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Full Length Research Paper

Landslide Disasters in Uttarakhand: A Case of Landslide Susceptibility Zonation of Alaknanda Valley in Garhwal Himalaya

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Abstract
The problem of landslides and mass wasting in the Himalaya are very high in comparison to those in most other parts of the world. The landslide susceptibility of a region is important for socioeconomic considerations and engineering applications. The aim of the present paper is to prepare the landslide susceptibility Zonation of Alaknanda valley of Garhwal Himalaya. The study area is very important from the point of view of previous landslides which took a heavy tool of human lives. Landslide locations were identified in the study area from interpretation of aerial photographs and field surveys. In the present study geo-environmental factors, such as lithology, slope, structure, relative relief, drainage conditions and land-use were considered for the assessment of susceptible zones for landsliding.

Key Words: *Landslide susceptibility Zonation; geo-environmental factors; landslide susceptibility value; landslide susceptibility index;*

Introduction
Landslide can be considered as one of the most destructive geological processes causing not only the enormous damage to roads, bridges, houses but even cause loss of life. Though, landslide hazards cannot be completely prevented but their intensity and severity can be minimized by taking effective mitigation measures and by planning for disaster preparedness. For this purpose, landslide hazard zonation maps are prepared. The landslide hazard zonation of an area aims at identifying the landslide potential zones and ranking them in order of the degree of hazard from landslides. In other words, it is the spatial prediction of landslide potential areas and they are useful for planning and implementation of various developmental schemes in hilly areas. Roads, building constructions, planning design and execution of developmental schemes, may not incorporate adequate details of geological and geotechnical considerations due to finance and time but detailed geological report even at the cost of increase in expenditure is highly desirable. These reports will adequately deal with hazard possibilities within the region. This also demonstrates the necessity of preparing landslide hazard zonation maps, based on various mountain conditions and using them as the basis for planning future development schemes (Z. A. Malik, 2013).

Study area
The area under investigation lies in the Alaknanda valley (district Chamoli), Garhwal Himalaya of Uttarakhand (Fig. 1). It falls in the Lesser and Higher Himalayan zones. The study area comes under the Survey of India toposheet Nos. 53N/6, 53N/7, 53N/10 and 53N/11. The toposheets have been enlarged up to the scale of 1:25,000 for the study.

The study area lies within 79°15' to 79°40' E longitudes and 30°20' to 30°25' N latitudes. Chamoli town is about 220 km away by road from the nearest railway station known as Rishikesh. The connecting road which runs along Alaknanda valley often shows landslides during the rainy season, which adversely affect the communication, trade and tourism. The area is drained by Alaknanda and its tributaries named as Gorsal gad, Balasuti gad, Bhimtala gad, Chinka gad, Pipalkoti gad, Garur Ganga, Belakuchi gad, Ganesh ganga, Kalp Ganga, Karamnasa, Dunli gad and Vishnu gad and Dhauliganga.

Methodology
In this work a simple and easily adopted methodology for the preparation of landslide hazard zonation maps was formulated following the methodologies suggested by Anbalagan (1992) and Department of Science and Technology (DST), New Delhi (1994). The data acquired from the various terrain factors that contribute to instability were recognized. Lithology, structure, slope, relative relief, hydrology including surface and subsurface drainage and landuse/land cover were identified as important terrain factors.
Maximum landslide hazard evaluation factors (LHEF) rating for the above mentioned contributory factors was determined as suggested by Anbalagan (1992). The LHEF rating scheme is a numerical rating system, which is based on major inherent causative factor of slope instability. In Table 1, the LHEF rating scheme is presented for macro zonation of the study area. The LHZ map of the

study area was prepared on 1:50,000 scale and the maximum LHEF rating for different categories are determined on the basis of their estimated significance in causing instability (Anbalagan 1993). Numbers 10 indicates the maximum value of the total estimated hazard (THED).

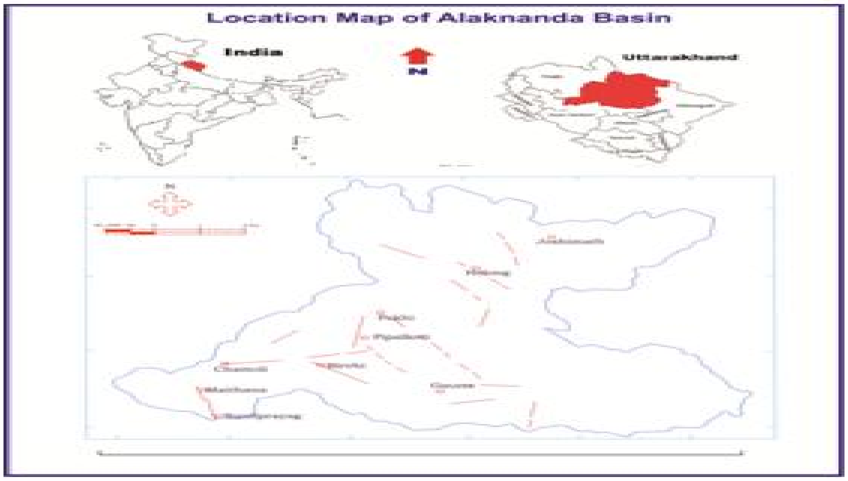

Table 1: Proposed maximum landslide hazard evaluation factors (LHEF) of different contributory factors

Contributory factor	Maximum LHEF rating
Lithology	2
Structure	2
Slope morphometery	2
Relative relief	1
Landuse and land cover	2
Hydrological conditions	1
Total (six factors)	10

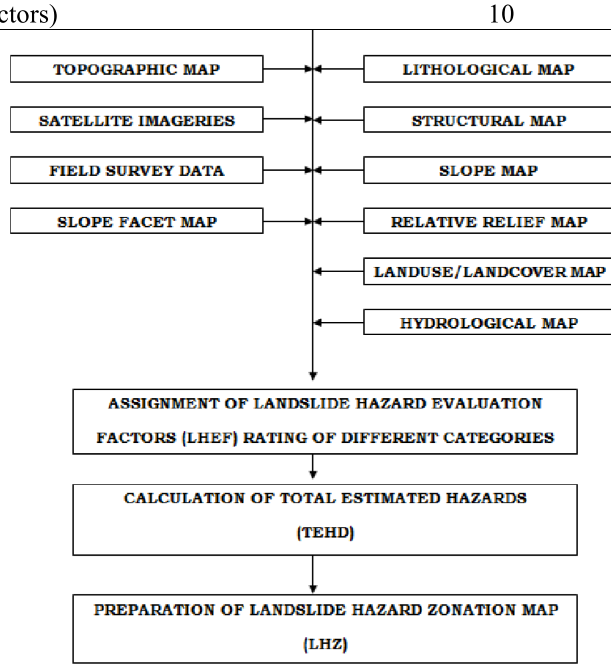

Fig 1 Flow Chart of Landslide Hazard Zonation Map

Preparation of thematic maps

A flow diagram depicting the various steps involved in the preparation of landslide hazard zonation map is given as Fig. 1. Various causes related to the instability of the slope were identified and their thematic maps were prepared on scale of on a scale of 1:50,000. These maps are based on the Survey of India toposheets as well as field data, and help from satellite data was also taken during their preparation.

(i) Lithology: Quartzites, slates, carbonates, schists and gneisses are the major rock types present in the area (Fig. 2). Nature and types of rocks along with its composition, texture and erodibility or the response to the processes of weathering and erosion are the main criteria in awarding the ratings for sub–categories of lithology.

Some of the slope facets are overlain by the soil. Therefore, in such case the genesis and age of soil are the main considerations in awarding the ratings. The slope composed by the compacted (older alluvium) material shows a high shearing resistance than the recent materials such as slide debris etc.

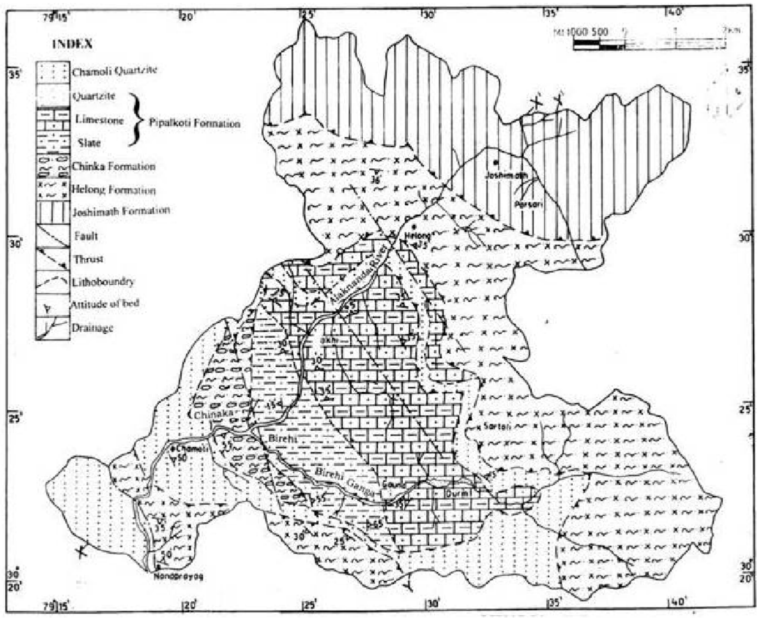

Fig 2 Geological Map of the Study Area

(ii) Structure: The area is traversed by a number of major and minor discontinuities of primary and secondary origin. Among them, joints, fault, thrust, shear zones are important one and they have a great influence on the stability of the slope. Furthermore, the intersection of two discontinuities increases the probability of slope failures. Besides the minor discontinuities, Main Central Thrust, Nandprayag, Birehi, Pakhi and Gulabkoti are the prominent faults zones present in the study area (Fig. 3). It was observed that concentration of slide zones was observed in the vicinity of the major faults/thrusts; therefore, the rating for structure was awarded on the basis of distance from the major thrusts and faults.

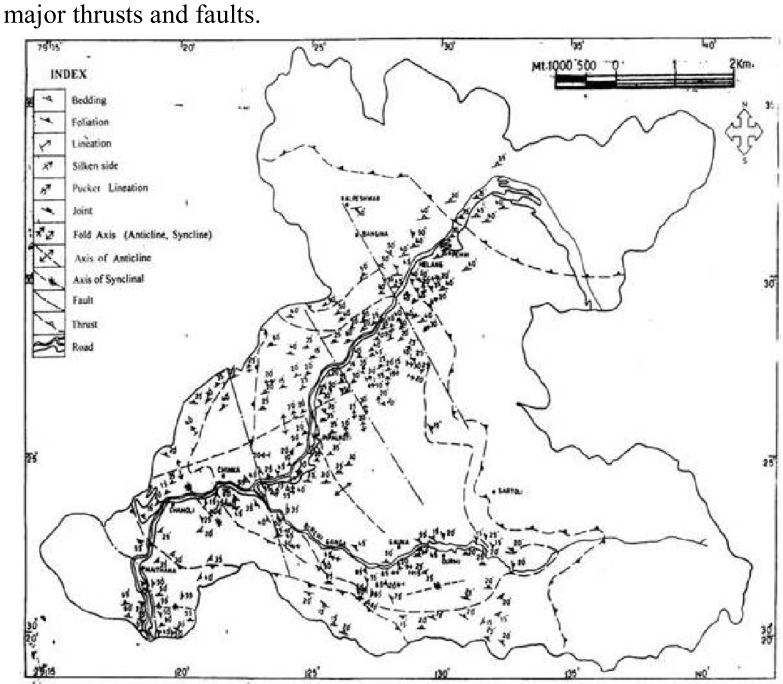

Fig 3 Structural Map of the Study Area

(iii) Slope map: On the basis of toposheets and field observations, a slope map of the area was prepared (Fig. 4). Furthermore, the individual slope category was divided into smaller facets of varying slope angles, which reflect a series of localized process and control, have been imposed on the facets (Anbalagan, 1992).

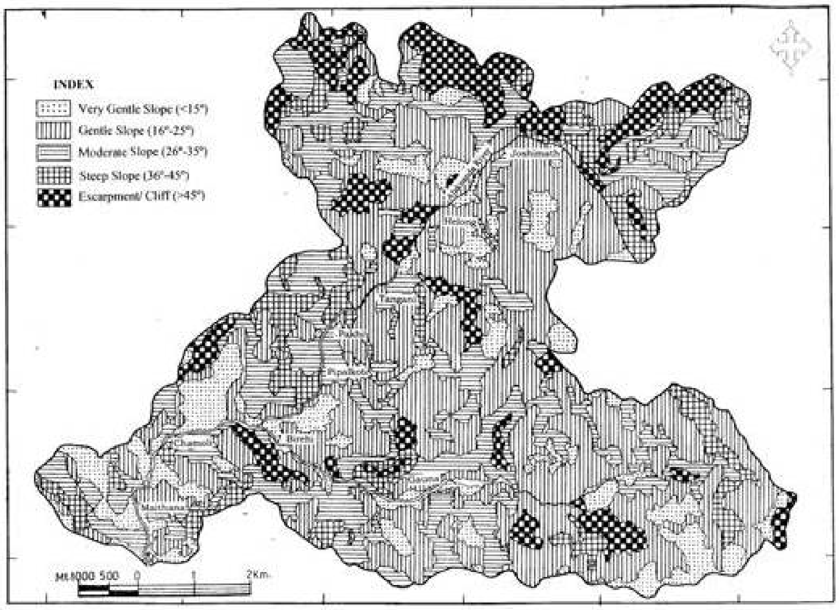

Fig 4 Slope map of the Study Area

(iv) Relative relief: The relative relief map was prepared with help of toposheets (Fig. 5) represents the difference between the highest and lowest heights within the individual facet. It gives a better understanding of the ruggedness of terrain as well as the range of the relief. The study area has been divided into seven categories of relative relief and they are <1400 m, 1401 to 2000 m, 2001 to 2600 m, 2601 to 3200 m, 3201 to 3800 m, 3801 to 4400 m, and >4400 m.

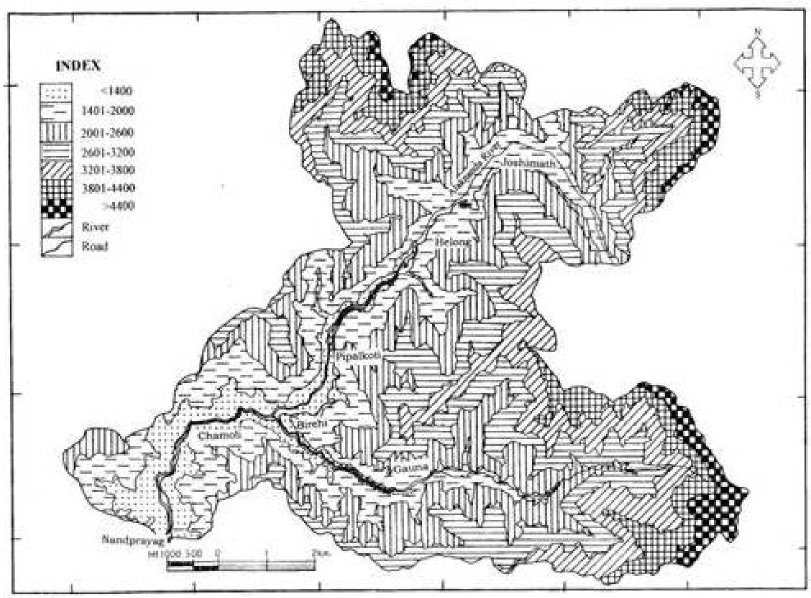

Fig 5 Relative Relief Map of the Study Area

(v) Landuse and land cover: The study area may be divided into three well defined landuse/land cover categories (Fig.6). Most of the slide zones are exists in barren land followed by cultivated landuse. Greater instability in the barren land may be understood by the rapid erosional activity, while the anthropogenic activities seem to be the major cause of the landslides in the agricultural landuse.

It was observed that gentle slope protected by cover of vegetation reduces the velocities of surface runoff and thus reducing the erosion. The dense forest cover over the slope smoothen the action of climatic agent, hence reduces the weathering and erosion processes. On the basis of the field observations, the rating has been awarded for the different categories of the landuse and land cover.

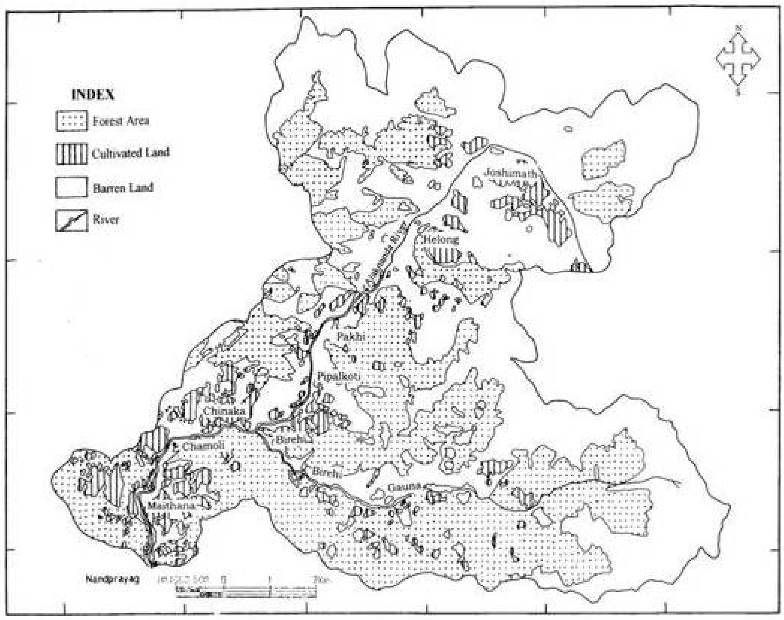

Fig 6 Landuse and Landcover Map of the Study Area

(vi) Hydrological conditions: The instability of the slopes is influenced by surface as well as sub-surface water. The study shows five drainage patterns (Fig. 7) depicted the condition of surface water. The rating for surface water was awarded on the basis of geomorphological significance. The ground water (sub-surface water) is generally controlled by the structural condition of the bed rocks and manifested in the form of springs. For the hazard zonation purposes, the surface indications of ground water was observed as dry, damp, wet, dripping and flowing conditions. These observations were taken for individual slope facets, after the monsoon period, provide probably the worst ground water conditions.

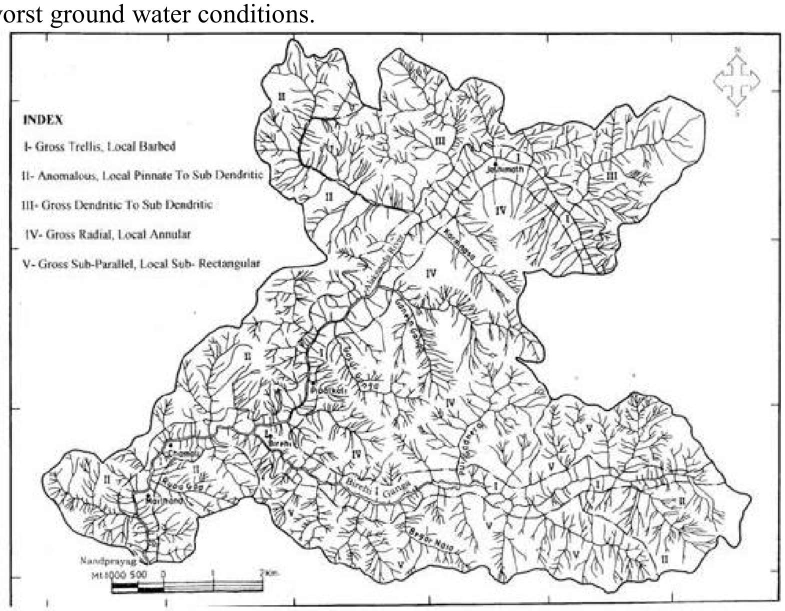

Fig 7 Drainage map of the Study Area

(vii) Slope facet map: The study area was divided into 364 small slope facets. With help of Survey of India toposheets, field and satellite data, slope facet map of the area was prepared (Fig. 8). A facet is the basic smallest unit consisting of one or more slope elements reasonably homogenous for all practical purposes and suited to a mapping scale of 1:50,000 to 1:1,00,000 (Mitchell,1973). It is a part of hill slope having more or less similar characters showing consistent slope direction and inclination. A detailed LHEF rating scheme, with ratings for a variety of sub-categories for individual causative factors is given in Table 2.

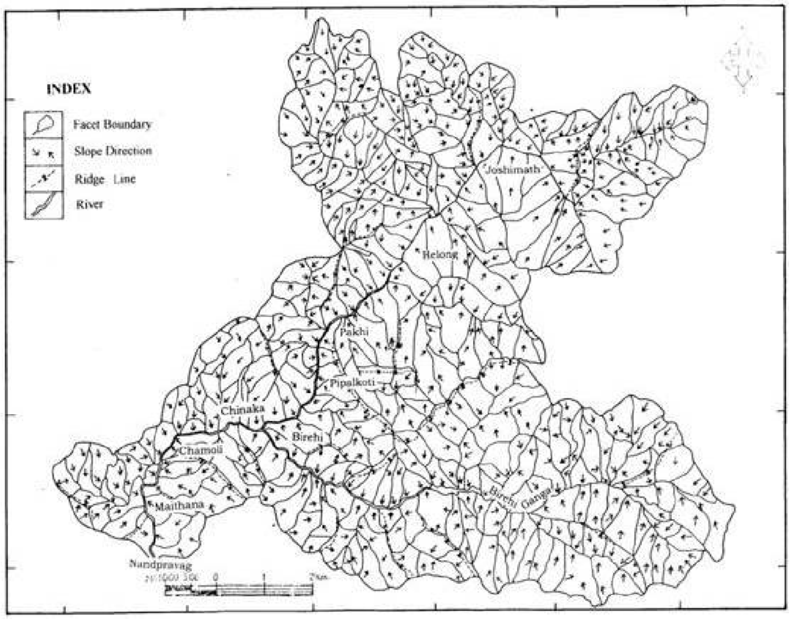

Fig 8 Facet Map of the Study Area

Results

On the basis of TEHD value, a landslide hazard zonation map of the area was prepared (Fig. 9). The study area was divided into five hazard zones viz. vary low hazard, low hazard, moderate hazard, high hazard and vary high hazard in terms of susceptibility of landslides (Table 3). The field investigations also suggest that most of the existing landslide zones are comes under the very high and high hazard category. The potential and minor slope failures fallen in the moderate and low hazard zones, while the area comes under the very low hazard are free from slope instability.

Table 2 Landslide hazard evaluation factor (LHEF) rating scheme

Description of the factor	Category	Rating
Lithology	Younger alluvium/ loose material	2.0
	Older alluvium	1.4
	Schist	1.3
	Slate/Phyllite	1.2
	Gneiss	0.4
	Carbonate	0.3
	Quartzite	0.2
Structure	< 0.5	2.0
(distance from major thrust/fault in km)	0.5 to 1.5	1.5
	1.5 to 2.5	1.2
	2.5 to5.0	1.0
	>5.0	0.5
Slope		
Escarpment or cliff	>45°	2.0
Steep slope	36° to 45°	1.7
Moderate slope	26° to 35°	1.2
Gentle slope	16° to 25°	0.8
Very Gentle slope	<15°	0.5
Relative relief	> 4400	2.0
(in meters)	3800 to 4400	1.8
	3200 to 3800	1.5
	2600 to 3200	1.3
	2000 to 2600	0.8
	1400 to 2000	0.5
	<1400	0.3
Landuse/Landcover	Barren land	2.0
	Forest land	1.5

	Cultivated land	0.8
Hydrology		
A.Ground water condition	(i) Flowing	0.50
	(ii) Dripping	0.40
	(iii) Wet	0.25
	(iv) Damp	0.10
	(v) Dry	0.00
B. Surface drainage patterns		
	(i) Anomalous local pinnate to sub-dendritic	0.50
	(ii) Gross trellis local barbed	0.40
	(iii) Gross sub- parallel local sub- rectangular	0.25
	(iv) Gross radial local annular	0.15
	(v) Gross dendritic to sub-dendritic	0.05

Table 3 Description of various hazard zones, on the basis of total estimated hazard (TEHD)

S. No.	Zones	Description of zones
1	Very Low Hazard (VLH)	Slopes composed mostly by the unweathered material with favorable discontinuities. Slopes are mostly stable.
2	Low Hazard Zone (LH)	Slopes constituted by unsaturated, slightly weathered material. Generally favorable discontinuities are present and some minor scars over the slope shows little failure or instability.
3	Moderate Hazard Zone(MH)	Slopes characterized by minor and local faults, moderately weathered and eroded, and partially saturated material. The zone contains unfavorable discontinuities and these are the potential zone of instability.
4	High Hazard Zone (HH)	Slopes characterized by presence of major faults and shears zones, moderate to highly weathered and eroded, and saturated material with unfavorable discontinuities. The zone shows minor to moderate slope failures.
5	Very High Hazard Zone (VHH)	It consist a number of existing landslide zones. Slopes are characterized by the presence of shear zones and faults, highly weathered, eroded and saturated earth material with unfavorable discontinuities.

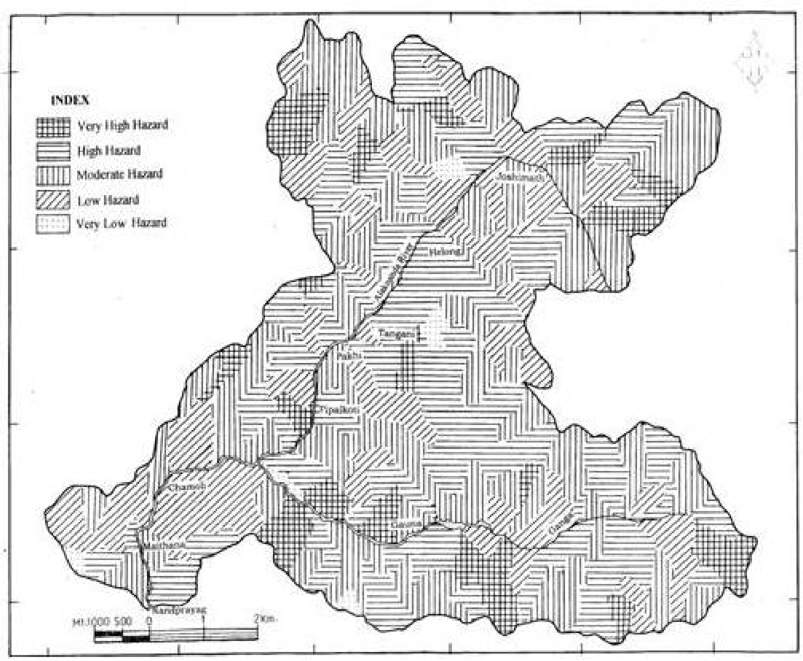

Fig 9 Landslide Hazard Zonation map of the Study area

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