Landslide susceptibility mapping in the downstream region of Sharavathi river basin, Central Western Ghats

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***Abstract*—Landslides are hazards encountered during monsoon in undulating terrains of Western Ghats causing geomorphic make over of earth surface resulting in significant damages to life and property. An attempt is made in this paper to identify landslides susceptibility regions in the Sharavathi river basin downstream using frequency ratio method based on the field investigations during July- November 2007. In this regard, base layers of spatial data such as topography, land cover, geology and soil were considered. This is supplemented with the field investigations of landslides. Factors that influence landslide were extracted from the spatial database. The probabilistic model -frequency ratio is computed based on these factors. Landslide susceptibility indices were computed and grouped into five classes. Validation of LHS, showed an accuracy of 89% as 25 of the 28 regions tallied with the field condition of highly vulnerable landslide regions. The landslide susceptible map generated for the downstream would be useful for the district officials to implement appropriate mitigation measures to reduce hazards.**

I. INTRODUCTION

Movement of a mass of rock, debris, or earth down a slope resulting geomorphic make over of earth surface and this active process contributes to erosion and landscape evolution is often referred as landslide [1,2]. This could be due to the temporal conjunction of several factors [3-5], such as: (i) the quasi-static variables, which contribute to landslide susceptibility, such as geology, slope characteristics (gradient, slope aspect, elevation, etc.), geotechnical properties, and long-term drainage patterns, etc.; and (ii) the dynamic variables, which tend to trigger landslides in an area of a given landslide susceptibility, such as rainfall and earthquakes.

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Depending on quasi static and triggering factors, landslides vary in composition as well as in the rate of movement ($0.5x10^{-6}$ to $5x10^{3}$ mm/sec). Landslides in vulnerable zones in India have lead to large scale loss of life and property [6]. In this context, identification, mapping and monitoring of landslide susceptible pockets would help in the mitigation as well as in the rehabilitation. These vulnerable pockets can be identified by by both direct and indirect techniques based on significance of causative factors in inducing instability. The assumptions that are generally made in identifying landslide hazard susceptibility (LHS) regions [7, 8] are: Occurrence of landslides follows past history in the region depending on geological, geomorphological, hydrogeological and climatic conditions. Identification of LHS involves dividing the region into zones depending on degrees of stability, significance of causative factors inducing instability, etc.

Identification and mapping of LHS zones aid in delineating unstable hazard-prone areas, so that environmental mitigation measures can be initiated. This also helps planners to choose favourable locations for site development projects. Even if the hazardous areas can not be avoided altogether, their recognition in the initial stages of planning will help to adopt suitable precautionary remedial measures.

Identification of LHS and mapping: Quasi static variables and dynamic variables are considered for likelihood frequency ratio (LRM) model and weighted linear combination (WLC) model. In this regard, slope angle, slope aspect, lithology, distance from drainage lines, distance from roads and the land-cover of the study area are considered as the landslide-conditioning parameters. [9] Other attempts considering lithology, slope angle, bedding attitude along with dynamic variable like rainfall [10]; distance from faults, parallelism between the fractures and the landslide scarps, land use, lithology, distance from the streams, orientation and steepness of slopes, orientation of layers compared to the slope [11]; slope, aspect, and curvature of topography, texture, material, drainage, and effective soil thickness and type, age, diameter, and density of timber, lithology, land use in probability and logistic regression methods [12]; geological structure of foliation, slope aspect and slope of the topography for frequency ratio analysis [13]; slope, curvature, soil texture, soil drainage, soil effective thickness, timber age, and timber diameter in

ANN and frequency ratio methods [12-16]; rainfall, slope angle, aspect, curvature, lithology, superficial deposits, geomorphology, and land use in the probabilistic evaluation of landslide hazard [17]; slope angle, slope aspect, slope curvature, slope length, distance from drainage, distance from lineaments, lithology, and land use and geomorphology in frequency ratio method [18].

The objective of the study is identification and mapping landslide prone zones of Sharavathi downstream using frequency ratio analysis. The Sharavathi river basin is situated in Central Western Ghats. Due to undulating terrain coupled with high intensity rainfall, ghats are prone to landslides causing significant damage to property and agriculture. Most of the episodes are triggered by rainfall with the changes in land cover. Effort is made to identify landslide susceptible regions.

II. STUDY AREA

The Sharavathi River (74.408°-75.32° E and 13.717°-14.432° N) is one of the important west flowing rivers of central Western Ghats, India (Fig 1). A hydro-electric dam was commissioned in 1964 at Linganamakki, which has waterspread area of 357 sq.km.). Subsequent to the dam, Sharavathi river loses height of 253m as series of rapids. The catchment area is about 2985km², with up-stream being 1988 km² and the downstream being 997km².

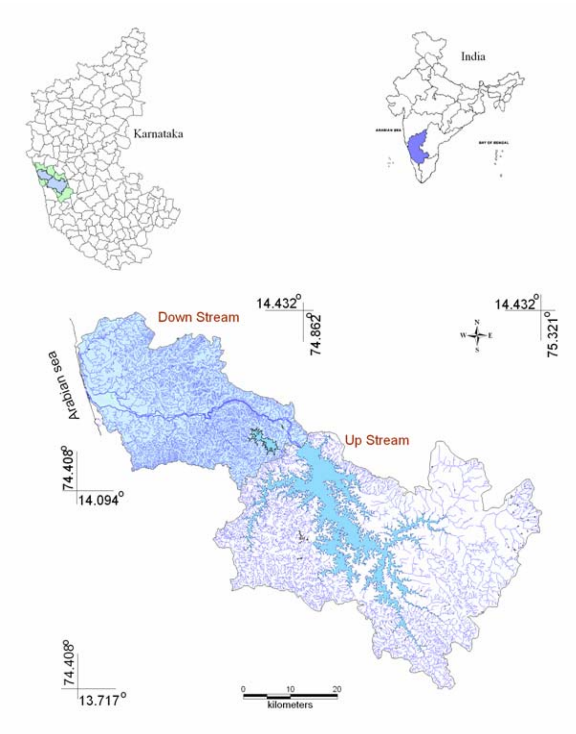

Fig 1: Sharavathi river basin, Central Western Ghats

Down stream of Sharavathi situated at 74.408° –74.862° E and 14.094°–14.431° N, with elevation varies from zero meters at sea level to 760 m at the ghats and having an average altitude of 237 m. The soil texture is mainly clayey, clayey-skeletal, sandy loam and sand distributed only along the mouth of the catchment. The region is made up laterite, migmatites and granodiorite. grey granite, metabasalt, greywacke, alluvium, and quartz chlorite schist with orthoquartzite are spread across the study area. Annual rainfall in the region ranges from …3521±619 mm (Honavar) 4339±1249 mm (Gerusoppa). Field investigations were carried out in the downstream region during August, September, and October months and 120 landslide location were located.

III. METHOD

Method adopted for landslide susceptibility analysis is given in Fig 2. Field investigations were carried out in the Sharavathi river basin located in central Western Ghats. Major components of the study are:

i.) Identification of causal variables: Review of literature indicates the major causal variables are: topographical (aspect, slope, curvature, drainage network), geo-morphological (lineament, genesis), lithological (lithology, soil texture, soil permeability and soil depth), infrastructure (road network, location of buildings), land cover (NDVI), land-use (agriculture, waterbodies, forests, built-up, barren land). Field surveys were carried out of landslide spots (temporal as well as latest ones), attribute data of training polygons of land use analysis using pre-calibrated GPS.

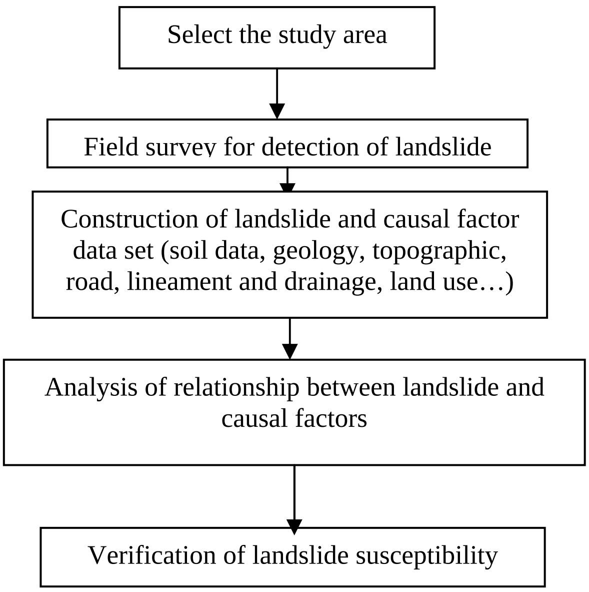

Fig 2: Flow chart of landslide susceptibility analysis

Table 1: Spatial data

Classification	Sub-classification	Data Type	Scale
Base layers	Topographic	Lines and points	1:50000
	Geological	Lines and polygons	1:250,000
	Soil	Polygon	1:250,000
	Elevation	GRID (SRTM)	90m x 90m
Remote sensing data	Land cover	GRID (IRS-1D)	23.5m x 23.5m
	Rainfall	Points	Taluk level
Geological Hazard	Landslide	Points	

ii.) Creation of base layers of spatial data – soil, geology, topography, geo-morphology, land use, etc. These information were collected from the respective government agencies and supplemented with the remote sensing data and other spatial layers. Indian Remote Sensing (IRS) 1C/1D satellite, LISS III (linear imaging self scanner) data of spatial resolution 23.5 m (acquired during Nov 2004), of bands 2, 3 and 4 (corresponding to G, R and IR bands of electro magnetic spectrum) were used for land use and land cover (NDVI) analysis. Supervised classification using Gaussian maximum likelihood classifier was carried out for deriving seven land use categories- agricultural, barren land, built up, moist deciduous forest, plantation, semi-evergreen forest and water body. Road and drainage networks with administrative boundaries were digitised from Survey of India (SOI) topographic maps (1:50,000 scale). Soil types and spatial extent were digitised from the soil map of National Bureau of Soil Sampling and land use planning (NBSS& LUP) of 1:250,000 scale. From this, texture, depth and permeability were derived. Spatial data with type are listed in Table 1.

Geomorphological variables such as lithology, lineament, rock type were extracted from geological and structural maps of Geological Survey of India (1:250,000 scale). Shuttle radar topographic mapping (SRTM 3 arc-sec) of 90 m resolution was used to derive layers of slope, aspect and curvature. This constitutes predisposing factors for the landslide activity.

Slope was classified into 10 classes. Aspect represents the angle between the geographic north and a horizontal plain for a certain point. This was classified in eight major orientations (N, NE, E, SE, S, SW, W, NW). The curvature controls the superficial and subsurface hydrological regime of the slope and the classes considered are concave, flat and convex slope areas, which were directly derived from the DEM.

The distance from drainage and road was calculated using the vectorised drainage and road from the topographical sheets of scale 1:50,000. The drainage and road buffer was calculated at 90 m intervals. The lithology and genesis was extracted from the available geology map prepared by the Geological Survey of India (GSI). In addition the lineament database from GSI, was used to create distance from lineaments map. The lineament buffer was calculated at 90 m intervals.

iii.) Development of spatial database: Considering the spatial resolution of the data available, all data layers were resampled to 90 m. Landslides (both latest and earlier ones) corresponding to 120 occurrences were used for computing LSI as well as for sensitivity analysis.

iv.) Frequency ratio: Frequency ratio is the ratio of occurrence of probability to non-occurrence probability, for specific attributes. In the case of landslides; if landslide occurrence event is set to B and the specific factor's attribute to D, the frequency ratio for D is a ratio of conditional probability. If the ratio is greater than 1, greater is the relationship between a landslide and the specific factor's attribute; and if the ratio is less than 1, the lower the relationship between a landslide and the specific factor's attribute.

v.) Computation of Landslide Susceptibility Index (LSI): Landslide Susceptibility Index (LSI) is the summation of each factor's frequency ratio values as in Eq. 1. Landslide susceptibility value represents the relative hazard to landslide occurrence, as higher values are associated with landslide hazards.

$$LSI = \sum_{i=1}^{n} Fr_i \qquad \text{----------} (1)$$

(where, LSI: Landslide Susceptibility Index; Fr: rating of each factor's type or range). The landslide hazard map was made using the LSI values.

Table 2: Frequency ratio – Spatial relationship between landslides and related factors

Factors with domain	No of pixels in domain	No of landslide	% of domain	% of landslide	Frequency ratio
Aspect					
South	15924	24	0.135	0.261	1.939
South-West	16018	13	0.135	0.141	1.044
North-West	16308	13	0.138	0.141	1.026
North-East	13337	11	0.113	0.120	1.061
South-East	12758	12	0.108	0.130	1.210
West	16085	5	0.136	0.054	0.400
East	11159	6	0.094	0.065	0.692
North	16795	8	0.142	0.087	0.613
Land use					
Agriculture land	25933	40	0.219	0.435	1.985
Barren Land	4536	6	0.038	0.065	1.702
Builtup	1145	2	0.010	0.022	2.248
Moist Deciduous Forest	32271	9	0.273	0.098	0.359
Plantation	3877	0	0.033	0.000	0.000
Semi-Evergreen Forest	45460	35	0.384	0.380	0.991
Water body	5162	0	0.044	0.000	0.000
Topographic curvature					
Convex	95956	77	0.811	0.837	1.033
Concave	22428	15	0.189	0.163	0.861
Distance from Drainage (m)					
Buffer 90	65833	30	0.5561	0.3261	0.5864
Buffer 180	32190	34	0.2719	0.3696	1.3591
Buffer -270	11125	22	0.0940	0.2391	2.5446
Buffer 360	4513	5	0.0381	0.0543	1.4256
Buffer 450	2074	0	0.0175	0.0000	0.0000
Buffer 540	1073	0	0.0091	0.0000	0.0000
Buffer 630	583	1	0.0049	0.0109	2.2072
Buffer 630<	993	0	0.0084	0.0000	0.0000
Rock type					
Plutonic rocks	8674	0	0.073	0.000	0.000
Metamorphic rocks	51253	55	0.433	0.598	1.381
Residual capping	32837	33	0.277	0.359	1.293
Unconsolidated sediments.	735	1	0.006	0.011	1.751
Volcanics / Meta volcanics	24885	3	0.210	0.033	0.155
Lithologic unit					
Grey granite	8675	0	0.073	0.000	0.000
Migmatites and granodiorite - tonalitic gneiss	31698	38	0.268	0.413	1.543
Laterite	32836	33	0.277	0.359	1.293
Alluvium / beach sand, alluvial soil	735	1	0.006	0.011	1.751
Greywacke / argillite	16343	11	0.138	0.120	0.866
Metabasalt & tuff	24885	3	0.210	0.033	0.155
Quartz chlorite schist with orthoquartzite	3212	6	0.027	0.065	2.404
Limeament (m)					

Buffer 90	9028	5	0.076	0.054	0.713
Buffer 180	10145	7	0.086	0.076	0.888
Buffer 270	10509	14	0.089	0.152	1.714
Buffer 360	10387	4	0.088	0.043	0.496
Buffer 450	9720	4	0.082	0.043	0.530
Buffer 540	8911	2	0.075	0.022	0.289
Buffer 630	8038	4	0.068	0.043	0.640
Buffer 720	7001	3	0.059	0.033	0.551
Buffer 810	6184	5	0.052	0.054	1.040
Buffer 900	5345	5	0.045	0.054	1.204
Buffer 900<	33116	39	0.280	0.424	1.515
NDVI					
<=-0.5	192	0	0.002	0.000	0.000
>0.5	47954	57	0.405	0.620	1.530
>10^-7 and <=0.5	62070	33	0.524	0.359	0.684
>-0.5 and <=-10^-7	8168	2	0.069	0.022	0.315
Slope (degree)					
0-5	534	0	0.005	0.000	0.000
5-10	1369	0	0.012	0.000	0.000
10-15	1647	4	0.014	0.043	3.125
15-20	1798	0	0.015	0.000	0.000
20-25	2162	3	0.018	0.033	1.786
25-30	2647	10	0.022	0.109	4.861
30-35	2476	1	0.021	0.011	0.520
35-40	2837	10	0.024	0.109	4.536
40-45	3782	14	0.032	0.152	4.763
45-90	99226	50	0.838	0.543	0.648
Soil depth					
Moderately shallow	21094	40	0.178	0.435	2.440
Deep	71508	49	0.604	0.533	0.882
Very deep	22732	2	0.192	0.022	0.113
Moderately deep	3050	1	0.026	0.011	0.422
Soil permability					
Somewhat excessively drained	11104	17	0.094	0.185	1.970
Imperfectely drained	12740	15	0.108	0.163	1.515
Well drained	94540	60	0.799	0.652	0.817
Soil texture					
Sandy	895	0	0.008	0.000	0.000
Clayey	45088	15	0.381	0.163	0.428
Clayey-skeletal	60556	57	0.512	0.620	1.211
Sandy loamy	11845	20	0.100	0.217	2.173
Distance form road(m)					
Buffer 90	16992	74	0.131	0.804	6.144
Buffer 180	14707	9	0.113	0.098	0.863
Buffer 270	12278	3	0.095	0.033	0.345
Buffer 360	10279	1	0.079	0.011	0.137
Buffer 450	8606	2	0.066	0.022	0.328
Buffer 540	7256	1	0.056	0.011	0.194
Buffer 630	5108	0	0.043	0.000	0.000
Buffer 720	6295	0	0.053	0.000	0.000
Buffer 810	4348	1	0.034	0.011	0.324
Buffer 810<	32515	1	0.251	0.011	0.043

IV. Results and Discussion

Frequency ratio computed for related factors are listed in Table 2. With high intensity rainfall, slope in the range of 35º to 45º with convex curvature, south and south–west aspect, land uses like barren or agricultural or built up and geological aspects such as metamorphic rocks (migmatites and granodiorite - tonalitic gneiss, laterite, and quartz chlorite schist with orthoquartzite) or residual capping or unconsolidated sediments are highly susceptible to landslides. LSI values computed were classified into five classes (Very high, High, Moderate, Low and Least) based the degree of vulnerability are listed in Table 3 and LHS map is given in Fig. 3. Higher values (14.39 % of study area) of LSI indicate higher probability of landslide occurrences (which coincides with the field data of latest occurrences). Validation of LHS map, showed an accuracy of 89% as 25 of the 28 regions tallied with the field data of highly vulnerable landslides.

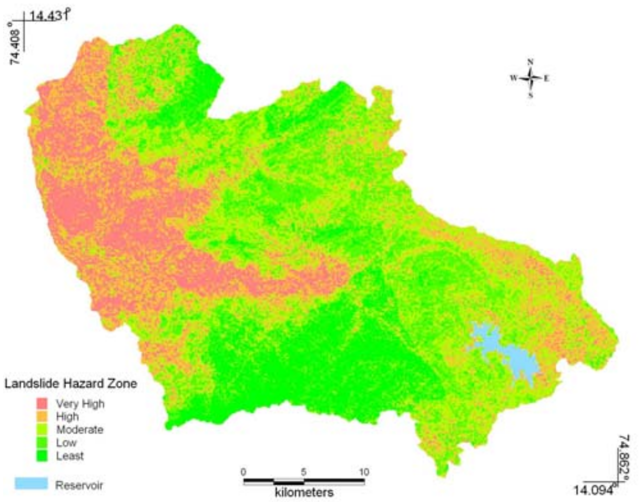

Fig 3: LHS map for Sharavathi Down stream using Frequency ratio

Table 3: LHS for the downstream of Sharavathi river basin

Category	LSI	Spatial Coverage	Validation Accuracy
Very high	18.3-27.8	14.39%	89%
High	14.9-18.3	21%,	
Moderate	12.3-14.9	27.98%	
Low	10.1-12.3	22.54%	
least	5.3-10.1	14.09	

V. Conclusion

Frequency ratio method based mapping of landslide for Sharavathi river downstream show that 14.39% of the study area is very highly susceptible to landslide and 14.09% of the area being very safe or least prone to landslide. The validation of the LHS map generated had an agreement of 89% between the susceptibility map and the field data.

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