LANDSLIDE HAZARD ZONATION MAPPING- A NEED FOR SUSTAINABLE DEVELOPMENT OF UTTARANCHAL WITH SPECIAL REFERENCE TO ROUTE LOCATIONS

R.Anbalagn*
Bhoop Singh**

Abstract

Well planned and all weather road networks are essential for the overall progress of mountainous regions as the roads are the important means of transportation. The newly formed Uttaranchal State requires good network of roads to provide access to remote villages as well as for its overall socio-economic development. Non-systematic planning and construction of roads and other development activities in mountainous regions often lead to adverse environmental impacts such as landslides. The systematic investigations incorporating adequate geological inputs will help to arrive at a favourable alignment with minimum possible adverse environmental effects. In this context the applications of landslie hazard zonation (LHZ) mapping during preliminary and detailed stage investigations may pave way for environmentally sound and cost effective route locations. The paper discusses technical details of carrying out systematic investigations adopting the landslide hazard zonation technique for route location in mountainous terrrains.

1. Introduction

Roads play a very important and vital role in the economic growth of hilly regions. The recently formed Uttaranchal State has an enormous potential of natural resources such as forest, mineral wealth, horticulture, hydropower and tourism. Since Uttaranchal State shares its boundary with China and Nepal, it occupies a strategically important place. Well planned road networks up to border areas are an essential requirement for the security of our country.

Road construction is a challenging task in the Himalayan terrain due to its complex geology, high seismicity, varied climatic conditions, and unfavourable hydrogeological conditions. These factors make the Himalayan terrain more vulnerable to landslides, which get aggravated due to non-systematic development activities. Almost 50 percent of landslides occur along the roads alone. Based on a study of landslides in the Gaula river catchment of Kumaun hills, it was observed that the frequency of landslides along the roads had a strong correlation with the rainfall intensity as well as the geologic formations and slope steepness (Bartarya and Valdiya, 1989). This emphasizes the fact that the route locations should be based on a carefully planned systematic investigation to select an alignment with minimum stability problems. In this context, it is emphasized that that Landslide Hazard Zonation (LHZ) is the first step towards achieving a

*Department of Earth Sciences, Indian Institute of Technology, Roorkee-24767, India
**DST, Government of India, New Delhi-110016, India

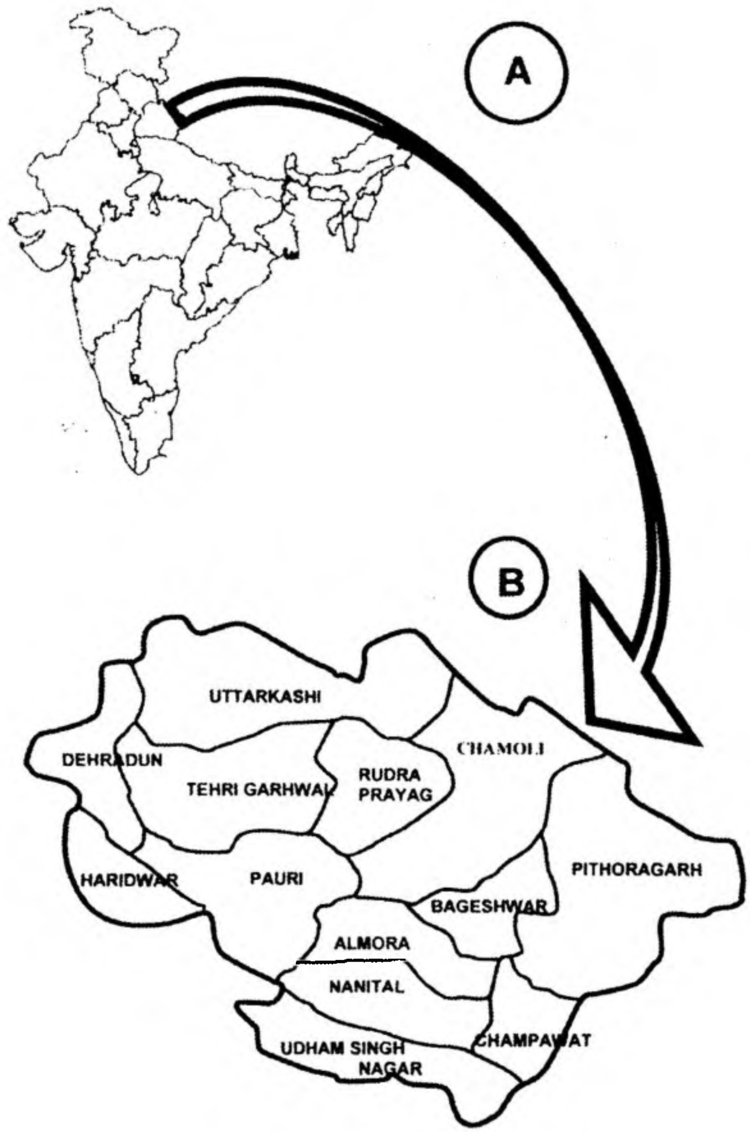

Fig 1 A. Location of Uttaranchal State
B. Division of Districts of Uttaranchal State

sustainable development in the Himalayan region.

1.1 Uttaranchal - An Overview

Uttaranchal State, carved out of Uttar Pradesh, had formally come in existence on November 9, 2000 and consists of 13 districts (Fig.1.). The population of Uttaranchal is 8.5 million with a population density of 157 persons per sq. km. Uttaranchal has a forest cover of 2.3 million ha, which is 43 percent of its total geographical area. Many National Highways such as NH-58, NH-73, NH-74 and NH-87 are passing through Uttaranchal. Presently the existing road network connecting the state capital, Dehradun, with all the District Headquarters and other major towns need to be strengthened. This may help in better adminstration and long-term economic development of the State as a whole. In addition, local roads should be planned to provide access to the villages located for off from the main road.

2. Landslide Hazard Zonation (LHZ) Map

A Landslide Hazard Zonation (LHZ) Map depicts the land surface into zones of varying degree of stability based on an estimated significance of causative factors in inducing instability (Anbalagan, 1992a). The LHZ maps have an important role in planning and implementation of development schemes in mountainous regions. These maps are useful for the following purposes :

i) Identification and delineation of unstable zones in the mountainous regions

ii) Implementation of ecologically sound mitigation measures

iii) Providing input data for preparing risk maps, which are helpful in landslide hazard management.

2.1 Landslide Hazard Evaluation Factor (LHEF) Rating Scheme

The reliability of a LHZ map is essentially dependent on the rating system adopted for preparation of the map. The landslide hazard evaluation factor (LHEF) rating scheme (Anbalagan, 1992a and 1992b) is more relevant as it is based on an empirical approach using important inherent causative factors of slope instability such as lithology, structure, slope morphometry, land use and land cover, relative relief and hydrogeological conditions. This technique had already been adopted as an Indian Standard (IS) Code by the Bureau of Indian Standards (IS 14496: Part 2, 1998).

The LHEF rating system has been well established in parts of Kumaun and Garhwal Himalaya of India (Anbalagan, 1992; Anbalagan, 1992 (a); Gupta et al, 1993; Gupta & Anbalagan, 1995; Anbalagan et al 1992; Anabalagan et al 1993; Anbalagan and Singh, 1996 and Anbalagan and Tyagi, 1996). In this scheme, the external contributory factors such as rainfall and seismicity have not been included. Since they are regional and eratic in nature, their impact on landslide potential cannot be estimated with particular reference to individual slopes. The maximum LHEF ratings for individual contributory factors are determined on the basis of their estimated significance in causing instability (Table 1). The number 10 indicates the maximum value of the total estimated hazard (TEHD).

Table 1 : Proposed maximum LHEF rating for different countributory factors for LHZ mapping

Contributory Factor	Maximum LHEF Rating
Lithology	2
Relationship of structural discontinuities with slope	2
Slope morphometry	2
Land use and land cover	2
Relative relief	1
Hydrogeological conditions	1
Total	10

2.1.1 Lithology

Lithology includes broadaly rock type and soil type. In case of rock type, the erodibility, or the response of rocks to the processes of weathering and erosion has been the main criteria in awarding the ratings for subcategories of lithoogy. Rocks are divided into three groups namely Type-I, Type-II, and Type-III. The Type-I includes rocks like quartzite, limestone and igneous rocks, which are generally hard, massive and resistant to erosion. In comparison, rocks of Type-II, which include terrigenous sedimentary rocks, are vulnerable to erosion and landslides. The rocks included in Type-III are phylites, schists and other soft rocks characterised by flaky minerals, which weather quickly and promote instability. Accordingly the LHEF ratings have been awarded. Whereever the rocks are weathered, a correction factor depending on the status of weathering has been awarded. Wherever the rocks are weathered, a correction factor depending on the status of weathering has ben included for rock Type-I and Type-II.

This correction factor is multiplied with the corresponding rating of rock to get the corrected rating. In case of soil, genesis and age are the main considerations in awarding the ratings. For example, older alluvium is generally well compacted and has a high shearing resistance. Recent materials such as slide debris are loose and have low shearing resistance.

2.1.2 Structure

Structure includes primary and secondary discontinuities in the rocks such as bedding, joints, foliations, faults, and thrusts. The disposition of structural discontinuities in relation to slope inclination and direction has a great influence on the stability of slopes. By. analysing these discontinuities present within a facet with the help of a stereonet, the important sets of discontinuities, which are unfavorably disposed, are chosen. In this connection the following three types of relations are considered important :

1) The extent of parallelism between the direction of the discontinuity or the line of interesection of two discontinuities and the slope.

2) The steepness of the dip of the discontinuity or the plunge of the line of interesection of the two discontinuities.

3) The difference in the dip of the discontinuity or the plunge of the line of interesection of the two discontinuities to the inclination of the slope.

The inter-relationship of these structural discontinuities with the slope is studied carefully to award the ratings. Structure has been divided judiciously into three cub-categories namely, favourable (<0.9), moderately favourable (0.9-1.4) and unfavourable (1.5-2.0). These values indicate the degree of impact of structures in inducing the landslides (Gupta, 1997).

In case of soil cover, chances of failure increases as the depth of soil cover increases upto a certain depth. Beyond that, stability increases due to compaction of soil by its weight. Therefore, the inferred depth is considered for awarding the ratings.

2.1.3 Slope Morphometry

Slope morphometry is another important causative factor. The slope morphometry map represents the zones of different slope inclination (Gupta and Anbalagan, 1995). The Slope morphometry map is prepared by dividing the large topographical map into smaller units called slope facets. Five sub-categories of slope morphometry are considered in the LHEF rating scheme, namely escarpment of cliff (>45^0), steep slope (36^0-45^0); moderately steep slope (26^0-35^0), gentle slope (16^0-25^0) and very gentle slope (<16^0). It is a known fact that steep slopes have higher chances of slope failure than the gentle ones. Therefore, five sub-categories of slope morphometry have been arranged in their hierarchical order to award ratings.

2.1.4 Land Use and Land Cover

Land use and land cover is an indirect indication of the stability of hill slopes. Vegetation cover commonly smothers the action of climatic agents on slopes and protects them from the effects of weathering and erosion. A well spread grass cover provides a blanket to the top layer of a slope and protects it from the direct impact of rain drops as well as checks the inflitration of water into the slope surface, which may subesquently reduce the shear strength of slope material. Similarly, well spread root system increases the shearing resistance of slope material. Five sub-categories of land use and land cover are considered in LHEF rating scheme namely agricultural land or populated flat land, thickly vegetated area, moderately vegetated area, sparsely vegetated area with lesser ground cover and barren land. Barren and sparsely vegetated areas show faster erosion and greater instability as compared to reserve or protected forests, which are moderate to thickly vegetated and generally less prone to mass wasting processes. Agriculture, in general, is practised on terraced fields in hilly region. The agricultural lands represent areas of repeated water charging for cultivation pruposes and as such may be considered stable. Based on criteria of intensity of vegetation cover, the LHEF rating is awarded.

2.1.5 Relative Relief

Relative relief is the maximum height within a slope facet, measured in the direction of slope (Gupta, 1997). There are three sub-categories of relative relief in LHEF rating scheme namely low relief (<100 m), medium relief (101-300m) and high releif (>300 m). It is an obvious fact that the chance of slope instability is more with increasing slope height. Therefor, LHEF ratings are given accordingly.

2.1.6 Hydrogeological Condition

Groundwater does not have uniform pattern in hilly terrain and it is generally channelised along weak planes of rocks. The observational evaluation of the groundwater behaviour on hill slopes is not possible over large areas. Therefore, in order to make quick appraisal, the nature of surface indications of groundwater is considered for hazard evaluation mapping purposes. The observation is to be made after the monsoon to assess the worst hydrogeological conditions of the study area.

2.2 Total Estimated Hazard (TEHD) Values

The total estimated harard (TEHD) value indicates the net probability of instability of a slope facet. It is calculated slope facet-wise, because adjoining slope facets may have entirely different stability conditions. The TEHD value of an individual slope facet is obtained by adding the ratings of each causative factor, obtained from the LHEF rating scheme for that slope facet. Thus, the total estimated hazard (TEHD) value = sum of ratings of all causative factors (lithology) + structure + slope morphometry + land use and land cover + relative relief + hydrogeological conditions). On the basis of TEHD values, five categories of landslide hazard zones are identified (Table 2). These landslide hazard zones are very low hazard (VLH), low hazard (LH), moderate hazard (MH), high hazard (HH), and very high hazard (VHH).

TABLE 2 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
I	3.5 -.0	Low Hazard (LH) Zone
III	5.1 - .0	Moderate Hazard (MH) Zone
IV	6.1 - .5	High Hazard (HH) Zone
V	> 7.5	Very High Hazard (VHH) zone

3. General Procedure for Landslide Hazard Zonation (LHZ) Mapping

The LHZ mapping comprises mainly two aspects i) desk study and ii) field study. The scope of desk study includes preparation of slope facet map on 1:50, 000 scale. The slope facets are segments of slope showing consistent slope direction and inclination. In most cases, the hill slopes are divided into facets delimited by ridges, spurs, gullies and rivers. If any appreciable change is observed in the amount of inclination or the direction of the slope, another facet can be made. The procedure to prepare a LHZ map of an area may be summarized as below.

i) Preparation of a slope facet map of the study area on 1:50, 000 scale

ii) Preparation of pre-field factorial maps of individual causative factors with the help of topomap, aerial photographs, satellite imageries, and regional geological maps

iii) Facet wise collection of field data of causative factors

iv) Preparation of final factorial maps using field data and other information

v) Calculations of total estimated hazard (TEHD) for each facet.

vi) Preparation of LHZ map with the help of TEHD value obtained facet wise.

4. Route Location Study

The LHZ technique can be effectively used for route location study by suitably modifying the method. It is particularly helpful in Himalayan region, where the roads often show slope instabilities. Therefore, systematic evaluation of slope instability before implementation of the road project is required for route location. The systematic investigations for route locations involve the following stages - i) Preliminary Investigations ii) Detailed Investigations iii) Design Investigations and iv) Construction Investigations.

4.1 Preliminary Investigations

The route location starts with desk study using the already available data and later it is followed by field study. The factors considered at this stage are mainly related to geology and topography including slopes, spot heights of ridges and valleys, location of important villages and towns, forest cover and other such factors. The already available data in the form of topomaps, regional geological maps, land use land cover maps, aerial photographs and satellite imageries can be used for this purpose.

The preliminary investigations may cover the area from valley floor to ridge top, along the planned route corridors (Anbalagan and Sharma, 1992). The investigations are carried out on 1:50,000 scale so that a number of possible alignments can be taken up for comparative evaluation. Initially 3 to 5 alternative alignments are selected based on various factors and local constraints. The information obtained by desk study can be supplemented by walkover surveys along the proposed alignments. Walkover surveys will help to identify the nodal points of the alignments on the surface. The aerial photographs and satellite imageries are useful in the study of landforms, delineation of rock and soil, geological structures, drainage pattern, landslide inventories as well as land use and land cover of the area. In addition, information may also be collected about existing means of communications like roads, bridal paths and footpaths in and around the area of investigations.

Slope facet map along the proposed alignments covering about 500m on either side of the alignment should be prepared. All factorial maps and landslide hazard zonation map of the area are prepared on 1:50,000 scale using LHEF rating scheme

(Anbalagan,1992). The individual straight reaches of road and their hazard levels can be determined from LHZ map. Later the average hazard level of each alignment can be worked out using the following equation:

$$\text{Average Hazard Level of Alignment} = \frac{\Sigma\,(\text{Length of road section X Estimated hazard (TEHD)})}{= \text{Total length of road}}$$

The alignment with a minimum total hazard percentage may be preferable for final selection.

4.2 Detailed Investigations

The detailed investigations consist of preparation of more detailed map of the selected alignment during preliminary stage investigations. The detailed investigations are carried out on a scale of 1:10,000 to 1:15,000 with contour intervals of 5 to 10 m covering 200m on either side. For this purpose topomaps, aerial photographs, satellite imageries, geological and other maps available on the required scale can be used. The alignments marked by the nodal points during preliminary investigations can be located correctly on the ground with the help of suitably spaced pegs as the investigation progresses.

The factorial and LHZ maps prepared during preliminary investigations may be used as a base maps to include more details. Slope facet map may be reviewed carefully at this stage and if larger facets needed, may further be divided as sub facets. Slope direction and inclination may be recorded again for the new sub facets and must be marked on the modified facet map.

The lithological map contains the distribution of rock and soil type. Local variation in the lithology and weathering status should be noted carefully and rating may be recalculated accordingly. In case of soil, thickness may be worked out from the geological cross sections for calculating the rating. Geophysical techniques may be used for more details of depth of soil and depth of water level if any.

The structural details of various geological discontinuities in the slope facets may be collected at two or three places of the slope facets preferably top, middle and the bottom and plotted on the map to see the orientation of discontinuities with respect to the orientation of slope facets. Structural data of individual facets may be plotted with attitude of slope on a stereonet to study their relationship and the nature of instability, if any. Major faults, thrusts and folds should also be plotted in the map for a judicious assessment of hazard ratings.

The slope morphometry map, showing various categories of slopes in different slope facets, is prepared from the topographic map. The average slope within the facets is calculated on the basis of contour spacing. The average number of contours over unit length of the map distance may give the average slope angle. This map may require modification at this stage of investigation if the slope facets have been changed.

Similarly, relative relief map also requires some modification if changes have been made in slope facet map. Average height difference of the alignment from the top of the individual slope facet to the bottom should also be calculated.

The groundwater in hilly terrain does not have uniform flow pattern. Therefore, nature of surface indications provides valuable information on the groundwater conditions. Geophysical techniques if required may be used to infer the depth of the groundwater in soil-covered areas.

Total Estimated Hazard (TEHD) for individual facets may be calculated by adding the ratings of individual causative factors. Finally LHZ of the area can be prepared using TEHD values of individual facet.

Further detailed studies in high hazard (HH) and very high hazard (VHH) zones must be carried out to collect more information on the nature of instability and to evolve precautionary and remedial measures during construction. For this purpose HH and VHH zones have to be mapped on 1:1,000 to 1:2,000 scale, geological cross-sections slope, field and laboratory test should be carried out to know engineering properties in detail for calculating Factor of Safety (FOS) of individual slide areas.

The selection of route alignment passing close to the river should ensure that it is located well above the High Flood Level (HFL). Wherever probabilities of Glacial Lake Outburst Floods (GLOF) or formation of landslide dams exist, they may constitute major danger to the existence of the alignment. Hence, the alignment may have to be shifted sufficiently to higher elevations. Cross-sections at 100-200 m interval including geological cross-sections are prepared from the topomaps and geological map of the area to decide about cut slope angles, fills, and haulage so that the cost estimates can be worked out in detail. If two alignments are under consideration, the one with lower cost may be preferred as the final choice.

4.3 Design Investigations

The geological map and the other thematic maps as well as hazard zonation map prepared during detailed stage provide basis for design purposes. The detailed maps prepared for the hazardous reaches like HH and VHH zones may be much useful for evolving proper designs as well as adopting precautionary measures during constructions.

During design investigations, the major activities include determination of final grades including design of horizontal and vertical profiles, cuts, and fills. Slope stability measures for the cut slopes may include design of retaining walls, breast walls, check dam, surface, and sub-surface drains, and river protection measures, in addition to design of bridges, pavements, culverts and chutes. Further estimation of quantities of constriction materials, rate analysis, cost estimates and preparations of contract documents are also carried out during this stage. At the end of this stage, all the data required for construction of the road are collected, which can be readily used for construction purposes.

4.4 Construction Investigations

During the construction stage, the hazardous reaches are given adequate attention to study the behaviour of the slopes. After excavations, the actual geological conditions should be mapped and if required, the remedial measures worked out earlier may be modified wherever required. It is essential to keep a record of site conditions before construction materials cover them. Especially the foundations of the bridges, retaining and breast walls fall in this category.

5. Conclusions

Uttaranchal, a recently formed state of India, requires many developmental projects to be implemented for its overall progress. For that purpose, stable all weather road networks throughout the state are required for implementing developmental projects. Well-planned and systematic investigations may help to construct roads with least problems of instability. The application of landslide hazard zonation (LHZ) mapping technique during preliminary and detailed stage of investigations will help to arrive at environmentally sound and cost effective route locations.

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