GIS-Based Landslide Hazard Mapping Along NH-3 in Mountainous Terrain of Himachal Pradesh, India Using Weighted Overlay Analysis

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Abstract. Landslide is the one of the most devastating geohazard in mountainous terrain that accounts for injury to human life and destruction in the property. It is a major concern due to an increasing trend of frequency of events especially in Himalayas. The present study presents a methodology for mapping of landslides in geographical information system (GIS) environment using remote sensing techniques. The methodology integrates the ground-based observations with geospatial technology. SRTM satellite dataset, slope aspect, slope degree, curvature, lithology, landuse/landcover and drainage density has been incorporated into GIS to demarcate the landslide hazard zones using weighted overlay method (WOM). The results of the study divide the area into very low hazard, low hazard, medium hazard and high hazard and very high hazard zones conferring to the severity of the landslides. The output map produced from the current study helps to plan and execute appropriate landslide mitigation strategies concerned in landslide risk reduction. Moreover, the study may also be beneficial for planning land-use activities in the study area.

Keywords: Geohazard · Landslides · Geospatial technology · GIS Mitigation

1 Introduction

Landslide is a variety of earth processes in which large masses of earth and rock suddenly moves downward. The process becomes geologic hazard when material involved in this is capable of causing significant impact on human life and environment. Himachal Pradesh is highly landslide susceptible state zone due to its steep mountainous terrains. The frequency of landslide events is more numerous than other disaster in the state. Unplanned land, swift urbanization and increase in population density are main triggering factors in the region. Occurrence of landslides is due to number of triggering and determining factors. Therefore, analysis of these factors requires quantification and identification. Landslide zonation depicts the information of slope failures and used for preparing evacuation, prevention, and mitigation plans to

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avoid severe loss of life and environment. The approach used in current study makes the contribution to the different criteria clearly and for various other criteria's with precise relative weighting system. Hence updated and accurate landslide hazard zones ensure safety to the property and people to avoid massive economic loss.

2 Materials and Methods

2.1 Description of the Study Area and Its Geological Settings

The Himachal Pradesh lies in Western Himalayas with a vast young terrain, which is morphologically active. The study area is located in Mandi and Kullu districts of Himachal Pradesh, and extended between latitudes 31°42′29″ and 31°57′28″ N and longitudes 76°55′52″ and 77°6′33″ E, covering the part of mid Himalayas (Fig. 1). The study area selected covers approximately 165.45 km^2 along National highway-3. Elevation ranges from 770 m to 1230 ms along the highway. The average temperature in the area falling under the Mandi region during summer ranges between 18.9 °C to 39.6 °C and between 6.7 °C to 26.2 °C in winters season. While in Kullu region, it ranges from 24 °C to 34 °C in summer and −4 °C to 20 °C in the winters. The study area is mostly monsoonal type, occurs in the months of June, July and August, having an average rainfall of 4 inch and 5.9 inch monthly in region of Mandi and Kullu respectively. The river named Beas flows along the selected highway in the whole section of the study area. Cultivated fields, which are mainly of small sizes and scattered type traced in the area. The field are in patches and are on variable slopes and heights. The terraced farming is mainly used in agricultural practices in the study area.

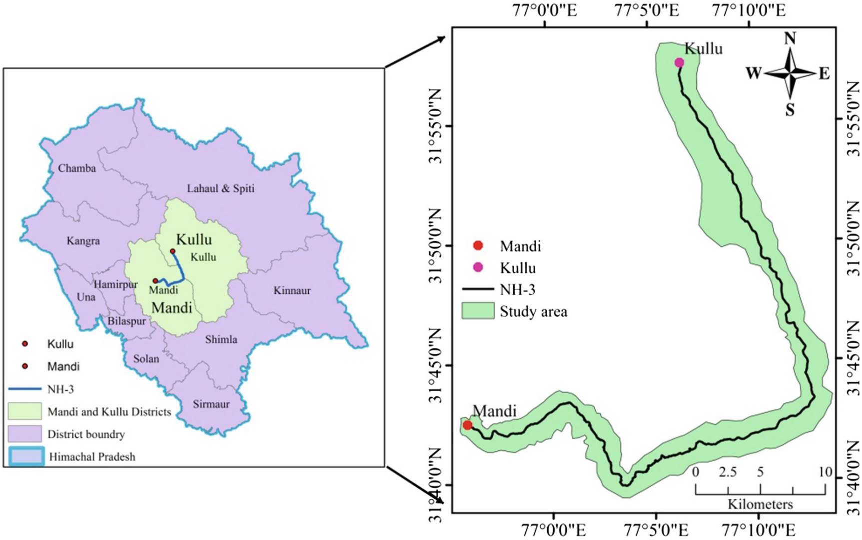

Fig. 1. Location of the study area

The study area comes in zone V under seismically active districts as per State Disaster Management Authority (SDMA). In past years, the severe earthquake events took place in the region. The area tracks the strike of main thrust plan along with steep inclined beds. Major rocks of the study area belong to gravel dominant followed by Batal formation. The geological sequence of these rocks is lower Proterozoic to upper Proterozoic. The majority of soil type extracted is of coarse loamy soil. The study area experience massive pressure due to development activities in the region. Selected area falls in lower Himalayan tectogen embrace between Main Central Thrust (MCT) and the Main Boundary Thrust (MBT). The Major portion of the study area comes under alluvium formation followed by Aut formation, which consists of light to grey dolomite with purple and grey limestone.

2.2 Data Used and Methodology

The study area is covered by Survey of India (SOI) topo-sheets 53a14, 53e02 and 53e01 (Scale-1:50,000). Geological setting of the study has been collected from Geological Survey of India (1:250000). Subsequently, by geo-referencing tool in GIS, the maps were digitized in Arc GIS software. Digital Elevation Model (DEM) for the study area was build based on SRTM having 30 meters-mesh of spatial resolution was used to produce maps of the study area. Intensive fieldwork has been done to generate landslide inventory and land-use/land-cover maps. Their validation is checked from the Google earth images as well. Drainage pattern was delineated by using the toptsheets from the survey of India and Google images along the section of the case study road. A 30 × 30 m grid cell size was used to convert thematic layers into raster format. Table 1 gives the data types and their sources used in current study.

A digital database on previous landslides was generated. Consequently, spatial analyst tools in GIS environment were executed in Arc GIS software. Spatial overlay analysis between each thematic layer and landslide hazard zone were performed. Further, to achieve a accurate weighted score for each causative factor and their respective sub classes, the information on existing landslide sites, which were extracted from satellite images and intensive field, were also comprehended. Subsequently, Ranking in executed to the thematic layers based on relationship between landslides affected area and variables.

The weighted overlay method (WOM) is a direct and adequate approach for assessments of potential landslides area (Sarkar et al. 1995; Ahmed et al. 2015; Roslee et al. 2017). It is a multiple criteria decision-making process. In this study, various environmental factors were integrated to divide the area into the zones using raster weighted overlay analysis. In this analysis, the cells of the feature class of thematic layer is allotted a numerical value to combine mathematically for producing a new value to the corresponding cell in the final output layer. For current study, the ranking of factors were assigned based on numerical value of 1–9 scale in order of importance. Subsequently, 0−9 ordinal scale was assigned to the factor classes. The lower value indicated the lesser weightage whereas higher value demarcated as greater value for landslide occurrence. The percentage of influencing weight values were allotted to each parameter depending upon the effect on landslides (Table 1). In the study, six parameters were incorporated for hazard mapping. The resultant map of this analysis

Table 1. Assignment of percentage of influence weight of percentage and scale weight

Sr. No.	Parameter	Feature class	Scale weight	% of influence
1.	Slope aspect	East	2	12%
		Flat	1	
		North	2	
		Northeast	3	
		Northwest	1	
		South	9	
		Southeast	8	
		Southwest	8	
		West	4	
2.	Slope degree	0–15	2	26%
		15–25	4	
		25–35	7	
		35–45	8	
		45–90	9	
3.	Drainage density	Very low density	1	21%
		Low density	2	
		Medium density	6	
		High density	8	
		Very density	9	
4	Curvature	Concave	9	10%
		Convex	1	
		Flat	5	
5.	Land-use/ land-cover	Agricultural land	7	15%
		Barren land	9	
		BuildUp land	3	
		Moderately vegetative land	5	
		Sparsely vegetative land	8	
		Thickly vegetative land	1	
		Water body	6	
6.	Lithology	Alluvium (gravel dominant)	9	16%
		Alluvium (sand/silt dominant)	1	
		Granite, mandi granite	4	
		Limestone/dolomite	2	
		Metavolcanics/mandidarlavolcanics	1	
		Phyllite/schists, bhalai formation	7	
		Phyllites/slates, batal formation	2	
		Sandstone with siltstone/clay	1	
		Schists, khokhan/kharmada formation	8	
		Slates, chamba formation	5	

yields a raster map with weighted index values, which were further used to classify the map in to hazard zone classes.

3 Results and Discussion

3.1 Slope Aspect

Slope Aspect play is crucial role in governing terrain stability in Himalayan regions. In study area, southern slopes have been considered as prone to landslide as compared to other slopes. It is because of the fact that the vegetation cover on these slopes are less and generally drier whereas in the north face slopes, vegetation growth is better and aspect in mostly moist. Further, the slope aspect has been generated in GIS by using spatial analyst tool and subsequently classified into nine classes (Fig. 2a).

3.2 Slope Degree

Slope is one of the significant parameter, which is considered for stability consideration. It is due to the fact that, as increase in slope angle the shear stress in soil increases. The probability of landslides in steeper slopes is more dominant than moderate or gentle slopes. In study area, it has been observed that the areas, which are steeper than 60°, the frequency of rock fall events, are more than landslides. The study area experiences frequent rock fall events along with debris flows. Subsequently, Slope map has been generated from digital elevation model (DEM) of 30 × 30 m grid size in GIS environment. Slope terrain is further divide into flat to steep surface. Lower value of the slope illustrated as flat while higher value of the surface as steep terrain. The area of the slopes has been represented in terms of degree and divided into five classes namely, 0°–15° (flat to gentle slope), 15°–25° (moderate slope), 25°–35° (fairly moderate slope), 35°–45° (steep slope), 45°–90° (very steep slope) classes (Fig. 2b).

3.3 Drainage Density

Drainage density is another chief parameter in landslide activities. In the study area, dendritic and parallel type of drainage pattern is traced which covers the central most part. Beas River flows parallel to the road, in the whole length of the study area. It is observed that frequency of landslides activities occurred is associated with the drainage. Further, the drainage density map has been classified as very low density, low density, medium density, high density and very high density. The classification system has been prepared through Jenks natural breaks (Fig. 2c). Drainage layer has been prepared using Arc hydro tool in ArcGIS software. Later, by using line density tool in GIS, drainage density map has been extracted. Further, the ordering of drainage density map has been executed based on Strahler's classification system (1964).

3.4 Curvature

Rate of change of gradient of slope in a particular direction is described as curvature. Usually, morphology of the area is denoted by slope curvature. In this study area,

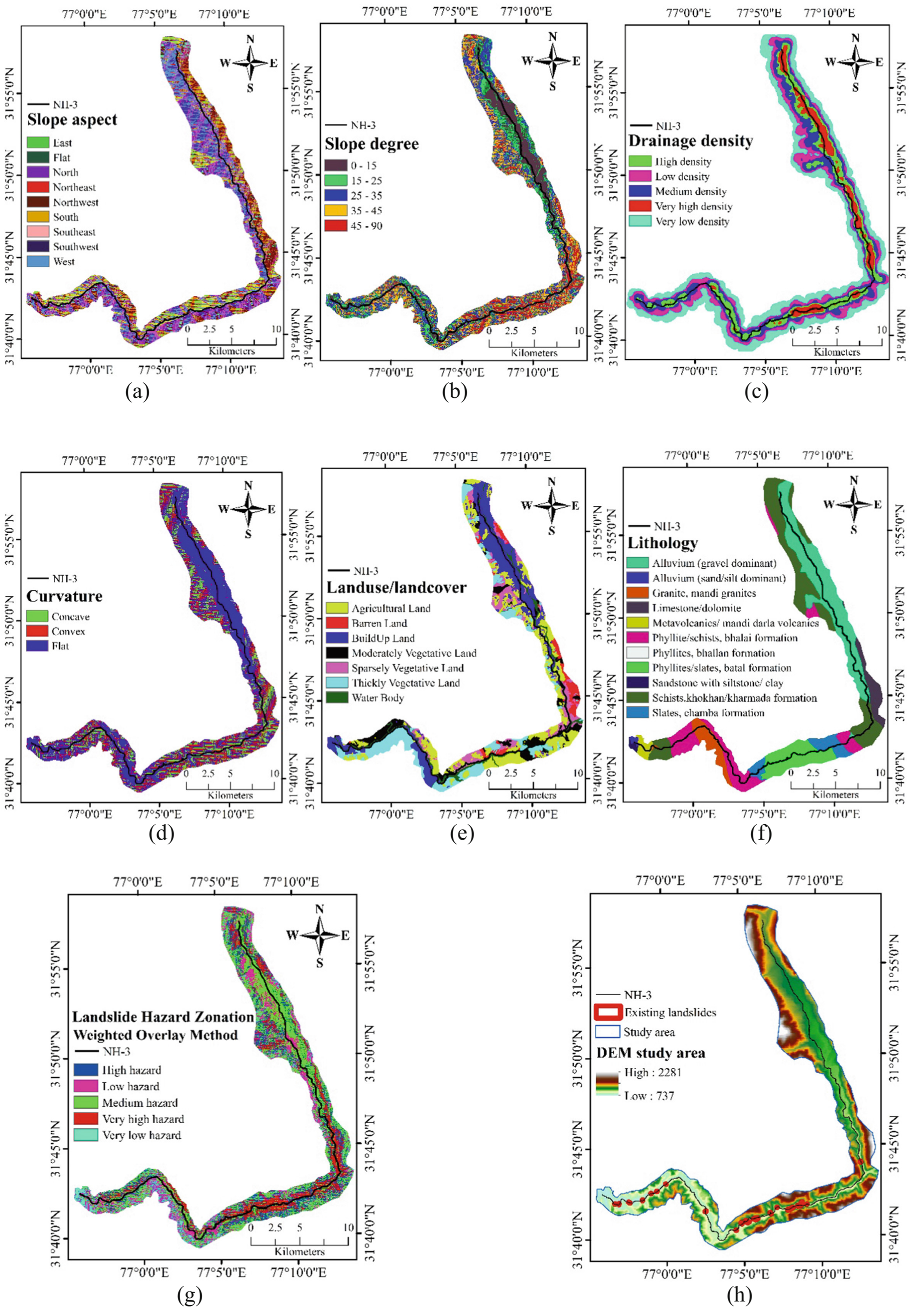

Fig. 2. (a) Slope degree (b) Slope aspect (c) Drainage density (d) Curvature (e) Landuse/landcover (f) Lithology (g) Landslide hazard zonation (LHZ) map (h) Inventory map of the study area

curvature has been categorized into three classes: concave, convex and flat (Fig. 2d). Mostly, the concave slopes are considered unstable while convex slopes are considered as stable slopes.

3.5 Landuse/Landcover

Presence of vegetation is a critical factor in stability of slopes due to greater bonding. Thus, barren slope are more prone to occurrence of landslides than dense vegetative lands. It designates the physical description of an area. Land-use pattern changes such as changes due to urbanization and agricultural are the governing factors, which make the area more susceptible to landslides. Weight of soil, cohesion, internal friction angle and pore water pressure are the major parameters, which purely depends upon the vegetation density, which pointedly affects the landslide occurrence. In order to access the contribution of various land-use/land-cover classes on destabilization of slopes, with help of Google earth, toposheets and intensive field reconnaissance, the study area is divide into various varieties of land-use/land-cover classifications. Build-up land, agricultural land, thickly vegetative land, barren land, sparsely vegetative land, water body and moderately vegetative land are the classes divided with the help of ArcGIS (Fig. 2e).

3.6 Lithology

The lithological properties lead to a change in strength and permeability of rocks and soils. Diverse types of rocks have varied structure and composition, which adds to their strength. Lithology factor is considered as an important parameter in numerous studies (Sharma and Mehta 2012). The lithology map has been prepared by digitizing the polygons from ground water prospects maps on scale 1:50000, prepared by Central Building Research Institute (CBRI) & published by National Remote Sensing Agency (NRSA), Government of India in vector layer. The eleven types of rocks have been marked in the study area (Fig. 1f): Schists & khokhan/kharmada formation, phyllite/schists & bhalai formation, granite & mandi granites, phyllite/schists & batal formation, alluvium sand/silt dominant, sandstone with siltstone/clay, metavolcanics & mandi darla volcanic phyllites & bhallan formation, alluvium, limestone/dolomite, slates & chamba formation. Phyllites/schists & Batal formation and bhalai formation of salkhala groups indentified to be the most probable occurrence lithological structure.

3.7 Landslide Inventory

Landslide inventory is the essential component in landslide hazard analysis. Figure 2h shows the landslide inventory map, which has been traced in the study area. Most of the landslides were close to the Beas river, which flows through major portion of the highway section. The locations have been confirmed through interaction with the local residents in the course of field visits. Further, by recognising the topographical features, which were explicated on topographic maps and aerial images the validation of events was accomplished. Subsequently, with the help of GIS software, the data has been digitized. A total of 25 number of landslides were recognised in the study area.

Historical records of Public Works Department (PWD) and existing landslide locations from National Highway Authority has also been considered in inventory mapping.

4 Conclusion

Landslide hazard zonation map was generated by WOM method in GIS environment. LHZ map divided into five zones, viz very low hazard zone, low hazard zone, medium hazard zone, high hazard zone and very high hazard zone (Fig. 2g). 13.3% of study area traced in very high zone and 9.2% of area in very low hazard zone. Whereas the areas low hazard, medium hazard and high hazard zone reported 20.6%, 35.4% and 21.5% respectively (Table 2). Area with very low and low hazard zones is mostly concentrated in Bhuntar and Mandi buildup land of the study area. Whereas, the very high zone and high zones traced in Hanogi, Dwada and Aut places of the area. Particularly in hilly region, the susceptibility of hazards decreases with the increase in distance from the drainage. However, in current study area, the river Beas flows along the selected path. In addition, slope plays a key role in hazard zonation mapping, because the intensity and frequency of the hazard depends on it. Present study area comprises of mostly steeper slopes, which are mainly formed by rocks. On the other hand, south facing direction traced most number of landslides as compared to others. Alluvium (gravel dominant) rock lithological formations identified maximum number of landslide events.

Table 2. Percentage area of landslide hazard zones

Hazard zones	Area (km^2)	Area percentage (%)
Very low hazard zone	14.8	9.2
Low hazard zone	33.0	20.6
Medium hazard zone	56.5	35.4
High hazard zone	34.4	21.5
Very high hazard zone	21.3	13.3

The present study established a precise relationship between GIS technique and remote sensing, which plays an important role in landslide hazard zonation mapping. WOM is an efficacious method in inaccessible terrain where inventory data are not available. In this study, six parameters were identified through literature survey and taken into the effect. Scores and weightage were given based on terrain knowledge and their concerned variables. The geospatial technology used in the study was subsequently validated with the field study. In spite of the attainment of the results of current study, research can be further implemented in future studies with other conditioning parameters.

References

Ahmed B (2015) Landslide susceptibility mapping using multi-criteria evaluation techniques in Chittagong Metropolitan Area, Bangladesh. Landslides 12(6):1077–1095

Roslee R, Mickey AC, Simon N, Norhisham MN (2017) Landslide susceptibility analysis (LSA) using weighted overlay method (WOM) along the Genting Sempah to Bentong highway, Pahang. Malays J Geosci (MJG) 1(2):13–19

Sarkar S, Kanungo DP, Mehrotra GS (1995) Landslide hazard zonation: a case study in Garhwal Himalaya, India. Mountain Research and Development, pp 301–309

Sharma RK, Mehta BS (2012) Macro-zonation of landslide susceptibility in Garamaura-Swarghat-Gambhar section of national highway 21, Bilaspur District, Himachal Pradesh (India). Nat Hazards 60(2):671–688

Strahler AN (1964) Part II. Quantitative geomorphology of drainage basins and channel networks. In: Handbook of applied hydrology. McGraw-Hill, New York, pp 4–39