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# Landslide hazard zonation of Dharasu -Tehri-Ghansali area of Garhwal Himalaya, India using remote sensing and GIS techniques

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## ABSTRACT

The landslide hazard zonation of Dharasu-Tehri-Ghansali area of Garhwal Himalaya has been carried out using Indian Remote Sensing (IRS) LISS II and SPOT (MLA) data for various geo-environmental parameters viz. lithology, structure, land use/land cover, slope and drainage. The forest types and density and other land uses in the reservoir rim area were delineated and also assessed the direct loss of forests, agricultural land, wastelands and other landuse in the submergence area of the Tehri dam. There are 71 landslides in the periphery of the Bhagirathi and the Bhilangana rivers, which will enclose the impounded reservoir. Out of 71 landslides 35 will get submerged during the reservoir-filling phase while remaining will continue to exist. By overlaying the thematic maps in Geographical Information System (GIS) environment and using statistical parameters, a landslide hazard zonation map has been prepared. Phyllite, dissected hills, slope $50^0$-$60^0$, agriculture and convex side of stream channel were to be found more susceptible for landslide. An area of 43.5 km$^2$ in the reservoir rim falls in the category of high to very high class as per the landslide hazard zone code.

## INTRODUCTION

Development activities, especially the multipurpose river valley projects, due to their associated ecological and environmental implications have been the focus of attention through out the world among environmentalists and public. Many times, these problems are perceived to be the result of insufficient or inaccurate scientific data and people's perception of development action. Tehri dam project, being executed in the Garhwal Lesser Himalaya is one such example, which has been besieged with controversies since its inception. The common environmental problems encountered during execution and operational phases of such type of projects include land degradation in the catchment and/or command areas, deforestation and associated loss of biodiversity, induced seismicity, increase in the incidence of water borne diseases and dramatic alteration or even complete disruption of socio-cultural set-up. Also, reduction in life and efficiency of impounded reservoirs and threat to life and property in downstream areas are the serious manifestations of the increased silt load. In view of the ecological/ environmental problems associated with the multipurpose river valley projects, it is now realized to take a comprehensive stock not only of the conventional economic considerations but also the multiple-ecological considerations so that corrective measures are ensured well in time to avoid or minimize the anticipated damages.

A study has been carried out in the Tehri dam reservoir rim area with an objective to make a landslide hazard zonation map and to assess the direct loss of forests, agricultural land, wastelands and other land uses by applying remote sensing and GIS technologies. The slopes immediately abutting the reservoir spread constitutes the 'rim' of the reservoir and are important in terms of the useful life of the impounded reservoir and the stability of its slopes.

## CHARACTERISTICS OF THE AREA

The study area is located in the Lesser Himalayan unit in the Bhagirathi and the Bhilangana river valleys, in the central part of Garhwal Himalaya, in Tehri district (Fig. 1) encompassing an area of approximately 284 km$^2$. The Tehri dam (770 masl, 24°44'N-78° 53'E), the first storage dam over river Bhagirathi in the Garhwal Himalaya, will be 260.5 m high earth and rock fill dam from the deepest foundation about 1.5 km downstream of the confluence of the Bhagirathi and the Bhilangana river near Tehri town at Ganesh Prayag. The Bhagirathi and the Bhilagana are the two major watersheds comprising 13 major sub-watersheds and have a total 7507.9 km$^2$ area. The maps prepared by using Survey of India (SOI) toposheets and remote sensing data indicate that the snow-covered area is the largest land cover occupying 3009.20 km$^2$ area, which is 40.08% of the catchment. Forest accounts for 2878.7 km$^2$ (38.34%) in the catchment, out of which, the closed forest area is 1688.7 km$^2$,


**Fig. 1: Location map of the study area**

i.e. 12.14% of the catchment area. The open forest area accounts for 23.51% occupying 992.90 km$^2$ area. The degraded forest area is 197.30 km$^2$ area, which is 2.63% of the catchment. In the 10 km radius around Tehri dam site forest cover has decreased by 10.38 km$^2$ during 1972-91. Density-wise, area under closed forest has decreased from 11.55 km$^2$ to 4.53 km$^2$.

The impounded reservoir will extend upto 44 km along the Bhagirathi and 25 km along the Bhilangana rivers covering an area of 52.80 km$^2$ at maximum flood level as per estimation from the SOI topographical maps. The annual rainfall around Tehri is 977 mm and mean daily temperature is maximum 28.9$^0$C and minimum 15 $^0$C (IMD 1989).

The total affected villages by the Tehri Dam Project (TDP) are 124, which are categorized into three classes, i.e. (i) affected villages due to creation of reservoir in the Bhagirathi River (full– 22, and partially– 74); (ii) will be affected villages due to construction of New Tehri Town (NTT) (fully – 13); and (iii) will be affected villages due to construction of Koteshwar reservoir to support Tehri dam (fully–2 and partially–14). The total population of affected villages is around 26299. The rates of sedimentation as calculated by different authorities and organization, vary from 8.1 ha m/100 km$^2$/year to 16.5 ha m/100 km$^2$/year (Table 1). The life span of the reservoir varies from 62 years to 160 years on the basis of rate of sedimentation.

## METHODOLOGY

Landslide map for the periphery of the impoundment by the dam (reservoir rim) was prepared using IRS LISS II and SPOT (MLA) data and field data. For landslide hazard zonation, slope map, drainage map, drainage buffer map, lithological map, structural map, landuse and land cover maps

**Table 1: Variability in data on sedimentation (Garg et al. 1995)**

| Data source | Estimate on sedimentation (ha m/100 $km^2$/yr) |
|---|---|
| Project Authorities (1969) | 8.10 |
| Central Water Commission (1972) | 12.50 |
| Ganga Discharge Organization (1986) | 16.53 |
| Central Water Commission (1987) | 14.86 |
| Project Authorities (1991) | 14.50 |

on 1: 50,000 scale were prepared. The landslide map was superimposed over each thematic map using overlay technique in GIS environment (Fig. 2). This leads to generation of frequency distribution of landslides in each unit within an geo-environmental theme, the area occupied by various theme units was used to derive landslide occurrence per $km^2$. Subsequently, an empirical 'Landslide Hazard Index', which shows susceptibility in terms of Landslide Hazard Factor (LHF) of individual units of each geo-environmental theme, was derived as:

$$\text{LHF} = \frac{\text{Landslide incidence in a particular unit}}{\text{Average landslide incidence in various units within a theme}}$$

A value of LHF > 1.0 indicates that a particular theme unit is more susceptible while a value < 1.0 represents more stable slopes. A value of 1.0 implies that the theme units have an average landslide incidence.

## GEOLOGICAL SETTING OF THE AREA

Various workers viz Jain (1971), Saklani (1972), Agarwal and Kumar (1973), Valdiya (1980), Rao and Pati (1982) and Singh (1982) have described the geological setting of this area. This area is bounded on the south by South Almora Thrust (SAT) and north in Bhilangana valley by Bhatwari Thrust and in Bhagirathi valley by Munsiari Thrust (MCT), while North Almora Thrust (NAT) passes in between SAT and MCT. The major lithounits of this area are Krol Nappe, Almora- Nappe and Inner Lesser Himalayan Unit. In the Krol-Almora-Nappe the major rock formations exposed are phyllites, quartzites, slates, limestones-dolomites and metabasic rocks. The Inner Lesser Himalayan Unit comprises mainly granite-gneisses, micaschist and augen gneiss. The major structural feature, the Srinagar thrust also known as NAT, dips 50°-55° S/SSW. In the Bhagirathi valley it is seen at Chham and in Bhilangana valley at Gadolia. The geological map (Fig. 3) represents nine lithological units viz. Quartzite interbedded with slate, quartzite, quartizite with basalt and tuffits, phyllite interbedded with siltstone/ wacke/ metavolcanic, phyllite/slate interbedded with limestone and conglomerate, dolomitic limestone interbedded with limestone and slate, quartzite with lentils of conglomerate/ slate/lavathows, greywacke siltstone and metawacke interbedded with schistose phyllite.

## DISTRIBUTION OF LANDSLIDES

Landslides, especially in the reservoir rim, are very important, as they are known to affect the actual life of the project in a significant way. Mapping of landslides involves characterizing the known landslides on the images and then extrapolating the same to identify the unknown (reference to as probable) landslides. In the present work, all the landslides were identified during the field visits and their positional details were transferred on the base map. The image characteristics were then extrapolated to detect 'probable' landslides using elements of interpretation mainly shape, tone and association.

There are about 71 landslides in the periphery of the Bhagirathi and the Bhilangana rivers, which will enclose the impounded reservoir rim area (Fig. 4). Out of 71 landslides 35 will get submerged during the reservoir-filling phase while the remaining will continue to exist. Many landslides are known to occur in the rim of Tehri dam reservoir due to the present fragile rock types. Some of these landslides are active while the others may get activated due to soaking of water from the impounded reservoir and the seismic activity.

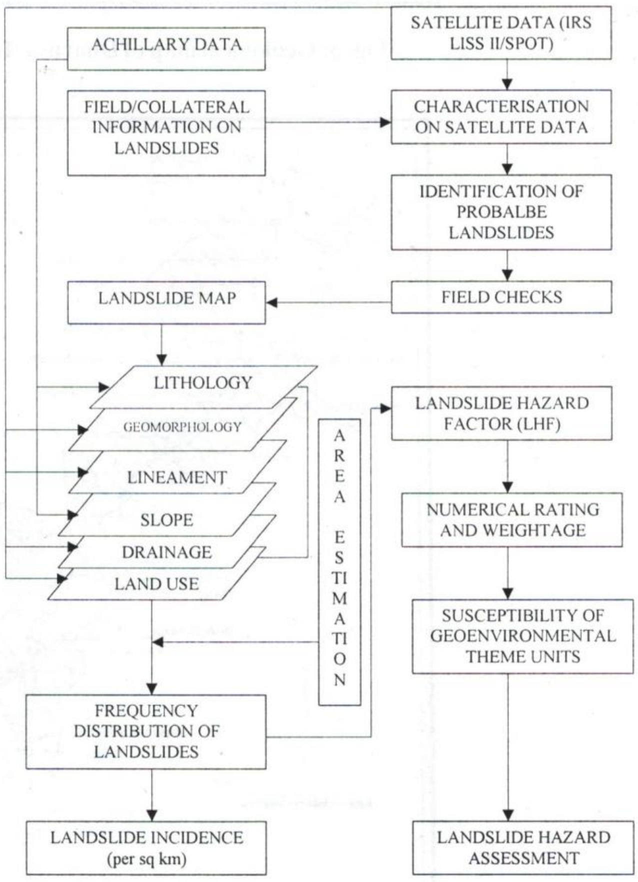


**Fig. 2: Schematic for geoenvironmental assessment of landslide**

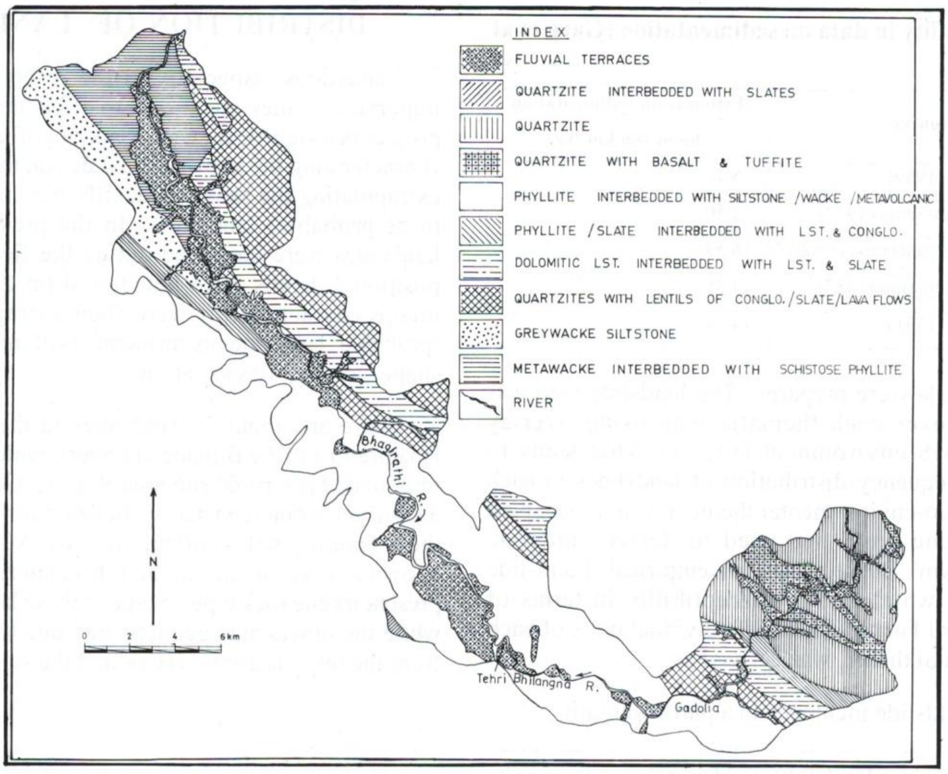


**Fig. 3: Geological map of Dharusa-Tehri-Ghansali area of Garhwal Himalaya**

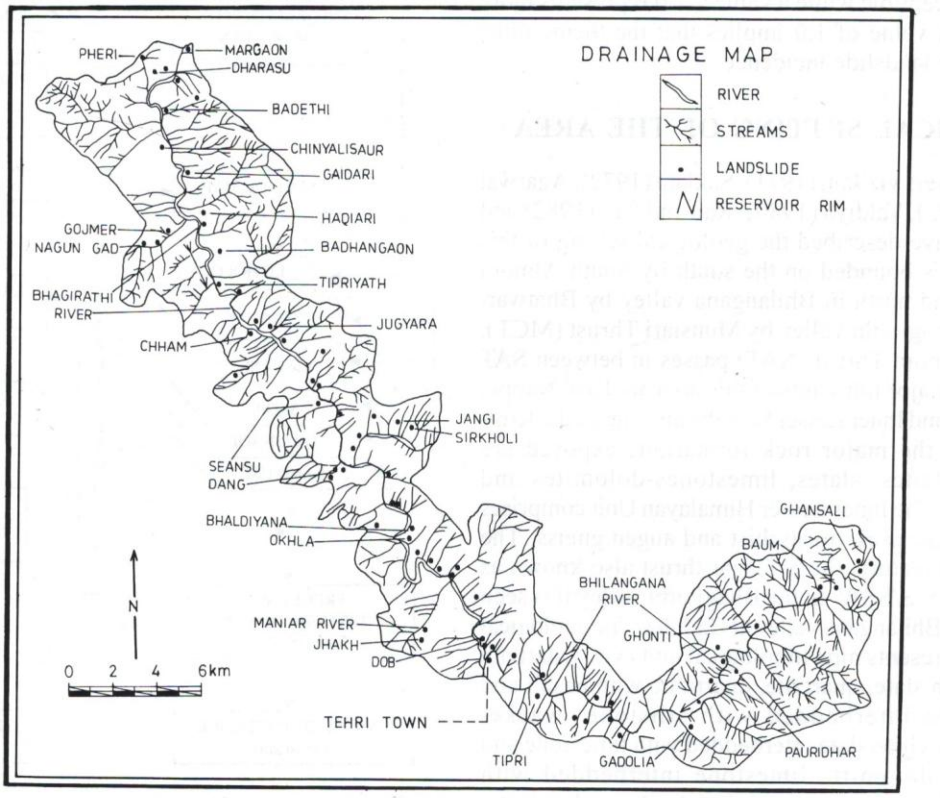


**Fig. 4: Drainage and landslide location map of Dharusa-Tehri-Ghansali area of Garhwal Himalaya**

## LANDSLIDE HAZARD ZONATION MAPPING

The following geo-environmental thematic maps were prepared and were used in the generation of landslide hazard zonation map. The details of geo-environmental theme units and landslide susceptibility classes are given in Table 2.

### Lithology

The geological map represents nine lithological units, simplified into five main lithological categories viz. phyllites, quartzites, dolomitic limestones, greywackes/siltstones and alluviums from landslide hazard zonation points of view. Lithology detemines the shear strength, permeability, susceptibility to weathering and other characteristics of rocks and soil which are responsible for slope failure. In the present area of study, the distribution of the quartzites is 36.35%, phyllites 33.75%, fluvial terrace 13.38%, carbonates 9.42% and slate 4.96%. The observation made in the field indicates that phyllites are highly susceptible to landslide. This was also confirmed by frequency analysis which has indicated that out of 71 landslides, 30 occur in phyllite followed by quartzites (17), fluvial terraces (15), carbonates (6) and slates (3). The flaky and brittle nature of the phyllites make it prone to sliding induced by triggering factors like cloudburst, blasting, road construction etc. The slides over phyllites, as encountered along the approach roads, leave a pile of clay and mica in powdered form over these roads and render the approach very sticky and slippery after a downpour. This is typical of slides with phyllite substrate. However, the slides with-substrate of relatively harder rock types like quartzites dolomitic- limestones etc., exhibit rolling of boulders, sometimes big enough in size to block vehicular traffic and damage approach roads, power lines, agricultural land etc.

**Table 2: Geo-environmental theme units and landslide susceptibility classes.**

| Theme unit | | FRQ | LHF | WHT | Area (km$^2$) | % Area Covered | INCID./ km$^2$ | Susceptibility |
|---|---|---|---|---|---|---|---|---|
| Lithology | | | | | | | | |
| A | Alluvium | 15 | 1.06 | 2 | 38.00 | 13.38 | 0.395 | Moderate |
| B | Phyllite | 30 | 2.11 | 3 | 95.86 | 33.75 | 0.313 | High |
| C | Quartzites | 17 | 1.20 | 2 | 103.23 | 36.35 | 0.165 | Moderate |
| D | Dolomitic limestone | 06 | 0.42 | 1 | 26.75 | 9.42 | 0.224 | Low |
| E | Greywacke/ siltstone | 03 | 0.21 | 1 | 14.10 | 4.96 | 0.213 | Low |
| Distance from nearest thrust in km. | | | | | | | | |
| A | <2.0 | 30 | 1.69 | 3 | 95.72 | 33.70 | 0.313 | High |
| B | 2.0-4.0 | 24 | 1.35 | 3 | 86.34 | 30.40 | 0.278 | High |
| C | 4.0 – 6.0 | 08 | 0.45 | 1 | 51.47 | 18.12 | 0.155 | Low |
| D | >6.0 | 09 | 0.51 | 1 | 44.41 | 15.64 | 0.203 | Low |
| Geomorphology | | | | | | | | |
| A | Dissected hills | 68 | 2.87 | 3 | 266.04 | 93.68 | 0.256 | High |
| B | Terraces | 03 | 0.13 | 1 | 11.27 | 3.96 | 0.266 | Low |
| C | Alluvial fan | 00 | 0.00 | 1 | 0.63 | 0.22 | 0.000 | Low |
| Slope | | | | | | | | |
| A | >60$^o$ | 15 | 1.06 | 2 | 46.86 | 16.50 | 0.320 | Moderate |
| B | 50$^o$ – 60$^o$ | 20 | 1.41 | 3 | 95.30 | 33.55 | 0.210 | High |
| C | 40$^o$ – 50$^o$ | 11 | 0.77 | 2 | 55.65 | 19.60 | 0.198 | Moderate |
| D | 30$^o$ – 40$^o$ | 11 | 0.77 | 2 | 46.18 | 16.26 | 0.238 | Moderate |
| E | <30$^o$ | 14 | 0.99 | 2 | 33.95 | 11.95 | 0.412 | Moderate |
| Land use | | | | | | | | |
| A | Agriculture | 38 | 2.68 | 3 | 153.51 | 54.05 | 0.248 | High |
| B | Scrub | 27 | 1.90 | 3 | 45.39 | 15.98 | 0.595 | High |
| C | Pine forest | 04 | 0.28 | 1 | 48.04 | 16.91 | 0.083 | Low |
| D | Oak forest | 02 | 0.14 | 1 | 15.37 | 5.41 | 0.130 | Low |
| E | Others* | 00 | 0.00 | 1 | 15.63 | 5.51 | 0.000 | Low |
| Drainage shape | | | | | | | | |
| A | Convex | 39 | 2.20 | 3 | 41.61 | 14.65 | 0.937 | High |
| B | Concave | 03 | 0.17 | 1 | 12.20 | 4.30 | 0.246 | Low |
| C | Straight | 19 | 1.07 | 2 | 87.26 | 30.72 | 0.218 | Moderate |
| D | Beyond 500 m | 10 | 0.56 | 1 | 136.87 | 48.19 | 0.073 | Low |

*Mixed forest and Degraded forest, FRQ: Frequency; LHF: Landslide Hazard Factor; WHT : Weightage; INCID: Incidence of landslide per km$^2$

### Structures

The structural maps which show thrusts, faults and major lineaments (Fig. 5) was prepared using SPOT (MLA/PLA), IRS LISS II data. A distinct relationship between the existing landslides and lineaments (structures) has been observed. A buffer zone of four kilometers around thrusts was found to be highly susceptible to landslides. The calculation shows that a total of 30 landslides occurred within 2-km distance of the lineament with the frequency progressively decreasing with increasing distance. Thus the area lying close to major tectonic features are more affected by landslide activity. The majority of landslides are in the proximity of major lineaments. Degree of fracturing and shearing play an important role in determining the slope susceptibility. The more the discontinuity or the line of intersection of two discontinuities tends to be parallel to the slope, greater will be the risk of failure (Anbalagan 1992). The number of landslides falling along the NW-SE trending lineaments are more than those falling orthogonal to it. The lineaments parallel to the main Himalayan axis (NW-SE) are more prone to mass movements as compared to those having a different trend.

### Slope

A slope map (Fig. 6) of the study area has been prepared by using Wentworth (1930) method, using Survey of India topographic maps and field checking. The map shows five categories of slope i.e. <30°, 30° - 40°, 40° - 50°, 50° - 60° and >60°. The present area covered by various slope units indicate that slope ranging between 50° - 60° tops the list (33.55%) followed by 40° - 50° (19.60%), > 60° (16.50%), 30° - 40° (16.26%) and <30° 11.95%). The steepness of slope indicates a state of potential instability. The slopes with angles varying between 50° - 60° have 20 slides followed by >60° (15), <30° (14), 30° - 40° (11), and 40° - 50° (11). It is obvious that the landslides per square kilometer area is highest in the slopes ranging between 50° - 60°.

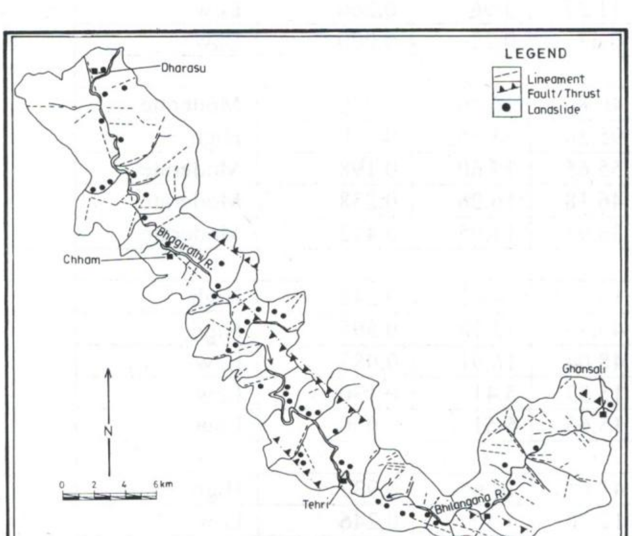


**Fig. 5: Structural map of Dharusa-Tehri-Ghansali area of Garhwal Himalaya**

### Drainage

The drainage map (Fig. 4) was prepared using satellite data and Survey of India topographical maps for newly evolved streams. The erosion potential of the steams decreases away from the main course of the Bhagirathi and Bhilangana rivers. Field observations indicate that there is greater incidence of landslides at sharp meander convexities of the Bhagirathi and Bhilangana due to erosion along the convex banks. At higher altitudes, the streams are non-destructive in nature, but where roads are constructed across the small streams few landslides are encountered. The roads especially closer or near water divide are virtually free of landslides. Drainage buffer map is also prepared of this area. Out of 71 landslides in the study area, 61 landslides have occurred in the proximity of major rivers. Of these, 39 landslides are associated with the convex banks of the sharp riverine meanders as against concave (3) and straight river course (19). This is attributed to toe erosion induced by the flowing water.

### Geomorphology

Visual interpretation of the satellite data was carried out at 1:50,000 scale to generate geomorphic map (Fig. 7). Three major geomorphic units viz. dissected hills, terraces and alluvial fans were identified from LHZ mapping point of view within the reservoir rim area. Dissected hills cover most of the study area encompassing cover 266.04 km$^2$ area out of the total 284 km$^2$ area of the rim. The terrain is primarily characterized by valley and spur landform comprising mainly sedimentaries/ metasedimentaries of varying lithounits like dolomite limestone, siltstone, greywacke, phyllite, quartiztes etc and alluvium. The hills are dissected by major rivers like the Bhagirathi and Bhilangana joined by numerous tributaries draining down the slopes and inflicting severe erosion. Resultantly, large number of landslides occurs over the dissected hills and foothills.

The terraces are mostly confined adjacent to major riverine courses of the Bhagirathi and the Bhilangana. These terraces are river terraces formed due to the depository action of these rivers in the geological past. Some of these terraces are utilized by the local people for agricultural activities. However, those with either steeper slopes or very coarse cobble/bouldery for farming are not used for agricultural purpose. Owing to the unconsolidated nature of these terraces, they exhibit disintegrating properties.

Alluvial fans are formed as a result of deposition of sediments by numerous streams, drawing down the lofty ranges, at the foothills. This unit does not exhibit any landslides. This may perhaps be attributed to the depository nature, gentle slope and less vigorous fluvial erosion within this unit. Out of 71 landslides 68 are present in dissent hills and remaining three occur in the terraces.

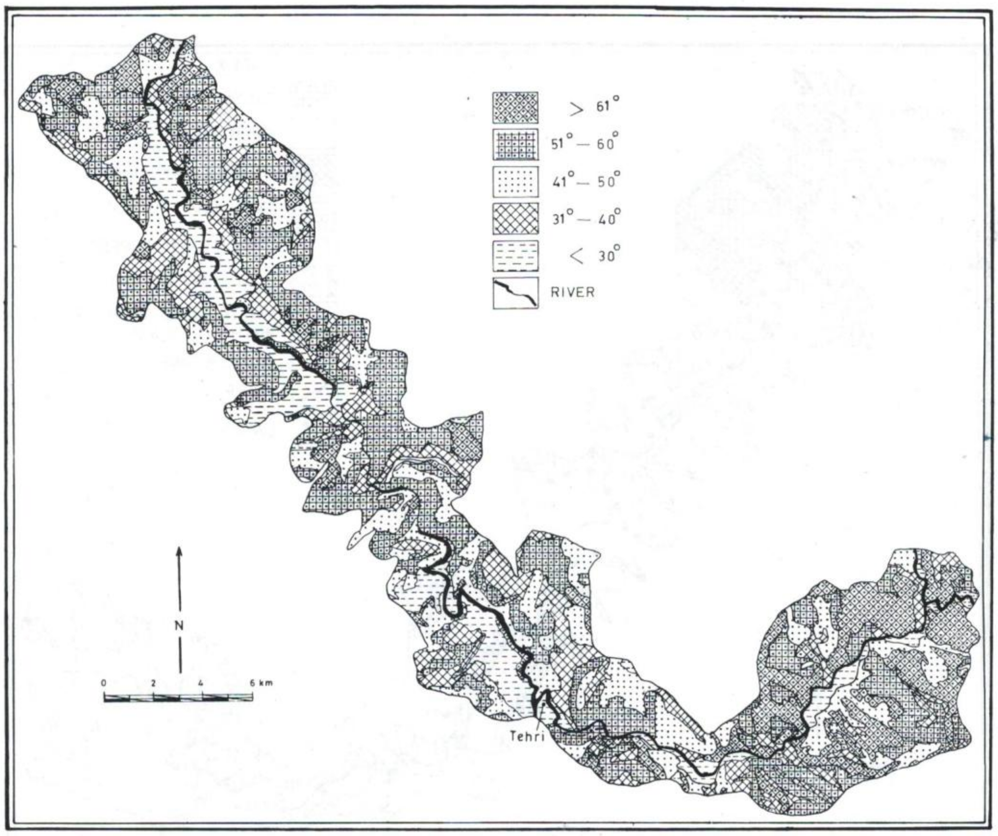


**Fig. 6: Slope map of Dharusa-Tehri-Ghansali area of Garhwal Himalaya**

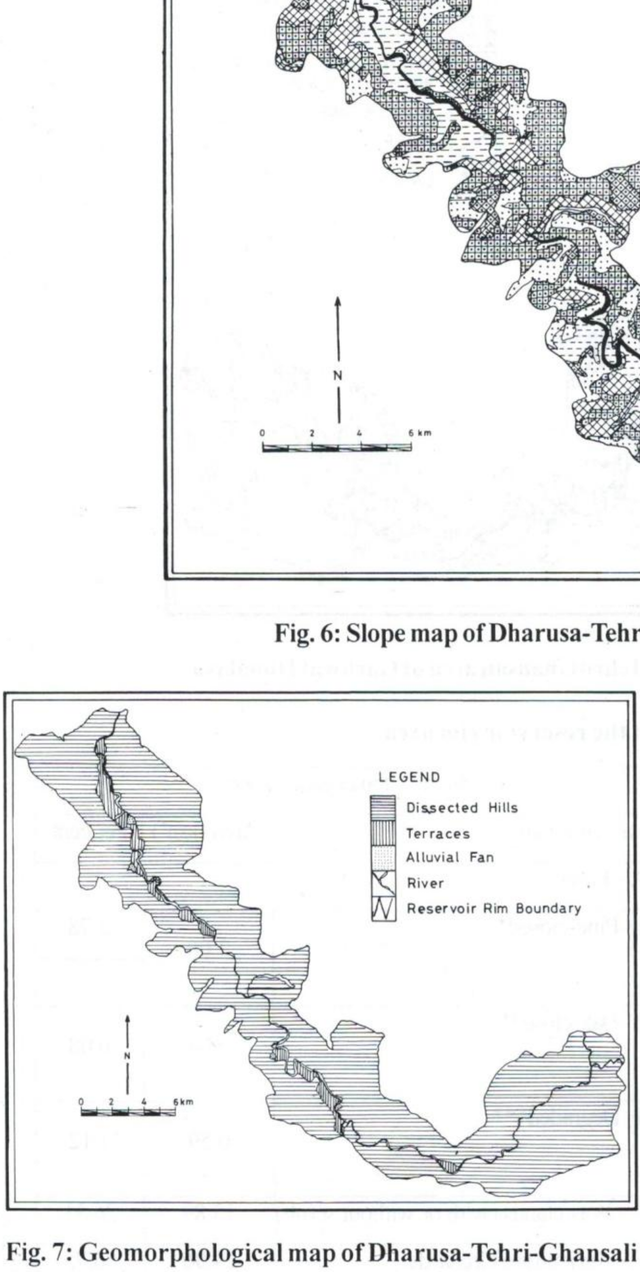


**Fig. 7: Geomorphological map of Dharusa-Tehri-Ghansali area of Garhwal Himalaya**

## Land Use/Land Cover

Land cover, especially the vegetation plays an important role in the stability of slopes and in the occurrence of landslides. In view of this forests and land use / land cover mapping has been done for reservoir rim area (Fig. 8). The reservoir rim area comprises three-forest type with varying densities: namely Pinus (pine) dominate, (Quercus) oak dominant and mixed. The forest in the reservoir rim accounts for 27.83 per cent (79.04 km$^2$) area. The degraded forests (less than 10% tree cover) along with wastelands with or without scrub besides other higher priority areas, assumes importance for soil conservation and slope stability measures. The effective forest cover would be 65.85 km$^2$ of which closed forest is 18.64 km$^2$ and rest (47.21 km$^2$) is open forest. Agriculture is the largest land uses (153.51 km$^2$) and accounts for 54.06 per cent area in the reservoir rim (Table 3).

In the submergence area of the impounded reservoir there would be direct loss of 2.63 km$^2$ of forest cover, which is 4.98 per cent. The forests in the submergence area are dominated by pine (*Pinus roxburghii*) and include closed, open and degraded forest. Agricultural land to get submerged is highly productive and is the single largest landuse accounting for 29.96 km$^2$ (56.75%) area. Wastelands with or without scrub occupy 13.89 km$^2$ (26.31%) area.

## Landslide Hazard Zonation

The landslide hazard map (Fig. 9) is divided into four units viz. low, moderate, high and very high. In this study, landslide hazard factor (LHF) values were grouped into three landslide susceptibility classes as given in Table 4.

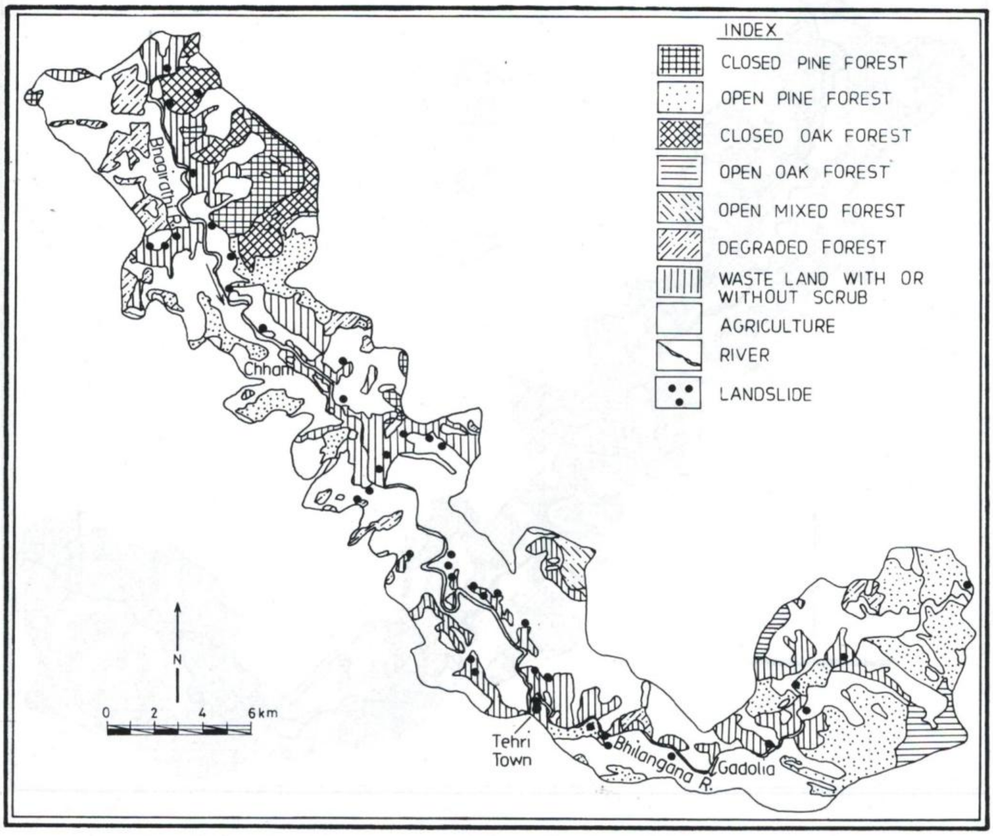


**Fig. 8: Land use/Land cover map of Dharusa-Tehri-Ghansali area of Garhwal Himalaya**

**Table 3: Land use classes in the reservoir rim area**

| In the reservoir rim | | | | In the submergence zone | | | |
|---|---|---|---|---|---|---|---|
| Land use classes | | Area ($km^2$) | Per cent | Land use class | | Area ($km^2$) | Per cent |
| A- Forest | | | | A - Forest | | | |
| 1 | Pine-closed* | 8.57 | 3.01 | 1 | Pine-closed* | 2.00 | 3.78 |
| 2 | Pine-open** | 39.47 | 13.89 | | | | |
| 3 | Oak-closed* | 10.07 | 3.54 | 2 | Oak-closed** | 0.04 | 0.08 |
| 4 | Oak-open** | 5.30 | 1.87 | | | | |
| 5 | Mixed-open | 2.48 | 0.88 | 3 | Degraded*** | 0.59 | 1.12 |
| 6 | Degraded*** | 13.15 | 4.63 | | | | |
| B- Wasteland (with or without scrub) | | 45.39 | 15.98 | B - Wastelands (with or without scrub) | | 13.89 | 26.31 |
| C – Agriculture/Orchards | | 153.51 | 54.06 | C - Agriculture/Orchards | | 29.96 | 56.75 |
| D – Others**** | | 6.06 | 2.14 | D – Others**** | | 6.32 | 11.97 |
| Total | | 284.00 | | | | 52.80 | |

(*Closed forest means crown density more than 40%; **Open forest means crown density less than 10%; ***Degraded forest means crown density less than 10 %, degraded forest class demarcated in the study area encompasses all the above mentioned forest types; ****Other categories includes river/streams, road and settlements).

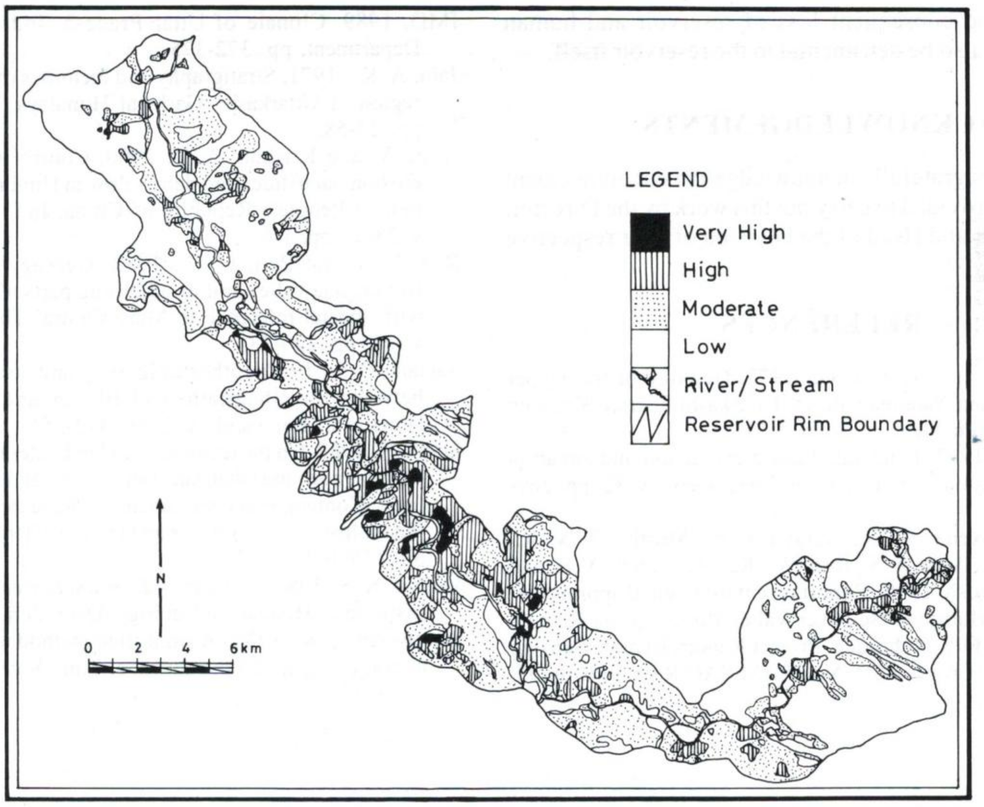


**Fig. 9: Landslide hazard map of Dharusa-Tehri-Ghansali area of Garhwal Himalaya**

**Table 4: Landslide hazard factors (LHF), weightages and susceptibility levels**

| LHF | Weightage | Susceptibility |
|---|---|---|
| < 0.67 | 1 | Low |
| 0.68-1.34 | 2 | Moderate |
| > 1.35 | 3 | High |

The perusal of landslide frequency in various units / sub-categories of different themes indicates that occurrence of landslides is highest in phyllite (30); <2 km distance from the thrust (30), dissected hills (68), slope range 50°-60°(20), convex banks of perennial rivers/stream (39) and agriculture on terraces (land use /cover) (38). The details about the various geo-environmental terrain themes and their landslide susceptibility are given in Table 4.

About 43.5 km$^2$ area in the reservoir rim lies in the high and very high landslide susceptibility zone and needs immediate attention for taking remedial measures.

## CONCLUSIONS AND RECOMMENDATIONS

(i) There are 71 landslides in the periphery of the Bhagirathi and the Bhilangana rivers, out of these 35 will get submerged in the impoundment while the remaining will continue to exist.

(ii) In the rim of the Bhagirathi and the Bhilangana rivers which will form the reservoir and its rim (284.00 km$^2$), forests occupy an area of 79.04 km$^2$ (27.83%) out of which closed forest is only 18.64 km$^2$ (6.55%).

(iii) Impounded reservoir will submerge an area of 52.8 km$^2$ at full reservoir level. The major land cover categories which will set submerge are forests mainly comprising pine and oak (2.63 km$^2$), agricultural land (29.96 km$^2$) and wastelands (13.89 km$^2$).

Catchment area development is an action, which appeals the interests of the project authorities and the people inhabiting the region as well. Catchment of the Tehri dam, especially the Bhagirathi valley south of Bhatwari upto the dam does not have enough good trees cover. Afforestation is desirable on a large scale, which will not only help in reducing the silt load in the reservoir but also help in the general improvement of ecological setup. This type of measure can be adopted as suggested by Joshi and Krishna (2000) in the catchment area.

Urgent steeps are required to be taken to stabilize the reservoir rim slopes. Once the reservoir is impounded, due to moisturizing and loosening of the rocks landsliding activity may escalate and cause serious damage to the settlements and consequent loss of reservoir and human life. This may also be detrimental to the reservoir itself.

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