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Landslide hazard zonation mapping of Tapovan – Helong hydropower project area, Garhwal Himalaya, India, using univariate statistical analysis

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ABSTRACT

Landslide hazard zonation mapping of Tapovan - Helong area of Garhwal Himalaya, where a hydropower scheme of 520 MW is proposed on Dhauli Ganga was carried out. The study area lies in the Main Central Thrust (MCT) zone, which receives majority of the southwest summer Monsoon. The study area belongs to Central Crystalline zone consisting of medium to high grade quartz-plagioclase-muscovite-biotite-garnet-kyanite and sillimanite bearing crystalline rocks. In the present study statistical analysis of various geo-environmental factors such as the lithology, slope, structure, relative relief, landuse and hydro-geological conditions were used. For preparing the landslide hazard zonation map a quantitative approach called landslide hazard evaluation factors (LHEF) rating has been used. The study indicates that structures, peri-glacial material resting on steeper angle of hill slopes and rainfall plays major role in triggering landslides in this part of the Himalaya. The main aim of this study was to select the best locations for the construction of barrage and sedimentation tank, selections of sites for the tunnels portal and the switchyard area and finally appropriate slope stabilization measures were also suggested. The study further suggests that in the investigation stage for river valley projects, landslide hazard evaluation factor (LHEF) rating scheme can provide rapid hazard assessment in a mountainous terrain.

Keywords: Landslide hazard zonation, hydropower porject area, univariate statistical analysis

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INTRODUCTION

Landslide hazard zonation refers to the division of a land surface into homogeneous areas or domains and their ranking according to degrees of actual/potential hazard caused by mass-movement. 'Hazard' is the probability of occurrence of a damaging phenomenon within a specified period of time and within a given area (Varnes 1984). The term susceptibility is often used when the time aspect is not taken into account (Brabb 1984; Aniya 1985). In the recent past, various methods and techniques have been proposed to analyse the causative factors of landslides and propose maps portraying the probability of occurrences of similar phenomena in future. Deterministic, statistical, empirical and monitoring methods are approaches that are often used for slope stability assessment (Hartle's and Viberg 1988). The deterministic approach expresses the stability of slope in terms of a safety factor (Mulder 1991), that is the ratio of forces tending to inhibit or resist slope movement to those tending to initiate or drive such mass movements (Terzaghi and Peck 1967). On a regional scale, application of the deterministics approach is fraught with difficulties because the variations in parameters included in the safety factor render accurate quantification problematic (Jibson and Keefer 1989; Amada et.al. 1995). Empirical (Zika et al. 1988) and monitoring approaches (Capecchi and Focardi 1988) need continuous long-term information on the landslides and their causal factors for a similar environmental condition or for the same site and these are often not available. The geo-environmental factors which control the stability of slope like lithology, slope morphometry, structure, relative relief, landuse and land cover and hydro-geological condition are generally considered as indexes for parameters included in the safety factor and can be quantified by statistical analysis (Gupta and Joshi 1990, Carrara et al. 1991, Pachauri and Pant 1992, Anbalagan 1992, Jade and Sarkar 1993, Gupta et al. 1993, Naithani et al. 1997, Yin and Yan 1988, Dhakal et al. 1999, Jeganathan and Chauniyal, 2000, Joshi et al. 2003, Sarkar and Gupta 2005, Pachauri 2007, Naithani 2007). The stability of an area depends on the combined effect of these factors. The reliability of Landslide Hazard Zonation (LHZ) mapping depends mostly on the amount and quality of available data used as well as the selection of the appropriate methodology for susceptibility and hazard assessment. On the other hand, the working scale also affects the quality of the results (Van Westen 1994). In this study we utilized the Remote Sensing data and employ univariate statistical analysis to define the factor contributing to trigging landslide because these factors can be easily gathered and ranked and are the most suitable for the susceptibility analysis. Hazard assessment and mapping are complicated tasks and require a great deal of subjective decision at various stages. Consequently, results are influenced to some extent by the method of the analysis and the factors employed in the analysis (Dhakal et al. 1999).

In the preliminary stage of geotechnical investigation of hydropower projects the landslide hazard evaluation factor (LHEF) rating scheme may effectively be used, as this is an economic and rapid hazard assessment technique. Landslide Hazard Zonation maps are of great help to the planner and field engineers for selecting suitable locations in order to implement developmental schemes in the mountainous terrain as well as, for adopting appropriate mitigation measures in hazardous prone areas. In this paper, a study pertains to landslide hazard zonation has been carried out in the Joshimath area of Garhwal Himalaya, where for 520 MW Hydro project investigation was carried out. It was important investigation from the strategic and developmental point of view (Fig. 1). On the left bank of Alaknanda and Dhauli Ganga

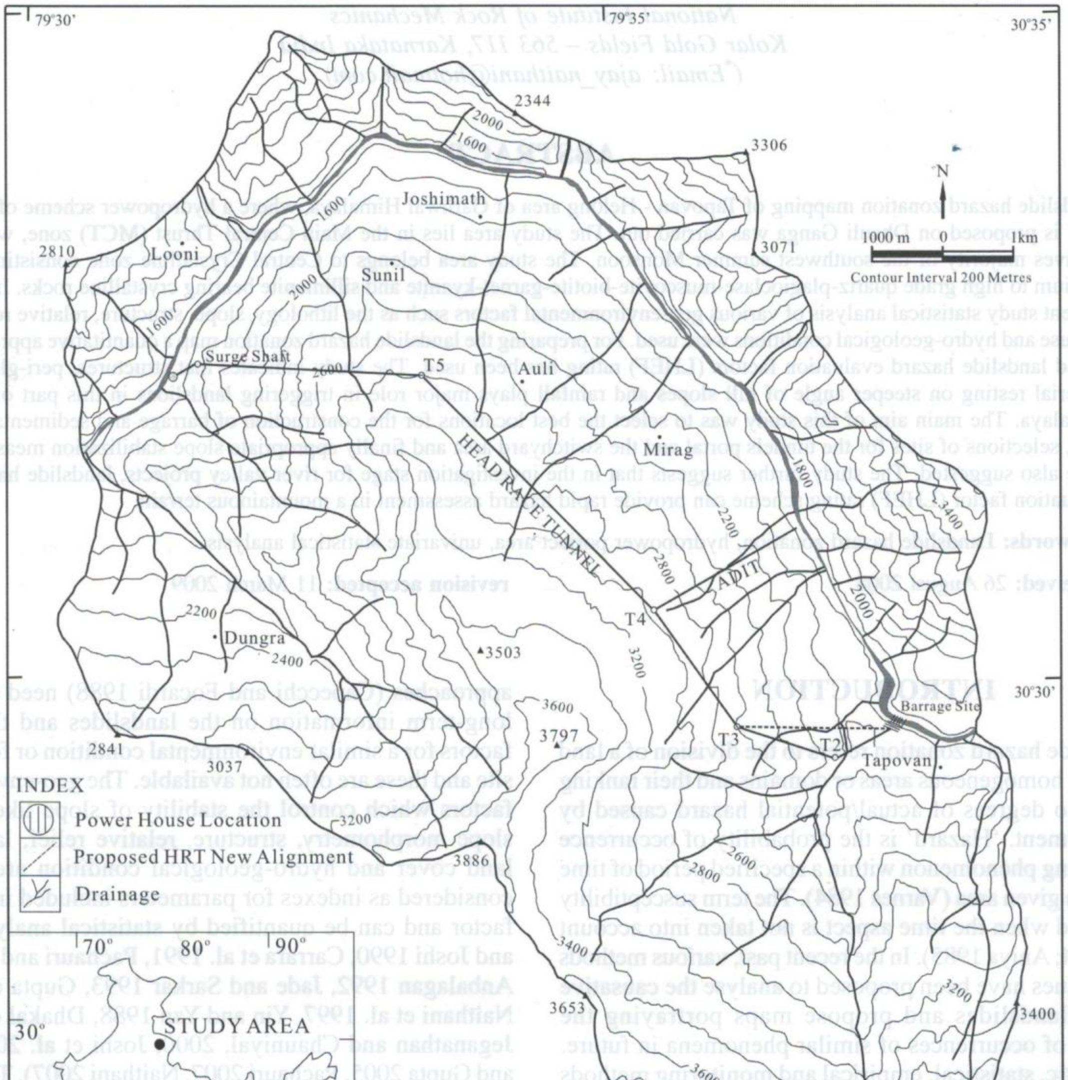

Fig. 1: Location map of the study area. Location of power house, barrage and alignment of head race tunnel are also shown.

where desiltation chamber, head race tunnel, power house and tail race tunnel are located. It was taken the whole catchment while in the right bank nearest ridge top taken into consideration because landslide on the other side i.e. backside of the ridge will not affect the project area. This area roughly falls in the Alaknanda watershed and is characterized by different types of crystalline rocks, undulating terrain, solifluction lobes and cool temperate climate. Steeper slopes, high relative relief, thick overburden over the rocky slopes and presence of weathered, fractured/sheared rocks in addition to unfavourable hydrological conditions are characteristic features of the area. The higher riches experience high snowfall during winter where frost and thawing is the common processes. The lower section is characterized by deep gorges along the main channel courses indicating high rate of rejuvenation. Numbers of problematic landslides (rockslides, debris slide) zones are observed along the road section. Every year a number of landslides cause heavy damage to life and property and even blockadge the road networks. If the instability of the slope is predicted in time, the occurrence and effects of landslides and mass wastings may be reduced to a great extent. The average annual precipitation in the area is nearly 96 to 122 mm (Table 1). 75% of the rainfall occurs during the Monsoon i.e., from middle of June to the end of August and rest of the rainfall occurs during winter i.e from January to April, which is the period of uncertain weather. The humidity of the area in the summer varies from 45 to 85%, during winter 70 to 98% and during Monsoon 85 to 98%. During summer temperature goes upto 39°C while during winter the minimum temperature 0.3°C was recorded. The aim of this work was to create a prototype map that is easy to read and understand and that can be useful in development planning of the area.

Table 1: Monthly rainfall data (in mm) over the years at Joshimath

Month	2002	2003	2004	2005	2006	2007
January	78.8	79.8	25.8	117.0	138.4	-
February	203.7	110.9	17.6	155.2	30.2	138.0
March	234.5	163.8	-	123.1	103.8	269.9
April	109.8	86.8	46.0	26.1	56.6	20.9
May	53.9	59.6	59.5	49.6	75.6	69.8
June	112.7	86.7	77.6	52.6	137.4	106.8
July	184.9	331.4	392.1	284.9	245.2	429.9
August	223.5	343.4	345.4	240.8	273.0	
September	224.6	103.8	100.3	221.0	89.6	
October	39.1	9.0	71.3	13.4	10.6	
November	1.0	9.6	1.0	4.4	10.7	
December	-	49.3	22.1	2.6	62.5	
Total	1465.7	1434.1	1158.7	1290.7	1233.6	
Average annual precipitation	122.14	119.50	96.55	107.55	102.80	

GEOLOGICAL SETTING OF THE AREA

The rocks exposed in project area belong to the Central Crystallines (Heim and Gansser 1939) composed mainly of medium- to high-grade metamorphics derived from pelitic, semi-pelitic, and psammitic sediments, which are sporadically interlayered with metabasics and, to a lesser extent (i.e. in the Dhak and Jharkula areas), calcareous rocks. Towards the south, the Central Crystallines are thrust over the Lesser Himalayan rocks of the Garhwal Group along the Main Central Thrust (Srivastava and Ahmed 1979; Valdiya 1980; Virdi 1986), which passes through the village of Helong located about 2 km downstream from the proposed powerhouse site (Fig. 2).

The grade of metamorphism increases northwards from Helong and Tapovan to Joshimath, ranging from biotite grade near the Karchhi and Animath villages to garnet grade near Tapovan and Shelong, and to kyanite grade near the Bargaon, Parsari, and Jogi Dhara areas. In a broader sense, the rocks of this area can be categorised into the Tapovan-Helong and Joshimath formations (Table 2). The Joshimath Formation comprises coarse-grained garnet gneisses and garnet-kyanite gneisses while the Tapovan-Helong Formation contains micaschists, garnet schists, amphibolites, augen gneisses, banded gneisses, and foliated gneisses dominated by biotite and quartz.

MATERIAL AND METHODHOLOGY

The macro Landslide Hazard Zonation (LHZ) mapping technique is an approach showing the probabilities of landslide hazards of a watershed area preferable on scale 1:25 000 or 1:50 000. The LHZ mapping comprises mainly

Table 2: Litho-tectonic setup of the Tapovan – Vishnugad area

Litho-units	Lithology	Grade of Facies	Metamorphic zones	Type Locality
Joshimath Formation	Coarse grained garnet-mica gneisses, garnet-kyanite gneisses	Amphibolite Facies	Kyanite Zone	Joshimath, Bargaon, Auli, Sunil, Parsari, Mirag
Tapovan-Helong Formation	Mica schists, augen gneisses, amphibolites, garnet-mica schists, fine grained banded gneisses,	Amphibolite Facies	Garnet Zone	Between Helong and Jharkula in Alaknanda Valley and Bargaon to Tapovan in Dhauli Ganga Valley
	Quartzites	Greenschist Facies	Biotite Zone	
Garhwal Group	Limestones, shales, quartzites and marbles	Greenschist Facies	Chlorite Zone	South of Helong in Alaknanda Valley

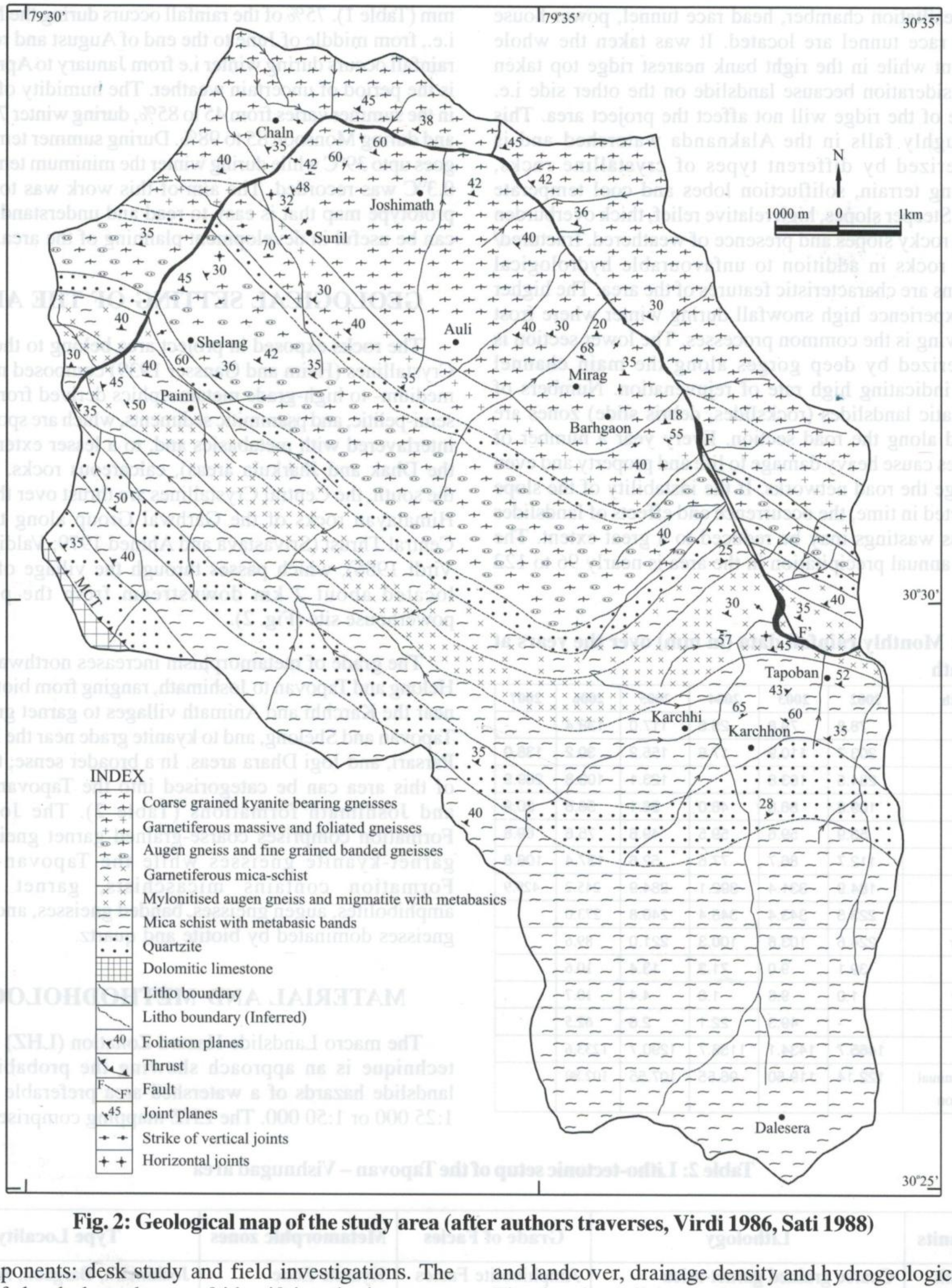

Fig. 2: Geological map of the study area (after authors traverses, Virdi 1986, Sati 1988)

two components: desk study and field investigations. The scopes of the desk study are of identifying the important parameters with the help of satellite imageries and toposheets. The precision geocoded merged FCCs of PAN and LISS-III (Indian Remote Sensing Satellite data IRS 1D) data were also used. The study involved the preparation of various types of pre-field maps on 1:25,000 scale, such as lithology, structural data, slope morphometry, relative relief, landuse and landcover, drainage density and hydrogeological maps. The already available geological map and satellite imageries were studied to understand the geological setting of the area as well as the adjoining areas. The information collected from the desk study help to plan and execute the field investigations systematically. During field study a more detailed lithological and structural maps were prepared. The detailed geological survey allowed us to distinguish the

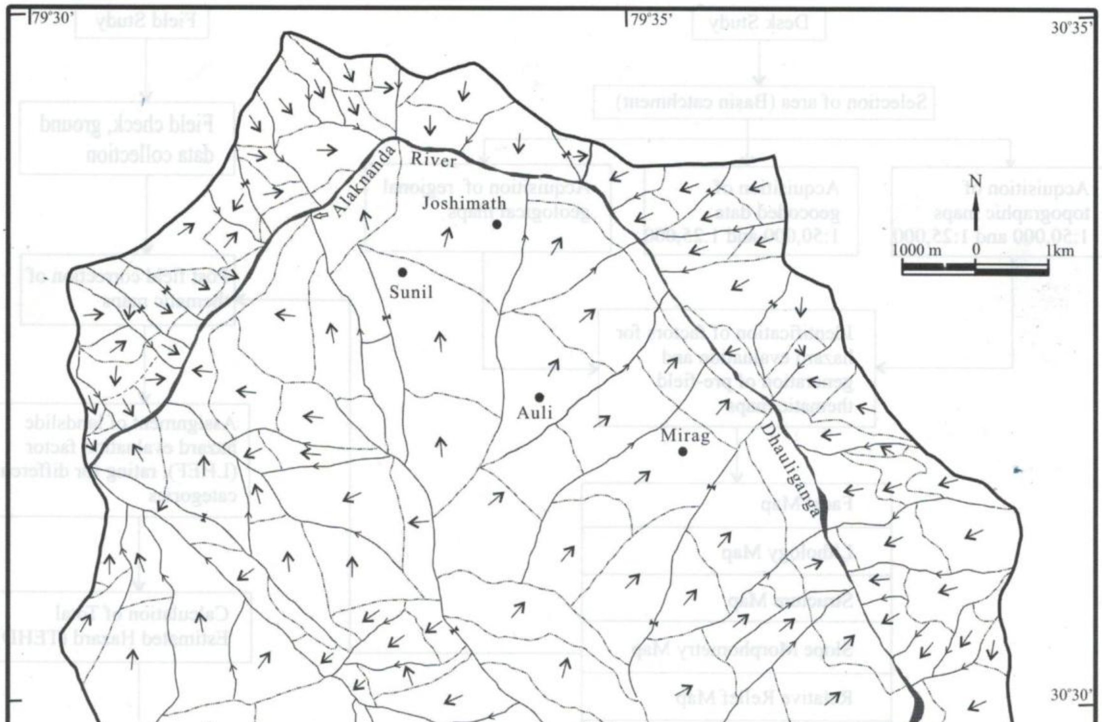

Fig. 3: Facet map of the study area

lithological types and subtypes, which are present and to define the structural elements which guide the weathering processes. The details of other maps prepared during the desk study were verified in the field and modified wherever necessary. The field studies carried out to collect the required data facet-wise for estimating the total hazard of the facets. A 'facet' is the basic smallest unit, which is considered to be consisting of one or more elements, which is reasonably homogeneous for all practical purposes and suited to a mapping scale of 1:50,000 to 1:10,00,000 (Mitchell 1973). According to Pachauri (1970) a facet is considered to be a homogeneous land unit, which has same geology and geomorphology at a suitable scale. A slope facet is a part of hill slope, which has more or less similar characters of slope, showing consistent slope direction and inclination. The slope facets are generally delimited by ridges, spurs, gullies and rivers (Fig. 3). The total estimated hazard (TEHD) indicates the net probabilities of instability and calculated facet-wise,

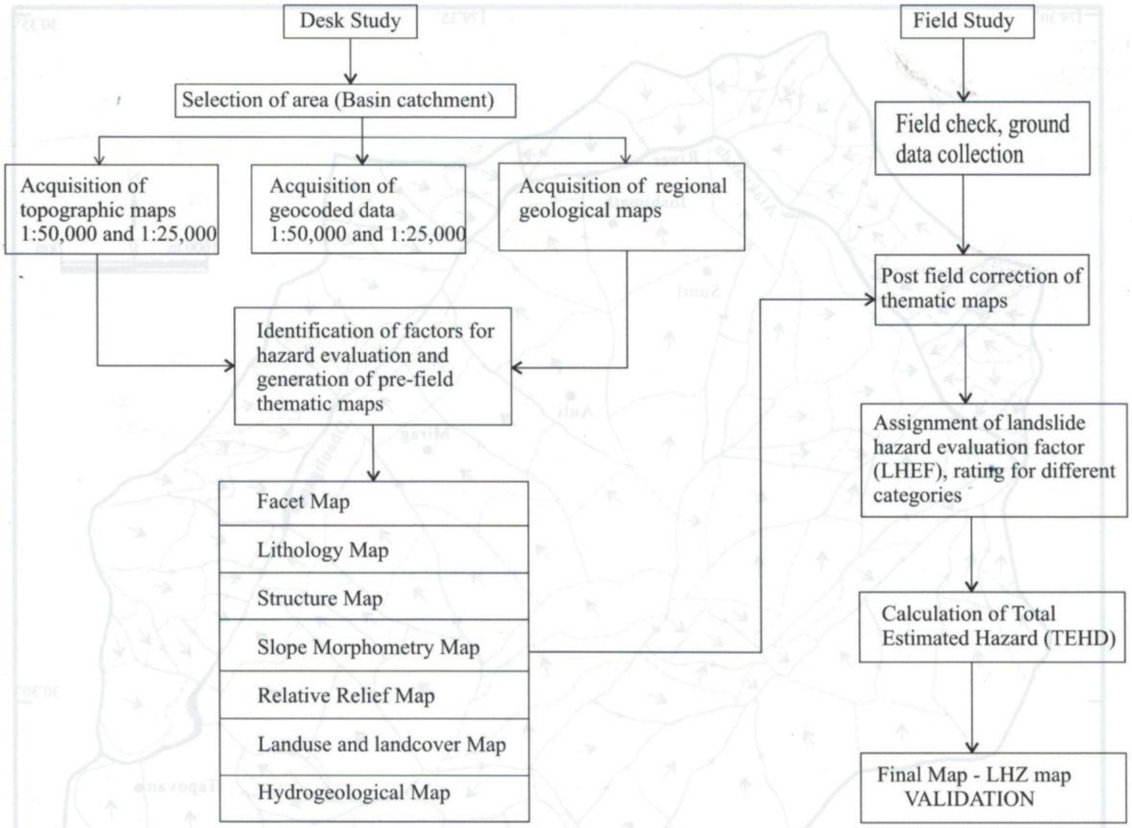

Fig. 4: Flow chart showing methodology for landslide hazard zonation mapping

since the adjoining facets may have entirely different stability conditions. The maximum LHEF ratings for different categories are determined on the basis of their estimated significance in causing instability (Anbalagan 1992; IS 14496 (Part 2), 1998). The TEHD of an individual facet is obtained by adding the ratings of the individual causative factors of lithology, structure, slope morphometry, relative relief, landuse and landcover and hydrogeological conditions obtained from LHEF rating scheme. The macro landslide hazard zonation map is prepared on the facet-wise distribution of TEHD values. The general procedure of landslide hazard zonation mapping technique has been outlined in the form of a flow chart (Fig. 4).

RELATION OF LANDSLIDE WITH ITS INHEREMT CAUSATIVE FACTORS

The inherent causative factors consider here are: i) lithology ii) proximity to major shear zone, iii) slope morphometry, iv) relative relief, v) landuse and landcover and vi) hydro-geological conditions.

Lithology

Lithology is one of the major causative factors for slope instability. The erodibility or the response of rocks to the processes of weathering and erosion are the main criteria in awarding the ratings for the sub-categories of the lithology. The rock types which are unweathered, hard, massive and more resistant to weathering form steep slope, while those rock which are vulnerable to weathering and erosion are generally form the depression and valleys. Accordingly the LHEF ratings are awarded. A correction factors on the status of weathering of rocks are also incorporated. As weathering attacks on the rocks, the strength and elasticity of the material decreases, porosity and saturation moisture content increases and grain size decreases. Such changes usually lead to decrease in shear strength thereby increasing the likelihood of landslides. In case of soil material and overburden the genesis, nature and age are the main considerations in awarding the ratings. The older alluvium is generally well compacted and has high strength whereas slide debris and glacial material are generally loose and have low shearing resistance and erosion resistance.

The rocks exposed in this area are garnetiferous mica schists, quartzites, augen gneisses, which occasionally are interlayered with metabasics and fine grained banded gneisses and coarse grained-biotite-garnet-tourmaline-kyanite bearing massive gneisses. The rocks of this area are broadly classified into two division namely, (i) Outer Crystalline, embracing the rocks of Main Central Thrust (MCT) zone, which are tectonically resting over the dolomitic limestone of Garhwal Group (Window Series) and (ii) Inner Crystalline consisting of high grade quartz-plagioclase-muscovite-biotite-garnet-kyanite and sillimanite bearing crystalline rocks. The rocks are mainly medium to high grade metamorphism from biotite grade to kyanite zone, which have been deformed repeatedly. The biotite schist of Tapovan area is highly fractured, jointed and crushed having the very low shearing resistant while the quartzite of Animath area where the under ground powerhouse is being constructed has the high resistant value. In the mica schists, fine grained gneisses and augen gneisses shear zones are very prominent. In the barrage site on the left bank highly fractured and jointed horizontally lying metabasics rocks are exposed showing very low strength. In the Chormi tunnel portal area, where the jointed quartzite is exposed the probability of rockfall is there during the construction of adit. In the powerhouse area, the portal of adit to powerhouse, the probability of toppling failure is more in the garnetiferous mica schist as compared to the quartzite.

The bedrocks are overlain by alluvial soil near the valley whereas the glacial moraines and solifluction lobes are common at higher elevation. Solifluction is a common process in the periglacial zones of frost heaving and frost creep. These lobes are generally triggered on permafrost action, as they swell and are converted into mud. The area covered by mica schists and metabasics rocks appear to be more prone to landslide occurrences because they are characterized by highly weathering and fracturing resulting thus promote instability. The approached road to surge shaft and power house will go all along the quaternary deposits for a good part. Out of seven problematic landslides along the roads section of the area, three occur on the unconsolidated overburden materials while four are rockslides.

Structure

Structure includes primary and secondary discontinuity in the rocks such as bedding planes, joints, foliations, faults and thrusts. Larger landslides are influenced by these features. The discontinuity in relation to the inclination of slope directions has greater influence of the stability of slopes. In this connection, three types of relations are important (a) the extent of parallelism between the directions of discontinuity or the line of intersection of two discontinuity and the slope, (b) steepness of the dip of discontinuity or plunge of the line of intersection of two discontinuities, (c) the difference in the dip of discontinuity or plunge of the line of intersection of two discontinuities to the inclination of slope. The LHEF ratings of the above three categories are assigned for various stability conditions. In case of soil and overburden the inferred depth are considered for awarding the ratings. A 100 m to 200 m strip on either side of major faults, thrust and intra-thrust zones are awarded an extra rating of 1.0 to consider higher landslide susceptibility depending upon intensity of fracturing.

Maximum numbers of landslides have been observed to occur within a distance of 1 km on either side of the tectonic planes, beyond which the frequency of landslide events gradually decreases (Valdiya 1989). This activity is possibly due to the occurrence of intensely fractured and sheared rocks and is also possibly due to some neotectonic movements. This area is characterized by Main Central Thrust near Helang and some minor faults, some of them have good geomorphic control also. Number of active landslides along these faults indicating that these faults are active at present. Main Central Thrust separates the Pre-Cambrian rocks of Garhwal Window Series from the Lower Crystalline of Proterozoic age. It forms a major dislocation structure in the area. It extends from near one and a half km south-west of Helang to south of Tapoban and form the base for the outer crystalline. The thrust is characterized by large scales mylonitisation and recrystallization rocks all along the contact with Garhwal Group rocks. The low gradesquartzite, chlorite-schist, schistose lime-silicate and associated rocks have been brought up along this thrust plane.

The area has revealed at least three phases of deformation. These phases correspond to three distinct orientation patterns of the deformation signature like planar, linear and curvi-planar structures. In the long process of deformation associated with changing stress directions, it has been found that the earlier imprints (fabric elements) are either superimposed or obliterated to a great extent by the subsequent imprints, depending upon the intensity of the stress field. The planar structures like foliation and joint planes have been studied in detail. All foliation planes trend in E-W and NW-SE with dips moderately towards N and NE respectively, except around Mirag and Barhgaon, where these foliations have a sharp rotation in dip direction from NE to NW. Joint planes are present in all the litho units but dominated in the Outer Crystalline rocks like quartzite, augen gneiss and fine grained gneiss. The curvi-planar (fold) structures are generally overturned asymmetric to symmetrical type with moderately dipping axial plane in NNW and NE directions. The interlimb angle measured for various folds ranges from 50° to 10° or some time even less than 10° therefore, they are categorized under closed, tight and isoclinal type folds. The dip of the axial plane varies from 45° to 52° and plunge ranges from 40° to 47°. The folds of the area range from recumbent, gently-plunging fold to steeply inclined, steeply-plunging folds.

Slope morphometry

Slope morphometry map defines slope categories on the basis of frequency of occurrence of particular angles of slope. The slope morphometry map is prepared by dividing the larger topographical map into smaller units within which the contour lines per kilometer of horizontal distance were calculated. Five categories representing the slopes of escarpment/ cliff, steep slope, moderately steep slope, gentle slope and very gentle slope are used (Fig. 5). Gentle slope covers 53% of the area followed by moderately steep slope (20%), very gentle slope and steep slope (each 10%) and very steep slope covering only seven percent of the area. It is observed that more landslides and subsidence zones occur in the northern slope as compared to the southern slope. In the southern slopes, on the right bank of river Alaknanda and Dhauliganga topple and wedge failures are common processes. In the barrage area the slope angle varies from 16

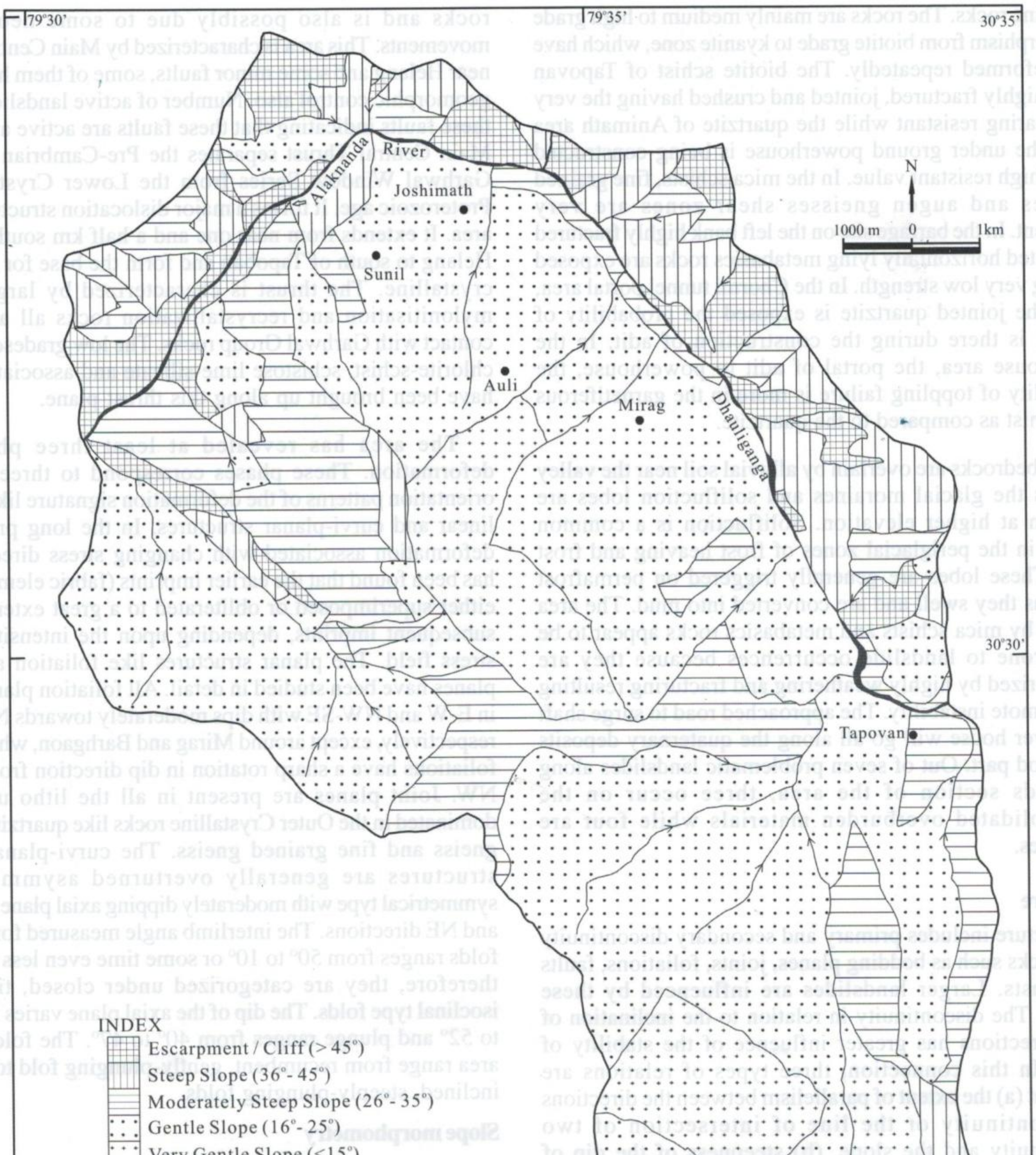

Fig. 5: Slope map of the study area

degree to 35 degree, while around the powerhouse area the slope varies from 36 degree to 60 degree. The Chormi portal adit comes under the gentle slope categories while the powerhouse and its portal area come under the very steep slope categories. The northern slopes are covered by thick overburden debris. Maximum anthropogenic activities are seen in such slopes. In the upper section is characterized by the gentle slope in the upper and middle part of the valley is characterized by past periglacial and glacial material. However, slopes are steeper towards the crest and are generally covered with snow for most part of the year. Snow patches supply continuous melt water from higher reaches, which recharges the springs present in the lower part. Continuous percolation of water from the upper slopes and

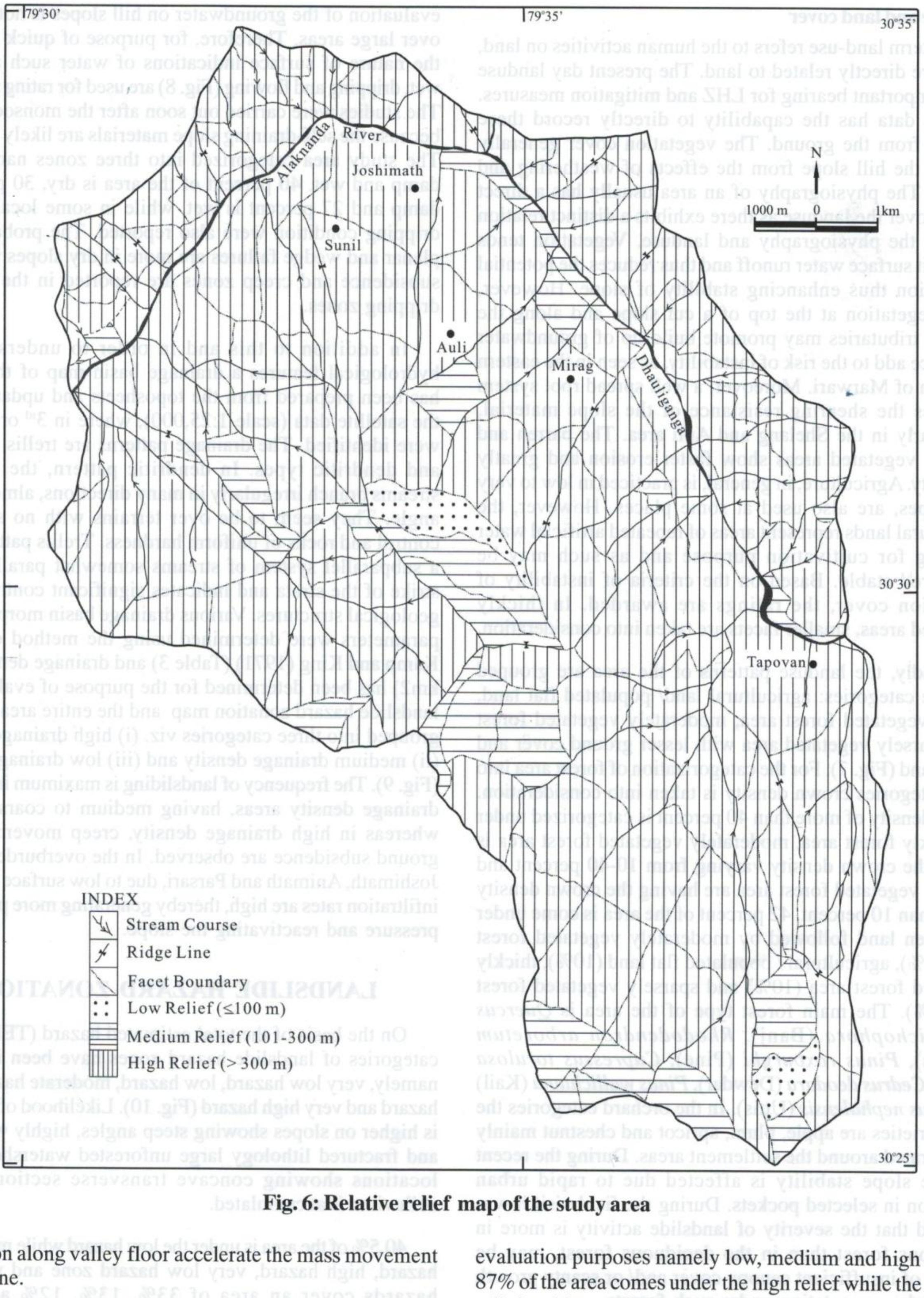

Fig. 6: Relative relief map of the study area

toe erosion along valley floor accelerate the mass movement in this zone.

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. Three categories of slope of relative relief are used for hazard evaluation purposes namely low, medium and high (Fig. 6). 87% of the area comes under the high relief while the medium relief and low relief cover twelve and one percentage of the total area respectively. Barrage site, portal of Chormi and portal of powerhouse all come under the high relief. During field investigation it was observed that relief is important factor, contributing to landslides.

Landuse and land cover

The term land-use refers to the human activities on land, which are directly related to land. The present day landuse has an important bearing for LHZ and mitigation measures. Satellite data has the capability to directly record these features from the ground. The vegetation cover generally protects the hill slope from the effects of weathering and erosion. The physiography of an area usually has a direct bearing over the landuse as there exhibits a distinct relation between the physiography and landuse. Vegetation tends to exhibit surface water runoff and thus reduces the potential for erosion thus enhancing stability of slope. However, dense vegetation at the top of a cut slope and along the slope of tributaries may promote build up of groundwater and hence add to the risk of instability, as seen in the eastern direction of Marwari. Moreover, a well spread root system increases the shearing resistance of the slope material, particularly in the Shelang and Auli area. The barren and sparsely vegetated areas show faster erosion and greatly instability. Agriculture, in general, is practiced in low to very low slopes, are also used at some places. However, the agricultural lands represent areas of repeated artificial water charging for cultivation purpose and as such may be considered stable. Based on the criteria of instability of vegetation cover, the ratings are awarded. In thickly populated areas, smaller facets are taken into consideration.

Broadly, the landuse patterns of the area are grouped into five categories: agricultural land/ populated flat land, thickly vegetated forest area, moderately vegetated forest area, sparsely vegetated area with lesser ground cover and barren land (Fig. 7). For the categorization of forest area into three categories crown density is taken into consideration. Crown density of more than 40 percent is categorized under the thickly forest area, moderately vegetated forest area is having the crown density varying from 10-40 percent and sparsely vegetated forest area are having the crown density of less than 10 percent. 42 percent of the area is come under the barren land followed by moderately vegetated forest area (25%), agricultural / populated flat land (10%), thickly vegetated forest area (10%) and sparsely vegetated forest area (9%). The main forest type of the area is *Quercus leucotrichophora* (Banj), *Rhododendron arboretum* (Burans), *Pinus roxburghi* (Pine), *Cupressus torulosa* (Surai), *Cedrus deodara* (Dewdar), *Pinus wallichiana* (Kail) and *Alnus nephalensis* (Uttis). In the orchard categories the main varieties are apple, plum, apricot and chestnut mainly concentrated around the settlement areas. During the recent past the slope stability is affected due to rapid urban expansion in selected pockets. During the field visit it was observed that the severity of landslide activity is more in coniferous forest than in the deciduous forest, may be because of insufficient canopy cover and/ or scanty growth of secondary vegetation under such forests.

Hydro-geological conditions

Since the groundwater in hilly terrain is generally channelized along the structural discontinuities of rocks, it does not have uniform flow pattern. The observational evaluation of the groundwater on hill slopes is not possible over large areas. Therefore, for purpose of quick appraisal the nature of surface indications of water such as damp, wet, dripping and flowing (Fig. 8) are used for rating purposes. The studies were carried out soon after the monsoon period because the self-draining slope materials are likely to be dry. The study area categorized into three zones namely dry, damp and wet. 40 percent of the area is dry, 30 percent is damp and 27 percent is wet, while in some local pockets dripping condition were also reported. The probability of planar and wedge failures are more in dry slopes while the subsidence and creep zones are reported in the wet and dripping zones.

In addition to this and in order to understand the hydrological features a drainage basin map of the terrain has been prepared from the toposheets and updated using the satellite data (scale 1:25,000), where in 3rd order basin were identified. The drainage patterns are trellis (parallel) and dendritic types. In dendritic pattern, the tributary streams branch irregularly in many directions, almost at any angle. They seem to be over terrains with no structural control and rocks of uniform hardness. Trellis pattern show a subparallel system of streams somewhat parallel to the strike of the strata and indicates significant control by the geological structures. Various drainage basin morphometric parameters were determined using the method of Doorn Kamp and King (1971) (Table 3) and drainage density (km/ km2) has been determined for the purpose of evaluation of landslide hazard zonation map and the entire area was thus grouped into three categories viz. (i) high drainage density, (ii) medium drainage density and (iii) low drainage density (Fig. 9). The frequency of landsliding is maximum in medium drainage density areas, having medium to coarse texture whereas in high drainage density, creep movements and ground subsidence are observed. In the overburden area of Joshimath, Animath and Parsari, due to low surface drainage, infiltration rates are high, thereby generating more pore water pressure and reactivating the slope.

LANDSLIDE HAZARD ZONATION

On the basis of the total estimated hazard (TEHD), five categories of landslide hazard zones have been identified namely, very low hazard, low hazard, moderate hazard, high hazard and very high hazard (Fig. 10). Likelihood of landslide is higher on slopes showing steep angles, highly weathered and fractured lithology large unforested watershed and at locations showing concave transverse sections where colluvium is accumulated.

40.5% of the area is under the low hazard while moderately hazard, high hazard, very low hazard zone and very high hazards cover an area of 33%, 13%, 12% and 1.5% respectivily. In the study area, old landslide and rock debris are accumulated very high hazard zone (VHH) are located along the valley of riverbed, in the Dhak Nala area where and along the escarpment of Karmnasa river. On the otherhand, high hazard zones are more common around the

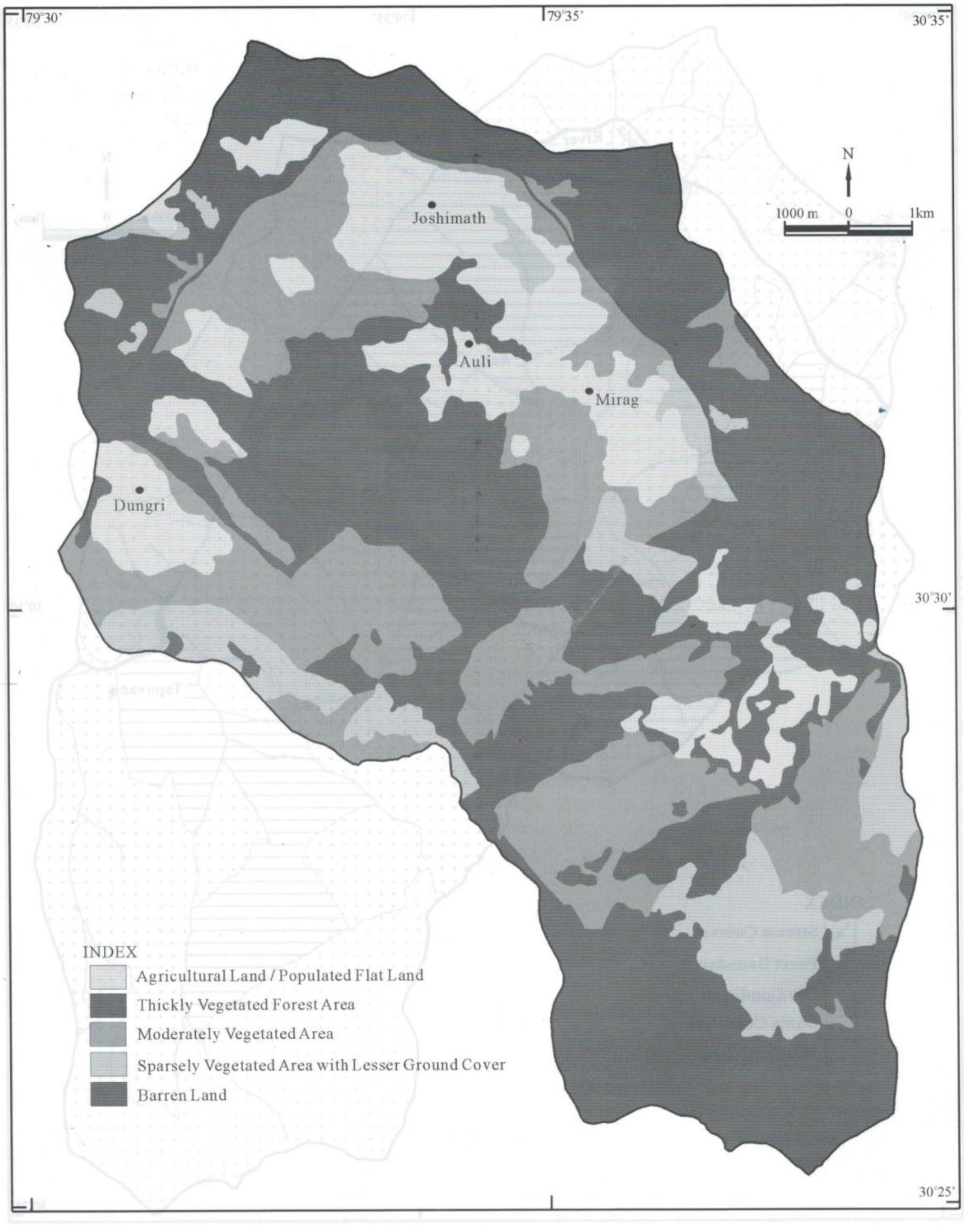

Fig. 7: Land use and land cover map of the study area

right bank of Alaknanda and Dhauliganag, around Pani, northeastern side of Joshimath, around Parsari and around Pangarchula and Delasera area. Moderate hazard zones are present in the north of Chaln, in the south of Aira, around Joshimath, Jharkula Chatti, in the west of Paini, around Urchyri, around Belagarh and in the eastern portion of Khulara. Low hazard and very low hazardous area are mainly restricted to cultivated fields, alpine zone and in the area with gentle slope with good vegetated cover. The barrage and surge shaft area come under the low hazardous zone while the powerhouse and Charmi tunnel portal area come under the moderate hazardous zone. The percentage wise distribution of inherent causative factors is given in Table 4.

With the help of landslide hazard evaluation factor (LHEF) rating scheme the area can be categorized into safer and

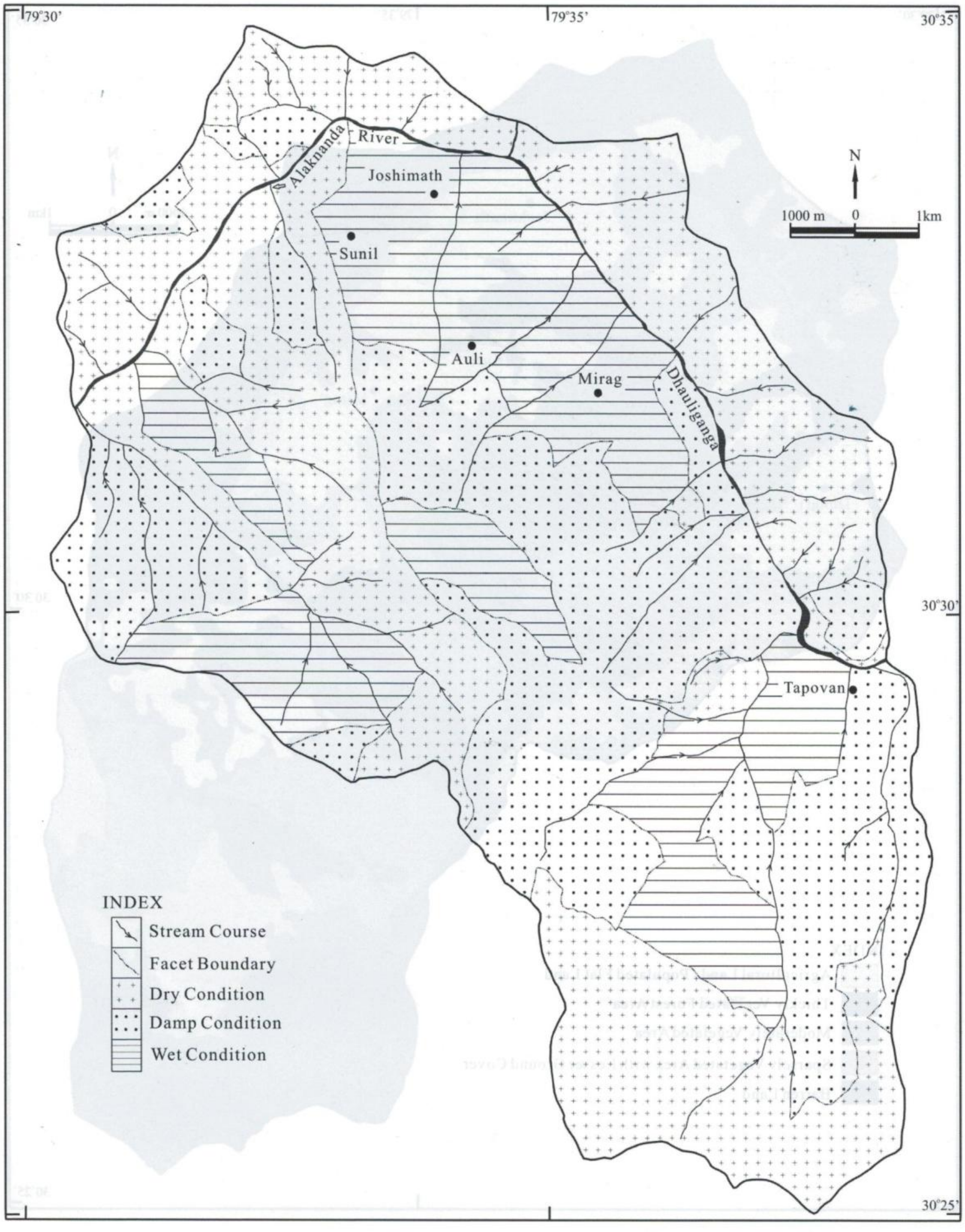

Fig. 8: Hydrogeological map of the study area

unsafer zones. Management practices like retention wall with drain holes, channelisation, slope modification, bio-technical measures, river training, planned mining, planned developmental activities, avoid further construction activities, forest conservation, afforestation and soil conservation can be taken into consideration for regional level planning. Low hazardous zone has wider applications during the hydropower constructions. Very low hazard and low hazard zones are considered safe for development schemes. The moderate hazard zones may contain some local vulnerable zones of instability. Detailed geotechnical investigations shall have to be carried out to identify these zones so as to adopt proper remedial measures. The High Hazard (HH) and Very High Hazard (VHH) zones mostly have

Table 3: Drainage density of various basins (Morphometric Analysis)

S. N.	N_1	N_2	N_3	L_1	L_2	L_3	$(\Sigma L)u$	Au	$D=(\Sigma L)u/Au$
01	9	1	-	8.95	1.6	-	10.55	3.85	2.740
02	1	-	-	1.1	-	-	1.1	1.25	0.88
03	6	1	-	8.95	0.6	-	9.55	3.45	2.768
04	2	1	-	1.75	0.95	-	2.7	0.875	3.085
05	2	-	-	1.75	-	-	1.75	1.55	1.129
06	3	1	-	1.9	0.45	-	2.35	1.175	2.0
07	6	2	-	6.6	1.55	-	8.15	3.95	2.063
08	6	1	1	6.05	0.95	1.95	8.95	3.225	2.775
09	9	1	-	8.15	2.05	-	10.2	2.7	3.777
10	4	2	1	3.45	1.4	0.9	5.75	1.45	3.965
11	6	1	-	5.55	0.45	-	6.0	3.25	1.846
12	4	1	1	3.9	0.45	1.25	5.6	3.575	1.566
13	6	2	1	5.45	4.4	3.05	12.9	5.7	2.263
14	4	1	-	1.75	1.4	-	3.15	2.325	1.354
15	11	3	1	10.5	2.9	3.55	16.95	13.44	1.261
16	7	2	1	5.95	3.05	2.45	11.45	7.465	1.533
17	8	3	1	6.95	2.05	3.05	12.05	3.875	3.109
18	7	3	1	6.95	3.25	2.1	12.3	7.265	1.693
19	7	2	1	5.05	1.25	4.45	10.75	2.1	5.119
20	4	1	-	5.45	0.95	-	6.4	2.35	2.723
21	4	2	1	3.9	1.6	2.9	8.4	3.5	2.4
22	9	3	1	9.55	6.1	2.95	18.6	7.59	2.450
23	6	1	-	10.05	4.45	-	14.5	6.465	2.242
24	10	2	1	10.75	2.55	1.55	14.85	5.75	2.582
25	8	1	1	15.45	2.55	5.65	23.65	14.940	1.582
26	7	1	1	8.95	1.1	4.95	15.0	6.515	2.302
27	16	5	1	14.45	4.55	3.05	22.05	7.365	2.993
28	5	1	-	4.45	0.55	-	5.0	3.325	1.503
29	13	4	1	9.55	2.9	2.05	14.5	3.45	4.202
30	5	2	1	3.75	1.4	1.55	6.7	3.175	2.110
31	4	2	1	5.45	0.75	0.55	6.75	1.975	3.417
32	4	-	1	4.15	-	4.55	8.7	3.075	2.829
33	3	1	-	5.05	2.15	-	7.2	5.175	1.391
34	2	1	1	0.55	0.95	1.45	2.95	1.125	2.662
Total							327.45	148.245	

N_1, N_2, N_3: Number of streams of Ist, IInd and IIIrd order, L_1, L_2, L_3: Length of streams of Ist, IInd and IIIrd order, $(\Sigma L)u$: Total length of streams in IIIrd order basin in km., Au: Area of IIIrd order basin in sq.km., D: Stream density $(\Sigma L)u/Au$), Total area cover by the river: 0.554 sq.km.

of unstable slope, which may be active specially in case of Very High Hazard (VHH) zones and could be avoided for implementing the development schemes like colony settlements etc. Detailed geotechnical appraisals of the unstable slope shall be carried out by mapping the slope on 1:1000 or 1:2000 scales in order to evaluate the nature of instabilities, so that proper precautionary measures could be adopted during construction as well as for evolving appropriate mitigation measures to protect the geo-environmental stability of the area. During the geotechnical investigation the factors like UCS, RQD, SMR factors and weathering of the rock parameters should be taken into consideration. The map shall be revised when this area would have been affected by major earthquakes, flash floods, developmental activities and cloudburst.

DISCUSSIONS

In the study area, the mass movements occur in the form of rockfall, debris slide, creep and complex slope failures. Old landslide features are very common in the form of colluvial cones and fan shaped debris flow along the scarp, steep and concave slopes. Secondary landslide patches are also observed over the old landslide debris. Along the main tributary channels, flash floods during the rainy season are very common phenomenon. Rockfall was expressed in many places because of high relief energy, frequent occurrence of very steep rockwalls and intersection of major joints. Silent witnesses of former rockfall activity were found virtually throughout the entire area. The rockfall in the higher reaches are generally associated with the winter phases of freezing and thawing.

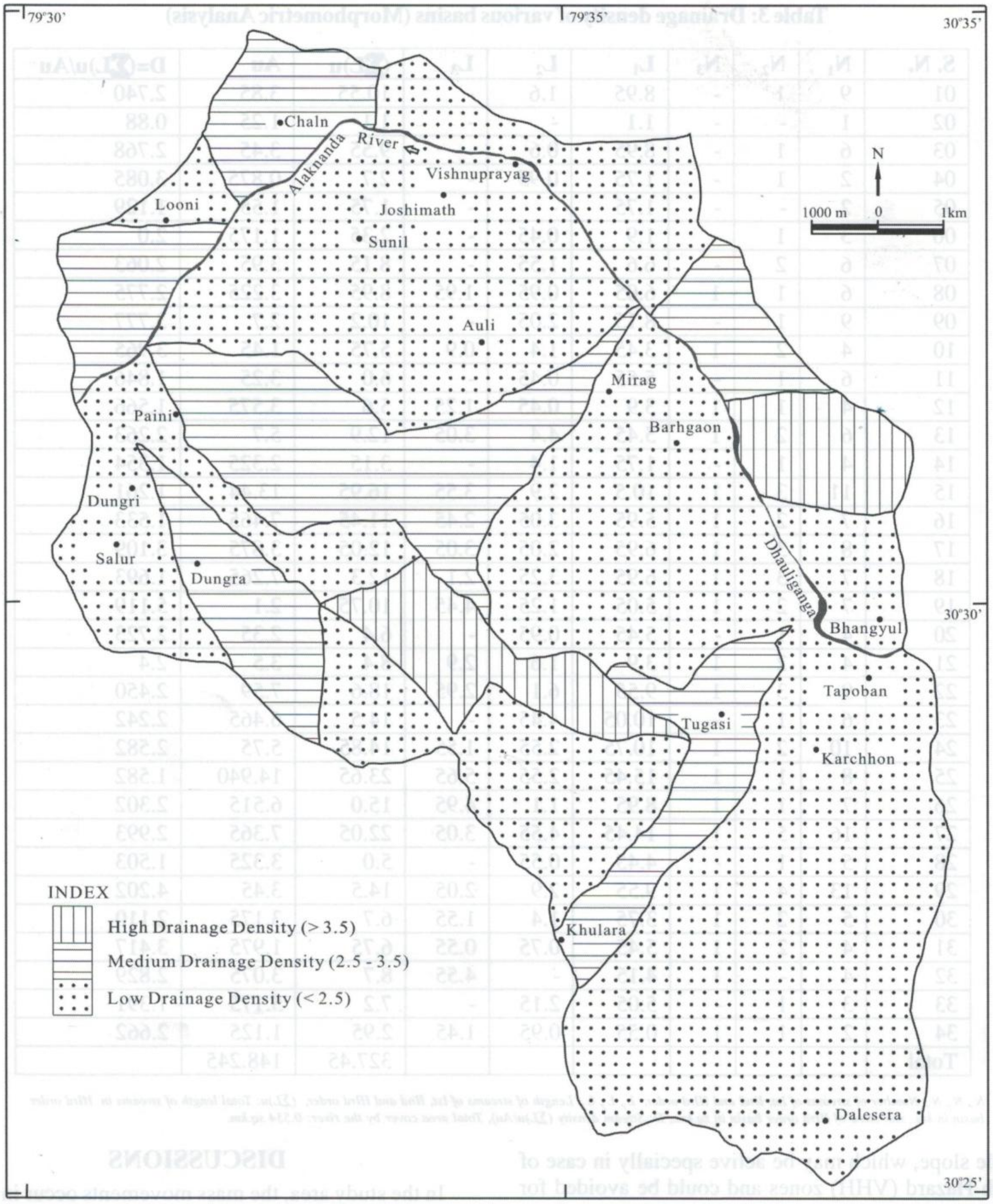

Fig. 9: Drainage density map of the study area

In the barrage area, the augen gneisses expose along the right bank of river course on either side of the axis and dipping into the right abutment. On the left bank of the river a steep scarp of highly jointed and shear metabasic rock with bands of gneisses and schist are exposed on the hill slope. The lower river levels is occupied by river borne materials. For the abutment of the barrage on the left bank, excavations of weathered, highly jointed and fractured metabasics and schists during construction phase and operational of the project will be involved for which suitable slope cuts with bolting and shotcreting will be required for a prevention of rock mass failure into the barrage area.

The study indicates that the foundation of sedimentation tank will be in the overburden of river borne material and sand. Upstream site of the axis, excavation of the debris material and jointed metabasic will be involved. This will necessitate design of proper slope cut and protection measures based on property of debris material. Similarly along the barrage axis and down stream site, rock excavation

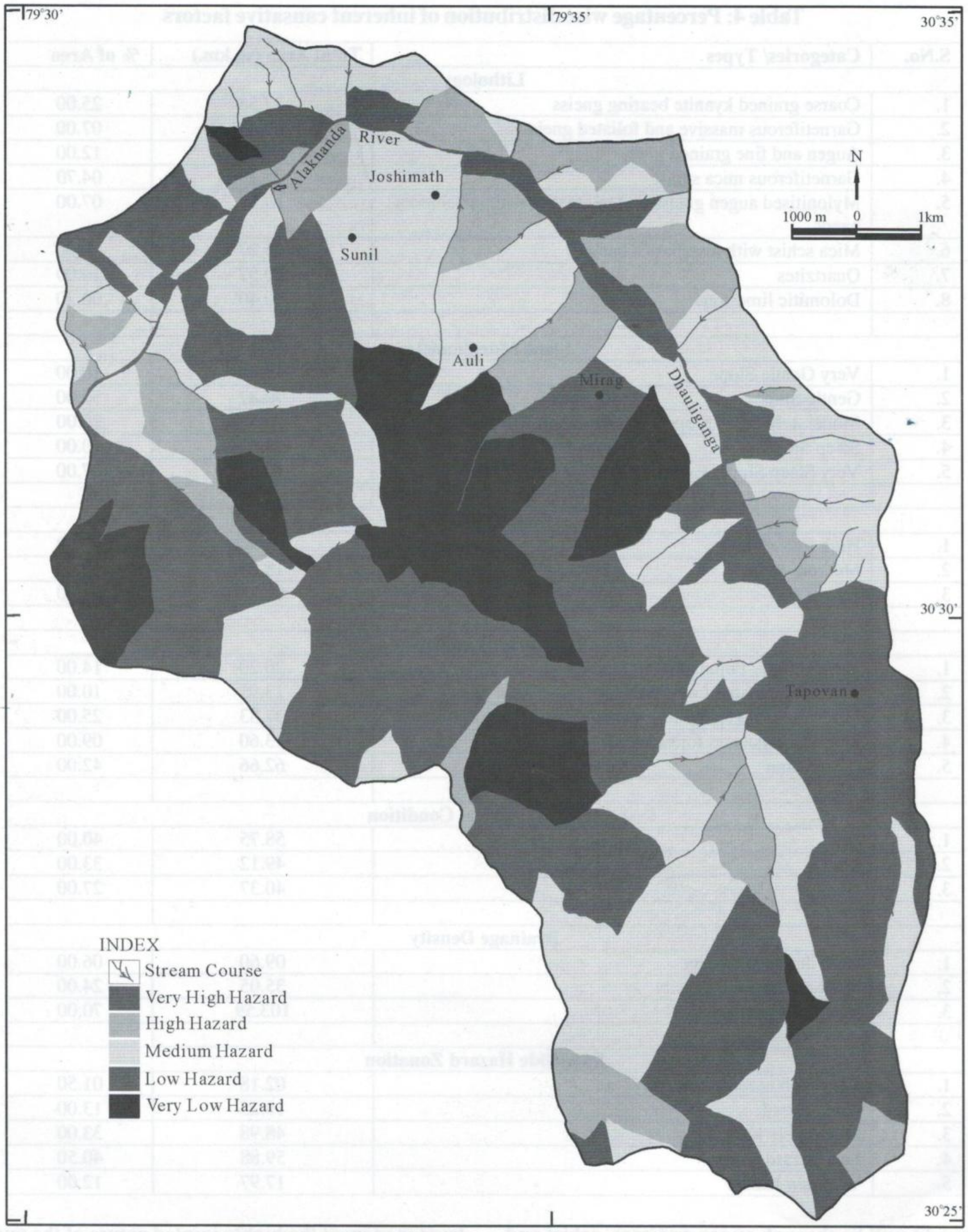

Fig. 10: Landslide hazard zonation map of the study area

of metabasics and schists from higher level (±1858 m) up to terrace level ± 1791 m and downwards will be through river borne material, which will call for suitable design for slope cuts including shotcreting and bolting for the prevention of this highly jointed rock mass failure during excavation or during operational stage.

In case of head race tunnel, the expodure in preliminary reaches from barrage site T1 towards T2 point Lower Crystalline unit consisting basically of metabasic and schistose rock. The strike of these cut across the tunnel alignment with dips towards and outwards from the barrage. Though the tunnel cuts across the strike of the rock in this reach, which are reckoned to be a favorable direction but at the intake portal, since the metabasic rock are highly jointed and horizontally disposed and the investigation stage drift had indicated the loosening effect up to a depth of 26 m from the surface slope the tunnel lining will have to be designed suitably along with proper method of tunneling practice and the portal area should be protected through proper measures.

Table 4: Percentage wise distribution of inherent causative factors

S.No.	Categories/ Types	Total Area (sq.km.)	% of Area
	Lithology		
1.	Coarse grained kyanite bearing gneiss	37.58	25.00
2.	Garnetiferous massive and foliated gneiss	09.43	07.00
3.	Augen and fine grained gneiss	17.80	12.00
4.	Garnetiferous mica schist	07.10	04.70
5.	Mylonitised augen gneiss and migmatite with metabasics bands	10.10	07.00
6.	Mica schist with metabasics bands	45.27	30.00
7.	Quartzites	20.57	14.00
8.	Dolomitic limestone	00.40	00.30
	Slope Morphometry		
1.	Very Gentle Slope	14.45	10.00
2.	Gentle Slope	78.87	53.00
3.	Moderately Steep Slope	29.52	20.00
4.	Steep Slope	14.57	10.00
5.	Very Steep Slope/ Escarpment	10.82	07.00
	Relative Relief		
1.	High Relief	129.42	87.00
2.	Medium Relief	18.83	12.00
3.	Low Relief	02.25	01.00
	Landuse / Landcover		
1.	Agricultural / Populated flat land	20.20	14.00
2.	Thickly vegetated forest area	13.95	10.00
3.	Moderately vegetated forest area	37.83	25.00
4.	Sparsely vegetated forest area	13.60	09.00
5.	Barren land	62.66	42.00
	Hydrogeological Condition		
1.	Dry	58.75	40.00
2.	Damp	49.12	33.00
3.	Wet	40.37	27.00
	Drainage Density		
1.	High drainage density	09.60	06.00
2.	Medium drainage density	35.05	24.00
3.	Low drainage density	103.59	70.00
	Landslide Hazard Zonation		
1.	Very high hazard	02.18	01.50
2.	High hazard	19.25	13.00
3.	Moderately hazard	48.98	33.00
4.	Low hazard	59.88	40.50
5.	Very low hazard	17.97	12.00

The Chormi adit will be through augen gneisses, schist and quartzited bands of Tapovan Formation, where in the portal quartzite will be met where the probability of slab failure is there, which should be protected through suitable supporting system.

The detailed slope stability studies around the surge shaft area has been carried out. The overburden is hardly of 1.5 m, which is also proved by drill hole. The rock types are augen gneisses and quartz mica gneisses with schist band. In the initial depth of surge shaft the rock quality is good but the rock cover might not be adequate, while at the lower level in view of the highly jointed nature of the quartz mica – gneisses as indicated by drill hole data suitable design for the weakly jointed strata will be required. The probability of slope failure is on the left bank Shelang ridge need adequate slope protective measures.

The pressure shaft will be excavated through foliated quartz mica - gneisses and mica–schist and quartzite at lower levels. The slope stability study indicating that the joints are not open, prominent shear zones are absent, and rock quality is fair to good, so there is no possibility of any slope failure during the construction of pressure shaft. Exploration by drifts have indicated that the rock mass is slumped up to a depth of 50 m at EL. 1562 m and to a depth of 15 m at EL. 1732 indicating availability of sound rock cover for the pressure shaft.

The quartzite of powerhouse area is classified into three categories like massive/blocky, jointed and highly jointed based on joints parameters. On the surface the probability of rock fall slide is on the highly jointed quartzite, along the old alignment of road section to Badrinath, but this will not affect any project component.

The location of the exit portal for the tail race tunnel will be in the massive foliated schist, where the probability of toppling failure is there, need to take some protective measures but have to be assessed in further details once the alignment is finalized. The open channel section of the tail race will have to be protected by retaining walls and drainage control, as creep movement was observed during the field work.

CONCLUSIONS

It can be concluded that the barrage, desilting basin, surge shaft and tunnel portal areas are considered not much vulnerable and could be controlled with appropriate slope measures. This is applicable for the natural for manmade slopes. Concrete retaining wall can be constructed in case of TRT open channel section, whose foundation should be in the bedrock or good soil below the slip surface. The switch yard area can be protected through concrete retaining wall with drain holes, slope modification upto the road level and drainage measures but have to be assesses in details once the area for switch yard are finalized. The Shelong, Bargaon and Bhangyul areas are come under the low and very low hazard categories, can be used for the colony settlement of the project. For the active landslide areas, management practices, like retention wall with drain holes, drainage control, slope modification and bio-technical measures can be taken into consideration.

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