Landslide Susceptibility Zone using Frequency Ratio Model, Remote Sensing &GIS –A Case Study of Western Ghats, India (Part of Kodaikanal Taluk)

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Abstract
Landslide is the most common natural hazards in hilly terrains due to factors like gravity, weathering, deforestation, earthquake, heavy precipitation etc results heavy loss causing widespread damage to property and infrastructure, besides loss of human lives almost every year. The aim of the study is to assess the Landslide susceptibility zones in the part of the area of Kodaikanal taluk, Dindigul District, Tamil Nadu using Remote sensing and GIS. In this Paper frequency ratio based on statistical methods is evaluated by interpretating the observed landslides and their controlling factors .The Most accurate results of frequency ratio is analyzed by using elevation, slope angle, slope aspect, geology, land use, distance to road, distance to drainage maps and confirmed by using previous empirical landslide zonation data's.
Keywords: Landslide, Remote Sensing, GIS, Frequency Ratio.

Introduction
Landslides are one of the natural hazards that effect of least 15%of land area of our country exceeding 0.49million sq.kms. Landslides are common in the Himalayas and in the southern India, especially in the Nilagris and Kodaiaknal hill ranges. Many parts of the mountains areas are exposed to landslide hazard occurrences, which most cases of landslide occurrence are soils slips, debris flow and caused by intense and continuous rainfall. Around 252 landslides were investigated with the kodaikanl taluk. Among these landslides 62 occurred within the study area. These landslide are result of excavation of the slope or it toe ,drawdown of reservoirs ,deforestation, improper discharging of sewage water from settlements ,creation of dumps of very loose water or artificial vibrations that may be caused due to road traffic or heavy machinery.

In areas landslides susceptibility, the main factories the availability of the weathered overburden that is susceptibility to sliding on unstable slopes, when induced by rainfall or earthquakes. In areas where rock fall occurs it is the density of fractures and the availability of weathered materials.

Throughout the world it is possible to find many studies on landslide susceptibility assessment, the basic concepts of landslide susceptibility was first introduced Rabbruch (1970).Guzetti et al (1999) and chacon et.al (2006) summarized most of the landslide susceptibility mapping studies.

Landslide susceptibility mapping may be defined as qualitative or quantitative, and direct or indirect (Guzzetti et al., 1999). Qualitative methods are subjective; they represent the susceptible levels in descriptive expressions, and depend on expert opinions. The most common types of qualitative methods basically use landslide inventories to recognize sites of comparable geological and geomorphologic characteristics that are susceptible to failure. However, weights of the parameters are determined from the knowledge of specialists on the subject and the area. The designating weights are thus, highly personal and may be include some virtual admission. Quantitative methods are based on numerical expressions of the relationship between controlling factors and the landslides. There are two types of quantitative methods: deterministic and statistical (Aleotti and Chowdhury, 1999). Deterministic methods are based on slope stability studies, expressed in terms of the safety factor (Refice and Capolongo, 2002; Zhou et al., 2003). The statistical approaches analyze the historical link between landslide-controlling factors and the distribution of landslides. Quantitative methods may be used to decrease the personality and bias in the weight assessment process. Therefore, more realistic susceptibility maps can be produced from an objective measure of values. During the past few years, quantitative methods have been implemented for landslide susceptibility zonation studies in different regions (Clerici et al., 2002; Suzen and Doyuran, 2004; Ercanoglu and Gokceoglu, 2004; Yesilnacar and Topal, 2005; Kanungo et al., 2006; Yalcin and Bulut;, 2007; García-Rodríguez et al., 2008; Nefeslioglu et al., 2008; etc.).

This study focused on the landslide susceptibility in parts of kodaikanal taluk ,Dindigul district Tamil Nadu a Remote sensing and geographic information system(GIS) containing landslides and the main environmental characteristic of the mountains.These parameters can be divided into three categories such as include topolographic,geologic,vegetation. It is based on an inventory of exitising landslides and physical factors related to landsliding .Remote sensing data were used to map existing ignition, such as slope, aspect, elevation, lineament, geomorphology, landuse, drainage and road. The result from the remote sensing interpretation were verified by the field investigation .All data related to landslide occurrences in the study area were transformed to digital formats and stored in the data base of the GIS.The study area includes 62240pixles and the landslides include 167pixels.

Material and Method

The study began with the preparation of landslides inventory map based extends field work, a previous inventory map and satellite images .Furthermore the following seven possible landslide causing layers :elevation,slope,aspect,distance to road ,distance to drainage,landuse,distance to lineament, and geomorphology were analyzed for landslide susceptibility mapping using frequency ratio method . Frequency ratio model is based on the observed associations between allocation of landslides and each associated factors of landslide occurrence to display the correlation between landslide locations and the parameters controlling landslide occurrence in the area (Lee, 2005).

Study Area

The Palani hills is situated in eastward spur of western ghats with a maximum east west length of 65 kms and north south with of 49kms.total area of Palani hills is about 2068sq.km Kodaikanal Taluk occupies a major part of Palani hills with 1050sq.km. Latitude10◦13'N, Longititude 77 ◦ 32'E. The altitude range from 380m to 2502m and the slope varies gentle to very steep. Geology is mainly consisting of charnockits. Rainfall is 1566mm and to receives maximum rainfall during the months of October, November and December. Annual mean maximum and minimum temperatures are 21.5c and 8.75c respectively. Population of Kodaikanal taluk is 100645(2001).

Study area administratively located in south direction of Palani Taluk, west direction of Dindigul Taluk, east direction of Udamalpet Taluk and north east part of Kerala State. The temperature of quasitemperate, with summer (AprilMay) temperatures touching 24°C maximum, 13°C minimum. Winter December January) temperatures hover between 16°C maximum and 7°C minimum. Rainfall is well distributed throughout the year, with an average precipitation of 1300 mm. annually. The climate of Kodaikanal is very unique, with a temperate fall, winter, and spring and a mild summer. Kodaikanal also receives a large amount of rainfall every year, making it an ideal environment for cultivation. Therefore, many varieties of fruits and vegetables are grown in the Kodaikanal region, many of which can only be grown here including: peaches, pears, grapes, plums, guava, jackfruit, hill banana, passion fruit, cauliflower, potatoes, garlic, carrots, and coffee. Many other varieties of plants inhabit the area including blue gum, eucalyptus, pine, walnuts and other fruit trees which are used for cultivation.

Landslide inventory map

The maps show the locations and properties of landslides that have moved in the past. These slope failures were related to geological, topographical, and climatic conditions, thus, they can often facilitate the prediction of locations and conditions of future landslides. Landslide inventory mapping is the systematic mapping of existing landslides in a region using different techniques such as field survey, air photo/satellite image interpretation, and literature search for historical landslide records. A landslide inventory map provides the spatial distribution of locations of existing landslides. The landslides in the study area were determined by comprehensive field surveys. The landslides which are currently indefinite in characteristics and boundaries were identified using old dated satellite images. As a result, the satellite images were very useful in determination of landslides inventory map (Yalcin and Bulut, 2007). In this study, the susceptibility mapping started with the preparation of an inventory map of 252 landslides from field studies, a previous inventory map, and satellite image analyses from cartosat image.

Lithology map

Lithology is one of the most important parameters in landslide studies because different lithological units have different susceptibility degrees (Dai et al., 2001; Yesilnacar and Topal, 2005; Yalcin and Bulut; 2007; Garcia-Rodriguez et al., 2008; Nefeslioglu et al., 2008).

Table 1: Frequency ratio of Geomorphology to Landslide occurrences

Geomorphology	No. of pixel	No. of landslide pixel	%of landslide	% of area	F/R
Colluvial fills	23186	31	18.56287425	36.0927771	0.51431
Deeply Dissected Deflection Slope	1726	3	1.796407186	2.6867995	0.6686
Less Dissected plateau	2085	8	4.790419162	3.24564134	1.47595
Moderately Dissected plateau	712	9	5.389221557	1.10834371	4.86241
Valley fills	36531	116	69.46107784	56.8664384	1.22148
	64240	**167**	100	**100**	

Slope map:
The major parameter of slope stability analysis is the slope angle (Lee and Min, 2001). Slope angle is very regularly used in landslide susceptibility studies, since landsliding is directly related to slope angle (Dai et al., 2001; Cevik and Topal, 2003; Lee, 2005; Yalcin, 2008; Nefeslioglu et al., 2008). The slope map of the study area was divided into six slope categories. ArcGIS 9.3 analysis was performed to discover in which slope group the landslide happened and the rate of occurrence was observed. The landslide percentage in each slope group class is determined as a percentage of slopes. The result indicates that most of landslides (27.54%) occur when the percentage of the slope more than 30-40.

Table 2: Frequency ratio of Slope to Landslide occurrences

Slope	No. of pixel	No. of landslide pixel	% of landslide	% of Area	F/R
0-10	7919	20	11.9760479	12.3272105	0.97151
10-20	17433	28	16.76646707	27.1372976	0.61784
20-30	18875	41	24.5508982	29.382005	0.83558
30-40	13377	46	27.54491018	20.8234745	1.32278
40-50	5239	21	12.5748503	8.15535492	1.54191
>50	1397	11	6.586826347	2.17465753	3.0289
	64240	**167**	**100**	**100**	1

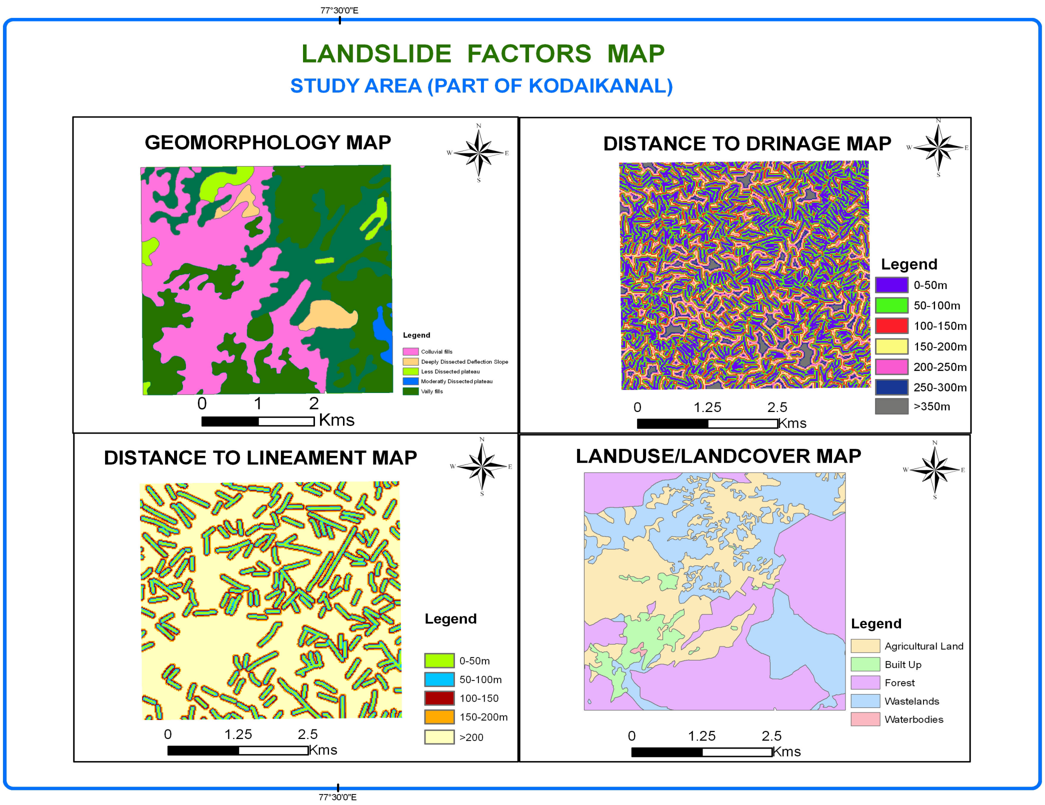


Figure 1: landslide contributing factors reclassified contributing factors on FR

Aspect

Aspect is also considered an important factor in preparing landslide susceptibility maps (Cevik and Topal, 2003; Lee, 2005; Yalcin and Bulut, 2007; Galli et al., 2008). Aspect associated parameters such as exposure to sunlight, drying winds, rainfall (degree of saturation), and discontinuities may affect the occurrence of landslides (Suzen and Doyuran, 2004; Komac, 2006). The association between aspect and landslide is shown with aspect maps. Aspect regions are classified in nine categories according to the aspect class as; flat (−1°), north (0°–22.5°; 337.5°–360°), northeast (22.5°–67.5°), east (67.5°–112.5°), southeast (112.5°–157.5°), south (157.5°–202.5°), southwest (202.5°–247.5°), west (247.5°–292.5°), and northwest (292.5°–337.5°). Analyses were performed using aspect and landslide inventory maps to determine the distribution of landslides, according to the aspect class, and the percentage of landslides that occurred in each aspect class.

Table 3: Frequency ratio of Aspect to Landslide occurrences

Aspect	No. of pixel	No.of.landslide pixel	% 0f landslide	% 0f area	F/R
Flat	10317	19	11.37724551	16.0600872	0.70842
North	11915	38	22.75449102	18.5476339	1.22681
Northeast	6693	13	7.784431138	10.4187422	0.74716
East	7332	12	7.185628743	11.4134496	0.62958
Southeast	6637	15	8.982035928	10.3315691	0.86938
South	5803	9	5.389221557	9.03331258	0.59659
Southwest	5196	17	10.17964072	8.08841843	1.25855
west	5365	30	17.96407186	8.3514944	2.151
Northwest	4982	14	8.383233533	7.75529265	1.08097
	64240	**167**	100	**100**	

Elevation:

Elevation is useful to classify the local relief and locate points of maximum and minimum heights within terrains. To calculate landslide densities for different relief classes, the relief map was divided into five altitude classes on 0-500-m basis and the study area reveals that the elevation ranges from 0 to >2000m above mean sea level.

Table 4: Frequency ratio of Elevation to Landslide occurrences

Elevation(m)	No. of pixel	No. of landslide pixel	% of landslide	% of area	F/R
0-500	1758	14	8.383233533	2.7366127	3.06336
500-1000	6453	20	11.9760479	10.0451432	1.19222
1000-1500	20843	47	28.14371257	32.4455168	0.86741
1500-2000	20448	73	43.71257485	31.8306351	1.37329
>2000	14738	13	7.784431138	22.9420922	0.33931
Total	**64240**	**167**	100	100	

Landuse/landcover:

The vegetation cover also introduces some mechanical changes through soil reinforcement and slope loading. The increase in soil strength due to root reinforcement has great potential to reduce the rate of landslide occurrence (Wu and Swanston, 1980; Blijenberg, 1998; Cannon, 2000; Beguería, 2006). Several researchers (Ercanoglu and Gokceoglu, 2004; Tangestani, 2004; Reis and Yomralioglu, 2006; Yalcin, 2007) have emphasized the importance of land cover on slope stabilities. In this study, a single date image of IRS LISS-IV on June, 2008 was used to generate the land cover types. The IRS LISS-IV image has six multi-spectral bands with 5.8 m resolution. (Reis and Yomralioglu, 2006). The study area was divided into five land cover classes (Table 5) being mostly covered with forest, and scrub land areas.

Table 5: Frequency ratio of Landuse/Land cover to Landslide occurrences

Landuse	No. of pixel	No.of.landslide pixel	% of landslide	% of area	F/R
Wastelands	18636	6	3.592814371	29.0099626	0.12385
Agriculture land	16660	35	20.95808383	25.9339975	0.80813
Builtup	7176	6	3.592814371	11.1706102	0.32163
Forest	21359	120	71.85628743	33.2487547	2.16117
Water bodies	409	0	0	0.63667497	0
Total	**64240**	**167**	**100**	**100**	

Distance to streams:
Distance to stream is one of the controlling factors for the stability of a slope. The saturation degrees of the materials directly affect slope stability. The proximity of the slopes to the drainage structures is also important factor in terms of stability. Streams may negatively affect stability by eroding the slopes or by saturating the lower part of material until the water level increases (Dai et al., 2001; Saha et al., 2002). In smaller, low-order streams, groundwater also provides much of increased discharge during and immediately following storms. The effect of streams to landslide increases all of these events. The study area was divided into seven different buffer ranges. Primary streams and secondary streams were branched and the proximity buffers were constructed for intervals of 0-50 m, although extra classes were defined for 0–50 m, 50–100 m, 100-150 m, 150-200,200-250,250-300 and above 300 m.

Table 6: Frequency ratio of Drainage to Landslide occurrences

Drainage	No.of pixel	No.of.landslide pixel	% of landslide	% of area	F/R
0-50	19967	42	25.1497006	31.0818804	0.80914
50-100	19002	28	16.76646707	29.5797011	0.56682
100-150	12674	40	23.95209581	19.7291407	1.21405
150-200	6816	41	24.5508982	10.6102117	2.31389
200-250	3172	9	5.389221557	4.9377335	1.09144
250-300	1435	7	4.191616766	2.23381071	1.87644
>300	1174	0	0	1.82752179	0
	64240	**167**	100	100	

Distance to Roads:
The road is one of the causal factors for landslides and is parallel to the effect of the distance to streams. The study area was divided into six different buffers categorized to designate the influence of the road on the slope stability. The landslide percentage distribution was determined according to the buffer zones by comparing the map of the distance to the road and the landslide inventory.

Table 6: Frequency ratio of Road to Landslide occurrences

Road(m)	No. of pixel	No. of landslide pixel	% of landslide	% of area	F/R
0-50	31274	62	37.1257485	48.6830635	0.7626
50-100	9812	49	29.34131737	15.2739726	1.921
100-150	7658	12	7.185628743	11.9209215	0.60277
150-200	6139	11	6.586826347	9.55635118	0.68926
200-250	5088	15	8.982035928	7.92029888	1.13405
>250	4269	18	10.77844311	6.64539228	1.62194
	64240	**167**	**100**	**100**	**1**

Lineament:
Lineaments may be continuous or discontinuous and, under certain circumstances, may be regarded as the surface manifestation of fault and fracture zones (Pal et al. 2006). Apart from the lineament buffer, lineament density is also used in landslide hazard assessment (Atkinson and Massari 1998; Pachauri et al. 1998; Sarkar and Kanungo 2004; Suzan and Doyuran 2004) as it is generally considered the probability of landslides occurring is greater in highly fractured areas (often associated with thrusts and folds; Cortes et al. 2003) compared to those with a lower fracture density. The distance of the buffer zones chosen varies from as small as 50 m (Nagarajan et al. 2000) up to 250 m (Pachauri and Pant 1992). Although most researchers did not given their reasons for

selecting a particular distance for the buffer zone, a few explained their choice was based on such factors as: field evidence of the extent of fragmented rock either side of the fracture itself (Nagarajan et al. 2000); the maximum landslides were observed to be within the determined distance from a lineament (Temesgen et al. 2001); an average threshold based on a comprehensive assessment of the distance of slope failures from mountain scarps, topographic breaks and any other linear futures (Ayalew and Yamagishi 2005); proximity of existing landslides to lineaments (Mathew et al. 2007); field observation of such effects as nappes, thrusts and strike-slip faults (Ruff and Czurda 2008).

Table 7: Frequency ratio of Lineament to Landslide occurrences

Lineament(m)	No. of pixel	No.of.landslide pixel	% of landslide	% of area	F/R
0-50	6384	17	10.17964072	9.93618677	1.0245
50-100	7362	12	7.185628743	11.4583658	0.62711
100-150	7965	17	10.17964072	12.3968872	0.82114
150-200	7653	28	16.76646707	11.911284	1.40761
>250	34886	93	55.68862275	54.2972763	1.02562
	64250	**167**	100	100	

Landslide susceptibility analyses:

In this study, the landslide susceptibility analyses were implemented using the methods of frequency ratio. In order to achieve this, landslide factors related to the causes of landslide occurrence in the study area, such as the geology, slope, aspect, elevation, land use/ land cover, distance to streams, and distance to roads layers were used. The Digital Elevation Model (DEM) was digitized from 1/ 25.000 scaled Standard Topographic Maps and the contours on these maps are drawn at 10 m intervals. The DEM of the study area was created using ArcGIS 9.3 software. 10×10 m pixel dimensions of the landslide and parameter maps were chosen. Landslide areas were determined using previous inventory map and Carrtosat Image and IRS LISS- IV images. Furthermore, the landslide data were achieved and confirmed in the field studies.

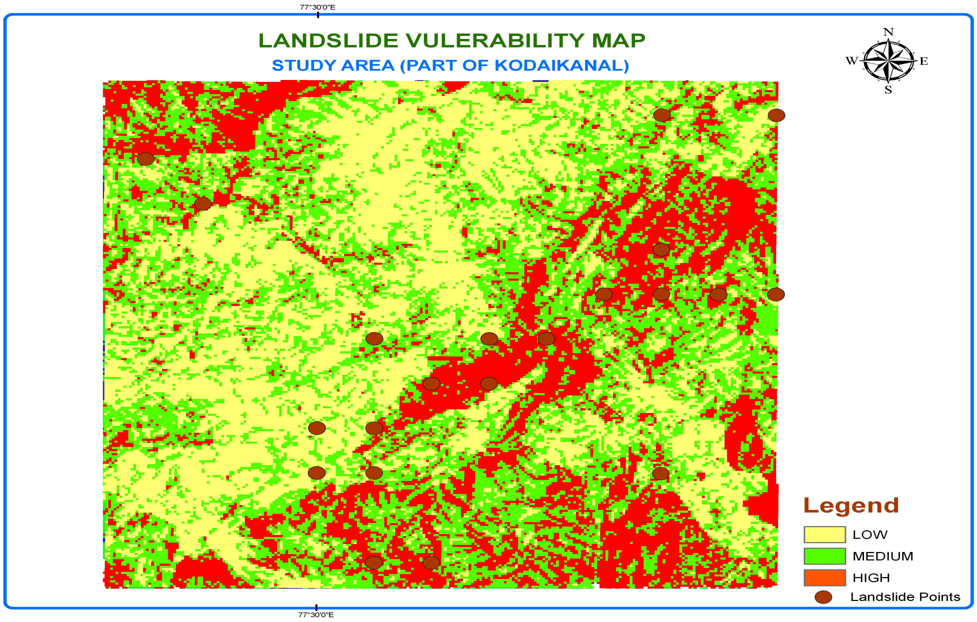
Frequency ratio method:

When evaluating the probability of landsliding within a specific period of time and within a certain area, it is of major importance to recognize the conditions that can cause the landslide and the process that could trigger the movement. The correlation between landslide areas and associated factors that cause landslides can be allocated from the connections between areas without past landslides and the landslide-related parameters. In order to prepare the landslide susceptibility map quantitatively, the frequency ratio method was implemented using GIS techniques. Frequency ratio methods are based on the observed associations between distribution of landslides and each landslide-related factor, to expose the correlation between landslide locations and the factors in the study area. Using the frequency ratio model, the spatial associations between landslide location and each of the factors contributing landslide occurrence were derived. The frequency is calculated from the analysis of the relation between landslides and the attributed factors. Therefore, the frequency ratios of each factor's type or range were calculated from their relationship with landslide events. The frequency ratio was calculated for sub-criteria of parameter, and then the frequency ratios were summed to calculate the landslide susceptibility index (LSI)
(Eq. 1) (Lee and Talib, 2005).

$$LSI = Fr1 + Fr2 + Fr3 +:::::: + Frn$$

Where, Fr is rating of each factor's type or range. According to the frequency ratio method, the ratio is that of the area where the landslide occurred, to the total area.

Figure3: Landslide Susceptibility map of the Study area.



Validation:
The map generated should be validated and unless it is validated the numerical method is useless and cannot be used. The validation is done to whether its predictions matched the expected results. The landslide inventory map which took into consideration the slope, landuse, Distance to Road, Distance to Lineament, and distance to drainage, Aspect, Elevation of the area, is overlaid on the landslide Hazard Map and the number of landslide falling in each susceptibility zone is calculated .In the landslide Hazard Map prepared for the study area and classified based on equal Interval Method.

The landslide susceptibility Zonation map is graded into three classes low, moderate, high using natural break method of jenks available in ArcGIS.Arcmap identifies break points by picking the class breaks that best group similar values and maximize the differences between classes. The features are divided into classes whose boundaries are set where relatively big jumps in the data values are.

Table 8: The validation in the number of landslides falling in different hazards classes

Name of LH Class	Landslides falling in LSS Zones defined by equal Interval		Landslides falling in LSS Zones defined by Natural Break Method	
	Number	Percentage	Number	Percentage
Low	9	5.38	9	5.38
Moderate	48	28.74	48	28.74
High	110	65.86	110	65.86
Total	167	99.98	167	99.98

Conclusion
Slope, Road and land use are the important landslide causing factors and high resolution data if available will help to prepare a detailed landslide hazard map. The kodaikanal areas close to road and the erosion of the bank of removal of support is one of the main processes responsible for landslides. Landslides are frequent in areas road sides. Majority of the landslide have occurred close to I order streams and hence, the incipient erosion taking place in the hills is one of the reasons for slope failure.

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