

Landslide Hazard around Mussoorie: The Lesser Himalayan Tourist Destination of Uttarakhand, India

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Abstract

Identification of hazard prone areas and regulation of developmental initiatives in these is the key to disaster risk reduction. Slope instability is the most common hazard in all hilly areas and inherent fragility of the terrain makes Himalayan region all the more susceptible to landslides. Landslide hazard evaluation factor rating scheme is utilized for delineating areas prone to slope instability in the proximity of Mussoorie that is a major tourist destination of Uttarakhand in India. Of the 58 Sq. km area taken up under the study 18.4, 12.5 and 1.0 Sq. km. respectively fall under moderate, high and very high landslide hazard class. Detailed stability assessment is therefore recommended for developmental initiatives in moderate hazard class while regulating anthropogenic intervention is recommended in both high and very hazard classes.

Keywords: Uttarakhand; Mussoorie; Hazard zonation; Slope instability; Landslide

Introduction

Landslide is generally understood as being downslope movement of rock mass, debris, soil and earth, with or without water, under the influence of gravity. It includes both consolidated and unconsolidated material originating from a variety of geomorphic features due to natural and manmade causes. Going by the above definition relief becomes a precondition for an area to be affected by landslides and it is relief that is a must for identifying any area as being mountainous. Landslides are therefore characteristic feature of hilly or mountainous areas.

Landslide causes immense and recurring loss of human lives, infrastructure and property and is often looked upon as being a curse for the hilly areas. This is however an important landform building process that promotes soil formation. It is therefore no wonder that large proportion of habitations in the hills are located in close proximity of old stabilized landslides as these provide suitable land for agricultural operations.

Like other hilly regions, landslides are common in the Himalayan state of Uttarakhand in India and particularly during the monsoon period, rainy season in the Indian subcontinent, their occurrence is particularly high. The present study is undertaken in the area around Mussoorie that is located in Lesser Himalaya in close proximity of Main Boundary Thrust (MBT) that brings Upper Proterozoic to lower Cambrian Lesser Himalayan tectogen in juxtaposition with Miocene to Pleistocene Siwalik Group of rock along a NNE dipping discontinuity. The rocks exposed in the area are highly fractured and sheared and the same is primarily responsible for geological fragility of the area. The area has also witnessed seismogenic mass instability during 1905 Kangara Earthquake [1].

Geology, slope morphometry, relative relief, geomorphology, hydrogeology and land use/land cover are generally considered to control distribution of landslides and therefore these parameters are largely taken note of while undertaking landslide hazard zonation related studies. Their distribution in space has been correlated with different natural and man-made factors that are likely to influence their occurrence. This is intended to help in formulating of a viable strategy for minimising the menace of landslides. GIS has been recognised as

an effective tool for studying landslide susceptibility [2-8] and the same has been utilized for these studies.

The Study Area

The present study covers 58 square kilometer area around Mussoorie that falls in Survey of India (SOI) toposheet number 53 J/3(1:50000 scale) that has been utilized for the preparation of base map and undertaking landslide hazard analysis (Figure 1).

Situated in close proximity of the state capital Dehradun, Mussoorie is popularly dubbed as the Queen of the Hills and is a famous tourist resort located on the first range of hills running east-west parallel to the Dehradun valley and the Siwaliks. Wide road running through the heart of Mussoorie between Library and Landour, the Mall is famous amongst the visitors. Mussoorie has a population of 33,651 of which 45% are females (Census of India, 2011). The population of the town is however highly variable and during the peak tourist season (from April/May to September/October) the same witnesses manifold increase.

Methodology

Landslide hazard evaluation factor rating scheme [9] has been utilized for slope instability analysis whereby all the thematic layers are prepared and correlated. These include slope facet, geology, structure, slope morphometry, relative relief, geomorphology, hydrogeology and land use/land cover. The results of the landslide hazard evaluation rating scheme are then correlated with the data collected in the field. Satellite imagery (LISS-IV) has been utilised for delineating land use/land cover characteristics and specific landforms; particularly lineaments. For analysis and correlation of various thematic layers Geographical

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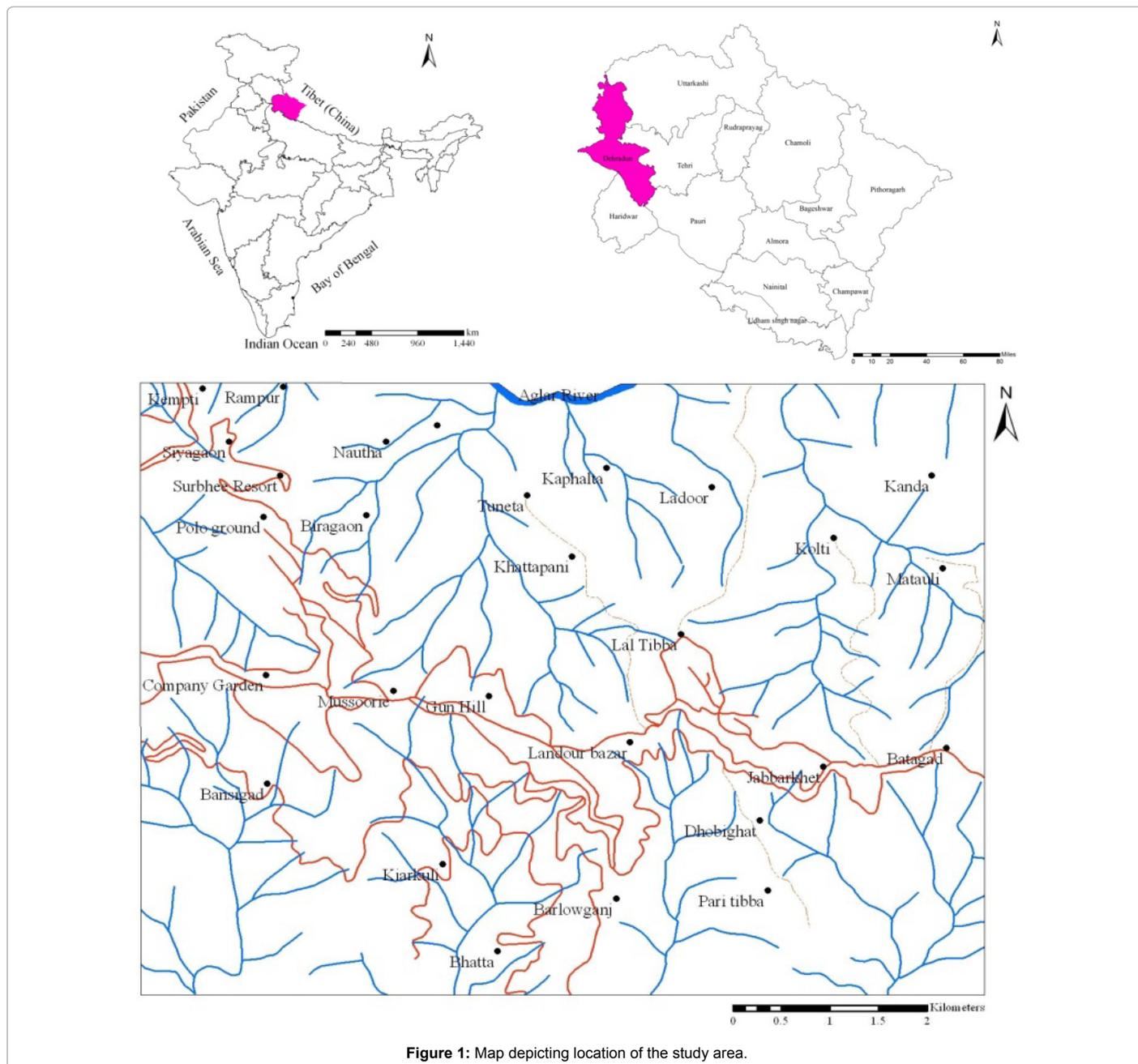


Figure 1: Map depicting location of the study area.

Information System (GIS) environment has been used. The complete process of macro zonation of landslides hazards is depicted in Figure 2.

Geomorphology

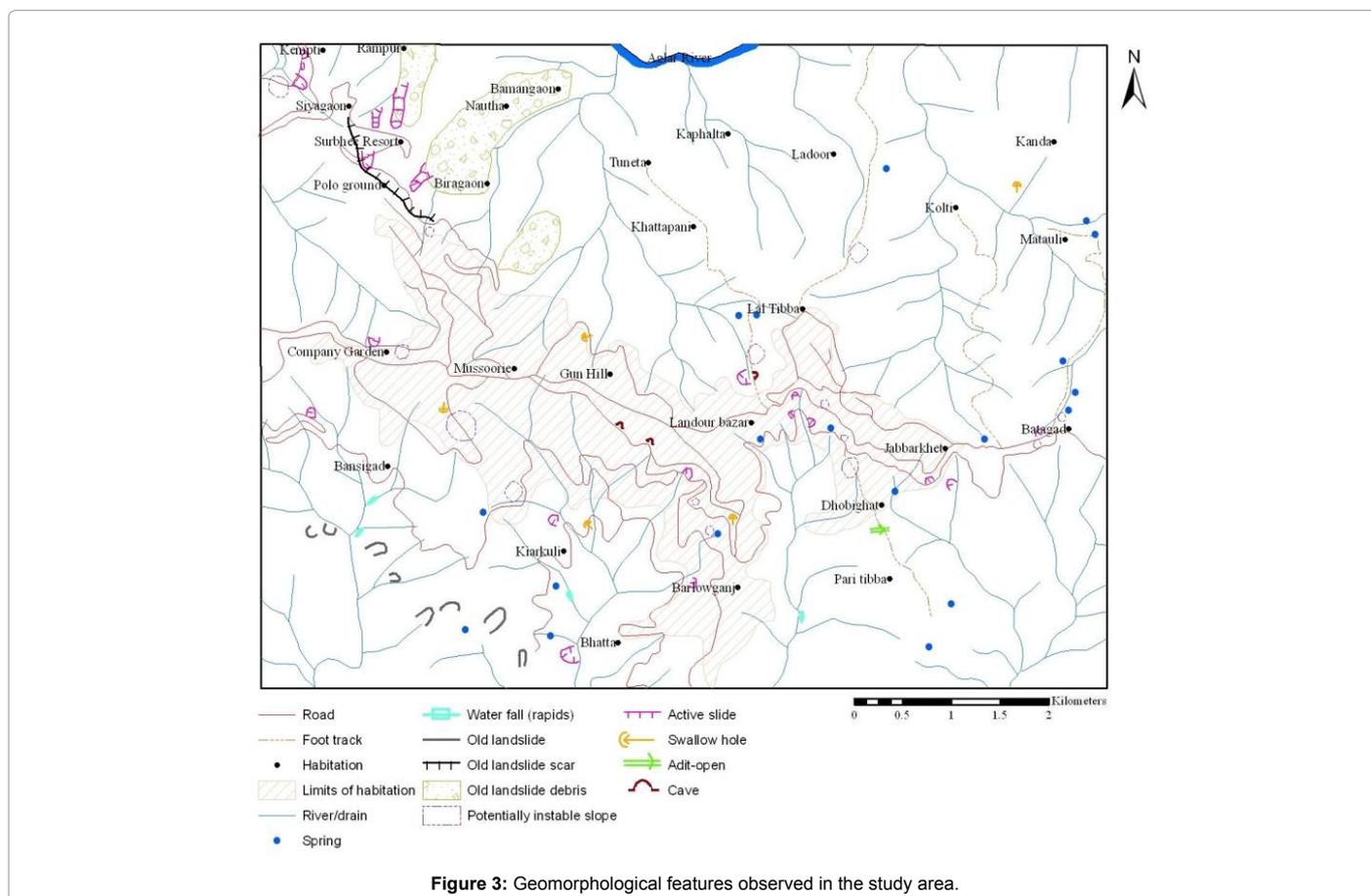
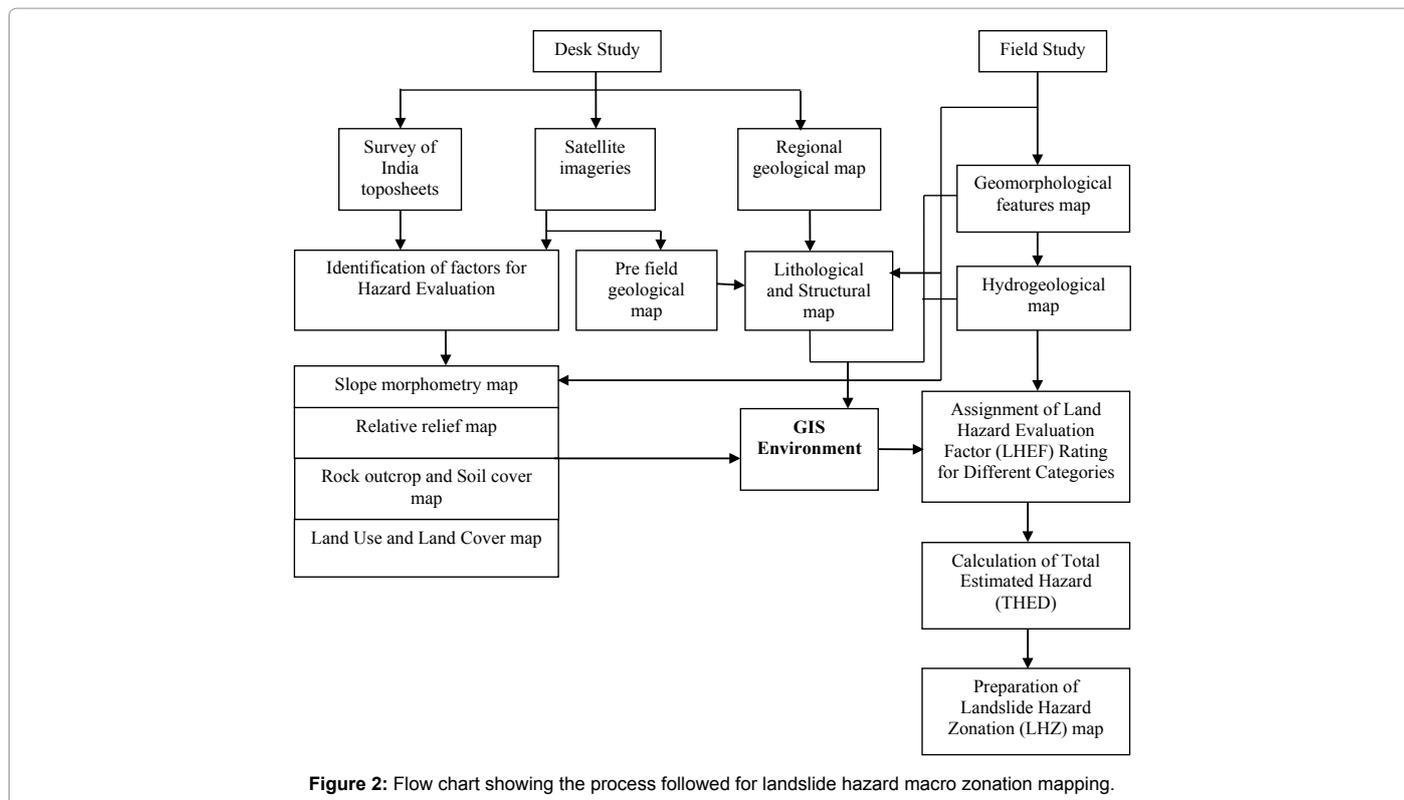
Geomorphological processes or changes in the morphology of the ground are often documented by pre-existing maps, satellite imageries and survey reports of the previous landslides. These are also sometimes documented in the records of careful observations taken over time by administration and local population. Topography has an important bearing upon the geomorphic evolution of an area, particularly so in the hills. The area around Mussoorie is observed to be dissected by several ridges and the ground elevations vary between 900 and 2290 meters above mean sea level (msl). Lal Tibba with height of 2290 meters above msl is the highest point of the area while second highest

point Gun Hill has an altitude of 2024 meters above msl. Company Garden and Mussoorie Lake respectively have elevations of 1870 and 1880 meters above msl.

The imprints of geological and structural control over geomorphology of the area are observed in the formation of strike ridges and valleys at some places. Steep scarps, deeply incised valleys and mass wasted scree slopes in the area have been carved out by denudational processes. Tectonic discontinuities have given rise to steep cliffs with well-developed scarp in Kempti, Bhatta and Lal Tibba areas and these areas fall in the zone of maximum risk. Main geomorphic features observed in the field are shown in Figure 3.

LHEF rating scheme

Landslide hazard evaluation factor (LHEF) rating scheme is a



numerical system based on major causative factors of slope instability that include lithology, structure, slope morphometry, relative relief, land use and land cover, rock outcrop and soil cover and hydrogeological conditions. The maximum LHEF ratings for causative

factors like lithology, structure, slope morphometry, relative relief, land use and land cover and hydrogeological condition are 2, 2, 2, 1, 2 and 1 respectively. Detailed LHEF ratings for individual causative factors are given in Table 1.

Contributory Factor	Description	Category	Rating		
(a)	Lithology	(i) Rock type	Type 1	Quartzite and limestone	0.2
			Granite and gabbro	0.3	
			Gneiss	0.4	
			Type 2	Well cemented terrigenous sedimentary rocks dominantly sandstone with minor beds of clay	1.0
			Poorly cemented terrigenous sedimentary rock dominantly sand rock with minor clay shale beds	1.3	
			Type 3	Slate and phyllite	1.2
		Schist	1.3		
		Shale with interbedded clayey and non-clayey rocks	1.8		
		Highly weathered shale, phyllite and schist	2.0		
		(ii) Soil type	Old well compacted alluvial fill material	0.8	
			Clayey soil with naturally formed surface	1.0	
			Clayey soil with naturally formed surface (Alluvial)	1.4	
			Debris comprising mostly rock pieces mixed with clayey/sandy soil (colluvial)		
			-Older well compacted	1.2	
-Younger loose material	2.0				
(b)	Structure	Relationship of structural discontinuity with slope			
		(i) Relationship of parallelism between the slope and the discontinuity	I	>30°	0.20
			II	21°-30°	0.25
			III	11°-20°	0.30
			IV	06°-10°	0.40
			V	<05°	0.50
		(ii) Relationship of dip of discontinuity and inclination of slope	I	>10°	0.30
			II	0°-10°	0.50
			III	0°	0.70
			IV	0°-(-10°)	0.80
			V	>(-10°)	1.00
		(iii) Dip of discontinuity	I	<15°	0.20
			II	16°-25°	0.25
			III	26°-35°	0.30
			IV	36°-45°	0.40
			V	>45°	0.50
		Depth of soil cover		<05 m	0.65
				06-10 m	0.85
				11-15 m	1.30
		16-20 m	2.00		
		>20 m	1.20		
(c)	Slope morphometry	(i) Escarpment/cliff	>45°	2.0	
		(ii) Steep slope	36°-45°	1.7	
		(iii) Moderately steep slope	26°-35°	1.2	
		(iv) Gentle slope	16°-25°	0.8	
		(v) Very gentle slope	≤ 15°	0.5	
(d)	Relative relief	(i) Low	<100/m	0.3	
		(ii) Medium	101-300 m	0.6	
		(iii) High	>300 m	1.0	
(e)	Land use/land cover	(i) Agricultural land/populated flat land		0.6	
		(ii) Thickly vegetated forest area		0.80	
		(iii) Moderately vegetated area		1.2	
		(iv) Sparsely vegetated area with lesser ground cover		1.5	
		(v) Barren land		2.0	
(f)	Hydrogeological condition	(i) Flowing		1.0	
		(ii) Dripping		0.8	
		(iii) Wet		0.5	
		(iv) Damp		0.2	
		(v) Dry		0.0	

Table 1: Landslide hazard evaluation factor (LHEF) rating scheme.

Thematic layers

Thematic maps are prepared on the basis of the data collected on various landslide causing factors that include geology, slope morphometry, relative relief and land use/land cover, hydrogeology. These are analysed facet wise and LHEF values are calculated for individual facets through extensive fieldwork undertaken in the area as also with the help of satellite imageries. All the thematic layers of contributory factors are generated in GIS environment. Preparation of all the thematic layers is described in the sections below.

Slope facet

A slope facet is a part of hill slope that has more or less similar slope characteristics and show consistent slope direction and inclination. Slope facets are generally delimited by ridges, spurs, gullies and streams. The entire area around Mussoorie is divided into 350 slope facets based upon SOI toposheet (Figure 4).

Geology

Apart from the historical data of landslides geomorphic and geological details constitute important source parameter for landslide hazard zonation [10]. Stability of a site is therefore often inferred from the geology [11] that is considered a key parameter conditioning landslide occurrence [12] as sensitivity to active geomorphological processes such as landslides is considered to vary with geology. Because of this geology has been used as an input parameter to assess landslide susceptibility [13-18].

Geological set up of the area is reconstructed after detailed fieldwork undertaken with an aim to identify lithological characteristics of the various rock slopes and landslide zones. For the purpose of present study Krol Formation is considered as one single lithounit represented by limestone/dolomitic limestone while Tal Formation is divided into five lithounits; (i) quartzite, (ii) micaceous siltstone, grey and black shale, (iii) calcareous sandstone/sandy shale, (iv) silty shale and (v) chert.

The area comprises of Krol and Tal Formations of Lesser Himalaya, with Krol Formation accounting for its major portion [19-23]. Dominant rock types include calcareous ferruginous shale interbedded

with argillaceous limestone (Upper Krol), thickly bedded grey dolomite with thick beds of shale that contain nodules and thin lenticular beds of black chert (Middle Krol), grey to dark grey dolomitic limestone with thin shale and pockets of gypsum and calcite layers (Lower Krol), coarse grained, white and pebbly quartzite (Upper Tal), calcareous purple sandy shale, micaceous sandy siltstone, black to grey colored banded shale and grey to black shale (Middle Tal) and chert with phosphorite and silty shale (Lower Tal). The structural setup of the area is delineated as a doubly plunging NW-SE trending syncline; the Mussoorie syncline that passes through Jaberkheth and Lal Tibba ridge and plunges at 10°-15° towards SE in the NW portion and at shallower angles towards NW in the SE portion [24].

Lithology

Erodibility or the response of rocks to the processes of weathering and erosion is the main criteria in deciding the ratings and therefore a correction factor on the status of weathering of rocks has been incorporated and for this rock exposures in the area have been mapped in detail. In case of different type of soil materials, assumed depth of overburden is considered for deciding the ratings (Figure 5).

Structure

Primary and secondary discontinuities present in the rocks are delineated and mapped. Stability of hill slopes largely depends upon the relationship between spatial deposition of the discontinuities with the surface slope and this has been taken care of while working out LHEF ratings. The faults, fractures and joints not only destabilize the area through deterioration of the strength of the rocks, but also accelerate the weathering process [25]. Displacement is observed in the calcareous sandy shale band located in the core of the syncline along a NW-SE trending fault running through Lal Tibba and Khattapani area.

Lineaments are linear features in a landscape that are considered to be the expression of the underlying geological structure. Presence of the lineaments delineated from the satellite imagery has been validated from the geomorphic expressions observed in the field. These are observed to represent tectonic discontinuities. It is important to note that most lineaments show a trend either parallel or transverse to the trend of the Mussoorie syncline. Most lineaments observed in north

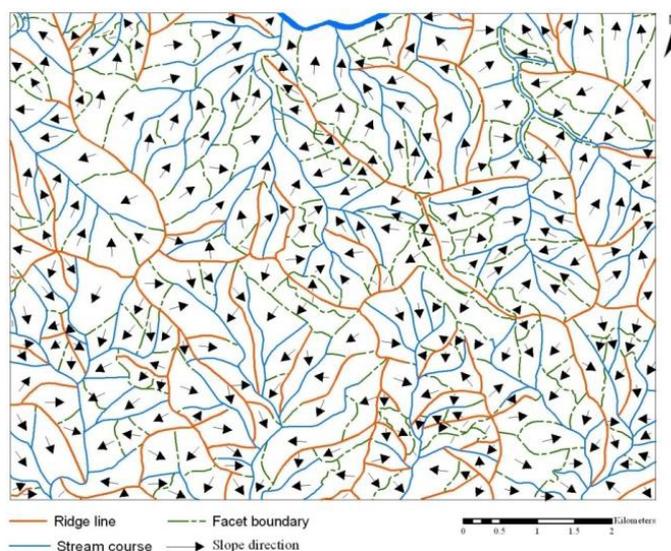


Figure 4: Slope facet map of the study area.

and east of Mussoorie town show NE-SW to ENE-WSW trend while significant lineaments showing NW-SE trend are located in Kempty-Surbhee Resort and Kolti-Bhatta areas (Figure 6). Buffer of 100 meters has been considered on either side of the lineaments that have been awarded an extra rating of 1.0 to accommodate for higher landslide susceptibility in their proximity.

Slope morphometry

Slope morphometry map defines slope categories on the basis of frequency of occurrence of particular angles of slope. This map is prepared by dividing the topographical map of SOI into smaller units with the contour lines having the same standard spacing, that is, the same number of contour lines per kilometer of horizontal distance. Furthermore, the individual slope category is divided into smaller

facets of varying slope angles, which reflect a series of localized process and control that have been imposed on the facets [26]. Five category of slope morphometry used for hazard evaluation include (i) escarpment/cliff, (ii) steep slope, (iii) moderately steep slope, (iv) gentle slope and (v) very gentle slope (Figure 7).

Relative relief

The relative relief map represents the local relief of maximum height between the ridge top to the valley floor measured in the slope direction within an individual facet. Relief of a facet is calculated by counting difference between elevations at bottom most point of a facet to top most point of the same, along slope direction. The area is thus divided into three categories representing low, medium and high relative relief (Figure 8).

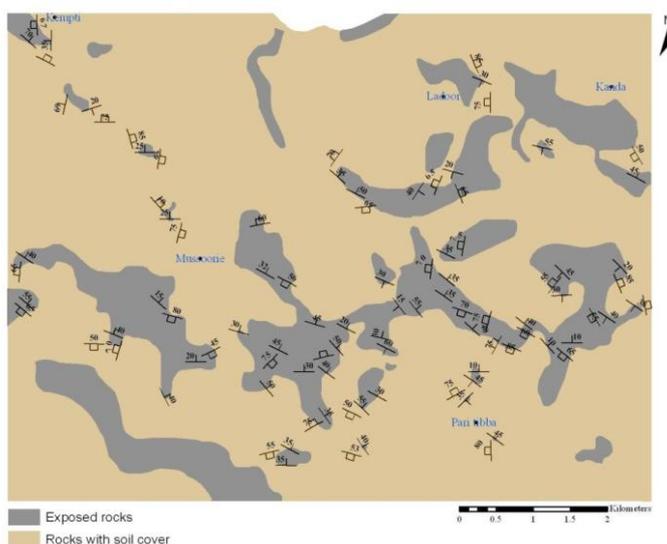


Figure 5: Map showing bed rock exposures in the study area.

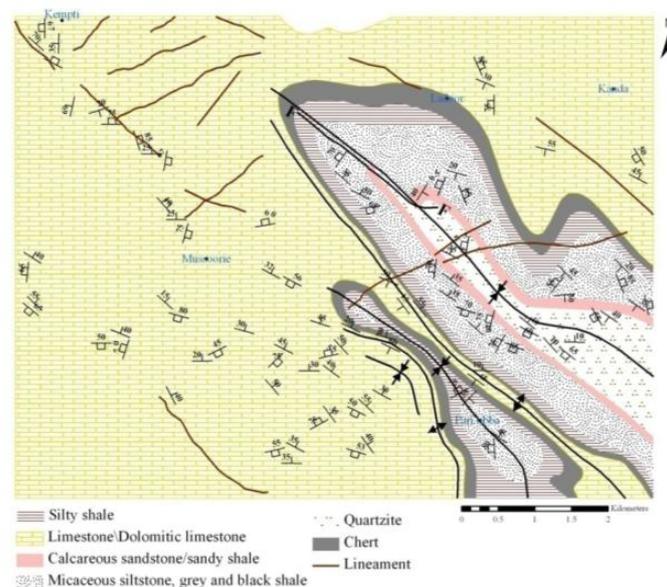


Figure 6: Structural map of the area around Mussoorie.

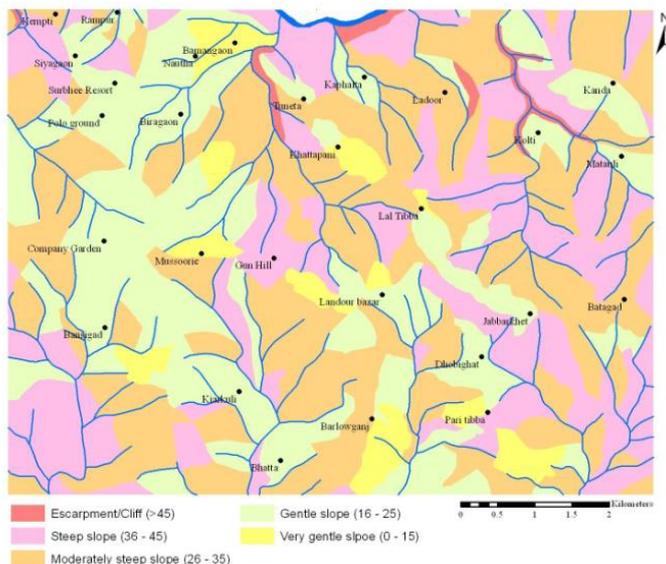


Figure 7: Slope morphometry map of the study area.

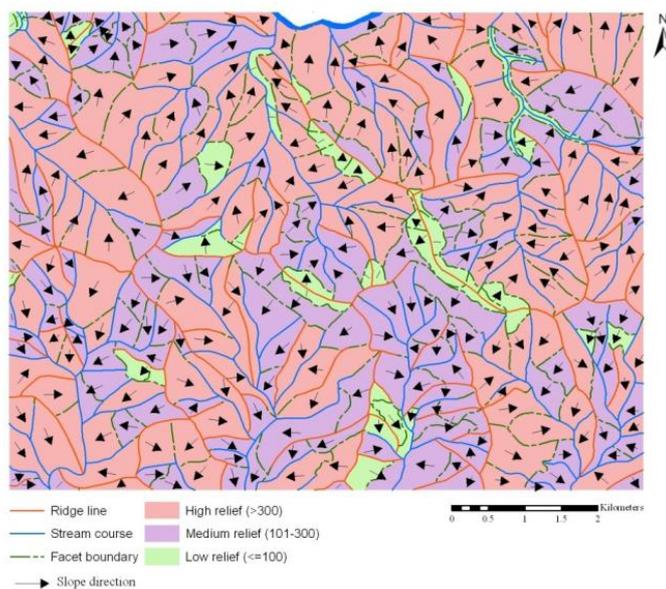


Figure 8: Map depicting relative relief of the area.

Land use/land cover

Landuse pattern of any area is decided by the interplay of numerous factors that include geology, slope, aspect, temperature, humidity, population pressure and nature of available economic opportunities. Landuse is recognised as having an important role in the instability of the slopes [27] and amongst various land use classes distribution of vegetation is often correlated with the occurrence of landslides. Vegetation is conceived to bind the soil together through an interlocking network of roots forming erosion resistant mat that stabilises the slopes [28]. Barren slopes are thus considered more prone to landslides [29]. Agriculture in general is practiced in low to very low slopes though moderately steep slopes are also observed to be under

agriculture at some places [30]. The agricultural lands represent areas of repeated artificial water charging for cultivation purposes and are generally stable. The land use/land cover is delineated from the satellite imagery. Seven land use/land cover classes identified in the area include (i) dense forest, (ii) open forest, (iii) scrub forest, (iv) habitation, (v) open area, (vi) agriculture and (vii) water body (Figure 9).

Hydrogeology

The hydrogeological condition of a slope is an important parameter to assess the stability of the slopes as water reduces the shearing strength of the slope forming material causing instability [31]. Groundwater in the hilly terrain is generally channelized along

structural discontinuities of rocks. It therefore does not have a uniform flow pattern. The observational evaluation of the groundwater on hill slopes is thus not possible over large areas. Therefore nature of surface indications of water such as damp, wet, dripping and flowing are used for rating purposes (Figure 10).

Total estimated hazard

Total estimated hazard (TEHD) indicates the net probability of instability and is calculated facet wise. The TEHD of an individual facet is obtained by adding the rating of the individual causative factors obtained from LHEF rating scheme. The final THED value is calculated facet wise by adding all value of slope instability parameters (IS 14496 Part 2). Total estimated hazard (TEHD) therefore equals ratings for lithology, structure, slope morphometry, relative relief, land use/

land cover and hydrogeological conditions [31,32]. Landslide hazard zonation (LHZ) map of an area on macro-scale is based on the facet-wise distribution of TEHD values that are given in Table 2.

Discussion and Conclusion

The final landslide hazard zonation (LHZ) map prepared on

Zone	TEHD Value	Description of class
I	<3.5	Very low hazard (VLH) class
II	3.5 to 5.0	Low hazard (LH) class
III	5.1 to 6.0	Moderate hazard (MH) class
IV	6.1 to 7.5	High hazard (HH) class
V	>7.5	Very high hazard (VHH) class

Table 2: Distribution of TEHD values and LHZ classes.

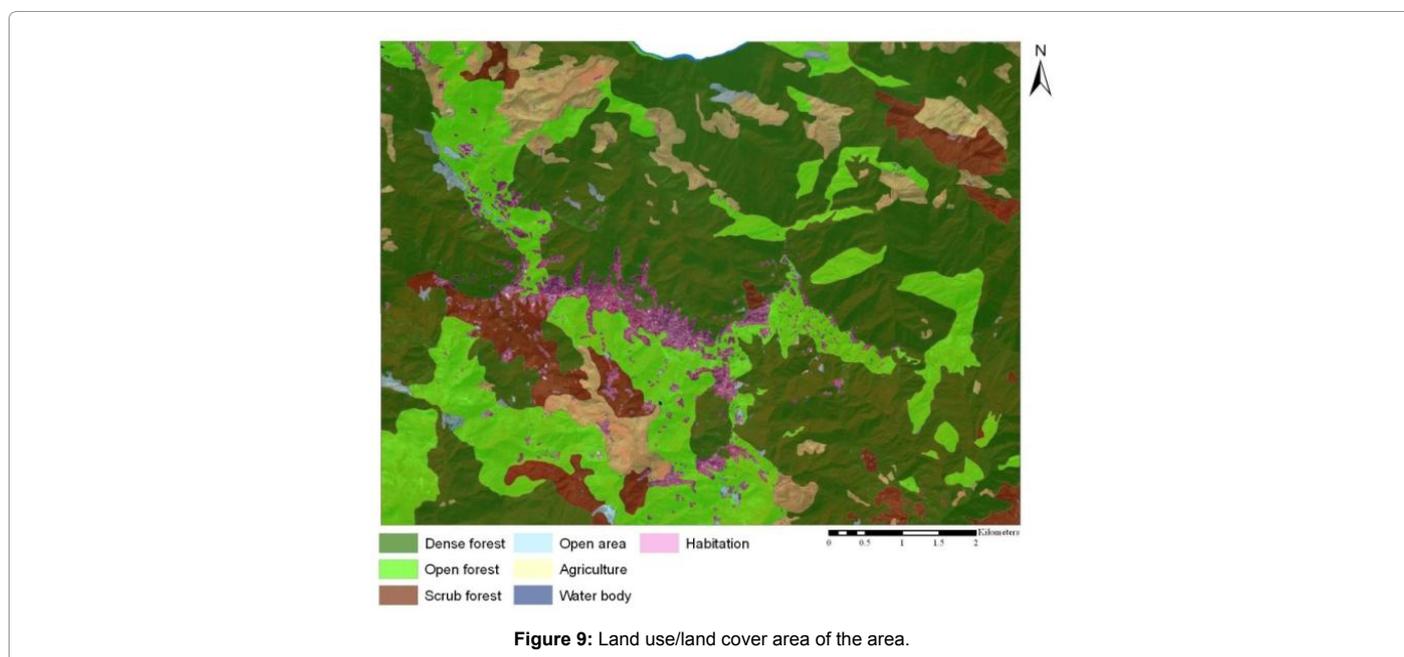


Figure 9: Land use/land cover area of the area.

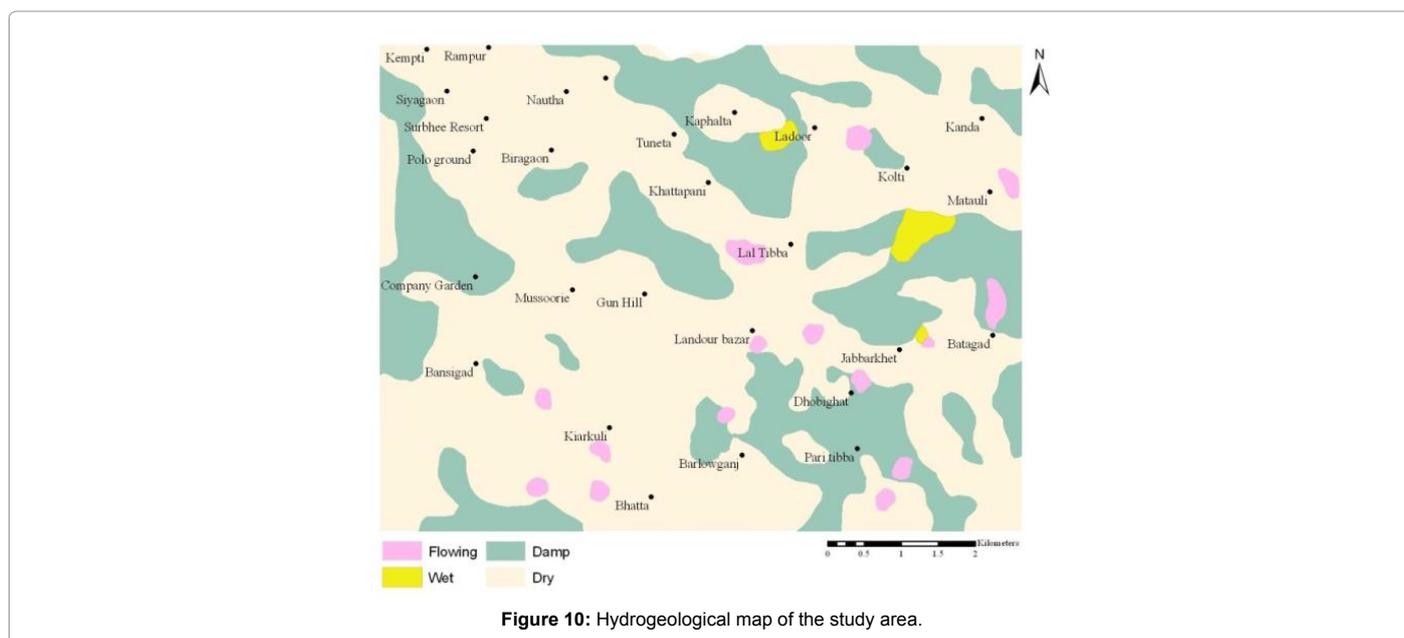


Figure 10: Hydrogeological map of the study area.

1:50000 scales has been categorized into five hazard classes that include (i) very high hazard, (ii) high hazard, (iii) moderate hazard, (iv) low hazard and (v) very low hazard (Figure 11). Details of the proportion of geographical area falling under different LHZ classes are described in the sections below.

Very high hazard class

Steep slope classes account for almost all the area falling under this hazard class. Area to the northwest of Bataghat and southwest of Lal Tibba is observed to fall under this hazard class. Even though these areas are fairly far from habitation anthropogenic intervention of any sort should be regulated in the areas falling under this class that is highly prone to landslides and not suitable for developmental works of any sort.

High hazard class

Numerous tectonic discontinuities that include lineament and fault plane are observed to traverse through this class. Many active landslides also occur in this class. Area to the north of Company Garden, north and east of Lal Tibba, west of Jaberkheth and southwest of Kiarkuli fall under this class. Anthropogenic intervention in these areas should be avoided to the extent possible.

Moderate hazard class

Several old landslides are observed in this class towards the western

extremity of the Mussoorie synclinal axis. Moderately steep slope class accounts for almost all the area falling under this class. Area to the east of Pari Tibba and Jaberkheth, west of Kiarkuli and Bhatta, northwest of Barlowganj and northeast of Khattapani fall under this zone. Special care is required in this class and areas with more than 25° surface slope should be kept free of anthropogenic intervention.

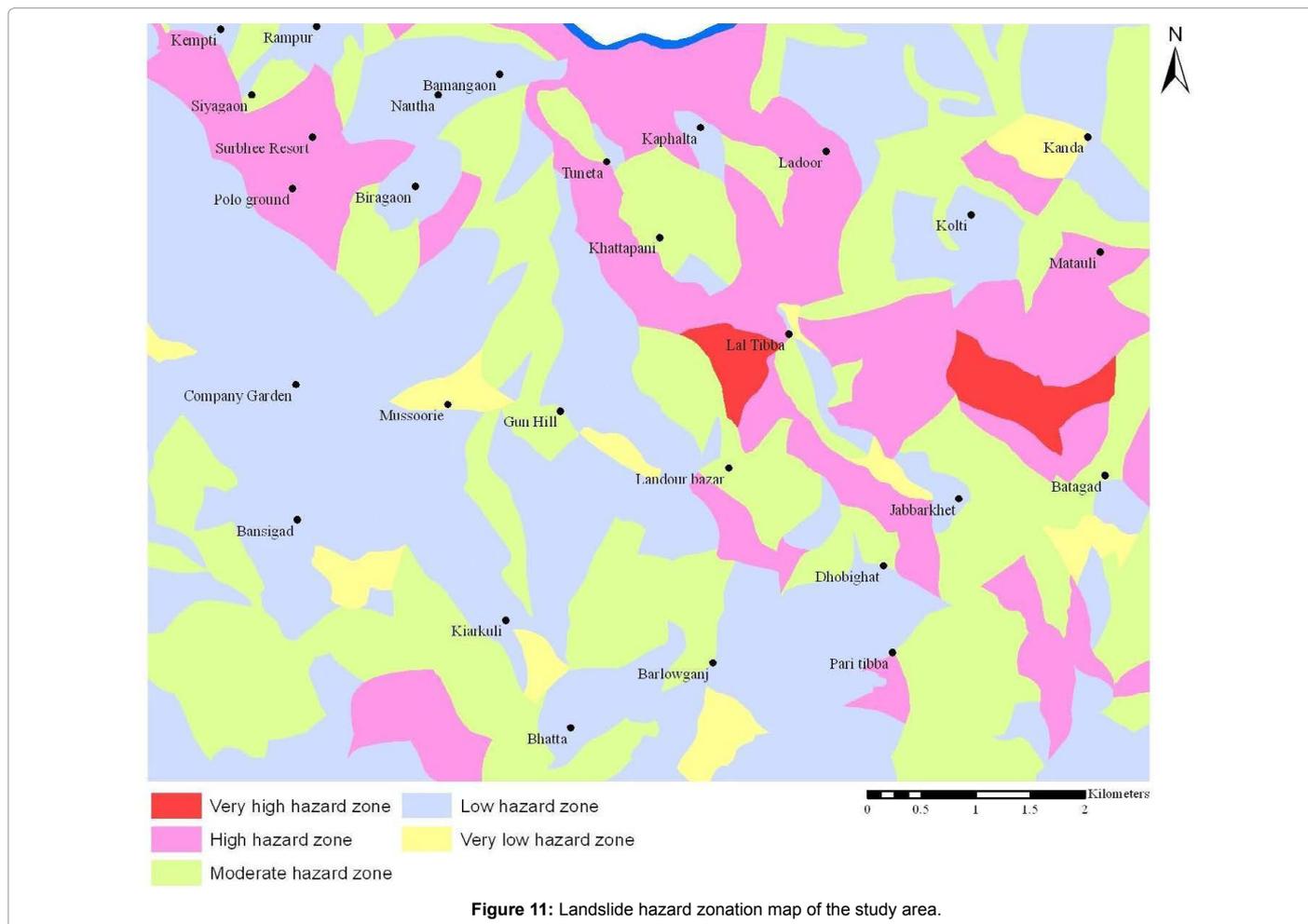
Low hazard class

This class is generally observed to have gentle to moderate slope angles and is largely covered by dense forest, open forest and settlements. Mostly the areas to the west of Mussoorie synclinal axis fall under this class. These areas are generally suitable for developmental works; prior detailed stability analysis however is a must in the hills.

Very low hazard class

Most area falling under this class has low slope angle and is often level surface or flat ground. The areas to the southeast of Gun Hill, Bansigad and Kiarkuli, south of Barlowganj and Bataghat and west of Kanda fall under this class. The chances of slope instability in this class are minimal because of low slope angle and therefore these areas are suitable for civil constructions.

Landslide hazard zonation (LHZ) map denotes spatial distribution of landslide hazard probability in an area. This can be used as an empirical guide for town planners to earmark relatively safe and unsafe



zones in the mountainous slopes. Civil constructions can accordingly be planned at suitable site after detailed stability analysis. Very low and low hazard classes are generally recommended as being suitable for developmental activities. Though susceptible to slope instability developmental works can be undertaken in moderate hazard class after detailed slope stability analysis. High and very high hazard classes mostly consist of unstable slopes and areas falling under these are typically inappropriate for development activities.

Macro scale landslide hazard zonation map prepared under the present study indicates that 31.6% of the total area falls in moderate hazard class, 21.6 in high hazard and only 1.7% in very high hazard class. In case of unstable slopes, detailed geological-geotechnical investigation is recommended on 1:2000 or 1:5000 scale in order to evaluate the nature of instability before identifying and designing suitable mitigation measures.

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