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Comparison of Landslides Susceptibility Analysis using AHP, SMCE and GIS for Nilgiris district, India

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In this study first locations of past occurrence were identified and an inventory form were created and integrated to GIS to derive landslide inventory map predictors. Secondly predictors causing landslides were identified from report of past landslides. Thirdly thematic maps of the identified predictors namely geomorphology, geology, drainage, rainfall, lineament, road, railway, soil, land use/land cover, slope and aspect were derived using Geographical Information System (GIS). Finally based on relative importance of factors and their categories influencing landslide susceptibility weights and ratings of predictors were calculated using two multi criteria approaches namely Analytical Hierarchy processes (AHP) and Spatial Multi Criteria Evaluation (SMCE). Weights and rating obtained for factors and predictors were overlayed using weighted overlay tool of GIS software to generate LS map with classified five zones namely very low, low, moderate, high and very high. Using field check and Receiver Operating Curve (ROC) the LS map were validated, using validate location set Area Under the Curve (AUC) AHP of 95.98% and SMCE of 98.86% were determined .

[Key words: Landslides – Susceptibility – Geographical Information System – Analytical Hierarchy Process Method – Spatial Multi Criteria Evaluation method– Nilgiris district

Introduction

Landslides are one of the catastrophic natural disasters occurring worldwide. Landslides are predominately tutored by dynamic process of geosystem of earth planet and caused due to intervention of human activities like slope modification, natural and anthropogenic phenomenon[1]. Inspite of technological advancements carried out in preventing these events they still continue to cause impact on socio-economic development of the community, loss of human lives, damages to properties of the region[2]. Keeping in view that same trend may continue to exist in future due to lack of planning with respect to anthropogenic activities, it is necessary to study the susceptibility of occurrence of the terrain, prime factors causing landslides and preventive measures[3].However degrees of impact of landslides varies at different regions[4].

The predictors governing the cause for slide does not have any standard guidelines, it depends on geographical features of the study area[5].Many geoscientists and engineering professionals are trying to employ various techniques for evaluating landslide susceptible zones,[6,7,8,9,10]were the first to introduce landslide susceptibility assessment as spatial distribution of predictors related to instability of slopes. Summarizations of various landslide susceptible (LS) methods were done by [11,4,12,13,14]. New approaches such as logistic regression models proposed by [15,16,17,18,19] geotechnical model due to slope failures proposed by [20,21,22,23],probabilistic models by[24,25,26,27,28,29,30], statistical and deterministic models such as infinite slope, 3D model, Artificial Neural Network(ANN),Data mining using Fuzzy Logic proposed by [4,12,13,14,31,32,33] have employed GIS methods for LS mapping. Based on multi criteria decision analysis (MCDA) approach proposed by [34,35,36,37], in this paper Analytical Hierarchy Process(AHP) and Spatial Multi Criteria evaluation (SMCE) model were employed for LS mapping for Nilgiris district.

Materials and Methods

The study area is located between 76° 14' and 77° 02' East and longitude and 11°10' and 11° 42' North latitude covering total area of 25438 sq km[38]. District comprises of four blocks viz Udhagamandalam, Coonoor, Kotagiri and Gudalur as shown in Fig 1. It is covered mostly by lateritic soil and small patches of sandy loam [38,39].

Nilgiri district lies at higher altitude and the relative temperature during summer is 21°C because of which it turned a tourist place [39].This lead to development of transportation network and human activities, playing a decisive role in environmental changes.

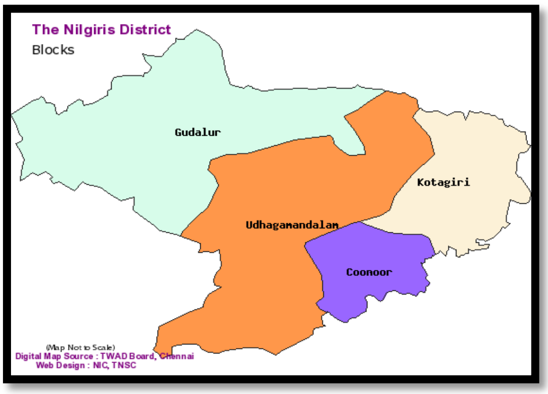


Fig. 1- Nilgiris district block map 2010

The urban activities result in the modification of slope due to widening of road and leveling of the terrain forms steep slopes and causes deforestation [39].

Rainfall in the study area occurs as outburst of cloud for several hours, locally defined as "NEER IDI" [39]. Rainfall is the prime controlling factor of landslide occurrence and is a dependent variable inducing underground hydrostatic pressure of water table and pore water pressure between the soil particles. Low permeability of clayey soil leads to sudden overloading on slopes causing compaction of soil, and also poor drain prevailing forms negative pore water pressure within the soil particle[39].When pore water pressure becomes equivalent to upper overloading stress of soil, shearing resistance of soil decreases leading to slope failure[39] as mass movement known as landslides. Soil type, its depth and their engineering properties are important factors governing slope failure causes landslides [57, 58]. Fig 2 shows interrelationship between predictors causing landslides.

Evaluation of LS map for the Nilgiris district involves development of spatial database of predictors using Arc GIS (ver.10.0). Database consists of (i) landslide location dataset for preparing landslide inventory map (ii) datasets of geographic condition (geology, geomorphology, slope, land use/ land cover, etc.) used for preparing thematic map.

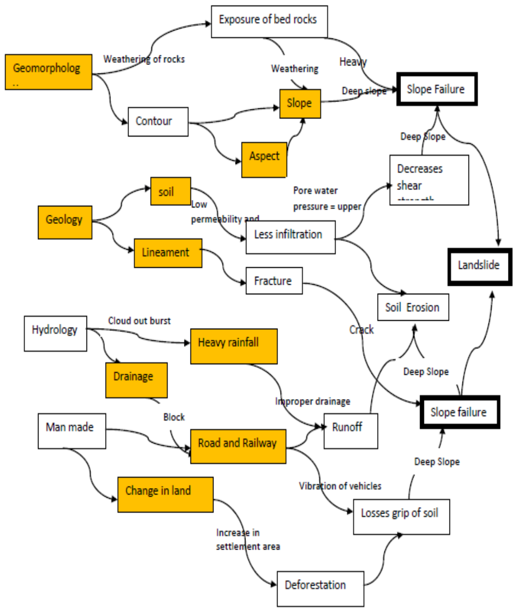
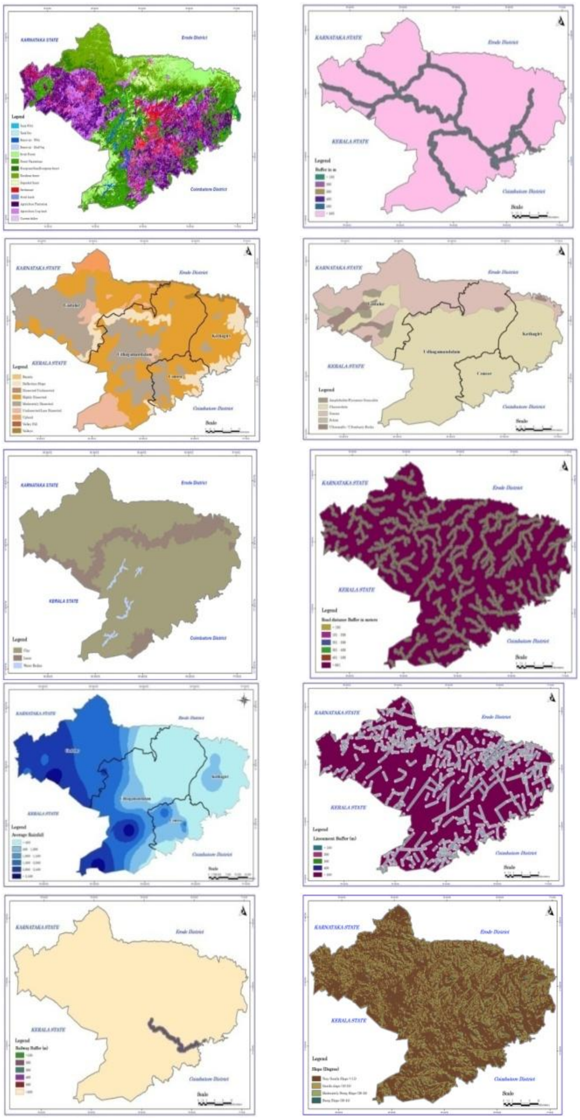


Fig. 2- Relationship between predictors of the study area

The spatial dataset with geographic condition for the predictors uses the following data source to generate its respective thematic maps.

1. Boundary map were digitised from topo-sheets 58A/6,7,8,10,11,12,14,15, available at Geological Survey of India (GSI) of scale 1:50000.
2. Geomorphology, Geology, drainage maps shown in Fig 3c, 3d and 3f were derived from satellite image IRS P6 LISS III of 23m resolution from National Remote Sensing Centre (NRSC), Hyderabad .
3. Soil map were collected from Agricultural Department, Coimbatore [38] – Nilgiris district Soil Atlas as shown in Fig 3e.
4. Drainage map were derived for major streams flow from topo-sheets as shown in Fig 3f.
5. Land use/land cover map as shown in Fig 3a were derived from satellite image IRS P6 LISS III February 2010 of 23m resolution from National Remote Sensing Centre (NRSC), Hyderabad .The overall accuracy of the study, kappa coefficient K is 0.7 commented as very good [41].



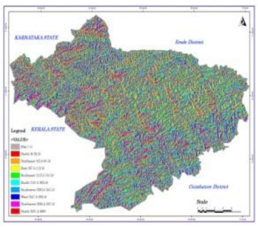


Fig. 3 - a) land use and land cover b) road buffer c) geomorphology d)geology e) soil f) drainage buffer g) rainfall h) lineament buffer i)railway line buffer j) slope k) aspect

6. Transportation map namely road and railway maps as shown in Fig 3b and 3i were derived from topo-sheets available at GSI of scale 1:50000.
7. Daily rainfall data at 23 rain gauge station [40] covering the whole district for 18 years (1996-2013) were collected from Indian Meteorological department (IMD), Tharamani, Chennai and rainfall map were derived as shown in Fig 3g.
8. Lineament map were derived from geology map fault map as shown in Fig 3h.
9. SRTM (Shuttle Radar Topography Mission) downloaded from Bhuvan site, derived Digital Elevation Model (DEM) with 90m x 90m interval, from which slope (0° – 55 °),aspect (0 ° – 360 °) maps were derived and field checked as shown in Fig 3j and 3k.

Landslide Inventory Map

Landslide Inventory map is referred to as landslide location map prepared from the historic records[42,43,44] for the purpose of landslide susceptibility, hazard and risk assessment[45,46,47,48,49,50,51].It consists of information such as location, classification, morphology, volume, slope, date of occurrence, triggering factor [52] etc. The district is recorded with more than 300 major landslides along road during 1978, 1979, 1981, 1982, 2009 and it has become annual incidence during heavy rainfall, most landslides are translational debris slide. To input the past and future field survey landslide locations and store it in database table, an inventory form were created using C sharp programming tool as shown in Fig 4. The created form connected to database using SQL including

Fig. 4- Inventory form

data integrity and the interplay between table and GIS were made through coordinates [53, 54] of the locations featured as points [5].Thus large data not only can be stored but also retrieved and evaluated based on users query and displayed in report. The inventory form developed includes all entities in common to different agencies.

In this paper dataset for inventory map were from two main records (i) southern railway slip register and (ii) report [39].Past landslides cannot be verified in the field, quality of inventory map depends on its accuracy, which is not straightforward and no standards are available [55] in turn depends on completeness of the data [51] which in turn depends on (i) experience and skill of the geologist investigating [14, 56] (ii) aim and objective of the agency.

About 520 locations were reported at Nilgiri district from 1978 to 2009 of volume between 100 to $1000m^3$ [39, 43, 44].The inventory dataset were split into two (i) training dataset (78% of landslide inventory) (ii) validation dataset. Training dataset implemented for statistical analysis as shown in Fig 5, whereas validation dataset were used for validating the proposed models.

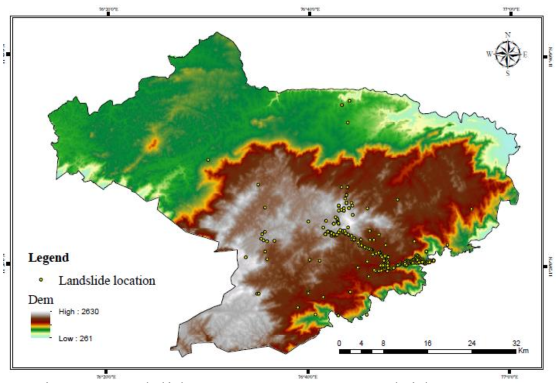


Fig. 5- Landslide Inventory Map overlaid on DEM

It is an independent geomorphologic characteristic feature causing landslides. It constitutes the earth features governing terrain behavior. About 49% of total study area constitutes of highly dissected land form constituting weathering sediments dumped and highly erodible plateaus.

Nilgiris district comprises of crystalline metamorphic rocks of Archaen age namely Charnockite and forms the bulk of the rock units covered by ubiquitous lateritic soil. Geology combined with various conditions such as compaction, deformation, fracturing, intrusions etc., and cause inclusion as factor influencing landslides.

Lineaments are weaker zones identified as linear feature representing fracture, faults, discontinuous and shear zones derived from geology map. Lineament map were extracted from satellite image. Buffer zones of 100m were created. Landslides of 67% have occurred at distance greater than 500m, thus contributes less importance.

Rainfall is the prime factor for causing landslides in the study area. Higher altitude areas, thickly vegetated areas like Udhagamandalam, Guddalor are recorded with heavy rainfall, but number of landslide occurrence is less, at railway and road even though rainfall is medium due to steep slope slides are more. Thus rainfall with slope influences more occurrences.

Gross radial with local dentritic and sub dentritic is predominant natural drainage pattern at Nilgiri district. Many streams originate from the slopes and formed several rivers from rivers in deep valley portions. During heavy rainfall runoff occurs and due to improper drainage infiltration rate increases causing landslides at steep slopes.

Road and railway buffer maps were derived from transportation map**.** In the study area road and railways lines travel parallel to each other. Railway line runs from Burliyar to Udhagamandalam in the district, and almost all villages and main cites were connected by roads. On either side of road and railway lines are manmade cut slopes of the hill and are very steep, during heavy rainfall soil mass slides over these slopes and cause landslides. In this study, major Road and railway buffer maps were derived from transportation map**.** In this study, major roads SH15 and NH67 are considered since it is reported with major landslides [39].

Weathering of rocks forms soil. Soil type, depth, properties are important factors governing slope failure leading to landslide occurrence[59,60].Soil forms a thick cover over the slopes. The district is covered mostly by lateritic soil and small patches of sandy loam.

Slope represents the rate of change of elevation for each DEM cell. It's the first derivative of a DEM. As slope increases probability of occurrence of landslide also increases. Slope is classified into six categories according to [39]. As slope angle increases landslide occurrence also increases.

Aspect identifies the down slope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no down slope direction are given a value of -1.The value of each cell in an aspect dataset indicates the direction the cell's slope faces. East and Northeastern direction contributes 55% of landslide occurrence.

Land use/land cover map shows urban and rural development, agricultural and forest lands. Roots of the plants and trees creates grip to soil and increases its shear strength and stabilizes slope and vice versa [57,58,61,62].The urban activities such as deforestation, widening of road and leveling of the terrain for settlement and change in land use pattern result in modification of slope.

It is important to study about interrelations, ranking of predictors and their dependence of causing slope stability based landslide [14]. The derived thematic maps were ranked and weighed using two multi criteria methods AHP and SMCE and spatially overlaid using spatial analyst GIS tool to derive LS maps as shown in Fig 6.

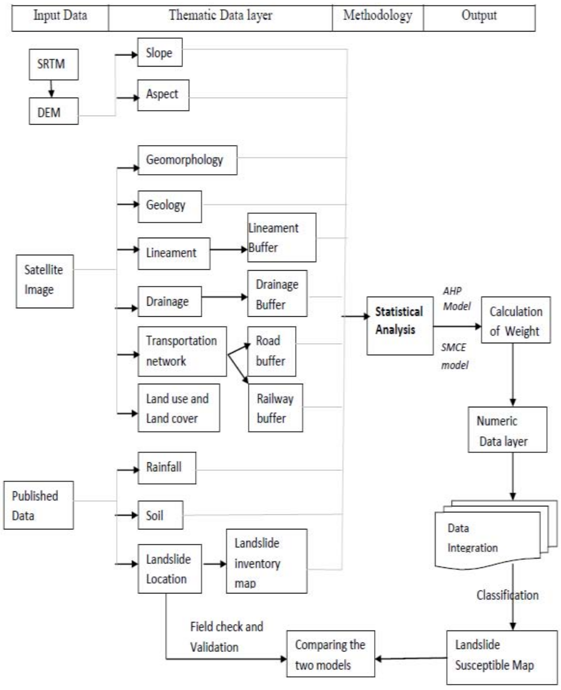


Fig. 6- Flow chart of the methodology

AHP Model

AHP is an semi quantitative, multi criteria ,multi objective method in which decision making weights are assigned to the predictors based on experts knowledge and experience in the form of pair-wise relative comparisons without any inconsistencies in the decision process [63,64,65,66,67].

Identified eleven predictors namely geology, geomorphology, rainfall, drainage ,lineament, road, railway, soil, slope, aspect and land use/land cover were arranged hierarchically and based on subjective judgments numerical values were assigned to each predictors and classes using 9-point rating scale based on [63]representing the relationship between the predictors. The eigen value matrix were given unit value for diagonal cells, right of the diagonal cells represents the scaling between the predictors. If their value is less than one then the row predictor is less importance to column predictor and vice versa. Left of diagonal values were calculated as reciprocal of the right diagonal values of the eigen matrix. In this study rainfall and soil were given equal importance. Rainfall, slope, land use/land cover and railway buffer were treated as strong predictors causing landslides as shown in table 1

Normalized principal eigenvector is obtained from the comparison matrix assigning weight to each predictor and classes [68].Consistency ratio (CR) is calculated to show the probability of judgment matrix.CR value is checked using eq 1, if greater than 0.1 then the model will be repeated with new scaling [63]. Finally landslide susceptibility index (LSI) is calculated using eq 2.

$$CR = CI/RI \text{ -------------------- eq1}$$

$$LSI = \sum_{j=1}^{n} (W_j w_{ij}) \text{-----------eq 2}$$

where CI= $(\lambda_{max}- N)/(N-1)$, λ_{max} is the largest principal eigen value of the matrix , N is the order of comparison matrix, RI is random consistency index[63], W_j is the weight value of predictor j, w_{ij} is the weight value of class i of causative factor j, n is the number of predictors. Using LSI spatially LS map were generated as shown in Fig 7.

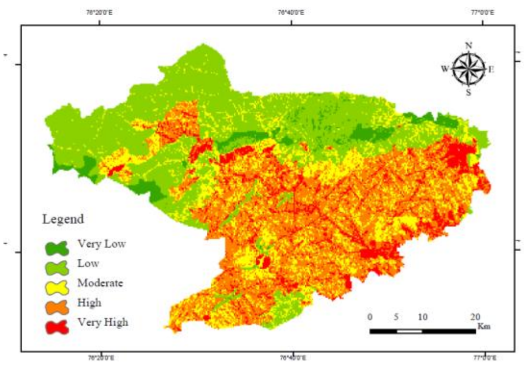


Fig.7- Landslide Susceptibility map using AHP Model

SMCE model

SMCE is an science based method that combines spatial analysis using GIS and multi-criteria evaluation (MCE) to transform spatial and non-spatial input to generate output decision [68,69].

Table 1 - The predictors and their calculation for their weighting coefficient for AHP method

Predictors	Rainfall	Drainage buffer	Railway buffer	Road buffer	Landuse and land cover	Geology	Lineament buffer	Soil	Geomorphology	Slope	Aspect	Wi
Rainfall	1	5	5	3	5	3	3	1	3	3	2	0.204
Drainage buffer		1	0.25	3	0.125	0.25	0.125	0.125	0.125	2	0.5	0.044
Railway buffer			1	0.5	0.125	0.25	0.2	0.125	0.25	0.2	0.2	0.027
Road buffer				1	0.125	2	0.5	0.2	2	2	2	0.077
Landuse and land cover					1	3	2	0.2	2	3	0.5	0.108
Geology						1	5	0.2	2	2	2	0.106
Lineament buffer							1	0.5	0.5	2	0.5	0.082
Soil								1	0.167	3	0.5	0.098
Geomorphology									1	0.5	0.5	0.074
Slope										1	2	0.068
Aspect											1	0.107

The multi criteria evaluation of AHP method has been used as the theoretical background of SMCE method for determining level of influence for groups and predictors. Grouping of predictors involves combining together all the related factors in one group. In this study four groups were identified namely geomorphology geology, hydrology and manmade as shown in table 2.

Each thematic map as shown in fig a-k is overlapped on landslide inventory map and number of landslides falling in each class of every predictor were counted. Landslide Related Frequency Ratio (LRF), landslide density of each class were determined using eq 3.

$$LRF = (\frac{LF}{CA}) / \sum(\frac{LF}{CA}) \text{ ----------------------- eq 3}$$

Where CA is percentage area and LF is landslide percentage of each class of a predictor.

Input layers in different units of measurements spatially were converted from its original value to 0-1 using normalization in eq 4 [70,71].

$$Nv = 0.8(Xi - Xmin|Xmax - Xmin) + 0.1 \text{------eq 4}$$

Pair-wise comparison between group and every predictors based on subjective judgments published by [63] were done as shown in table 3.

Hydrological and manmade factors found to influence more. Rainfall, land use/land cover Predictors weighed more and showed high level of influence.

Table 2 - Weight value for each predictors groups and classes using pair-wise comparison for SMCE model

Factor	Predictors	Weight	CR
Hydrology	Rainfall	0.833	0
	Drainage buffer	0.167	
Manmade	Railway buffer	0.083	0.057
	Road buffer	0.083	
	Land use	0.723	
Geology	Geology	0.244	0.082
	Lineament buffer	0.067	
	Soil	0.689	
	Geomorphology	0.131	
Geomorphology	Slope	0.667	0.097
	Aspect	0.192	
Factor			
	Hydrological	0.433	0.068
	Hydrological	0.433	
	Man made	0.295	
	Geomorphology	0.200	
	Geology	0.072	

Table 3 - Spatial relationship between landslide locations and landslide predictors

Predictors/ classes`	**Classes**	**no of landslides**	**% of landslides (LF)**	**area of subclass in km^2**	**% of subclass area (CA)**	**LF/ CA**	**LRF**	**a**	**b**	**c**	**d**
Geomorphology	Bajada	0	0	0.35	0	0	0	0.1	0.131	0.200	0.003
	deflection slope	219	54	252.15	10	5.4	0.675	0.9	0.131	0.200	0.024
	dissected/un dissected	0	0.0	11.19	0	0	0	0.1	0.131	0.200	0.003
	highly dissected	86	21	1260.24	49	0.4	0.053	0.163	0.131	0.200	0.004
	moderately dissected	89	22	858.08	34	0.6	0.080	0.195	0.131	0.200	0.005
	undissected/ less dissected	13	3	62.23	2	1.5	0.187	0.322	0.131	0.200	0.008
	upland	0	0	62.81	2	0	0	0.1	0.131	0.200	0.003
	valley fill	0	0	0.27	0	0	0	0.1	0.131	0.200	0.003
	valleys	0	0	39.54	2	0	0	0.1	0.131	0.200	0.003
Geology	amphibolite/ pyroxene granulite	0	0	40.1	2	0	0	0.1	0.244	0.072	0.002
	charnokite	403	99	1682.8	66	1.5	0.974	0.9	0.244	0.072	0.016
	genesis	4	1	735.7	29	0.03	0.022	0.1	0.244	0.072	0.002
	schist	0	0	18.1	1	0	0	0.1	0.244	0.072	0.002
	ultramafic	0	0	70.1	3	0	0	0.1	0.244	0.072	0.002
Soil	clay	406	99.800	2174.9	85.39	1.17	0.999	0.9	0.689	0.433	0.269
	loam	1	0.00	372.1	14.61	0.00	0.000	0.1	0.689	0.433	0.030
Land use and land cover	settlement	50	12	162.2	6.36	1.884	0.210	0.73	0.787	0.295	0.171
	scrub forest, scrub land	90	22.1	306.4	12.02	1.837	0.204	0.718	0.723	0.295	0.153
	agricultural plantations and forest crop lands	115	28.3	1200.7	47.14	0.600	0.067	0.303	0.723	0.295	0.065
	evergreen /semi evergreen forest	112	27.5	347.3	13.63	2.017	0.224	0.779	0.723	0.295	0.166
	deciduous and degraded forest	20	5	450.6	17.69	0.283	0.031	0.194	0.723	0.295	0.041
	current fallow	20	5	53.7	2.10	2.372	0.264	0.9	0.723	0.295	0.192
	tank and reservoir	0	0	26.1	1.02	0.000	0.000	0.1	0	0	0.000
Lineament buffer(m)	0-100	56	14	185.1	7	2.000	0.366	0.9	0.067	0.072	0.004
	100-200	27	7	200.2	8	0.875	0.160	0.1959	0.067	0.072	0.001
	200-300	25	6	204.7	8	0.750	0.137	0.1	0.067	0.072	0.000
	300-400	28	7	201.7	8	0.875	0.160	0.192	0.067	0.072	0.001
	> 500	271	67	1755.4	69	0.971	0.177	0.251	0.067	0.072	0.001
Railway buffer(m)	0-100	159	39	6.59	0.259	150.6	0.617	0.9	0.083	0.295	0.022

	100-200	7	2	6.38	0.275	7.3	0.030	0.141	0.083	0.295	0.003
	200-300	25	6	6.1	0.239	25.1	0.103	0.23	0.083	0.295	0.006
	300-400	32	8	5.9	0.232	34.5	0.141	0.281	0.083	0.295	0.007
	400-500	26	6	5.84	0.229	26.2	0.107	0.237	0.083	0.295	0.006
	>500	158	39	2516.19	98.790	0.4	0.002	0.1	0.083	0.295	0.002
Road buffer (m)	0-100	186	46	60.5	2.38	19.33	0.669	0.912	0.083	0.295	0.022
	100-200	35	9	55.5	2.18	4.13	0.143	0.258	0.083	0.295	0.006
	200-300	13	3	52.82	2.07	1.45	0.050	0.148	0.083	0.295	0.004
	300-400	18	4	50.68	2	2.00	0.069	0.173	0.083	0.295	0.004
	400-500	11	3	48.71	1.91	1.57	0.054	0.148	0.083	0.295	0.004
	>500	144	35	2278.79	89.44	0.39	0.014	0.1	0.083	0.295	0.002
Drainage buffer (m)	0-100	61	15	177.7	7	2.143	0.244	0.9	0.167	0.433	0.065
	100-200	50	12	174.59	7	1.714	0.195	0.7	0.167	0.433	0.051
	200-300	33	8	171.23	7	1.143	0.130	0.35	0.167	0.433	0.025
	300-400	40	10	167.39	7	1.429	0.163	0.5	0.167	0.433	0.036
	400-500	40	10	163.57	6	1.667	0.190	0.65	0.167	0.433	0.047
	>500	183	45	1692.53	66	0.682	0.078	0.1	0.167	0.433	0.007
Rainfall (mm)	0-500	0	0	56	2.198	0	0.000	0.1	0.833	0.433	0.036
	500 – 1000	160	39	312.18	12.25	3.18	0.411	0.1	0.833	0.433	0.036
	1000 – 1500	131	32	1010.02	39.65	0.80	0.104	0.30	0.833	0.433	0.109
	1500 – 2000	88	22	685.57	26.91	0.81	0.106	0.30	0.833	0.433	0.110
	2000 – 2500	19	5	464.05	18.21	0.27	0.035	0.16	0.833	0.433	0.061
	>2500	9	2	19.19	0.75	2.65	0.343	0.76	0.833	0.433	0.277
Slope(degree)	0-5	31	8	577.54	22.68	0.35	0.040	0.16	0.667	0.200	0.022
	5 to 15	109	27	1088.96	42.75	0.632	0.072	0.212	0.667	0.200	0.028
	15 to 25	129	32	564.23	22.15	1.445	0.165	0.374	0.667	0.200	0.050
	25 to 35	101	25	244.19	9.59	2.608	0.298	0.545	0.667	0.200	0.073
	35 to 55	37	9	61.74	2.42	3.713	0.424	0.9	0.667	0.200	0.120
	>55	0	0	10.34	0.41	0.000	0.000	0.1	0.667	0.200	0.013
Aspect	north	75	18	211.82	8	2.250	0.262	0.9	0.192	0.200	0.035
	northeast	104	26	310.67	12	2.167	0.252	0.866	0.192	0.200	0.033
	east	119	29	384.34	15	1.933	0.225	0.776	0.192	0.200	0.030
	southeast	40	10	285.83	11	0.909	0.106	0.377	0.192	0.200	0.015
	south	19	5	333.9	13	0.385	0.045	0.174	0.192	0.200	0.007
	southwest	10	2	258.12	10	0.200	0.023	0.1	0.192	0.200	0.004
	west	21	5	243.48	10	0.500	0.058	0.217	0.192	0.200	0.008
	northwest	19	5	518.84	20	0.250	0.029	0.12	0.192	0.200	0.005

a: Normalized value b : Predictors value c : Predictors group value d : Final weight

Product of normalized value , predictors value and group value gives the final weight of each predictor as shown in table 3. Using spatial analyst tool in Arc GIS the thematic maps of every predictors were overlaid based on the weights calculated and final LS map were derived [72,73] and classified into five categories namely very low, low, moderate, high and very high as shown in Fig 8.

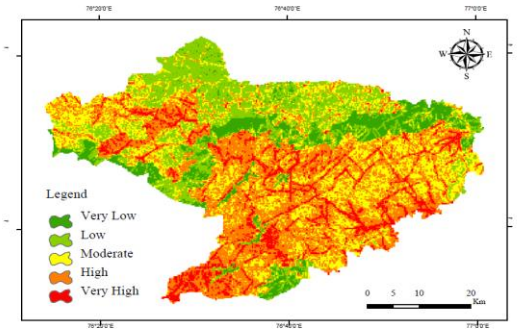


Fig.8-Landslide Susceptibility map using SMCE

Results and Discussion

Landslides have been recorded during heavy rainfall and it is viewed as the prime factor for the cause. From the rainfall map obtained Fig 3h it is evident that Gudalur, and southern parts of Udhagamandalam blocks receives heavy annual rainfall but number of landslide occurred are less because of prevailing gentle slope. At railway and road lines due to steep slopes (<15°) and vibration of traffic causes loss of strength to soil along the slopes which causes mass movement, landslides during heavy rainfall. Deflection slopes and charnockite classes of geomorphology and geology, clayey soil covering the whole district, due to its low permeability are recorded with more occurrences due to their physical characteristics in the study area. Agricultural plantation and evergreen and semi evergreen forest lands are recorded with numerous landslides because of change in land use pattern and deforestation. Settlement areas are also affected with landslides where damages are severe with human losses. Majority of landslides (80%) have occurred close to road and railway track within a distance of 100m and the remaining (>500m) have occurred in places like tea estate, settlement. Table 3 shows about 43%, nearly half of landslides fall at distance within

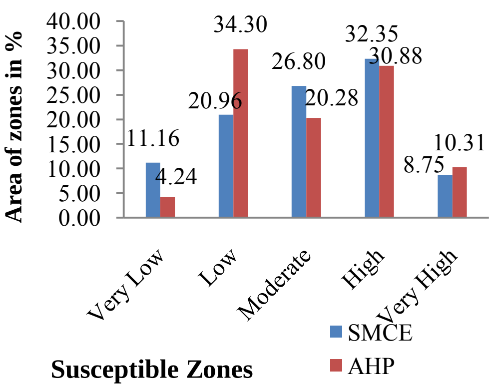


Fig.9 - Comparison of area of landslide susceptibility

100m drainage buffer, this is due to the blockage of drain lines for the formation of manmade features such as roads, railway lines and buildings. Rainfall in combination with other predictors such as slope, land use/ land cover , soil type, drainage condition triggers landslides.

Landslide Susceptibility map

Discussing the two LS maps of the models, it shows that spatial distribution of zones along transportation networks is similar and most of the areas show low and very low susceptibility. Further it revealed that north western part of study area consisting of deciduous forest at Gudalur and Udhagamandalam block shows very low and low susceptibility in AHP model whereas SMCE model shows low and moderately susceptible areas as shown in Fig 7 and 8. In reality Gudalur block suffers less number of landslides with moderate susceptibility because of its geographical conditions. It prevails with very heavy and heavy rainfall records, gentle slope, agricultural plantations and crop lands geographically. Udhagamandalam, Coonor and Kothagiri blocks prevailing with steep slopes shows very high and high susceptibility in AHP model whereas SMCE model shows moderate and very high susceptibility. Always these three blocks are recorded with more number of landslides and they naturally fall under moderate and very high susceptibility zones [40] in reality. Regarding the spatial development of landslide susceptible classified zones SMCE method showed more of high and very high areas than AHP model as shown in Fig 9 which when verified in field showed similar results **.**

Validation

As it is obvious to know the limitation of the models which can be accessed through receiver operating curve (ROC)[74,75.]This method has been widely used as a measure of performance of predictive value[76,77] ROC measures the percentage of correctly predicted by the models and area under curve (AUC) serves as a global accuracy statistic for the model [71,] the curve is obtained by plotting true positives (TP) and false positive (FP). The threshold value of AUC is 0.5-1 for good fit [78.]In this paper AHP model showed 0.9558 and SMCE model showed 0.9866 as shown in Fig 10a and 10b respectively, which indicates both the models are of with good ability, but the physical validation in the field showed good results to SMCE model rather than AHP model.

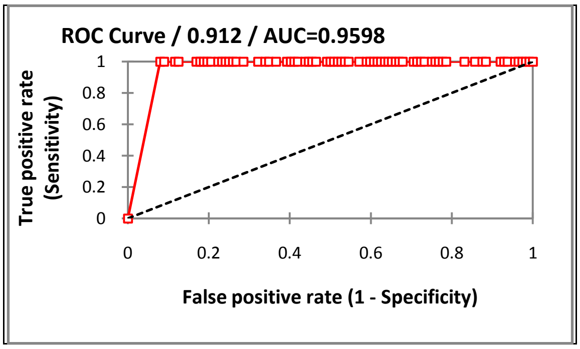


Fig. 10a- ROC curve of AHP

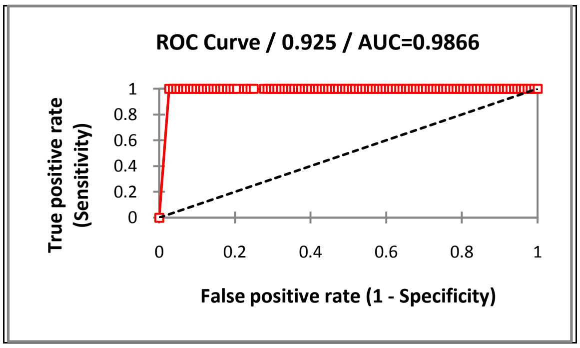


Fig. 10b - ROC curve of SMCE models

Conclusion

In the study area road and railway both travel parallel, and are affected equally hence more landslides have occurred both at <100m and >500m. Blocks Udhagamandalam, Kothagiri and Coonor are very high susceptible to landslides. The objective of this study, to compare the multi criteria methods to know the effective tool for weightage and ranking predictors which influence the occurrence of landslides in Nilgiris district reveals that SMCE will be more effective than AHP. Comparison is been done under two views (i) susceptibility area (ii) validation area. In susceptibility area SMCE model shows more field accurate areas than AHP model. In validating the models even though AUC area of both the models were similar SMCE model shows better and appropriate results regarding spatial distribution and susceptible zones when compared in field. Thus concludes "The past and present are keys to the future"[79] is the prime principle of prediction.

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