Landslide Hazard Zonation Mapping and Digital Elevation Model (DEM) Development of a Part of Tehri Dam Reservoir Area Pertaining to Bhilangna Valley

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ABSTRACT

The mountainous terrains such as Himalaya are characterized by steep slopes, high relative relief, weathered, fractured and folded rocks in addition to unfavourable hydrogeological conditions. The mountainous terrains such as Himalaya, though look to be mighty and strong, have inherent weak geological features such as thrust, faults, shear zones, joints and bedding. In addition, the pace of the modern development has been accelerated in the recent times with the construction of dams, roads, buildings, industries and a number of civil structures. These constructions seldom take into consideration the existing slope instability. The planning, design and execution of development schemes in these terrains should take into account the existing instabilities of the area. Moreover the unstable zones facing environmental degradation have to be identified and studied in detail for evolving suitable mitigation measures. For that purpose a quantitative approach based on the numerical rating called landslide hazard evaluation factor (LHEF) rating scheme has been used for preparing the Landslide Hazard Zonation (LHZ) map of a part of Tehri Dam Reservoir Area pertaining to Bhilangna Valley.

Keywords: Landslide; Dam; Stability; Reservoir; Hazard; Zonation.

1. INTRODUCTION

A 260.5 m high rock-fill dam is now built across Bhagirathi river downstream of the confluence of the river Bhilangna near Tehri township (Fig 1). The gross storage at El 840 m which would create a long reservoir in both Bhagirathi and Bhilangna is estimated to be $35.5 \times 10^8 m^3$. The Tehri lake will extend upto 44 km along river Bhagirathi and 25 km along river Bhilangna and it is flanked by high hills all along both the sides. Part of this reservoir area pertaining to Bhilangna valley constitutes study area. The water level in the lake will vary by 90 m between the normal maximum reservoir level and the dead storage level from October to June every year. According to Mazari (1983) the shear parameters may be adversely affected because of saturation of rocks and the slopes along the reservoir rim may slide causing large scale movements due to fluctuation in the lake. He felt that large scale hill slides in the reservoir may pose serious threats to the dam by formation of 'seiches (huge water waves)'. Small scale slides can cause siltation and deforestation. Fears have been expressed regarding large scale hill slides in Tehri reservoir area.

Landslide hazard zonation (LHZ) map is an important tool for the planners, field engineers and geologists. A landslide hazard zonation (LHZ) map classifies the land surface into zones of varying degree of hazards based on the estimated significance of causative factors which influence the stability (Anbalagan, 1992a). The LHZ map is a rapid hazard assessment of the land surface and is useful for the following purposes:

(i) The LHZ maps help the planners and field engineers to avoid hazard prone areas and choose favourable location for site development schemes. Wherever they are unavoidable, their recognition before construction helps to adopt proper precautionary measures.

(ii) The LHZ maps identify and delineate the hazardous areas of instability for adopting sound mitigation to check further environmental degradation of the area.

The reliability of LHZ map is essentially dependent on the rating system of causative factors adopted, which has been well established in parts of Kumaun and Garhwal Himalaya of India (Gupta et al., 1993; Gupta & Anbalagan, 1995; Anbalagan et al.,1992; Anbalagan et al., 1993; Anbalagan and Singh, 1996 and Anbalagan and Tyagi, 1996).

2. LANDSLIDE HAZARD ZONATION MAPPING BASED ON LANDSLIDE HAZARD EVALUATION FACTOR (LHEF) RATING SCHEME

The landslide hazard evaluation factor (LHEF) rating scheme (Anbalagan, 1992b) is a numerical rating system, which is based on major inherent causative factors of slope instability namely lithology, structure, slope morphometry, relative relief, land use and land cover and groundwater conditions. The maximum LHEF ratings for different categories are determined on the basis of their estimated significance in causing instability (Table 1). The numeral 10 in Table 1 indicates the maximum value of the total estimated hazard (TEHD). The detailed rating scheme includes various sub-categories of major causative factors as show in Table 2. The LHZ map is prepared on the basis of distribution of TEHD in an area on the basis of Table 3 (Anbalagan, 1992a).

3. LANDSLIDE HAZARD ZONATION OF THE STUDY AREA

The present investigation covers a part of Tehri Dam reservoir area falling between Tipri and Ghonti villages, (Fig. 2).

Table 1 - Proposed maximum LHEF rating for different contributory factors for LHZ mapping

Contributory Factor	Maximum LHEF Rating
Lithology	2
Relationship of Structural discontinuities with slopes	2
Slope Morphometry	2
Relative Relief	1
Landuse and Landcover	2
Groundwater	1
Total	10

3.1 Geology of the area

The Garhwal Himalaya falls in one of four well-defined tectonic geomorphic zones (Deoja et al., 1991), each being a distinct geologic unit - (i) Siwalik or outer Himalaya, (ii) Lesser Himalaya (inner lesser Himalaya and outer lesser Himalaya), (iii) Great Himalaya, and (iv) Tibetan Himalaya (Fig. 3). The area of study lies in the outer lesser Himalaya of Uttarakhand. The rocks exposed in the study area belong to the Chandpur formation of Jaunsar Group (Fig. 4). The rocks of the Chandpur formation are low grade metamorphosed lusturous and shiny phyllites. These phyllites are olive green and grey in colour interbedded and finely interbanded with metasiltstone. The Chandpur formation is delimited towards north by a thrust trending roughly northwest-southeast and dipping southwest. The stratigraphic sequence of the study area is shown below (Valdiya, 1980):

Group	Formation	Rock type
Jaunsar Group (Lower Palaeozoic to Proterozoic)	Nagthat – Berinag Formation	Quartzites interbedded with slates and phyllites
	Chandpur Formation	Grey phyllites interbedded with meta-siltstone and quartzitic phyllites
Tejam Group (Proterozoic)	Deoban Formation	White and light pink dolomites
Damtha Group (Proterozoic)	Rautgara Formation	Quartzites interbedded with sublitharenites, slates and metavolcanics

3.2 Landslide Hazard Zonation Mapping

The LHZ map of this area has been prepared on 1:50,000 scale using LHEF rating scheme. For that purpose a facet map of the area has been prepared (Fig. 5). A facet, is a part of hill slope which has more or less similar characters of slope, showing consistent slope direction and inclination. The thematic maps of the area namely lithological map, structural map, slope morphometry map, land use and land cover map, relative relief map, ground water condition map have been prepared using the detailed LHEF rating scheme (Table 2).

3.2.1 Lithology

Lithology is one of the major causative factors for slope instability. The rock types observed in the area and its vicinity is phyllite. Phyllites are exposed on either bank close to Bhilangna river. On the left bank, the phyllites are generally weathered close to the surface and support thin soil cover.

3.2.2 Structure

The structures used for landslide hazard zonation mapping includes joints and foliations. The general trend of the structural discontinuities for the area of study is given below. The inter-relation of the structural discontinuity with slope is studied carefully to award the ratings (Table 2).

Discontinuity	**Orientation**	
	Dip Direction	Dip Amount
1. Foliation	N216°	38°
2. Joint set J1	N199°	46°
3. Joint set J2	N110°	79°

3.2.3 Slope morphometry

The slope morphometry map represents the zones of different slopes, which have specific range of inclination. The area of study has a good distribution of slope categories. The area to the left bank of Bhilangna mainly occupied by terrace deposits fall in the category of very gentle slope. Gentle slopes are mainly confined to the agricultural fields. It has a good distribution throughout the area of study. Moderately steep slopes are also present throughout the area of study (Fig. 6). The steep slopes are present at relatively fewer locations. Very steep slopes/escarpments occur in small patches mainly close to the water courses possibly because of toe erosion.

3.2.3 Land use land cover

Vegetation cover generally smoothens the action of climatic agents and protects the slope from weathering and erosion. The nature of land cover may indirectly indicate the stability of hill slopes. The agriculture lands/populated flat lands are extensively present in some central parts of study area. The thickly vegetated areas are mainly present in eastern parts of study area. Moderately vegetated area is having good distribution throughout in study area. The sparsely vegetated and barren lands are mainly confined to right bank of Bhilangna river (Fig. 7).

3.2.5 Relative relief

Relative relief is the maximum height between the ridge top and valley floor within an individual facet. Medium relief is the most prominent in area of study. High relief is present mainly on right bank of river (Fig. 8).

3.2.6 Ground water condition

The surface manifestation of ground water such as wet and damp have been observed in the study area. The area dominantly shows damp condition. Wet conditions are present in a number of facets on left bank of the river (Fig. 9).

3.2.7 Landslide hazard zonation

The sum of all causative factors within an individual facet gives the total estimated hazard (TEHD) for a facet. The TEHD indicates the net probability of instability within an individual facet. Based on the TEHD value, facets are divided into different categories of hazard as shown in Table 3 and Fig. 10 (Anbalagan, 1992b).

Table 3 - Landslide hazard zonation on the basis of total estimated hazard (TEHD)

Zone	TEHD Value	Description of Zones
I	< 3.5	Very Low Hazard (VLH) Zone
II	3.5 - 5.0	Low Hazard (LH) Zone
III	5.1 - 6.0	Moderate Hazard (MH) Zone
IV	6.1 - 7.5	High Hazard (HH) Zone
V	> 7.5	Very High Hazard (VHH) Zone

The three categories of hazards, namely, low hazard (LH), moderate hazard (MH), high hazard (HH) are found to be present in the study area. The areas showing very low hazard (VLH) and very high hazard (VHH) are not present. The areas showing moderate hazard are the most prominent one. HH zones represent areas of greater instability where detailed investigations have to be carried out.

4. APPLICATION OF GIS

Digital Elevation Model (DEM) prepared by using GIS package ILWIS 1.4, shows that area of study consists of number of steep slopes (Fig. 11). DEM has been prepared after digitization of contours, rasterization and interpolation. Drainage map of area of study shows dendritic drainage pattern (Fig. 12).

5. CONCLUSIONS

In the planning of development schemes in mountainous terrains the existing instabilities of slope should be taken into consideration so that the schemes may be executed with minimum disturbance to the environment of the area. For that purpose the LHZ maps help to identify the high and very high hazard areas. The VLH and LH zones are generally considered safe for development schemes. The MH zones may contain some local vulnerable zones of instabilities. Wherever HH and VHH zones are unavoidable for implementing the development schemes, detailed investigations to understand the nature of instability may have to be carried out in order to find environmentally sound remedial measures.

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Table 2 - Landslide Hazard Evaluation Factor (LHEF) Rating Scheme

Contributory Factor	Category	Rating	Remarks
Lithology *Rock Type*	*Type-I*		*Correction factor for weathering :* (a) Highly weathered - rock discoloured joints open with weathering products, rock fabric altered to a large extend; Correction factor C_1 (b) Moderately weathered - rock discolored with fresh rock patches, weathering more around joint planes, but rock intact in nature; correction factor C_2. (c) Slightly weathered - rock slightly discolored along joint planes, which may be moderately tight to open, intact rock; Correction factor C_3. **The correction factor for weathering should be multiplied with the fresh rock rating to get corrected rating** *For rock type I* $C_1 = 4$, $C_2 = 3$, $C_3 = 2$ *For rock type II* $C_1 = 1.5$, $C_2 = 1.25$, $C_3 = 1.0$
	Quartzite & Limestone	0.2	
	Granite & Gabbro	0.3	
	Gneiss	0.4	
	Type-II		
	Well-cemented terrigenous sedimentary rocks, dominantly sandstone with minor beds of claystone	1.0	
	Poor cemented terrigenous sedimentary rocks, dominantly sandstone with minor clay shale beds	1.3	
	Type-III		
	Slate & phyllite	1.2	
	Schist	1.3	
	Shale with interbedded clayey & nonclayey rocks	1.8	
	Highly weathered shale, phyllite and schist	2.0	
Soil Type	Older well-compacted fluvial fill material (alluvial)	0.8	
	Clayey soil with naturally formed surface (eluvial).	1.0	
	Sandy soil with naturally formed surface (alluvial).	1.4	
	Debris comprising mostly rock pieces mixed with clayey/sandy soil (colluvial)		
	I. Older well compacted	1.2	
	II. Younger loose material	2.0	
			Contd…..

Table 2 - Continued

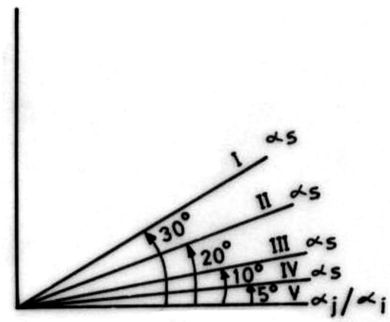
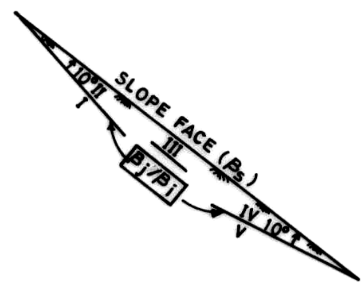
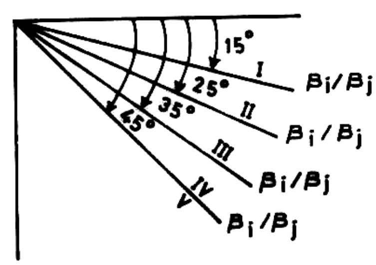
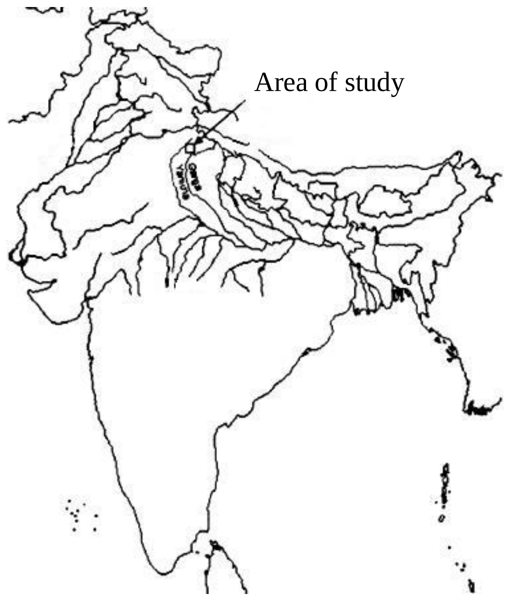
Contributory Factor	Category	Rating	Remarks
Structure *Relationship of structural discontinuity with slope.*			
*Relationship of parallelism between the slope and the discontinuity.** PLANAR (α_J - α_s) WEDGE (α_I - α_s)	I > 30° II 20°-30° III 11°-20° IV 6°-10° V≤ 5°	0.20 0.25 0.30 0.40 0.50	 Parallelism between the slopes and discontinuity (α_j/α_I- α_s) 
Relationship of dip of discontinuity and inclination PLANAR (β_j - β_s) WEDGE (β_j - β_s)	I > 10° II 0°-10° III 0° IV 0° - (-10°) V -10°	0.30 0.50 0.70 0.80 1.00	Relationship of dip of discontinuity and the inclination of slope (β_i/β_I - β_s) 
Dip of discontinuity PLANAR - β_j WEDGE - β_j	I ≤ 15° II 16°-25° III 26°-35° IV 36°-45° V > 45°	0.20 0.25 0.30 0.40 0.50	**Dip of discontinuity (β_i/β_j)** α_j = dip direction of joint. α_I = direction of line of intersection of two discontinuities. α_s = direction of slope inclination. β_j = dip of joint. β_i = plunge of line of intersection. β_s = inclination of slope. **Category** I = Very favourable, II = Favourable, III = Fair, IV = Unfavourable, V = Very unfavourable * Discontinuity refers to the planar discontinuity or the line of intersection of two planar discontinuities, whichever, is important concerning instabilities.

Table 2 - Continued

Contributory Factor	Category	Rating	Remarks
Slope Morphometry			
Escarpment/Cliff	> 45°	2.00	
Steep slope	36°-45°	1.70	
Moderately steel slope	26°-35°	1.20	
Gentle slope	16°-25°	0.80	
Very gentle slope	≤ 15°	0.50	
Relative Relief			
Low	≤ 100 m	0.3	
Medium	101 - 300 m	0.6	
High	> 300 m	1.0	
Landuse and Landcover			
Agricultural land/ populated flat land		0.65	
Thickly vegetated area		0.80	
Moderately vegetated area		1.20	
Sparsely vegetated area with lesser ground cover		1.50	
Barren land		2.00	
Groundwater Condition			
Flowing		1.00	
Dripping		0.80	
Wet		0.50	
Damp		0.20	
Dry		0.00	



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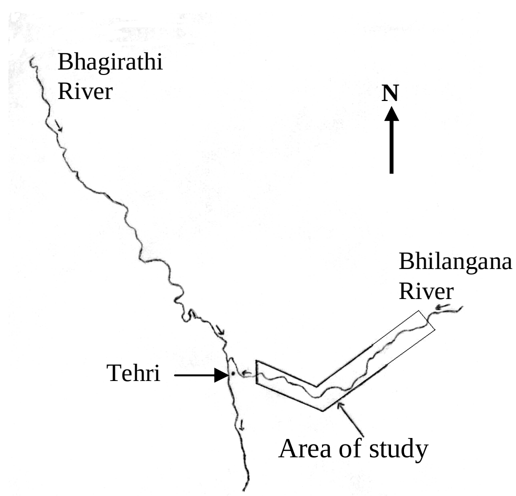

Fig. 1 - Location map of the study area

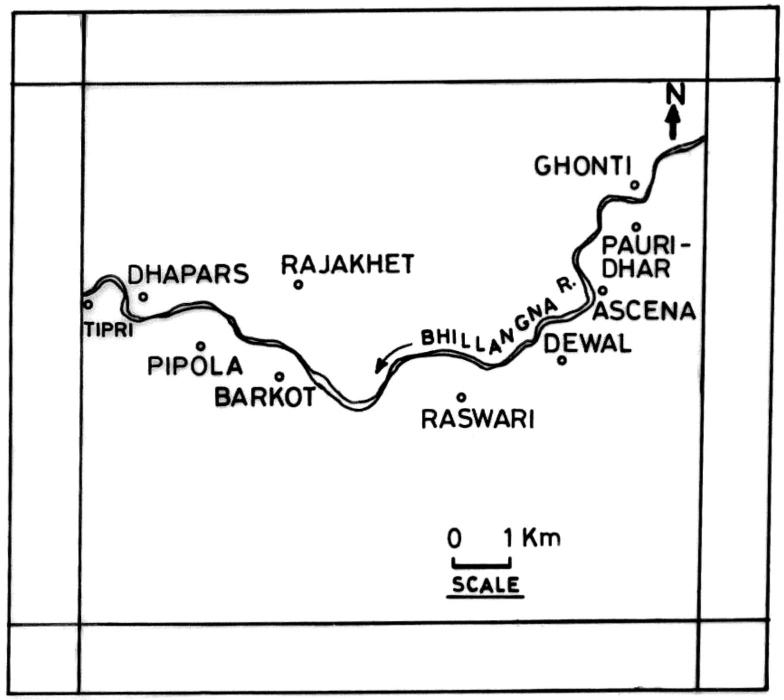

Fig. 2 - Location of villages around Bhilangna river in study area

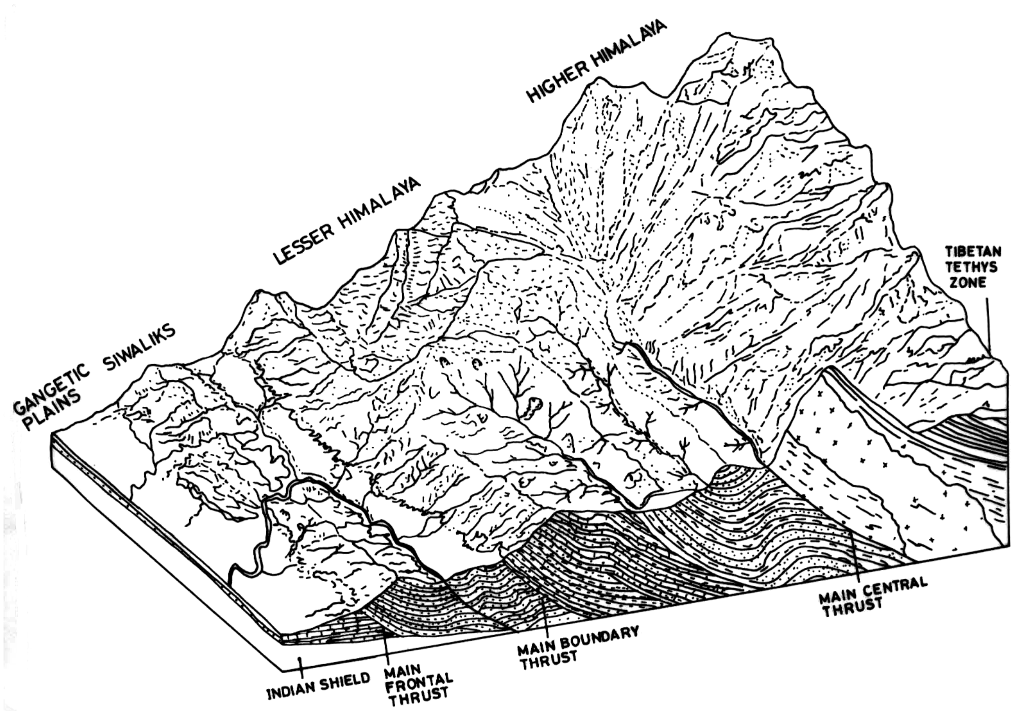

Fig. 3 - Block Diagram of the Himalaya (Deoja et al., 1991)

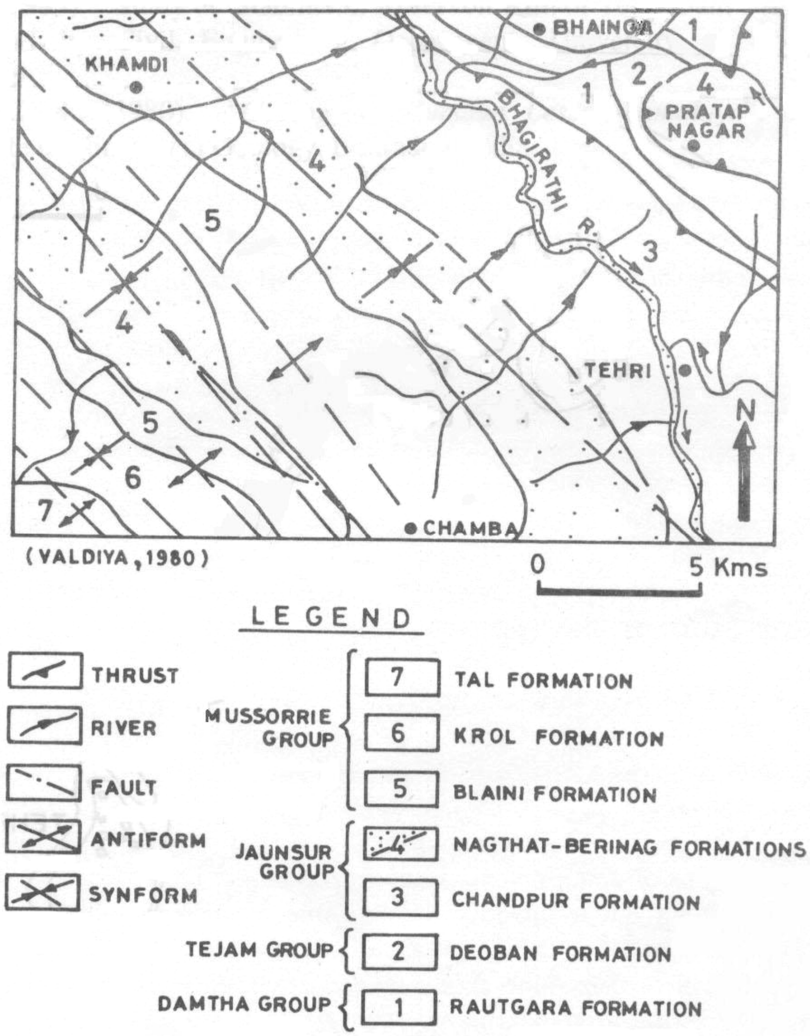

Fig. 4 - Geological map of the study area (Valdiya, 1980)

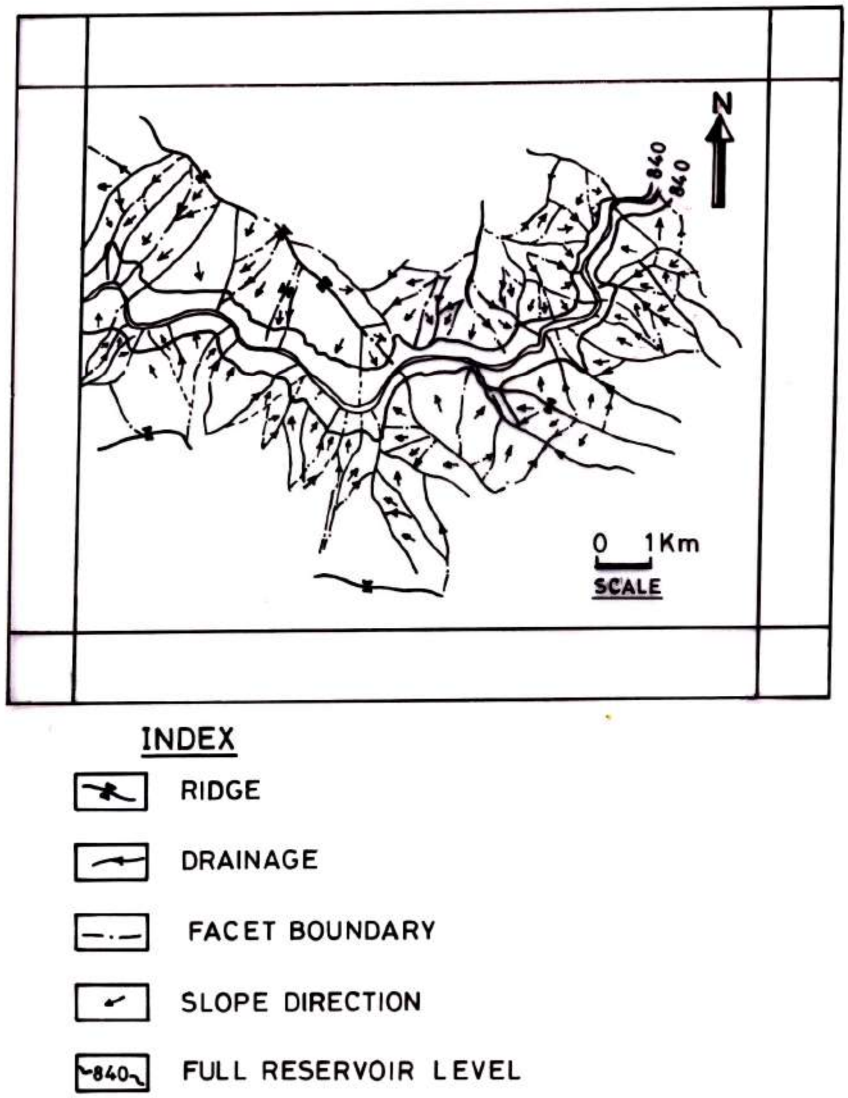

Fig. 5 - Facet map of the study area

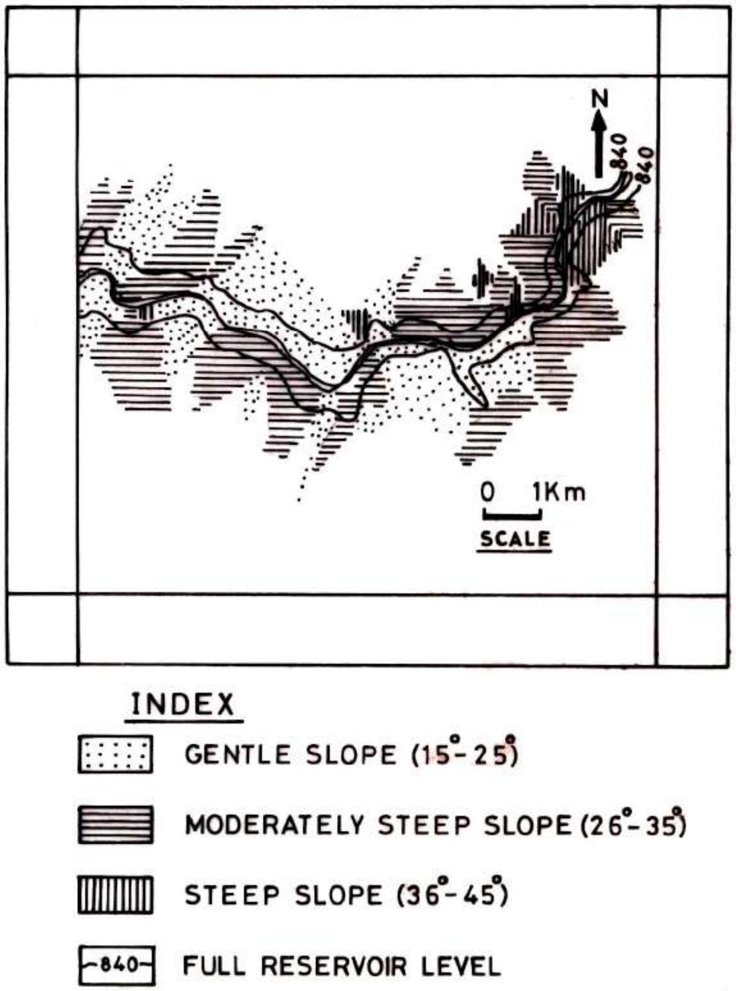

Fig. 6 - Slope morphometry map

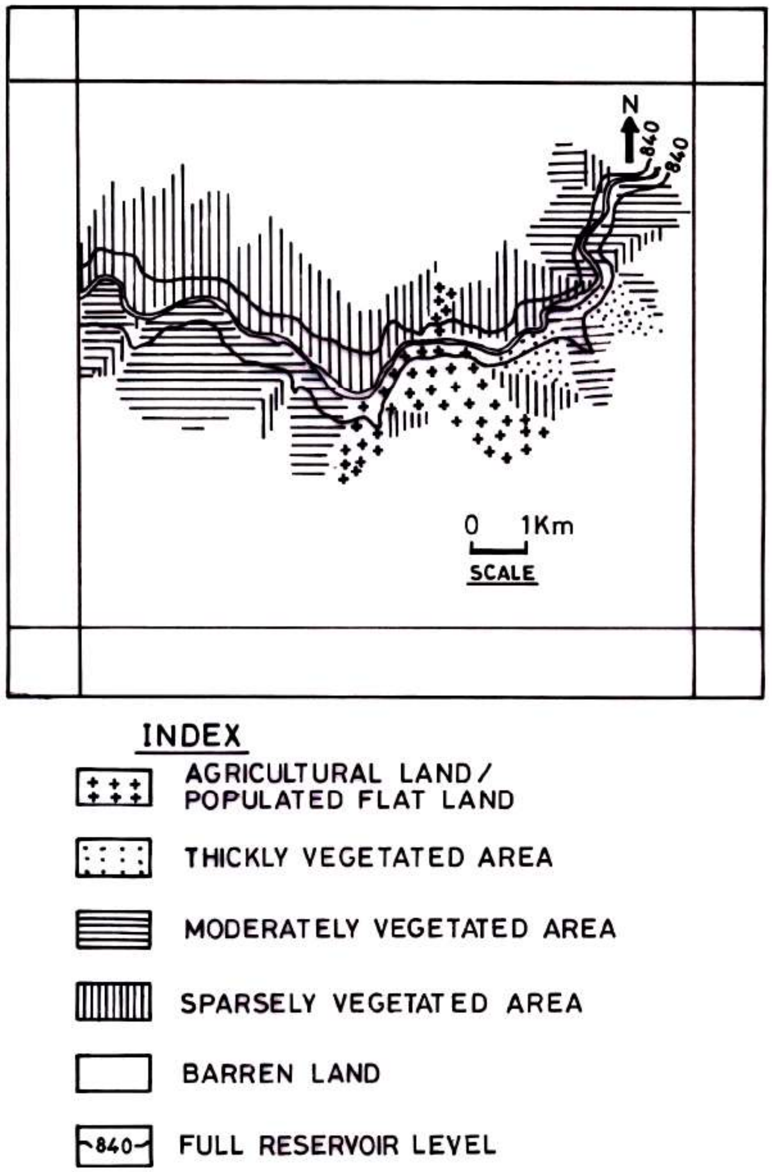

Fig. 7 - Land use and land cover map

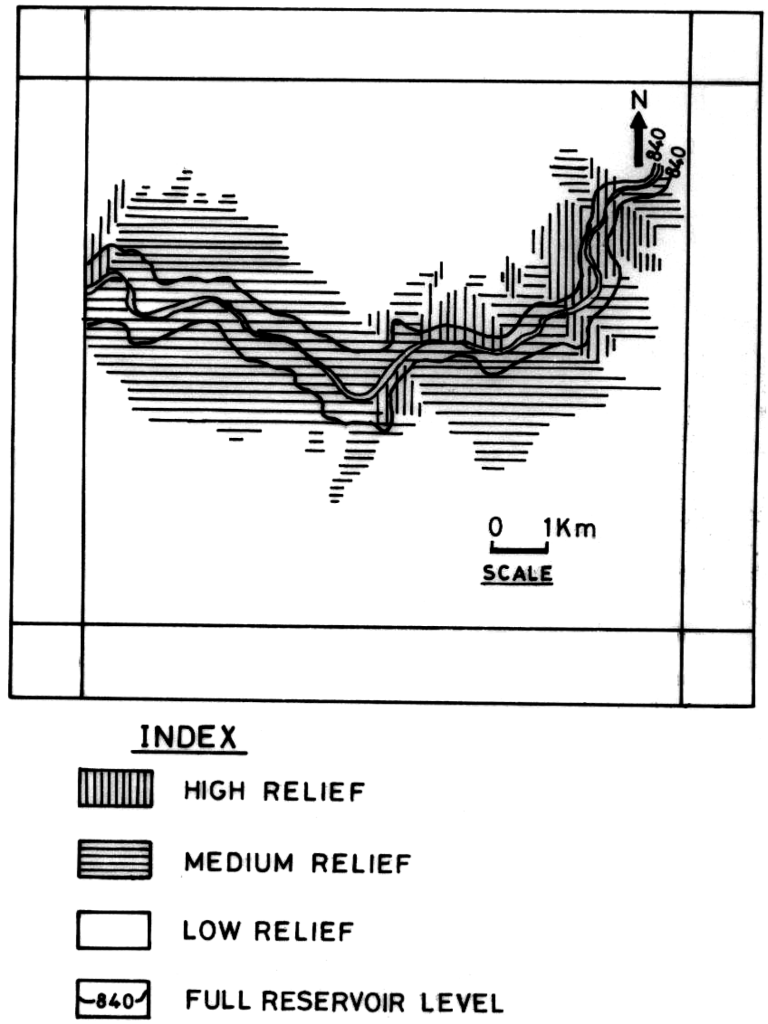

Fig. 8 – Relative relief map

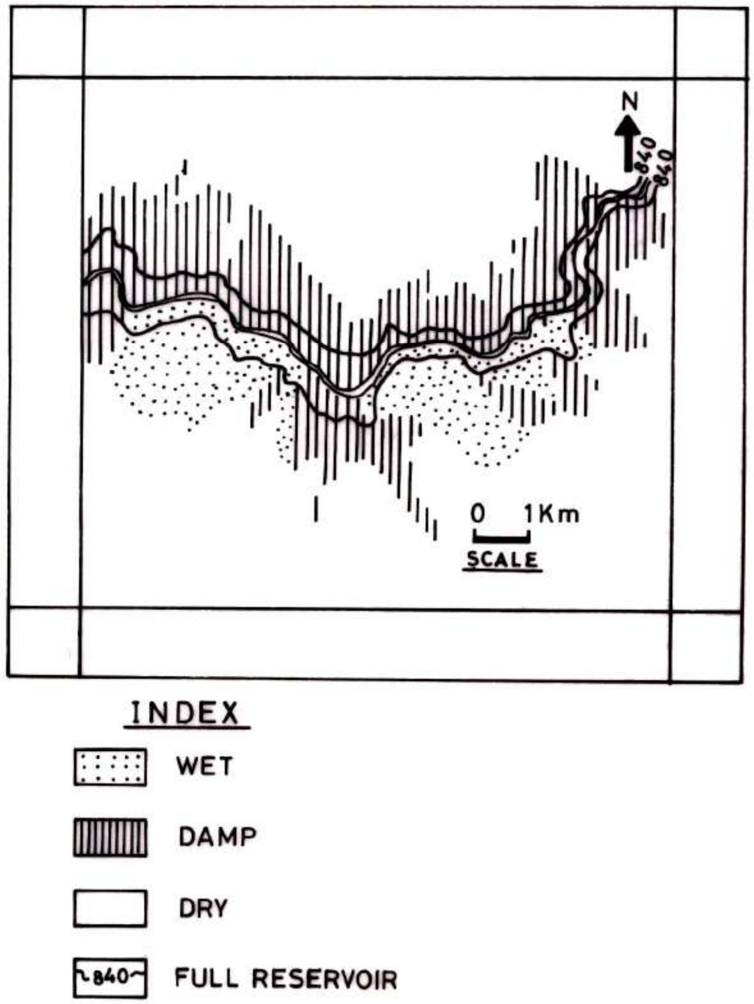

Fig. 9 - Groundwater condition map

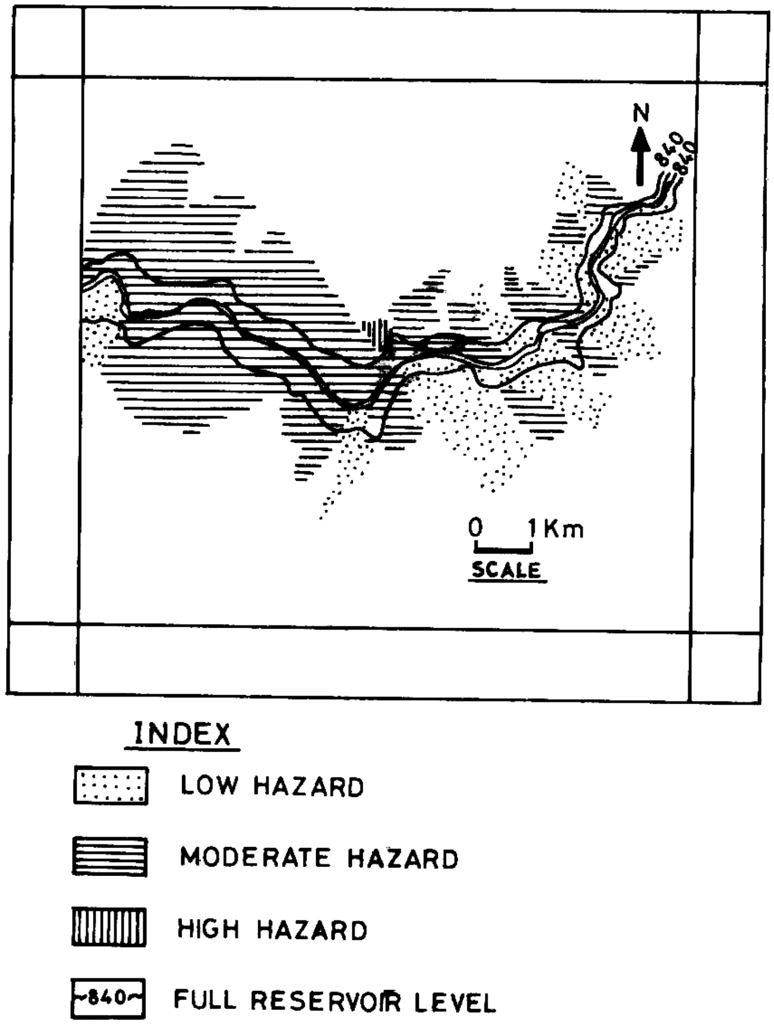

Fig. 10 – Final landslide hazard zonation map

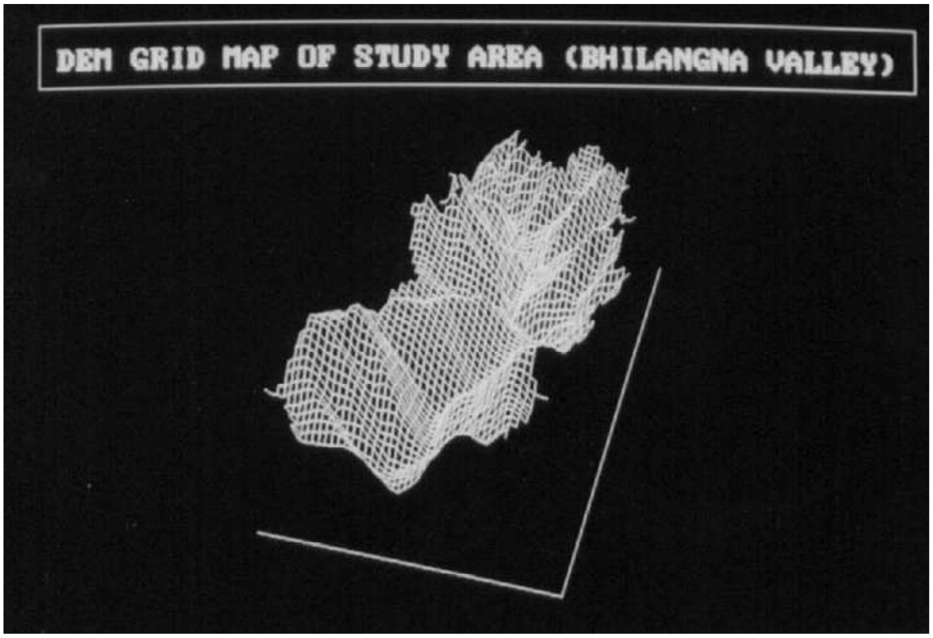

Fig. 11 - Digital elevation model (DEM) of the study area

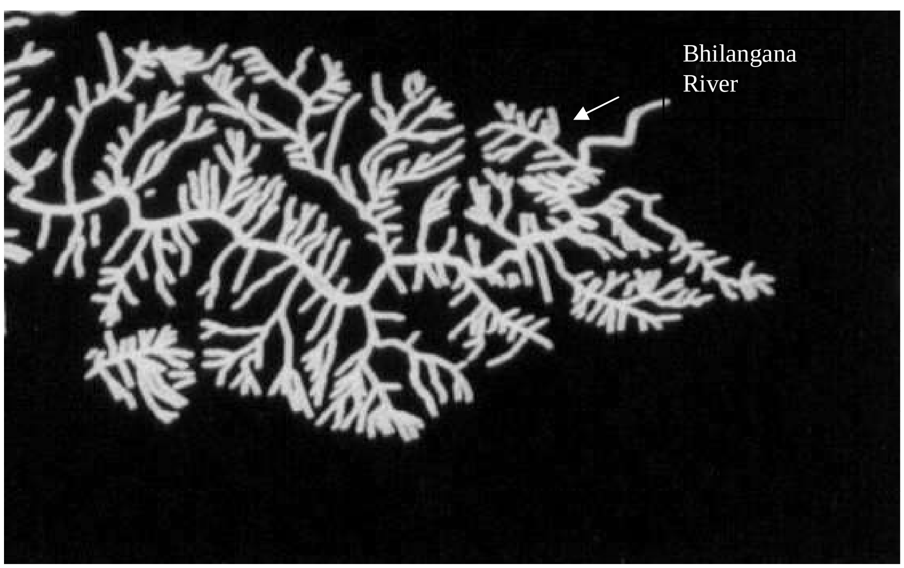

Fig. 12 - Drainage map