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Landslide Vulnerability Zone by Weights of Evidence Model using Remote Sensing and GIS, in Kodaikanal Taluk (Tamil nadu, India)

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***Abstract*: Incidences of landslides are common in India. According to Geological Survey of India approximately 0.49 million km^2 or 15% of land area of the country is vulnerable to landslide hazard of which, 0.098 million km^2 is located in the north eastern region and the rest 80% is spread over Himalayas, Nilgiris, Ranchi Plateau and Eastern and Western Ghats (GSI, 2006). The area selected for the study, Kodaikanal taluk is located within the high landslide prone zone, where debris slides, soil slips and rock slides are a major threat for the population living in this area. The present study is the assessment of landslide vulnerability using weights-of-evidence model in Kodaikanal Taluk, Tamil Nadu. In the first stage, landslide locations were identified in the study area from interpretation of high resolution of cartosat data and Google maps, and field surveys. In the second stage, ten data layers are exploited to detect the most vulnerable areas. These factors are TIN, Aspect, Slope, Geomorphology, Land use, Soil, Distance from Roads, Distance from Lineament, Distance from Streams, Rainfall. Next, landslide vulnerable areas were analyzed using the weights-of-evidence model and mapped using landslide conditioning factors.**

Key Words:- Remote Sensing, GIS, Weights of evidence, Landslide, Kodaikanal Taluk.

INTRODUCTION

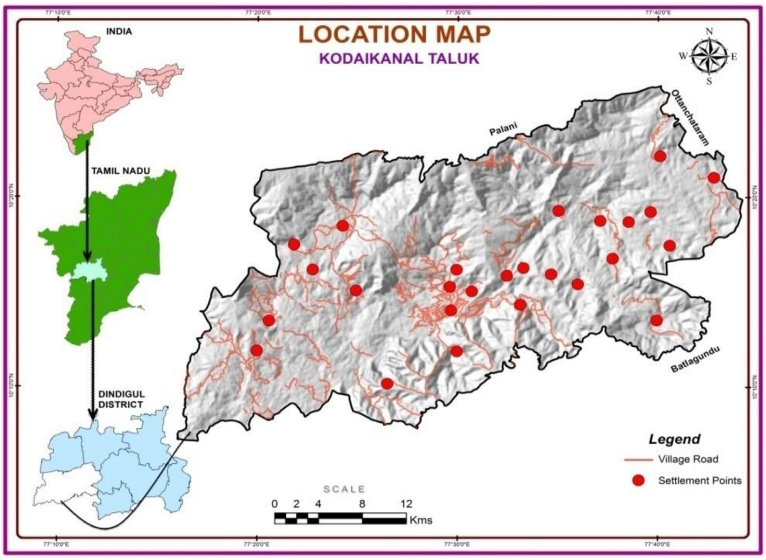
Landslide is a “mass wasting” which denotes any down slope movement of soil and rock under the direct influence of gravity and a disaster that can potentially affect the general quality of life in very many ways. These are complex phenomena, whose time-space distribution results from an interaction of numerous factors such as geological, geomorphological, physical, and human (Varnes, 1978; Crozier, 1986; Cruden and Varnes, 1996).

The devastating effect of Landslide causing irrevocable loss of property of billions of dollars and terminating the invaluable life of loss of thousands of people and cattle as well and injuring are equal number every year makes ‘Landslide’ in Natural systems are of the most fearful ‘Natural Hazards’ at global level (Crozier and Glade, 2005). Chung et. al. (1995) make a pointed observation that the worst affected are the developing countries where in occur 95% of the of the landslides causing an annual loss of 0.5% gross national products.

The International Landslide Centre of the University of Durham recorded in 2007 that the most seriously affected country was China with 695 landslide-induced deaths, followed by Indonesia (465), India (352), Nepal (168), Bangladesh (150) and Vietnam (130). 89.6% of the fatalities worldwide were caused by landslides triggered by intense and/or prolonged precipitation. Other triggering processes were construction (mostly undercutting of slopes) (3.4%), mining and quarrying (1.8%) and earthquakes (0.7%), while no cause would be identified for 3.4% of the landslides (Petley, 2008).

STUDY AREA

The Palani Hills are an Eastward spur of the Western Ghats with a maximum East-West length of 65km., and a North-South width of 40km with a total area of 2064sq.km, Kodaikanal located at Latitude10◦13‘N, Longitude 77 ◦ 32‘E is situated in Palani hills and Kodaikanal Taluk is spread over 1050sq.km . The foothills to 800m consist of thorn forest at the lower range and then dry deciduous forest typical of Peninsular India. Sub-montane evergreen forest accompanied by shrub savannah can be seen up to 1600m. From 1600m to 2000m, the outer montane slopes are characterized by grassland savannah and Shola forests. The upper part of the hills is undulating plateau interspersed with occasional peaks rising to c. 2,500m. (Area 385sq. km, average altitude 2,200m). The upper montane



grasslands are interspersed with Shola forests. NilgiriTahr, *HemitragusHylocrius*, the state animal of Tamil Nadu can be seen in the upper reaches.

MATRIALS AND METHOD

The studies cited above have been used for WoE objectives and expert- informed subjective methods. 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. The methods identified for the present study are Weights of Evidence (WoE) with the following parameters.

Rain Fall,Slop,Aspect,Elevation,Road,Soil,Drainage,Lineaments,Geomorphology,Land use/Land cover. were analyzed for landslide susceptibility mapping using Weights of Evidence (WoE). Weights of Evidence (WoE) 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).

CARTOSAT(2005) 5.3m resolution, IRS P6 LISS-III (2005) 30m resolution and IRS LISS-IV (2009)5.8 m resolution satellite data products were used as the primary data sources for the present study, collected from National Remote Sensing Agency. Survey of India topographical maps bearing serial numbers 58F 7, 8, 11&12 1:50,000 scale published in 1969 and 1:25000 scale published in 1994 were used to extract base map features.

LANDSLIDE INVENTORY MAP

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 213 (total pixel 4095) landslides from field studies, a previous inventory map, and satellite image analyses from cartosat image.

Weighting of Geomorphology

Geomorphology is considered as an important factor closely related to landslide occurrence because geomorphological units are created on the integration of the topological characteristics, Geological structures, Geotectonic movements, and morphometries. Geomorphology map for Kodaikanal was collected from SOI at scale 1:50, 000. The Kodaikanal is characterized by Colluvial fills, Bajadas, Deeply Dissected Defection Slope, Less Dissected Plateau, Moderately Dissected Plateau, Pediments, Valley fills and others. Colluvial fills forms thirty five percent of the watershed . Next to it valley fills occupies twenty one percent of the Kodaikanal.

Weighting of Slope

The slope of the study area ranges from 0° to > 50°. In general, the steeper the slope, the easier it is for gravity to initiate a landslide. Slopes are classified into six classes according to the gradients that represent terrain morphology such as gently sloping (0–10°), undulating (10–20°), moderately steep (20– 30°), steep (30–40°) and very steep (40°-50°) and (>50°) Slope angle has a positive effect in the range between 20 – 50° based on the positive weighted contrasts. Slope range in class 20°-30 has the most significant spatial association with landslide occurrence.

SLOPE (degree)	NPX1	NPX2	NPX3	NPX4	W+	W-	C
0-10	255	3840	280058	863102	0.2542	1.242	-0.9878
10-20	907	3188	307362	835798	0.8238	1.0648	-0.241
20-30	1963	2132	289904	853256	1.8902	0.6975	1.1927
30-40	736	3359	192315	950845	1.0684	0.9862	0.0822
40-50	194	3901	50689	1092471	1.0684	0.9968	0.0716
>50	40	4055	22832	1120328	0.4891	1.0104	-0.5213

Weighting of Elevation

Altitude or elevation is another frequently used conditioning factor for landslide susceptibility analysis. In the present study, the DEM of the study was obtained from topographic maps in 1:50,000 scale with a contour interval of 20 m. The elevation of the study area ranges from 500 to >2000 m. The elevation values were divided into five categories by using an interval of 500m. Elevations 0 – 500 m display some negativities association with landslides. The elevation between 500 and 2,000 m shows a positive association with landslide occurrence.

ELEVATION	NPX1	NPX2	NPX3	NPX4	W+	W-	C
0-500	359	3736	103528	1039632	0.968	1.0032	-0.0352
500-1000	1004	3091	165494	977666	1.6936	0.8826	0.811
1000-1500	1589	2506	359212	783948	1.2349	0.8924	0.3425
1500-2000	1016	3079	239815	903345	1.1827	0.9515	0.2312
>2000	127	3968	275111	868049	0.1289	1.2761	-1.1472

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Weighting of Aspect

Aspect is the as horizontal direction to which a mountain or hill slope faces. Which is expressed clockwise, from 0 to 360 degree. In terms of aspect, flat or non-orientated areas have a negative spatial association with landslide occurrence. In other landslide susceptibility assessments (Abdallah, Chorowicz, Bou Kheir, & Khawlie, 2005; Lee & Dan, 2005; Lee and Talib, 2005) that have investigated aspect, south-facing slopes were found to be most susceptible to landslides.). Aspects are grouped into 9 classes such as Flat, North, Northeast, East, Southeast, South, Southwest, West, and Northwest.

ASPECT	NPX1	NPX2	NPX3	NPX4	W+	W-	C
Flat	15	4080	115755	1027405	0.0362	1.1086	-1.0724
North	418	3677	159017	984143	0.4273	1.043	-0.3092
Northeast	295	3800	108922	1034238	0.6878	1.0257	-0.2696
East	634	3461	103872	1039288	1.7039	0.9296	0.7743
Southeast	337	3758	151624	151624	0.6205	6.919	-6.2985
South	660	3435	149775	993385	1.2301	0.9653	0.2648
Southwest	640	3455	111945	1031215	1.596	0.9353	0.6607
West	801	3294	121079	1022081	1.8468	0.8997	0.9471
Northwest	295	3800	121171	1021989	0.6796	1.038	-0.3583

Weighting of Land use/Land cover

Land use is the factors related to the effects caused by human activities on landslide occurrence. The study area is covered mainly by forest and waste lands, a lesser extent of grasslands and residential areas mainly in the form of small settlements occupy the study area. By using IRS images, the land use map of the study area was produced and then boundaries were determined in conformity with field visit. In terms of land cover, land cover classes showed Agriculture land and Water bodies in negative weighted contrasts. Built-up land, Waste land and Forest showed the positive contrast value.

LANDUSE/ LANDCOVER	NPX1	NPX2	NPX3	NPX4	W+	W-	C
Wastelands	679	3416	115593	1027567	1.6398	0.928	0.7118
Agriculture land	611	3484	274950	868210	0.6204	1.1202	-0.4999
Builtup	249	3846	7722	1135438	9.0017	0.9456	8.0561
Forest	2556	1539	742887	400273	0.9605	0.5175	0.443
Water bodies	0	4095	2008	1141152	0	1.0018	-1.0018

Weighting of Streams

Many of the landslides in hills occur by the erosion associated with drainage. The hilly area is drained by perennial and non-perennial streams; it flows in the Northern part of the study area. The study area depicts dendritic drainage pattern, which is the most common, and looks like the branching pattern of tree roots. Proximity to drainage is derived from drainage map with buffer zones on either side of the drainage lines. It is categorized into six classes (in meters)—0–50; 50–100; 100–150; 150-200; 200-250 and more than 250 (Table 4.19). As higher stream buffer negative is W+ their relation to the occurrence of landslides is not clear .

STREAM(m)	NPX1	NPX2	NPX3	NPX4	W+	W-	C
0-50	1323	2772	317515	825645	1.1632	0.9372	0.2259
50-100	881	3214	253593	889567	0.9698	1.0086	-0.0388
100-150	890	3205	286811	856349	0.8663	1.0448	-0.1785
150-200	506	3589	138165	1004995	1.0224	0.9969	0.0254
200-250	304	3791	78662	1064498	1.0789	0.9942	0.0847
>250	191	3904	68414	1074746	0.7794	1.014	-0.2347

Weighting of Road

One of the controlling factors for the stability of slopes is road construction activity. The Ghats road may represent a barrier or a corridor for water flow, a break in slope gradient, or, in any case, may tempt instability and slope failure mechanisms. The widening of the road is a possible triggering factor and source of landslide vulnerability. The distance from the road is computed as the minimum distance between each of the cells and the nearest road represented in vector format. The distance to roads is calculated in meters and divided into six classes such as 0–100m, 100–200m, 200–300m, 300–400m,400-500m, and >500m. Distance from road between 0-500m displayed a positive contrast value, while distance > 500m showed a negative contrast value. The road between 0-100m shows a positive association with landslide occurrence. To classify road network proximity, buffer analysis was applied. This study uses multiplied distance.

LINEAMENT	NPX1	NPX2	NPX3	NPX4	W+	W-	C
0-100	169	3926	47625	1095535	0.9906	1.0004	0.9906
100-200	74	4021	53716	1089444	0.3846	1.0303	-0.6458
200-300	67	4028	55993	1087167	0.334	1.0343	-0.7003
300-400	79	4016	56544	1086616	0.39	1.0317	-0.6417
400-500	183	3912	56429	1086731	0.9053	1.0049	-0.0996
>500	3523	572	872853	270307	1.1267	0.5907	0.536

Weighting of Lineament

The lineament was extracted from IRS images. Proximity (buffers) to these structures increases the likelihood of occurrence of landslides as selective erosion, and movement of water along structural planes promotes such phenomena (Lee 2007; Pradhan et

ROAD(m)	NPX1	NPX2	NPX3	NPX4	W+	W-	C
0-100	1165	2930	39892	1103268	8.1525	0.7414	7.4112
100-200	536	3559	36210	1106950	4.1323	0.8975	3.2347
200-300	449	3646	33802	1109358	3.7081	0.9175	2.7907
300-400	420	3675	32756	1110404	3.5794	0.9239	2.6555
400-500	239	3856	32307	1110853	2.0652	0.969	1.0961
>500	1286	2809	968193	174967	0.3708	4.4818	-4.111

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al. 2009; Pradhan 2010). The buffer of the lineament as follows (in meters)— 0–100m, 100–200m, 200–300m, 300–400m,400-500m, and >500m (Table 4.21). Distance from fault between 100-500 m displayed a negative contrast value, while distance > 500 m showed a positive contrast value. Results show that lineament between 0-100 m have a strong relationship with landslide occurrence.

Weighting of Rainfall

The mean annual precipitation in Kodaikanal ranges from 132mm over lowlands to 1238 mm over highlands. Rainfall distribution map was produced using an empirical equation that relates altitude to the mean annual rainfall over the Kodaikanal Taluk. Rainfall value from 900 to 1200, >1200 showed a positive contrast value and others showed a negative contrast value. The highest contrast value determined in the Rainfall classes was class rank >1200. The second highest was class 900-1200.

RAINFALL	NPX1	NPX2	NPX3	NPX4	W+	W-	C
0-300	0	4095	1574	1141586	0	1.0014	-1.0014
300-600	13	4082	78774	1064386	0.0461	1.0706	-1.0245
600-900	299	3796	355302	787858	0.2349	1.345	-1.1101
900-1200	1449	2646	309871	833289	1.3054	0.8864	0.419
>1200	2334	1761	397639	745521	1.6386	0.6594	0.9792

Weighting of Soil

Soil in the study are, are sandy clay, sandy clay loam, sandy loam, loamy sand, clay, sand, clayloam, and others (Table 4.23). Nearly 56.5% of the total area has sandy clay loam. The soil cover in the study area is shallow and varies from a minimum depth of 70 cm in the proximity of Vilpatti to a maximum of 126 cm in the extreme south-eastern part of the study area near Ayyaraganam. The soil texture represents the relative proportions of sand, silt and clay. The term "texture" refers to the size of the individual soil particles and has nothing to do with the amount of organic matter present in the soil. It has been observed that the soil affects the landslides mainly through these two soil characteristics. High ground water conditions occurring in sandy soils may liquefy the masses resting on the slopes during an earthquake. This can cause a landslide on a slope even as gentle as 10 to 20 percent.

SOIL	NPX1	NPX2	NPX3	NPX4	W+	W-	C
Sandyclayloam	2053	2042	423794	719366	1.3523	0.7924	0.5599
Loamysand	69	4026	6301	1136859	3.057	0.9886	2.0684
Clay	315	3780	65162	1077998	1.3495	0.9789	0.3706
Sandyclay	521	3574	142475	1000685	1.0208	0.997	0.0238
Sandyloam	1060	3035	483941	659219	0.6115	1.2852	-0.6738
Sand	0	4095	77	1143083	0	1.0001	-1.0001
Clayloam	0	4095	15	1143145	0	1.0001	-1.0001
Others	77	4018	21395	1121765	1.0047	0.9999	0.0048

WEIGHTS OF EVIDENCE MODEL

In this study, the weights-of-evidence modeling was used for the large-scale landslide susceptibility mapping. The weights-of-evidence model has many advantages compared to the other statistical methods. Weights-of-evidence is a data-driven method that is basically the Bayesian approach in a log-linear form using prior and posterior probability and is applied where sufficient data are available to estimate the relative importance of evidential themes by statistical means (Bonham-Carter 1994). The weights of evidence modeling use the Bayesian probability approach and were originally designed for mineral potential assessment (Bonham-Carter, 1988; Bonham-Carter, 1994). This method was also being applied in landslide susceptibility mapping in the past one decade (Lee et al., 2002; Van Westen et al., 2003; Dahal et al., 2008 and Regmi eta al., 2010). If F represents the presence and F represents absence of a potential landslide factor and If L represents the presence and L represents absence of landslide, then WoE method calculates the positive and negative weights of the respective factor classes based on the probability ratios (Bonham- Carter, 2002) as follows.

$$W^{+} = log_{e}\left(\frac{P\{F|L\}}{P\{F|\bar{L}\}}\right) \tag{1}$$

$$W^{-} = log_{e}\left(\frac{P\{\bar{F}|L\}}{P\{\bar{F}|\bar{L}\}}\right) \tag{2}$$

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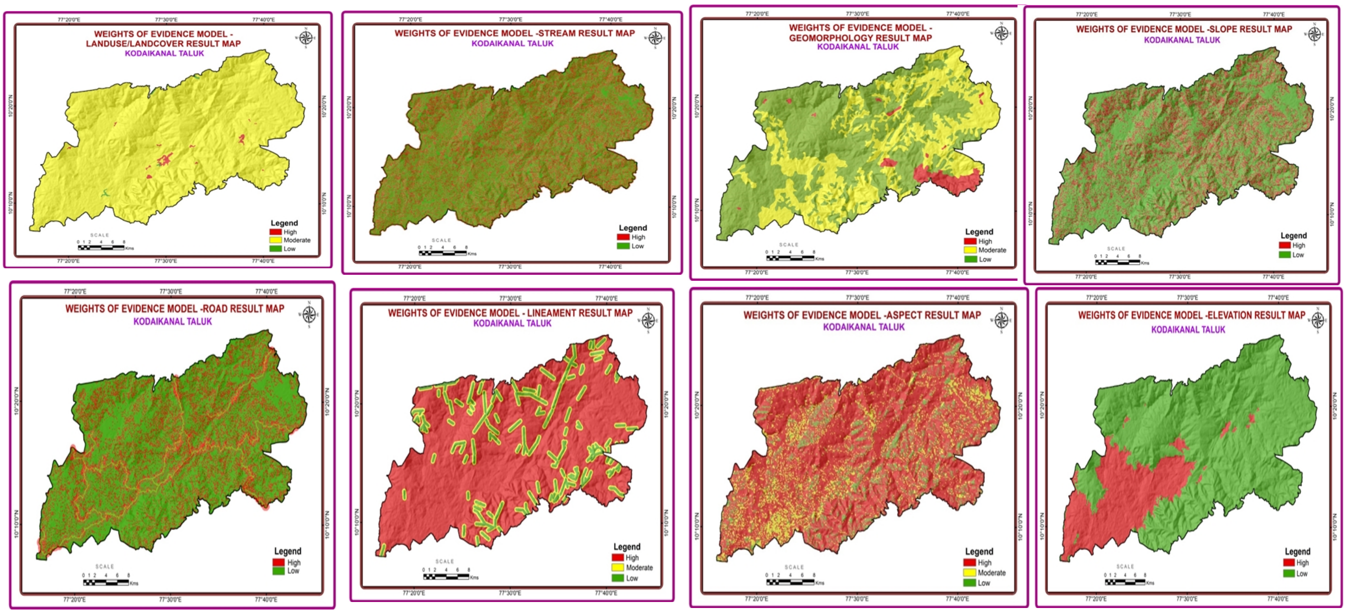
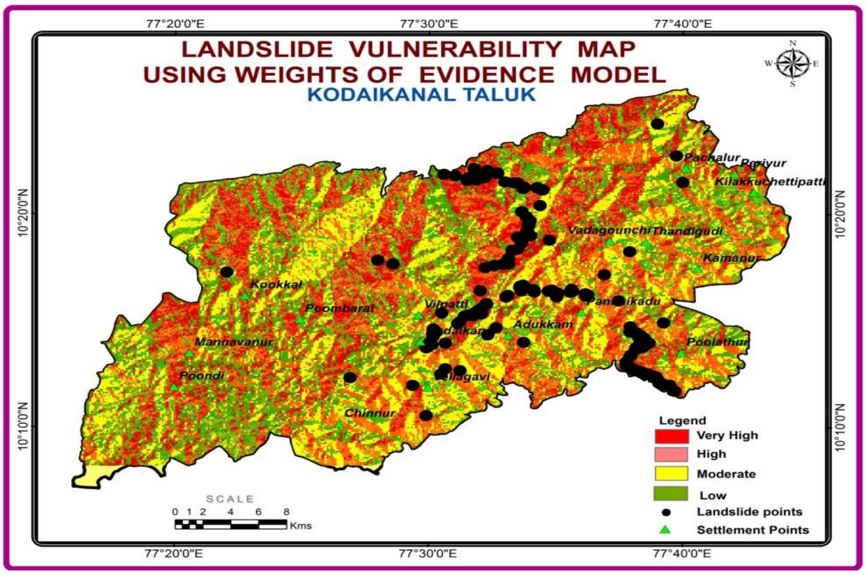
For each factor positive weight (W+) indicates the present of spatial association between conditioning factor (*F*) and landslides (L) while the magnitude of this weight indicates the positive correlation between the presence of the predictive factor and the landslides. A negative weight (W-) indicates an absence of the spatial association between predictive factor (*F*) and landslides (L) while the magnitude shows the level of negative correlation.



The weight contrast values were assigned to each respective class within each of the predictive factor thematic layers in ArcGIS 10 using "Raster calculator". The resulting weighted raster layers were added together to obtain a raster layer of the landslide susceptibility index

$LSI = Wf$ Slope + WfAspect + WfElevation + WfGeomorphology + WfLineament + Wf Landcover + WfDrainage+ WfRoad + WfSoil+ WfRainfall

The result of WoE modeling is a probabilistic map based on evidence of landslides. Weights calculated individually for the ten parameters to produce estimated evidence. Different weights can be summed by using the natural logarithm of odds called log it. In this case the contrast C (C = W + - W-) gives a measure of spatial association between the predictors and landslides (Yannick Thiery et al.2005). Calculations of values of W + and W-for all selected variables used to calculate the posterior probability, update the prior probability. When multiple predictors are combined, areas that have a weight higher or lower respectively correspond to a greater or smaller probability of finding the landslides. Local knowledge of the landslide susceptibility in the Kodaikanal taluk suggested ten binary predictor patterns of topography namely, soil, geomorpholgy, slope, aspect, elevation, streams, lineament, road, rainfall and land cover which are useful evidence for predicting landslide vulnerability, each of the landslide-related factors, the weights and contrast were calculated using the weights-of-evidence method. The total number of pixels in the study area was 1143160, and the total number of landslide occurrences was 4095.



All the controlling parameters by giving different weight age value for all the themes, the final LVZ map is prepared and categorized into 'Very High', High, 'Moderate', and 'Low' vulnerability zones. Low 8.3% of the area which contains 41.4% of the observed landslides has a high landslide vulnerability 16.9% of the study area which has 33.9% of the observed landslides has a high landslide vulnerability. 38.4% of the study area has a modrate landslide vulnerability which contains 19.8% of the observed landslides. 6.03% of the study area which

Landslide Vulnerability class using Weights of Evidence Model

Classification method	Susceptibility classes	No. of Area pixel	No.of Landslide Pixel	Area (Percent)	Landslide (Percent)	Landslide Density
Natural Break(Jenks)	Low	411975	197	36.038262	4.8107448	0.000478184
	Moderate	442461	813	38.705081	19.85348	0.00183745
	High	193256	1696	16.90542	41.416361	0.007187358
	Veryhigh	95468	1389	8.3512369	33.919414	0.017765115
Total		1143160	4095			

contains 4.8% of the observed landslides has a low landslide vulnerability.

ACCURACY ASSESSMENT

The accuracy of the final LVZ map is evaluated on the basis of the observed landslides. First, the final LVZ map is checked by overlaying with the observed landslide map. 187 of the 213 observed landslides are good predicted, and only 26 of the total landslides are wrongly predicted. The LVZ map with the observed landslides indicating the different levels of prediction.Most of these areas which are situated in Vadakavunji, Adukkam and Perumalmalai have verified conditions of slope, geomorphology and elevation, but some key features are noticeable as, Slope angles are normally higher than 20°, and predominantly, higher than 40°. All wrongly predicted landslides occurred mainly in Pachalur, Periyur. These areas have various unfavourable conditions for landsliding.

Accuracy of prediction	Observed landslides	
	Number	Percentage (%)
Good	187	87.79342723
Wrong	26	12.20657277
Total	213	100

CONCLUSION

Four different classification methods were used to classify landslide vulnerability index into susceptibility classes; low, moderate, high, and very high. Natural break classification method gave the best result. Sixty percent of the landslides fall closer to the road authenticating the relationship between landslide and proximity to the road. 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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