Weight of Evidence(WofE) Method for landslide susceptibility mapping in Coonoor macro-watershed, Nilgiris district, Tamil Nadu, India.

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Abstract

The present study Coonoor macro-watershed falls in the north-eastern part of Bhavani River Sub-Basin, Nilgiris District, Tamil Nadu, India where severely affected by landslide during 1978 and 1979. Weight of Evidence Method (WofE) is a quantitative data-driven method used to combine datasets. It also uses to take the parameters associated with dependant variables. WofE model used to prepare the landslide susceptibility map. A pair of weights, i.e, W+ and W-, is calculated for each sub-variables of a layer, which are dependent on the spatial relationship between the landslides and evidences. This calculation is done by applying likelihood ratios, which describe the possibility of occurrence of landslides in the presence and absence of evidences. The final product of this analysis is a map showing relative proneness of the terrain landslides i.e., landslide susceptibility based on certain evidences. The LSM is categorises into five classes viz., very low, low, moderate, high and very high based on Natural Breaks method. The landslides are overlaid on the LSM prepared and the number of landslides falling in each landslide susceptibility class is determined. The landslide susceptibility map helps to people in practically and cost effective way to identify the areas where the landslides occurred in past or may occur in future.

Key words: Coonoor macro-watershed, Bhavani River Sub-Basin, Landslide, Weight of Evidence Method, Nilgiris District.

1.Introduction

A landslide is a geological phenomenon which includes a wide range of ground movement, such as rock falls, shallow debris flows, deep seated, shallow landslides, etc. They are characteristic of mountainous regions and cause extensive damage to life and property(Gerrard,1994). Although the action of gravity is the primary driving force for a landslide, there are other contributing factors affecting the slope stability. These parameters include geological and/or geomorphologic as well as environmental conditions and can be triggered by heavy precipitation, earthquakes and human activity. Landslides pose serious threats to human settlements and to infrastructure, power projects, highways, railways, waterways, pipelines, etc.

Landslide or slope failure is one of the major natural hazards in the Himalayan region where landslides are annual phenomenon. In the mountainous regions of Peninsular India, landslide hazard is moderate to high and widespread landslide events occur once or twice in a decade. The areas in Peninsular India where landslides affect the community are in Western Ghats and the maximum incidence of landslides is recorded in the Nilgiris mountains. The increase in landslides is due to extensive urbanisation, developmental activities and deforestation during the past five decades with exponential increase in population and tourism. Large tracts forest lands have been converted in to tea estates and agricultural lands, settlements have been established in areas that are susceptible to landslide hazard and roads have been widened for smooth flow of traffic. These developmental activities invariably lead to steepening of slope as the land is levelled to facilitate the construction of houses and for laying roads.

Landslides have happened in Nilgiris during the past but are less frequent and widespread landslides events occurred only in the years 1978 followed by 1979. Since then the frequency of landslides and the fatalities due to landslides have increased. Further, earlier events were restricted to tea estates and areas where vegetable crops were cultivated with few close to settlements but since the year 2000, landslides are taking place in settlements causing fatalities. Hence, it has become necessary to identify safe zones where developmental activities can be allowed and to safeguard the areas wherein settlements were already established.

The Nilgiris has found a place in the landslide hazard map of India when wide spread rains caused over 350 landslides in the years 1978 and 1979. The frequency of landslides has increased in recent years with major slides with large number of deaths occurring in 1990, 1993, and 2009 (Ganapathy et al., 2010). The landslide which occurred on 11th November, 1993 in Marappalam on Mettupalaiyam – Uthagamandalam Highway washed away 18 homes situated in the village killing 12 and 15 persons missing. The slide also resulted in the death of 21 passengers in two busses which went rolling down on steep slopes (Ganapathy and Hada, 2012). The 1990 cloud bust resulted in a massive landslide which buried 35 families in Geddai village.

Due to heavy rains in the Coonoor and Ketti areas for three days from 8th to 10th November, 2009 over 150 landslides occurred killing 42 people and damaging more than 2000 houses. In the past landslides 1978-79, most of the landslides occurred in the tea estates and areas where vegetable crops are cultivated and few houses suffered damage. The only major fatality in 1979 is in Selas where two women and two children were buried alive by a landslide on the slopes of a hill causing a run out of approximately 500 m.

The landslides in Nilgiris have been investigated in the past and were generally on individual slides (Srinivasan, 1961). When the district was devastated by landslides in the years 1978 and 1979, the Department of Geology and Mining and Geological Survey of India made a detailed joint investigation and documented the landslide events and prepared a landslide hazard zonation following a geomorphic approach (Seshagiri et al. 1982). Ramakrishnan et al. (2002), have investigated the landslides in Nilgiris using satellite data and GIS. Ganapathy et al. (2010) made a report on the landslides that took place in Nilgiris in November, 2009.

The study hence involves collection of spatial data of the factors that cause landslides and assess their relationship with the occurrence of landslides. The landslide inventory map which gives the location of past landslides is the basis of the analysis. The relationship between the landslide and the landslide inducing factors is evaluated by conducting statistical bivariate analysis and calculation of Weight of Evidence method.

For the landslide-hazard assessment, the important steps were collection of data and spatial database construction to the relevant parameters was extracted, followed by evaluation of the landslide susceptibility using the relation between the landslide events and landslide causing parameters and validation and results. A main thought of this approach is that the past and present is the key to the future. In other words, the possibility of occurrence of landslides could be comparable with actual frequency of landslides .The scope of present objective is to utilize and to recognize the implications Weight of Evidence Method to preparing the LSM in the study area.

2.Study area

The study area Coonoor macro-watershed, (Fig.1) falls in the NE part of Bhavani River Sub-Basin of Tamil Nadu. It lies between Latitudes 11°18'27.42" N - 11°24' 35.426" N and Longitudes 76°41'19" E – 76°53'20" E in the Survey of India Toposheet (SOI) Nos. 58 A/11/SE, 58 A/15/NW, 58 A/15/SE, & 58 A/15/SW. It covers an area of about 134.9 sq. kms with a maximum length of 22 kms in East – West direction and 12 kms in NE – SW direction. The minimum altitudes of the watersheds are 340 m and the maximum altitudes are 2600 m above MSL. The macro-watersheds can be divided into four sub-watersheds viz., Upper Coonoor, Upper Katteri, Lower Coonoor and Lower Katteri. The area is selected for study as it is severely affected by landslides.

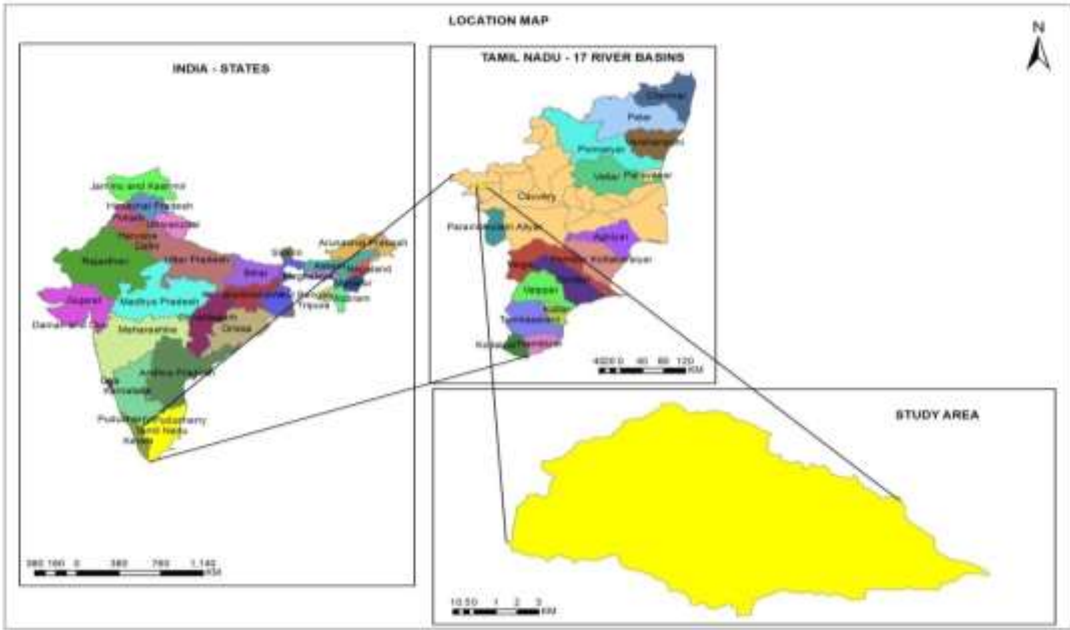

Fig.1 Location map of Coonoor macro-watershed

3.Materials and Methods

The landslide inventory map of the area prepared by the interpretation of aerial photos was scanned and georeferenced. The landslide location was digitized by using of point data in ArcGIS software. Also, the field visit has done in every macro-watershed and enquired the local peoples for the evidence of landslides. The sites were inspected to verify whether landslide has taken place. Mostly the landslides are shallow debris and deep earth slides, but it is difficult to recognize the shallow debris slides due to vegetation covered and the paleo scars preserved for evidence of deep earth slides. One hundred and two landslides have taken place in the study area during the landslide event in 1978 and 1979 and the total study area of 134.9 km^2. The scope of the study using various factors such as slope, aspect, drainage density, distance from drainage, lineament density, distance from lineament, geomorphology, land use, soil and distance from road are used to generate the landslide susceptibility map.

4.Results and Discussion

4.1.Slope

Slope is an important factor affecting slope stability (Anbalagan, 1992; Pachauri et al., 1998; Saha et al., 2002; Yalcin, 2008) since the driving force of mass movement increases with increasing slope (Guillard and Zezere, 2012). The slope for the study area ranges from 0 to 60° with steep slopes found in the major portion of the study area. Slope map is divided into 6 classes viz., 0 - 10°, 10 - 15°, 15 -25°, 25 - 35°, 35 - 45° and 45 - 60°. The highest slopes ranging from 45° to 60° was found in lower Coonoor watershed and other micro watersheds like upper coonoor, upper katteri and few areas in lower katteri.

4.2Aspect

The aspect of a slope may also contribute to slope failure and has been used by several in landslide susceptibility analysis (Gokceoglu and Aksoy,1996; Panikkar and Subramanyan, 1996: Lee and Min, 2001; Lineback, et al., 2001; Brardinoni, et al., 2003; Lan, et al., 2004; Lee and Choi, 2004; Gomez and Kavzoglu, 2005; Saha, et al., 2005; Wang and Sassa, 2006; Akgun, et al., 2007; Caniani, et al., 2007; Mathew, et al., 2007).

The aspect shows that the aspect is controlled by NW-SE trending ridges. The aspect map of the study was categorised into eight classes such as north, northeast, east, southeast, south, southwest, west and northwest with the addition of flat area. Among these flat classes is a horizontal surface.

4.3Drainage Density

The factors like Drainage density, length of streams per sq.km. also important factor controlling landslides. High drainage density and presence of deep narrow streams, which are often blocked due to erosion and deposition of debris, result in to flash floods and debris flows that trigger landslides (Pankaj Thapa, etal., 2015). The drainage density categorized in to 5 classes namely very low, low, moderate, high and very high.

4.4.Distances from Drainage

The distance to drainage map prepared by spatial analyst tool of ArcGIS and subdivided in to five classes viz, 0 -50 m, 50-100 m, 100-150 m, 150-200 m and 200-600 m. Most of the landslides occurred within a distance of 100 m from the streams. These indicate that erosion action of the stream is influencing the landslides and this pattern resultant with drainage density and areas with more streams have more landslides.

4.5.Soil

Soil is an important causative factor for landslide. The soil with more sand, instability slope and severe rainfall which constitute most dominant factors of landslide, cause severe damage to the land (Patanakanog 2001). The following types of soils category observed in the study area are clay, clayloam, habitation, loam, loamysand, rockoutcrop, sandyclay, sandyclayloam and sandyloam. The soil layer was procured from soil Atlas, Tamilnadu Agriculture University, Coimbatore and field check was carried out to confirm the characteristic of the map.

4.6.Geomorphology

Geomorphologic factors plays vital role which induces the landslide in the study area. The study area is divided into four geomorphic units such as deflection slope, highly dissected plateau, moderately dissected plateau and valley fills by (Seshagiri et al., 1983). Highly dissected land form is the dominant class followed by, moderately dissected, deflection slope and valley fill and the features were verified in the field.

4.7.Lineament density and Distance from Lineament

The lineament layer was vectorised in ArcGIS from satellite imagery using Landsat ETM+ FCC image. The lineament density map was generated by using density tool in extension Spatial Analyst of ArcGIS. The lineament density of the study area grouped into five classes viz., very low, low, moderate, high and very high.

The distance to lineament map prepared using spatial analyst tool of Arc GIS software. The distance to lineament classified into 7 classes as 0 to 100 m, 100 to 200 m, 200 to 300 m, 300 to 400 m, 400 to 500 m and > 600 m.

4.8.Land Use

Landuse and Landcover are major constituent factor for landslides in the mountainous regions. It is learned from the history that the causes of landslides are human activities, conversion of natural forest to agricultural and settlement and combination with intense rainfall induce landslides in the Nilgiris district which emphasis on land use land cover pattern changes (Nalina, P et al, 2014).

The landuse and landcover of the study area classified into nine categories viz., Built-up, crop land, forest, forest plantations, land with scrub, tea plantations, tank bed cultivation, tank bed vegeatation and reservoir

4.9.Distance from Road

Distance from road is similar to the effect of the distance from drainage, occurrence of landslide along road and on the side of the slopes affected by roads (Pachauri and Pant 1992; Pachauri et al. 1998; Ayalew and Yamagishi 2005; Yalcin 2005). Distance from road map was prepared by using multiple ring buffer techniques in ArcGIS spatial analyst tool and is classified 6 classes with 100 m interval as 0 to 100 m, 100 to 200 m, 200 to 300 m, 300 to 400 m, 400 to 500 m and > 600 m

Factor	Class	Npix1	Npix2	Npix3	Npix4	W^+	W^-	WofE
Slope	0 – 10°	20	82	21438	103207	0.057	-0.013	*0.036*
	10 – 15°	37	65	22690	101955	0.299	-0.108	*0.374*
	15 – 25°	30	72	21845	102800	0.225	-0.068	*0.259*
	25 – 35°	12	90	20454	104191	-0.145	0.023	*-0.202*
	35 – 45°	3	99	19641	105004	-0.729	0.062	*-0.824*
	45 – 60°	0	102	18578	106067	0.000	0.070	*-0.104*
Aspect	Flat	0	102	13901	110744	0.000	0.051	*-0.061*
	North	7	95	16865	107780	-0.295	0.032	*-0.337*
	Northeast	9	93	13264	111381	-0.081	0.009	*-0.100*
	East	12	90	15048	109597	-0.011	0.002	*-0.023*
	Southeast	21	81	18232	106413	0.148	-0.031	*0.170*
	South	17	85	16178	108467	0.109	-0.019	*0.117*
	Southwest	19	83	12027	112618	0.286	-0.045	*0.321*

	West	15	87	10017	114628	0.262	-0.033	*0.285*
	Northwest	2	100	9110.3	115535	0.000	0.024	*-0.035*
Drainage Density	0 to 2 Km^2	8	94	19036	105609	-0.289	0.036	*-0.352*
	2 to 4 Km^2	37	65	28079	96566	0.207	-0.085	*0.265*
	4 to 6 Km^2	31	71	31382	93263	0.082	-0.031	*0.087*
	6 to 8 Km^2	24	78	26698	97947	0.041	-0.012	*0.026*
	8 to 10 Km^2	2	100	19452	105193	-0.901	0.065	*-0.992*
Distance from Drainage	0 - 50 m	36	66	36987	87658	0.075	-0.036	*0.094*
	50 - 100 m	29	73	31283	93362	0.054	-0.020	*0.057*
	100 - 150 m	25	77	23564	101081	0.113	-0.031	*0.127*
	150 - 200 m	7	95	17246	107399	-0.305	0.034	*-0.355*
	200 - 250 m	5	97	15566	109079	-0.406	0.036	*-0.459*
Lineament Density	very low	33	69	65990	58655	-0.214	0.158	*-0.323*
	low	11	91	31660	92985	-0.372	0.078	*-0.401*
	moderate	28	74	10074	114571	0.531	-0.103	*0.682*
	high	26	76	10942	113703	0.463	-0.088	*0.599*
	very high	4	98	5979	118666	-0.087	0.004	*-0.043*
Distance from Lineament	0 - 100 m	27	75	23754	100891	0.143	-0.042	*0.178*
	100-200 m	16	86	21265	103380	-0.036	0.007	*-0.050*
	200 - 300 m	16	86	19043	105602	0.011	-0.002	*0.007*
	300 - 400 m	11	91	17295	107350	-0.109	0.015	*-0.131*
	400 - 500 m	14	88	15756	108889	0.036	-0.005	*0.035*
	500 - 600 m	13	89	14406	110239	0.042	-0.006	*0.042*
	> 600 m	5	97	13124	111521	-0.332	0.026	*-0.365*
Geomorpho logy	Deflection Slope	8	94	29279	95367	-0.476	0.081	*-0.684*
	Highly Dissected plateau	69	33	49652	74994	0.230	-0.269	*0.373*
	Moderately Disssected plateau	19	83	29853	94793	-0.109	0.029	*-0.265*
	Valley Fill	6	96	15863	108783	0.000	0.033	*-0.159*
Soil	Clay	0	102	7936	116709	0.000	0.029	*-0.081*
	Clayloam	0	102	6559	118086	0.000	0.023	*-0.076*
	Habitation	4	98	12770	111875	-0.417	0.030	*-0.499*
	Loam	1	101	10476	114169	-0.933	0.034	*-1.019*
	Loamysand	46	56	21833	102812	0.411	-0.177	*0.535*
	Rockout crop	15	87	12473	112172	0.167	-0.023	*0.138*
	Sandyclay	16	86	21732	102913	-0.046	0.009	*-0.107*
	Sandy clay loam	17	85	19915	104730	0.018	-0.004	*-0.030*

	Sandy loam	3	99	10948	113697	-0.475	0.027	*-0.554*
Landuse/ Land cover	Built-up	8	94	11222	113423	-0.060	0.005	*-0.394*
	Crop land	6	96	10465	114180	-0.154	0.012	*-0.495*
	Forest	1	101	15556	109089	-1.105	0.054	*-1.487*
	Forest Plantations	1	101	12748	111897	-1.018	0.043	*-1.389*
	Land with scrub	3	99	9267	115378	-0.403	0.021	*-0.752*
	Tea Plantations	83	19	44901	79744	0.354	-0.536	*0.561*
	Tank bed cultivation	0	102	6825	117820	0.000	0.024	*-0.353*
	Tank bed vegetation	0	102	6811	117834	0.000	0.024	*-0.353*
	Reservoir	0	102	6854	117791	0.000	0.025	*-0.353*
Distance from Road	0 - 100 m	25	77	19426	105219	0.197	-0.049	*0.239*
	100 - 200 m	20	82	19091	105554	0.107	-0.023	*0.124*
	200 - 300 m	23	79	23878	100767	0.071	-0.019	*0.083*
	300 - 400 m	14	88	19728	104917	-0.062	0.011	*-0.079*
	400 - 500 m	8	94	17857	106788	-0.262	0.032	*-0.299*
	500 - 600 m	12	90	24667	99978	-0.226	0.041	-0.273

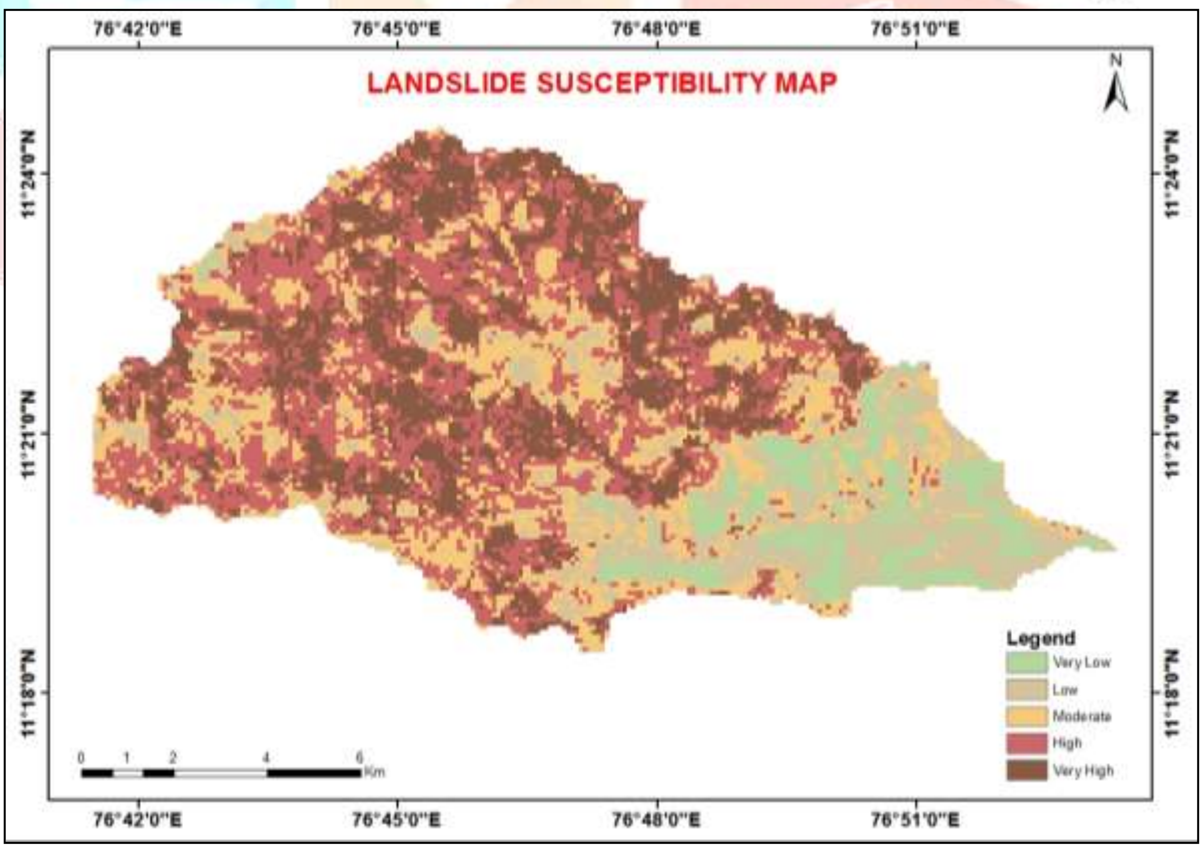

Fig.2 Landslide susceptibility map generated from WofE method

The WofE values for slope ranges from -0.824 to 0.374. The negative values for slope ranges 25 - 60° classes and positive values for the slope class 0 - 25° and WofE value is 0.374 has highest value followed by 15 - 25° slope class WofE is 0.259 and 0 - 10° WofE value is 0.036 indicating that the contribution of slope class to the landslide susceptibility is high.

The aspect class and classified into 9 sub variables viz., flat, north, northeast, east, southeast, south, southwest, west and northwest. The southwest aspect has high WofE value of 0.321 followed by west, southeast and south and north aspect has a high negative value of -0.337 and indicating moderate contribution.

The WofE values worked out for drainage density class shows that values ranges from -0.992 to 0.265 with negative values for the drainage density class is 8 to 10 Sq.Km. i.e., -0.992 and the positive values obtained maximum in 2 to 4 Sq.Km. In distance from Drainage, the Weights of Evidence values calculated for the 5 sub classes of 100 - 150m and 0 - 50m shows higher probability as evident from positive weightage. However, negative weightage is obtained in distance of 150m to 250m from stream.

The WofE values calculated for lineament density class shows that the values ranges from -0.401 to 0.682 with negative values for the lineament density class is Very low, low and very high and positive values obtained maximum in moderate class. In distance from lineament the WofE values calculated for the five sub variables and it ranges from -0.365 to 0.178 with negative values obtained in class are 100 – 200 m, 300 – 400 m and more than 600 m. The positive values ranging 0.178 to 0.007 and maximum values obtained for the 0 – 100m buffer zone i.e., 0.178 suggesting that the contribution of distance from lineament to the landslide susceptibility is high.

The WofE worked out for geomorphic sub variables namely, deflection slope, highly dissected, moderately dissected and valley fill shows that deflection slope, moderately dissected plateau and valley fill has negative values. Whereas, highly dissected plateau has positive value indicating moderate contribution. In Soil factor, the Weight of evidence (WofE) value was worked out for the nine soil sub variables and negative values obtained clay, clay loam, habitation, loam, sandy clay, sandy clay loam and sandy loam. However, other sub variables loamy sand and rock outcrop obtained positive values indicates the highest landslide susceptibility.

In Land use, the WofE values worked out for the 9 sub variables, the tea plantations have shown positive values of Weight of Evidence indicating the high degree of landslide susceptibility and other sub variables obtained negative values. In distance from road, The WofE values calculated for the six sub variables. The distance from road exhibits rather strong influence with values ranging from -0.299 to 0.239 and highest value is obtained for the 0 to 100 m buffer zone indicating the high degree of landslide susceptibility.

5.Conclusion

In this study, results from the susceptibility map have been validation represent 77.92% of landslide occurred in high and very high susceptibility class. The Density increases in high and very high landslide susceptibility classes show that the Landslide Susceptibility Map (LSM) (Fig: 2) is reliable.

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