Landslide Hazard Zonation Mapping of Tehri-Pratapnagar Area Garhwal Himalaya

Pankaj Gupta and R. Anbalagan
Department of Earth Sciences,
University of Roorkee,
Roorkee 247 667, India
Fax : 091-13332-73560, Telex : 597-201 UORIN

ABSTRACT

The mountainous terrains such as Himalaya are characterized by steep slopes, high relative relief, weathered, fractured and folded rocks in addition to unfavorable hydrogeological conditions. 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 LHZ map of Tehri-Pratapnagar area.

1. INTRODUCTION

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 [2]). 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 favorable locations for site development schemes. Wherever they are not 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 measures to check further environmental degradation of the area.

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

The landslide hazard evaluation factor (LHEF) rating scheme (Anbalagan,[1]) 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 (Table-2) includes various sub-categories of major causative factors. The LHZ map is prepared on the basis of distribution of TEHD in an area on the basis of Table-3 (Anbalagan, [2]).

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

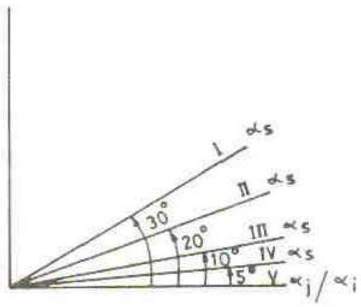
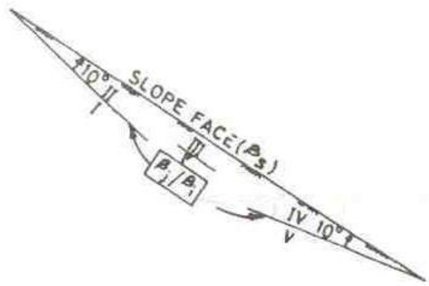
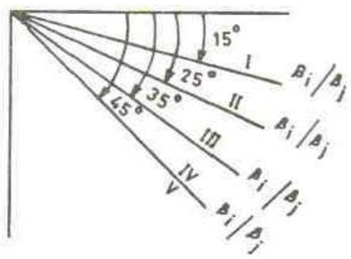
Contributory Factor	Maximum LHEF Rating
Lithology	2
Relationship of Structural discontinuities with slopes	2
Slope Morphometry	2
Relative Relief	1
Landuse and Landcover	2
Groundwater Condition	1
Total	**10**

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

TABLE 2.
LANDSLIDE HAZARD EVALUATION FACTOR (LHEF) RATING SCHEME.

Contributory Factor	Category	Rating	Remarks
Lithology *Rock Type*			*Correction factor for weathering :*
	Type-I		
	Quartzite & Limestone	0.2	(a) Highly weathered – rock discolored joints open with weathering products, rock fabric altered to a large extent; correction factor C_1.
	Granite & Gabbro	0.3	
	Gneiss	0.4	
	Type-II		
	Well-cemented terrigenous sedimentary rocks, dominantly sandstone with minor beds of claystone.	1.0	(b) Moderately weathered – rock discolored with fresh rock patches, weathering more around joint planes, but rock intact in nature;correction factor C_2.
	Poorly cemented terrigenous sedimentary rocks, dominantly sandstone with minor clay shale beds.	1.3	(c) Slightly weathered – rock slightly discolored along joint planes, which may be moderately tight to open, intact rock; Correction factor C_3.
	Type-III		**The correction factor for weathering should be multiplied with the fresh rock rating to get the corrected rating**
	Slate & phyllite	1.2	*For rock type I*
	Schist	1.3	$C_1 = 4$, $C_2 = 3$, $C_3 = 2$
	Shale with interbedded clayey & nonclayey rocks	1.8	
	Highly weathered shale, phyllite & schist.	2.0	*For rock type II* $C_1 = 1.5$, $C_2 = 1.25$, $C_3 = 1.0$
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	
			Cont...

Contributory Factor	Category	Rating	Remarks
Structure *Relationship of structural discontinuity with slope.*			
Relationship of	I > 30°	0.20	
parallelism between	II 21°-30°	0.25	
the slope & the	III 11°-20°	0.30	
*discontinuity.**	IV 6°-10°	0.40	
PLANAR (α_j-α_s)	V ≤ 5°	0.50	
WEDGE (α_i-α_s)			Parallelism between the slopes and discontinuity (α_j/α_i-α_s).
Relationship of dip of	I > 10°	0.30	
discontinuity and	II 0°-10°	0.50	
inclination.	III 0°	0.70	
PLANAR (β_j-β_s)	IV 0°-(-10°)	0.80	
WEDGE (β_i-β_s)	V <-10°	1.00	
Dip of discontinuity	I ≤ 15°	0.20	
PLANAR — β_j	II 16°-25°	0.25	
WEDGE — β_i	III 26°-35°	0.30	
	IV 36°-45°	0.40	Relationship of dip of discontinuity and
	V > 45°	0.50	the inclination of slope (β_j/β_i-β_s).
Depth of soil cover.	≤ 5 m	0.65	
	6-10 m	0.85	
	11-15 m	1.30	
	16-20 m	2.00	
	> 20 m	1.20	
Slope Morphometry			
Escarpment/Cliff	> 45°	2.00	
Steep slope	36°-45°	1.70	
Moderately steep slope	26°-35°.	1.20	
Gentle slope	16°-25°	0.80	Dip of discontinuity (β_i/β_j)
Very gentle slope	≤ 15°	0.50	*Cont...*

Relief – missing here but given in IS code drafts.

Contributory Factor	Category	Rating	Remarks
Landuse and Landcover			
Agricultural land / populated flat land	...	0.65	α_j = dip direction of joint. α_i = direction of line of intersection of two discontinuities.
Thickly vegetated area	...	0.80	α_s = direction of slope inclination.
Moderately vegetated area	...	1.20	β_j = dip of joint. β_i = plunge of line of intersection.
Sparsely vegetated area with lesser ground cover	...	1.50	β_s = inclination of slope.
Barren land	...	2.00	Category
Groundwater Condition			I = Very favourable. II = Favourable. III = Fair.
Flowing	...	1.00	IV = Unfavourable. V = Very unfavourable.
Dripping	...	0.80	
Wet	...	0.50	*Discontinuity refers to the planar discontinuity or the line of intersection of two planar discontinuities, whichever, is important concerning instabilities.
Damp	...	0.20	
Dry	...	0.00	

3. LANDSLIDE HAZARD ZONATION OF TEHRI-PRATAPNAGAR AREA

The present investigation covers Tehri-Pratapnagar area falling between Latitude ($30^{0}22'15"$-$30^{0}30'5"$) and Longitude ($78^{0}25'$-$78^{0}30'$), (Fig-1).

3.1 Geology of the area

The study area lies in Tehri District of Uttar Pradesh. The rocks of the area belong to Damtha, Tejam and Jaunsar Groups. The stratigraphic sequence of the area and its vicinity is as follows (validiya [3]).

Nagthat - Berinag Formation	-Jaunsar Group
Chandpur Formation	
Deoban Formation	-Tejam Group
Rautgara Formation	-Damtha Group

The area has been mapped on 1:50,000 scale for studying the lithology and structure. The rocks exposed in the area include phyllites of Chandpur Formation interbedded with sublitharenites of Rautgara Formation, dolomitic limestone of Deoban Formation and quartzites of Nagthat - Berinag Formation. The phyllites are grey and olive green interbedded with metasiltstones and quartzitic phyllites. The Rautgara Formation comprises purple, pink and white colored, medium grained, quartzites interbedded with medium grained grey and dark green sublitharenites and minor slates as well as metavolcanics. The Deoban Formation consists of dense, fine grained dolomites of white and light pink colors with minor phyllitic intercalations. They occupy topographically higher ridges. The Nagthat-Berinag Formation includes purple, white and green colored quartzites interbedded with greenish and grey slates as well as grey phyllites.

The Chandpur Formation is delimited towards north by a well defined thrust called North Almora Thrust trending roughly northwest - southeast and dipping southwest. Moreover the Deoban and the Nagthat - Berinag Formations have a thrusted contact, the thrust trending parallel to North Almora Thrust and dipping northeast. The thrust is called Pratapnagar Thrust. The rocks are badly crushed in thrust zones.

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.2). 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 (Fig.3), structural map (Fig.4), slope morphometry map (Fig.5), land use and land cover map (Fig.6), relative relief map (Fig.7), ground water condition map (Fig.8) 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 major rock types observed in the area include phyllite, quartzite and dolomitic limestone. In addition, fluvial terrace materials are present in abundant to right of the river Bhagirathi all along its course.

Phyllites are exposed on either bank close to Bhagirathi river. Though older terrace materials are present at lower levels, thick eluvial and colluvial soil cover at places are present in the upper levels on the right bank. On the left bank, the phyllites are generally weathered close to the surface and support thin soil cover. At places the thickness of soil cover is more increasing upto 5m.

The North Almora Thrust separates the Chandpur phyllites on the South from the quartzites of the Rautgara Formation. The Rautgara quartzites interbedded with minor slates and metavolcanics are pink, purple and white colored, well jointed and medium grained. The rocks and soil types in the area have the following distribution : phyllite - 44.174% quartzite - 27.412%, marl/limestone- 12.478%, metabasics 0.251%, river terrace material 6.114%, phyllite with thin eluvial soil cover 6.164% and quartzite with thin soil cover 3.408% of the study area respectively.

3.2.2 *Structure*

The major structural features seen in the area are North Almora thrust and Pratapnagar thrust which forms part of the Berinag Thrust. The structures used for landslide hazard zonation mapping includes beddings, joints and foliations. The disposition of the structures have been plotted in a stereonet for individual facets. The inclination of the slope of the facet is also plotted to decide about possible type of failures. The inter-relation of the structural discontinuity with slope is studied carefully to award the ratings (Anbalagan, [2]).

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 west of Bhagirathi river mainly occupied by terrace deposits falls 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 mainly occur in the central and eastern part of the area. The steep slopes occur in the northern part of the study area adjoining the Jalkur stream.

In fact, Jalkur stream flows through a tight, narrow, V-shaped gorge in this reach. Very steep slopes / escarpments occur in small patches mainly close to the water courses possibly because of toe erosion. The area has the following distribution - 6.14%, 31.922%,42.32%, 11.375% and 8.269% of very gentle slope, gentle slope, moderately steep slope, steep slope and very steep slope / escarpment respectively.

3.2.4 *Land use land cover*

Vegetation cover generally smothens 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 central, southeastern, southern and parts of northeastern areas. The thickly vegetated forest areas are seen in Pratapnagar - Bangdwara area. The moderately vegetated areas are mainly present in small patches to the West of thickly vegetated areas. The sparsely vegetated and barren lands are mainly confined to quartzitic and parts of dolomitic limestone terrains where steep to very steep slopes are present. These types of slopes are seen along the Bhagirathi valley adjoining the river courses generally on steep slopes. The five categories of land use and land cover namely agricultural lands / populated flat lands, thickly vegetated forest area, moderately vegetated area, sparsely vegetated area and barren land have the distribution of 65.44%, 5.938%, 1.729%, 3.784% and 23.102% respectively in the study area.

3.2.5 *Relative Relief*

Relative relief is the maximum height between the ridge top and valley floor within an individual facet. The three categories of relative relief namely high relief, medium relief and low relief occupies 75.529%, 15.96% and 8.745% of the study area respectively.

3.2.6 *Ground water condition*

The surface manifestation of ground water such as wet, damp and dry have been observed in the study area. The area dominantly shows dry condition in about 54.86% of the area, damp condition in about 40.96% of the area and 4.8% of the study area is covered by wet ground water condition. Dry condition is mainly observed in the northern part and well distributed in rest of the study area. Damp and wet conditions are present in a number of facets in the southern, eastern and central part of the study area.

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 zones (Anbalagan, [1]) (Fig.9).

The five categories of hazards, namely, very low hazard (VLH), low hazard (LH), moderate hazard (MH), high hazard (HH) and very high hazard (VHH) are found to be present in the study area. The areas showing VLH and LH constitute about 2.33 % and 43.272% of the study area respectively. They are well distributed within the area. MH zones are mostly present in the immediate vicinities to the east of the Bhagirathi river. HH and VHH zones occur as small patches, mostly close to the water courses. They represent areas of greater instability where detailed investigations have to be carried out.

4. 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.

5. ACKNOWLEDGMENT

The first author wishes to express his gratitude to Council of Scientific and Industrial Research (CSIR) for generous financial support for this research work.

6. REFERENCES

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(3). Valdiya, K.S. (1980) "Geology of Kumaun Lesser Himalaya", Wadia Institute of Himalayan Geology, Dehradun, India. pp 291.

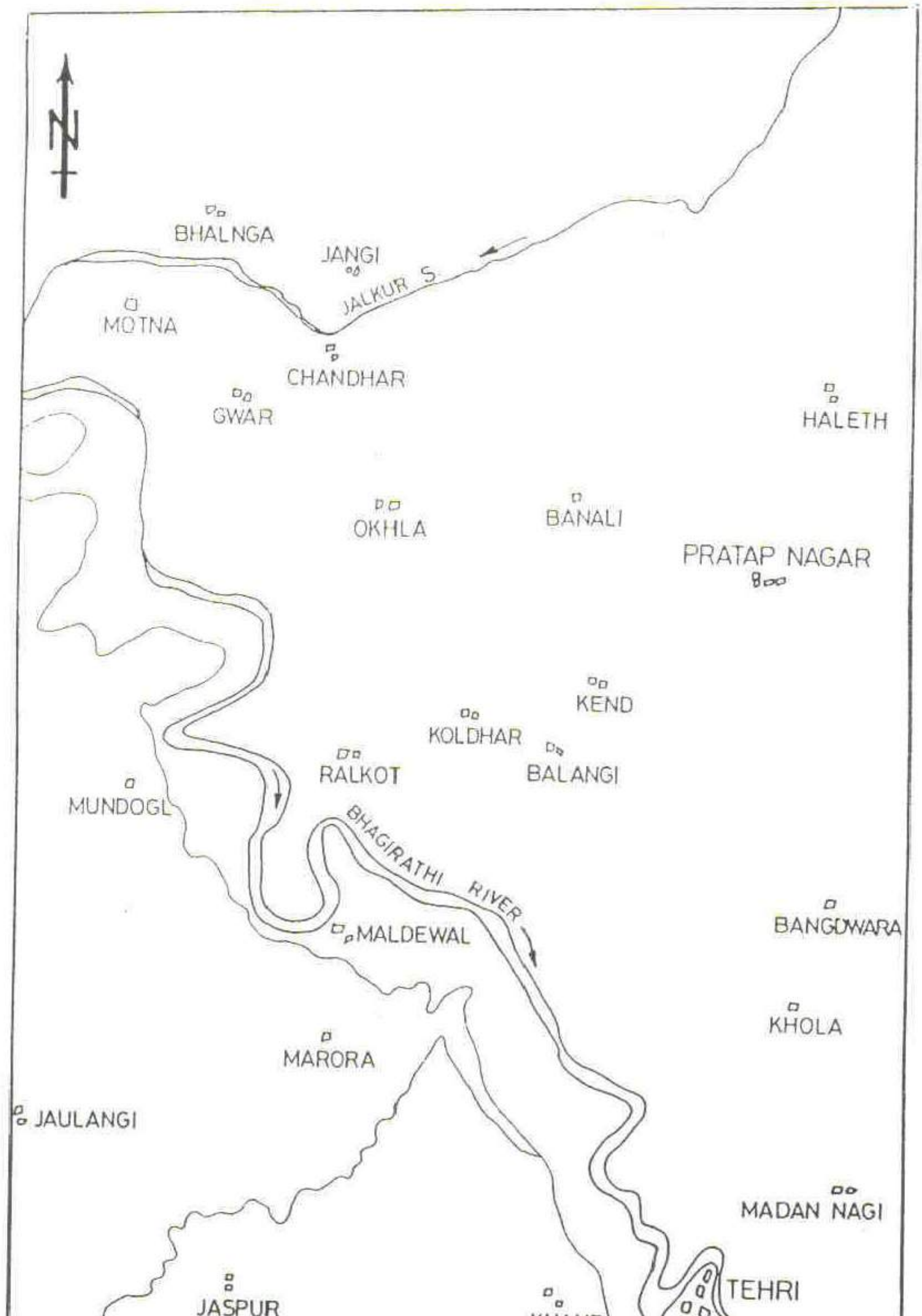

FIG.1 LOCATION MAP OF THE STUDY AREA.

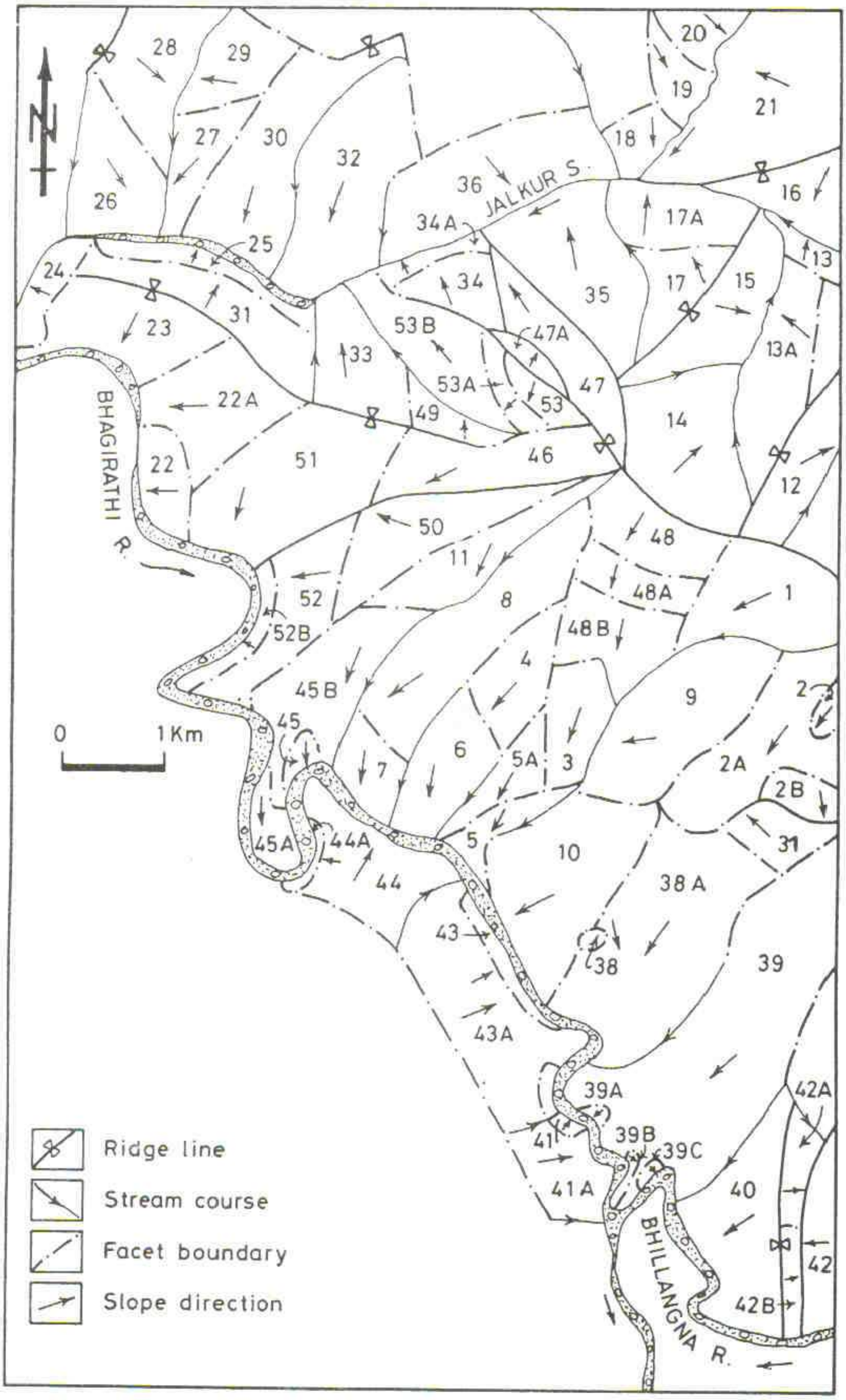

FIG.2 FACET MAP OF THE STUDY AREA

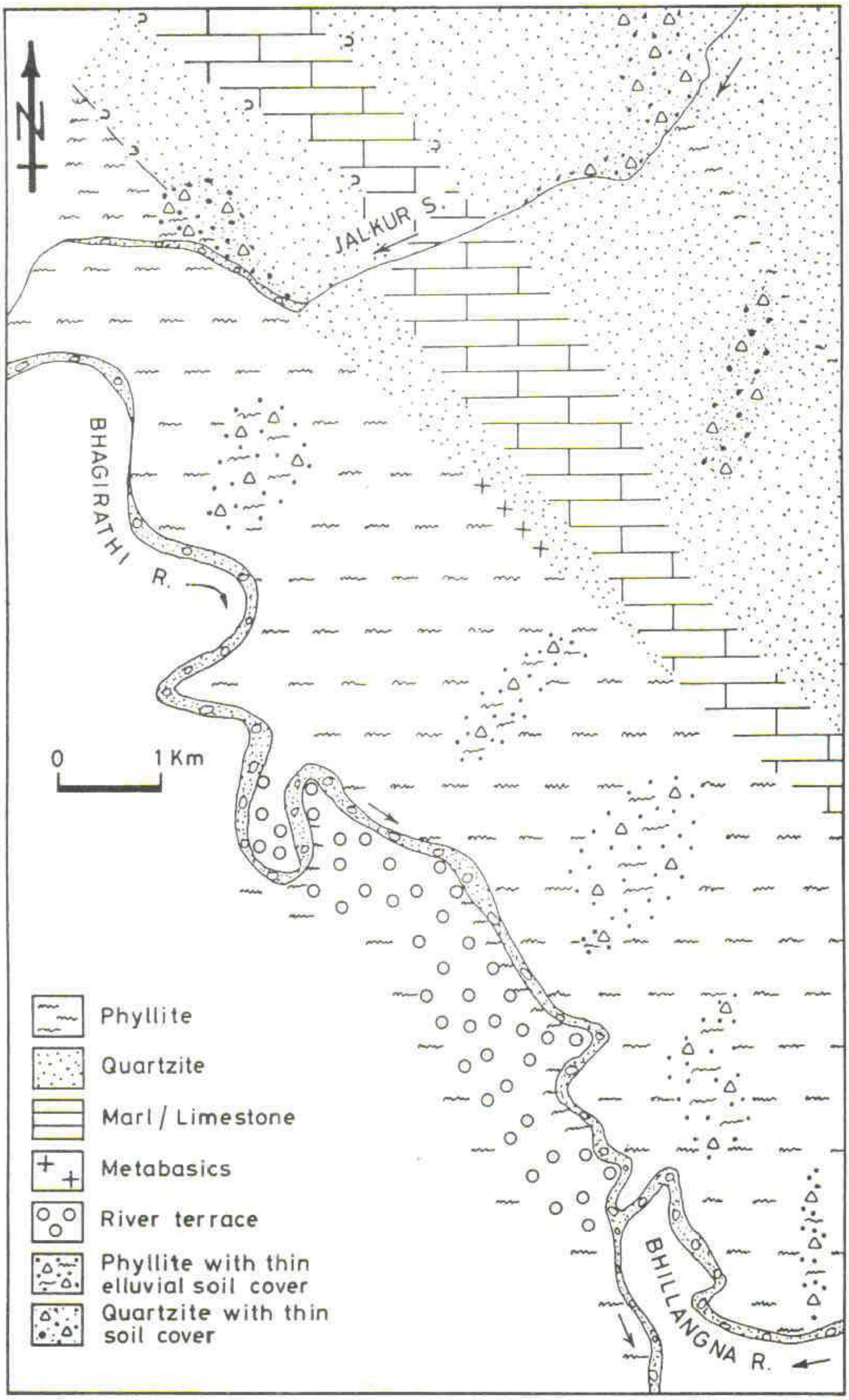

FIG.3 LITHOLOGICAL MAP.

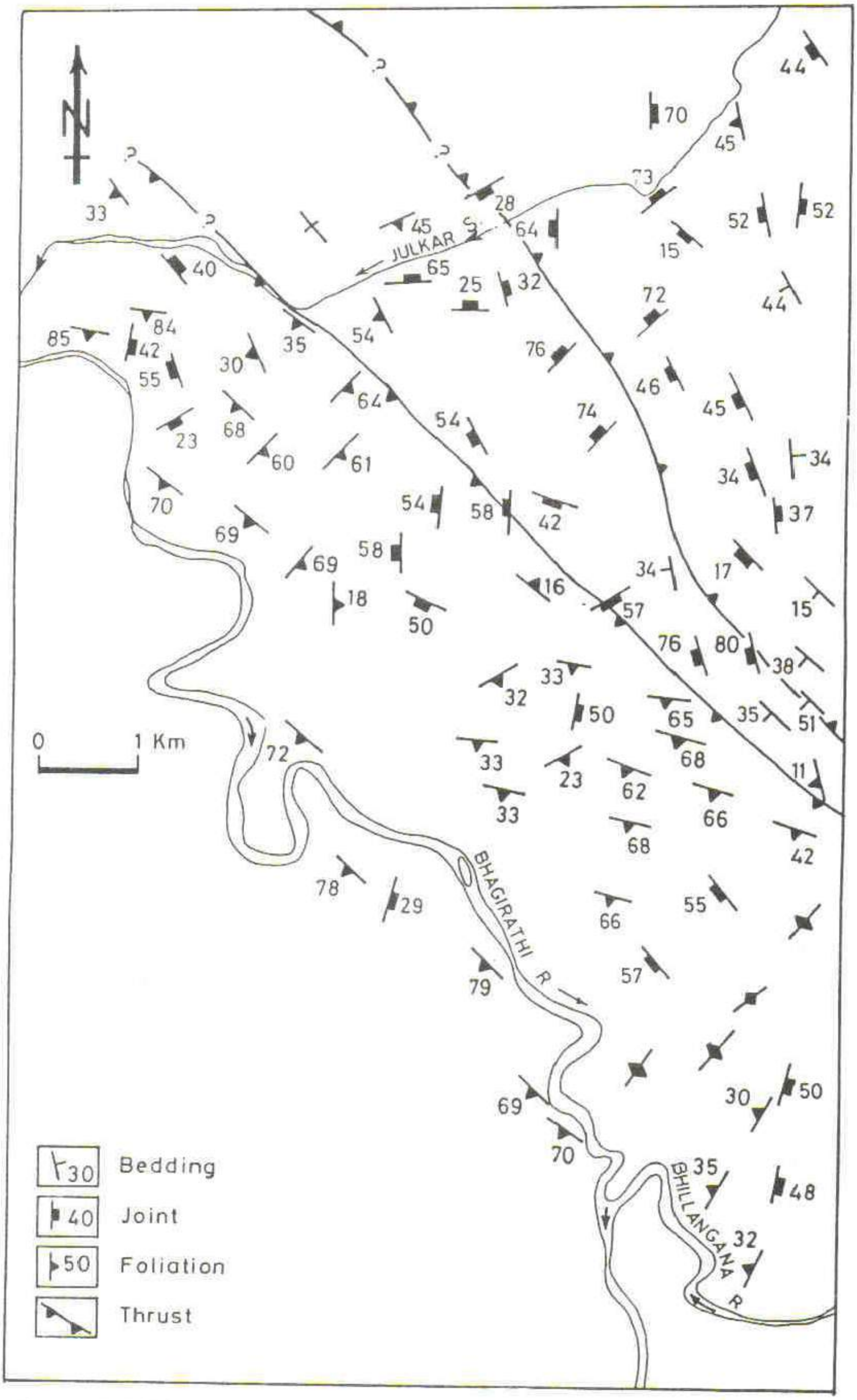

FIG.- STRUCTURAL MAP.

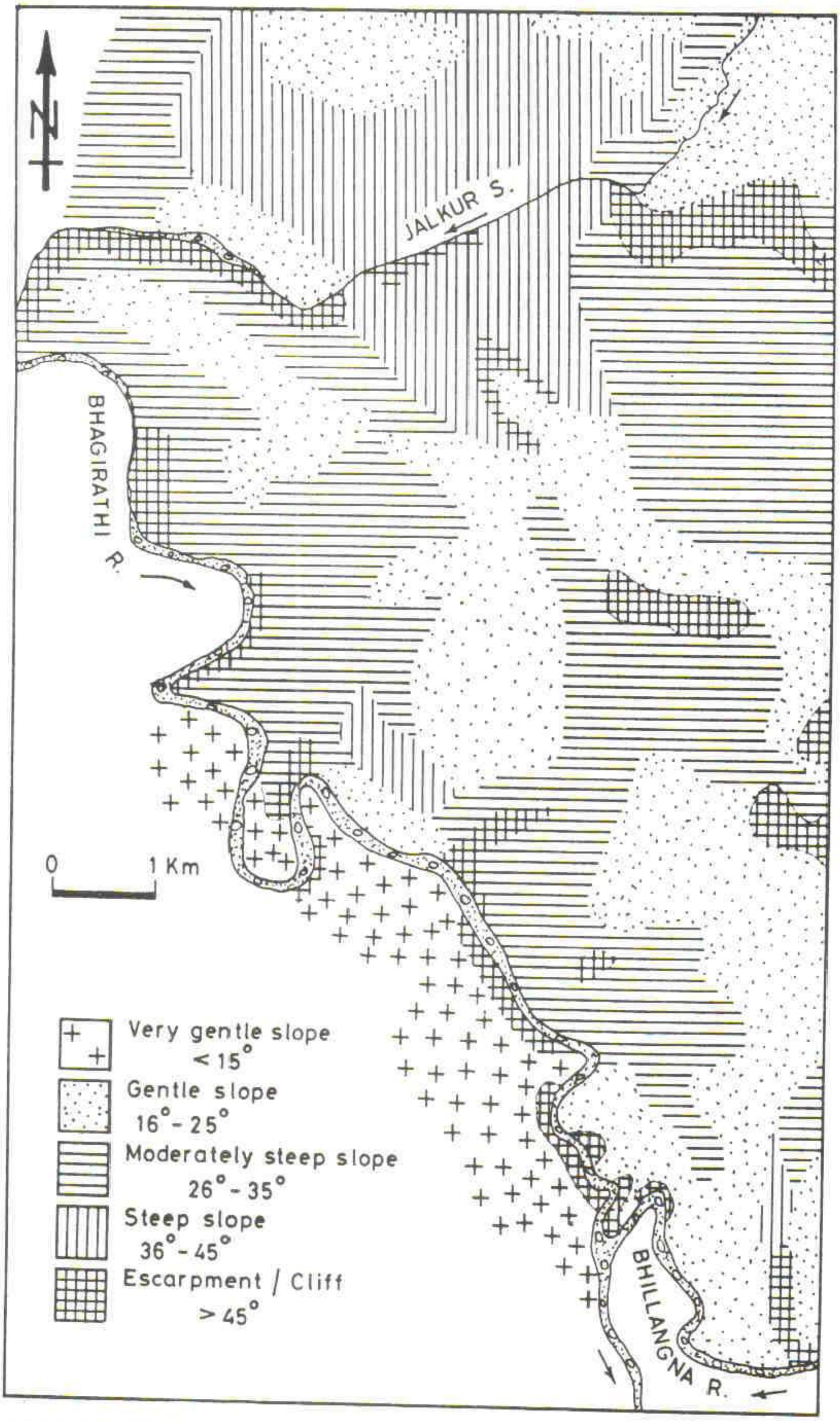

FIG.5 SLOPE MORPHOMETRY.

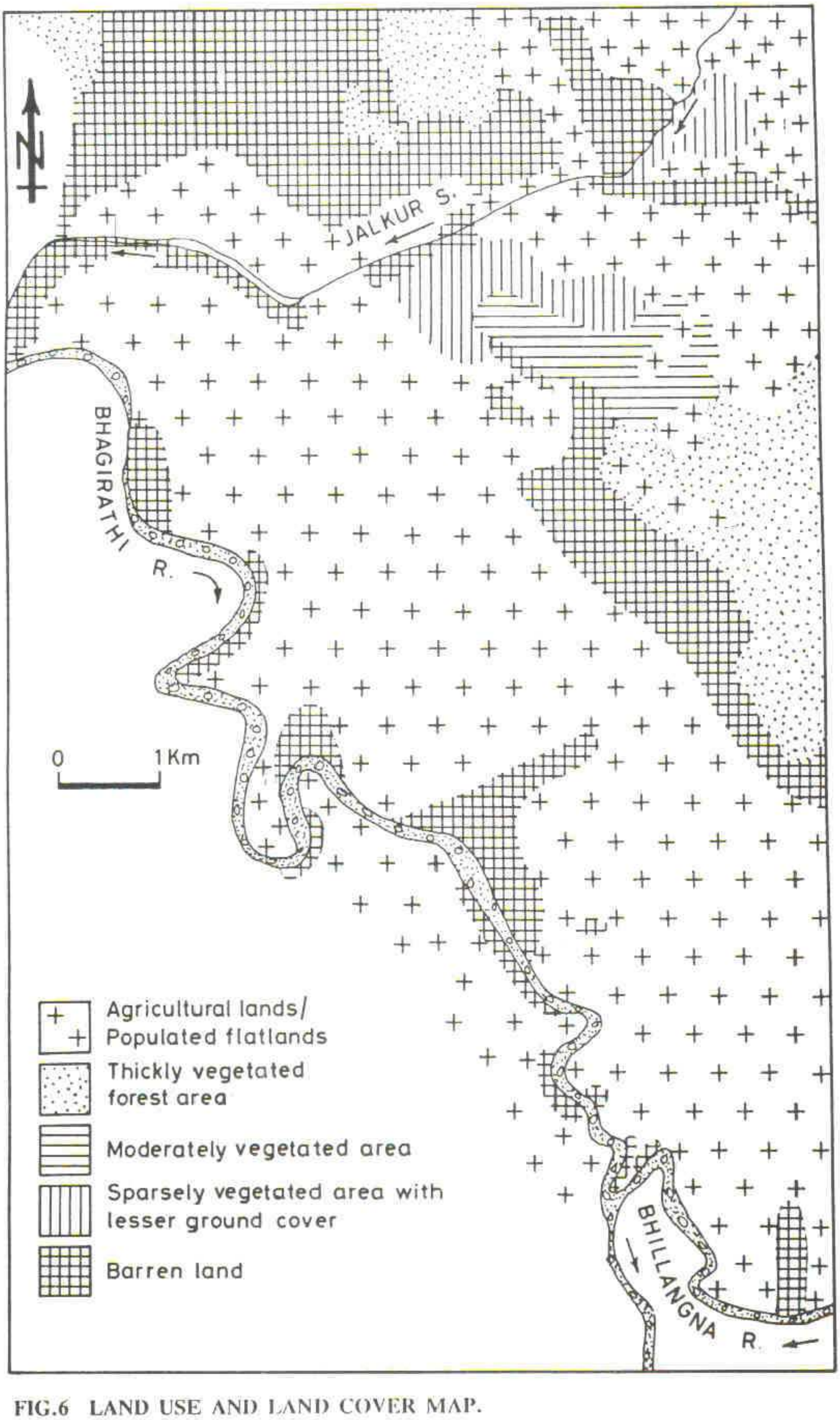

FIG.6 LAND USE AND LAND COVER MAP.

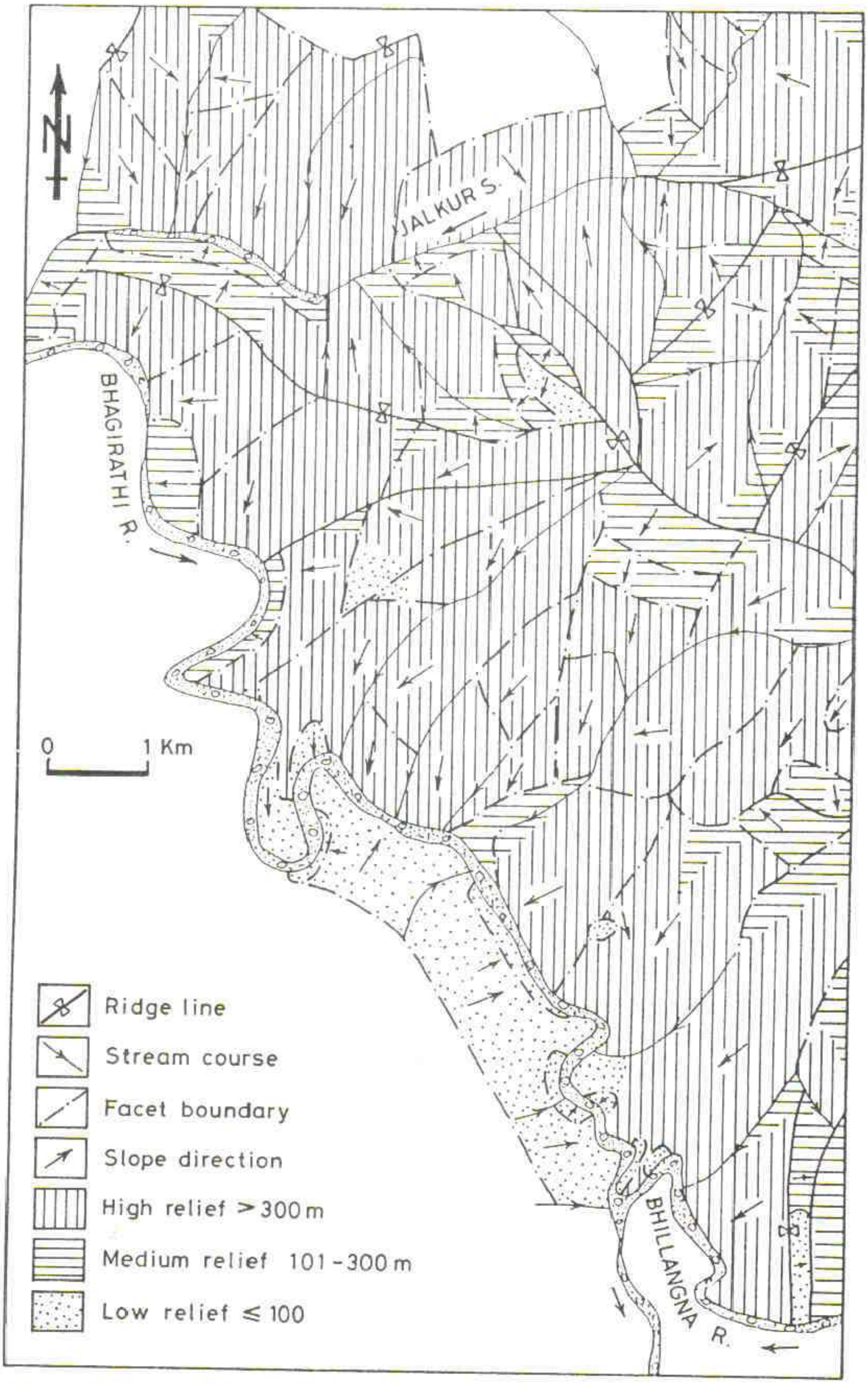

FIG.7 RELATIVE RELIEF MAP.

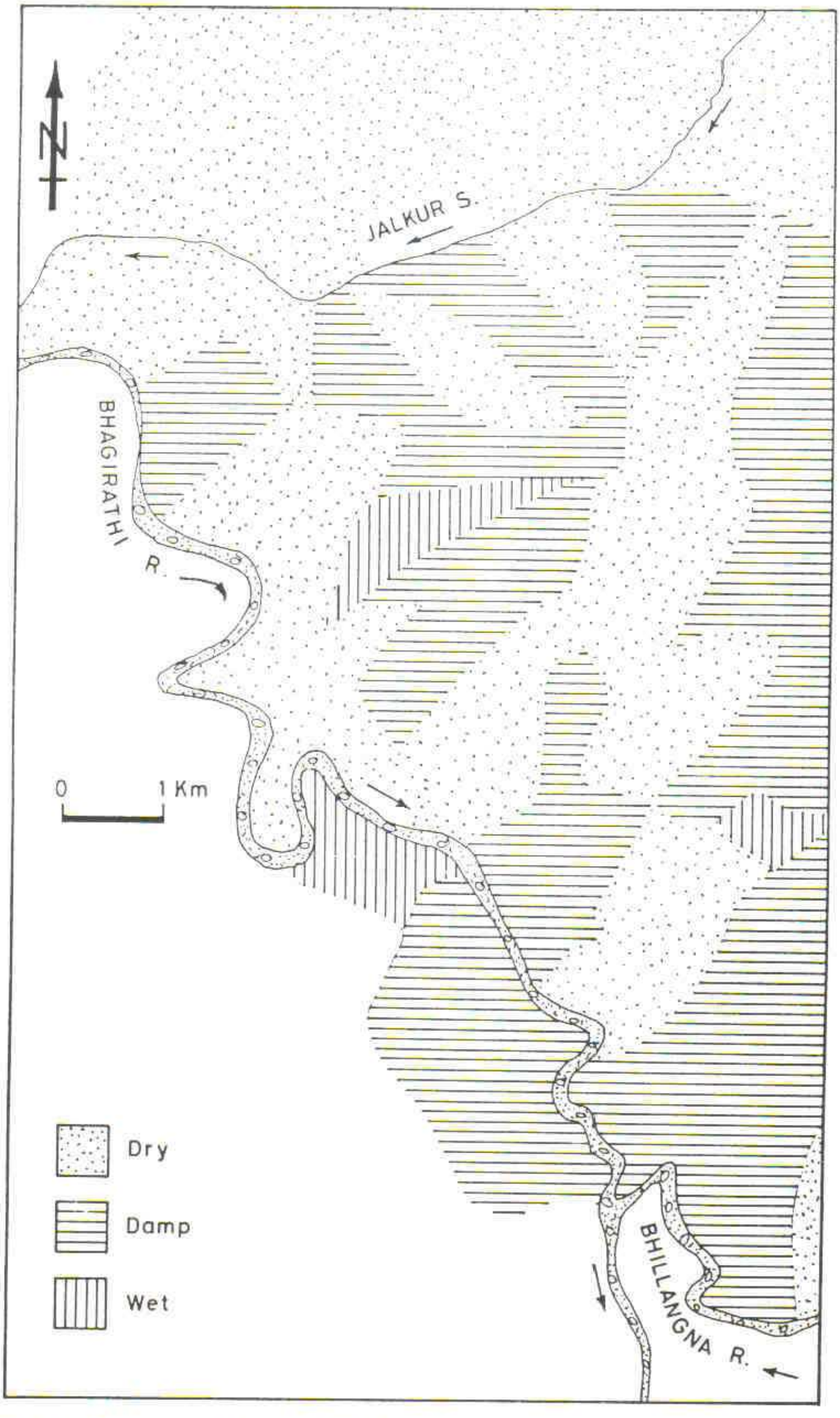

FIG.8 GROUNDWATER CONDITION MAP.

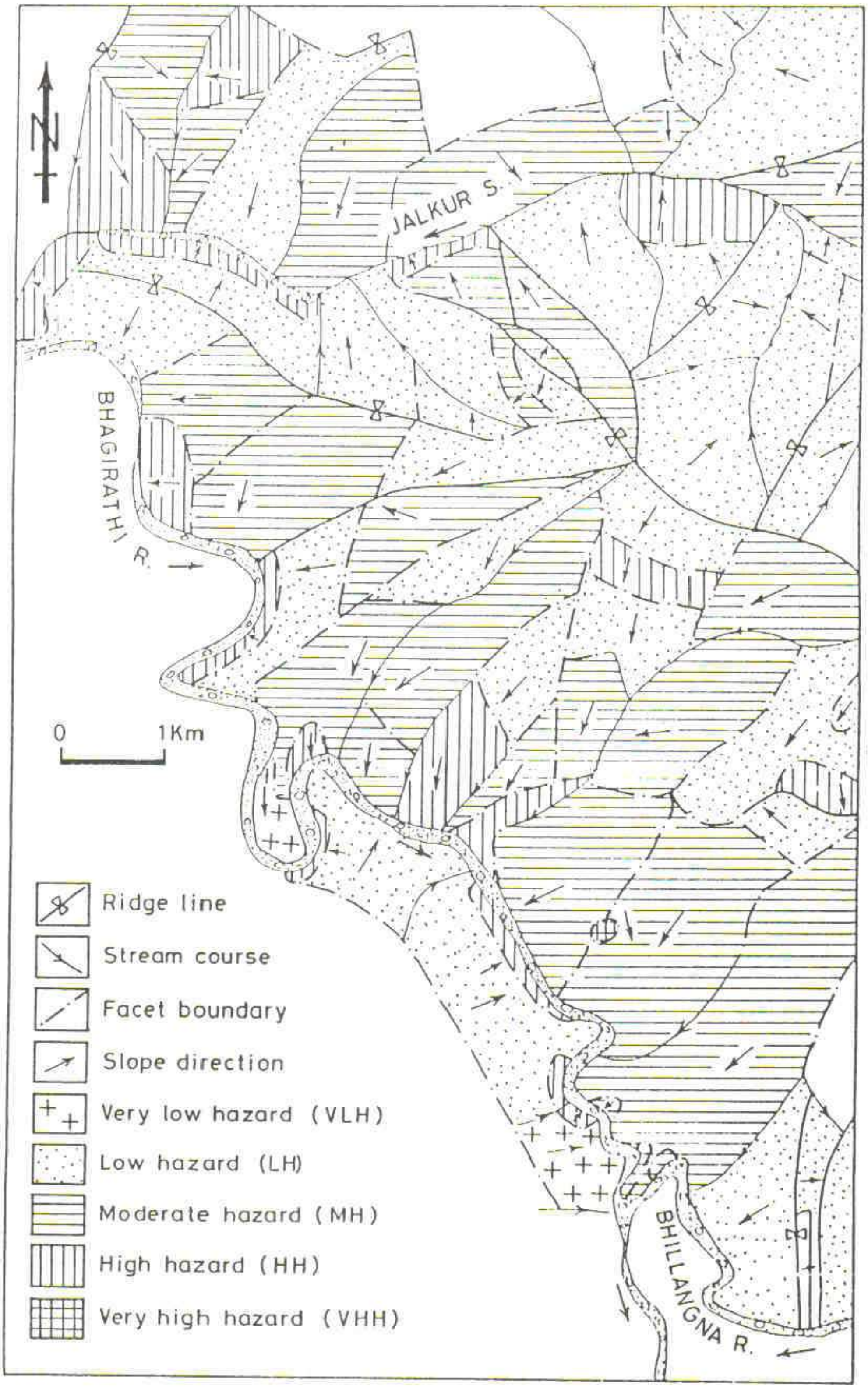

FIG.9 LANDSLIDE HAZARD ZONATION MAP.