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Identification of Geomorphic and Geological Risk Based on Landslide

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Abstract – Identification of hazard inclined zones and guideline of formative activities in these is the way to catastrophe chance decrease. Avalanche is commonly comprehended as being down slant development of shake mass, garbage, soil and earth, with or without water, affected by gravity. It incorporates both consolidated and unconsolidated material originating from an assortment of geomorphic includes because of common and synthetic causes. Passing by the above definition help turns into a precondition for a region to be influenced via avalanches and it is alleviation that is an unquestionable requirement for identifying any territory as being precipitous. Avalanches are in this manner trademark highlight of bumpy or uneven territories. Slant instability is the most well-known hazard in every single bumpy region and inherent fragility of the territory makes Himalayan locale even more powerless to avalanches. Avalanche hazard evaluation factor rating scheme is used for outlining territories inclined to slant instability in the closeness of Mussoorie that is a noteworthy traveler goal of Uttarakhand in India. Of the 58 Sq. km region taken up under the examination 18.4, 12.5 and 1.0 Sq. km separately fall under moderate, high and extremely high avalanche hazard class Detailed stability evaluation is in this manner suggested for formative activities in moderate hazard class while regulating anthropogenic intercession is prescribed in both high and very hazard classes.

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1. INTRODUCTION

Landslides are one of the major geological hazards which not just purpose immense loss of lives and properties yet in addition influence numerous practical exercises. These are regularly come about because of slope unearthing in feeble geological formation and this is a typical wonder in Himalayan regions especially along the street cut slopes. Streets are frequently uncovered without earlier information of the stone mass strength and slope stability. Such sorts of slope disappointments should be captured rapidly generally these become incessant avalanche issues. General surveys on various types of remedial measures are accessible in numerous works. As indicated by these, modification of slope geometry, retaining structures, inside slope support and seepage are a couple of the remedial measures commonly considered to stabilize precarious slope.

Avalanche causes immense and repeating loss of human lives, framework and property and is frequently viewed just like a revile for the bumpy zones. This is anyway a critical landform building process that promotes soil formation. It is thusly no big surprise that substantial extent of homes in the slopes are located in nearness of old stabilized landslides as these give appropriate land to agrarian activities.

Like other bumpy regions, landslides are basic in the Himalayan territory of Uttarakhand in India and especially amid the storm time frame, rainy season in the Indian subcontinent, their event is especially high. The present investigation is attempted in the zone around Mussoorie that is located in Lesser Himalaya in nearness of Main Boundary Thrust (MBT) that conveys Upper Proterozoic to bring down Cambrian Lesser Himalayan tectogen in juxtaposition with Miocene to Pleistocene Siwalik Group of shake along a NNE plunging discontinuity. The stones uncovered in the territory are exceedingly fractured and sheared and the equivalent is essentially in charge of geological fragility of the zone. The zone has likewise seen seismogenic mass instability amid 1905 Kangara Earthquake.

Topography, slope morphometry, relative help, geomorphology, hydrogeology and land use/land spread are commonly considered to control dissemination of landslides and in this way these parameters are to a great extent observed while undertaking avalanche hazard zonation related investigations. Their circulation in space has been corresponded with various characteristic and man-made factors that are probably going to impact their event. This is proposed to help in defining of a reasonable procedure for limiting the threat of landslides. GIS has been perceived as an effective tool for examining avalanche vulnerability and the equivalent has been used for these investigations.

2. STUDY AREA

The present investigation covers 58 square kilometer territory around Mussoorie that falls in Survey of India (SOI) toposheet number 53 J/3(1:50000 scale) that has been used for the arrangement of base guide and undertaking avalanche hazard examination.

Arranged in closeness of the state capital Dehradun, Mussoorie is prominently named as the Queen of the Hills and is a popular traveler resort located on the main scope of slopes running east-west parallel to the Dehradun valley and the Siwaliks. Wide street going through the core of Mussoorie among Library and Landour, the Mall is popular among the guests. Mussoorie has a population of 33,651 of which 45% are females (Census of India, 2011). The population of the town is anyway exceptionally variable and amid the pinnacle visitor season (from April/May to September/October) similar observers complex increment.

3. RESEARCH METHODOLOGY

Landslide hazard evaluation factor rating scheme has been used for slope instability examination whereby all the thematic layers are arranged and corresponded. These incorporate slope aspect, topography, structure, slope morphometry, relative help, geomorphology, hydrogeology and land use/land spread. The aftereffects of the landslide hazard evaluation rating scheme are then associated with the information gathered in the field. Satellite imagery (LISS-IV) has been used for depicting land use/land spread attributes and explicit landforms; especially lineaments. For examination and relationship of various thematic layers Geographical Information System (GIS) condition has been utilized. The total procedure of large scale zonation of landslides hazards is delineated in Figure 1.

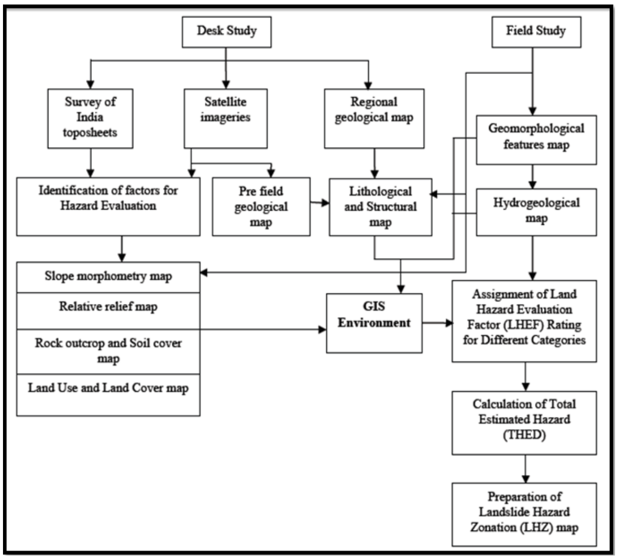

Figure 1 Flow chart showing the process followed for landslide hazard macro zonation mapping.

3.1 Geomorphology

Geomorphological processes or changes in the morphology of the ground are regularly recorded by prior maps, satellite symbolisms and study reports of the past landslides. These are likewise now and then archived in the records of watchful perceptions assumed control after some time by administration and neighborhood population. Geography has an imperative bearing upon the geomorphic advancement of a region, especially so in the slopes. The zone around Mussoorie is observed to be dismembered by a few edges and the ground heights differ somewhere in the range of 900 and 2290 meters above mean ocean level (msl). Lal Tibba with stature of 2290 meters above msl is the most astounding purpose of the territory while second most astounding point Gun Hill has an elevation of 2024 meters above msl. Organization Garden and Mussoorie Lake separately have rises of 1870 and 1880 meters above msl.

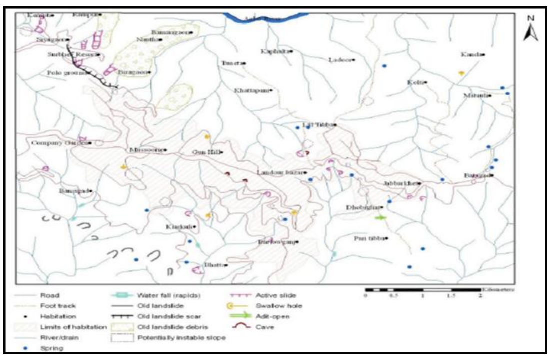

Figure 2 Geo-morphological features in Mussoorie

The engravings of geological and basic command over geomorphology of the territory are observed in the formation of strike edges and valleys at certain spots. Soak scarps, profoundly chiseled valleys and mass squandered scree slopes in the zone have been cut out by denudational processes. Structural discontinuities have offered ascend to soak precipices with all around created scarp in Kempty, Bhatta and Lal Tibba regions and these regions fall in the zone of most extreme hazard. Primary geomorphic features observed in the field are appeared in Figure 2.

3.2 LHEF rating scheme

Landslide hazard evaluation factor (LHEF) rating scheme is a numerical framework dependent on major causative factors of slope instability that incorporate lithology, structure, slope morphometry, relative alleviation, land use and land spread, roc k outcrop and soil spread and hydro-geological conditions. The greatest LHEF ratings for causative factors like lithology, structure, slope morphometry, relative help, land use and land spread and hydrogeological condition are 2, 2, 2, 1, 2 and 1 individually. Point by point LHEF ratings for individual causative factors is given in Table 1.

Table 1 Landslide hazard evaluation factor (LHEF) rating scheme

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
					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

3.3 Thematic layers

Thematic maps are set up based on the information gathered on various landslide causing factors that incorporate geography, slope morphometry, relative help and land use/land spread, hydrogeology. These are investigated feature insightful and LHEF values are determined for individual aspects through broad hands on work attempted in the region as likewise with the assistance of satellite symbolisms. All the thematic layers of contributory factors are produced in GIS condition. Readiness of all the thematic layers is described in the segments beneath.

3.4 Slope facet

A slope feature is a piece of slope that has pretty much comparable slope attributes and show steady slope course and tendency. Slope aspects are commonly delimited by edges, goads, gorges and streams. The whole zone around Mussoorie is separated into 350 slope aspects dependent on SOI toposheet (Figure 3).

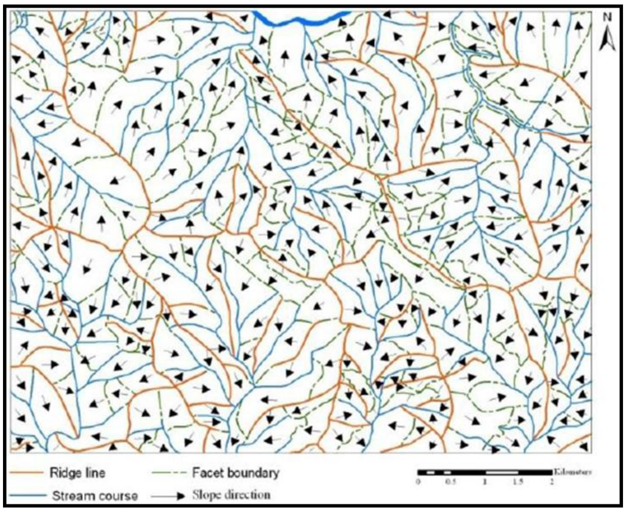

Figure 3 Slope facet of Mussoorie

4. GEOLOGY

Aside from the recorded information of landslides geomorphic and geological subtleties comprise vital source parameter for landslide hazard zonation. Stability of a site is subsequently frequently gathered from the geography that is viewed as a key parameter molding landslide event as affectability to dynamic geo-morphological processes, for example, landslides is considered to differ with topography. Due to this topography has been utilized as an information parameter to assess landslide defenselessness.

Geological set up of the territory is reconstructed after point by point hands on work embraced with an expect to recognize litho intelligent qualities of the various shake slopes and landslide zones. With the end goal of present investigation Krol

Formation is considered as one single litho unit spoken to by limestone/dolomitic limestone while Tal Formation is isolated into five lithounits; (I) quartzite, (ii) micaceous siltstone, dark and back shale, (iii) calcareous sandstone/sandy shale, (iv) silty shale and (v) chert.

The region includes Krol and Tal Formations of Lesser Himalaya, with Krol Formation representing its major portion. Overwhelming rock types incorporate calcareous ferruginous shale between had relations with argillaceous limestone (Upper Krol), thickly had relations with dim dolomite with thick beds of shale that contain nodules and flimsy lenticular beds of dark chert (Middle Krol), dim to dim dolomitic limestone with slight 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, dark to dim hued grouped shale and dim to dark shale (Middle Tal) and chert with phosphorite and silty shale (Lower Tal). The structural setup of the zone is outlined as a doubly diving NW-SE slanting syncline; the Mussoorie syncline that goes through Jaberkhet and Lal Tibba edge and dives at 10°-15° towards SE in the NW portion and at shallower edges towards NW in the SE portion.

4.1 Lithology

Erodibility or the reaction of rocks to the processes of weathering and disintegration is the primary criteria in choosing the ratings and in this manner an adjustment factor on the status of weathering of rocks has been consolidated and for these stone exposures in the zone has been mapped in detail. If there should be an occurrence of various kind of soil materials, expected profundity of overburden is considered for choosing the ratings (Figure 4).

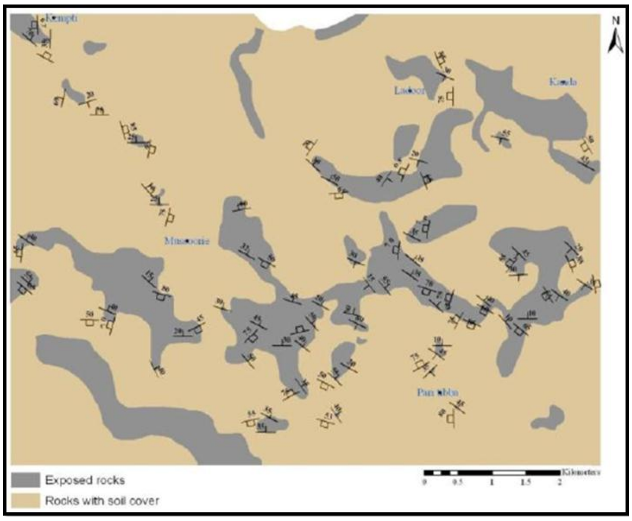

Figure 4 Bed rock exposures in Mussoorie

4.2 Structure

Primary and secondary discontinuities present in the stones are depicted and mapped. Stability of slope slopes to a great extent relies on the connection between spatial testimony of the discontinuities with the surface slope and this has been dealt with while working out LHEF ratings. The issues, cracks and joints not just destabilize the zone through crumbling of the strength of the stones, yet additionally quicken the weathering procedure. Displacement is observed in the calcareous sandy shale band located in the center of the syncline along a NW-SE drifting flaw going through Lal Tibba and Khattapani territory.

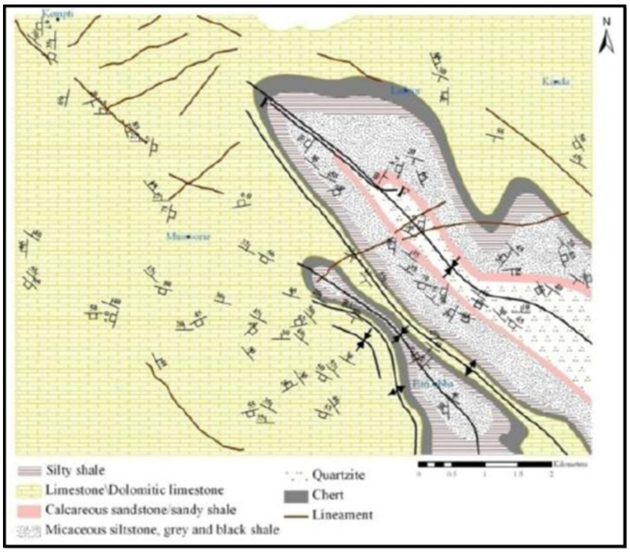

Figure 5 Structural map of the area around Mussoorie

Lineaments are direct features in a scene that are viewed as the declaration of the basic geological structure. Nearness of the lineaments portrayed from the satellite imagery has been approved from the geomorphic articulations observed in the field. These are observed to speak to tectonic discontinuities. It is essential to take note of that most lineaments demonstrate a pattern either parallel or transverse to the pattern of the Mussoorie syncline. Most lineaments observed in north and east of Mussoorie town show NE-SW to ENE-WSW pattern while noteworthy lineaments demonstrating NW-SE pattern are located in Kempty-Surbhee Resort and Kolti-Bhatta regions (Figure 5). Cushion of 100 meters has been considered on either side of the lineaments that have been granted an additional rating of 1.0 to oblige for higher landslide susceptibility in their proximity.

4.3 Slope morphometry

Slope morphometry map characterizes slope classifications based on frequency of event of specific edges of slope. This guide is set up by isolating the geographical guide of SOI into littler units with the form lines having a similar standard dispersing, that is, a similar number of shape lines per kilometer of horizontal separation. Besides, the individual slope category is partitioned into littler aspects of shifting slope points, which reflect a progression of limited procedure and control that have been imposed on the features. Five category of slope morphometry utilized for hazard evaluation incorporate (I) ledge/bluff, (ii) soak slope, (iii) decently soak slope, (iv) delicate slope and (v) delicate slope (Figure 6).

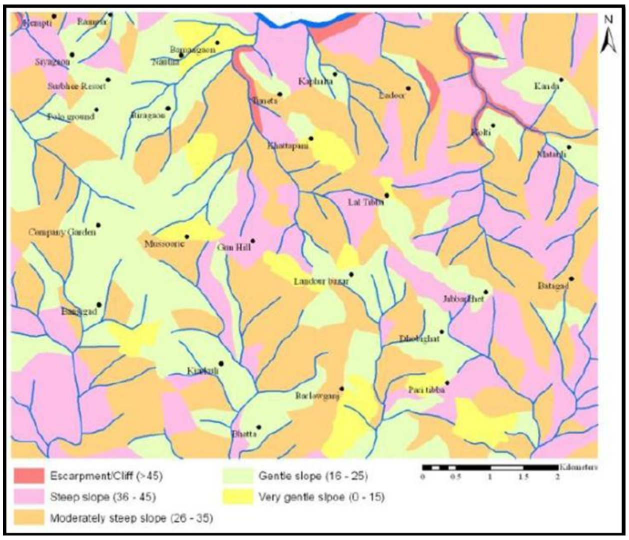

Figure 6 Slope morphometry map of Mussoorie

4.4 Relative relief

The relative alleviation map speaks to the neighborhood help of most extreme tallness between the edge top to the valley floor estimated in the slope course inside an individual facet. Help of a facet is determined by tallying contrast between elevations at base most purpose of a facet to top most purpose of the equivalent, along slope course. The area is in this manner separated into three classifications speaking to low, medium and high relative help (Figure7).

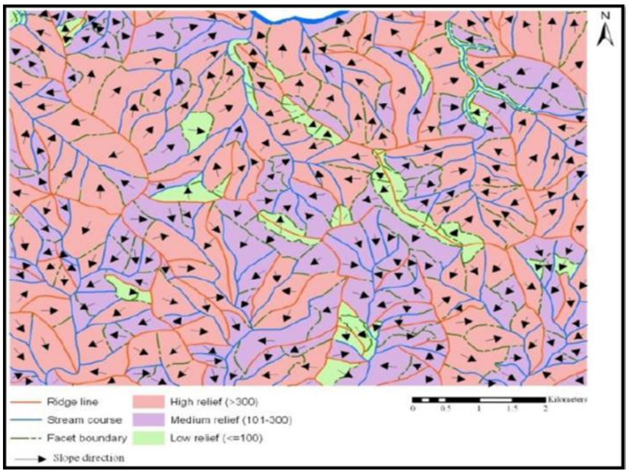

Figure 7 Relative relief of the area

4.5 Land use/land cover

Land use example of any area is chosen by the exchange of numerous factors that incorporate topography, slope, perspective, temperature, stickiness, population weight and nature of accessible monetary chances. Land use is perceived as having an imperative job in the instability of the slopes and among various land utilize classes' conveyance of vegetation is frequently connected with the event of landslides. Vegetation is considered to tie the soil together through an interlocking system of roots shaping disintegration resistant tangle that stabilizes the slopes. Fruitless slopes are in this manner considered progressively inclined to landslides. Horticulture by and large is rehearsed in low to low slopes however moderately soak slopes are likewise observed to be under agribusiness at certain spots. The farming terrains speak to areas of rehashed counterfeit water charging for cultivation purposes and are commonly steady. The land use/land spread is depicted from the satellite imagery. Seven land use/land spread classes distinguished in the area incorporate (I) thick woodland, (ii) open timberland, (iii) scrub backwoods, (iv) residence, (v) open area, (vi) agribusiness and (vii) water body (Figure 8).

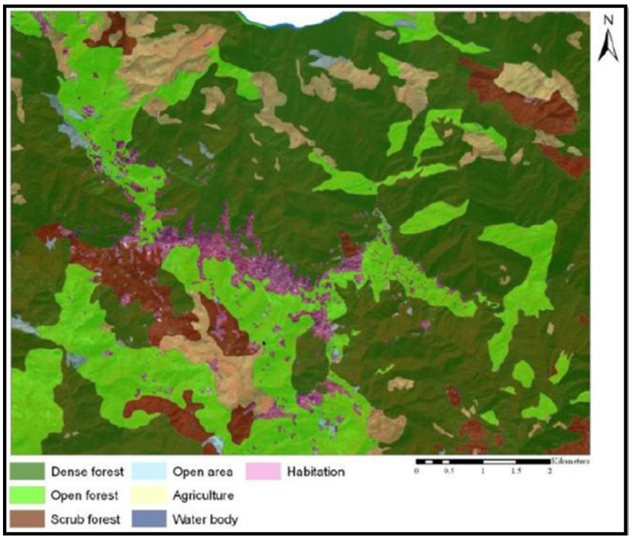

Figure 8 Land use/land cover area

4.6 Hydrogeology

The hydro-geological state of a slope is an imperative parameter to assess the stability of the slopes as water decreases the shearing strength of the slope framing material causing instability. Groundwater in the uneven landscape is for the most part channelized along structural discontinuities of rocks. It consequently does not have a uniform stream design. The observational evaluation of the groundwater on slope slopes is in this manner unrealistic over huge areas. In this way nature of surface indications of water, for example, soggy, wet, trickling and streaming are utilized for rating purposes (Figure 9).

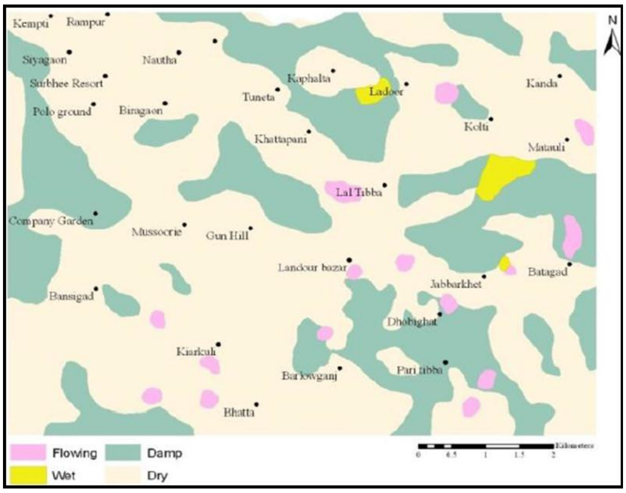

Figure 9 Hydro-geological map of Mussoorie

4.7 Total Estimated Hazard

Total estimated hazard (TEHD) demonstrates the net likelihood of instability and is determined facet shrewd. The TEHD of an individual facet is acquired by including the rating of the individual causative factors got from LHEF rating scheme. The last THED esteem is determined facet astute by including all estimation of slope instability parameters (IS 14496 Part 2). Total estimated hazard (TEHD) in this way equals ratings for lithology, structure, slope morphometry, relative help, land use/land spread and hydro-geological conditions. Landslide hazard zonation (LHZ) guide of an area on full scale depends on the facet-wise distribution of TEHD values that are given in Table 2.

5. RESULT AND DISCUSSION

The last landslide hazard zonation (LHZ) map arranged on 1:50000 scales has been ordered into five hazard classes that incorporate (I) extremely high hazard, (ii) high hazard, (iii) moderate hazard, (iv) low hazard and (v) exceptionally low hazard (Figure 10). Details of the proportion of geological area falling under various LHZ classes are described in the areas beneath.

Table 2: Distribution of TEHD values and LHZ classes

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

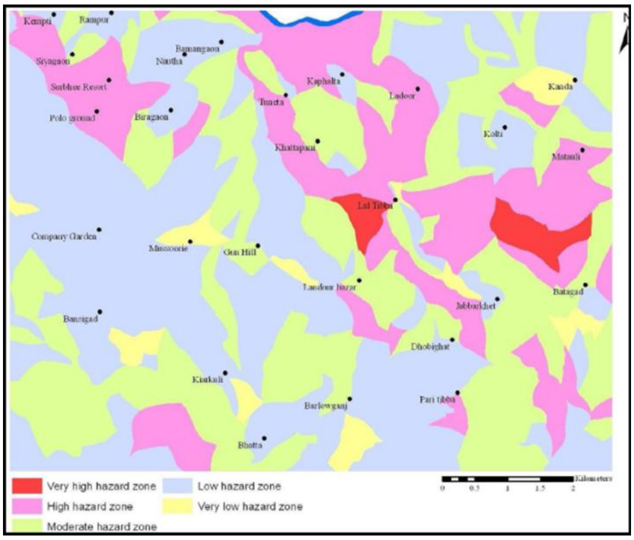

Figure 10 Landslide hazard zonation map

- **Very high hazard class -** Steep slope classes represent practically all the area falling under this hazard class. Area toward the northwest of Bataghat and southwest of Lal Tibba is observed to fall under this hazard class. Despite the fact that these areas are genuinely a long way from habitation anthropogenic intervention of any sort ought to be directed in the areas falling under this class is very inclined to landslides and not suitable for developmental works of any sort.

- **High hazard class -** Numerous tectonic discontinuities that incorporate lineament and blame plane are observed to navigate through this class. Numerous dynamic landslides additionally happen in this class. Area toward the north of Company Garden, north and east of Lal Tibba, west of Jaberkhet and southwest of Kiarkuli fall under this class. Anthropogenic intervention in these areas ought to be kept away from to the degree possible.

- **Moderate hazard class -** Several old landslides are observed in this class towards the western limit of the Mussoorie synclinal pivot. Moderately steep slope class represents practically all the area falling under this class. Area toward the east of Pari Tibba and Jaberkhet, west of Kiarkuli and Bhatta, northwest of Barlowganj and upper east of Khattapani fall under this zone. Extraordinary consideration is required in this class and areas with more than 25° surface slope ought to be kept free of anthropogenic intervention.

- **Low hazard class -** This class is commonly observed to have delicate to moderate slope angles and is to a great extent secured by thick backwoods, open woods and settlements. For the most part the areas toward the west of Mussoorie synclinal hub fall under this class. These areas are commonly suitable for developmental works; earlier detailed stability examination anyway is an unquestionable requirement in the slopes.

- **Very low hazard class -** Most area falling under this class has low slope point and is frequently level surface or level ground. The areas toward the southeast of Gun Hill, Bansigad and Kiarkuli, south of Barlowganj and Bataghat and west of Kanda fall under this class. The odds of slope instability in this class are insignificant in light of low slope point and along these lines these areas are suitable for common developments.

Landslide hazard zoantion (LHZ) map indicates spatial distribution of landslide hazard likelihood in an area this can be utilized as an exact guide for town planers to reserve relatively protected and dangerous zones in the rocky slopes. Common developments can as needs be arranged at suitable site after detailed stability investigation. Low and low hazard classes are commonly prescribed as being suitable for developmental exercises. Despite the fact that helpless to slope instability developmental works can be embraced in moderate hazard class after detailed slope stability examination. High and extremely high hazard classes for the most part comprise of unstable slopes and areas falling under these are commonly improper for advancement exercises.

Macro scale landslide hazard zonation map arranged under the present investigation demonstrates that 31.6% of the total area falls in moderate hazard class, 21.6 in high hazard and just 1.7% in high hazard class. If there should be an occurrence of unstable slopes, detailed geological-geotechnical examination is suggested on 1:2000 or 1:5000 scale so as to assess the idea of instability before identifying and planning suitable relief measures.

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