BIS Methodology for Landslide Hazard Zonation – A case study from Bhimtal and Naukuchhia *Tal* area, District Nainital, Uttaranchal

*Harsh Gupta

Abstract

Landslide hazard zonation is a vital tool for rapid evaluation of study of geohazards and slope instability on regional or meso-scale planning of urban agglomerations. Various techniques have been propounded after workers from all over the world. BIS method being one of these has been used in evaluating the slope susceptibility studies related to urban planning of Bhimtal and Naukuchhia Tal areas. The paper discusses the observations made in categorization of the slopes in this area and also discusses the relevance of the method used for recommending activities and cautions to be adopted by the district administrators in the execution of the developmental activities envisaged in the Bhimtal and Naukuchhia Tal areas. Author also recommends site specific studies based on determination of finite parameters such as 'c' and 'ϕ' and natural moisture content and pore-pressures, etc. in evaluating stability and designs of civil structures.

Introduction

Landslide Studies for slope susceptibility and zonation using techniques evolved over the period are vital tools for rapid evaluation of geo-hazards in the country as needed for priority level of mapping in our country (Gupta, Harsh and Singh, B.K.). Categorisation of slope in terms of different grades of stability on regional scale and meso-scale have been attempted elsewhere and in our country in the form of landslide zonation. Mainly following three approaches *viz.*, the statistical method that uses multivariate data on a grid pattern, while the second method, the probabilistic approach makes use of landslide incidences in a particular area *vis-à-vis* other slope forming characteristics and the SMR (slope mass rating) after Romana[2] *et al.* (1985). This has been widely accepted for regional landslide zonation on meso-scale in Himalaya.

The third approach is based on rating of different causative factors followed as per the *Bureau of Indian Standards - code: IS 14496 (Part 2)*. This being a numerical system, each factor is assigned a maximum Landslide Hazard Evaluation Factor (LHEF) rating on the basis of its estimated significance in causing instability. These ratings of all the factors are added up to get total estimated hazard of a slope based on which landslide hazard zones are made. This methodology of using a semi-quantitative assessment, therefore, is more suited for the categorisation of slopes in terms of determining their potential to failure, particularly in the areas where existing incidences of failures are fewer in number, and hence, has been prefered over others.

This method of BIS – practice for preparation of Landslide Hazard Zonation map has been utilised by the author (2002) in evaluating the landslide susceptibility of Bhimtal and Naukuchhia Tal areas in Nainital District of Uttaranchal for urban planning of the agglomeration.

*Geological Survey of India, Northern Region, Lucknow

Due to ever increasing pressure on the environment and ecological set up of Nainital township, the district authorities have prepared a master plan to develop the Bhimtal and Naukuchhia Tal as analogous satellite township, in order to avoid further overcrowding around Nainital.

General Layout and Geology

Bhimtal Master Plan area lies east of Nainital at a general ground elevation of 1370m above the mean sea level. The area has its importance due to the presence of the famous Bhimtal and Naukuchhia *Tal* lakes, of Nainital District in the Uttaranchal State. Bhimtal and Naukuchhia *Tal* lakes, which have found significance over the years from the Vedic period and is also a place of attraction for the tourists and pilgrims.

An area of 2465.52 ha. is envisages to be developed. Although this area has been inhabited from a very long time and developed since then; the first check dam for irrigation purpose was made during the period of Chand Rajas in the year 1638 and was improved upon during the successive British rule and after the independence, most of the construction activities had remained confined close to the "dat" – headwork of the dam.

The area under study stands out in the form of a Plateau comprising rocks of Bhimtal Formations consisting pink to purple quartzite with thick bands of greenish grey /purple Phyllites, dark grey and earthy brown phyllite and Bhowali Volcanics with basic intrusives. Balia *Nala* bounds the area to the west and Gola river lies to the southwest of the area. The high hills on these three margins have moderate to steep slopes ranging from 30° to 45°, whereas, generally flat plateau, in the central part, is occupied by alluvial and other overburden deposits, having gentle to nearly flat angles of 7° to 12°.

Technique and observations

With a futuristic view for a well planned development of the agglomeration, survey and specialised studies are taken up with an objective to check unplanned and uncontrolled construction activities in the vicinity, besides providing well planned residential colonies, it also caters civil and tourist amenities and a good network of communication.

Landslide Hazard Zonation Map is the final product of various thematic maps that include Slope Morphometry Map, Slope Forming Material Map, Landuse & Soil Cover Map, Relative Relief Map and tabulation of data.

Based on the slope morphometry of the area 852 slopes facets of different categories have been identifies on the basis of the slope angle, slope direction and relative relief. Further each facet has been assigned individual rating based on the lithology, structural relation to slope direction, their dip and trends. Ratings on their landuse type, soil cover and hydrology have also been evaluated individually as per BIS. A compilation of LHZ map (Fig. 1) is also prepared on the basis of the *Total Evaluated Hazard Rating* tabulated for this purpose.

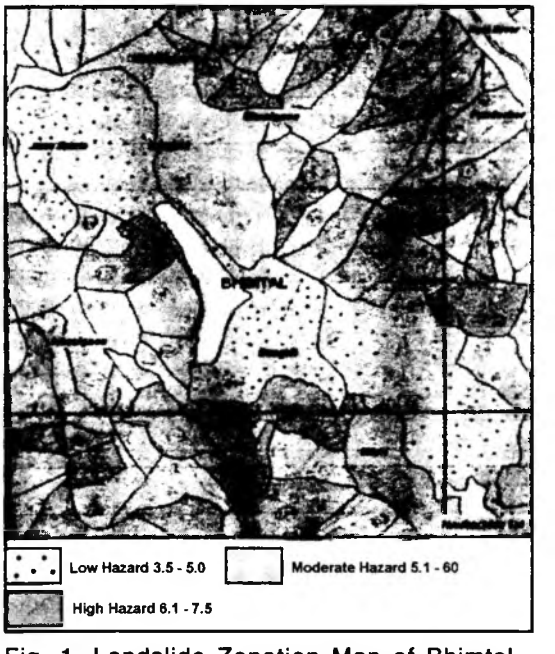

Fig. 1. Landslide Zonation Map of Bhimtal - Naukuchhia Tal Area, District Nainital, Uttaranchal

The landslide Hazard Map of Bhimtal – Naukuchhia *Tal* area has accordingly been prepared by grouping the slope facets of the area into four major categories only in order of increasing TEHD values. The lowest of the above categories, the Very Low Hazard Zone being not assignable the area has been demarcated with Low Hazard, Moderate Hazard, High Hazard and Very High hazard zones. Based on the TEHD values the total of 852 slope facets studied and analysed in the area have following distribution :

Zone	No. of Slope Facets Facets	% of Total Slope
Very Low Hazard	0	0
Low Hazard	78	9.15%
Moderate Hazard	413	48.47%
High Hazard	359	42.13%
Very High Hazard	2	0.35%
Total	**852**	**100.00 %**

A review of the slope stability evaluation and preparation of landslide zonatlon map thereof, for multi-faceted development for urbanisation of Bhimtal -Naukuchhia *Tal* areas indicates that for example, the slopes falling in Matiyali, Lamasaur, Senkhan, Gairkhan and Kimu lie in the moderate to high hazard zones (Fig. 1). East of Lamasaur, Gairkhan, and Koluti the slopes have indicated high TEHD values.

Based on the studies carried in the area of the total slope facets identified in the TEHD categories 5.1 to 6.0 and 6.1 to 7.0 lie in high relief category with RR ratings of 0.6 and 1.0 in the moderate and high hazard zones (Figs. 3 and 4). Relation between the dip of discontinuity and inclination of slope also shows that these fall in the above two categories and particularly so when the dip of the planes is less than the ground slope (Fig. 5).

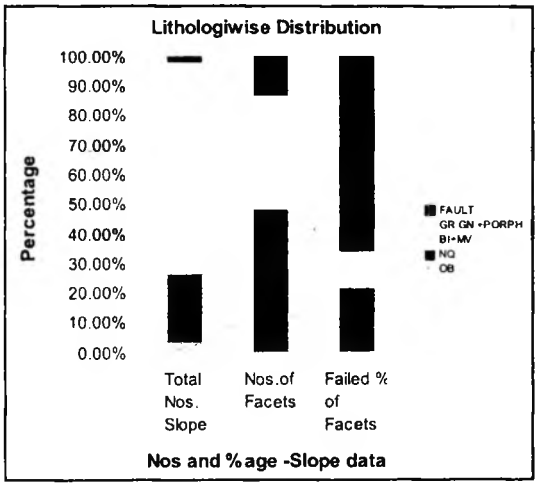

Fig.2. Lithological distribution of Total, Failed slopes in Bhimtal Naukuchhia Tal area

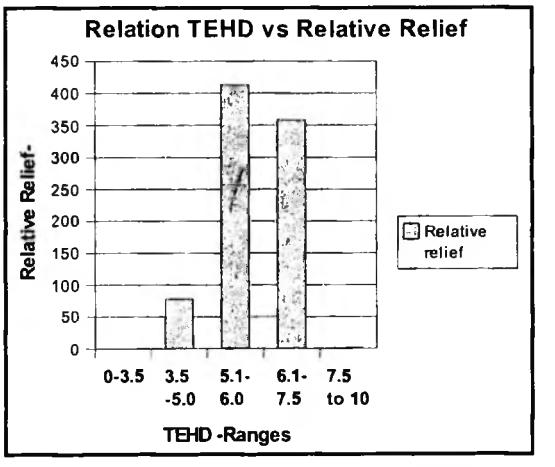

Fig.3. Relation between TEHD ratings and distribution of slope facets by R.R. In Bhimtal and Naukuchhia Tal areas

Towards south of Bhowali, low-lying area with small lake-lets and ponds in Babyan Thok and Tirchhakhet occupy the valley floors characterised with undulatory topography. These areas fall in the low hazard zone. The moderate to gently sloping topography south of Phorsoli and at Mahragaon, Bhagturiya, Nisalgaon, Gorakhpur, Sanguri, Bhimtal, Bilaspur, east of Dungsil and Siloti has moderate to thick cover of soil. The ground slopes vary from < 5° to as much as 27°, have been classed under low hazard category.

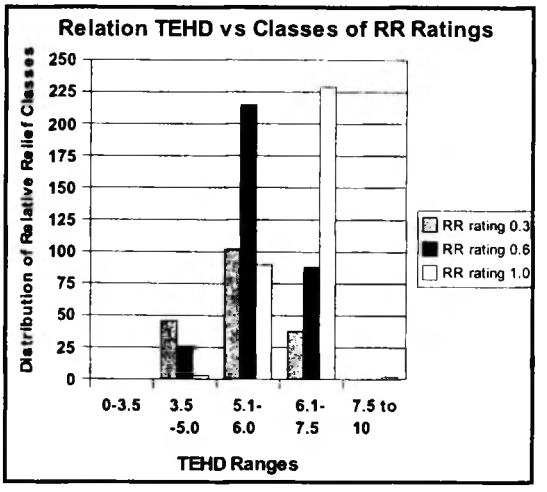

Fig.4 Relation between TEHD ratings and distribution of slope facets by R.R. ratingsIn Bhimtal and Naukuchhia Tal areas

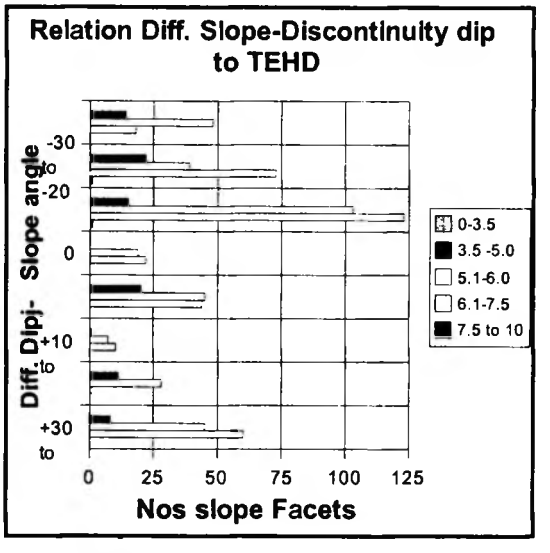

Fig.5 Relation between TEHD ratings and distribution of slope facets by Difference of slope-Discontinuity dip, Bhimtal and Naukuchhia Tal areas

These areas are considered, generally, suited for developmental and construction activities. However, the stability of ground slopes in drastically changed profiles consequent to extensive cutting of back slopes for erecting buildings, making roads, etc., shall have to be dealt with reference to site specific conditions and structural requirements. Other low hazard zones of smaller extent are in Sat-*Tal*, Puna-*Tal*, west of Jantwalgaon, Dehra, Amiyan and Chanpoi, forming river terraces along Kalsa *Nadi*.

Moderate to high hazard areas as per the methodology adopted for this study lie in moderate to steep grounds with slopes varying from 32° to 45°. Thus, adjoining the plains of Bhimtal, areas around localities such as Pandegaon, Karkot, Simalgoan, Sirwa, Mahragaon, Siloti, Chanoti, Kharki, hills west of Sat Tal, hills of Mallakun, Tallakun, Maherakhet, east of Babiyan Thok, Panyali, etc., lie in High Hazard zones. Bilaspur, Bigroli, Shakhola, Jun Estate, the area northwest of Bhimtal lie in the moderate to high hazard zones. Construction activities in all these areas shall have to be taken up with caution.

Major causative factors responsible, independently or inter-dependently, for the stability of slopes have been considered in BIS method are as follows. Each factor on the basis of its estimated significance in causing instability, has been assigned a maximum numerical LHEF rating as shown in the following table:

Table-1 Maximum LHEF Ratings for Different Causative Factors

Sl. No.	Causative Factors	Max. LHEF Rating
1.	Lithology	2
2.	Structure	2
3.	Slope Morphometry	2
4.	Relative Relief	1
5.	Landuse	2
6.	Hydro-geological conditions	1

The slope forming materials, defined by the lithology of areas are basically derived from bedrock and also include overburden or drift materials. Besides ratings adopted for normal fresh grade rock, correction

factors C1, C2, and C3 for different weathering grades namely; for Rock Type-1 (generally igneous and metamorphic suit of rocks), values for C1, C2 and C3, which are multiples of 4, 3 and 2 respectively for highly weathered, moderately weathered and slightly weathered conditions have been assigned. For Rock Type-2 (comprising sedimentary rocks quartzite, shale and limestone etc.), these values for HW, MW and SW are 1.5, 1.25, and 1.0, for highly weathered, moderately weathered and slightly weathered conditions respectively. Various categories of slope types based on lithology have been observed, showing percentage of slope facets in each class (Fig. 2).

Slope Morphometry Map is primarily required as a base map for the preparation of a LHZ map. It exhibits amount and direction of inclination of total slope facets delineated in the area. An overlay was prepared to demarcate the divides defining limits of micro-basins of streamlets, as far as possible, of 1st order along with the slope facets occurring within them, covering areas as small as 0.25 sq km. Each slope facet was subsequently numbered basin-wise and its direction (αs) and amount of inclination (βs), and Relative Relief (i.e. difference in elevation between the crest and toe of each slope facet) were computed from 20m contour lines and plotted. Slope Morphometry Map was then prepared and facet wise data have been tabulated.

The fourth important parameter is the Relative Relief (RR), which represents maximum height of the slope between its crown and its toe measured in the slope direction, in a given facet. Three categories of slopes are identified on the basis of their RR.

Category		Rating	
I.	Low Height	<100m	0.3
II.	Medium Height	101-300m	0.6
III.	High Height	> 300m	1.0

Presence or absence of water in a slope significantly influences the shearing resistance of the slope forming material, and hence, its stability, want of reliable hydrologic data remains a major constraint. To overcome this five categories of generalized hydro-geological conditions as given here are assumed, which can be assessed visually to give idea of pore pressures involved.

Category		Rating
I.	Flowing	1.0
II.	Dripping	0.8
III.	Wet	0.5
IV.	Damp	0.2
V.	Dry	0.0

Of the six parameters given above, parameters all the parameters except parameter 5, i.e. - landuse; fulfil the requirement of causative factors that are needed for evaluating finite or quantitative values of the Factor of Safety under normal conditions for slope stability, and hence may be termed as causative factors that directly influence the instability of a slope. However the 5th parameter that defines the landuse, indicates the suitability or the requirement of the development of a particular activity going on in the area or envisaged for future development respectively. As such these factors influence the instability to a limited order and may be grouped under additional factors or risk factors.

In determining the factors of safety of slopes, Hoek and Bray (1977) give the following relations for dry and saturated ground conditions respectively;

$$F.S. = \frac{(2c/\gamma H).\mathrm{cosec}\psi p + (1-\mathrm{Cot}\psi s).\mathrm{Cot}\psi p.\sin\psi p.\tan\phi}{(1-.\mathrm{Cot}\psi s).\sin\psi p} \quad \ldots. (1) \text{ for dry conditions}$$

and

$$F.S. = (cA + (w\cos\psi p - U - V\sin\psi p)\tan\phi)/w\sin\psi p + V\cos\psi p \quad \ldots. (2) \text{ for wet conditions}$$

where, c is cohesion, (in case of intact rock it is represented by c_p, , which denotes the cohesive/compressive strength of the intact rock material), U and V are the vertical and horizontal components of the uplift pressure and ψp the angle of rupture or discontinuity plane of failure.

In simple case of planar failure following relation for ψp may be resolved giving;

$$2\psi p = \psi s + \phi - [\cos^{-1}(2c/\gamma H.\sin(\psi s+\phi))] \quad \ldots. (3)$$

where, ψs is the angle of the cut or ground slope, H is the height of the cut or ground slope as the case may be, γ is the unit weight of the rock mass.

This is the most critical plane of failure and forms the rupture plane of failure in case of massive or favourably jointed rocks, which may be very closely jointed or weathered. In case of many areas such planes may be discerned on the spurs, where slumped cracks have developed, indicated by the extent of slump line. In case of jointed rockmass the most unfavourably oriented joint plane becomes the plane of failure.

It can be observed that the parameters 1 to 4 and 6 adopted for BIS code of practice fulfil the requirements of the relations that govern the deterministic values, although to a semi quantitative extent in case of the BIS. Basically this approach has therefore been used in adopting the BIS - Method of Landslide hazard zonation studies in the Bhimtal and Naukuchhia *Tal* areas for urban planning.

Conclusions and Recommendations

Importance of landslide hazard zonation studies lies in the fact that they provide a foresight into rationally conceiving the vulnerability of the slopes to fail which is highly unpredictable in time, space, and dimensions due to both human activities as well as natural factors.

The map acquires further significance by identifying such areas where certain restraints shall have to be observed in planning and construction of civil structures and communication network. This important aspect is governed by the landuse of a particular area and hence need to be considered as additional or risk factor.

In order to find out suitability for developing analogous geo-environment friendly as well as tourism encouraging satellite urban agglomerations around over loaded Nainital town, slope stability evaluation has been carried out around Bhimtal, Naukuchhia *Tal* using BIS code of practice.

Landslide zonation maps offer a general idea about the stability of an area; these cannot serve the purpose of designing of civil structures in toto. Application of design criterion to the site specific conditions and construction activities, however require a deterministic approach, for which detailed exploration, laboratory back-up and larger scale of mapping suiting to site specific conditions would be necessary.

Acknowledgement

The author is highly grateful to Dr. P.N. Razdan, Dy. Director General, Geological Survey of India, N.R., Lucknow, for kindly permitting the publication in the forthcoming one-day workshop and brainstorming session, conducted by the Indian Society of Engineering Geology at Lucknow, proposed on the 22 December, 2006. The author also thanks the editors for their critical review and scrutiny of the paper.

References

Gupta Harsh, and Singh, B.K. : "The Need for the Priority of National Level Landslide Hazard Zonation", Jour. of Engg. Geol. (ISEG): vol. XXVII, no. 1-4.

Romana, N. (1988): 'Practice of SMR

classification for Slope Appraisal'. Proc. Fifth Int. Symp. Landslides, Laussane. V.2. pp. 1227-1231.

Bureau of Indian 'Preparation of Landslide Hazard Zonation Standards (1998). Maps in Mountainous Terrains - Guidelines. Part 2, Macro-Zonation. ISC 07.040. IS Code: 14496 (Part 2).

Gupta, Harsh (2002): Unpublished GSI Report on Evaluation of Slope Stability for Urban Planning in Bhimtal - Naukuchhia *Tal* area, District Nainital, Uttaranchal.

Hoek, E. & Bray, J.W. (1977): 'Rock Slope Engineering', Institute of Mining and Metallurgy, London, 2nd edition, pp. 154.