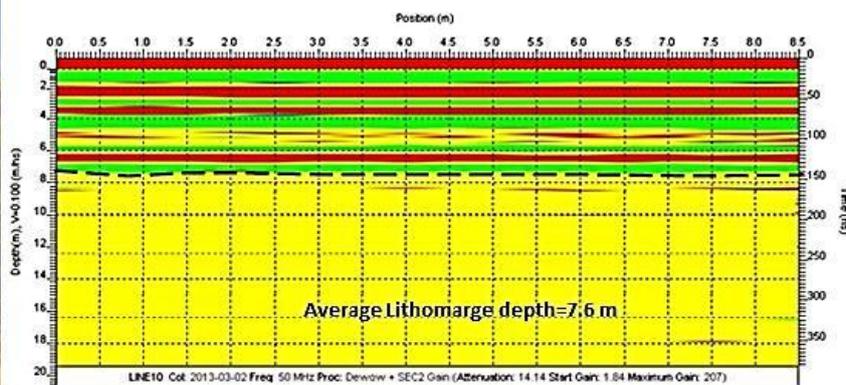


Fig 10.1: The GPR profile indicates the depth of the weathered zone to be 7.6m, whereas the measured depth is only 5.1m. This is because it is not possible for us to know the depth of the weathering horizon below the surface up to which tape measurement was made. Since it lies on the side of the road, there is always a possibility that water seeps through the sides and hence the rock would be weathered vertically downward. Accordingly the actual depth of the weathered zone is 7.6m in this location. The second layer below the weathered zone has been removed for better visualization.

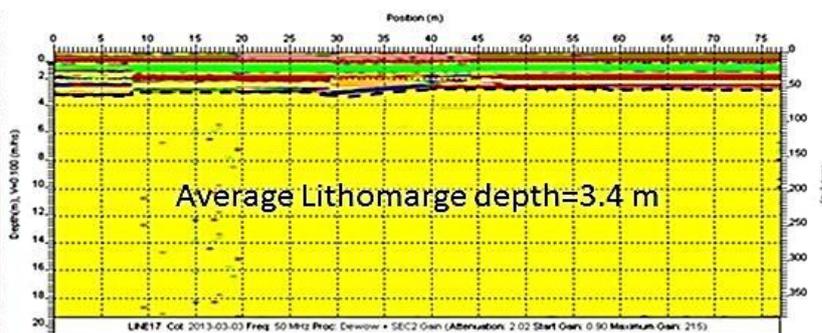


Fig 10.2: Another example of GPR profiling along road cutting

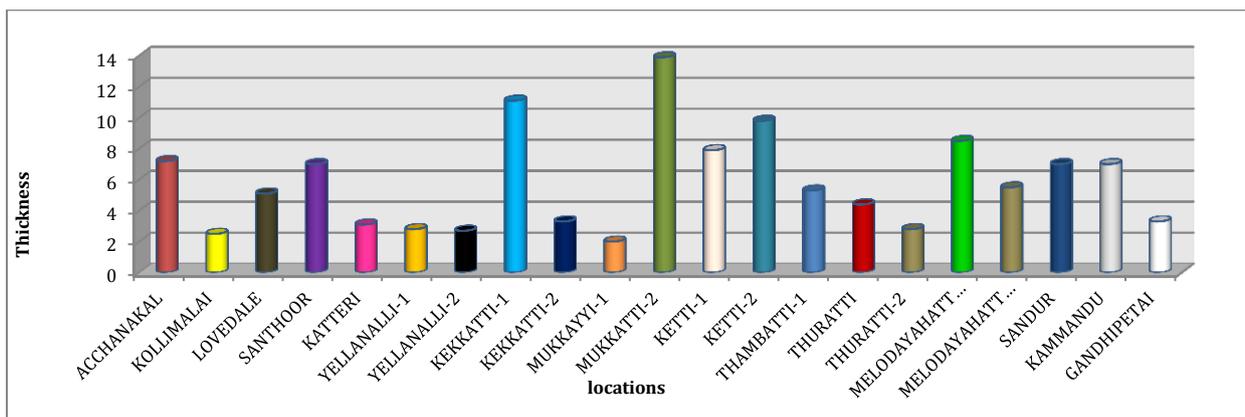


Fig.11 Spatial variation of lithomarge thickness in study area

12) are associated with high susceptible zone where as thin lithomarge are found in less susceptible zone. It is clear from this relation that thicker the lithomarge, more will the weathering effect and hence more will be the availability of material to slide
 Some of the GPR profiling were carried out in the road cutting sections to know the extent of vertical weathering is shown in figure 9. The lithomarge depth values are utilised in the preparation of lithomarge thickness map in GIS environment by thiessen polygon method, which represent the spatial variation of the thickness in the vector map format (fig 9). This map is used in GIS analysis for arriving at landslide hazard zonation map.

3.1.8 Integration and GIS analysis.

The themes have been assigned rank and weights according to its susceptibility to landslide occurrence. Seven factors, as discussed earlier have been overlaid to arrive at final landslide hazard zonation map. Susceptibility index is estimated from composite weight of all the themes, which is the sum of the product of rank and weight of each overlaid theme. (Rajakumar and Sanjeevi, 2007)

$$\text{Susceptibility index} = \Sigma (R1.W1+R2.W2+R3.W3+R4.W4 +R5.W5 +R6.W6 +R7.R7)$$

- Where R1.W1= Rank and weight of slope
- R2.W2= Rank and weight of drainage density
- R3.W3= Rank and weight of lineament density
- R4.W4= Rank and weight of landuse
- R6.W5= Rank and weight of lithomarge
- R9.W6= Rank and weight of geomorphology
- R10.W7= Rank and weight of aspect

The mean (μ) of the suitability index was found to be 266.74 where as the standard deviation (σ) was 53.44. Five zones were derived from mean and standard deviation (table 6.2) which forms the susceptible boundary for the occurrence of landslide depth is only 5.1m. This is because it is not possible for us to know the depth of the weathering horizon below the surface up to which tape measurement was made. Since it lies

on the side of the road, there is always a possibility that water seeps through the sides and hence the rock would be weathered vertically downward. Accordingly the actual depth of the weathered zone is 7.6m in this location. The second layer below the weathered zone has been removed for better visualization.

The above zone (table 3) was used as a legend and the final landslide hazard zonation map of the Katteri Watershed was prepared.

Table 3 Susceptibility boundary for the occurrence of landslide

zones	Value	Remarks
$< \mu - 2\sigma$	< 159.86	Not Susceptible
$\mu - 2\sigma - \mu - \sigma$	159.86-213.3	Less susceptible
$\mu - \sigma - \mu + \sigma$	213.3-320.18	moderate susceptible
$\mu + \sigma - \mu + 2\sigma$	320.18-373.62	high susceptibility
$> \mu + 2\sigma$	> 373.62	very high susceptibility

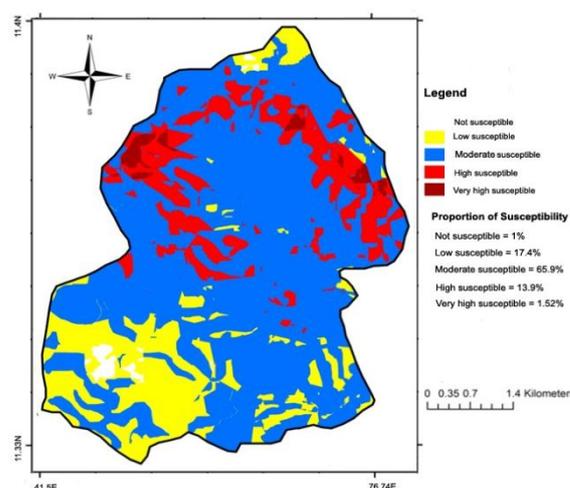


Fig.12 landslide susceptibility map of the study area

About 65.9 % of the total area (30km²) falls under moderate susceptible zone, 17.4% in low susceptible zone, 13.9 in high susceptible, 1.52% in very high susceptible whereas only 1% of the total area is free from susceptible zone.

Table 4: Ranks and weights of themes

Theme	Weight	Subtheme	Rank
Slope	31	Slope angle	1
		(0-10) ⁰	3
		(11-25) ⁰	4
		(26-35) ⁰	5
		(35-60) ⁰	
Drainage density	7	very low	7
		Low	5
		Medium	3
		high	1
Lineament density	12	low	3
		Medium	5
		High	8
land use	10	dense forest	1
		mixed horticulture	3
		Settlement	6
		tea plantation	4
		wasteland	2
Geomorphology	7	Denudational hills	4
		Stuctural valley	3
		Mound	1
		Erosional valley	2
Lithomarge thickness	24	Very thin	1
		Thin	3
		Medium	5
		Thick	7
		Very thick	9
Aspect	10	East	6
		North	1
		North east	1
		Northwest	1
		South	7
		Southeast	8
		Southwest	6
		west	6

4. Validation

An overall assessment of the landslide susceptibility map has been made by studying the locations in which major landslides along the study area has occurred. For validation of the prepared map, the past landslides occurrence data from GSI (pub no:57, 1982) was used . There is good correlation between areas defined as highly susceptible and moderately susceptible zones and the known landslides. There were several landslides in the study area and many of them coincide. Figure 6.5 shows the map with past landslide location.Ten (10) of twenty seven (27) slides falls on the moderately susceptible zones.whereas fifteen (15) slides falls on high susceptible zone and two (2) on less susceptible zones. Hence 55% of the past landslide occurred in the study area falls under high susceptible zone of the prepared map, similarly37% falls under moderate susceptible zone and only 7.4% of the past landslide falls under less susceptible zone.

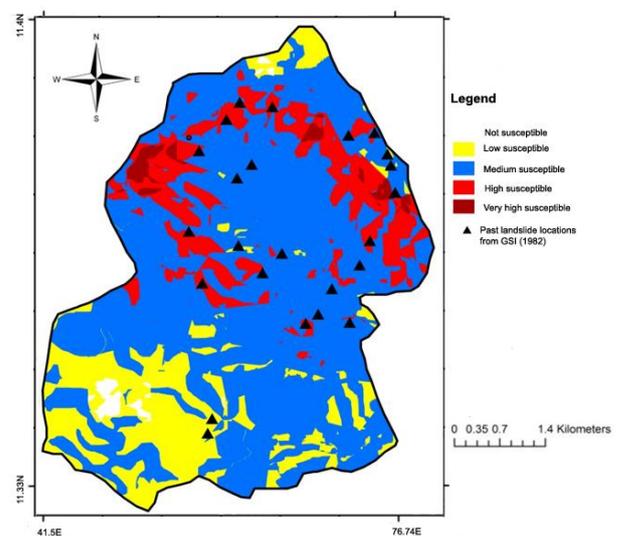


Fig.13 Validated landslide susceptibility map

The landslide Susceptibility map arrived is verified and it reveals that around 80% of the slides have taken place in range between moderately susceptible to very high susceptible classes.

Conclusions

The conclusions drawn based on the various studies conducted in the study area are as follows

1. Remote sensing and GIS could be used as an ideal tool for mapping the factors responsible for the occurrence of landslide. Interpretation of satellite images helped accurately to determine the factors responsible for the occurrence of landslide.
2. Ground Penetrating Radar survey is one of the best method for determining the thickness of the weathered material (lithomarge) in a monolithologic terrain, weathering of such terrain represent distinct two layer lithology in GPR profiles indicating first layer to be weathered zone.
3. This study has focused on assessing the utility and accuracy of surface GPR reflection travel time for Lithomarge thickness estimation under natural conditions. The result shows the wide variation in thickness ranging from 2m to 14 m, which is one of the important factor for occurrence of landslide. This study marks the first attempt to quantify the thickness using GPR in the present area.
4. High to very high lithomarge thickness are associated with high susceptible zone where as thin lithomarge are found in less susceptible zone. It is clear from this relation that thicker the lithomarge, more will the weathering effect and hence more will be the availability of material to slide.
5. There is huge amount of weathered material present, as the slope of the area is such that, it does not allowed the material to flow as soon as it weathered. Very steep slope is found in northern region, steep slope is observed in the northern and north western regions, whereas moderate and gentle slope are widely scattered throughout the study area. The area with very high slope is found to be highly susceptible to landslide and the susceptibility decreases with the decrease in slope.
6. North eastern and north-western region of the watershed is under high to moderate susceptible for landslide, the central portion is moderately susceptible whereas the south western portion are less susceptible.
7. Tea plantation and mixed horticulture regions, which falls under the central portion of the watershed is found to be having moderate susceptibility, whereas the dense forest region in the extreme north are less susceptible.
8. Drainage plays a vital role in weathering and hence in turn to landslide, the coarse drainage locations are more prone than that of finer drainage i.e, more the drainage density, less is the area susceptible to landslide

9. Moderate to high lineament density area falls on moderate to high susceptible region. As stated earlier lineament density is controlled by three factors- lineament length, lineament frequency and lineament intersection. This is because, longer the lineament deeper it is, so more the lineament length more will be the vertical weathering, resulting in more material for sliding. Similarly more the intersection more will be the result of weathering product.
10. The landslide Susceptibility map prepared is verified and the fact around 80% of the slides have taken place in rang moderate to Very High susceptibility classes which shows that the methodology is sound for the present study.

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