Potential landslide susceptibility mapping using weighted overlay model (WOM)

Pravat Kumar Shit, Gouri Sankar Bhunia & Ramkrishna Maiti

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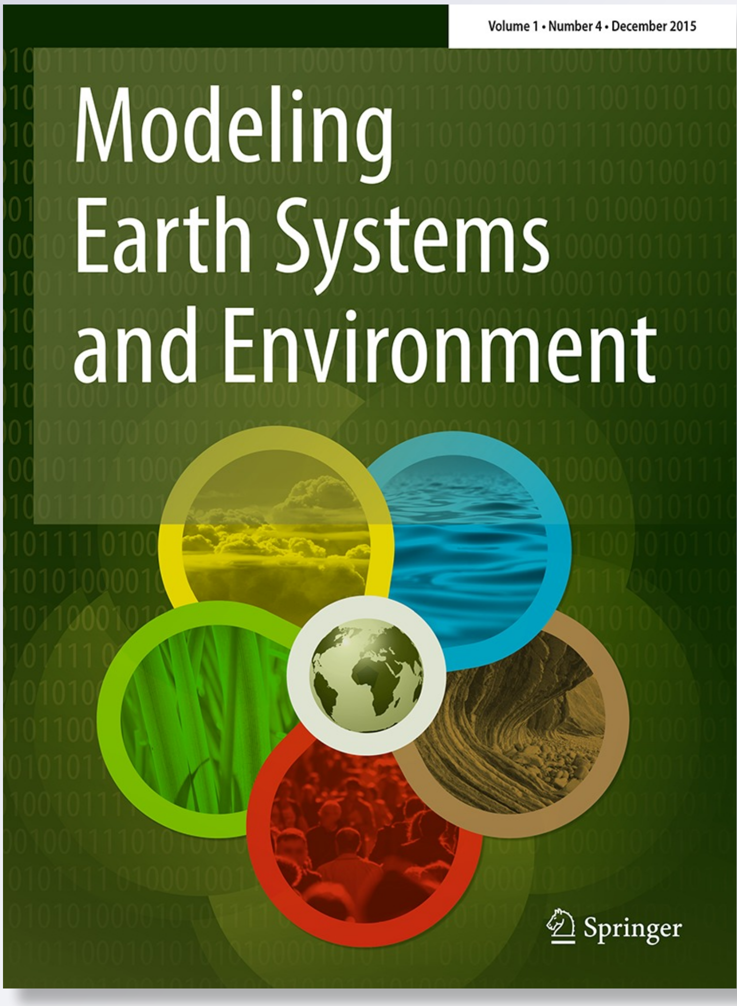

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SHORT COMMUNICATION

Potential landslide susceptibility mapping using weighted overlay model (WOM)

Pravat Kumar Shit[1] · Gouri Sankar Bhunia[2] · Ramkrishna Maiti[3]

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Abstract Present study presented a methodology for landslide susceptibility mapping using an integrated geospatial technology and ground based observation. IRS LISS-III satellite data, drainage, slope, aspect, geology, geomorphology and land use were integrated into GIS platform to delineate landslide susceptibility zone based on weighted index overlay method. The resulting landslide susceptibility map identified five zones of susceptibility of landslide hazards, viz very high hazard zone (10 %), high hazard zone (23 %), moderate hazard zone (25 %), low hazard zone (32 %), and very low hazard zone (15 %). The outcome was confirmed by relating with the landslide occurrences in different classes.

Keywords Landslide · Remote sensing · GIS · Weighted overlay index

✉ Pravat Kumar Shit
pravatgeo2007@gmail.com

Gouri Sankar Bhunia
rsgis_gouri@rediff.com

Ramkrishna Maiti
ramkrishnamaiti@yahoo.co.in

[1] Department of Geography, Raja N.L.Khan Women's College, Gope Palace, Medinipur 721102, West Bengal, India

[2] Bihar Remote Sensing Application Centre, IGSCPlanetarium, Bailey Road, Patna 800001, India

[3] Department of Geography and Environment Management, Vidyasagar University, Medinipur 721102, West Bengal, India

Introduction

The most devastating natural hazard in mountainous environment is landslides, that accounted for heavy loss and injury to human life and damaged property and infrastructure throughout the world (Raghuvanshi et al. 2014a; Pardeshi et al. 2013). EMDAT (2007, 2010) reported that landslide causes loss of around 1000 lives and property worth $4 billion annually. According to the Centre for Research on Epidemiology of Disasters, landslides and related processes have killed more than 61,000 people all over the world in the period between A.D. 1900 and A.D. 2009 (EMDAT 2007).

Landslide is a multifaceted process which is caused because of intrinsic and external parameters which elicits the process of landslide. Based on the preliminary stage of geo-technical investigations, Sharma et al. (1996) proposed varying grades of landslide susceptibility of Himalayan zone. Previous study described that the intrinsic parameters administer the constancy condition of the slope, like geological factors (lithology, soil type, structural discontinuity characteristics, shear strength of the material, groundwater condition), geometry of slope (slope inclination, aspect, elevation and curvature) and land use and land cover (Raghuvanshi et al. 2014b; Wang and Niu 2009). Varnes and IAEG (1984) outlines the term zonation as the procedure of dissection of land surface into parts and grading of these areas based on the degree of actual or probable hazard from landslides or other mass movements. Courture (2011) explained the concept of landslide hazard as division of land into somewhat homogeneous areas or domain and their ranking according to the degrees of actual or potential landslide susceptibility, hazard or risk or applicability of certain landslide related regulations.

In weighted overlay method, weights are allocated based on the relationship of landslide predominant factors with the landslide occurrence. Sarkar et al. (1995) proposed a methodology of landslide hazards zonation (LHZ) for Rudrapeayag district in Garhwal Himalayas, India and numerical weightages of predominant factors were assigned based on their associations to the landslide occurrence. Panikkar and Subramaniyan (1997) carried out landslide hazard assessment using GIS based weighted overlay method in the area around Dehradun and Massori of Uttar Pradesh, currently Uttarakhand in India. The study revealed that rapid deforestation and urbanization have triggered landslides in the study area. Several earlier studies have also been conducted to define the comparative significance of landslide causative factor in landslide occurrence (Parise 2002; Preuth et al. 2010; Cardinali et al. 2002). Nagarajan et al. (2000) reported that bivariate discriminant function for grading and weighting of landslide illustrative variables can be efficiently considered to generate landslide susceptibility map. A comprehensive study of the indigenous geological possessions and the inventory of past landslides in the same region, as well as the attainment of existing information on historical slope failures would pointedly improve the model. Till date, very less number of information is available in association with landslide susceptibility in Dehradun, Uttarakahnd which is considered to be worst affected zone for landslide. Geospatial technology will provide us the updated information accurately and timely in these inaccessible areas. Therefore, the present study is conducted to delineate potential landslide susceptibility mapping using weighted overlay method (WOM) and ground base observation.

Materials and methods

Description of the study area

Maldeota is located in Dehradun district, and extended between 30°21″N to 30°24″E latitudes and 78°06″ to 78°09″E longitudes, covering the part of south east Mussorie Hill and the Garhwal Himalaya, Uttarakhand. The study area covers approximately 30 sq km, covering village like Maldeota, Naryanpur, Manandrapur, Binvil, Sarkhat and Bhorkhandi (Fig. 1).

Geomorphologically, the study area is an undulating topography. Structural hill and flood plain are two major types of physiographic divisions. The average elevation is 1100 m above the mean sea level (msl) with medium to very steep slope. The river Bandal and its tributaries drains into the study area. Bandal River almost divides equally the whole study area and flows towards southern direction. Number of drainage is maximum in the southwest and northwest direction due to the steepness of the slopes (Fig. 2a). The soil of region is generally blackish mountainous type. However, in the floodplain zone the soil is mostly of sandy-loamy formation. The soil of the region is very fertile and suitable for agricultural activities. In some small patches peaty soil is also observed. The region is covered by open mixed jangle, basically Oak, Pines and Deodar or Mix-deodar. Forests are degraded by local people in Garhwal Himalayas (Gupta and Anbalagan, 1995). The average annual rainfall is 1800 mm and almost 90 percent is received during the monsoon period. The average temperature varies from 6° to 30 °C. Agriculture is the main source of income that involves more than 75 % of the population. The cultivated fields are scattered and are of very small size. Field is found in patches and on different heights and slopes and mostly terraced farming is in practice (Fig. 2b).

Methodology and data used

The region is covered by 53 J/3 (scale—1:50,000) of Survey of India (SOI) Toposheet. Toposheet has been registered based on Universal Transverse Mercator (UTM) projection system with World Geodetic Survey (WGS) 84 datum with nearest neighbor resampling method. Geology and geomorphology of the study area were collected from the Geological Survey of India (Table 1). Map to map registration process was used to rectify the thematic maps. Consequently, the spatial databases on geology and geomorphology have been generated in Arc GIS software v 9.1. IRS Resourcesat-1 LISS-III satellite data (Path/Row—96/50 23rd October 2008) was downloaded from the Bhuvan website (http://bhuvan.nrsc.gov.in/data/download-/index.php). The land cover were generated from LISS–III (Spatial resolution—23.5 m) satellite data based on supervised classification technique and maximum likelihood algorithm in ERDAS Imagine v9.0 software. For the reference, Google Earth was used to observe the land use type and for each class five training sites were collected. Kappa statistics was used to calculate the accuracy of classification results (Foody 2002).

A Digital Elevation Model (DEM) for the study area was built based an Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) elevation data. Slope and aspect map were prepared from the ASTERDEM in ArcGIS software v 9.1. Consequently, the drainage map was prepared from the topographical sheet and validated with the satellite data. A digital point database on previous landslide hazard map was generated. Spatial analysis tools were implemented within GIS environment with the use of ArcGIS software package v9.1. Spatial overlay analysis between landslide hazard zone and each of the thematic layers were performed. On the other hand, the information

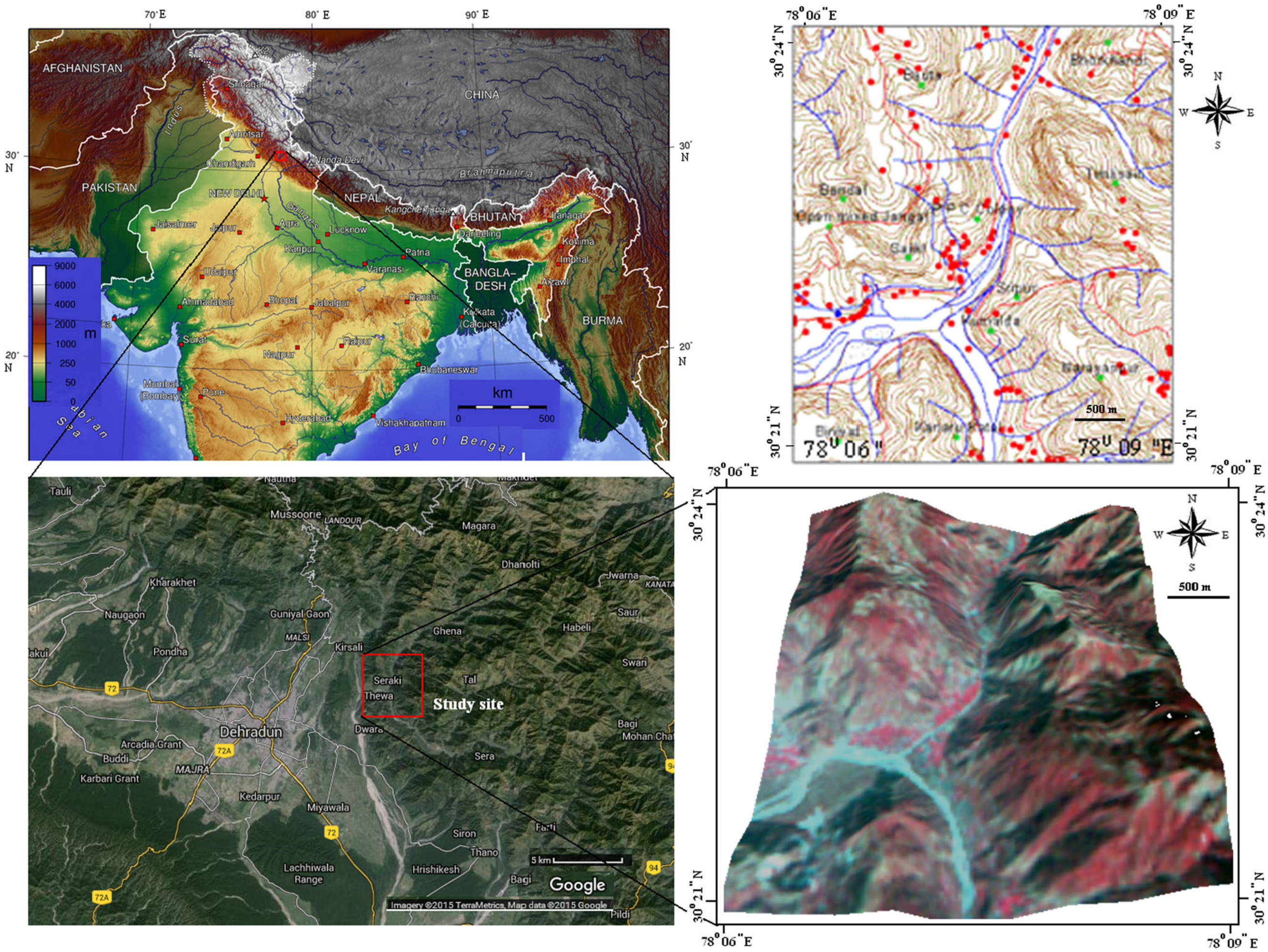

Fig. 1 Location of the study area (Maldeota and surrounding area, Dehradun, India)

on current landslide sites, composed during the ground investigation and deduced from the satellite data were also assimilated to attain a precise weighted score for each causative factor and their respective sub classes. Finally, the thematic layers were ranked based on the spatial correlation between variables and landslide affected areas.

The identification of potential landslide areas requires the factors to be organized based on their relative importance. This may be achieved by developing a rating scheme, in which the factors and their classes are assigned numerical values. A rating scheme was developed based on the associated causative factors for landslides surveyed in the field and on the knowledge by expertise on landslide causes from previous work (Sarkar and Kanungo 2004; Pareta et al. 2012; Rawat et al. 2015; Ghorai et al. 2015). In this study, the factors were assigned a numerical ranking on a 1–9 scale in order of importance. Weights were also assigned to the classes of the factors on 0–9 ordinal scale, where higher weightage indicates greater influence for landslide occurrence.

The weighted overlay method is a simple, direct, and adequate methodology for evaluations of potential landslide area (Erener and Uzgun 2008; Bachri and Shresta 2010; Intarawichian and Dasananda 2010; Ahmed et al. 2014). In this study five environmental factor maps were used for assessment of landslide susceptibility mapping. In order to combine these in performing the analysis, each cell from each map layer must be reclassified into a common preference scale, such as 1–9, with 9 being the most favorable. All thematic maps were integrated using Weighted Overlay Model (WOM) (Eq. 1).

$$s = \frac{\sum w_i s_{ij}}{\sum w_i} \quad (1)$$

where, W_i is the weight ith factor map, Si_j is the ith spatial class weight of jth factor map, S is the spatial unit value in output map.

These weighted factor maps were integrated into GIS platform using WOM analysis to prepare a susceptibility landslide hazard zonation (LHZ) map. The Fig. 3 explains

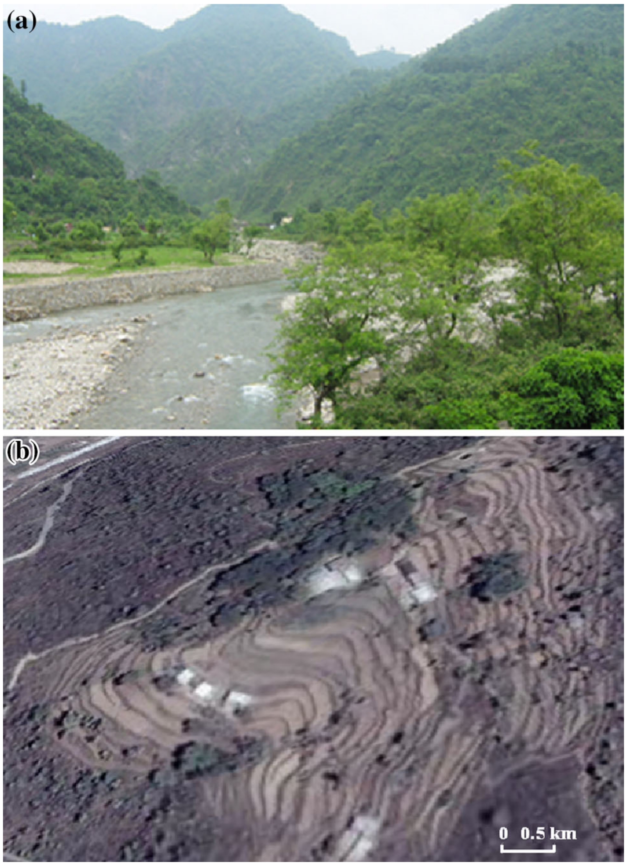

Fig. 2 **a** Bandal riverbed cultivated and forest area, **b** Terraced cultivation (Source—Google Earth)

the general methodology implemented in the present study for WOM method based Landslide susceptibility zonation Mapping.

Result and discussion

Drainage

Drainage density appears to be the most important, promising and useful variable in morphometric analysis of drainage networks, as it is related to the dynamic nature of the stream segments and area. The lower values indicate old stage and higher values indicate early mature to youth of geomorphic development. Because, drainage density in particular may be controlled to varying degrees by any of these thresholds, and each different threshold may produce a different functional relationship between drainage density and factors related to climate, geology, and relief (Tucker and Bras 1998). Howard (1997) report that a detachment-limited model in which the relationship between drainage density and mean erosion rate depends on the dominant hillslope transport process through landslide and the presence or absence of a threshold for runoff erosion.

Geology

Geologic map of Maldeota and surrounding area is shown in Fig. 4b. Tectonically, this Valley comprises two separable major lithostratigraphic units—the Garhwal Group and the Central Crystalline Group (Gupta et al. 1999). The rock types, of which the study area falls is Pre-Tertiary rock, belong to Pre-Crembrian age. Folded structures with some minor lineament are also seen in the region. Besides, the Main Boundary Thrust (MBT) is passing through the extreme eastern part of the Maldeota area; therefore, this area is tectonically very active (Prakash et al. 2015). The extreme north-eastern part of the study area is covered with the Krol-Shale and in the extreme south-western part is covered by the Damta group of rocks. Geologically, the area is divided into four groups of rocks as sandstone, quartzite, shale and slate and they were assigned the scores of 4, 6, 7 and 5 respectively. Consequently, the weightages of these sub-variables were multiplied with the corresponding ranks 9.3 of the geology layer.

Land use/land cover characteristics

Present LULC map was prepared from IRS 1C LIIS-III satellite data. Topographical map and Google earth were used for the visual interpretation of satellite data. LULC map of the study area comprises of six classes (Fig. 4b). These are agriculture, river, settlement, mining area, open forest, barren land (Fig. 3c). Out of total area the forest covers about 60 percent areas, followed by agriculture. The forest area is mainly present on the hill top and the foothill regions. More than 75 percent population of the study area is engaged in agriculture. The agricultural fields are seen mainly in the flood plain regions of the Bandal Nadi. In the river valleys and plain area cluster type of settlement are seen, while in the hilly tracts sparse types of settlement prevail. The study also reveals that about only 10 percent area is covered by settlement of the study area. The river valleys are composed of new alluvium and are very suitable for the cultivation of paddy. It is mentionable that the famous *Basmati Rice* is cultivated in the Bandal river valley and some small patches of the area.

The sub classes of LULC were allocated the scores of 1, 2, 2, 9, 7 and 8 as agriculture, river, settlement, mining area, open forest, barren land respectively; and these sub-variables were multiplied with the corresponding ranks 7 of LULC layer (Table 2).

Geomorphology

Geomorphological aspect is the one of the most significant factors for landslide. The study area comes under the typical Himalayan physiography and it processes a very

Table 1 Data layers of the study area

Data layers	Data type	Sources of data
Geomorphology	Polygon coverage	Geological Survey of India
Geology	Polygon coverage	Geological Survey of India
Slope (%)	Polygon coverage	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data
Aspect	Polygon coverage	ASTER data
Drainage	Line coverage	Topographical sheet, Survey of India (Scale 1:50,000), Satellite data
Land use/land cover	Polygon coverage	IRS Resourcesat-1 LISS-III (Toposheet No. H44G04 23oct08)
Landslide inventory	Polygon coverage	IRS Resourcesat-1 LISS-III, Toposheet, Google Earth and field survey data

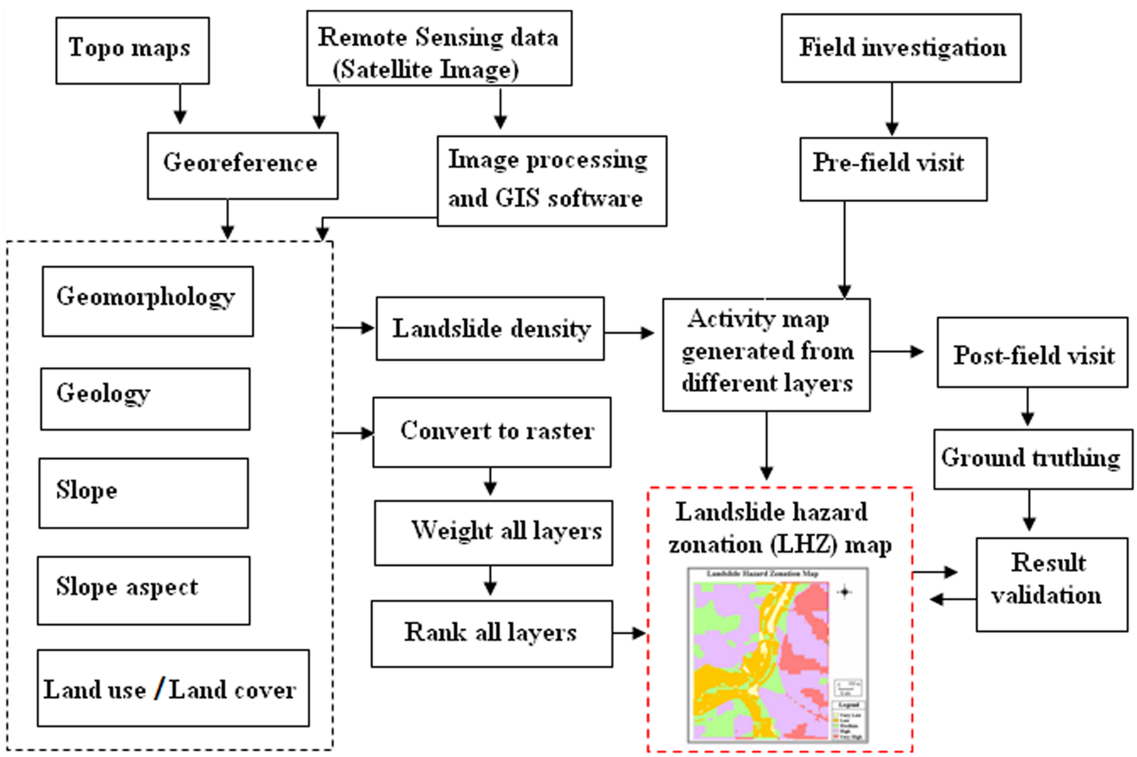

Fig. 3 Methodology flow chart of the study area

rugged and mountainous terrain with deep narrow valleys along with erosional and depositional features. High peaks are present on the north-east part of the study area. The area is characterized by the structural mountains, denudational plain and flood plain area (Pham et al. 2015). The entire area is dissected into numerous small ridges, spurs; deep 'V' shaped valleys and others erosional features. The area is mainly dominated by gully erosion, scarp, perennial and ephemeral channel, flood plains and river bank erosions and landslide zone (Pham et al. 2015). Gully erosion was seen at tributary source region, because tributary source region are moderated slopping area.

The geomorphology layer had 6 sub variables namely—structural hill, flood plain, bank erosion, gully erosion, riverine plain, and scarp (Fig. 4d) and were assigned the scores of 7, 1, 4, 5, 3 and 5 (Table 2). Successively, the scores of these sub-variables were multiplied with the analogous weightage 8.5 of the geomorphology layer and thus these six groups have respectively amassed the landslide susceptibility. Landslide zone we are found mainly at Bandal channel sides.

Slope and aspect

The relief aspects of Maldeota and its surroundings have been analyzed on the basis of contour map prepared from the ASTER DEM, with an interval of 20 m. On the other hand slope constitutes a very important parameter in landslide hazard zonation studies, since its stability form the basis for the frequency and intensity of hazard study.

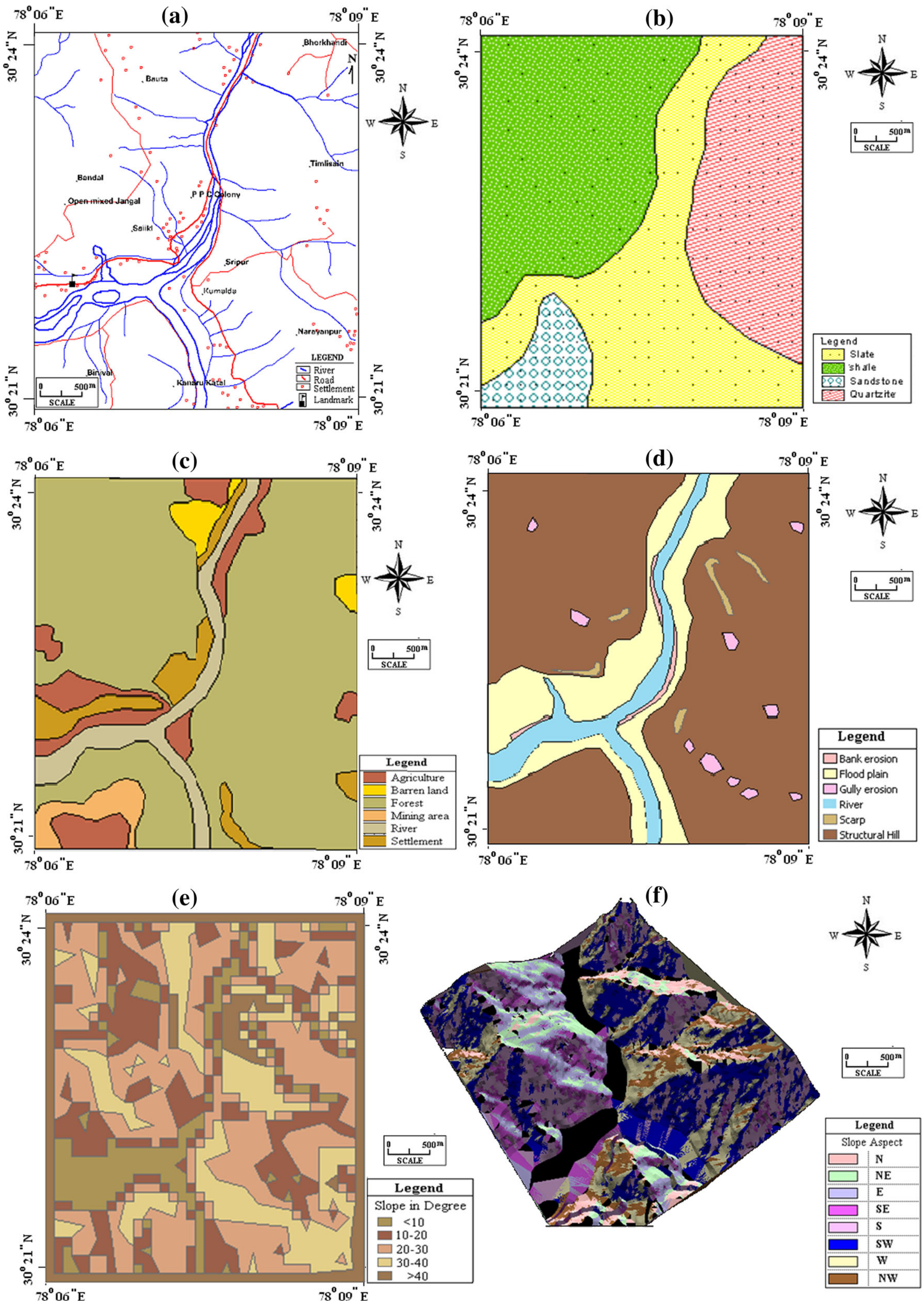

Fig. 4 Landslide factor maps. **a** Drainage and settlement map, **b** geological map, **c** land use, **d** geomorphology map, **e** slope map, **f** aspect map

Table 2 Assignment of ranking and weightage values of different thematic layers

Parameter	Ranks	Category	Weight
Geomorphology	8.5	Structural Hill	7
		Flood plain	1
		Bank erosion	4
		Gully erosion	5
		River	3
		Scarp	5
Geology	9.3	Quartzite	4
		Sandstone (grey-wacke).	6
		Shale	7
		Slate	5
Slope	9.5	<10°	1
		10–20°	3
		20–30°	6
		30–40°	8
		>40°	9
Slope aspect	5	North-facing (337.5–22.5)	1
		NE (22.5–67.5)	3
		East-facing (67.5–112.5)	5
		SE (112.5–157.5)	6
		South-facing (157.5–202.5)	9
		SW-facing (202.5–247.5)	6
		West-facing (247.5–292.5)	5
		NW (292.5–337.5)	2
Land use	7	Agriculture	1
		River	2
		Settlement	2
		Mining area	9
		Open forest	7
		Barren land	8

Particularly, in the hilly region the chance of occurrences of landslides hazards is more in higher slopes. In the study area slope varies from 0 to more than 60°. The current slope map is divided into five categories in Fig. 4e; <10, 11°–20°, 21°–30°, 31°– 40° and >41°. The scores of these sub-variables were multiplied with the analogous weightage 9.5 of the slope layer.

Aspect is very important in any landslide hazards Zonation mapping. Aspect the study area was divided into eight categories (Fig. 4f) and multiplied with the corresponding weightage 5. In general, south-east and some pockets of south-west slopes are influential in creation of landslides due to availability of moisture during rainy season. As such, tectonic events as a result of lengthier moisture resilience during warm seasons, which is concomitant with formation of fine-grained accumulations that have the maximum susceptibility of landslide.

Landslide inventory

Landslide in the image showed spoon shaped topography. Based on satellite imagery and field visit 18 landslides were observed and shown in Fig. 5 of the Maldeota and surrounding area. Maximum numbers of landslides were observed along Bandal channel sides and most of them were triggered due to the July 2008 excessive rainfall event which caused loss of lives and property.

Potential landslide hazard map

The scheme was suitably modified based on the literature using different combinations of weights. The rating scheme is given in Table 2. Landslide hazard zonation (LHZ) map was prepared by weighted overlay index (WOI) method on GIS platform. LHZ map was divided into five zones of susceptibility of landslide hazards, viz very high hazard zone (VHHZ), high hazard zone (HHZ), moderate hazard zone (MHZ), low hazard zone (LHZ), and very low hazard zone (VLHZ). The landslide hazard zonation (LHZ) sharing five zones were shown in Table 3. Figure 6 clearly shows that 15 % of the study area has a very high landslide hazard potential and 10 % area has very low hazard potential. Whereas, the areas that account for low hazard (LHZ), medium hazard (MHZ), and high hazard (HHZ) were 23, 25 and 32 % respectively. Majority of the study area (9.6 km^2) has high hazard (HHZ) potential. High hazard zones are mostly concentrated in the north-western and south-eastern parts of the study area. Very high hazard zone (VHHZ) covers mostly the north-eastern part of the study area with area coverage of about 4.5 km^2. Medium hazard (MHZ) zones are relatively scattered and cover about 7.5 km^2 of the study area. Areas with low (LHZ) and very low hazard (VLHZ) potential zones are mostly concentrated along the Bandal river and cover areas of about 6.9 and 3.0 km^2 respectively.

In general, the degree of landslide hazard decreases with increasing distance from drainage and settlements etc. Slope and aspect is very important in landslide hazards zonation mapping, since its stability form the basis for the frequency and intensity of hazard. Steeper the slope the more the tendency for instability will be (Hoek and Bray, 1981). Particularly, in the hilly region the chance of occurrences of landslides hazards is more in higher slopes. In the present study steep slope (>30°) are formed mainly by rocks, with less vegetation which are more prone for instability where 70 % landslide occurred. Landslide is maximum when the slope angle is between 35° and 40° which is corroborated with the earlier study (Panikkar and Subramaniyan 1997; Pham et al. 2015). Besides, bare soils, crops and grass cover have the highest frequency of slope failure as slope increases. On the other hand, landslides

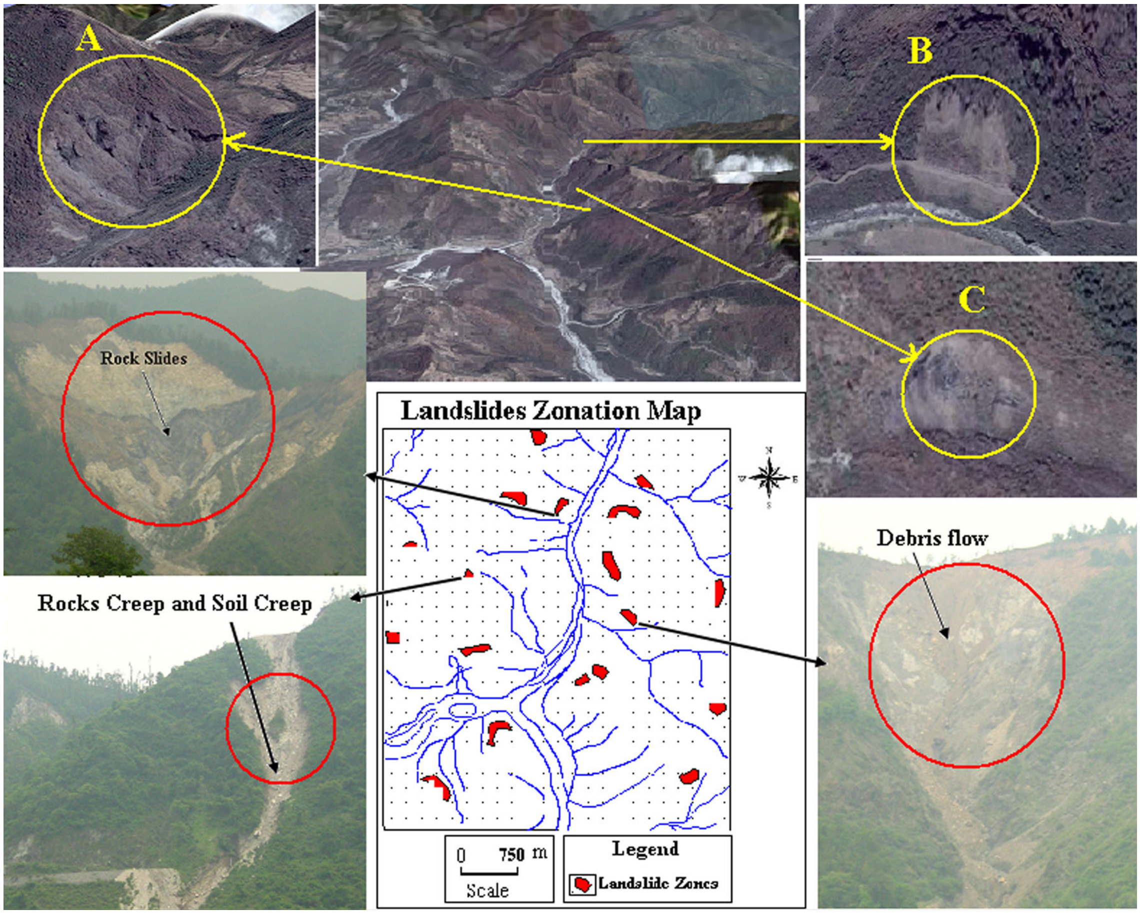

Fig. 5 Landslide map of the study area

Table 3 Percentage area of risk zones

Susceptibility class	Area (km^2)	Area percentage	Cumulative area percentage
Very low hazard zone	3.0	10	10
Low hazard zone	6.9	23	33
Medium hazard zone	7.5	25	58
High hazard zone	9.6	32	90
Very high hazard zone	4.5	15	100

were observed toward east and south-west directions of slope facing. The possible reason for this may be related with the groundwater flow direction. Several numbers of springs were present in the slope facing south-west directions, which perhaps indicates the possible groundwater flow toward south-west direction. In general, shear stresses on the slope material proliferate with growing of slope degree and it is predictable that landslides will ensue in the sharpest slopes. Tension cracks may be twisted as a consequence of a growth in anxiety on the back of the slope due to vicissitudes in topography and the diminution of weight (Yalcin, 2008).

Hoek and Bray (1981) observed that groundwater plays an important role in slope instability condition. High frequency of landslides toward south-west (30 %) directions very well demonstrates the role of groundwater in inducing instability to slopes in the study area. 30 % of the landslides have occurred in the elevation class between 600 and 800 m. Poor irrigation or inadequate cultivation practices on such terraced land may lead to excessive recharge of groundwater which may result in instability of slope (Raghuvanshi et al. 2014b). Cultivated land showed high frequency (22 %) of past landslides. Again this may be related to poor irrigation practice which might have resulted into instability of slopes. Consequently, agricultural land in the study area mostly comprises of alluvial soils which are prone for instability (Anbalagan 1992; Raghuvanshi et al. 2014a) that is why a

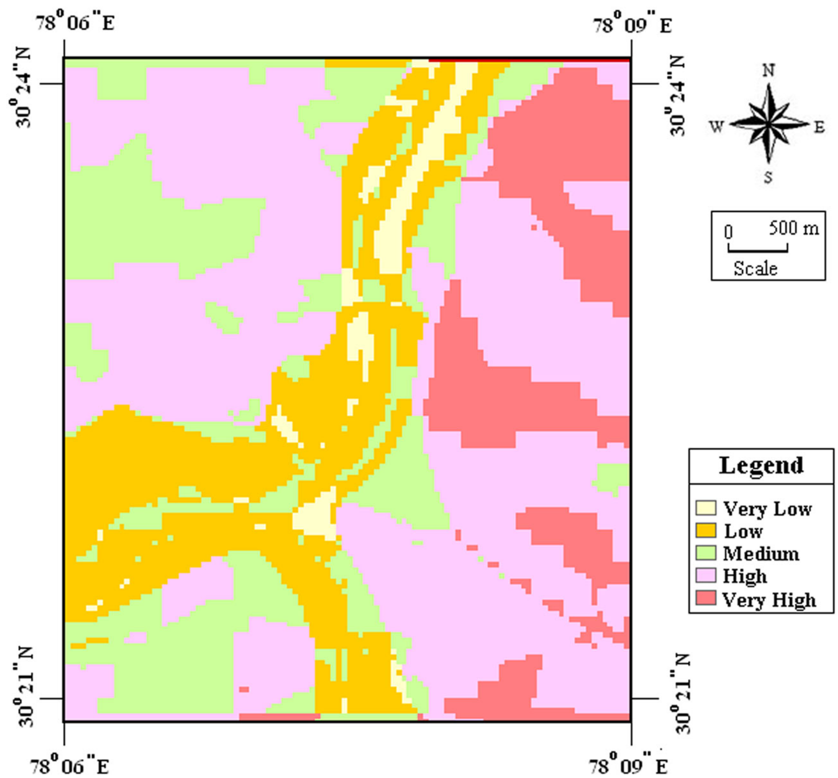

Fig. 6 Landslide hazard zonation (LHZ) map

high frequency of landslides was observed in this class. The shaping of the present topography, relief and landforms are significantly predisposed by the neo-tectonics which possesses the hilly environment prone for landslide. GPS locations were interrelated with landslide susceptibility zones (Fig. 5).

Conclusion

This present study brings out a definite relationship between remote sensing and GIS techniques, which play a significant role in Landslide Hazard Zonation Mapping (LHZM). WOI is an effective method in plotting a vast area where earlier records of landslides are not accessible or the terrain is unapproachable. Five parameters relating to landslides were nominated after thorough literature survey and weightages and scores were given on the basis of knowledge about the terrain and the visibly esteemed influence of various terrain variables over landslides. The geospatial technology based analysis has directed to the documentation of landslide susceptible zones which were further validated with field study. Despite the achievements in this research, there are currently several limitations that need further improvement in the future. These results can be used as base data to support slope managing and land use planning, but the approaches used are effective for widespread planning and assessment tenacities.

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