

## **Landslide Hazard Zonation Map of Nainital Region Using Remote Sensing and Geographical Information System (GIS)**

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**Abstract:** *The present work is mainly focused on the Landslide Hazard Zonation of the area in Nainital Region. Uttarakhand, India. 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. The input parameters used in this study area are satellite 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 and remote sensing data base, compiled from existing digital map, satellite data, and field investigations to assessment of landslide hazard zonation of area around Nainital. The resultant landslide hazard map has will prepare in three classes with different values. The value classes represented various zone with varying probable intensity of occurrence of hazards. The each class is based on the level of potential intensity of the hazard. These classes are as follows Low hazard, Medium hazard and High hazard.*

**Keywords—** Landslide, GIS & RS, Geomorphology, Geology, Lithology, Thematic maps, Landslide Hazard Zonation.

### **I. INTRODUCTION**

Landslides constitute one of the major natural catastrophes, which account for considerable loss of life and damage to communication routes, human settlements, agricultural and forestland. Most of the terrain in mountainous areas have been subjected to slope failures under the influence of variety of terrain factors and figured by events such as extreme rainfall or earthquake. About 15% land area i.e. about 0.49 million square kilometre of India country covering the entire Himalayan Mountain Chain, North-eastern parts, parts of the Eastern Ghats and the Western Ghats and Nilgiri Hills in the southern parts of India is highly susceptible to landslide.

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 utilization is further restricted by stringent environmental regulations as also the terrain characteristics.

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 year's 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.

Advancement in remote sensing technology will enable us to identify the finer features on the terrain and to create high resolution Digital Elevation Model (DEM). Most of the landslide modelling using GIS involves contour interval of 20 meters or 10 meters and thematic maps generated from remote sensing data of resolution 30 meters. This thesis evaluates the landslide hazard zonation using different kinds of spatial data (aerial photographs, satellite imagery) and also discusses the technological improvements in remote sensing sensors which greatly influence the accuracy of Landslide Hazard Zonation (LHZ) mapping.

Remote sensing and GIS plays a very important role in preparation of LHZ. Many thematic maps such as geology, geological structures, landforms, land use/land cover, slope, drainage, and aspect are needed for this purpose.

#### **1.1. AIMS AND OBJECTIVES**

The aim of the current study was to carry out a GIS based mapping exercise using conventional topographic maps, coupled with remote sensing data of the area and the available Geological, Hydrological and Geomorphological maps to prepare landslide hazard maps. Accordingly the objectives of the study are:

- To develop a GIS/RS database from secondary data on various aspects of the Nainital.
- To produce reliable and updated maps of topography, geology, hydrology, geomorphology, land use etc.
- Using above maps, identify landslide hazard prone areas.
- Using landslide hazard map, identify suitable areas for urban (mega construction sites, roads, bridges and building construction) and agriculture development.

### 1.2. STUDY AREA

In order to appropriately address the objectives of the study the area under present investigation is restricted to municipal limits of the Nainital town ( $29.388297^{\circ}$  /  $79.454242^{\circ}$ ). It covers the entire catchment of Naini Lake and the stretch along Balia nala up to Birbhatti together with Khurpatal.

The Nainital region has tropical climate with pleasant summers and cold winters. Average summer temperature is around  $25^{\circ}\text{C}$  while the winter temperature might even drop to  $0^{\circ}\text{C}$ . During the winters the township often experiences snow fall. The precipitation during the monsoon season is generally heavy.

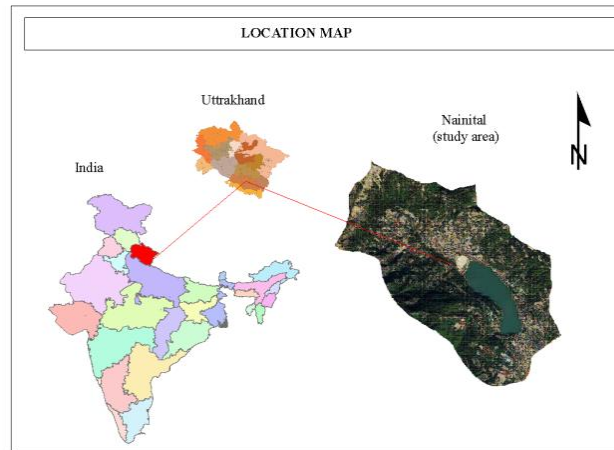


*Figure: 1 Location map*

## II. METHODOLOGY

With the advent of new techniques in analysis, hazard mapping is greatly assisted by analytical studies (e.g. GIS/RS) of different maps and satellite data, (Guzzetti et al. 2012). Consequently, this study includes an elaborate program of data collection and subsequent analysis using these new GIS/RS tools. In essence, the research primarily relied on secondary datasets that were acquired from various sources. These datasets included published and unpublished materials, internal reports, hand written notes, maps, drawings, tabulated and non-tabulated data and oral discussions. Some digital data was also acquired as USGS digital library to prepare a DEM for this study. The printed datasets were digitized and entered into computer routines suitable for GIS analysis.

Digitization included on screen digitization of various maps and their features. Subsequently, data were processed by using Arc map and arc scene software. The analysis techniques included overlaying, crossing, quarrying and Geo-referencing. Some of the techniques/methods are further explained in the following sections.

### 2.1. DATA COLLECTION

The subject study relied on secondary datasets that include different maps collected from various sources. These sources include Dem, USGS website (<https://www.usgs.gov/earth-explorer-ee>) and earth explorer, Geology department of M. G. Science Institute, Gujarat University, Ahmedabad, Gujarat and Geological Survey of India (GSI). These maps include a set of two topographic maps, a guide map of the study area which was used to make the base map on which the database was built further. One land use map, two geological maps, one hydrological map and a District Census Report (DCR) was used for the bulk of information in the database. Scanning, digitization and Geo-referencing: The said maps were first converted to digital data base for computer processing. The conversion mostly involved scanning at high resolution (300 dpi) with occasional manual data input. Since the GIS software used was Arc map and Arc catalog and Arc scene to digitized maps and converted the file into desired file format of the software. In GIS as the name applies, the data must have a geographic reference, so the scanned maps, digital data had to be geo-referenced. For this a main coordinate system was created to geo-refer the entire data sets. The same coordinate system was used for Georeferencing all of the other maps.

### 2.2. DATA DESCRIPTION AND COMPILATION

The basic data needs to prepare the hazard map is a set of variety of maps and raw information. The raw information is usually obtained through fieldwork, interviews and direct observations. Maps are the refined form of the raw data. These data sets need to be compiled, modified and/or re-tabulated to suit the needs of this study. Among the available maps some are maps of hydrology, geology, topography, land use etc. For GIS based synthesis these maps have to be first converted to the desired format and then desired information is extracted. In the following section various maps that have been used as 'raw data', to eventually prepare hazard maps, are discussed in detail.

### 2.3. GEOLOGY AND STRUCTURAL SET UP

The Krol group of rocks, comprising slates, marls, sandstones, limestone and dolomites with a few small dykes intrusive, is the dominant geological formation of the lake's surroundings. The lake is deduced to have been formed tectonically.

Balia Nala, which is the main stream feeding the lake is along a fault line and the subsequent streams align parallel to major joints and faults. 26 major drains feed the lake including the 3 perennial drains. The lake catchment has highly folded and faulted rocks due to poly phase deformation. Landslides are a frequent occurrence in the hill slopes surrounding the lake, which are steep. The slopes are highly vulnerable to landslides and mass movement due to various geological and human factors. Several landslides have occurred in the past (pictured) around the lake. Many settlements around the lake are located in landslide areas. 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.

#### **2.4. LITHOLOGICAL MAP**

The concern of the current study is to identifying the landslide hazard potentials in the study area and the level of vulnerabilities. To do this it is important to identify specific rock types that react differently in different hazards. For example, to determine the effects of an earthquake on settlements, it is important to know the type of the rocks on which building foundations are resting. Similarly, to determine the vulnerability of an area for a potential land sliding event, it is essential to know about the land use and population along with the slope, water content and rock type of that area. Thus in a hazard mapping exercise a lithological map is more useful instead of a geological map. To create the lithological map of the study area, two geological maps, covering the portions of the city were compiled together on same scale.

**Dolomite:** The dolomite of Upper Krol and Middle Krol Formation covers the moderate portion of the study area. Dolomite has massive bedding 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 color and muddy fine grained sandstone. Due to faulting it is highly sheared and fractured which is the reason for landslide during rainfall, therefore it should be totally avoided for construction purposes.

**Marlite:** Marlite Of Krol Formation covers the major portion of study area which is a calcium carbonate or mud or mudstone which contains variable amounts of clays and silt. The dominant carbonate mineral in most marls is calcite, but other carbonate minerals such as aragonite, dolomite, and siderite may be present. Marlite was originally an old term loosely applied to a variety of materials, most of which occur as loose. The areas covering these lithology are risky for mega constructions, however to some extent suitable for normal construction.

**Sandstone and shale:** Sandstone and Shale of Tal Group covers the moderate portion of study area which is fine to very fine grain, heavily jointed, fractured, sheared and soft to moderately hard. These are thinly bedded and laminated at certain places. These two have a sharp contact with each other. Shale is slough in nature. The areas covering this lithology are highly risky for constructions In addition, faults also exist in the study area, which is a threat in case of any landslide hazard.

**Slates:** Slates of Karol formation cover the narrow strip portion of study area. Slate, massive, grey and blue dolomite, limestone and argillaceous limestone with subordinate slate of same color. It is highly sheared and fractured so it is not well. Recommended for any construction. However by forestation the risk can be decreased and can be used for normal construction.

#### **2.5. 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.

#### **2.6. DIGITAL ELEVATION MODEL**

DEM's store the information of continuously varying variables e.g. elevation, groundwater depth, wind presser or soil thickness etc. (reference) There are three major techniques to create a Digital elevation model:

**Photogram metrical technique:** In this method stereoscopic aerial photographs or satellite images sample a large number of points, with X, Y and Z values. These points are picked through specialized remote sensing software and interpolated into a regular grid (raster).

**Point Interpolation Technique:** If the point data of elevation is available for an area then point interpolation can be used to generate a DEM. **Interpolation of Contour Lines Digitized from Existing Maps:** A tedious but precise method of generating a DEM is by digitization of contours from a topographic map and subsequent interpolation.

The DEM of the study area is acquired from (Figure 3) a 30m resolution Aster Image of north India by photogram metrical technique using GIS/Remote sensing software, the Arc GIS.

Following sections discusses the generation and further classification of slope and topography maps created from the DEM.

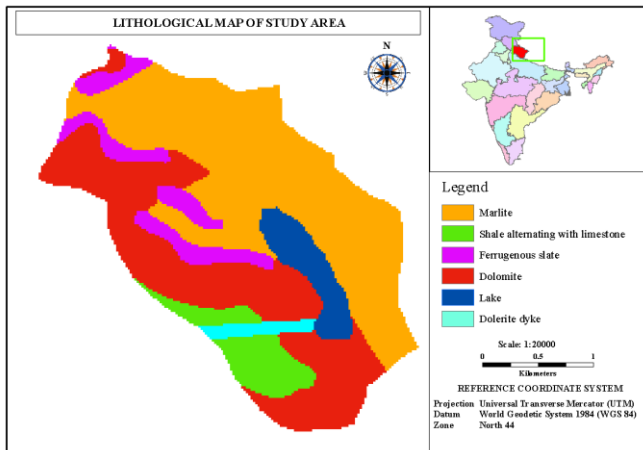


Figure: 2. Lithological map of study area {digitized from International Journal of Humanities & Social Studies (ISSN 2321 – 9203)}

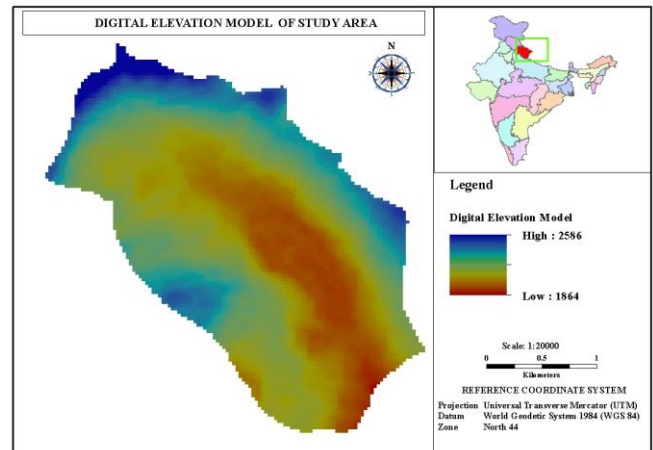


Figure: 3, Digital Elevation Model

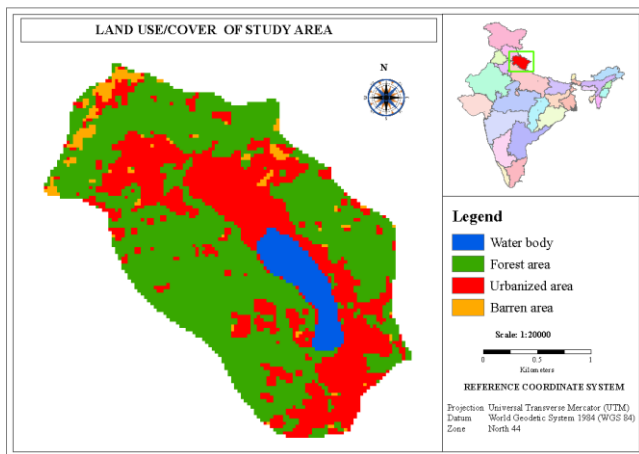


Figure: 4 Land use/cover map of study area

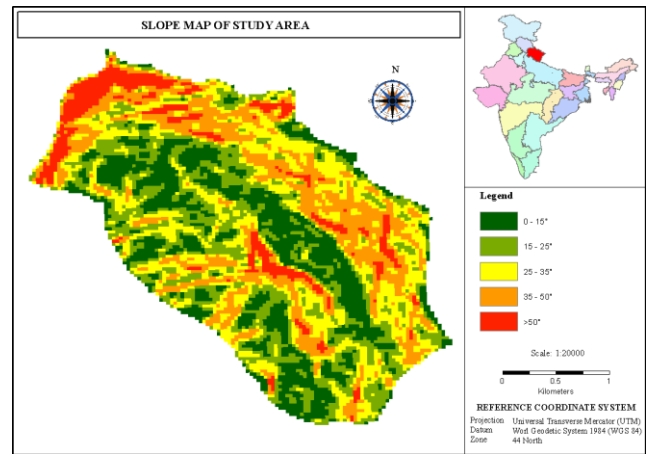


Figure: 5 Slope map of study area

| LULC Class     | Area in Sq. m | % of the total |
|----------------|---------------|----------------|
| Water bodies   | 354600        | 5.369310439    |
| Forest area    | 3892500       | 58.9397656     |
| Urbanized area | 2169900       | 32.85636413    |
| Barren area    | 187200        | 2.834559826    |
| Total          | 6604200       | 100            |

Table 1: Land use / land cover distribution based on the World view-2 multispectral satellite imagery of 22th Nov, 2016.

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

Table 2: Slopes in degree and type

## 2.7. LAND USE/COVER MAP

There were 4 classes in the existing land use map which were reclassified in broad divisions having 4 classes (Fig 4) according to the need of the study.

Urbanized area: This is the major class of the study area including residential land, government housing, offices or Utility facilities, commercial, army, graveyard, mosque shrine, etc.

Thickly forest: Forest is an important resource of the area which also covers a major portion of the land in the study area.

Moderately forest: The moderately forest cover a moderate portion of the study area.

Barren area: The barren area covers a small portion of the study area.

## 2.8. SLOPE

Digital Elevation Model (DEM) and slope map of the area have been prepared using Satellite imagery of Landsat 8 (USGS). Five different slope classes have been identified in the area de-pending on the variation in the surface slope amount. These areas as given in table 2. And (Fig 5)

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.

### **III. RESULTS**

The study area is highly prone to landslide hazard but a comprehensive landslide map of the area is not available. In order to analyse the vulnerability and risks to the inhabitants of the district a landslide map was prepared. For the preparation of landslide hazard map different sub-maps of various factors that influence the degree of landslide hazard were analysed using standard GIS commands. These sub-maps include:

1. Slope map
2. Hydrological map
3. Lithology map
4. Topography map
5. Land use/cover map

Each map was divided into classes with pre-assigned weight values. The weight values are assigned to give importance to features of the maps based on ground reality. An arbitrary range of weight value from 0 to 10 was selected. The smallest value is representing the highest importance of that class. As the weight value increases the importance of the particular class decreases thus a particular class in map having high weight value is of less importance from hazard perspective. Then the input data was recalculated with these weight values and accordingly weight maps were produced.

#### **3.1. SLOPE WEIGHT MAP**

The slope weight map thus generated, from an agricultural prospective, was based on three classes of the inclination (Table 3). The slope of 0-20 degree is considered to be as gentle slope good for agricultural and residential uses because at this slope the land remains stable and erosion is least. The hazard on these slopes. So the minimum weight value (i.e., high importance) of 3 was assigned to this class. With increase in slope the land starts losing its stability and the soil layer also gets thinner so there is a gradual change in the situation. In other words, the importance of land starts decreasing with the increase in slope. At slopes of 20-40 if the lithology is weak then there are more chances of mass movement because of increased gradient and precipitation and thus the weight value of 7 was assigned to this class. At 40 degrees and higher slopes, the land starts to lose its importance from all aspects except forest because at such slopes there is less or no soil cover, more rock outcrop, least water retaining capacity and increased erosion. Thus these slopes were assigned a value of 10 i.e., the least important from an agricultural perspective (Table 3 and Figure 6).

#### **3.2. LITHOLOGICAL WEIGHT MAP**

There are five main lithologies in the study area. On the basis of characteristics weight values were assigned to these lithologies. Dolomite in the area is highly crushed because of its presence in the disturbed zone along active fault area having the weight value of 18. While the lime stone in the area have the weight value of 3 which is the lowest weight value because it is relatively stable (Table 4. and Figure 7).

#### **3.3. HYDROLOGICAL WEIGHT MAP**

Presence of water generally decreases shear strength of slope forming material and thereby increasing the probability of slope failure. Since it is difficult to assess subsurface flow of groundwater quantitatively for entire face, visual estimation of field condition have been considered as an alternative measure to award the rating. For better representative groundwater condition assessment, it is advisable to make field data after monsoon. Maximum rating for this parameter is 20. The qualitative hydrological condition of facet is rated as (Table 5 and Figure: 8)

#### **3.4. LAND USE/LAND COVER WEIGHT MAP**

Change in land cover and land cover time greatly influences the slope stability and erosional activities. Land use change is depended on the population and their needs for survival that include deforestation, conversion of forest for agricultural purposes and unplanned or unprofessional slope cutting for infrastructure developments. To create the Land use/land cover weight map, first the district was divided into four classes. Different weight values were assigned to the different cover classes. The first classes ranging in forest area was assigned weight value of 5 indicating that the land use has great importance in the study area while the last class ranging barren area was assigned weight value of 18. (Table 6. and Figure 9)

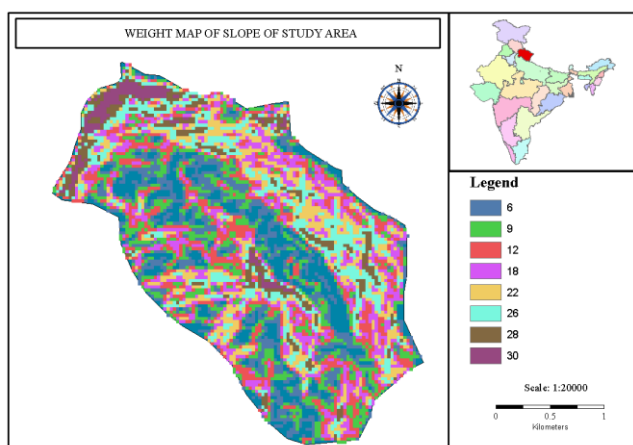


Figure 6: Weight map of slope of Nainital

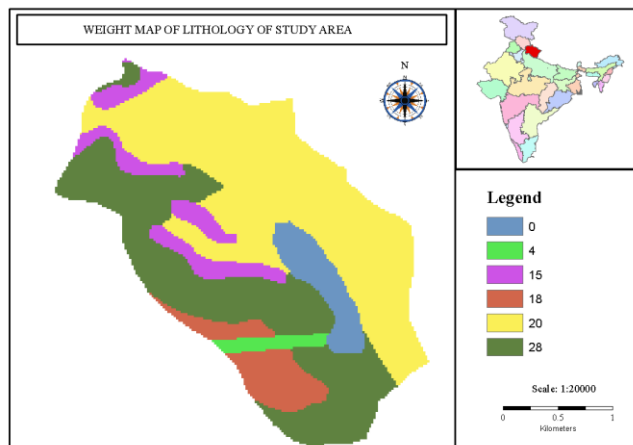


Figure 7: Weight map of Lithology

| Classes | Slope (degree) | Weight value |
|---------|----------------|--------------|
| 1       | 0°-15°         | 6            |
| 2       | 15°-25°        | 12           |
| 3       | 25°-35°        | 22           |
| 4       | 35°-50°        | 26           |
| 5       | >50°           | 30           |

Table: 3 Weight values of slope classes

| Lithology            | Value weight |
|----------------------|--------------|
| Marlite              | 20           |
| Dolomite             | 28           |
| Shale with limestone | 18           |
| Ferruginous slat     | 15           |
| Lake                 | 0            |

Table: 4 Weight values of lithology classes

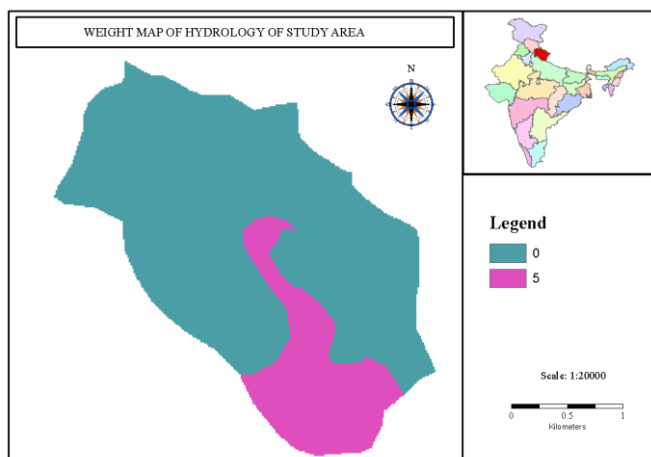


Figure 8: Weight map of hydrological

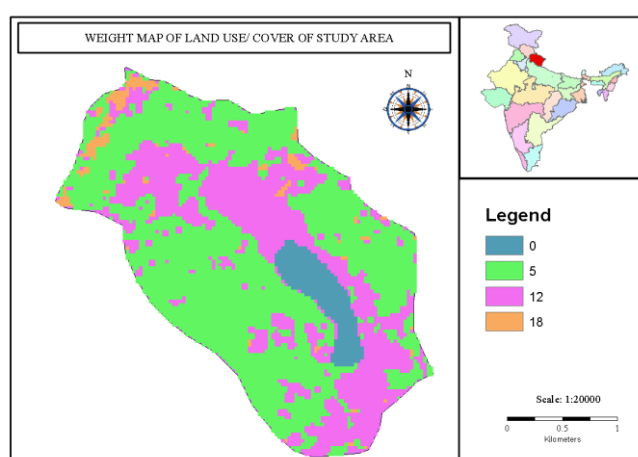


Figure: 9 Weight map of land use and land cover

| Hydrological condition | Weight value |
|------------------------|--------------|
| Flowing                | 20           |
| Dripping               | 16           |
| Wet                    | 10           |
| Damp                   | 5            |
| Dry                    | 0            |

Table 5: Weight values of hydrological condition

| Land use/cove  | Weight value |
|----------------|--------------|
| Barren area    | 18           |
| Forest area    | 5            |
| Urbanized area | 12           |
| Water body     | 0            |

Table 6: Weight values of land use and land cover

### 3.5. LANDSLIDE HAZARD ZONATION MAP

After assigning the weight values, all these weight maps were crossed to produce a landslide hazard map. The resultant landslide hazard map has three value classes represented various zone with varying probable intensity of occurrence of hazards. The each class is based on the level of potential intensity of the hazard. These classes are as follows (Figure 10)

- Low hazard
- Medium hazard
- High hazard

This classification was based on specific set of parameters that are akin to the ground realities. For example, the area having gentle fall in medium zone of hazard while the areas having weak lithology, steep slopes (mostly above 35 degree) and medium to high altitude fall in the category of high hazard zone.

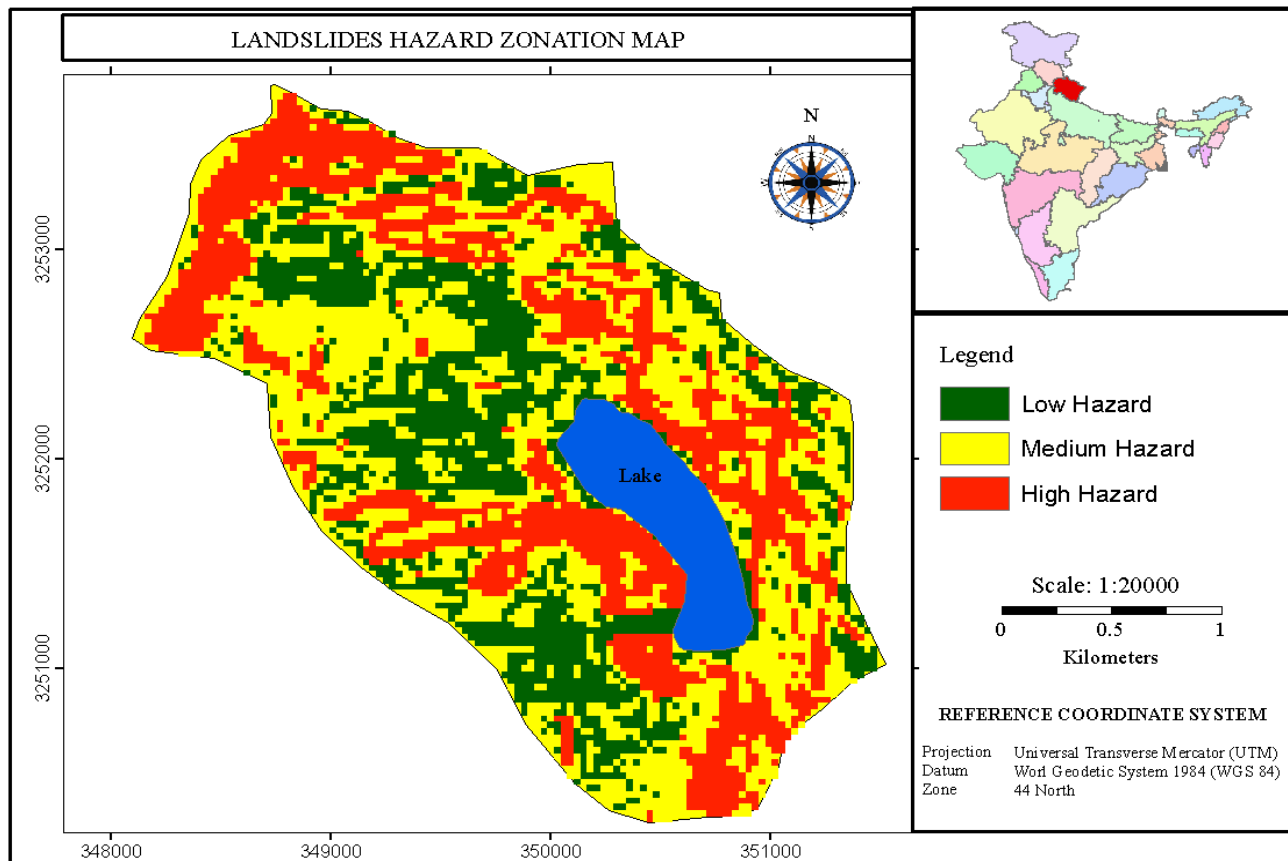


*Figure 10: Landslide Hazard Zonation Map of study area*

#### IV. DISCUSSION AND CONCLUSION

The sedimentary terrain requires carefully studies with regard to slope instability and for 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.

The landslide hazard map is divided into three main zones. The low hazard zone is calculated on the basis of suitability of main lithology which is alluvium, and little exposures of limestone. The slope is in between 0-20°. The land is dominantly under the use of built-up area. The medium hazard zone has 20-40° slopes, sandstone and shale, limestone and slates as the main lithologies. The north eastern part of the city falls under high hazard zone because many factors are conducive to the landslide hazards e.g. the area is characterized by high altitude and weak lithology (mostly dolomites with little slates and sandstone/shale). The precipitation in the area is also high (max 1800 mm) which is an additional factor to trigger the landslides on high slopes. Being in high hazard zone this land is less important for any developmental scheme but excellent candidate for forestation.

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