International Journal of Advanced Technology & Engineering Research (IJATER)
www.ijater.com

LHZ MAPPING OF THE AREA AROUND NAINITAL USING BIVAIRIATE STATISTICAL ANALYSIS

Peeyush Gupta and Swati Uniyal, Uttarakhand Space Application Centre, Dehradun,, Uttarakhand, India

Abstract

The hilly terrain is presently faces with the dilemma of maintaining a balance between development and environmental conservation. In the hills the land available for undertaking various developmental initiatives is severely limited and its utilization is further restricted by stringent environmental regulations as also the terrain characteristics. Most disasters have so far spared urban centres of Uttarakhand and Nainital is amongst a few that having recorded history of massive and repeated devastations. Even through habitation around the Naini Lake commenced only after 1841 the city has witnessed a number of devastating mass movements since 1867and the town has been devastated by slope movement in 1880, 1893, 1898, 1924, 1989, and 1998.Bivariate statistical index method has been utilized for demarcation of areas likely to witness slope instability. The input parameters used in this study area are quick bird imagery, world view-2 imagery, topographic map, soil map, geological map and ground observations. All the thematic layers (geology, slope, aspect, structure, drainage, lineament, geomorphology, road network and land use/land cover) have been correlated for assessment of landslide hazard zonation mapping on the basis of observations made therein. This paper describe the use of a GIS data base, compiled from existing digital map, satellite data, bivariate statistical analysis and field investigations to assessment of landslide hazard zonation of area around Nainital.

Key words- Landslide, GIS, landslide hazard zonation.

Introduction

The hilly terrain is presently faced with the dilemma of maintaining a balance between development and environmental conservation. In the hills the land available for undertaking various developmental initiatives is severely limited and its utilisation is further restricted by stringent environmental regulations as also the terrain characteristics.

Habitation in Nainital started only after 1841 and the township has been repeatedly devastated by mass movements since 1867. In the past a number of persons have investigated the causes of slope instability in the area and based upon the recommendation made from time to time many sincere efforts have been made from different quarters to set right the state of affairs and to ensure that incidences of mass movement in the area are averted. With the passage of time most mitigation measures have however been forgotten and age old practices discontinued. Unplanned, unregulated and rapid development initiatives on the vulnerable slopes around the Naini Lake have destabilised the delicate balance brought forth in the geo-environment of the area through the efforts of several decades. Absence of appropriate regulatory mechanism, non-compliance and disregard of the various safety related provisions together with non-appreciation and disrespect of the existing provisions have complicated the situation. This is reflected in enhanced pace of erosion, rapid siltation of the lake and dwindling lake level. The situation warrants well planned corrective actions backed by firm political will. Moreover these efforts have to be initiated before it is too late to react.

This study is largely based upon the observations made during the fieldwork and satellite imagery undertaken in the area around Nainital. The land use/land cover changes introduced in the area around the Naini Lake in the previous six years clearly reflect maintaining anthropogenic pressure on the vulnerable slopes.

Landslide is merely down slope movement of rock mass resting on the hill slopes or comprising the hill slopes under the influence of gravity. The mass likely to move down rest in the critical state of stability and requires a trigger to intimate the downhill movement. The instability of the rock mass as also the trigger is controlled by a number of parameters and their complex interrelationship. It is therefore important to precisely identify the various parameters likely to cause both slope instability and the down slope movement.

Study Area

In order to appropriately address the objectives of the study the area under present investigation was initially restricted to municipal limits of the Nainital town. It was however extended subsequently to include other areas that are presently undergoing active mass wastage and have the potential of threatening human interests still so; the Municipal limits have been major focus of the field investigations. However condition in other areas has also been taken note of. It covers the entire catchment of Naini lake as also the stretch along Balia nala upto Birbhatti together with Khurpatal.

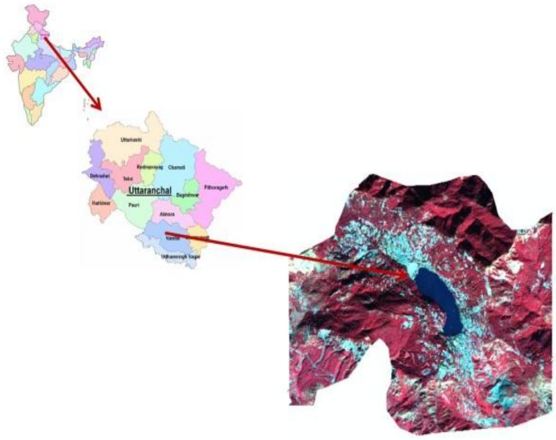


Figure 1. Study Area of the Nainital and around area

The Nainital region has tropical climate with pleasant summers and cold winters. Average summer temperature is around 250 C while the winter temperature might even drop to 00 C. During the winters the township often experiences snow fall. The precipitation during the monsoon season is generally heavy.

Method and Methodology

The study is based upon independent field observations. Nevertheless help has been taken from various other sources. Apart from the above, data from various other sources has also been captured and analysed. Toposheets of Survey of India (SOI) together with satellite imagery (Cartosat-1,Quick bird and World view-2) have been used for studying topographic characteristics, depicting land use / land cover characteristics and delineating specific land forms; particularly lineaments.

Geographical Information System (GIS) environment using Arc GIS 10 software has been used for mapping and analysing the data while ERDAS Imagine 10 has been used for digital image processing. Statistical index method (van Westen, 1997) has been utilized for slope instability studies whereby all the thematic layers (geology, slope, aspect, structure, lineament, geomorphology, road, drainage and land use / land cover) are correlated with the mass wastage map so as to decide upon the weight value of each and every parameter class of the individual thematic layers. The individual weight values are defined as the natural logarithm of the mass wastage density in the class divided by the mass wastage density in the entire map. Weighted map have thus been prepared for each theme layer and these have been integrated to prepare the hazard map. The results of the hazard map so prepared have also been correlated with the hazard map prepared in the field on the basis of observations made therein.

Geology and Structural Set up

Auden (1942) identified the area around Nainital as forming a prominent physiographic unit of kumaun Himalaya synclinal basin. Middlemiss (1890) was the first to study the geology of the area around Nainital and the carbonate rocks exposed in the area were identified by him as belonging to Krol. Holland (1897) gave a detailed account of the geology of the area. Subsequently Heim and Gansser (1939), Auden (1942), Nautiyal (1949), Hukku and Jaitley (1964), Valdiya (1988), Sharma (1998) and Jiang and others (2002) together with many others contributed towards better understanding of the stratigraphy and structure of the area.

Table 1. Lithostratigraphic succession

Group/Formation		**Lithology**
Siwalik Group		Sandstone and shale
		MBF/Krol Thrust
Tal Group		Carbaceous pyrite shale with subordinate grey stromatolitic limestone, purple shale and silt stone interbreded with fine grained brownish to muddy sandstone and mud stone
Karol Group		Unconformity
		Red purple and black shale, light yellowish, green-grey and light brown Calcareous slate, massive, grey and blue dolomite, limestone and argillaceous lime stone with grey wacke and purple and brown siltstone with subordinate slate of same colour and muddy fine grained sandstone
Baliana Group	Infra Karol Formation	Purple slate associate with ash grey and black shale with limonitic staining
	Balaini Formation	Conglomerate associated with purple slate, sand stone and dolomitic limestone. The pebble to cobble sized, rounded to sub rounded clasts of quartzite, slates and dolamites are embedded in the matrix of green to brownish sand stone or limestone.

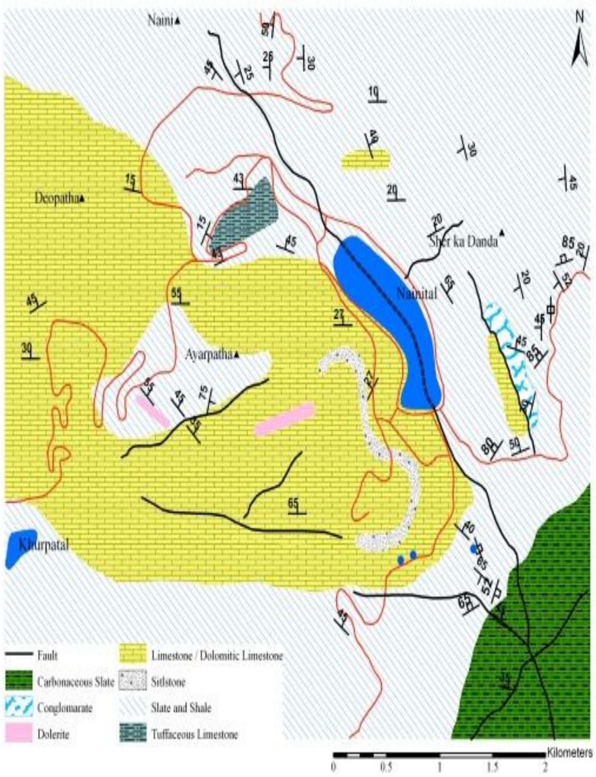


Figure 2. Geological map

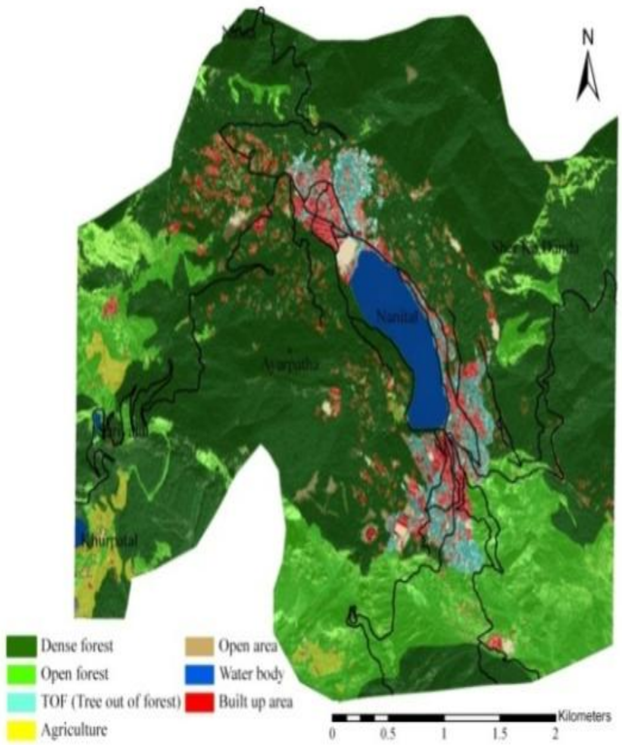


Figure 3. –Land use / Land cover map

Structural Set up

The rocks exposed in the area are observed to be highly jointed, fractured and sheared. Geomorphic and field observations show the presence of a number of shears that have rendered the area highly disturbed and prone to mass wastage.

Land use / land cover

Study of land use / land cover characteristics of an area and changes therein is universally accepted as being an important tool for depicting the nature of anthropogenic pressure on that area. These studies are increasingly being used for policy planning and effective management of the area.

For the purpose of present study high resolution multispectral 8 band World view-2 satellite imagery (50 cm resolution) of 24th December, 2010 has been used for delineating the present land use / land cover characteristics of the area around Nainital. The satellite data has been analyzed using the facilities available in arc GIS 10 and ERDAS Imagine 10 software.

The following seven land use / land cover classes (Viz. Dense forest, open forest, Tree out forest, water bodies, open area, agriculture, urban / built up) have been delineated after detailed study of the satellite data along with limited ground truth verification.

The present land use / land cover map shows the most area around the Naini lake has appreciable vegetation cover, significant portion of which is observed to fall under dense forest class. Most built up area around the lake is observed to extend between the northern end of the lake and Barah Pathar, the southern end of the lake and Krishnpur (mostly along right bank of Balia nala) as also in the vicinity of the vicinity of the Mall road that runs along the eastern fringe of the lake.

Table 2. Land use / land cover distribution based on the World view-2 multispectral satellite imagery of 24th December, 2010.

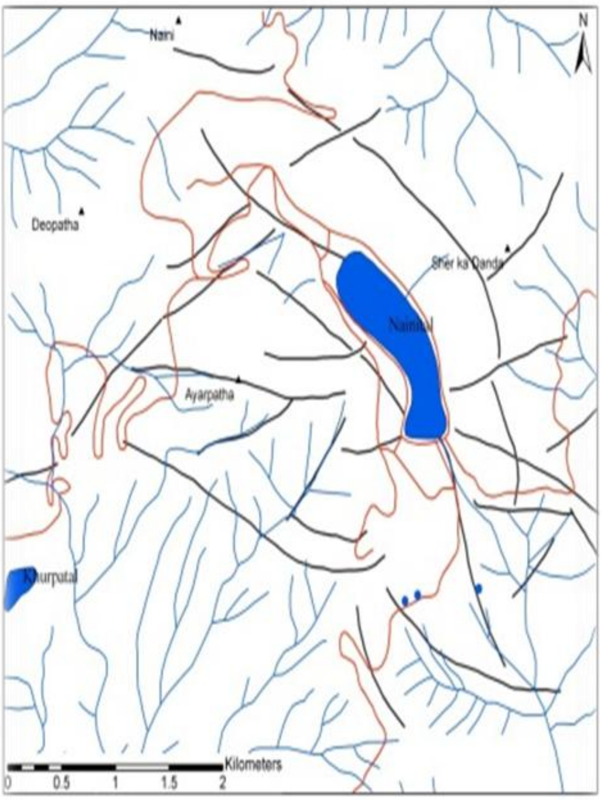
LULC Class	Area in Sq. m	% of the total
Built up area	9,26,982.07	005.29
Open area	2,35,067.78	001.34
Tree clad	7,04,877.81	004.02
Open forest	39,73,041.66	022.68
Dense forest	1,09,34,723.86	062.41
Agriculture	2,79,058.03	001.59
Water bodies	4,67,488.30	002.67
Total	1,75,21,239.51	100.00

Both soil development and soil moisture content are determined to a great extent by gradient and aspect of the slope, particularly in the hills. Excessive solar insolation on certain slope aspect is known to reduce soil moisture levels and even lead to break down of the soil nutrient cycle. Aspect of the slope also affects the distribution of atmospheric precipitation in the hills. Slope and aspect therefore have important bearing upon the distribution of vegetation in the hills.

Lineaments

The lineaments thus represent weak zones along which mass wastage is likely and therefor mapping of the lineaments was undertaken in the area. Both Survey of India toposheets and World view-2 satellite imageries were used for delineating the lineaments. It was encouraging to note that some of the lineaments correlate positively with the structural discontinuities even through the two does not exactly overlap each other.

Figure 4. Lineament map



Presence of some of the lineaments delineated from the satellite imagery has also been validated from geomorphic expressions observed in the field. These are tectonic lineaments and represent tectonic discontinuities.

It is important to note that the lineaments are observed to show a trend both parallel and transverse to the alignment of the Naini lake. Most lineaments show NE-SW to NNE-SSW and NW-SE trend. A significant lineaments showing NNW-SSE trend is observed to traverse through Hanumangarhi area while another one trends parallel to Balia nala.

Geomorphology

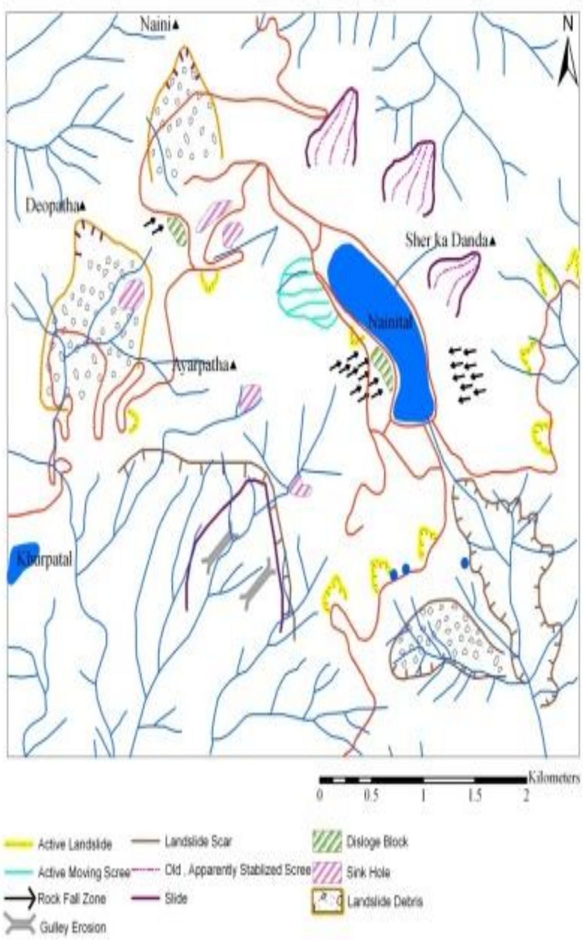


Figure 5. Geomorphology Map

Geomorphology encompasses the study of landforms along with various processes that shape these. It thus includes the study of a number of surface features and has an important bearing upon the mass wastage pattern of any region. Geomorphological processes or changes in the morphology of the ground are often documented by pre-existing maps, satellite imageries, survey reports of the previous landslides, as also from the record of the care full observations taken over time by the administration and local population.

Topography

Topography has an important bearing upon the geomorphic evolution of any area, particularly so in the hills. Apart from observations Survey of India (SOI) toposheet (53/O7, Survey year 1984-85) has been used for these studies.

The area around Nainital is observed to be dissected by several ridges and the ground elevations vary between 1694 to 2611.5 meters above mean sea level (msl). Naini peak (earlier known as China peak) with height of 2611.5 m above msl is the highest point of the area while sher ka danda, Deopatha and Ayarpatha respectively have altitude of 2402, 2435.1and 2352 m above msl. Naini and Khurpatal lakes respectively have elevations of 1935.5 and 1570m above msl. The area is prone to landslide due to high relief, presence of overburden and high precipitation.

Digital Elevation Model (DEM) and slope map of the area have been prepared using Cartosat 1 satellite image. Five different slope classes have been identified in the area depending on the variation in the surface slope amount. These areas as given below:

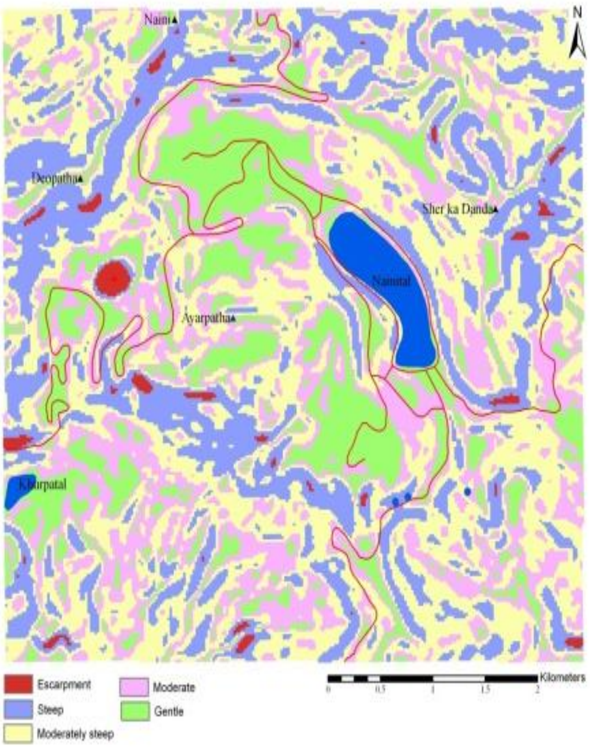


Figure 6. Slope map

Table 3. Slopes in degree and type

Sl No.	Slope in Degree	Slope Type
1	0˚-15˚	Gentle Slope
2	15˚-25˚	Moderate Slope
3	25˚-35˚	Moderately Steep Slope
4	35˚-50˚	Steep Slope
5	>50˚	Escarpment and cliffs

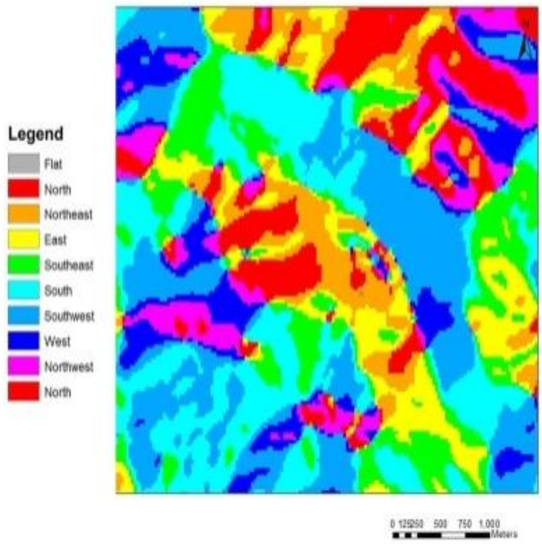


Figure 7. Slope aspect map

The surface slope in the area; particularly in the catchment of Naini lake is observed to be gentle to moderately steep. Large areas with gentle slope occur along the north western and south eastern extremities of the lake. Small areas running almost parallel to both eastern and western boundaries of the Naini lake, however Show steep slope.

Depending on the aspect of the hill slopes the surface receives differential solar insolation that is a major parameter deciding the moisture retention capacity of the soil. The rainfall pattern is also affected locally in the hills by this parameter. The aspect of the surface slope in the hills is thus a major factor affecting the pace of mass wastage as also the distribution of vegetal cover. Aspect of the hills slopes around the Naini Lake is delineated from the DEM. South-westerly aspect is observed to determine the area around the Naini lake.

Results

The surface slope in the area around the Naini lake is generally observed to be moderate to moderately steep. Many areas of Sher ka Danda,Naini peak, Golf course, Deopatha and Krishnapur however also show steep slopes and the Balia nala flowing roughly in south-easterly direction has carved out a deep valley due to intense shearing in the area.

Hazard Zonation

Extrapolating the basic geological premise that present is the key to the past (Principle of uniformitarianism) one is sure to come out with the conclusion that the same natural laws and processes that operate in the universe now, shall continue to operate in future as well and would apply everywhere in the universe. So based upon the delineation of different conditions that promote landslides in the present attempt has been made to demarcate areas with similar conditions and it is postulated that these areas have high probability of hosting landslide in future.

Statistical index method (Van Westen, 1997) has been utilised for demarcation of areas likely to witness slope instability. All the thematic layers (geology, slope, aspect, structure, drainage, lineament, geomorphology, road network, land use / land cover) have first been correlated with the mass wastage map so as to decide upon statistically the influence of individual themes on the occurrence of landslides in the area. Weight values of each and every parameter class of the individual thematic layers are thus worked out. The individual weight values are defined as the natural logarithm of the mass wastage density in the class divided by the mass wastage density in the entire map. Weighted maps have been prepared for each theme layer and subsequently integrated to prepare the hazard map. The hazard map so prepared categories the area in three hazard categories viz. high, medium, and low.

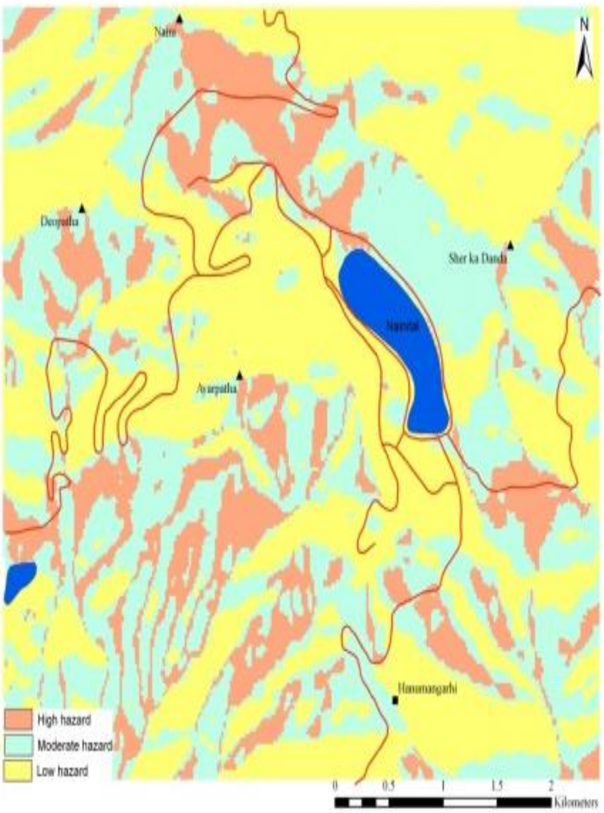


Figure 8. Landslide hazard map

The hazard map of the area around Nainital shows that large portion around the Naini lake falls in low and moderate hazard zones. Zone of high hazard is however observed to be spread out in a linear fashion running NW-SE between Naini peak and the northern fringe of the Naini lake. It may be noted that large portion of this area has been affected by mass movement in the past and the presence of fissile rocks in the area makes it susceptible to mass wastage. It also includes areas around Barah Pathar and Tiffin Top that are observed to be vulnerable to rock fall incidences.

The areas around Balia nala –Brewery, IDH colony and Golf course also fall in zone of high hazard. In these areas active mass wastage is observed to be taking place and in the absence of appropriate mitigative measures the pace of mass wastage might be enhanced.

The hazard map shows that most area to the east of the lake falls under moderate hazard zone while that to the west of the lake falls mostly under low hazard zone.

It is highly recommended that any developmental initiatives in the areas earmarked as falling under high and moderate hazard zones should necessarily be backed by appropriate geotechnical investigations. At the same time slope modification in these areas should not be allowed as it can lead to changes in ground water regime that might trigger down slope movement.

Conclusion

The sedimentary terrain requires carefully studies with regard to slope instability and for safe designing of the planned infrastructure. Generally low strength of the rock is primary feature of these areas and there is sharp deterioration in the strength of the rocks with increasing weathering intensity. Detailed investigations and in depth study of the engineering geological properties of the rocks is thus a must in these areas for all developmental initiatives. These help in the preparation of component design with appropriate techno economic considerations. Proper engineering design backed by geotechnical studies are essential, particularly when the structures have to be erected on vulnerable slopes and founded on the overburden / weathered and softer rock.

The qualitative assessment of the rock strength has been carried out for the area around Naini lake and the disposition of structural discontinuities together with slope, relative relief, land use / land cover and ground water condition has been taken note of with regard to the stability of the slopes.

References

[1] Coulson, A.L., 1928, Report on the hill sides of Nainital, Geological Survey of India.

[2] Sharma, V.K., 1996, A probabilistic approach of landslide zonation mapping in Garhwal Himalaya, 7th

International symposium on Landslide, Trondheim, Norway.

[3] Valdiya, K. S., 1979, An outline of the structural setup of the kumaun Himalaya, Journal of Geological Society of India, 20, 145,157.

[4] Van Westen, C. J., 1997, Statistical landslide hazard analysis, ILWIS application guide, International Institute of Aerospace Survey and Earth Sciences, Enschede, The Neatherlands, 73 84.

[5] Van Westen, C. J.,1997, Deterministic landslide hazard zonation , ILWIS application guide, International Institute of Aerospace Survey and Earth Sciences, Enschede, The Neatherlands, 85 98.

[6] Varnes, D.J., 1978, Slope movement types and processes, In special report 176, Landslides: Analysis and control (eds. R.L. Schuster and R.J. Krijek), TRB, National Research Council, Washington, D.C., 11-33.

Biographies

First A. Peeyush Gupta received the master degree in environmental science from CSJM University, Kanpur, UP, in 2007 and master of technology in remote sensing and GIS from SRM University, Chennai, TN, in 2009. Currently, he is project Scientist in Uttarakhand Space Application Centre, Dehradun, Uttarakhand. His research areas are mainly disaster management. Peeyush Gupta, Project Scientist may be reached at peeyushgis@gmail.com

Second B. Swati Uniyal received the master degree in environmental science from Gurukul Kangri University, Haridwar, UK, in 2007 and master of technology in remote sensing and GIS from IIRS, Dehradun, UK in 2009. Currently, she is research fellow in Uttarakhand Space Application Centre, Dehradun, Uttarakhand. Her research areas are mainly natural resource management. Swati Uniyal, Research Fellow may be reached at uniyal.swati@gmail.com

Acknowledgments

The authors are highly thankful to Dr. Piyoosh Rautela, Executive Director, DMMC, for the geological study materials and ground truthing data availability.