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Original Research Paper

Landslide Susceptibility Modelling of Aghanashini River Catchment in Western Ghats of Uttara Kannad District, Karnataka, India

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ABSTRACT

For landslide susceptibility mapping, this study applied frequency ratio to Aghnashini river catchment of Uttara Kannada district of Karnataka, India using Geographic Information System (GIS). Landslide locations were located in the study area by intensive field surveys; and a spatial database was constructed from topographic maps, soil type, forest cover, geology and land cover. The frequency ratio factor's rating for landslide susceptibility mapping was evaluated. Then the landslide susceptibility map was verified and compared with known landslide locations. The method can be used to reduce hazards associated with landslides and to landuse change planning.

INTRODUCTION

The movement of mass of rocks, debris or earth down the slope resulting in geomorphic alteration of earth's surface which contributes to landscape evolution is often referred as a landslide (Cruden 1991, Guzzetti 2005). Landslides could be due to the temporal conjunction of several quasi-static and dynamic factors (Wu & Sidle 1995, Atkinson & Massari 1998, Dai & Lee 2001). Quasi-static factors, such as geology, slope characteristics (gradient, slope aspect, elevation, etc.), geotechnical properties, long-term drainage patterns, etc. contribute to landslide susceptibility, while dynamic variables, such as rainfall, earthquakes, etc. tend to trigger the landslides.

Depending on quasi-static and triggering factors, landslides vary in composition as well as in rate of movement (0.5×10^{-6} to 5×10^{3} mm/sec) (International Union of Geological Sciences Working Group on Landslides 1995). Landslides in vulnerable zones in India have lead to large scale loss of life and property (International Federation of the Red Cross and Red Crescent Societies 2001). In this context, identification, mapping and monitoring of landslide susceptible zones and safer zones would help in the mitigation of landslides as well as in rehabilitation of victims. These vulnerable zones can be identified by both direct and indirect techniques based on the significance of causative factors in inducing instability. The assumption that is generally made in identifying landslide hazard susceptibility (LHS) regions is that occurrence of landslides follows past history in the region depending on geological, geomorphological, hydrogeological and climatic conditions (Hutchinson 1995, Varnes 1984). 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 aids in delineating unstable hazard-prone areas, which in turn provide baseline data for planners during selection of favourable locations for developmental projects. It also assists in implementing disaster mitigation strategies. Even if the hazardous areas cannot be avoided altogether, their recognition in the initial stages of planning will help to adopt suitable precautionary remedial measures.

Several studies have used frequency ratio to identify landslide susceptibility zonas across the globe (Jibson 2000, Luzi et al. 2000, Clerici et al. 2002, Donati & Turrini 2002, Lee & Min 2001, Lee et al. 2002, Lee & Choi 2003, Zezere et al. 2004, Lee & Pradhan 2007, Lee & Talib 2005, Lee & Sambath 2006, Vijith & Madhu 2007a, 2007b, Akgun et al. 2008, Pradhan & Lee 2009). However, only a few reports are available in Western Ghats region so far on landslides. The work on landslides pertain to Maharashtra (Nagarajan et al. 2000) or Kerala states (Thampi et al. 1997, Sankar 2005, Sekhar 2006, Vijith & Madhu 2007a, 2007b) done by few groups. However there is no report on landslide of Aghanashini river catchment area.

An attempt has been made here to identify and map landslide prone zones of Aghnashini river catchment using frequency ratio analysis.

STUDY AREA

The Aghnashini river catchment (74.32°-74.92° E and 14.26°-14.62° N), spreading across an area of 2985 km^2, is one of the important westerly flowing rivers of central Western Ghats (Fig. 1). This river catchment in Uttara Kannada district of Karnataka state is neither disturbed by major developmental projects or industries nor does it has a major town.

Elevation of the catchment vary from zero meters at sea level to 784 m at the Ghats with an average altitude of 396 m. 655 settlements exist in the area. The soil texture mainly clayey, gravelly clayey comprises of 85% of the catchment. The region is made up of migmatites and granodiorite, pink granite, quartz chlorite schist with orthoquartzite, metabasalt, greywacke, laterite and alluvium. Annual rainfall in the region varies from 3581±687 mm (Kumta), 2450±485 mm (Sirsi) and 2969±704 mm (Siddapur) (all the three rain gauge stations are just outside the catchment). Field investigations were carried out in the region during post monsoon months of 2007 and 2008 with 237 and 53 landslide locations being recorded respectively.

MATERIALS AND METHODS

Base layers of spatial data like soil, geology, topography, geo-morphology, land use, etc. were created from the information collected from the respective government agencies and supplemented with the remote sensing data. LANDSAT, ETM (Enhanced Thematic Mapper) data of spatial resolution 30 m of bands 2, 3, 4 and 5 (corresponding to green, red, infra red and near infra red bands of the electromagnetic spectrum) were used for land use and land cover (NDVI) analysis. Road networks with administrative boundaries were digitised from Survey of India (SOI) topographic maps (1:50,000 scale). Soil types and spatial extents were digitised from the 1:250,000 scale soil map of the National Bureau of Soil Sampling and Land Use Planning (NBSS & LUP). From soil map, texture, depth and permeability were derived.

Geomorphological variables such as lithology, lineament, and rock type were extracted from geological and structural maps of the 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 nine orientations (flat, N, NE, E, SE, S, SW, W and NW). The topographic features control the superficial and subsurface hydrological regime of the slope and the classes considered are alluvial plain shallow, back swamp, beach, butte, channel island, coastal plain, denudational hills, dissected pediment, inselberg, intermontane valley, lateritic plain shallow, pediment, pediplain shallow, plateau slightly dissecte, residual hills, river/stream, valley and valley fill shallow. These topographic features were taken from spatial layer provided by National Resource and Data Management Centre (NRDMS). The distance from lineaments and road was calculated by buffering at 90 m intervals.

Considering the spatial resolution of the data available, all data layers were resampled to 90m and total number of cells was 165042. Landslides corresponding to 237 and 53 occurrences in 2007 and 2008 respectively were used for computing LSI as well as for sensitivity analysis. Of the total number of landslides, 83% were due to road cutting.

Frequency ratio: Frequency ratio is the ratio of occurrence probability to non-occurrence probability for specific attributes (Lee 2005). In the case of landslides, if landslide occurrence event is set to x and the specific factor's attribute to y, the frequency ratio for y 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, lesser will be the relationship between a landslide and the specific factor's attribute.

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

$$LSI = \sum_{i=1}^{n} Fr_i$$

Where, LSI is Landslide Susceptibility Index, Fr is rating of each factor's type or range. The landslide hazard map was generated using the LSI values.

The model was validated by comparing the calculated probability values for different cells and their actual present condition of landslide. This was achieved using Receiver Operator Characteristic (ROC) curve analysis. The ROC curve is a plot of the probability of true positive identified landslides versus that of false positive identified landslides, as the cut-off probability varies. Equivalently, it is a representation of the trade-off between sensitivity and specificity. Sensitivity is the probability that a slided cell is correctly classified, and is plotted on the y-axis in an ROC curve. 1-sensitivity is the false negative rate. Specificity is the probability that a non-slided cell is correctly classified. 1-specificity is the false positive rate and is taken along the x-axis of the curve. The area under the curve represents the

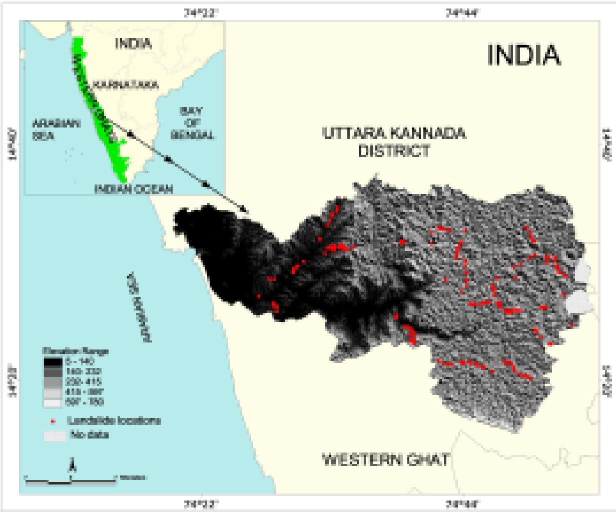

Fig. 1: Aghnashini river catchment, Uttara Kannada District, Central Western Ghats, India.

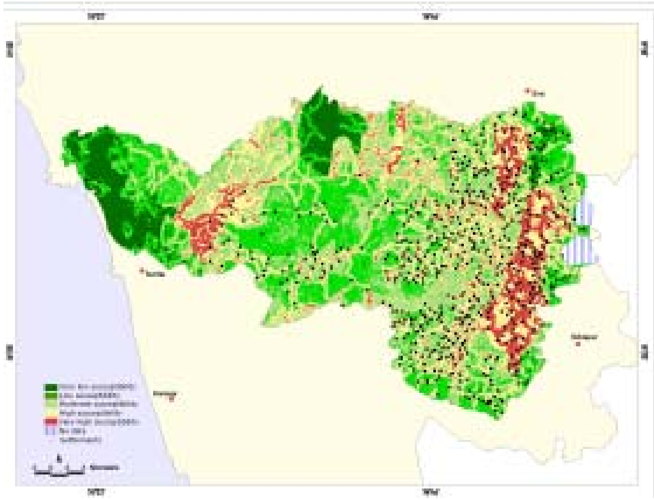

Fig 2: Landslide susceptibility zonation map of the Aginashini river catchment along with settlements.

probability that the model-calculated landslide susceptibility value for a randomly chosen slided cell would exceed the result for a randomly chosen non-slided cell.

RESULTS AND DISCUSSION

On developing landslide susceptibility map, area was divided into five categories, very high, high, moderate, low and very low based on the degree of vulnerability (Fig. 2). 16.95 % of the study area was classified as very high susceptible, 9.5% of the area as very low susceptible zone, 25.43% as high, 27% as moderate and rest i.e., 21.3% as low susceptible to landslide. The area in the upper side of Ghat has most of the very high susceptible zone as the region notices maximum anthropogenic activity. The regions with high intensity rainfall, slope in the range greater than 45° with dissected pediment, southwest aspect and geological parameters such as metamorphic rocks (greywacke/argillite and metabasalt) or volcanic/meta volcanic are highly susceptible to landslides in the area. Even soil like gravely clay soil with moderate erosion, moderately deep, and well drained has high landslide susceptibility in the study area.

Of the 655 settlements in the catchment, 18% and 41% of them fall into very highly and highly susceptible categories, respectively, while 2.44% of the area is categorised as very low susceptible regions. This shows that the area which is highly populated has the high probability of occurrence of landslide.

Table 1: Area under the receiver operator characteristic curve.

Area	Standard error [a]	Asymptotic signature[b]
.867	.017	.000

The test result variable(s): V2 has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased; a Under the nonparametric assumption; b Null hypothesis: true area = 0.5

Validation of the model: The area under the ROC curve can be used as a measure of the accuracy of the model. The ROC curve for the model developed is given in Fig. 3. The area under the curve is 0.867, which gives an accuracy of 84.6% for the model developed using weights of evidence (Table 1). The asymptotic significance is less than 0.05, which means that using the model to predict the landslide is better than guessing.

CONCLUSION

Frequency ratio method based mapping of landslide for Aghnashini river catchment showed that the region with settlements and highly undulating is very highly susceptible to landslide and the region near the coast and region with gravelly clay soils and strongly gravelly in the subsoil, which is associated with clayey soils, is very safe or least prone to landslide. The validation of the LHS map generated had an agreement of 86.7% between the susceptibility map and the field data.

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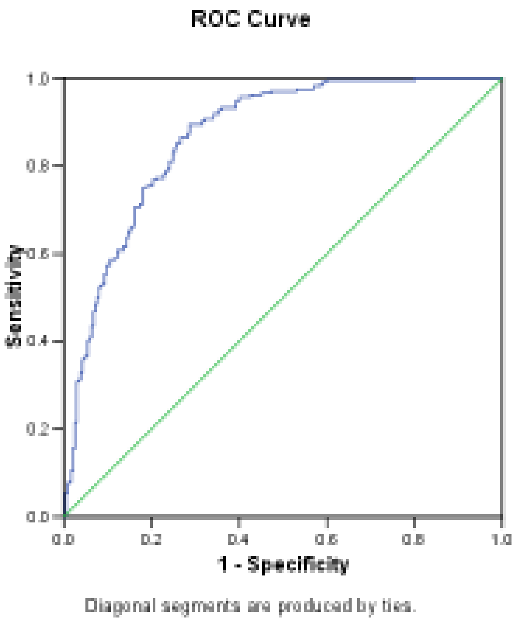

Fig 3: Receiver operator characteristic curve of the developed model. Diagonal segments are produced by ties.

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