LANDSLIDE HAZARD ZONATION MAPPING AROUND NATHPA DAMSITE AREA, KINNAUR DISTRICT, HIMACHAL PRADESH

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Abstract

Landslides in Himalayas are common and natural phenomenon often triggered by human activities. The studies of landslides get more focused in the areas where civil engineering projects are to be taken up or being taken up. Nathpa area is very prone to landslides in relation of other areas in Himalayas due to its rigorous topographic, structural and tectonic framework. Since Nathpa-Jhakri hydroproject is one of the pioneer projects in India, hence the work on landslide hazard zonation. The study indicates that half of the area lies under low landslide hazard zone; however, nearly 20% of the area is covered by high to very high hazard risks. The remaining 30% of the area falls under moderate hazard zone. The area occupied by moderate to high hazard zones should be further investigated on a microscale and preventive and/or remedial measures be suggested to ensure safety of the project and the region.

Introduction

Natural phenomena like earthquakes, landslides, avalanches, floods, cyclones, droughts and volcanic eruptions have been inducing widespread devastation at one time or the other in different parts of the world and throughout the earth's history (Acharya and Narula, 2000). In high mountainous terrains, landslides and other slope failure processes are the most common natural calamities occurring under varied natural conditions prevailing there. This phenomenon is more pronounced in areas of high relief in the Himalayas, which constitutes a very fragile and delicate ecosystem. The magnitude of damage caused every year by these sudden and undesired earth movements in the Himalayan terrain is enormously high. This has resulted in adversely affecting the socio-economic conditions and environment of the region (Bartarya and Valdiya, 1989; Haigh et al., 1989; in Lakhera and Champatiray, 1996).

The study area is located in the Western part of Kinnaur district of Himachal Pradesh, lying between latitude 31°30` to 31°36`N and longitude 77°56` to 78°E. It is a part of Lesser Himalayan formation, falls in the Survey of India toposheet No.-53 E/ 14 (fig. no. 1) and is accessible by Hindustan Tibet road (NH-22). The area has very rugged topography with mountains and the altitude varies from 1350m along riverbed to 5000mts at peaks. Large and small glaciers often cover the higher peaks. The area is characterized by numerous cascades and deep gorges. Structural, lithologic and climatic controls have played important role in shaping the current topography of the area. The area is drained by river Satluj and its tributaries. The drainage system is of antecedent type and the pattern is dendritic. The climate is of subtropical type, the temperature varies

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from 35^{0}C (in summer) to -10^{0}C (in winter) and average rainfall is around 200mm/ annum The common trees are oaks, pines, apricots, apples, walnuts, almonds, grapes etc. The study area comes under the seismic zone IV in the seismo-tectonic map of India.

The area has been investigated particularly because of presence of a number of hydroelectric projects. The Satluj Jal Vidyut Nigam Limited (formerly Nathpa Jhakri Power Corporation Limited) is located in Kinnaur and Shimla districts of Himachal Pradesh. It was incorporated on May 24, 1988 as a joint venture of the Government of India and Government of Himachal Pradesh with an authorized capital of Rs. 1000 crore. The present authorized capital of the company is Rs. 4500 crore. 1500 MW Nathpa Jhakri Hydro-electric Project is the flagship project of the company (booklet, Powering The Nation, Satluj Jal Vidut Nigam Limited). This project is a run-off the river type development scheme. It is proposed to harness hydroelectric potential of the upper reaches of the river Satluj. The project is one of the biggest underground ventures in the world (source:-http://drsksingh.tripod.com/ Drsksingh).

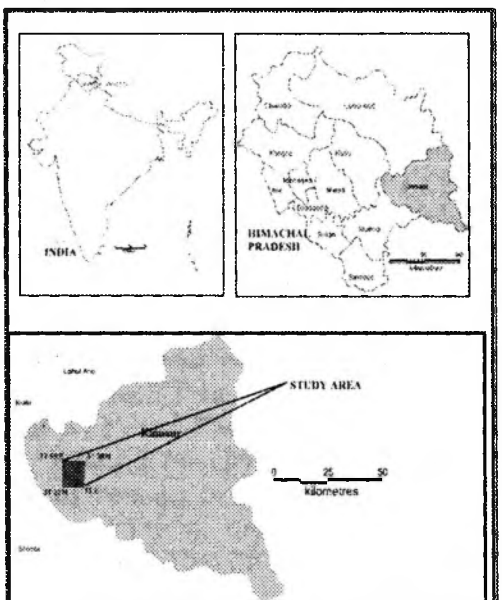


Fig 1 Location map of the study area

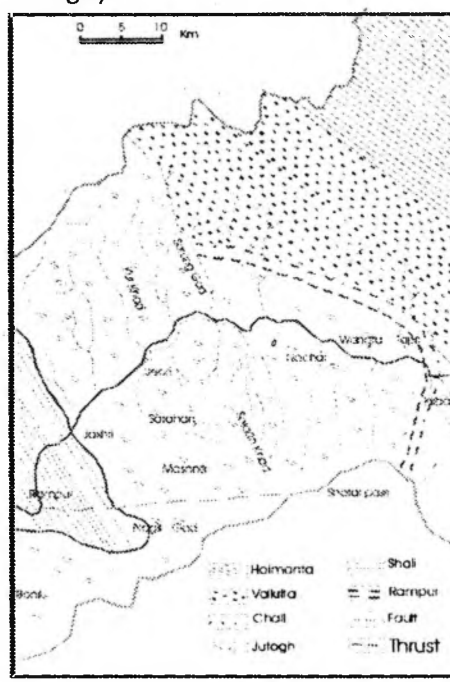


Fig 2: Regional Geological Map of the area

Methodology

The whole process of research involved detailed analyses of toposheet, petrography of samples, strength determination of samples, structural mapping, computer based work and photography. It involved sample collection, mapping of different linear and planar features, hydrologic regimes delineation, and landuse and landcover mapping. A number of softwares such as MS-WORD, MS-EXCEL, ARCVIEW 3.1, COREL DRAW-11, and Abode Photoshop were used for the preparation of different maps and data interpretation. For strength determination, collected samples were cored on the platform of coring machine. By the use of lapping machine the end faces of above prepared samples were made parallel which was normal to the axis of loading. These samples were tested on compression testing machine and uniaxial compressive strengths were determined.

Review of Previous work

S K Gupta (1988) attempted landslide zonation in a part of Satluj valley, Himachal Pradesh on the basis of slope angles along with distribution, lithology and relative strength of bedrock and overburden materials, rainfall of the area and incidences of active and dormant landslides. Gupta and Joshi 1990, (in Vijay Kr., 1995) did hazard zonation mapping in Ramganga catchment area. Michael D Gee (1991) gave a classification of landslide hazard zonation methods. P Jagannath Rao and D. Mukherjee (1992) prepared a hazard zonation map covering the hill slopes adjoining Kathgodam-Nanital highway. Mehrotra, Sarkar and Dharmraju (1991) prepared landslide hazard zonation map in Rishikesh-Tehri area, Garhwal Himalayas. Choubey, Chaudhari and Litoria (1991) attempted landslide hazard zonation in Uttarkashi and Tehri districts of then Uttar Pradesh Himalayas. Anbalagan, Sharma and Tyagi (1993) prepared a landslide hazard zonation map of a part of Doon valley, Garhwal Himalayas. V K Sharma and G C Kandpal (1995) did landslide hazard mapping in parts of Uttarkashi and Tehri districts of Garhwal Himalayas. R. Anbalagan and Bhawani Singh (1996) attempted landslide hazard and risk assess mapping of mountainous terrains in parts of Kumayun Himalayas. Piyoosh Rautela, Sudip K Paul and V C Thakur (1999) did landslide hazard zonation in Kumayun-Garhwal Himalaya in Kali, Kaliganga and Madhyamaheshwar river valleys using Geographic Information System. Mitra and Ghosh (2000) worked for landslide hazard zonation maps on 1:25,000 in the East Sikkim districts (along the NH-31A) and the Darjeeling district (Ramman Hydroelectric project stage II area and Kalimpong Municipal area). A K Pachauri (2001) did landslide hazard zonation of Chamoli region using GIS software like ARCVIEW, MICROSTATION and ILWIS.

Central crystalline zone in the southern part of higher reaches of Himachal Himalaya forms the area, which has been investigated in detail. These are Wangtu Gneissic Complex, Karcham group and Haimanta group. Wangtu Gneissic Complex is present as basement rock. The first account of geology of this area was given by Stoliczka (1866). A detailed report of mineral resources was described by Mallet (1866) while Shimla-Wangtu section was studied by McMohan (1866) who recorded the petrological characters of some amphibolites and quartz diorites. Different parts of the area were studied by Hayden (1904) and Berthelson (1951) who discussed the geology and tectonics of the area. The rocks occuring between Nirath and Shipki-La was divided into the Chail Series, Rampur series and Jangi Formation (Haimanta) by Kathiara and Venugopal (1965, vide Tewari et. al., 1978). The term "Jutogh Formation" was given by Sharma (1976) for all the metamorphic rocks exposed between 5km NE of Rampur to about 3km NE of Karcham, along the Satluj valley. He, thereafter, recognised "Vaikrita Thrust" to designate the overlying rock formations as Vaikrita Group. Tewari et. al. (1978) studied the areas around Baspa and Satluj valleys. They gave a brief description of lithounits but made no comments on stratigraphy. The regional geology of the area lying between Kulu, Rampur and Karcham was given by

Bhargava (1982). Earlier it was thought that a thrust is present at the top of Rampur quartzite but Kakar (1988) negated the presence of such thrusts. This conclusion displaced the thinking that Rampur window contains a tectonic inlier known as Wangtu Gneissic Complex.

Landslide Hazard Zonation Map

Varnes (1984) has defined Landslide Hazard Zonation (LHZ) as "the division of land surfaces into homogenous areas or domains and their ranking according to the degrees of actual/potential hazard caused by mass movements" (in Champatiray, 1996). The Landslide Hazard Zonation Map (LHZ) of Western Kinnaur district has been prepared on the basis of Landslide Hazard Evaluation Factor Rating Scheme (LHEF) given by Anbalagan (1992). The mapping has been carried out for several factors on 1:1,000, scale which are responsible for slope stability. A number of maps such as lithological, slope morphometry, relative relief, landuse and landcover and hydrogeological maps have been prepared. The nature and distribution of these causative factors have been shown on these thematic maps. Each causative factor has been discussed in detail. It serves as a tool for the preparation of final landslide hazard zonation map.

Lithology

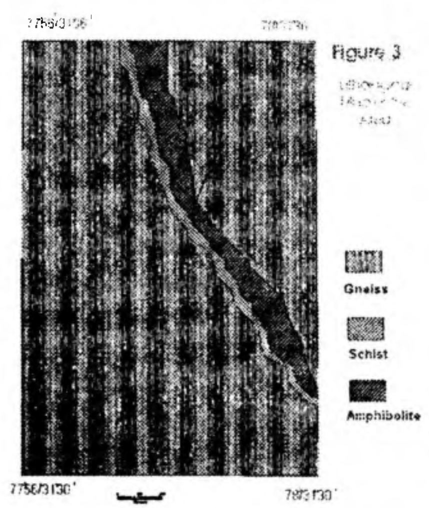
Lithology is considered to be one of the most important factors in slope stability studies. Different rocks have different behaviour of rock stability because of their differing weathering characteristics. A maximum value of 2 has been assigned in the Landslide Hazard Evaluation Factor (LHEF) rating scheme. Percentage of area covered by different lithologies has been shown in table 1. Megascopic and microscopic studies of samples show that there are four (including minor pegmatite) major rock types in the area. Fig. 2 shows the lithological units of the area.

Table 4.1: Percentage distribution of different lithologies in the study area.

Lithology	% of the area
Gneiss (minor Pegmatite also)	89.56
Schist	3.08
Amphibolite	7.35

Structure

Both primary and secondary structures are present in the area. Primary structures include bedding whose strike varies from N60° W-S60° E to N80° E-S80° W with southerly dips of 25° to 35° except near Karcham where the strike is roughly N-S with 45° easterly dip. Secondary structures include foliation, joints, folds and faults. The trend of foliation varies from N70° W-S70° E to N70° E-S70° W having average dips of the order of 35° in the northerly direction. In some parts the strike changes to NW-SE (35°-65° dip), N-S(20°-30° dip), E-W



(35° -50° dip). Joints are more prevalent in gneisses. Prominent sets of joints strike N-S to N20° E-S20° W/70° on either side to subvertical; NE-SW/35° westerly; N25° E-S25° W/45° SE; N65° W-S65° E/60° SW; E-W/ 30° S. The rocks are openly folded. The axial trend of the major folds runs in NW-SE direction to E-W direction. Minor folds have been superimposed on these major folds. The major folds of the area strike NE-SW, NW-SE, N20° W-S20° E to N-S, ENE-WSW, N70° W-S70° E. Almost all the fold axes in the area are near parallel to each other. The exposures on scarp faces show that in the axial portion of the fold the rocks are crushed and sheared. Four major faults have been identified whose attitudes are NW-SE/high angle fault, N25° E/70° SE, N40° W/60° NE and NW-SE.

Slope Morphometry

Slope morphometry map defines slope categories. It shows the distribution of zones of the same frequency of occurrence of a particular slope angle. This map has been prepared with the help of toposheet of the area under study and verified with field slope data. Survey of India toposheet no. 53-E/14 has been used in slope morphometry studies. The percentage distribution of different slopes has been given in table 2.

Table 2: Percentage distribution of different slope morphometry categories in the study area.

Categories	Slope angle	% of the area
Very gentle slope	<14^0	0.0
Gentle slope	14-26^0	11.91
Moderately steep slope	26-36^0	48.20
Steep slope	36-45^0	29.06
Escarpment/Cliff	>45^0	10.83

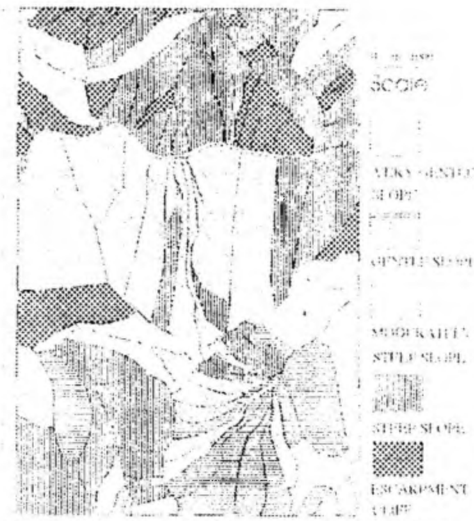


Figure 4 Showing Slope Morphometry in the Area

Nearly half of the study area is covered with moderately steep slopes. It is distributed all over the area. Steep slopes cover about 30% of the area which is present dominantly in nothern and southern parts. Escarpments are present mostly north of river Satluj and two patches south of the river. Very gentle slopes are lacking in the area. Gentle slope area is present only in 1/10th of the area mostly in southernmost part. The table shows that over 40% of the area is occupied by very steep slopes and cliffs/escarpments. Figure 3 shows the slope morphometry map of the area.

Relative Relief

This map represents the distribution of different categories of relief in the study area. This has been prepared using the Survey of India toposheet no. 53-E/14 following the principle given by Singh (1984). Relative relief plays a comparatively less dominant role in inducing slope stability amongst causative factors; however, it cannot be left behind. It has been assigned a maximum rating value of 1 out of 10 (Table 3.5). Only two categories of relative relief occur in the study area. High relative relief constitutes 97.38% of the total area under study. The area does not have a low relative relief facet. The remaining area comes under moderate relief categories found scattered at a number of places. The percentage distribution of relief categories have been given in table 3 and has been shown in the map (fig. no- 4). Facet wise distribution has been tabulated in table 7.

Table 3: Percentage distribution of different relative relief categories in the study area.

Categories	Relative Relief (m)	% of the total area
Low	< 100	0.0
Medium	101-300	2.62
High	> 300	97.38

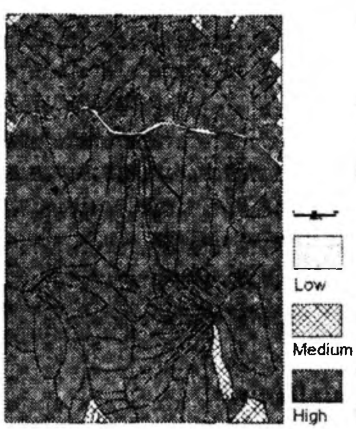


Fig 5 Relative Relief map of the area

Landuse & Landcover

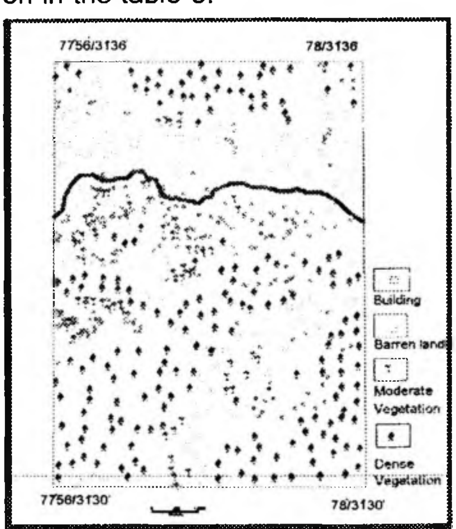
Landuse refers to the activities done on land by man. Landcover denotes the natural surface covering like forest, vegetation etc. This map has been prepared using the toposheet of the study area and field observation. Based on the above studies, the whole area has been divided into five categories as follows. **Category-I** is agricultural and populated flat land which covers a little more than 1/4th of the area (table 4.4). This is mainly located along the river banks and scattered in many areas also. **Category-II** is thickly vegetated and hence having dense forest cover. It constitutes about 35.95% of the study area. **Category-III** is characterised by moderate vegetation forming 12% of the area. This category is scattered all over the area. **Category-IV:** 11.82% of the study area falls under this zone having sparse vegetation. It is concentrated mainly on hill tops. **Category-V:** This is barren area and forms 12.5% of the study area. It is found mainly in areas having gneissic rocks. The distribution of landuse and landcover has been shown in the map (fig.5). The percentage distribution has been given in table 4 and facetwise distribution has been shown in table.7.

Table 4: Percentage distribution of different landuse and landcover in the study area.

Description	Category	% of the total area
Agricultural and Populated land	I	27.70
Dense forest	II	35.95
Moderately vegetated area	III	12.00
Sparsely vegetated area	IV	11.82
Barren land	V	12.50

Hydrogeological (Surface Moisture) Condition

As it is very problematic to evaluate the behavior of groundwater in large areas in hilly terrains, the nature of surface indications is used in landslide hazard zonation studies. Water plays an important role in inducing landslide. The surface moisture map (fig. no.6) has been prepared using toposheet and subsequent observation during field studies. Nearly 3/4th of the area comes under damp condition. Such conditions are generally prevalent in dense, medium forest covered area and on agricultural and populated flat lands. Dry condition has also been observed which is very minimal at about 3.64% of the total area. Dry conditions are indicative of sparsely vegetated area to barren lands. Wet condition was observed in the area adjacent to Satluj river, its tributaries and near the springs . About 22% (nearly 1/4th) of the area is covered by wet condition. Hot springs have been observed near Nathpa. Dripping condition has been found along road sides covering only about 2.13% of the study area. Flowing condition is prevalent in very small area especially in Satluj and its tributaries forming about 1.13% of the study area. Facet wise distribution of LHEF ratings for the hydrological condition has been given in the table 7 and the percentage distribution of different hydrologic regimes has been given in the table 5.



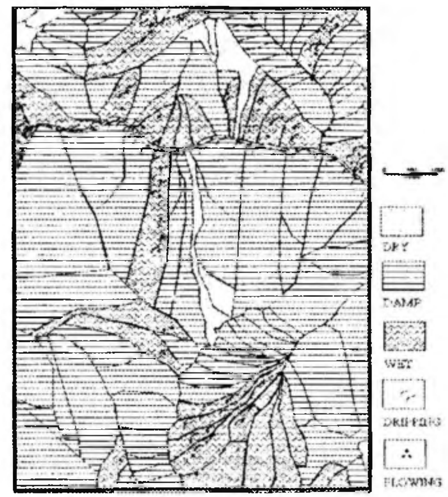


Fig 7 Hydrological map of the Study area

Table 5: Percentage distribution of different hydrologic regimes in the study area.

Description	Categories	% distribution of the total area
Dry	I	3.64
Damp	II	71.47
Wet	III	21.42
Dripping	IV	2.13
Flowing	V	1.34

Calculation of Total Estimated Hazard (TEHD) and Preparation of Landslide Hazard Zonation (LHZ) Map of the Area

Total estimated hazard (TEHD) is the value obtained by adding the rating values of all causative factors inducing instability. It indicates the probability of instability in a facet. The TEHD value of all the 122 facets have been given in table 7. The TEHD values in the study area range from 4.3 to 8.3. Very low hazard zone is not present in the area. Very high hazard is present only in three facets forming nearly 1% of the area. Nearly half of the area is under low hazard zone. Moderate hazard zone is around 31.58% whereas the high hazard zone is nearly one fifth of the total area.

TABLE 6: PERCENTAGE DISTRIBUTION OF VARIOUS HAZARD ZONES IN THE STUDY AREA.

ZONE	TEHD	HAZARD ZONES	AREA (%)
I	0-3.5	VERY LOW HAZARD	0.0
II	3.5-5.0	LOW HAZARD	47.17
III	5.1-6.0	MODERATE HAZARD	31.58
IV	6.1-7.5	HIGH HAZARD	19.82
V	7.5-10.0	VERY HIGH HAZARD	.96

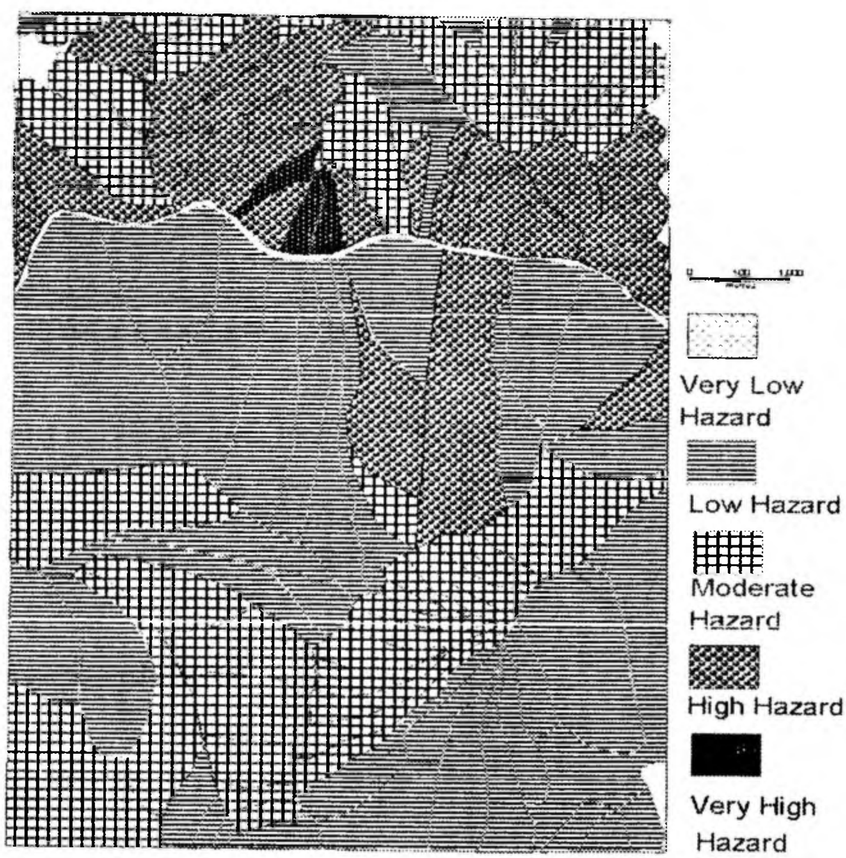


Fig 8 LANDSLIDE HAZARD ZONATION MAP OF THE STUDY AREA

Summary

The study based on causative factors has been carried out to access the suitability of the area. As the area houses one of the most adventurous projects in the world, Nathpa Jhakri Hydel Project, the study gets added significance. The study reveals that half of the area is characterised by moderate to high hazard zones. Human activities will require to induce correction & preventive measures to ensure safety of the project and its personal. Slope protection measures will be required in places where the risks are likely to increase in artificial conditions.

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