

**International Journal of Innovative Research in Science,
Engineering and Technology**

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Landslide Susceptibility Zonation along Rishikesh - Gangotri highway, Bhagirathi valley, Uttarakhand Himalaya

K.S. Sajwan¹, M.K. Parmar²

Geologist, Disaster Mitigation and Management Centre (DMMC), Department of Disaster Management, Government
of Uttarakhand, Uttarakhand Secretariat, Rajpur Road, Dehradun, Uttarakhand, India¹

Guest Faculty, Department of Rural Technology, H.N.B. Garhwal Central University, Srinagar Garhwal, Uttarakhand,
India²

ABSTRACT: Every year, landslide incidences cause widespread damage and destruction to infrastructure, human lives and environment in the Himalaya. Transportation network often get closed due to frequent occurrence of landslides, induced by heavy monsoonal rains. The present research paper embodies landslide susceptibility zonation of Bhagirathi valley of Uttarakhand Himalaya. The Sacred Gangotri Shrine is located at the upper most end of Rishikesh - Gangotri highway (NH - 108). This route is not only significant for transportation and communication but also essential for the tourism and pilgrimage point of view. As the NH - 108 lies in the study area so lots of problems are regularly faced by the tourist, pilgrim and local public due to road blockade by landslides. It has been observed during recent years frequency and severity of landslides are increased. A systematic approach for terrain evaluation was used for preparing landslide hazard zonation map of the study area. Landslide inventory map was prepared on the basis of landslide location identified in the area from interpretation of aerial photographs and field investigation. On the basis of total estimated hazard (TEHD), the study area divided into five categories of relative landslide susceptibility, namely, Very low, Low, Moderate, High and Very high hazards. These LHZ maps would be useful for the better understanding of safe and unsafe zones for the infrastructure development and planning.

KEYWORDS: Landslide hazard zonation, Bhagirathi valley, Geo-environmental factors and LHEF rating.

I. INTRODUCTION

Landslides constitute one of the most destructive natural phenomenon deteriorated the Himalayan ecosystem. In the study area, the problem of slope instability is serious due to high degree of tectonic activity. As a result of tectonic activity, seasonally intense rainfall, deforestation and extensive anthropogenic activities e.g., excavation for the construction of buildings, roads and hydropower projects have been intensified erosion and triggered slope failures. Debris slides, rock cum debris slide, rock slides, debris flow and rock fall are prominent type of slides present in the area.

Landslide hazard zonation involves various terrain parameters and sub-parameters which control the stability of slope. In this study, various geo-environmental factors viz. lithology, structure, slope, relative relief, drainage and landuse / land cover were taken as basic parameters. The thematic/base maps of the study area were prepared using the Survey of India (SOI) Toposheet No. 53 J/1, J/2, J/5, J/6, J/9 and J/10 on a scale of 1: 50,000. These thematic maps were enumerated by giving them a relative score. Geological, structural as well as geo-morphological mapping was carried out on scale 1:50,000.

II. STUDY AREA

The study area falls in Lesser and Higher Himalayan region, along Rishikesh-Gangotri Highway (from Dharasu to Bhatwari), Bhagirathi valley, Uttarakhand Himalaya (Fig. 01.). Administratively, the area situated in the Uttarkashi

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

district of Uttarakhand Himalaya. The area lies within $78^{\circ}09'57''$ to $78^{\circ}38'26''$ E longitude and $30^{\circ}36'24''$ to $30^{\circ}56'37''$ N latitude, covering a stretch of 60.5 km length of road section with a total catchment area of 679.13 km². The national highway - 108 runs along the Bhagirathi valley often shows landslides during monsoon season, toe cutting, bank erosion by the river generate several type of slides along the river course. The area is drained by Bhagirathi river and its tributaries i.e. Khurmola Gad, Rano Gad, Syalam gad, Asi Ganga, Ganwan Gad, Kumalti Gad, Nahar Gad and Devekund Gad.

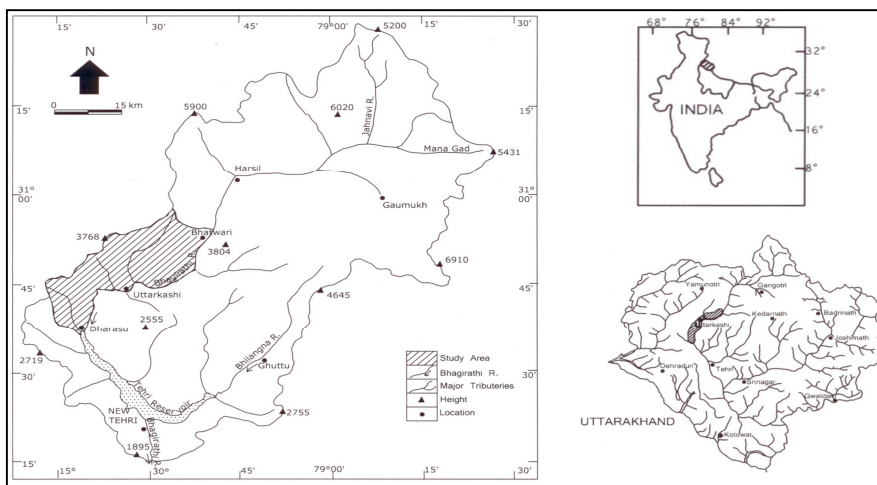


Fig. 01 Location map of the study area

III. REVIEW OF PREVIOUS WORK

In Indian context many workers like Seshagiri and Badrinarayan (1982); Takei (1982); Pachauri and Pant (1992); Gupta and Joshi (1990); Anbalagan (1992 and 1993); Saha *et al.*, 2002, etc. have carried out the studies of landslides in different parts of the country. Some of the recent attempts on the study of landslides were carried out by Rautela and Thakur (1999), Naithani (2002), Paul *et al.* (2000), Sah *et al.* (2003), Sarkar *et al.* (2005), Asthana and Sah (2007), Gupta and Ahmed (2007) etc. Pareta *et al.* (2012) was carried out landslide hazard zonation study using quantitative method in GIS in Giri river watershed.

IV. METHODOLOGY

The landslide hazard zonation (LHZ) study was carried out in order to demarcate the hazard prone areas with varying degrees of instability. The methodology adapted is based on the analysis of the data acquired from various geo-environmental factors, which govern the stability of the slopes. Lithology, structure, slope, hydrology including surface drainage as well as groundwater condition, relief and landuse / land cover has been taken into consideration for assessment of landslide susceptibility zones.

The topographic maps of Survey of India, on a scale of 1:50,000 were used as the base map. Detailed field investigations were also carried out during different phases of the study. In this work, the methodology suggested by Anbalagan (1992) have been mainly adopted. Maximum landslide hazard evaluation factors (LHEF) ratings for the above mentioned contributory factors for macro-zonation was determined as suggested by Anbalagan (1992), is presented in table 01. The LHEF rating scheme is a numerical rating system, which is based on major inherent causative factors of slope instability. Numbers 10 indicates the maximum value of the total estimated hazard (TEHD).

Preparation of thematic maps: A flow diagram depicting the various phases of activities involved in the preparation of landslide hazard zonation map is given as Fig. 02. Thematic maps were based on the analysis of the data acquired

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

from various geo-environmental factors, which govern the stability of the slopes and is prepared on a scale of 1:50,000. Thematic maps are based on the Survey of India toposheets and field survey as well as help from satellite data was also taken during their preparation.

Lithology: Bedrock influences landslide occurrence in several ways. Weak, incompetent rock is more likely to fail than strong, competent rock. It is an important factor in controlling the stability of rock, quartzite, slate, gneiss, schists, migmatite and carbonate are prominent lithological units present in the study area (Fig. 03). It has clearly indicated that comparatively softer and structurally deformed litho-units are more prone to landslides. The bed rocks are overlain by fluvial sediments along the valley side. Such slope facets which are overlain by the soil in this case recent materials are unconsolidated and loose and have low shearing resistance while the older alluvium is generally compacted and has a higher shearing resistance. The genesis and nature of soil (loose and compacted) are the main consideration in awarding the ratings. Quaternary deposits are vulnerable for the slope instability; road construction and bank erosion by river further aggravate landslides along these.

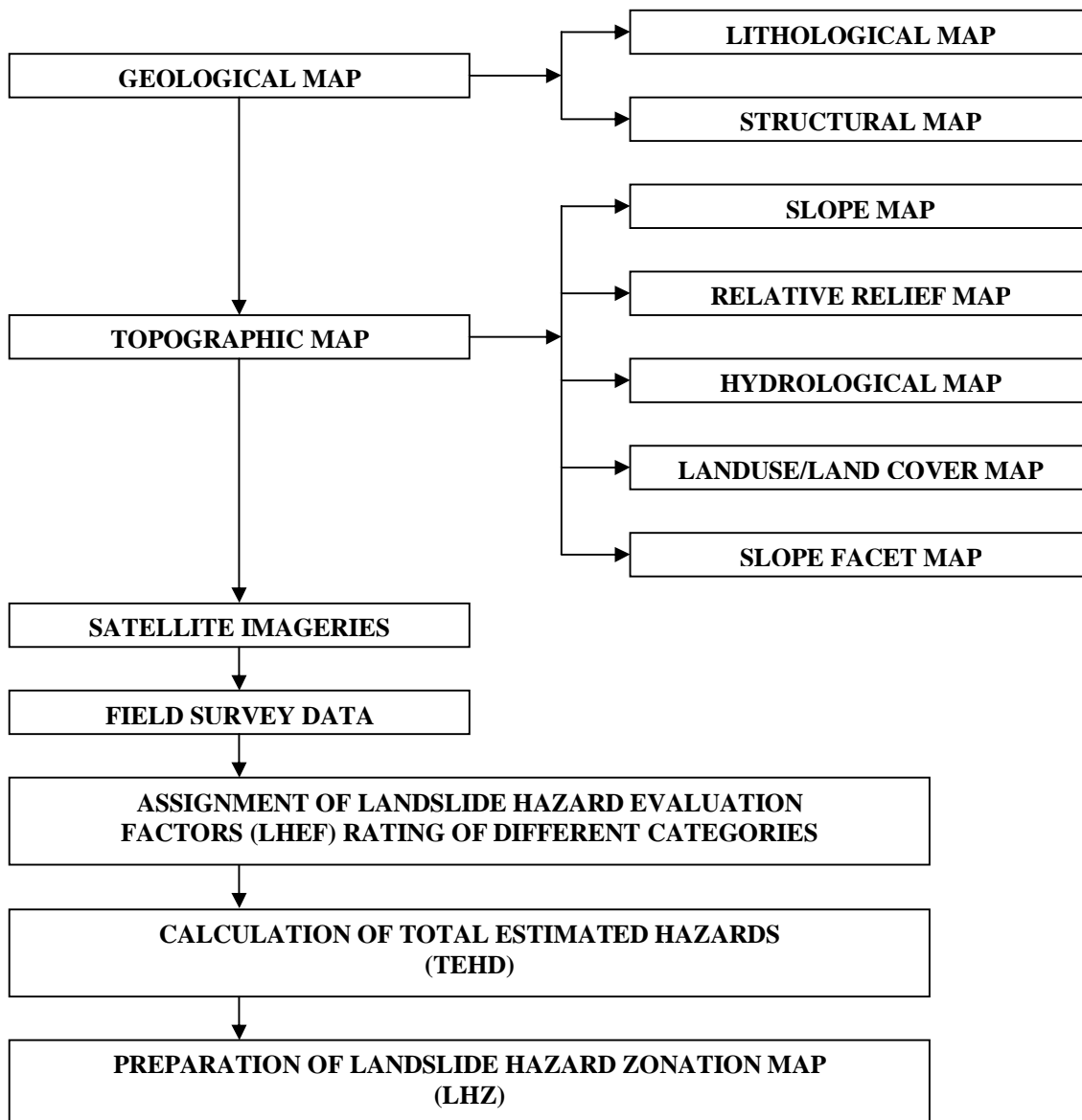


Fig. 02 Flow Chart of Landslide Hazard Zonation

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

Structure: Structure includes discontinuities in rocks such as joints, folds, faults, thrusts and shear zones. The faults, fractures and joints not only tend to destabilize the area through deterioration of the strength of the rocks, but also accelerate the weathering process (Mathew et al., (2007). The Main Central Thrust (MCT) and North Almora Thrust (NAT) are the major structural dislocation of the study area (Fig.03). Besides these two, several other faults Khattukhal, Dunda, Rano Gad, Baragadi, Matli, Syalam Gad faults appear to be minor faults present in the area. These thrust and faults might have triggered landslides and reduced the stability of slopes.

The incidence of landslides has been studied with respect to the distance from major thrust and faults. As the distance from the thrust increases, the hazard of landslide decreases. The data reveals that frequency of landslide is maximum in sector 1st (<0.5 km) followed by successive sectors from 2nd and 5th. It is evident that maximum numbers of landslides are located within 5 km range and the frequency of landslides progressively decreases with the increase in distance from thrust/faults.

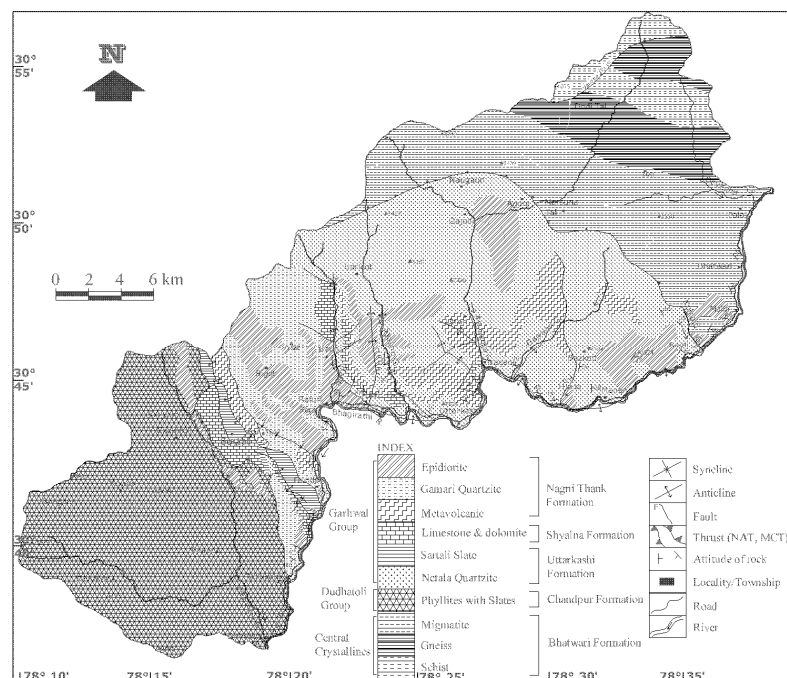


Fig. 03 Geology and structural map of the study area (modified after Agarwal and Kumar, 1973)

Slope: Slope map was made to determine the nature, rate and effect of the process at work over the slope. A slope is an inclination of a terrain that forms the part of a landscape included between the crest of hill and drainage line (Leopold et al., 1964). Based on the field data and Survey of India toposheet a slope inclination map was prepared (Fig. 04). In slope map, the terrain is divided into small facets of varying slope angles. The entire facets are to be marked with the direction as well. Furthermore, the individual slope category was divided into smaller facets of varying slope angles, which reflect a series of localized process and control that have been imposed on the facets (Anbalagan, 1992). It was observed that uniform geology, climate, soil and relief are the main factors, which control the slope inclination and direction. The debris slopes are relatively gentle in comparison to rocky slopes.

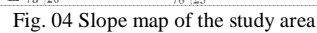


Fig. 05 Relative relief map of the study area

12133

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

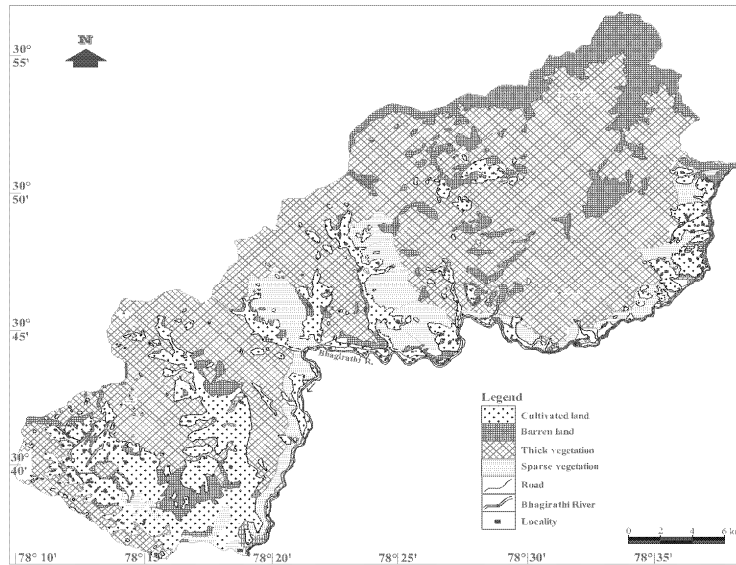


Fig. 06 Landuse / landcover map of the study area

On the basis of the field observations, the rating has been awarded for the different categories of the landuse. In this area majority of landslides are found in sparsely vegetated land, indicating that deforestation has accentuated mass movements. After that frequency of landslide is shown by barren landuse category, followed by cultivated land and thick vegetation categories. It shows that landslides are not confined to a particular landuse type, similar observation were taken by Rautela and Thakur (1999) in Kaliganga and Madhymaheshwar valleys of Garhwal Himalaya.

V. HYDROLOGY

- (a) **Drainage pattern:** An attempt was also made to assess the influence of drainage pattern on occurrences of landslide. Mainly, five drainage patterns are observed in this area (Fig. 07). The permeability and porosity are very important to determine the stability of any slope, and they are related to slope hydrology. The drainage has a strong dependence on pore water pressure and slope hydrology; therefore, landslide processes are strongly linked to the drainage pattern over the slope.

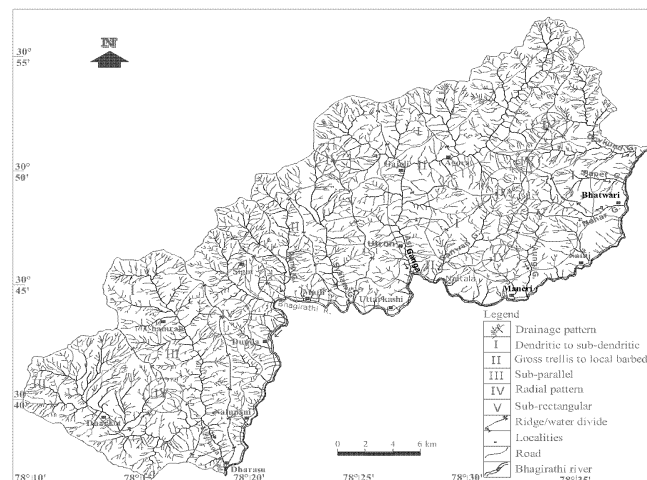


Fig. 07 Drainage map of the study area

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

- (b) **Drainage density:** Drainage density is the ratio of the total length of streams to the area of the drainage basin, higher the drainage density, the lower the infiltration and the faster the movement of the surface flow. It is defined as length of streams/unit area and used as a factor determining the time of travel by water (Horton, 1945). To prepare the map of drainage density of the study area, first, second and third order streams of the drainage network were taken into account (Fig. 07). On the basis of values of drainage density, the entire area has been divided into five categories (Fig. 07). The drainage density has direct influence on landslide occurrences, since a higher drainage density indicates a more rapid erosion and removal of debris. The places where the drainage density is high, water washes out the cementing material from soil and rock masses.

VI. SLOPE FACET MAP

The slope facets have been identified on the topographic map and commonly they are demarcated by natural boundaries like drains, ridge, spurs etc. Facet is a polygonal area of hilly terrain which has more or less similar characters of slope, showing consistent slope direction and inclination. In all 610 facets were delineated from the study area on the basis of visual interpretation of topographic maps (Fig. 08). Finally, the total estimated hazard (TEHD) of an individual facet is obtained by adding the ratings of individual causative factors obtained from the thematic maps as per the LHEF rating scheme (Anbalagan, 1992). Landslide hazard evaluation factor (LHEF) rating schemes given in Table 02.

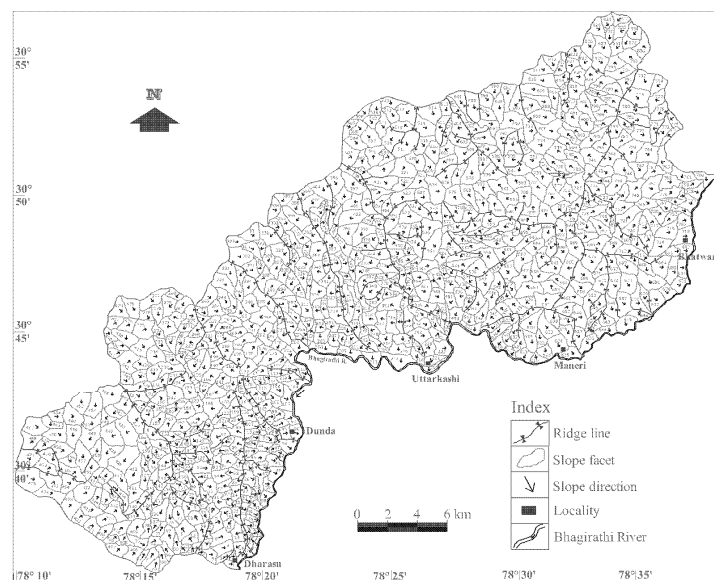


Fig. 08 Slope facet map of the study area

VII. DISCUSSION AND CONCLUSION

On the basis of TEHD, the study area divided into five categories of landslide hazard zones in terms of susceptibility of landslides (Table 2 and Fig. 09), these zones are very low hazard (VLH), low hazard (LH), moderate hazard (MH), high hazard (HH) and very high hazard (VHH) zones. It is significant to note that slopes coming under very high and high hazard zones are comprised of existing landslide areas, while the slopes under moderate and low hazard zone has shown potential and minor failures and the slopes under very low hazard zones are free from slope instability. The landslide hazard zonation map of the study area indicates that 6.0% of the area falls in very low hazard, 43% area in low hazard, 39% in moderate hazard, 07% in high hazard and 5.0% in very high hazard zones categories.

The highly susceptible areas are mostly underlain by overburden material, weathered and jointed quartzite, phyllite, gneiss/migmatite and schists at many places within close proximity of faults and thrust. Mostly landslides occur moderately steep sloping areas which are affected by an increase in slope angle due to change in angle of repose. Uncontrolled blasting during road construction further aggravates slope failure. It is observed during this study that very steep slopes / escarpment ($> 45^\circ$) made up of rock exposures, free from structural discontinuities are mostly stable.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

The areas coming under very high hazard class indicates that are more vulnerable to occurrence of landslides compared to very low hazard areas which mainly associate to comparatively stable areas made up of gentle slope. The area mostly underlain by jointed, sheared and weathered rock i.e. slate, quartzite and migmatite / gneiss shows maximum susceptibility to landslides. It is observed during this study that vicinity to thrust / faults (e.g. MCT), frequencies and magnitude of landslides are increased; further road construction along these and unfavorable dips aggravate slope failure. Geo-morphologically areas forming highly dissected hills, moderate to steep slope (35° - 45°) and situated along river / tributaries are found more susceptible to slope instability.

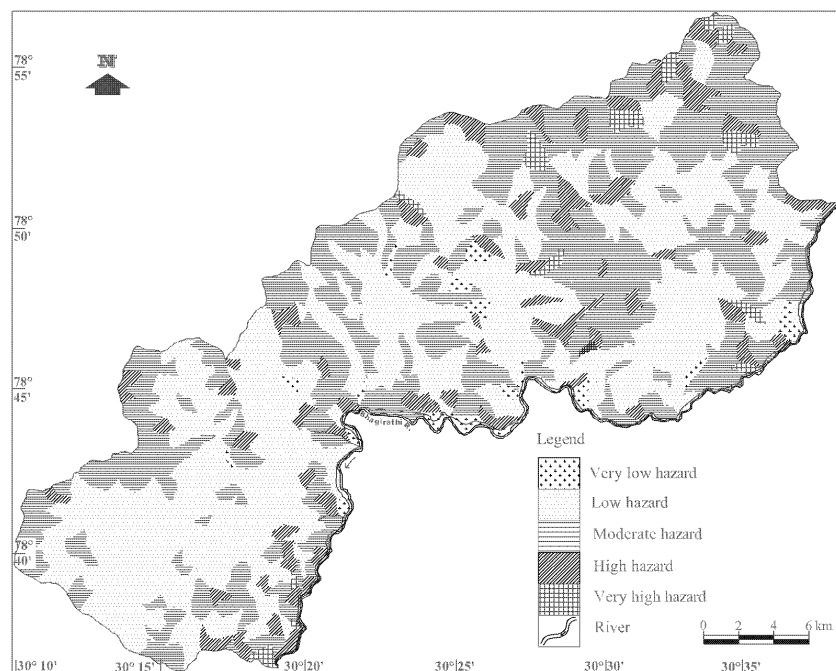


Fig. 09 Landslide Hazard Zonation (LHZ) map of the study area

Table 02 Landslide hazard evaluation factor (LHEF) rating scheme

Description of the factor	Category	Rating
(i) Lithology:		
Rock type-I	Basalt, quartzite, massive limestone & dolomite	0.2
	Granite, gabbro & dolerite	0.3
	Granite gneiss, Epidiorite & metavolcanics	0.4
Rock type-II	Well-cemented terrigenous sedimentary rocks (dominantly sandstone) with minor beds of claystone and gneissic rocks	1.3
	Poorly cemented terrigenous sedimentary rocks (dominantly sandstone) with minor clay shale beds.	1.0
Rock type-III	Well foliated gneiss	1.0
	Shale, slate, phyllite & other argillaceous rocks like siltstone, mudstone and claystone	1.2
	Schistose rocks	1.4
	Shale with inter-bedded clayey rocks (siltstone, mudstone etc.)	1.8
	Weathered shale & other argillaceous rocks, phyllite and schis-tose rocks	2.0

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

(ii) Structure:		Ratings
Distance of the facet from the structural feature	< 0.5 km	2.00
	0.5 to 1.0 km	1.50
	1.1 to 1.5 km	1.20
	1.6 to 2.0 km	1.0
	> 2.0 km	0.50
(iii) Slope:		
Escarpment or cliff	>45	2.00
Steep slope	36°-45°	1.70
Moderately steep slope	26°-35°	1.20
Gentle slope	15°-25°	0.80
Very gentle slope	<15 °	0.50
(iv) Relative relief:		
Very high	>3200 m	1.00
High	2601-3200 m	0.75
Medium	2001-2600 m	0.60
Low	1400-2000 m	0.45
Very low	<1400 m	0.30
(v) Landuse and land cover:		
Cultivated land & settlement		0.65
Dense forest / thickly vegetated area		0.80
Open mixed or sparsely vegetated area		1.50
Barren land		2.00
(vi) Hydrology:		
A. Surface drainage patterns:		
Dendritic to sub-dendritic		0.50
Gross trellis to local barbed		0.40
Sub-parallel		0.25
Sub rectangular		0.15
Gross radial		0.05
B. Drainage density:		
>7.5		0.50
5.1-7.5		0.40
2.6-5.0		0.25
1.0-2.5		0.10
<1.0		0.00

Table 3 Landslide hazard zonation of the area on the basis of total estimated hazard (TEHD)

Sl. No.	Zones	TEHD value
01.	Very low hazard (VLH)	<3.5
02.	Low hazard (LH)	3.5-5.0
03.	Moderate hazard (MH)	5.1-6.0
04.	High hazard (HH)	6.1-7.5
05.	Very high hazard (VHH)	>7.5

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

REFERENCES

- [1] Agarwal, N. C. and Kumar, G., "Geology of the Upper Bhagirathi and Yamuna valleys, Uttarkashi District, Kumaun Himalaya", Him. Geol., 3, 1-23, 1973.
- [2] Anbalagan, R., "Landslide hazard evaluation and zonation mapping in mountainous region", Engineering Geology, 32, 269-277, 1992.
- [3] Anbalagan, R., Sharma, L. and Tyagi, S., "Landslide hazard zonation (LHZ) mapping of a part of Doon valley, Garhwal Himalaya, India", In: Chowdhury, R.N. and Shivkumar, M. (Ed.), Environment Management, Geo-water and Engineering Aspects, Rotterdam, A.A. Balkema, 253-260, 1993.
- [4] Asthana, A.K.L. and Sah, M.P., "Landslides and cloudbursts in the Mandakini Basin of Garhwal Himalaya", Himalayan Geology, 28(2), 59-67, 2007
- [5] Gupta, R.P. and Joshi, B.C., "Landslide hazard zonation using the GIS approach - A case study from the Ramganga catchment, Himalayas" Engg. Geology, 28, 119-131, 1990.
- [6] Gupta, V. and Ahmed, I., "Geotechnical characteristics of Surabhi Resort Landslide in Mussoorie, Garhwal Himalaya, India" Himalayan Geology, 28(2), 21-32 pp, 2007.
- [7] Horton, R.E., "Erosional development stream and their drainage basins: Hydrological approach to quantitative morphology", Bull. Soc. Amer, 51, 275-375, 1945.
- [8] Leopold, L.B., Wolman, M.G. and Miller, J.P., "Fluvial processes in geomorphology", San Francisco and London, 1964.
- [9] Mathew, J., Jha, V.K. and Rawat, G.S., "Weights of evidence modeling for landslide hazard zonation mapping in part of Bhagirathi valley, Uttarakhand", Current Science, 92(5), 628-637, 2007.
- [10] Naithani, A.K., Kumar, D. and Prasad, C., "The catastrophic landslide of 16 July 2001 in Phata Byung area, Rudrapur District, Garhwal Himalaya, India", Current Science, 82(8), 921-923, 2002.
- [11] Pareta, K., Kumar, J., and Pareta, U., "Landslide hazard zonation using quantitative method in GIS. International Journal of geospatial engineering and Technology", Vol. 1, No. 1, pp. 1-9, 2012.
- [12] Pauchauri, A.K. and Pant, M., "Landslide hazard mapping based on geological attributes", Engg. Geol., 32, 81-100, 1992.
- [13] Paul, S.K., Bartarya, S.K., Rautela, P. and Mahajan, A.K., "Catastrophic mass movement of 1998 monsoons at Malpa in Kali Valley, Kumaun Himalaya (India)". Geomorphology, 35, 169-180, 2000.
- [14] Rautela, P. and Thakur, V.C., "Landslide hazard zonation in Kaliganga and Madhyamaheshwar valleys of Garhwal Himalaya: A GIS based approach" Himalayan Geology, 20(2), 1999, 31-44, 1999
- [15] Saha, A.K., Gupta, R.P. and Arora, M.K., "GIS based landslide hazard zonation in the Bhagirathi (Ganga) Valley, Himalaya" Int. J. Remote Sensing, 23(2), 357-369, 2002
- [16] Sah, M.P., Asthana, A.K.L. and Rawat, B.S., "Cloud burst of August 10, 2002 and related landslides and debris flows around Budha Kedar (Thati Kathur) in Balganga valley, District Tehri", Himalayan Geology, 24(2), 87-101, 2003.
- [17] Sarkar, S., Kanungo, D.P., and Patra, A.K., "Landslides in the Alaknanda Valley of Garhwal Himalaya", Quarterly Journal of Engineering Geology and Hydrogeology, 39, 79-82, 2005.
- [18] Seshagiri, D. N., and Badrinarayanan, B., "The Nilgiri landslides", GSI Misc Pub No. 57, 1982.
- [19] Takei, A., "Limitation methods of hazard zones in Japan", Kyoto Univ. Erosion Contr. Lab. Res., Bull., 1(7-25). 336, 1982