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Landslide Hazard Zonation in Raigad District of Maharashtra: A Multivariate Approach

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Abstract: *The identification, mapping and monitoring of landslide susceptible zones helps in the mitigation of landslides as well as in rehabilitation of affected people. This paper aims at preparing a landslide susceptibility zonation map of the Raigad district of Maharashtra using multivariate analysis. The morphology of slope failure clearly reflects the processes and causative factors behind the occurrence of landslides. Thus, various hillslope form attributes such as total ground length covered by the landslide, surface irregularity and crest curvature of the landslide scar have been estimated for all the landslides reported from Western Ghat and Konkan region of Raigad. These attributes subsequently were used to derive landslide form attributes such as dilation index, tenuity index, displacement index etc. Finally, a landslide susceptibility zone map has been prepared on the basis of the estimated susceptibility index. It can be seen from the map that the Western Ghat foot hill spurs and hilltops in the southeastern part of the district are prone to landslides. The coastal lateritic areas to the south are relatively more susceptible than northern coastal areas covered by basalt flows of aa type. The northern and north eastern hilly regions of the district covered by pahoehoe flows also show more than 52% susceptibility to landslides.*

Introduction

The movement of a mass of rock, debris or earth down a slope which contributes to erosion and landscape evolution is often referred to as a landslide. Occurrence of landslides depends on a number of variables, which determine landslide susceptibility of a region. These include gradient, slope aspect, elevation, geotechnical properties, drainage patterns and a few dynamic variables such as rainfall and earthquakes. Depending on these factors landslides vary in their morphology, composition and rate of movement. Landslides in vulnerable zones lead to large scale loss of life and property.

Identification, mapping and monitoring of landslide susceptible zones helps in the mitigation of landslides as well as in rehabilitation of affected people. Vulnerable pockets can be identified through direct and indirect techniques based on the significance of causative factors in inducing instability. The recognition of the landslide hazard prone areas in the initial stages of planning will help to adopt suitable precautionary and remedial measures. The assumption generally made in identifying landslide hazard or susceptibility zones, is that the occurrence of landslides follows the past history depending on geological, geomorphological, hydrogeological and climatic conditions. Identification of such areas involves dividing the region into zones depending on degrees of stability and significance of causative factors inducing instability.

Study area

District Raigad in Maharashtra extends between 17°53' N and 19°08' N latitudes and 72°51' E and 73°42' E longitudes. Its north-south extension is about 120 km, while the average east west width is about 48 km. Major part of the district is highly dissected. The coastline is characterised by numerous headlands, bays and beaches, while the middle tract shows many plateau and valleys. The more rugged part of the Sahyadri ranges slowly merges with the foothill towards the east. Ulhas, Patalganga, Amba, Kundalika and Savitri are the main rivers draining the district. These rivers are tidal for a distance of about 40 to 50 km from their mouths. During summer temperature rise up to 43 °C and in winter it decreases to about 20 °C. The average annual rainfall is about 3,500 mm.

The entire district is covered by basaltic lava flows of Late Cretaceous to Early Eocene (GSI, 1976), which are intruded by numerous dykes (Fig. 1). Near the coast the basalt flows are extensively altered or covered by laterites. The major joints displayed by the basalt flows

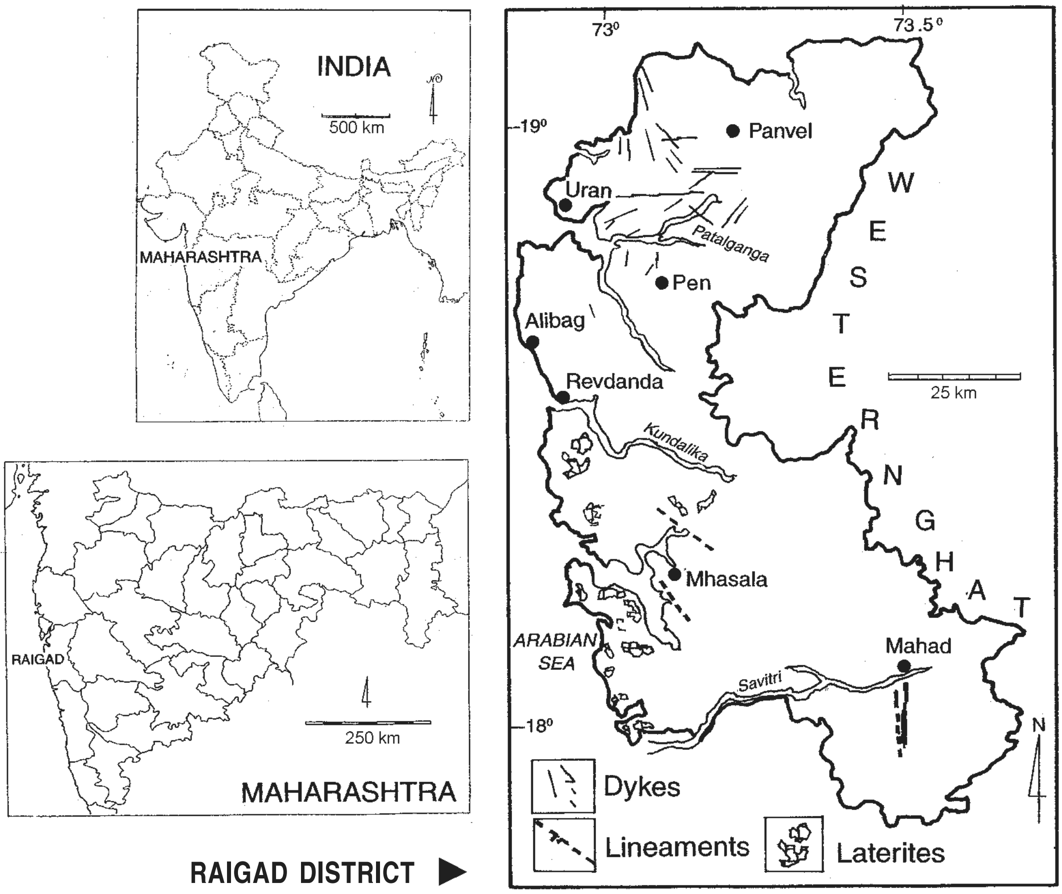

Figure 1. Location of study area

are N–S in direction. Columnar or vertical joints are noticed in aa flows. Closely spaced joints simulating fractures are also noticed at places. A large number of dykes, two to four metres in width, intrude the lava pile (GSI, 1976).

Landslides and slope failure incidences are reported from many parts of the district especially from coastal and foot hill Sahyadris. The mass movements of various types like soil creep, rock fall, debris slide and landslides were recorded at various sites (Fig. 2). The terrain aspects at these sites are generally

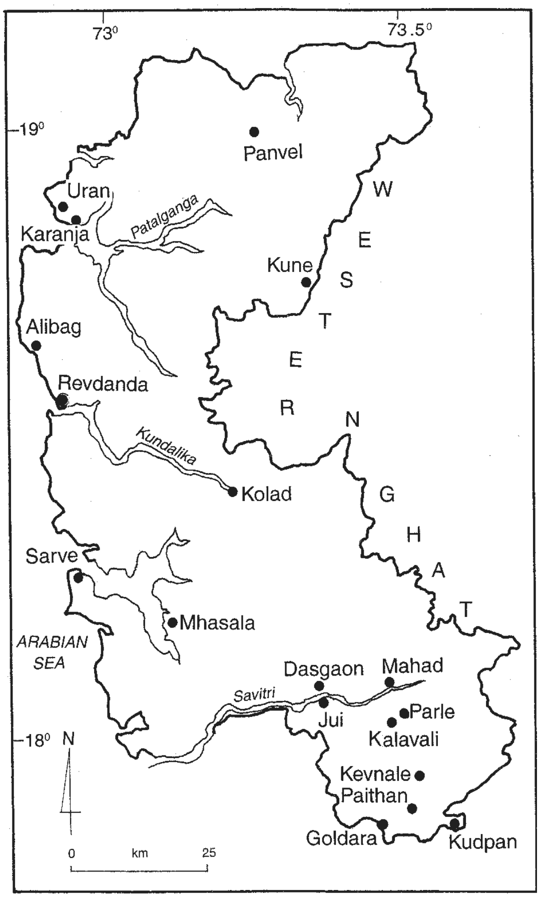

Figure 2. Locations of studied landslides in Raigad

similar but the amount of mass movement in these sites was found to be of varying magnitude. Many of these landslides occurred in remote and inaccessible areas of Sahyadri and its offshoots. The amount of loss to the life and property was found to be limited. In addition to this some other consequences such as development of cracks in agricultural fields, subsidence of land and damming of river courses were also recorded at few places.

Objective

The objective of the study is to identify and map the landslide prone zones of Western Ghat area and coastal plain areas of Raigad district of Maharashtra. Due to undulating terrain coupled with high intensity rainfall, the Western Ghats are prone to landslides, causing significant damage to property and agriculture. Most of the episodes are triggered by rainfall with the changes in landcover.

The main aim of this work is to measure and analyse the hill slope and landslide attributes of a few reported landslides in the Western Ghats and Konkan region of Raigad district of Maharashtra.

The paper attempts to recognise the probable sites of landslide occurrence and tries to assess their relation with hill slope gradient, slope aspect and curvature, soil texture, soil drainage, soil effective thickness, timber age, timber diameter, distance from drainage, distance from roads, distance from faults, distance from lineaments, parallelism between the fractures, lithology, geological structures, geomorphology and land use. Even a dynamic variable like rainfall has also been considered in the analysis.

Previous works

Much of the literature on landslides has been event specific, often consisting of case studies. Such studies have been instrumental in simulating and complementing systematic research into the mechanism of mass wasting and slope failure. The role of deforestation, slope attributes and rock type has been explained by many. Landslide classification schemes were suggested by Young (1972), Cooke and Doornkamp (1974), Crozier (1986) and Hutchinson (2001). Landslide zonation for hill areas using aerial photographs and satellite images was attempted by many scholars. Attempts were made to delineate landslide prone zones with the use of DEM models developed from digital contour maps (Ramakrishnan *et al.*, 2002; Esmail and Ahmadi, 2003; Ghafoori *et al*., 2006). The thematic database in such studies is usually prepared for slopes, soils, rainfall, geology and landuse in the landslide affected areas.

Materials and methods

Places where major landslides and slope failures were reported from the district were visited and attempts were made to measure and quantify different hill slope and landslide attributes. These measurements included, total ground length covered by the landslide, distance of displaced material, width of convex and concave parts of the headwall near the landslide scar etc.

These attributes were subsequently used to derive landslide form attributes such as dilation index, tenuity index, displacement index etc. Multivariate analysis was undertaken to obtain the landslide hazard zonation maps on the basis of susceptibility index.

Digital terrain models (DTM) for attributes like average annual rainfall, percentage of forest cover, summer and winter maximum temperatures, were created by using SURFER version 6.04 to obtain the values of these variables for landslide affected sites. These models were subsequently used to get the amount of rainfall, forested land, summer and winter temperatures for all the landslide affected places in the district. Instead of using DEM for altitudinal values, these were measured in the field using GPS. The slope was determined from the difference in altitude at the crest and at the foot of the landslide scar, divided by the ground length. The range of seasonal temperature is used to know the intensity of rock weathering in humid tropical environment (Birkland, 1974). In general more the range, more is the degree of weathering. The range of temperature between May/June and January was calculated for every landslide affected site. Ranks/ weightages were assigned to each attribute i.e. crest altitude, gradient, precipitation, forest cover, maximum summer temperature and range of temperature (Table 2). While assigning the weights, attribute tendencies triggering landslides were taken into account. Higher values of crest altitude, gradient, precipitation, summer temperature and range of temperature were assigned more weightage (high ranks) and higher values of forest cover were assigned low ranks as there is a low probability of landslide occurrence in thickly forested areas than the sparsely forested areas. The data regarding maximum and minimum altitude, ground length of landslide affected area (GL), height of headwall (H), width of upslope concave section (W_c), width of down slope convex section (W_x), length of displaced material (L_m), length of concave part (L_c) and length of surface of rupture (L_r) were collected in the field (Table 1 and 2, Fig. 3) following the technique suggested by Crozier (1973). These parameters were used to analyse the morphology of landslides in the area and to calculate the various indices of movements such as dilation index (W_x/W_c), tenuity index (L_m/L_c) and displacement index (L_r/L_c) as shown in Table 2.

Variables such as slope of landslide area and the range of temperature were calculated and a multivariate analysis was carried out to obtain the landslide susceptibility index for each reported site. The following multiple regression equation was used to obtain susceptibility index values.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6$$

(Where y denotes susceptibility index, x_1 is altitude of landslide crest, x_2 is amount of rainfall, x_3 is slope of the area, x_4 is amount of

Table 1. Some parameters measured at selected landslide sites, Raigad district

Place	Lat / Long (degrees)	Max height (m)	Min height (m)	Relative relief (m)	Slope length (m)	Heading (degree)	Ground length (m)	Displacement (m)
Kudpan	17.87 / 73.55	797	761	36	87	87	1015	928
Goldara	17.88 / 73.45	497	411	86	700	186	1,746	1,046
Kalavali	17.04 / 73.49	188	145	43	176	187	299	123
Parle	18.04 / 73.45	228	157	71	236	107	590	354
Lohare	18.1 / 73.46	347	249	98	367	283	1,019	652
Paithan	17.90 / 73.48	235	194	41	175	225	353	178
Kevnale	17.95 / 73.55	382	336	46	71	15	183	112
Dasgaon	18.1 / 73.35	166	111	55	119	185	374	255
Jui	18.07 / 73.35	102	66	36	109	346	280	171
Mhasala	19.20 / 73.10	220	139	81	574	267	1,805	1,231

Table 2. Average attributes at landslide sites, Raigad district (after Crozier, 1973)

Attributes	Foothill spurs of Sahyadri	Coastal areas
Head (m)	30	57
Ground length of landslide affected area, GL (m)	132	200
Width of upslope concave section, W_c (m)	31	125
Width of down slope convex section, W_x (m)	15	72
Length of displaced material, L_m (m)	55	100
Length of surface of rupture, L_r (m)	21	44
Length of bare surface, L_f (m)	13	30
Length of concave part, L_c (m)	36	92
Perimeter (m)	232	590
Dilation Index (W_x/W_c)	0.48	0.58
Tenuity Index (L_m/L_c)	1.53	1.1
Displacement Index (L_r/L_c)	0.58	0.48

Note: See Fig. 3 for diagrammatic representation of the attributes

forest cover, x_5 is summer temperature and x_6 is range of temperature)

The strength of the computed equation was ascertained by calculating explained variance

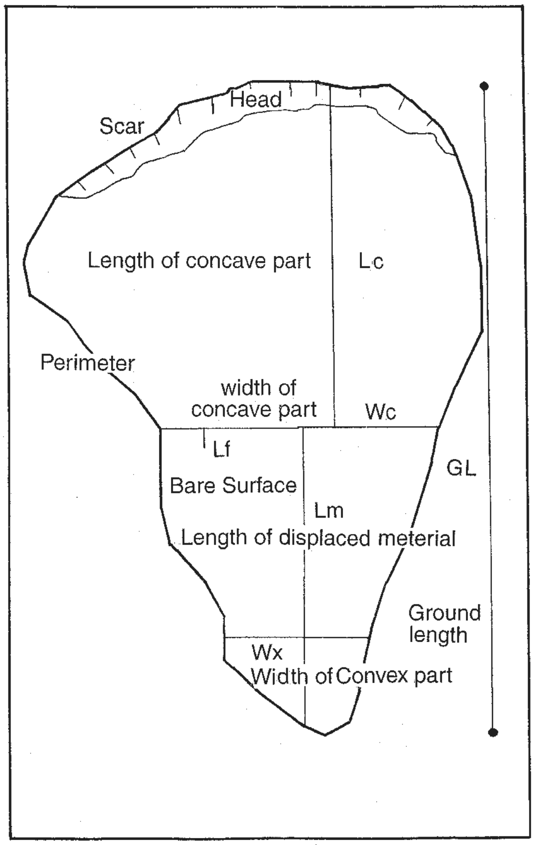

Figure 3. Different attributes of a landslide (based on Crozier, 1973)

Table 3: Estimation of Landslide Susceptibility index in selected sites, Raigad district

Place	Lat / Long (degrees)	Max height (m)	Slope (degree)	Average rainfall (mm)	Forest cover (%)	Average June temperature (°C)	Average January temperature (°C)	Temperature range (°C)	Landslide Susceptibility. Index or SI
Kudpan	17.87 / 73.55	797	2.03	3,311	42.1	26.2	20.5	5.7	0.625
Goldara	17.88 / 73.45	497	2.82	3,260	27.4	26.6	21.1	5.5	0.625
Kalavali	17.04 / 73.49	188	8.18	3,914	10.4	27.5	23.9	3.6	0.625
Parle	18.04 / 73.45	228	6.87	3,324	25.0	26.2	21.5	4.7	0.594
Lohare	18.1 / 73.46	347	5.49	3,290	25.9	25.9	21.4	4.5	0.563
Paithan	17.90 / 73.48	235	6.62	3,272	38.0	26.2	21.0	5.2	0.563
Kevnale	17.95 / 73.55	382	14.1	3,345	25.9	25.5	20.5	5.0	0.625
Dasgaon	18.1 / 73.35	166	8.37	3,263	26.3	26.7	20.4	6.3	0.594
Jui	18.07 / 73.35	102	7.32	3,263	25.0	26.8	20.5	6.3	0.594
Mhasala	19.20 / 73.1	220	2.57	3,199	40.6	28.4	22.7	5.7	0.531
Khandala	18.76 / 73.3	520	2.30	2,767	49.2	26.2	21.7	4.5	0.473
Khopoli	18.75 / 73.3	361	2.28	3,185	50.4	26.6	22.4	4.2	0.532
Uran	18.85 / 72.9	246	2.00	3,009	50.0	28.9	24.1	4.8	0.490
Kolad	18.41 / 73.2	346	2.30	2,910	24.3	27.2	22.3	4.9	0.468
Sarve	18.27 / 72.9	161	1.40	2,961	25.1	28.0	23.5	4.5	0.462
Velas	17.96 / 73.0	129	1.10	3,014	15.8	27.9	24.4	3.5	0.529
Birwadi	18.12 / 73.4	101	9.60	3,287	25.7	25.9	20.9	5.0	0.594

of the regression equation. The equation was further used to estimate the susceptibility index values for potential landslide sites on the basis of altitude, slope, rainfall, forest cover, maximum summer temperature and range of temperature which gives an idea of weathering intensity at the site (Birkland, 1974). The susceptibility index values were then interpolated by krigging interpolation method and the map showing landslide prone areas was obtained.

Results and discussion

Mass movements in various forms have been increasing in Raigad district of Maharashtra since the last few years and have become a frequent phenomenon in the foothill spurs and coastal region of the district.

An attempt is made here to prepare the data base for Raigad district to estimate the landslide susceptibility index of various sites using multivariate analysis technique. It was found that the technique is more or less reliable as it uses all the necessary variables very effectively to estimate susceptibility indices (Table 3).

Matrix of all the ranks and weightages assigned to various attributes at different sites along with their susceptibility index was used to compute the multiple regression equation. The regression equation obtained was:

$$y = 0.501 + 0.0035h - 0.0066s + 0.033p + 0.0038f - 0.0057m - 0.012r$$

(Where *y* denotes susceptibility index or SI, *h* is altitude of landslide crest, *s* is slope of the area, *p* is amount of rainfall, *f* is amount of forest cover, *m* is summer temperature and *r* is range of temperature). The equation explains 73.88% of variance in the data. Since this value of explained variance is quite satisfactory as a major strength of the equation, it could be used for the estimation of susceptibility index values for the other landslide prone sites in the district.

It can be seen from the map (Fig. 4) that the Western Ghat foot hill spurs and hill tops in the south eastern part of the district are more susceptible to landslides (SI > 0.65). The coastal lateritic areas to the south are relatively more susceptible (SI > 0.52) than northern coastal areas covered by basalt flows of aa type. The northern and north eastern hilly region of the district covered by pahoehoe flows also shows more than 52% susceptibility to landslides.

The morphological attributes computed by Crozier's scheme of classification are given in Table 2. These attributes bring out the morphological differences in landslides in Sahyadri and coastal areas in the district. The differences in terms of head height, ground length and areal spread indicated by perimeter are very striking. These morphological differences are also reflected in the process attributes like dilation, tenuity and displacement of the material.

There is a great variation in the landslides as regards the ground distance covered by displaced material from 112 m to 1,231 m. The material is comprised of basaltic boulders in the landslides near foothills of Sahyadri. The material of the slides is a loose, unconsolidated deposition of lateritic boulders and gravels in the matrix of lateritic clay in the coastal areas to the south. The exposed head of the landslide shows that all the material overlying the weathered basalt has slided down along with the trees.

The landslide scars are usually 5 to 8 m high and the displacement of lateritic material was seen up to a horizontal distance of 1,200 m. The thickness of the displaced material was not more than 3 m anywhere in the area. Along with the boulders and other materials, trees were also displaced from the hilltop. The down slope movement of the dislodged material is arrested by the forest cover on the toe slope, thus protecting the settlements below.

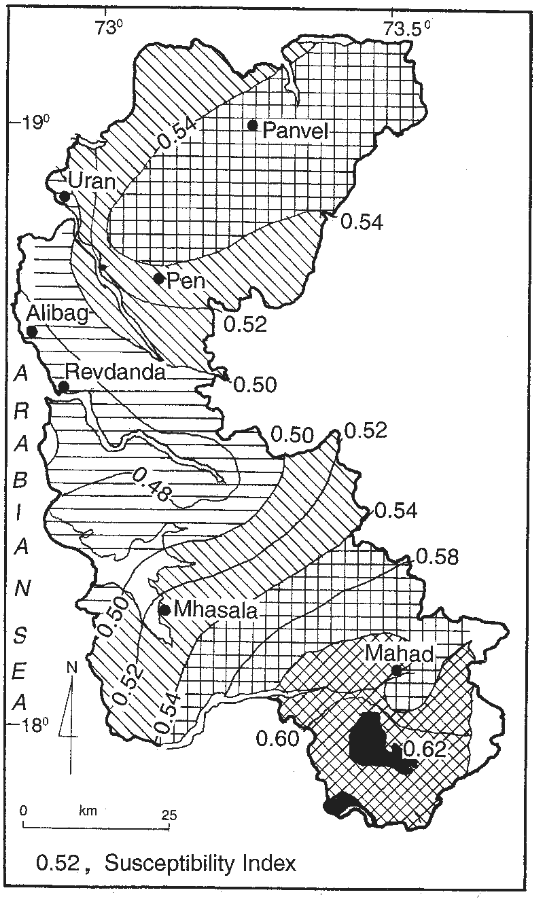

Figure 4. Landslide hazard zonation map of Raigad

The displaced material is usually unreformed. The head height is usually not more than 10 m. The lateral spread of the material is also not much due to hilly and rugged nature of the terrain characterised by numerous gullies and small river courses. All the landslides occurred in the altitude range of 100 to 800 m, involving basaltic regolith resting on hill tops and spurs to cause debris flow. Most of these landslides have left concave shaped scars near the head. The landslides in the region are oriented in N–W, NNW–SSE as well as E–W directions. Their height varies from 35 to 100 m (36 to 98 m).

Conclusion

The landslides in Raigad district of Maharashtra are the result of instability of slopes created by deforestation, road cutting and increase in the water content of weathered rocks and decrease in lateral support. The landslides in coastal areas show slightly more dilation than those in the Sahyadris. The displacement index is however more in case of landslides in the Sahyadris.

Acknowledgement

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