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RESEARCH ARTICLE

Using InfoVal Method and GIS Techniques for the Spatial Modelling of Landslide Susceptibility in the Upper Catchment of River Meenachil in Kerala

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Abstract A GIS-based statistical methodology for landslide susceptibility zonation is described and its application to a study area in the Western Ghats of Kerala (India) is presented. The study area was approximately 218.44 km^2 and 129 landslides were identified in this area. The environmental attributes used for the landslide susceptibility analysis include geomorphology, slope, aspect, slope length, plan curvature, profile curvature, elevation, drainage density, distance from drainages, lineament density, distance from lineaments and land use. The quantitative relationship between landslides and factors affecting landslides are established by the data driven-Information Value (InfoVal) – method. By applying and integrating the InfoVal weights using ArcGIS software, a continuous scale of numerical indices (susceptibility index) is obtained with which the study area is divided into five classes of landslide susceptibility. In order to validate the results of the susceptibility analysis, a success rate curve was prepared. The map obtained shows that a great majority of the landslides (74.42%) identified in the field were located in susceptible and highly

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susceptible zones (27.29%). The area ratio calculated by the area under curve (AUC) method shows a prediction accuracy of 80.45%. The area having a high scale of susceptibility lies on side slope plateaus and denudational hills with high slopes where drainage density is relatively low and terrain modification is relatively intense.

Introduction

Landslides are one of the most visible destructive phenomena in hilly mountainous terrains and are frequently responsible for considerable loss of lives and money. The severity of the landslide problem worsens with increased urban development and change in land use in hilly tracts. Weak geological structures, steep and rugged land surfaces and extreme climatic conditions result in a high degree of fragility. Mitigation of disasters due to landslides can be successful only with detailed knowledge about the expected frequency, the character and the magnitude of mass movements in an area. Hence, identification of landslide-prone regions is essential for carrying out quicker and safer mitigation programmes, as well as future strategic planning of the area.

The landslide susceptibility zonation (LSZ) of an area aims at classifying the area into different landslide susceptibility zones ranging from stable zones to very high susceptible zones. Numerous efforts have been devoted in the last three decades to develop landslide susceptibility maps, with the explicit or underlying aim of contributing to improved management practices concerning mass movements. It is known that a landslide susceptibility map relies on a rather complex knowledge of slope movements and their controlling factors. Mapping of areas, which are not currently subjected to landsliding, is based on the assumption that future landslides occur under similar conditions as those observed in the past. Guzzetti *et al.* (1999) and van Westen (2000) summarized the current techniques used in the landslide susceptibility evaluation studies. The process of GIS-aided landslide susceptibility mapping at present involves several methods that can be considered as either qualitative or quantitative. Qualitative methods depend on expert opinions, and are often useful for regional assessments (Aleotti and Chowdhury, 1999; Carrara *et al.*, 1999; van Westen *et al.*, 2003). To remove subjectivity in qualitative analysis, various statistical methods have been employed for LSZ studies. Quantitative methods rely on observed relationships between controlling factors and landslides (Guzzetti *et al.,* 1999). Of late, there have been many studies on landslide susceptibility evaluation using GIS (Thampi *et al.,* 1997; Jeganathan and Chauniyal, 2000; Lee and Min, 2001; Clerici *et al*., 2002; Dai and Lee, 2002; Saha *et al.,* 2002, 2005; Ayalew *et al.,* 2004; Lana *et al.,* 2004; Suzen and Doyuran, 2004; Brenning, 2005; Fall *et al.,* 2006; Lee and Biswajeet, 2006; Akgün and Bulut, 2007; Vijith and Madhu, 2007a,b).

The study area is characterized by rugged hills with steep long side slopes on which rests the loose, unconsolidated soil and earth materials that have suffered a lot of damage due to landslides. Most landslides in the study area exhibit a climatic signal. Heavy precipitation during monsoon provides an important triggering mechanism causing landslides resulting in the development of new lower order streams on the slopes or widening of existing streams and subsurface seepages. The present study aims at producing landslide susceptibility zoning for upland catchment of river Meenachil in Western Ghats of Kerala (India), using GIS-based Information Value (InfoVal) method.

Study area

The study area, which forms the upland catchment of river Meenachil in Kottayam district, Kerala, India is enclosed between 9^0 37’ 00" to 9^0 52’ 00" North latitudes and 76^0 44’ 00" to 76^0 56’ 00" East longitudes, covering an area of 218.44 km^2 (Fig. 1). The two major rivers flowing through the area confluence in Irattupettah to form the river Meenachil, flowing through the rolling plains of Kottayam and finally debouches into the Vembanad estuary. The elevation varies from 40 m in the west to 1100 m in the east, above mean sea level. Crystalline rocks cover the study area and the major rock types are quartzite, charnockite, biotite gneiss, pink/gray granite and dolerite, in which charnockite occupies a majority of the area. The basic intrusive dykes cross-cut the study area into different blocks with a general trend of NNW-SSE. The area experiences high rainfall during the southwest and northeast monsoons. The measured rainfall varies from 350 mm – 900 mm / day. Temperature of the area varies from 20^0 – 34^0 and the maximum in the summer seasons.

Methodology for landslide susceptibility evaluation

Landslide susceptibility assessment was fulfilled using a data-driven approach: the Information Value

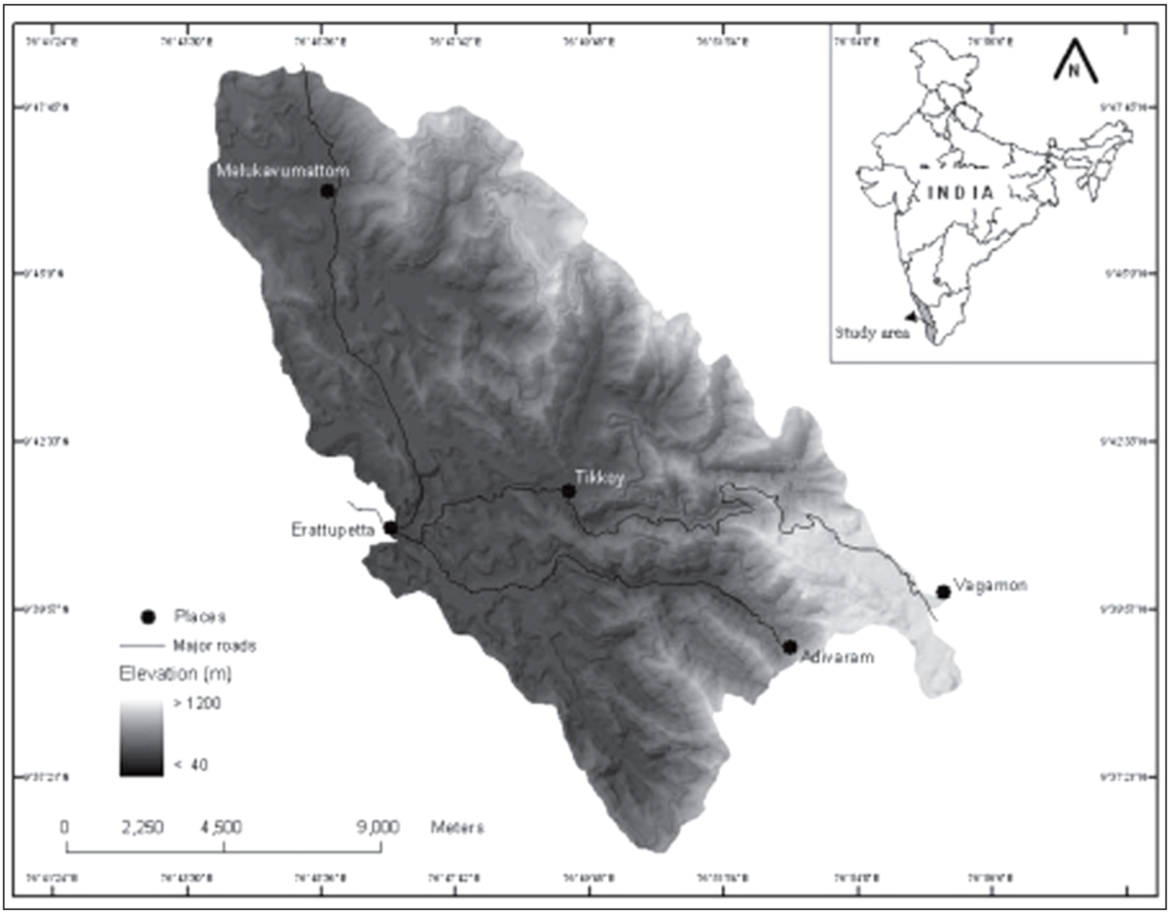

Fig. 1 Study area location map.

Method (Yin and Yan, 1988; van Westen, 1997; Wu *et al.*, 2000; Zezere, 2002). The Information Value Method (InfoVal) is an indirect statistical approach that has the advantage of assessing landslide susceptibility in an objective way. The method allows the quantified prediction of susceptibility by means of a score, even on terrain units that are not yet affected by landslide occurrence. Each instability factor is crossed with the landslide distribution, and weighting values based on landslide densities are calculated for each parameter class, as it happens with all bivariate statistical methods. The method implies prior definition of terrain units and the selection of a set of instability factors. In this method the information value for each parameter class is determined by the following equation *Wi* (Eq. 1):

$$Wi = \log\,(\text{Densclass} / \text{Desnsmap}) =$$

$$\log\left[(Npix(Si)/Npix(Ni))\Big/\left(\sum_{i=1}^{n} Npix(Si)\Big/\sum_{i=1}^{n} Npix(Ni)\right)\right] \quad (1)$$

where, *Wi* is the weight for the i^{th} class of a particular thematic map (i.e., plateau or side-slope plateau or escarpment in the thematic map “Geomorphology”), *Densclass* is the failure density in the factor class, *Densmap* is the failure density within the whole study area, Npix (*Si*) is the number of failed pixels in the i^{th} factor class, Npix (*Ni*) is the number of pixels in the i^{th} factor class, and *n* is the number of classes in the thematic map.

Selection and acquisition of thematic data base

While preparing a landslide susceptibility zonation map for a particular site, it is of primary importance to recognize the conditions that caused instability of the slope and the processes that triggered the movement (Popescu, 1994; Ercanoglu *et al.,* 2004). In the present study, the independent thematic data layers used in the analysis were derived from the existing topographic maps (scale 1:50,000) prepared by the Survey of India (SoI), remote sensing data (IRS P6 LISS 3), and field surveys. Table 1 shows the environmental variables used for the preparation of landslide susceptibility zonation map. The generated various thematic data layers have been resampled to 23×23 m^2 grid size to go with the nominal spatial resolution (23.5 m) of IRS LISS 3 image.

Table 1 Environmental attributes used for the preparation of landslide susceptibility zonation

Attributes	Definition
Geomorphology	Earth surface features
Slope	Change in elevation divided by horizontal distance
Aspect	Slope azimuth
Slope length	Distance between two slope gradients
Plan curvature	Contour curvature
Profile curvature	Slope profile curvature
Altitude	Height above sea level
Drainage density	Length of drainage in unit area
Distance from drainages	Buffer distance from drainage
Lineament density	Length of lineament in unit area
Distance from lineaments	Buffer distance from lineament
Land use	Utilization of the land for various purposes.

The most crucial information layer, one that represents former landslides, is a prerequisite to perform statistical analysis on the relation between the distribution of landslides and influencing parameters. It is now becoming universal that susceptibility mapping starts with the inventory of landslides (Ayalew *et al.,* 2004). In the present study, a series of systematic field surveys have been conducted with aim of locating previous the landslides. A total of 129 landslides of various dimensions have been identified from the study area and locations are mapped using the Global Positioning System Garmin MAP 76.

The geomorphological layer includes 9 classes (plateau, side slope plateau, escarpment, denudational hill, denudational slope, residual mounds, valley fill, and pediment and water body). This layer was drawn over the topographic map, taking in account information from the IRS P6 LISS III data.

A Digital Elevation Model (DEM) representing the terrain is a key to generate various topographic parameters, which influence the landslide activity in an area. The digital elevation model (DEM) portrays accurate representation of land surface which is suitable for medium scale mapping (Nagarajan *et al.,* 1998). Here, DEM has been prepared by digitizing contours at 20 m interval from the topographic map, interpolated and resampled to 23×23 m^2 pixel size. From this DEM, very significant derivative layers slope angle, slope aspect, slope length, plan curvature, profile curvature and altitude have been prepared. Slope data layer, an important parameter in slope stability considerations, comprises of five classes. Aspect is referred to as the direction of maximum slope of the terrain surface. It is divided into nine classes, namely, Flat, N, NE, E, SE, S, SW, W and NW. The slope length which determines the beginning of deposition was also calculated and is divided into five classes. The slope curvatures are an important variable that control the superficial and subsurface hydrological regime of the slope, erosion and deposition rate and soil characteristics. The plan and profile slope curvatures are divided into three classes, namely concave, flat and convex slopes. The layer altitude, which corresponds to the height above the mean sea level, is sliced into six classes.

In mountainous regions, drainage density provides an indirect measure of groundwater conditions, which have an important role to play in landslide activity (Sarkar and Kanungo, 2004; Saha *et al.,* 2005). For this reason, the drainage map (scale 1:50,000) has been digitized, computed on a larger grid size of 1000×1000 m^2 and classified into three classes (low, moderate and high) to generate the drainage density layer. The distance from drainage was calculated using the vectorised drainage lines by applying the distance function available in the ArcGIS. Six classes corresponding to distance from drainage were calculated at 50 m intervals.

Lineaments interpreted from the IRS P6 LISS III data was used to prepare the lineament density map and map showing distance from lineaments. The lineament density map was divided into three classes namely, low, moderate and high. The distance from lineaments was used to represent the area of influence of the structural tectonic features on the occurrence of landslides in the area and was divided into six classes.

The land use layer classifies the land use and vegetation type in a stratified general type mode. The land-use or vegetation cover plays an important role on the stability of slopes. Several researchers emphasized the importance of vegetation cover or land-use characteristics on the stability of slopes and they used these to assess the conditioning factors of the landslides. The classification takes into account the characteristics that were believed to be controlling factors for landslide activity in the study area. Land use was visually interpreted using IRS P6 LISS III multispectral image (in green, red, near-infrared and shortwave-infrared wavelength bands at 23.5 m spatial resolution) and verified in the field. The 9 classes identified and delineated are natural vegetation, grass land, barren land, rocky out crop, rubber plantation, tea plantation, cleared area, crop land, built-up-land and water body.

Lithology plays an important role in landslide activity. The lithology map was extracted from the available geology map prepared by the Geological Survey of India and cross checked in the field. The major rock types present in the study area are quartzite, charnockite, biotite gneiss, pink/gray granite and dolerite. In the present study the layer lithology was eliminated because, unlike in the Himalayan region, the basement lithology was not involved in the landslide process in the study area and a majority of the area (more than 94%) is covered with Charnockite of Precambrian age with minor variations and less weathering effect.

Landslide susceptibility assessment and validation of result

To evaluate the contribution of each factor towards landslide susceptibility, the existing landslide distribution data layer has been compared with various thematic data layers separately. The number of landslide pixels falling in each class of the thematic data layers has been recorded and weights have been calculated on the basis of InfoVal (Eq. 1).

The analysis of relationship between landslide occurrence and geomorphology shows that the maximum InfoVal weights are associated with feature classes like side-slope plateau followed by the escarpment and denudational hill, which indicate the high probability of landslide occurrence. All other classes indicate very low probability of landslide occurrence. In the case of slope angle, areas with slope more than 35^0 showing maximum InfoVal weights indicate high probability of landslide occurrence. But effect of the slope aspect was eliminated since all the directional slopes show equal distribution of landslides.

It was observed that, more number of slide occurrences were noted in the elevation ranges between 300m and 800m. These elevation ranges together with the convex slope curvatures indicate a high probability of landslide occurrence, while the influence of drainage density and the lineament density in the occurrence of landslides is very negligible. At the same time a distance between 100–200m from drainage lines and 300–450 m from the lineaments show high InfoVal weights indicating a high probability of landslide occurrence. In the case of the relationship between existing land use and landslide occurrence, more number of landslides are observed in the rubber plantations. Thampi *et al.* (1997) during their studies noted that, the incidence of slide occurrence was more in the time rubber replantation process and terrain modification for the mixed crop cultivation in the rubber plantations. Heavy rainfall associated with the monsoon seasons act as the triggering mechanism in the region.

The weights were assigned to the classes of each thematic, respectively, to produce weighted thematic maps, which have been overlaid and numerically added using the raster calculator to produce a Susceptibility Index (SI) map. The SI values thus produced are found to lie in the range from -12.26 to 6.34. Dividing these values into susceptibility classes was, however, not easy as there are no statistical rules which can guide the categorizing of continuous data automatically. The problem of changing continuous data into two or more categories always remains unclear in landslide susceptibility mapping. In the present study the cumulative frequency curve of susceptibility index values has been segmented into five classes representing near equal distribution to yield five landslide susceptibility classes, viz., non susceptible, less susceptible, moderately susceptible, susceptible and highly susceptible (Fig. 2). The landslide susceptibility classes, area covered in percentages and its description are given in Table 2 and the percentage distributions of the susceptibility classes are shown in Fig. 3.

The landslide susceptibility analysis result was tested using the set of landslides used to build the model. Testing was performed by comparing the known landslide location data with the landslide susceptibility map. Based on a given LSZ map, the cumulative percentage of landslide occurrences in various susceptibility classes ordered from highly susceptible to non susceptible can be plotted against the cumulative percentage of the area of the susceptibility classes. This curve, referred to as the

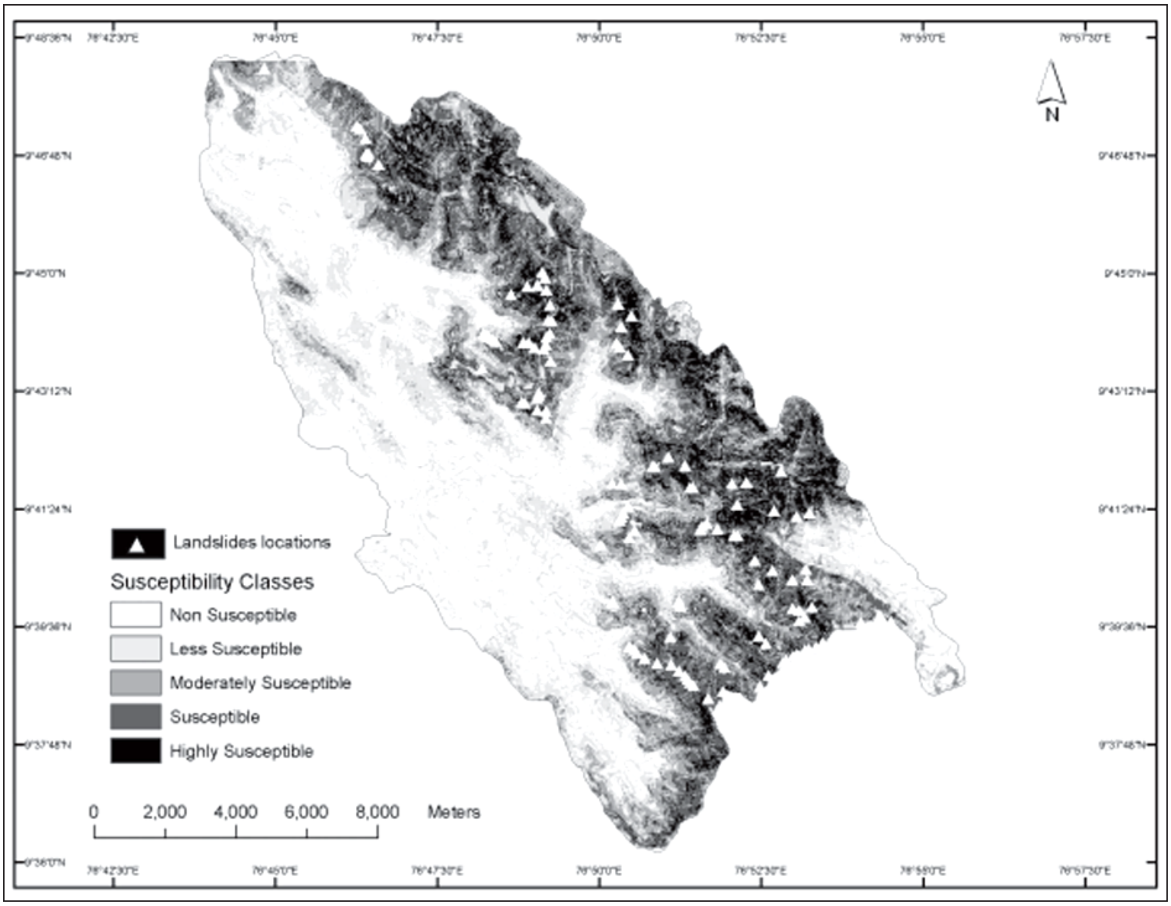

Fig. 2 Landslide susceptibility zonation map based on InfoVal model.

Table 2 Landslide susceptibility class definition by the Susceptibility Index (SI)

LS class	Area (%)	Susceptibility	Description
1	7.81	Highly Susceptible	Very high certainty of landslide occurrence
2	19.48	Susceptible	High certainty of landslide occurrence
3	19.46	Moderately Susceptible	Medium certainty of landslide occurrence
4	21.51	Less Susceptible	Very low certainty of landslide occurrence
5	31.74	Non Susceptible	No chance of landslide occurrence

success rate curve in the literature (Chung and Fabri, 1999, 2003; Lu and An, 1999; Remondo *et al.,* 2003) is used to select the suitability of a particular LSZ map. The success rates curve thus prepared using the comparison results are shown in Fig. 4 as a line graph and it explains how well the model and factor

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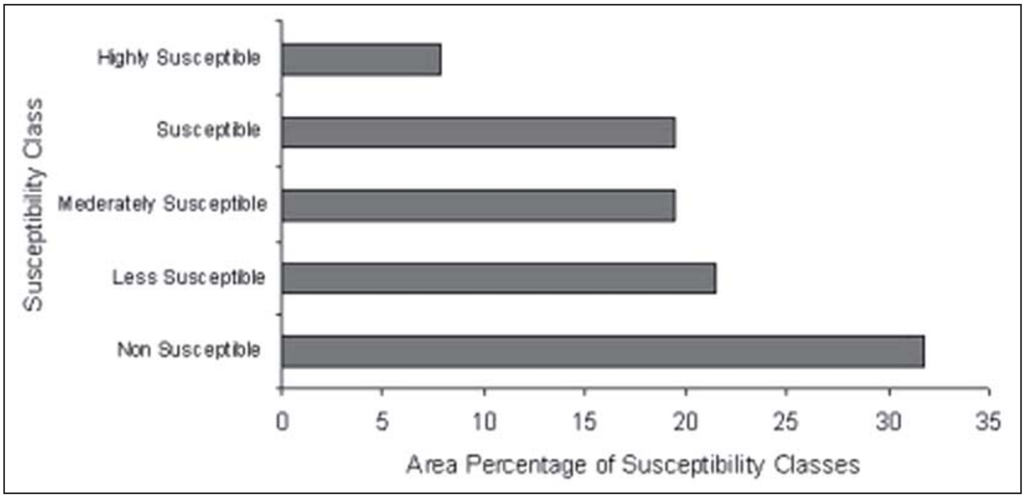

Fig. 3 The percentages distribution of the susceptibility classes.

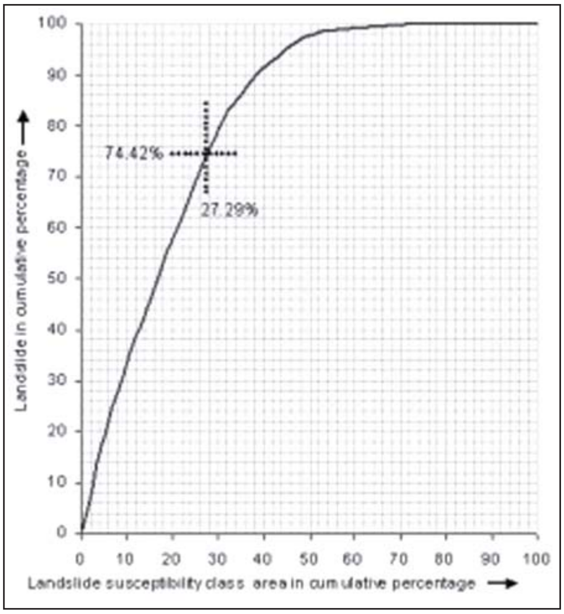

Fig. 4 Prediction performance of the InfoVal model.

predict landslides. The graph represents the potential capability of the InfoVal model. For example, the classes covering 27% of the highest hazard values manage to map 74% of all landslides that occurred in the study area.

The area under a curve (AUC) can be used to assess the prediction accuracy qualitatively (Lee and Sambath, 2006). To compare the results quantitatively, the areas under the curve were re-calculated as the total area is one which means perfect prediction accuracy. The area ratio calculated for Fig. 4 was 0.8045 and we could say that the prediction accuracy is 80.45%.

Result and conclusion

A landslide susceptibility zonation map depicts division of the land surface into zones of various degrees of stability based on estimated significance factors which are important in an area. The LSZ map prepared in the present study is the result of a combination of various factors responsible for landslide susceptibility, in which each factor has relative importance to a probable landslide activity. A reliable and accurate susceptibility map depends on the inclusion and proper determination of the role of these parameters. In this study, twelve landslide-controlling parameters, namely geo-morphology, slope, aspect, slope length, plan curvature, profile curvature, elevation, drainage density, distance from drainages, lineament density, distance from lineaments and land use/land cover, were considered.

The quantitative relationship between the affecting factors and landslides is achieved by the Information Value (InfoVal) method. The obtained information value weightage for the classes are summed up to produce the output map representing the spatial distribution of the landslide susceptibility zones. Further, the map was reclassified based on the SI values into 5 categories showing different landslide susceptibility classes. Most highlands together with the side slope plateaus, denudational hills with high slopes where relatively low drainage density and intensive agricultural practices are present fall into either highly susceptible or susceptible classes. As expected, relatively low lying areas are designated to be non susceptible and less susceptible. In the present study, the major climatic factor, rainfall is not considered in the analysis due to the lesser number of observation points. But it is observed that most of the landslides occurred during the southwest and northeast monsoon periods. The high rainfall intensity accelerated the sliding in the weak zones.

The landslide susceptibility assessment results need to be transferred to decision makers and local administrative authorities who should implement landslide loss-reduction strategies, in order to reduce the likelihood of occurrence of damaging landslides and minimise their social and economic effects. It is also hoped that local people can be made aware of the causes of landslides and the risks associated with prevailing management practices so as to utilise the environment in such a way that those risks are minimised.

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