# LANDSLIDE HAZARD ZONATION OF TEHRI GARHWAL DISTRICT, UTTARAKHAND

## A DISSERTATION

Submitted in the partial fulfilment of the requirements for the award of the degree of

**MASTER OF TECHNOLOGY**

in

**DISASTER MITIGATION AND MANAGEMENT**

By

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Under the guidance of

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**MAY, 2019**

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## CANDIDATE’S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled **“Landslide Hazard Zonation of Tehri Garhwal District, Uttarakhand”** in partial fulfillment of the requirement for the award of degree of **Master of Technology** in **Disaster Mitigation And Management,** and submitted in the Centre of Excellence in Disaster Mitigation and Management of Indian Institute of Technology Roorkee, is a record of my own work carried out during a period from July 2018 up to November 2018 under the supervision of **Prof. B.K. Maheshwari,** Professor in the Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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## CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of our knowledge and belief.

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# ABSTRACT

As we know landslide is a natural phenomenon as well as extremely catastrophic natural hazard. It has a potential to damage any natural landscape, road, railway track, human life, and property. India has many landslide prone states wherein with each passing day, an increase in the population of the country has become a concern for landslide. A larger part of Uttarakhand is already affected by the landslide. This makes it compulsory for us to have a proactive approach for the prevention from landslide rather than waiting for a disaster to occur (NDMA, 2009).

To quantify the susceptibility of landslide, the Central Building Research Institute (CBRI), Roorkee uses Landslide Susceptibility Score (LSS), while Bureau of Indian Standards (BIS 14496 Part 2) for uses Landslide Hazard Evaluation Factor (LHEF). Once the problem of landslide is quantified, various decision regarding planning and mitigation can be made in a more logical and systematic manner.

In respect to that, a Landslide Inventory of the Tehri Garhwal District of Uttarakhand was created, along with it various causative factors such as slope, curvature, aspect, geology, drainage etc. were studied. The various methods employed for hazard zonation were studied thoroughly and Overlay method was employed to give weightage to the various causative factors. Finally GIS (Geographic Information System) was used for the analysis and display of the result.

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**Chapter 1**

# Introduction

## 1.1 Landslide

Landslide is a one form of ground failure, which impacts communities all across the world. Despite the advance in technology, losses increased to result in life losses, human suffering, billions of dollars of property and environmental humiliation. As day by day population is increasing and communities have become more complex, the cost of a landslide in terms of economics, societal, and ground failure is rising day by day. As a nation, it is required to understand the capabilities, identify the landslide hazards and also the strategies to apply mitigation measures. The development mechanism to provide a set of mitigation measure for a particular landslide according to its characteristics is needed in minimizing the infrastructural damage and other losses.

Landslide denotes downward and outward moment to slope forming material under the action of its own weight. It is the movement of rock, debris or the earth down the slope. They result from the failure of the material which makes up the hill slope and is driven by the gravity alone. These are also sometimes termed as a landslide or slope failure. The various types of landslides have been described in Table 1.1

**Table 1.1:** Type of Landslide (After  Varnes,1978)

| TYPE OF MOVEMENT | | TYPE OF MATERIAL | | |
|---|---|---|---|---|
| | | BEDROCK | ENGINEERING SOILS | |
| | | | Predominantly coarse | Predominantly fine |
| FALLS | | Rock fall | Debris fall | Earth fall |
| TOPPLES | | Rock topple | Debris topple | Earth topple |
| SLIDES | ROTATIONAL | Rock slide | Debris slide | Earth slide |
| | TRANSLATIONAL | | | |
| LATERAL SPREADS | | Rock spread | Debris spread | Earth spread |
| FLOWS | | Rock flow (deep creep) | Debris flow (soil creep) | Earth flow |
| COMPLEX | | Combination of two or more principal types of movement | | |

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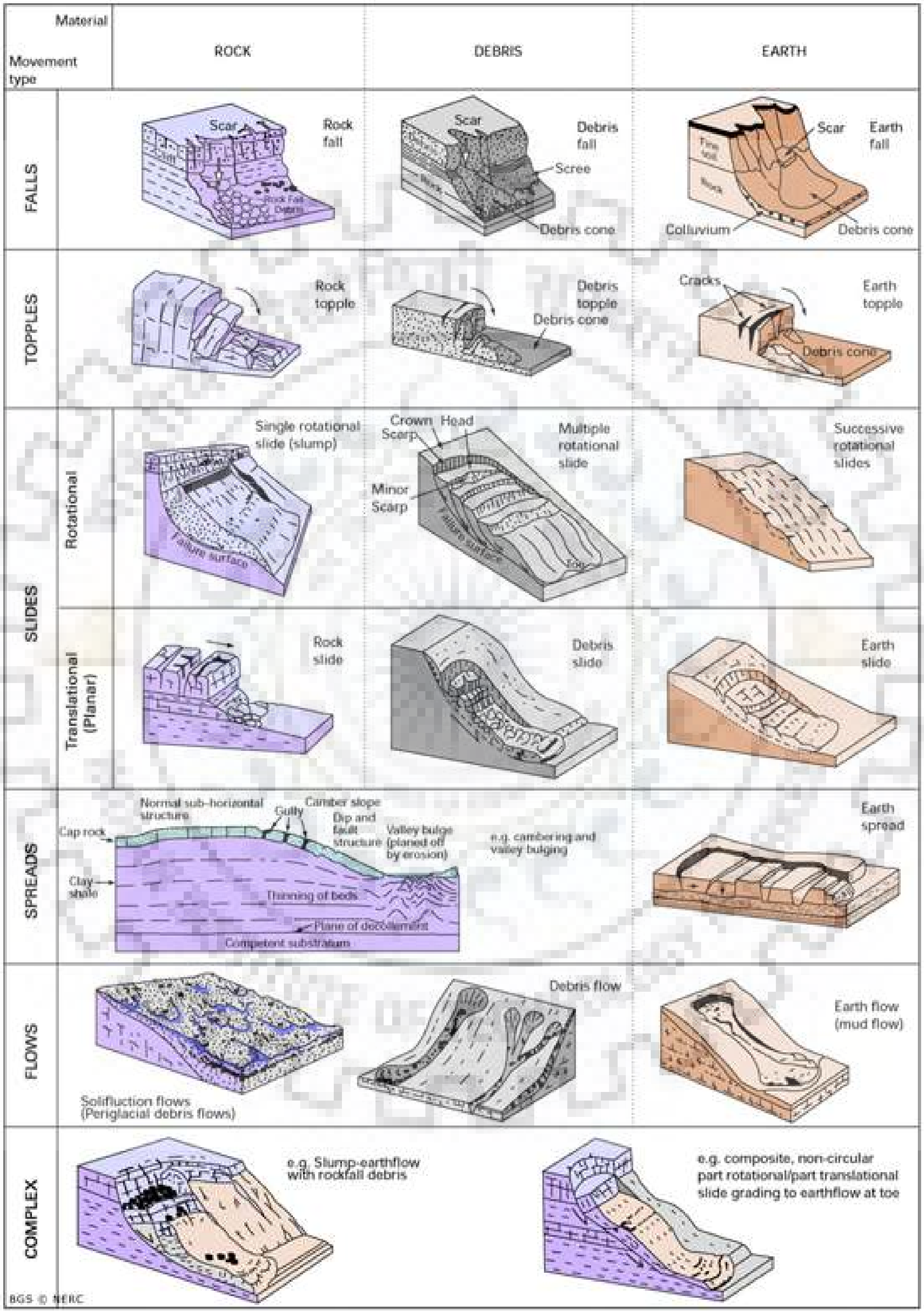
**Table 1.2:** Landslide moment classification (After Hungr et al., 2014)



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## 1.2 Causes of Landslide

Landslide causes can be classified into various headings. These may include natural and anthropogenic factors.

Natural causes included:

1. Rise of pore water pressure due to long duration of rainfall in the area saturating the sloping material
2. Vibration due to the earthquake,
3. Undercutting of cliffs and banks by waves or river erosion and
4. In some case volcanic eruption too.

Anthropogenic causes include:

1. Interference with or changes to natural drainage,
2. Unsustainable cutting of trees on the slope,
3. Modification of slope, overloading of slopes
4. Mining and quarrying activities,
5. Excavation and displacement of rocks.

It can also be classified under heading such as preparatory and triggering factors.

**Preparatory factors:** The preparatory factors, which make the slope susceptible to failure without actually initiating it and there by tending to place the slope in a marginally stable state, such as geology, structures, slope and aspect, relative relief, geomorphology, soil, drainage pattern, land use/land cover (Dai et al, 2002).

**Triggered factors:** The triggering factors shift the slope from a marginally stable to an unstable state and thereby initiating failure in an area of given susceptibility, such as heavy rainfall and earthquake (Wu and Siddle 1995).

As per the report by National Disaster Management Authority, the list of states in India which got affected due to landslide in the past few years is given in the Table 1.3

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**Table 1.3:** Landslide events in India

| Year | Event |
|---|---|
| **1948** | Guwahati landslide, Assam |
| **1968** | Darjeeling landslide, West Bengal |
| **1998** | Malpa landslide, Uttarakhand |
| **2000** | Mumbai landslide, Maharashtra |
| **2001** | Amboori landslide, Kerala |
| **2013** | Kedarnath landslide, Uttarakhand |
| **2014** | Malin landslide, Maharashtra |

## 1.3 Need for the Study

Due to the increasing frequency of water- related disasters that occur due to heavy rainstorm event and earthquakes, which are the triggering factors for any landslide, landslide hazard zonation is becoming day by day more important. According to the NDMA report, India is unique in its geographical, economic and social conditions, so it has a high degree of floods, droughts, hurricanes, tsunamis, earthquakes, urban floods, landslides, snowfalls and wildfires in its various region with varying degree of vulnerability due to the population distribution. Of the 36 provinces and territories in the country, 27 are vulnerable to disasters. Of the 7,516 km coastline, 5,700 km is susceptible to hurricanes and tsunamis, and 8% of cultivated land is susceptible to drought, mountainous areas are at risk of landslides and avalanches, 15% of which are landslides prone and 58.5% of the total landmass are prone to earthquakes (National Disaster Management Authority, 2016).

The major landslide prone areas in India include:

- Western Ghats and Konkan Hills (Tamil Nadu, Kerala, Karnataka, Goa and Maharashtra)
- Eastern Ghats (Araku region in Andhra Pradesh)
- North-East Himalayas (Darjeeling and Sikkim)
- North West Himalayas (Uttarakhand, Himachal Pradesh, Jammu and Kashmir)

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Uttarakhand falls in seismic zone 4 and zone5. Most of its GDP is due to tourism and travel industry. Presence of power projects increases the hazard exposure to a great extent.

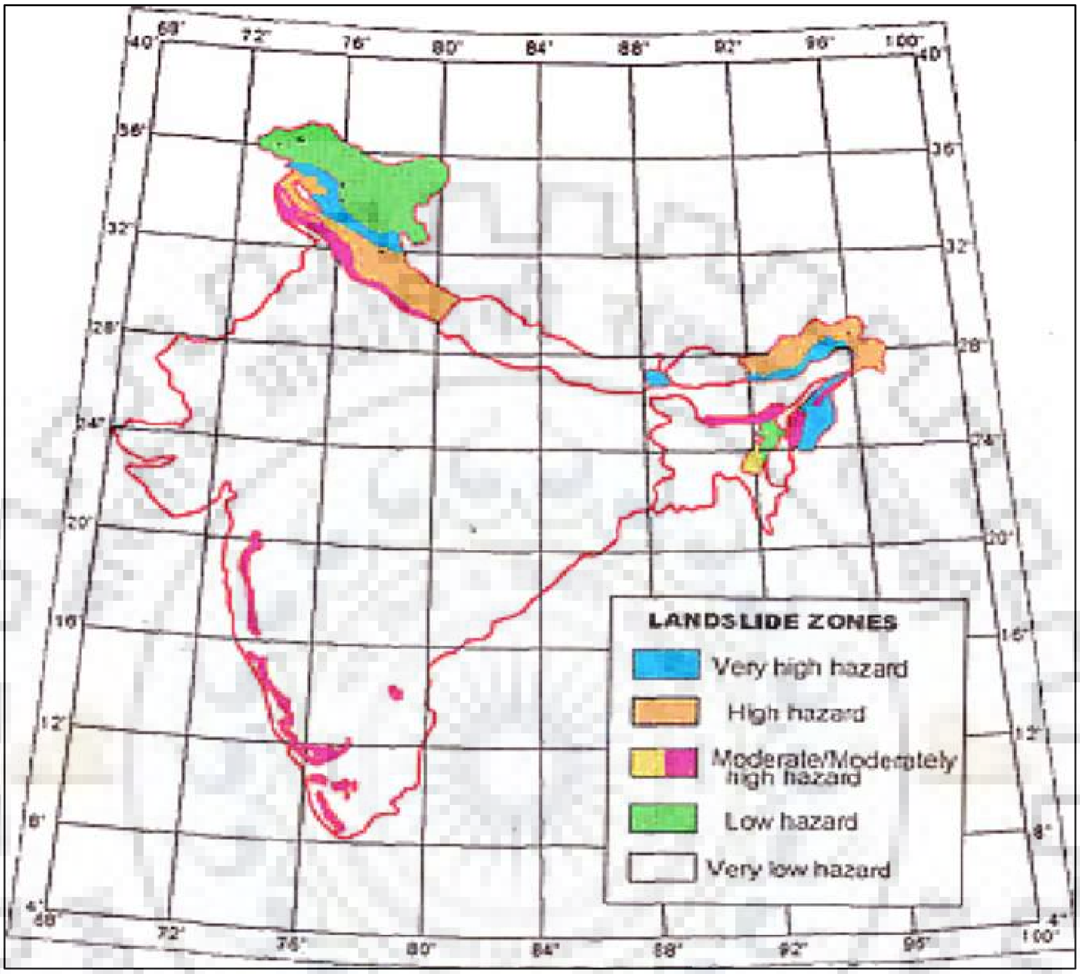


**Figure 1.1:** Landslide Zonation Map of India (Source: ndma.gov.in)

## 1.4 Aim and Objectives

The study aims at successfully generating the landslide hazard zonation map of Tehri Garhwal district, Uttarakhand.

The present study is taken up with the following objectives:

- To create landslide inventory of Tehri Garhwal, Uttarakhand
- Critical analysis of the various factors causing landslide in the area
- To determine the weightage of each individual factor
- Finally, to prepare a landslide hazard zonation map of the region.

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## 1.5 Methodology

The present chapter deals with the steps involved with the generation of landslide hazard zonation map of Tehri Garhwal, Uttarakhand. The steps of methodology are given below.

1. Collection of region specific data
2. Development of inventory of the study area
3. Stud0y of various techniques that helps in giving weightage to various causing factors of landslide.
4. Development of thematic layers of various causing factors
5. Application of one of the techniques to calculate weightage of various layers
6. Generation of landslide hazard zonation map of the area.

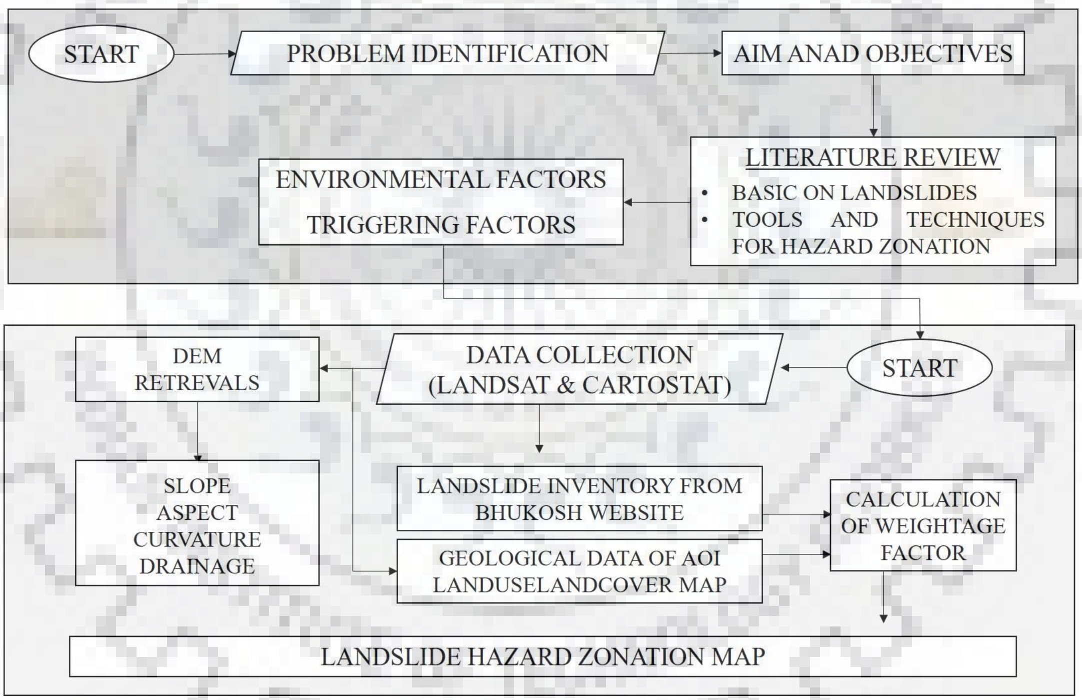


**Figure 1.2:** Analytical Frame Work

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## 1.6 Chapterization

- Chapter1 provides an overview about the landslide, causes of landslide, aim and objectives of the study, and brief about the recent landslides experienced in India.
- Chapter 2 provides the review of the study carried out by various researchers and suitable methods of landslide hazard zonation.
- Chapter 3 discusses in brief about the study area and data used for further study process.
- Chapter 4 is about an overview of the method to conduct hazard zonation. It explains the steps involved in hazard zonation.
- Chapter 5 provides the work to be done in future.

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Chapter 2

# Literature Review

## 2.1 Background

More than 3000 deaths have been reported in Uttarakhand alone, according to Government of India between the years 2001 – 2012 (data.gov.in). The Kedarnath floods and landslide of June 2013 resulted in perishing of more than 5000 individuals. In 2014, rainfall and landslide caused 17 people to be buried under the debris in Kath Bangla area of Dehradun city. In 2015, incessant rainfall in monsoon caused landslides in many districts of the state obstructing the smooth running vehicles on the roads and bringing the lifelines to a standstill. The damage to infrastructure is immense and each event of landslide pushes the development process out of the way affecting the social and economic condition of inhabitants, often leaving a trauma in the minds of victims.

According to a report by National Institute of Disaster Management titled "Uttarakhand Disaster – 2013", Uttarakhand region has experienced 11 earthquakes of magnitude greater than 6 during the last century. Landslide is manly common in two zones lying in close proximity of two major tectonic discontinuities:

- Main Boundary Thrust (MBT)
- Main Central Thrust (MCT)

Apart from that, according to Earthquake Hazard Zonation Map of India, out of 13 district of Uttarakhand Bageshwar, Chamoli, Pithoragarh, Rudraprayag, and Uttarkashi fall under seismic zone-V. Being so much seismically active, combination with fragile slope of young Himalayas renders the major cities established in valleys of these mountains highly prone to landslide caused devastation as earthquake is one of the major triggering factors for the genesis of landslide. In the surrounding regions, snow-covered higher altitudes of holy shrines of Hemkhund Sahib, Badrinath, Kedarnath, Gangotri and Yamunotri, the hazard of avalanche also become prominent. Similar is the scenario of most of the hilly states of the country. The fragile and young slopes of Himalayas are highly prone to landslide due to instability.

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Some spectacular events of tragedies are reported as Varnavat landslide, Uttarkashi District, Malpha landslide Pithoragarh district, Okhimath landslide in Chamoli district, UK and Paglajhora in Darjeeling district as well as Sikkim, Aizawl sports complex, Mizoram. These are some of the more recent examples of landslides. The problem therefore needs to be tackled for mitigation and management for which hazard zones have to be identified and specific slides to be stabilized and managed in addition to monitoring and early warning systems to be placed at selected sites.

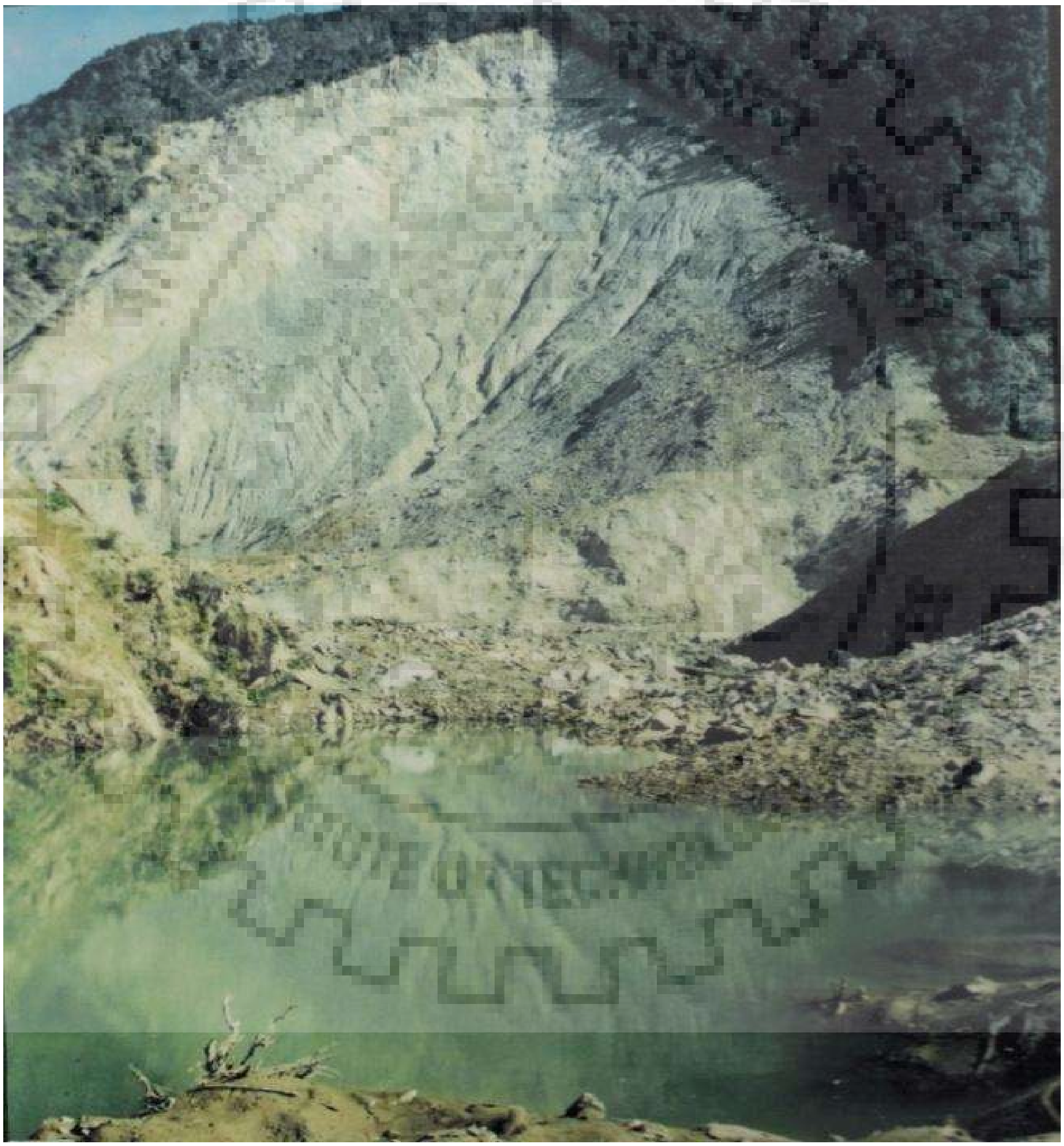

**Figure 2.1:** Okhimath Landslide which formed a Lake in Madhyamaheswerganga, Rudraprayag (Source: www.ndma.gov.in)

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## 2.2 NDMA Guidelines on Landslides

National Disaster Management Authority has taken a review on the disaster management mechanism which was done by the Government in June 2002 and the matter of disaster management was shifted from the Ministry of Agriculture to the Ministry of Home Affairs. Subsequently, the Geological Survey of India was declared the nodal agency for landslides by the Government in January 2004. The prevention of loss of life and property due to natural calamities is being viewed very seriously by the Government of India. As a part of this strategy, the Government decided to institute task forces for landslides. The work done by them is-

a) **Geological and Geotechnical Investigations:** To predict a landslide, people must find when and where it happens, as well as the degree and speed of action. To design landslide control measures, it is necessary to understand the type of landslide various possible methods of failure, and the site of the collapse of the earth, the limiting shear force of the boundary, the characteristics of the shear force and the Pore pressure as it changes during the movement. Geotechnical studies for mass movements such as rapid landslides, multi-level landslide, rock falls and landslides avalanches may have other investigation requirements.
b) **Landslide Risk Treatment**: Risk treatment needs to be the ultimate goal of risk management. It helps to mitigate the effects of natural disasters. Once the risk has been analyzed, the strategy is aimed at identifying solutions and approaches to responding to risks. The risk of an accident can be mitigated by five methods used individually or collectively as Restricting Development in Landslide Prone Areas, Codes for Excavation, Construction and Grading, Protecting Existing Developments, Monitoring, and Warning Systems.
c) **Landslide Monitoring and Forecasting**: Landslide monitoring is generally not practiced in our country. Therefore, few landslides get identified for monitoring and early warning. Methods used for monitoring landslides can be Surface Measurements of Landslide Activity and Sub-Surface Measurements of Landslide Activity.
d) **Hazard Zonation Mapping**: NDMA divided the whole country in different landslides zones for the easiness of the study.
e) **Awareness and Preparedness**: The knowledge and awareness level for the landslide has been quite low compared to other disasters like earthquakes, floods, and cyclones.

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State governments/ SDMA's of landslide affected areas in collaboration with the nodal agency and other key stakeholders are making special efforts to mobilize communities to carry out landslide mitigation efforts. Organizations and institutions like the GSI, NIDM, IITs, CDDM, and other knowledge-based institutions including some NGOs will be entrusted with the responsibility of preparing material for awareness generation campaigns pertaining to the landslide prone states in the country in a scheduled manner.

f) **Training, Documentation, Research, and Development**: The nodal ministry in consultation with the TAC and in collaboration with the MoM-GSI. The SDMAs/DDMAs, BRO, NGOs, central and state education departments, IITs, universities and other academic institutions with the help of technicians, administrators, and rescue workers who have been well trained and oriented to act during emergency situations contribute significantly in reducing the impact of disasters.

## 2.3 Landslide Hazard Zonation

"The division of the land in homogeneous areas or domains and their ranking according to degrees of actual / potential hazard caused by mass movement" (Varnes, 1984).

"Map showing the subdivision of the terrain in zones that are characterized by the probability of occurrence of landslides of a particular intensity. Landslide hazard maps should indicate both the zones where landslides may occur as well as the runout zones" (Bulletin of engineering geology and the environment).

"A landslide hazard zonation (LHZ) map divides the land surface into zones of varying degrees of stability, based on an estimated significance of causative factors in inducing instability"(Anbalagan, 1992).

The zonation studies are not perfectly idealized studies. It is marked with certain assumptions and as such they may not always give the full proof result. But the accuracy can certainly increase to a large extent when proper data is available. The following assumptions are the generalized in any zonation study:

1. Future failures are believed to occur in similar hydrological, geomorphologic and geological situations that have led to previous fail.

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2. In a particular study area, factors that cause landslides can be classified or weighted.

3. Once the conditions that promote instability can be identified, it is often possible to estimate their relative contributions and assign some quantitative spatial indicators.

**LHZ maps have several uses, some of which are listed below.**

- LHZ maps and identifies unstable areas of instability so that environmental remediation programs can be initiated with appropriate mitigation measures.
- These maps can help planners choose suitable locations for seating development planning, such as towns, dams, roads, and other developments.
- General purpose planning and land use planning.
- Prohibit new development in high risk areas.

## 2.4 Landslide Studies

A range of factors influencing soil collapse, such as hydrological parameters, geological parameters, artificial parameters and current landslides all contribute to destabilization the slope. It can be analyzed according to the frequency of landslides and can be digitally balanced accordingly. Since then, the study area has been divided into five unstable areas and the results have been checked. The frequency of landslides, the number of landslides per square kilometer, is calculated for each type on the coefficient map to determine the sensitivity of each landslide group. A numerical weightage group called LANDSLIDE SUSCEPTIBILITY INDEX was assigned to each group (Sarkar et al., 2017).

A comprehensive study for the identification of landslide susceptible zones using landslide frequency ratio and fuzzy logic on GIS platform was presented for Tehri reservoir rim region (Uttarakhand, India). Landslide and other causative factors layers were prepared by using temporal remote sensing data. Primary and secondary topographic attributes namely slope, aspect, relative relief, profile curvature, topographic wetness index, and stream power index, were derived from digital elevation model. Landslide frequency ratio technique was used to find relationship between factors and landslides. Further, fuzzy logic method was used to the summation of factors (causative factor) to map landslide susceptible zones. Normalized frequency ratio value was used for the fuzzy membership function and various fuzzy

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operators were considered for the preparation of landslide hazard index map (Kumar and Anbalagan, 2015).

To assess the earthquake induced landslide hazard in the considered region, a weighted multiclass index overlay method is used to categorize the landslide hazard class. A total 5 factors viz. slope angle, slope aspect, slope curvature, vegetation factors such as normalized difference vegetation index (NDVI) and seismicity of the area are used as input geo factors. CartoDEM and Landsat 4-5 TM imageries were considered as basic data sources for generating these layers. These factors along with landslide inventory are used to calculate ratings and weights required for the landslide hazard assessment. The rating maps were integrated in geographic information system (GIS) to obtain the qualitative landslide hazard map (Maheswari, n.d.).

Fuzzy member functions were calculated for all individual parameters such as active passive slope, convex slope, discharge density, anatomical slope, geology, topography, road density, road frequency , linear density, soil / soil coverage, drainage density, non-separable slope, geology, topography, linear density, frequency linear, very shallow slope, soil and water level. The application of various Fuzzy operators on these parameters leads to Hazard Zonation Map (Uvaraj and Neelakantan, 2018).

Potential risk of landslides was first assessed to assess the potential hazards of the study area. The work began with the identification of major landslides and possible landslides from Pipalkoti to Pandukeshwar in Alaknanda Valley. To assess the severity of landslides, they have determined the severity of landslides by estimating the size and velocity of landslides. The landslide areas are set on satellite imagery and the thickness of landslides is determined from field surveys. The rate of slide corresponding to different types is based on documented data available at that time. To quantify the intensity momentum was used which further was considered to classify into various hazard zones (Sarkar et al., 2017).

The impact of different layers of information on the occurrence of landslides has been identified and classified by the experts in various fields based on the landslide occurrence rate and then Fuzzy functions of ‘SUM’, ‘PRODUCTION PRODUCT & GAMA’, ‘AND’ or ‘OR’ were used to create the final zonation map. The model applied in this study operates under uncertain conditions, based on ambiguous logic theory to analyze inaccurate and

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somewhat vague variables, and is affected by probability factors and uncertainty properties suitable for phenomena such as landslide (Amirahmadi et al., 2017).

Qualitative methods of landslide hazard assessment are used with expert knowledge and experience. It is simplest method of landslide hazard zonation; it can be used directly in the field by geomorphologists or geologist. This method was mostly used during 1970 to 1980 (Aleotti et al, 1999). The risk of landslide is based on geological and topographical characteristics, and these are important attributes for regional scale mapping. Quantitative methods have been developed to overcome high levels of autonomy with a better assessment of expert judgment. This assessment involves identifying different variables, which are the main cause of instability in the early stages after these methods are implemented for stable regression and areas with similar conditions (Marrapu and Jakka, 2014).

Fuzzy membership values were chosen based on personal estimates of the relative importance of map class. Anabalgan proposed a numerical classification scheme based on an empirical approach to causes of land collapse, such as geology, steep scale, relative reduction, land use, soil cover, groundwater conditions, etc. Set the maximum rating to 2 or 1 for different subcategories of each cause factor. A revised classification scheme for the study area, since most of the elements introduced by Anabalgan essentially make the area's slope unstable and due to similarities between subtypes a modified rating scheme, was proposed.

There were three objective associated with GIS-based land-use suitability analysis: a critical overview(Malczewski 2004):

(i) To provide an introduction to geographical information technology along with an historical perspective on the evolving role of Geographic Information Systems (GIS) in planning
(ii) To overview relevant methods and techniques for GIS- based land-use suitability mapping and modeling, and
(iii) To identify the trends, challenges and prospects of GIS-based land-use suitability analysis

A numerical factor classification system has been developed to analyze spatial data in GIS. The resulting map of breakthrough capabilities identifies areas of different areas in four relative sensitivity categories: high, medium, low and very low. Sensitivity maps are

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validated by linking ground collapse frequencies to different types. This indicates that there is a close relationship with instability in the current area (Sarkar et al., 2004).

Based on an important analysis of available documents and the experience gained in many projects at different levels, the authors estimate the risk of landslides starting from the first division between qualitative methods and quantitative methods. Proposing classification method according to a scheme similar to those proposed by authors such as Carrara (1982, 1988), Hutchinson (1995), Leroi (1996) and Soeters and van Westen (1996). There is no single method recommended. In fact, only a few articles have reported studies comparing different methods (Carrara et al. 1990; Jennings et al., 1991). Moreover, the choice of a certain project approach depends heavily on economic concerns (cost benefit analysis, political comfort, etc.) as on the technical nature of the problem. (Aleotti and Chowdhury, 1999)

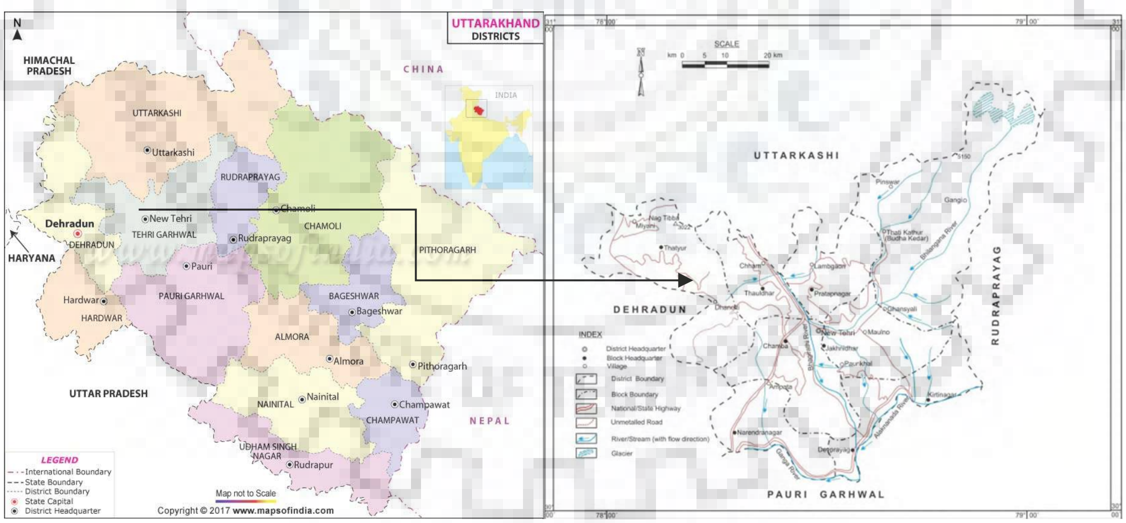
Chapter 3

# Study Area and Data Used

## 3.1 Location

District Tehri Garhwal (latitude30.3012° N and longitude 78.5661° E) extends from the Himalayas covered with snow from Thalia Sagar, Gunli and Gangutri to the hillside near Rishikesh. The division of the Bhagherati region divides the area into two parts, while the rivers Belangna, Alkandha, Ganga and Yamuna seem to touch the east and west. Tehri Garhwal is surrounded by Uttarkashi in the north, Pauri Garhwal in the south, Rudraprayag in the east and Dehradun in the west.

Tehri Garhwal is located on the southern flank of the Himalayan Center, one of the sacred hilly district of Uttaranchal province. Before creating the mythical universe, it was believed that Brahma meditated on this holy place. Moni Ki Reti and Tappovan in the province are penance places for munis and rishis in the ancient times. The mountainous area and lack of easy communication helped keep her culture almost intact. Tehri and Garhwal are two words collectively called Tehri Garhwal (tehri.nic.in).




A B

**Figure 3.1:** Location Map of the Study Area
A: Map of Uttarakhand (Source: mapsofindia.com)
B: Map of Tehri, Garwhal District

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**Table 3.1:** Geographical and Climatic Condition of Tehri Garhwal, Uttrakhand (Source: tehri.nic.in)

| | |
|---|---|
| **Area of the district** | 4,080 $km^2$ |
| **Latitude (New Tehri Town)** | 30.3012° N |
| **Longitude (New Tehri Town)** | 78.5661° E |
| **Average elevation** | 1,676m |
| **Average annual temperature** | 15.3 °C |
| **Average annual rainfall** | 1943mm |

## 3.2 Geological setting

Many geological studies have been carried out in the study area. The most important study was done by Valdiya (1980). The study area is a part of the physiographic entity called Lesser Himalaya and consisting of inner as well as outer Lesser Himalaya. The rock forms a part to the inner as well as the outer Lesser Himalaya. The inner Lesser Himalaya is depicted by the rocks of Rautgara Formation of Damtha Group, Deoban and Mandhali Formation of Tejam Group, and Berinag Formation of Jaunsar Group. On the other side, the rocks exposed in the outer Lesser Himalaya belong to the Chandpur and Nagthat Formation of Jaunsar Group and Blaini Formation of Mussoorie Group. The middle part of the area is represented by Chandpur Formation. Rocks formed out of Chandpur Formation are low grade meta morphosed lustrous phyllites and highly weathered quartzites. Western part has Nagthat rock formation. Rocks of Nagthat Formation are characterized by white, purple, and green coloured quartzites with subordinate intercalation of grey and olive green slates with silt-stones. In the eastern part of the study area, North Almora Thrust (NAT) separates Jaunsar Group of rocks from Damtha Group (Rautgara Formation). Rocks of Rautgara Formation consists  purple, pink, and white coloured, well jointed, medium grained quartzites, minor

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slates and metavolcanics. Deoban Formation is exposed in eastern and north eastern parts. It is present between Rautgara Formation and Berinag Formation in the south. Deoban Formation consists of fine grained dolomitic limestone with minor phyllitic intercalations. These rocks are mainly found at the higher ridges. Rocks of Berinag Formations are present in the eastern part of the area. It is separated by Berinag thrust at its base. These rocks are mostly quartzites. Bliani Formations are found in the western part of the study area. This formation comprises quartzites, slates and carbonate rocks. Major as well as minor structures have been observed in the study area. The major structural features include the NAT, exposed in the north- eastern region. The south-easterly dipping NAT separates the Chandpur phyllites from the Rautgara Formation towards north. A number of antiforms and synforms in the central and south-western regions, which together form a part of the Mussoorie syncline (Valdiya, 1980) have been observed.

## 3.3 Data Used

The analysis depends upon the data in hand. For this study, data of varying attribute such as geological, geomorphologic, remote sensing were layered together. These layers were then analyzed on GIS platform using Overlay analysis.

### 3.3.1 Landslide Inventory

In India the major problem that lies in the field of landslide is the lack of knowledge of dataset creation about previous landslide. National Disaster Management Authority has taken a review on the disaster management mechanism which was done by the Government in June 2002 and the matter of disaster management was shifted from the Ministry of Agriculture to the Ministry of Home Affairs. Subsequently, the Geological Survey of India was declared the nodal agency for landslides by the Government in January 2004. Geological survey of India is now managing and updating portal for such kind of information. New mobile applications are being launched by National Disaster Management Authority of India.

Proper analysis of any landslide includes not only the geographical coordinate of it, but also various other parameters such as triggering factor, area occupied, volume of the mass movement, underlying geology etc.

Therefore, such information of all the landslides in the study area was collected from the website managed by the Geological Survey of India. The web link is www.bhukosh.gov.in.

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- Inventory was created from the website managed by Geological Survey of India (Source: bhukosh.gov.in)
- More than 600 landslides in the region were analysed. The parameters used for inventory creation included:
    - Coordinate
    - Area
    - Volume
    - Length
    - Width
    - Height
    - Triggering factor
    - Geology

### 3.3.2 DEM Data

Digital Elevation Model raw data was obtained from BHUVAN website and has been used to generate slope, aspect, curvature, elevation and drainage map of the district. For the analysis, CARTOSAT-DEM data having 30m resolution is used (Accessed date: 18/11/2018). The Cartosat-1 Digital Elevation Model (CartoDEM) is a National DEM developed by the Indian Space Research Organization (ISRO).

Primary topographic attribute such as slope, aspect, curvature and relief were obtained as DEM derivatives. These layers were created by spatial analyst tool in ArcGIS.

ARC HYDRO toolset was used to obtain drainage map of the study area from the DEM file.

### 3.3.3 Geological Data

Geological, geomorphologic parameters play a vital role in the analysis of landslides. Therefore, a geo-formation map and lineament map was prepared and was validated from the maps prepared by Geological Survey of India. The data was available on the platform managed by the same. The URL link is www.bhukosh.gov.in. The major formations were Chandpur Formation followed by Nagthat - Berinag Formation and Chakrata Formation.

The lithology was observed to be of three different types in the region as:

- Sedimentary And Metamorphic Rocks

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- Hypabyssal And Volcanic Rocks
- Igneous Plutonic Acid Rock

### 3.3.4 Land use and Land cover Data

LULC maps were prepared using data from the Landsat 8 satellite. These data were obtained from the portal managed by United States Geological Survey. The web link for downloading the data is: https://earthexplorer.usgs.gov/. Supervised classification was done into five classes as:

- Snow
- Water
- Vegetation
- Barren
- Built up

### 3.2.5 Road Map

The road map of the study area was obtained from the following websites:

- www.bhukosh.gov.in
- www.diva-gis.org

These maps were then validated using Google Earth portal. Three categories were considered for the analysis. These were Primary road, Secondary road and Trunk road.

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Chapter 4

# Analysis

## 4.1 General

Cosine Amplitude function was used to assign the weightage of each class. The formula for the same is given by eq.4.1.

$$CA = \frac{N_{CELL}(L_i)}{\sqrt{N_{CELL}(C_i) * N_{CELL}(L)}} \quad \textbf{(eq. 4.1)}$$

Where $N_{cell}(L_i)$ is the number of landslide cells in the category i, $N_{cell}(C_i)$ is the total number of cells in the category i, $N_{cell}(L)$ is total number of landslide cells and $N_{cell}(C)$is the total number of cells. In this case, the membership value is calculated as ratio between number of landslide cells in the category and the square root of its product with the total number of land-slide pixels in the dataset. Unlike FR the output values do not have to be normalized because they already fall in interval [0, 1].

## 4.2 Raster Overlay

For the input in GIS platform these values of various classes were scaled down to values in between 0 to 9. Then the various raster files were reclassified according to the same corresponding scaled value. And the raster overlay analysis was performed.

In general, there are two methods for performing overlay analysis—feature overlay (overlaying points, lines, or polygons) and raster overlay. Some types of overlay analysis lend themselves to one or the other of these methods. Overlay analysis to find locations meeting certain criteria is often best done using raster overlay (although you can do it with feature data). Of course, this also depends on whether your data is already stored as features or raster. It may be worthwhile to convert the data from one format to the other to perform the analysis.

In raster overlay, each cell of each layer references the same geographic location. That makes it well suited to combining characteristics for numerous layers into a single layer. Usually,

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numeric values are assigned to each characteristic, allowing you to mathematically combine the layers and assign a new value to each cell in the output layer.

## 4.3 Development of Thematic Layers

Although, there are no standard guidelines for selecting landslide controlling factors which affect landslide occurrence. In this study 10 layers have been prepared for the study purpose.

### 4.3.1 Landslide Inventory Map

A total number of 610 landslides were taken to prepare the landslide inventory. This landslide was encountered within an area of 4,080 $km^{2,}$ in which about 544613190 cubic meter of material was displaced. High degree of slope and active faulting form high hazard zones in the area, which is responsible for slope failure. A landslide inventory map of Tehri Garhwal district indicating the location of landslides is shown in Fig. 4.1

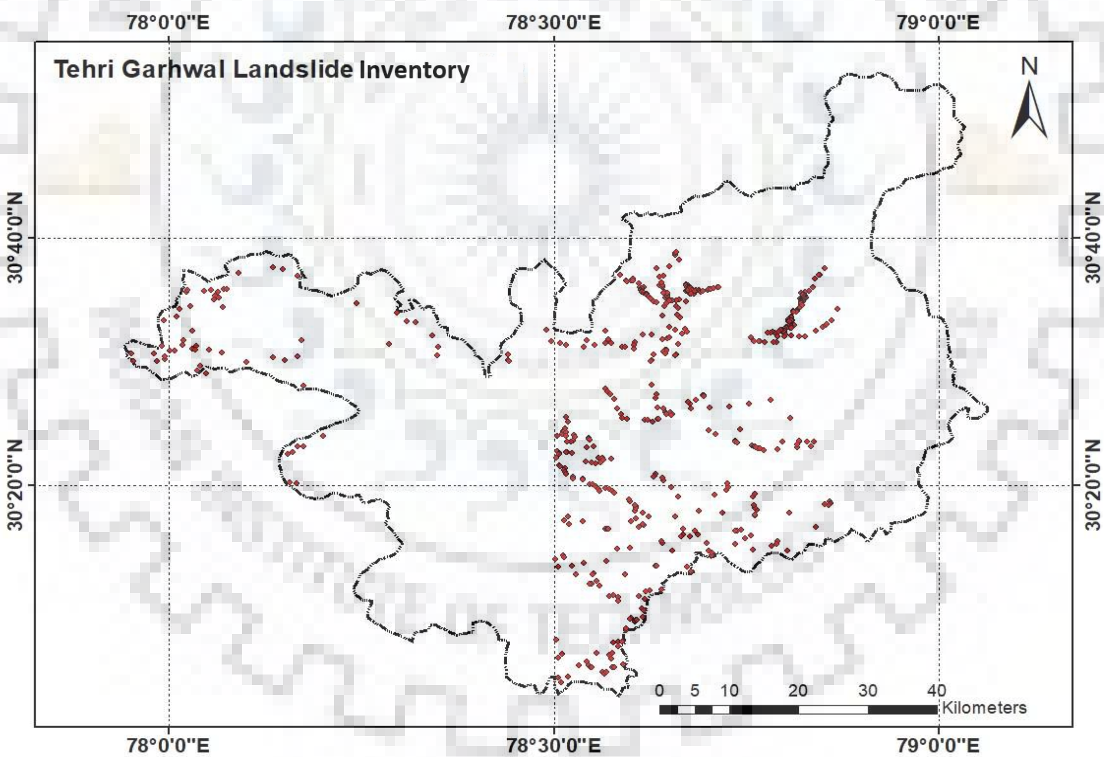


**Figure 4.1:** Landslide Inventory Map

### 4.3.2 Slope Map of the study area

Slope usually represents the change in the cell value of the Digital Elevation Model. Usually the frequency of a landslide increases as the slope increases until a maximum value is reached after which it decreases. As slope increases the values of gravity influenced shear stress in soil also increases. When working on a site specific problem of a very large scale landslide problems tend to converge into slope stability problems. Slope map of the area is shown in the figure 4.2.

In the present study, slope has been divided into five classes as: <10 0, 10-200, 20-300, 30-400, >400. The frequencies of the landslide were seen to be the maximum in the range of 30-400 class with 175 landslides encountering in it. The details are shown in the table 4.1.

**Table 4.1:** Slope Table

| SLOPE | LANDSLIDE INCIDENCES | COSINE AMPLITUDE VALUES | LANDSLIDE AREA(metre$^2$) |
|---|---|---|---|
| $<10^0$ | 18 | 0.000860787 | 39529 |
| $10\text{-}20^0$ | 51 | 0.001848413 | 145742 |
| $20\text{-}30^0$ | 113 | 0.004150724 | 428310 |
| $30\text{-}40^0$ | 175 | 0.009058596 | 922380 |
| $>40^0$ | 66 | 0.006050559 | 497419 |

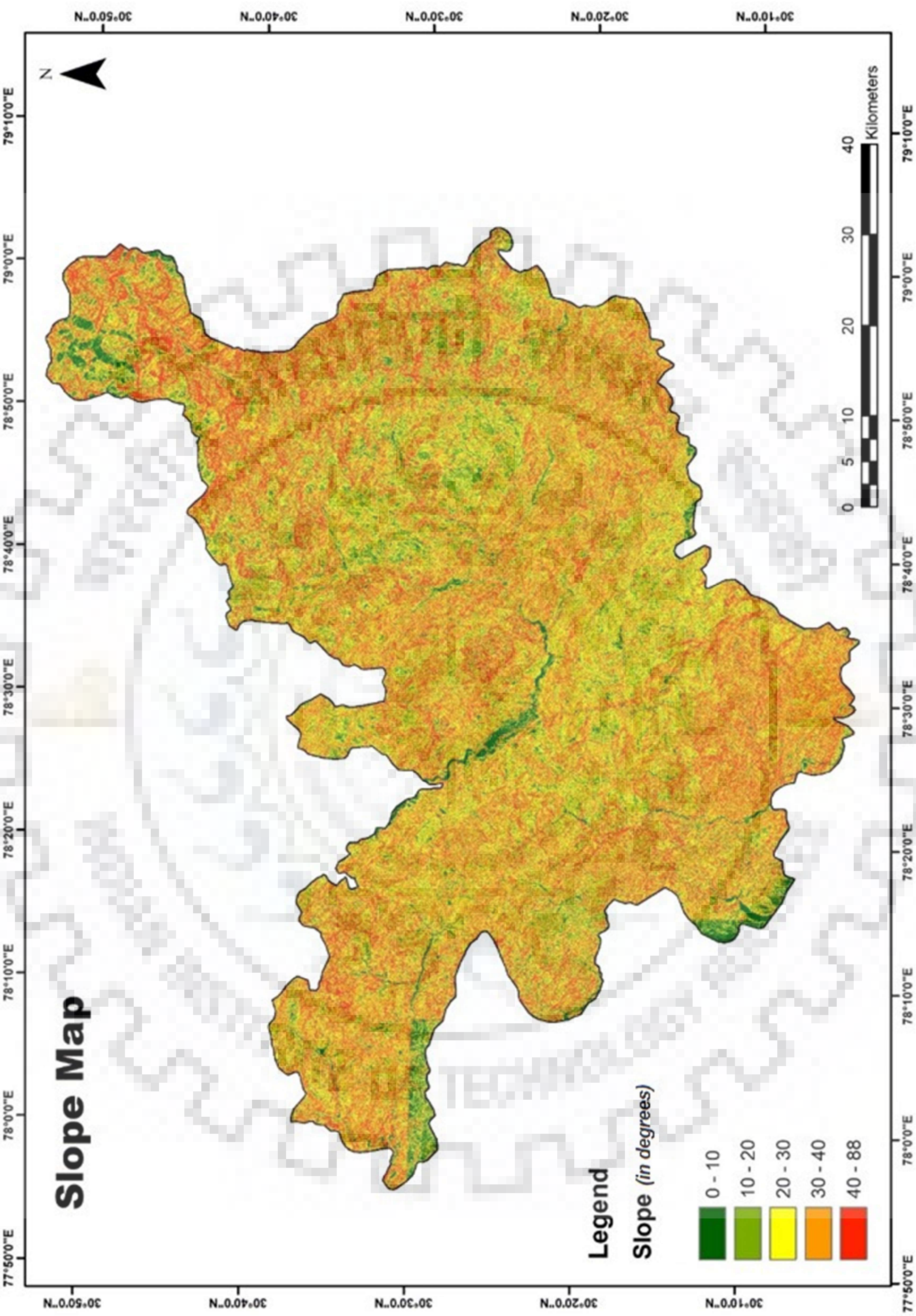


**Figure 4.2:** Tehri Garhwal Slope Map

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### 4.3.3 Aspect Map of the Area

Slope aspect is defined as the direction of the slope. Moisture retention capacity and vegetation are generally affected by the slope direction. This may affect the soil strength and therefore susceptibility to landslides. The effect of slope aspect can be seen as the south facing slopes are generally warm, and thickly forested, while the north facing slopes are dry and cold. As such majority of the landslides took place on the south facing slopes as shown in the figure 4.3. In the present study aspect have been classified into nine classes as: Flat, Northeast, East, Southeast, South, Southwest, West, Northwest, and North. The details about the landslide incidences in various classes are given in the table 4.2.

**Table 4.2**: Aspect Table

| SLOPE | LANDSLIDE INCIDENCES | COSINE AMPITUDE VALUES | LANDSLIDE AREA(metre$^2$) |
|---|---|---|---|
| Flat | 0 | 0 | 0 |
| North | 9 | 0.000564109 | 13325 |
| Northeast | 31 | 0.002621809 | 86192 |
| East | 52 | 0.004631109 | 156327 |
| Southeast | 70 | 0.011822295 | 396412 |
| South | 71 | 0.010898747 | 379640 |
| Southwest | 68 | 0.012730323 | 439170 |
| West | 74 | 0.012163007 | 418711 |
| Northwest | 3 | 0.003939037 | 125788 |
| North | 12 | 0.000814131 | 18315 |

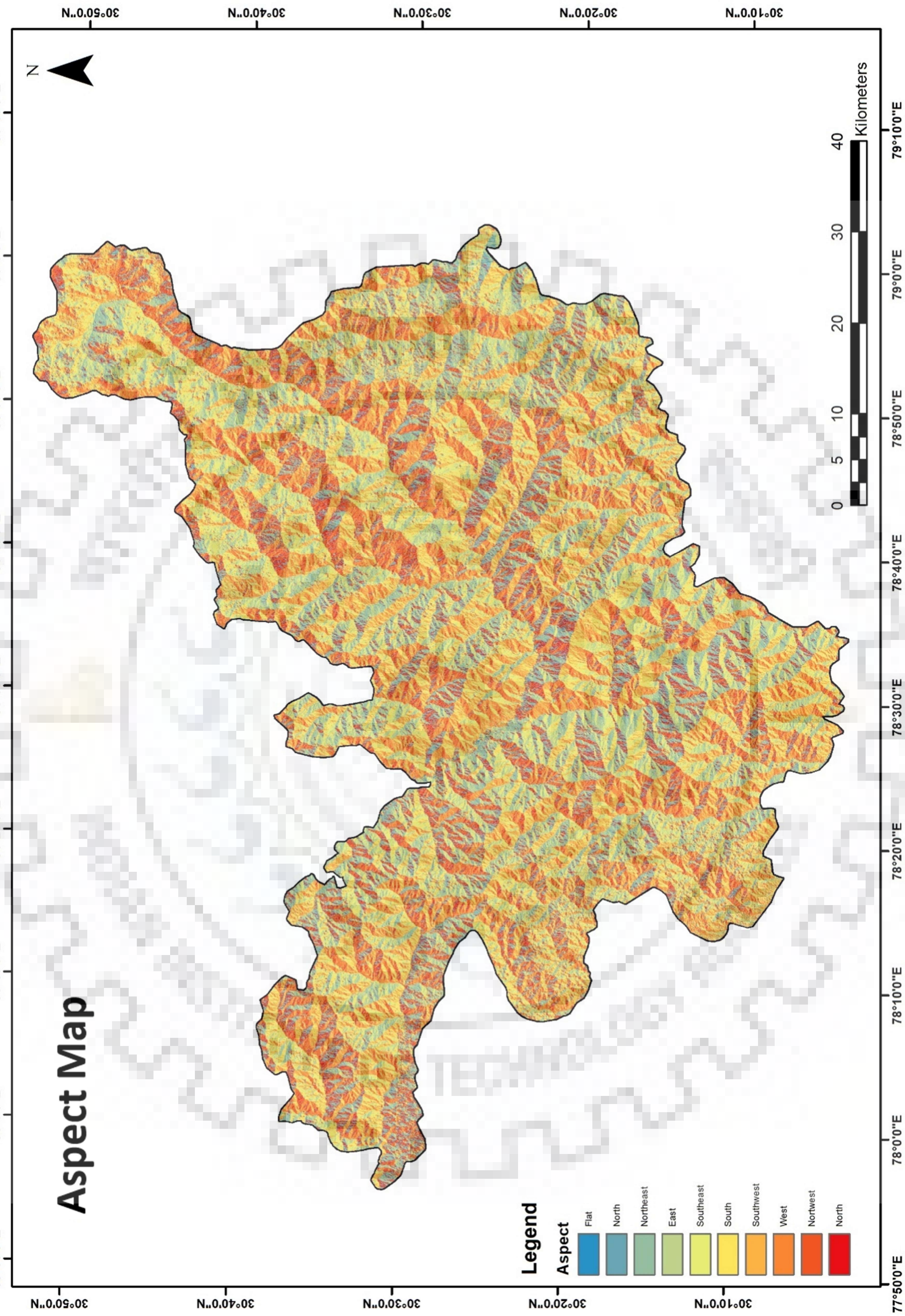


**Figure 4.3:** Tehri Garhwal Aspect Map

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### 4.3.4 Curvature Map of Study Area

Surface curvature at a point is the curvature of a line formed by the intersection of the surface with a plane with a specific orientation passing through this point. Profile curvature was used in this study. It is computed parallel to the direction of maximum slope, where a negative values infer a convex slope upward while a positive values infers a concave slope upwards. Zero values depict a linear profile. It affects the rate of mass movement on the slope to some extent.

In this study broadly two classifications has been done of the curvature as concave and convex. The details about the various landslide incidences into curvature classes are given in the table

**Table 4.3:** Curvature Table

| CURVATURE | LANDSLIDE INCIDENCES | COSINE AMPLTUDE VALUES | LANDSLIDE AREA(metre$^2$) |
|---|---|---|---|
| Convex | 217 | 0.016948046 | 1161509 |
| Concave | 206 | 0.013252982 | 871871 |

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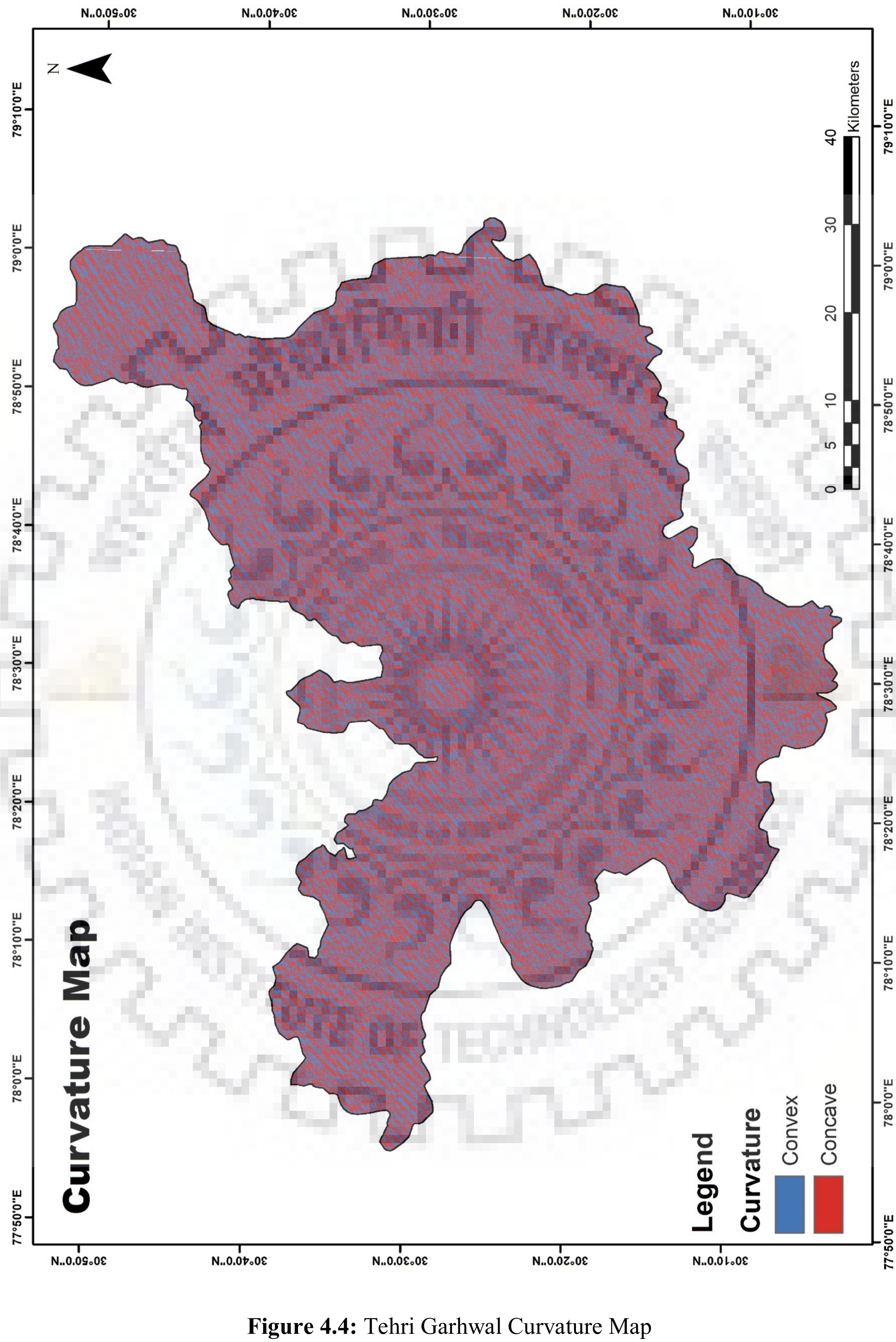


**Figure 4.4:** Tehri Garhwal Curvature Map

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### 4.3.5 Geology Map of the Area

It plays a very important role in controlling the landslide. They depict the age as well as the minerals present at a particular location. In the study are we have found out that there are 15 different geological formation each having varying area of exposure and influence on the landslides. The maximum number of landslides took place in the Chandpur Formation followed by Nagthat - Berinag Formation and Debguru - Porphyroid. The map is shown in the Figure 4.5.The details of the various landslides in different geological formation are given in the Table 4.4.

**Table 4.4:** Geological Formation

| GEOLOGICAL FORMATION | LANDSLIDE INCIDENCES | COSINE AMPLTUDE VALUES | LANDSLIDE AREA(metre$^2$) |
|---|---|---|---|
| Bansi Formation | 0 | 0 | 0 |
| Blaini Formation | 7 | 0.005398147 | 161406 |
| Chakrata Formation | 25 | 0.001298971 | 58898 |
| Chandpur Formation | 102 | 0.013524047 | 853301 |
| Debguru Porphyroid | 59 | 0.006877075 | 167465 |
| Deoban (Gangolihat) | 4 | 0.002027091 | 26220 |
| Granite - Granodiorite & Augen Gneiss | 33 | 0.011477749 | 102130 |
| Joshimath Formation | 0 | 0 | 0 |
| Krol Formation | 3 | 0.000673887 | 5165 |
| Mandhali (Sor + Thalkedar) Formation | 1 | 0.000367815 | 6600 |
| Nagthat - Berinag Formation | 82 | 0.003541244 | 298316 |
| Nathuakhan & Betalghat m. Bhatwari & Barkot units | 49 | 0.003237777 | 162245 |
| Not Mapped | 0 | 0 | 0 |
| Rautgara Formation | 19 | 0.002146629 | 53815 |
| Saryu - Gumalikhet & Munsiari Formations | 34 | 0.001346914 | 99800 |
| Tal Formation | 5 | 0.001250355 | 38019 |

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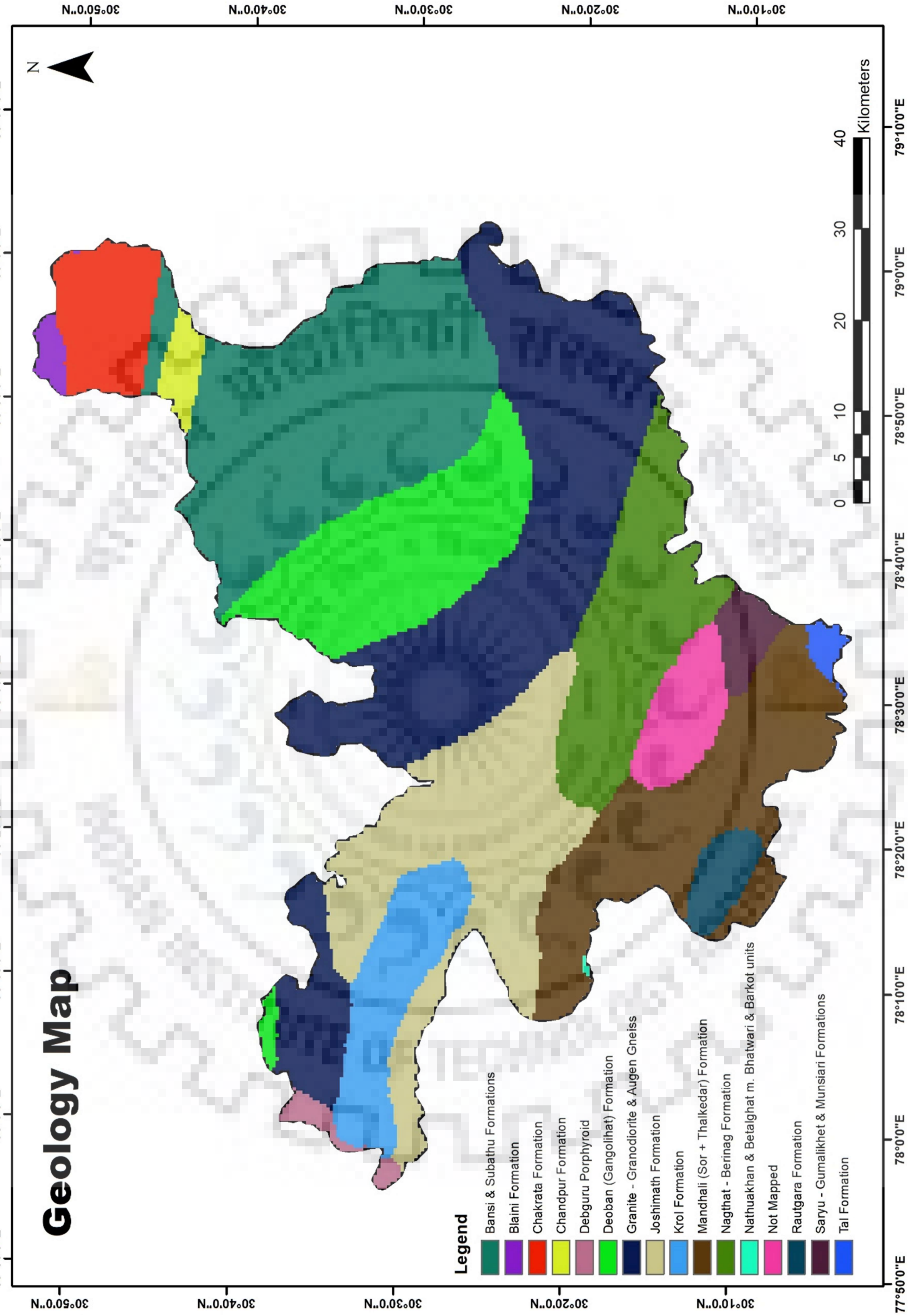


**Figure 4.5:** Tehri Garhwal Geology Map

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### 4.3.6 Lithological Map of India

Soils are basically unconsolidated weathered portion of rocks. Every soil has a different proportion of cohesion and internal cohesion based on which they are classified into various class such as: clay, silt, organic etc. The type of weathering and the mode of transportation also has a significant effect on the properties. But, soils formed from the same rock or lithological origin tends to behave in similar way on a certain scale. Lithological map is shown in the figure 4.6. Based on this assumption a lithological map of the study area was prepared. Broadly there were three different kinds of that were observed. These included Sedimentary and Metamorphic Rocks, Hypabyssal and Volcanic Rocks and Igneous Plutonic Acid Rock. Sedimentary and metamorphic rocks covered almost the entire region corresponding to newly formed young Himalyan series. The details of the various landslide events in the various lithological classes are given in Table 4.5.

**Table 4.5:** Rock Type

| ROCK TYPES | LANDSLIDE INCIDENCES | COSINE AMPLITUDE VALUES | LANDSLIDE AREA(metre$^2$) |
|---|---|---|---|
| Sedimentary& Metamorphic | 405 | 0.021618765 | 2004755 |
| Igneous Plutonic Acid Rock | 8 | 0.000517634 | 6450 |
| Hypabyssal And Volcanic Rocks | 10 | 0.00135807 | 22175 |

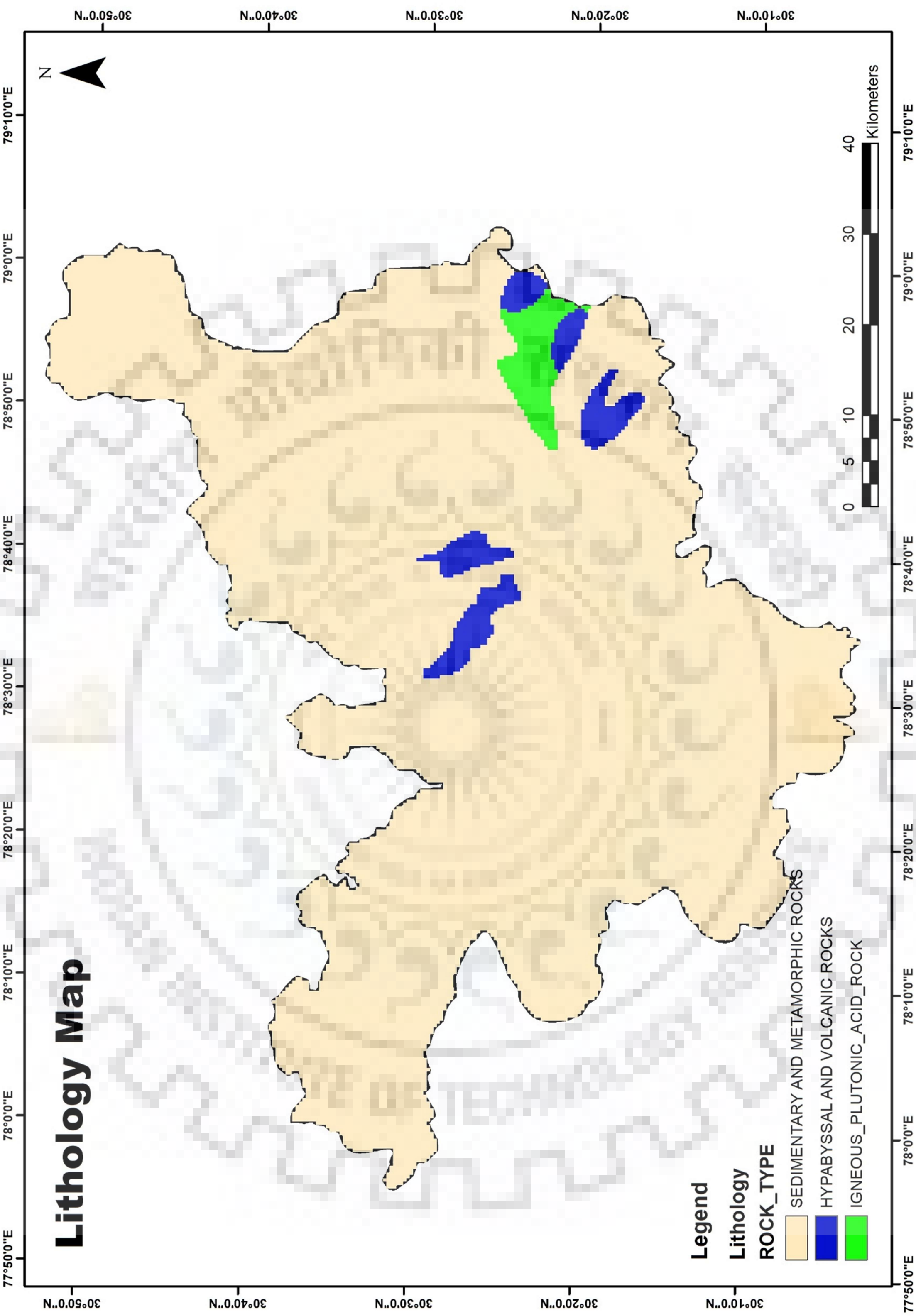


**Figure 4.6:** Tehri Garhwal Lithology

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### 4.3.7 Road Map of Study Area

Anthropogenic factors play a vital role in landslide incidences. In hilly areas when man made activity occurs it destabilize the slope. Cutting if not well protected try to regain their original form and thus are very susceptible to landslides. It is seen that the decrease in normal stress of displaced mass on cut slope induces an increase in shear stress in bedding planes and that at the toe of the cut slope. The released stress leads to gravitational instabilities of cut slope due to the decrease in normal stress and the increase in shear stress along the bedding planes.

The roads considered under the study are Primary, Secondary and Trunk road in the region. Tertiary kinds of road usually have a very shallow depth of cutting and thus are not considered. The road map is shown in the figure 4.7.

A multiple buffer along the road with a distance of 50, 100, 200 and >200 meters is created. Usually after 200 meters the effect of road cutting starts to diminish. A significant number of 114 landslides took place in the nearby road buffer of 50 meters.The details of various landslide incidences in different buffer class are shown in the table 4.6.

**Table 4.6:** Road Buffer

| ROAD BUFFER | LANDSLIDE INCIDENCES | COSINE AMPLITUDE VALUE | AREA OF LANDSLIDE(metre$^2$) |
|---|---|---|---|
| 0-50 | 114 | 0.018653562 | 221147 |
| 50-100 | 6 | 0.001693114 | 19024 |
| 100-200 | 8 | 0.005589329 | 84060 |
| >200 | 295 | 0.018503791 | 1709149 |

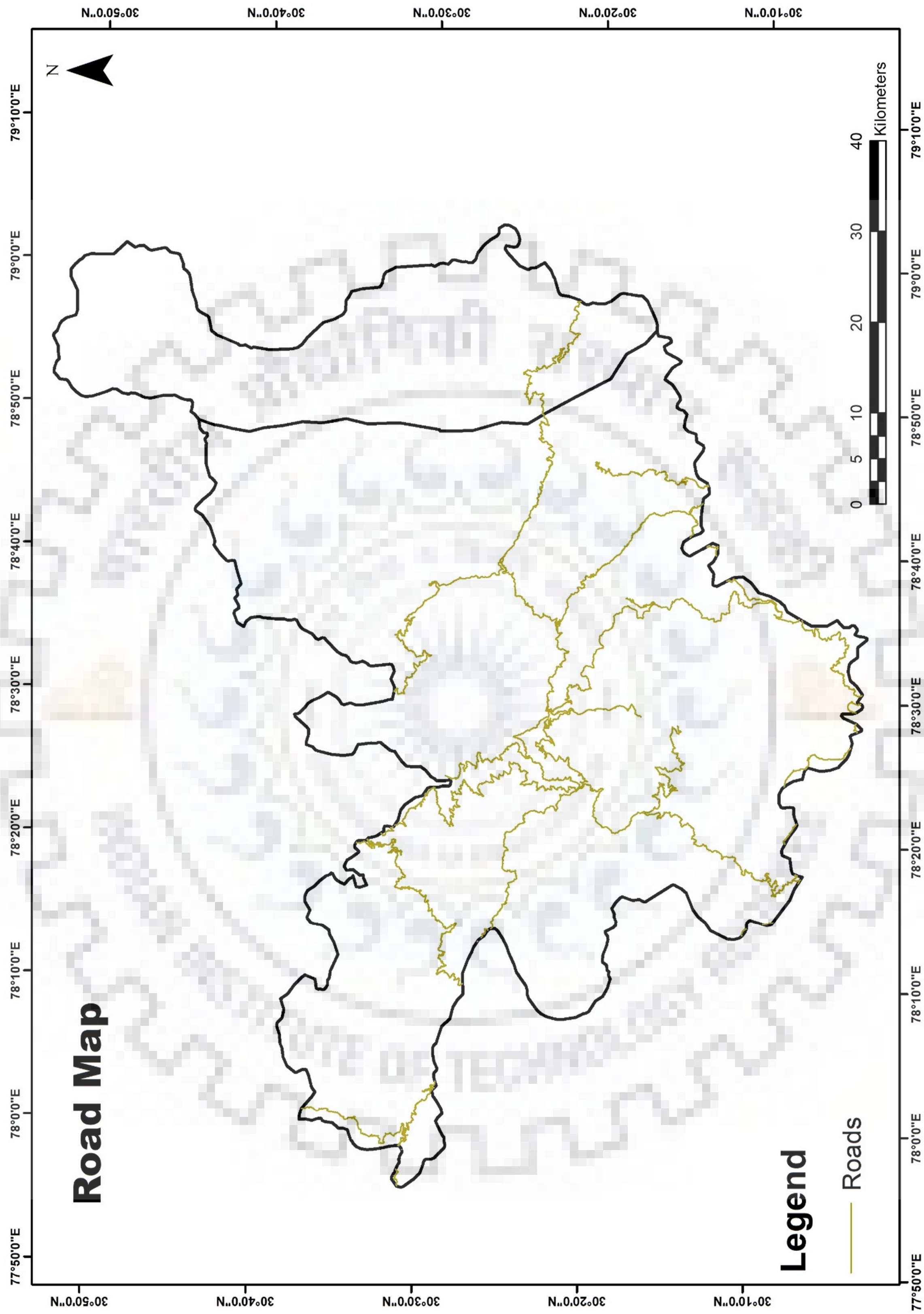


**Figure 4.7:** Tehri Garhwal Road Map

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### 4.3.8 Drainage Map of Study Area

Landslide tends to need a triggering factor to start mobilizing. The triggering factor may have an immediate effect or a prolonged one. Usually earthquake and intense rainfall falls under this category of factors. As most of the landslides in the study area are triggered by the rainfall therefore drainage becomes an important parameter to be considered in the analysis.

A strong correlation can be seen in the landslide incidences and the drainage pattern as most of them occurred in the vicinity of a nearby stream. The major cause of it can be that as the water rises in tends to saturate the soil masses which increases the pore water pressure and reduces the effective stress in the soil. As such it loses its shear strength. The river also tends to erode the toe of the slopes. The drainage map of the study area is shown in figure 4.8.

In the present study, streams up till fourth order is considered because as the slopes are highly undulating a number of smaller streams starts to contribute. The drainage pattern is seen to be dendritic and the major stream is Bhagirathi. Multiple buffer at a distance of 50, 100, 200, >200 meters are created for the analysis.

The details of the various landslide incidences in various buffer classes are given in the table 4.7.

**Table 4.7:** Drainage Buffer

| DRAINAGE BUFFER | LANDSLIDE INCIDENCES | COSINE AMPLITUDE VALUES | LANDSLIDE AREA(metre$^2$) |
|---|---|---|---|
| 0-50 | 29 | 0.005391875 | 75268 |
| 50-100 | 28 | 0.007122331 | 90372 |
| 100-200 | 55 | 0.014673869 | 259681 |
| >200 | 311 | 0.017591815 | 1608059 |

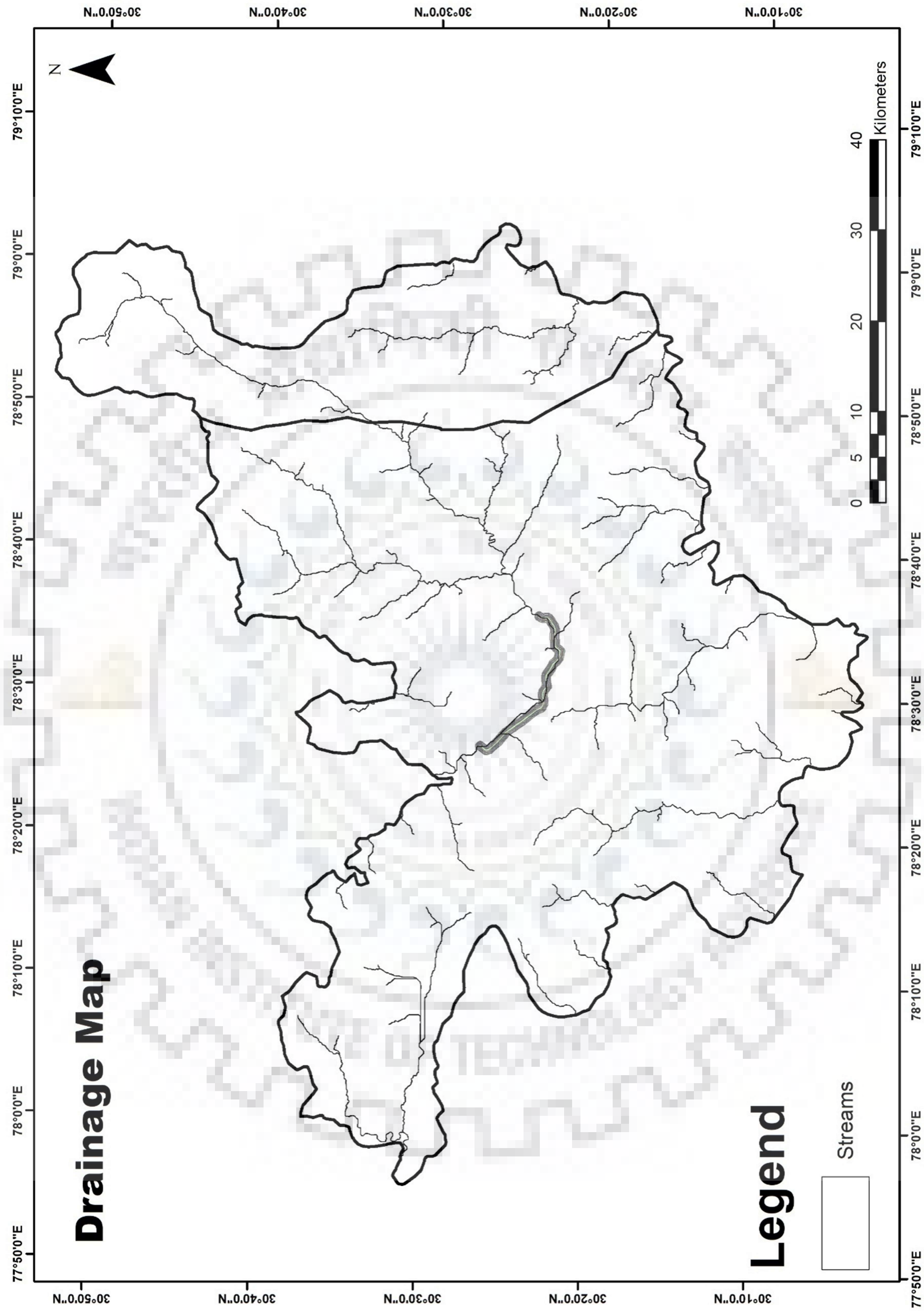


**Figure 4.8:** Tehri Garhwal Drainage Map

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### 4.3.9 Land Use and Land Cover Map of the Area

A land use map generally shows the distribution of vegetation, water bodies, barren area, built-up area, forest etc. These different classes have different effects on the susceptibility of the landslide. Anthropogenic factors have a greater significance than the natural factors. As they tend to destabilize the natural form of the area. Supervised classification has been done to create Land Use and Land Cover map of the area. The area has been classified into five different classes as: Snow, Vegetation, Water, Built-up and Barren. Barren area corresponds to the maximum number of landslides owing to the fact that lack of vegetation does not hold the soil masses together. As they are directly exposed to the sunlight they become dry and losses its shear strength. Total 376 number of maximum landslide incidences took place in the barren class .A number of small townships were also seen near the foothills and drainage stream; they usually cut the side slopes and therefore destabilizes the slope. The map is shown in the figure 4.9.

The details of the various landslide incidences in various classes have been shown in the table 4.8.

**Table 4.8:** Land Use Class Map

| LAND USE CLASS | LANDSLIDE INCIDENCES | COSINE AMPLITUDE VALUES | LANDSLIDE AREA(metre$^2$) |
|---|---|---|---|
| Water | 0 | 0 | 0 |
| Snow | 1 | 2.13722E-05 | 1400 |
| Vegetation | 14 | 0.000783402 | 43870 |
| Barren | 376 | 0.01464035 | 1533231 |
| Built up | 32 | 0.013925508 | 454879 |

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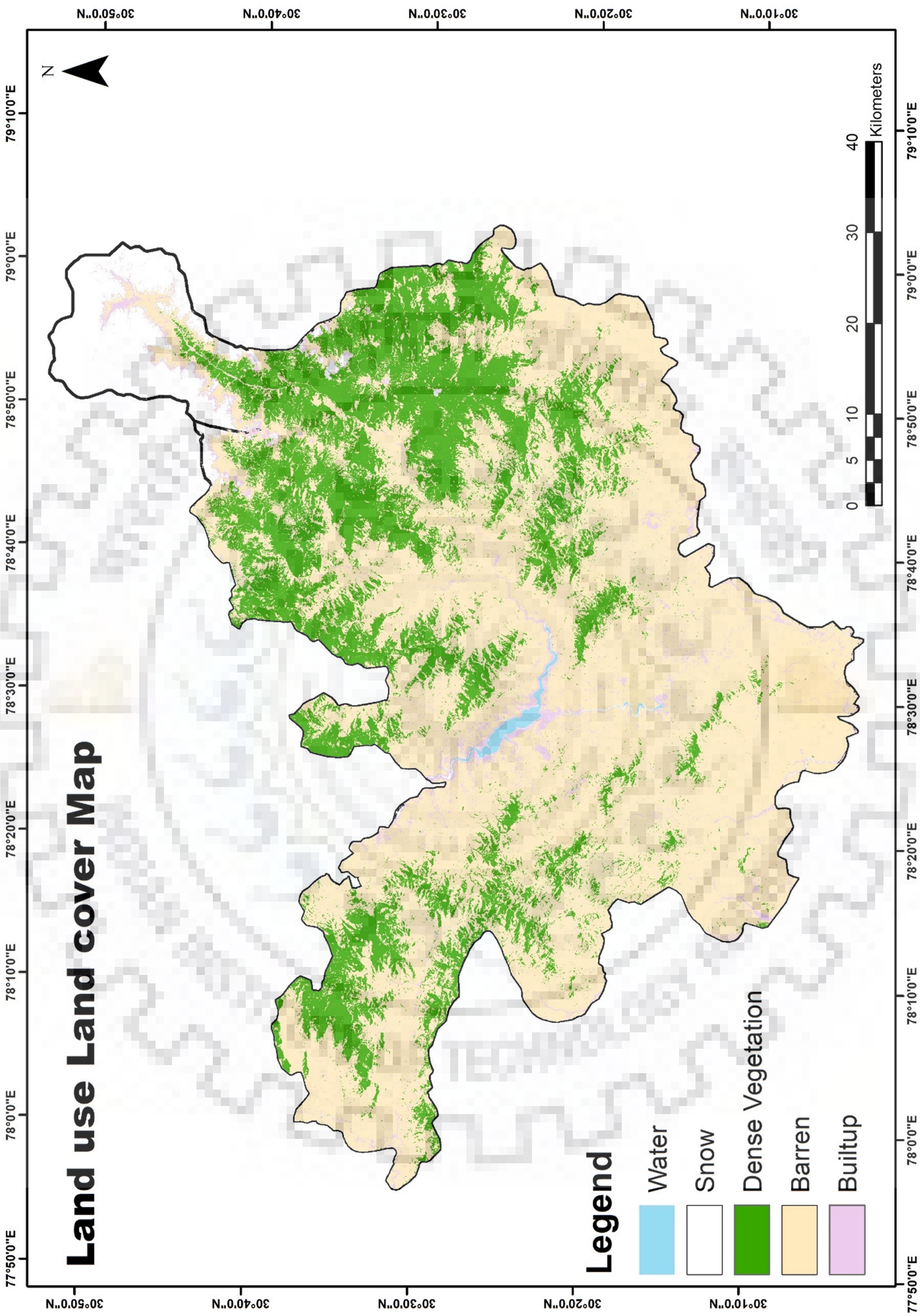


**Figure 4.9:** LULC Map

### 4.3.10 Reservoir

Tehri Dam is one of the highest dam in the world with height 260.5 meters. Its construction has resulted in formation of a huge reservoir corresponding to a length of 67 km in the Bhagirathi valley and Bhilangna valley as shown in figure 4.10. The reservoir water fluctuates between the Maximum Reservoir Level at 830 meters and Dead Storage Level at 740 meters. When the reservoir is at maximum level it saturates the side slopes and therefore the effective stress is now being characterized by the submerged weight therefore the effective stress reduces. When the water level goes down drawdown condition occurs which reduces the effective stress again.


**Figure 4.10:** Tehri Reservoir (Source: https://www.google.com/intl/en_in/earth)

An image of the Tehri Reservoir is shown in the figure. For the analysis purpose, a multiple buffer has been created around the reservoir. The influence of reservoir on each buffer layer has been normalized to a scale of 1-9 based on the literature available (Kumar and Anbalagan, 2015). Some pictures of the effect of reservoir can be seen in the figure 4.11.

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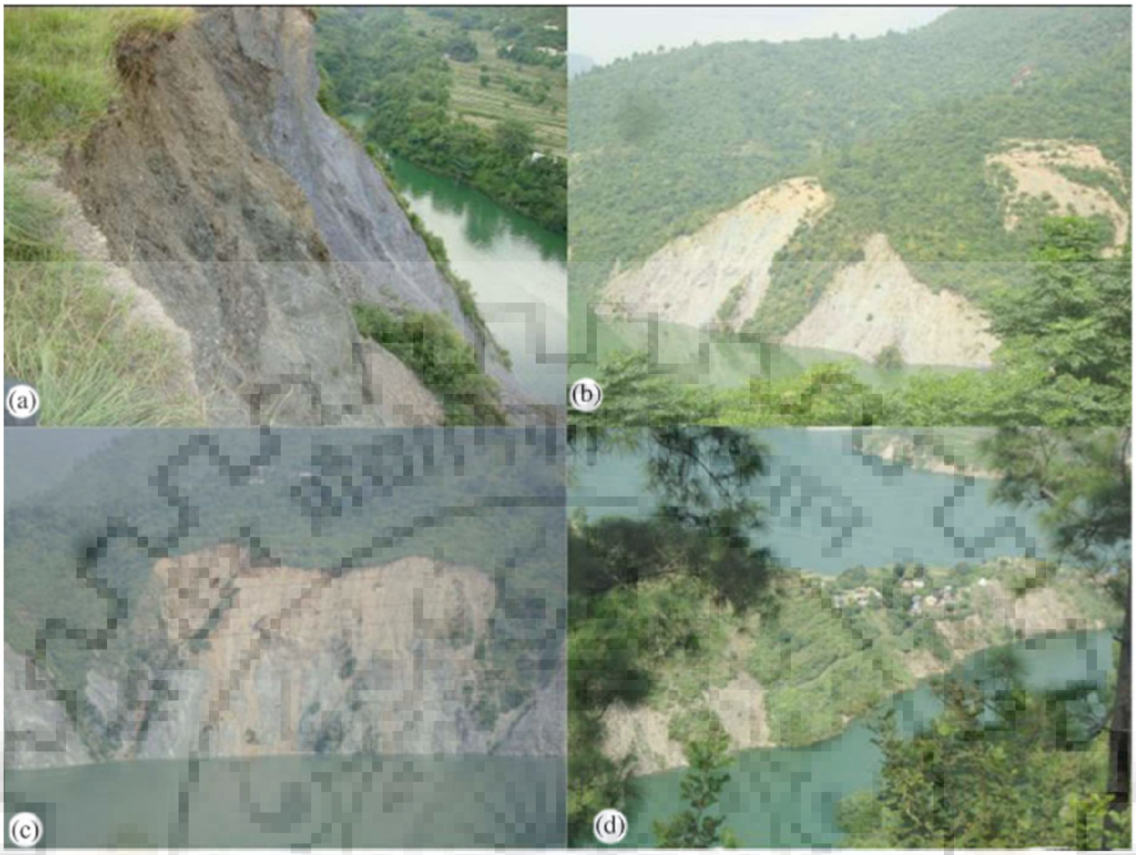


**Figure 4.11:** Effect of Tehri Reservoir (After R Kumar and Anabalgan)

**Table 4.9:** Reservoir Buffer Table

| RESERVOIR BUFFER | NORMALISED VALUE |
|---|---|
| 100 | 0.388050314 |
| 200 | 0.332704403 |
| 300 | 0.140251572 |
| 400 | 0.039622642 |
| 500 | 0.067295597 |
| >500 | 0.032075472 |

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### 4.3.11 Tectonic Thrust Arc

Thrust tectonics or contractional tectonics is concerned with the structures formed by, and the tectonic processes associated with, the shortening and thickening of the crust or lithosphere. The collision with the Eurasian Plate along the boundary between India and Nepal formed the orogenic belt that created the Tibetan Plateau and the Himalaya Mountains, as sediment bunched up like earth before a plough. With the Indian plate constantly moving, a large amount of stress is induced in the crust along the boundary. These stresses usually get released during the earthquakes, forming faults.

**Table 4.10:** Lineament Buffer

| Lineament Buffer | Landslide Incidence | Cosine Amplitude Values | Landslide Area(metre$^2$) |
|---|---|---|---|
| 250 | 31 | 0.007268569499 | 192362 |
| 500 | 31 | 0.00504721146 | 134100 |
| 1000 | 83 | 0.01328476728 | 482325 |
| 2500 | 124 | 0.01226969237 | 661848 |
| 5000 | 92 | 0.006783741041 | 358780 |
| >5000 | 49 | 0.002997252704 | 178365 |

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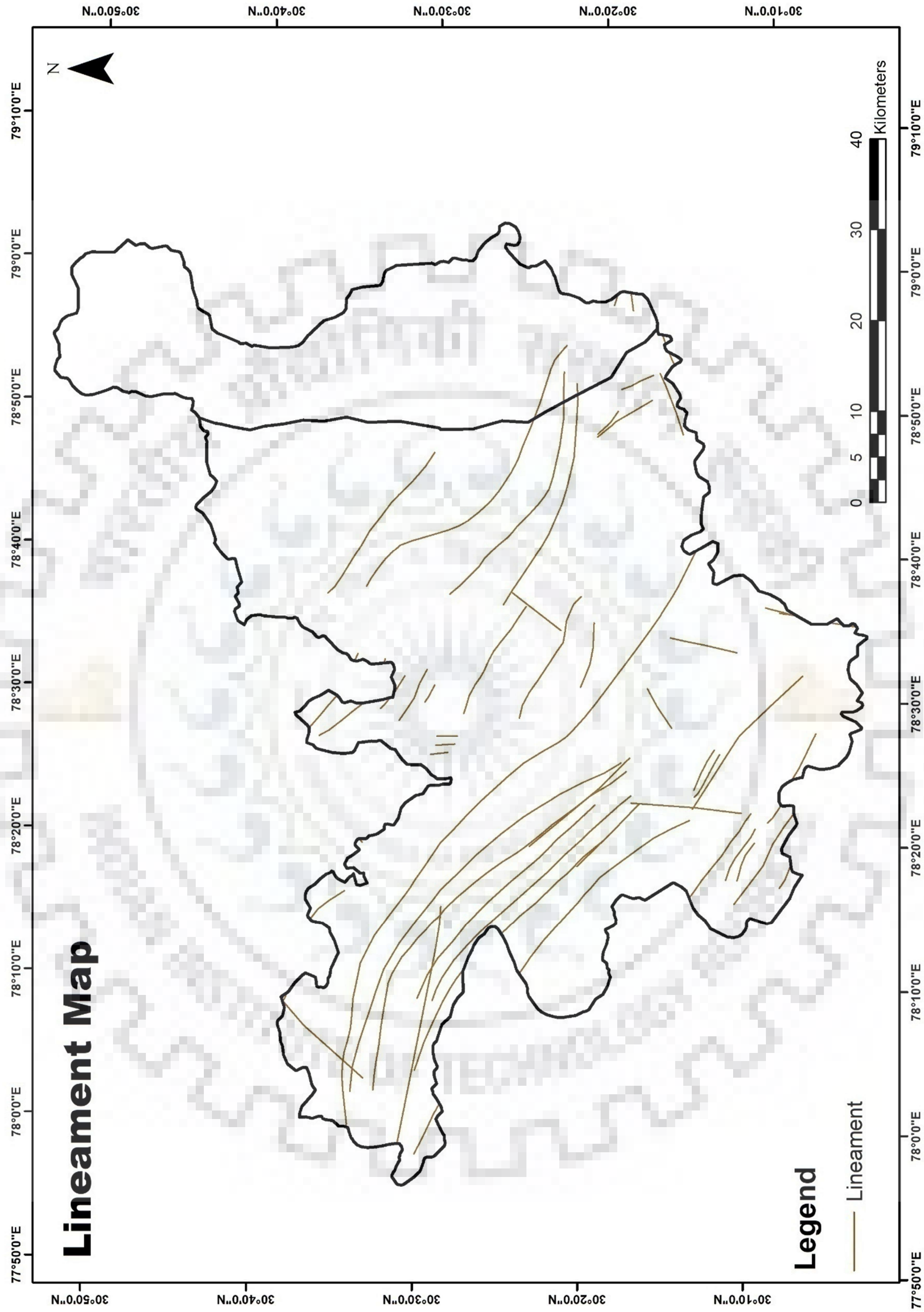


**Figure 4.12:** Tehri Garhwal Tectonic Map

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### 4.3.12 Seismic parameter

Earthquake plays an important role as triggering factor. But the problem in India lies in the lack of proper documentation of earthquake induced landslides. Although past studies have shown a significant influence of earthquake on landslide.(Maheshwari and Sangeeta, 2018).

The first seismic code in India was published in the year 1962 and has been revised subsequently five times.The current version is IS 1893 (part 1) – 2002. The country has been divided into four zones. Each zone is reflected by the seismic zoning factor, based on the anticipated intensity of shaking. The zoning map is based on expected maximum seismic intensity on the modified Mercallis Scale. The table below shows the values of zone factor.

**Table 4.11:** MMS Zone Factor

| Zone 2 | Zone3 | Zone4 | Zone5 |
|---|---|---|---|
| 0.10g | 0.1g | 0.24g | 0.36g |

The study area mainly lies in Zone 4 but a small portion of it lies in Zone 5. To quantify the effect of different seismic zone a modification factor has been used. This modification factor is multiplied with the observed cosine amplitude function to get new values, which has been further normalized on the scale of 1-9.

MODIFICATION FACTOR (M.F.)

$$M.F_i = \frac{Z.F._i}{(Z.F._i)min.}$$

Z.F. = Zone Factor

**Table 4.12:** Modification factor for Seismic Zone

| SEISMIC ZONE | LANDSLIDE INCIDENCE | COSINE AMPLITUDE VALUES | MODIFICATION FACTOR | AREA OF LANDSLIDE |
|---|---|---|---|---|
| ZONE4 | 392 | 0.02308145932 | 1 | 1956855 |
| ZONE5 | 31 | 0.001784743227 | 1.2 | 76525 |

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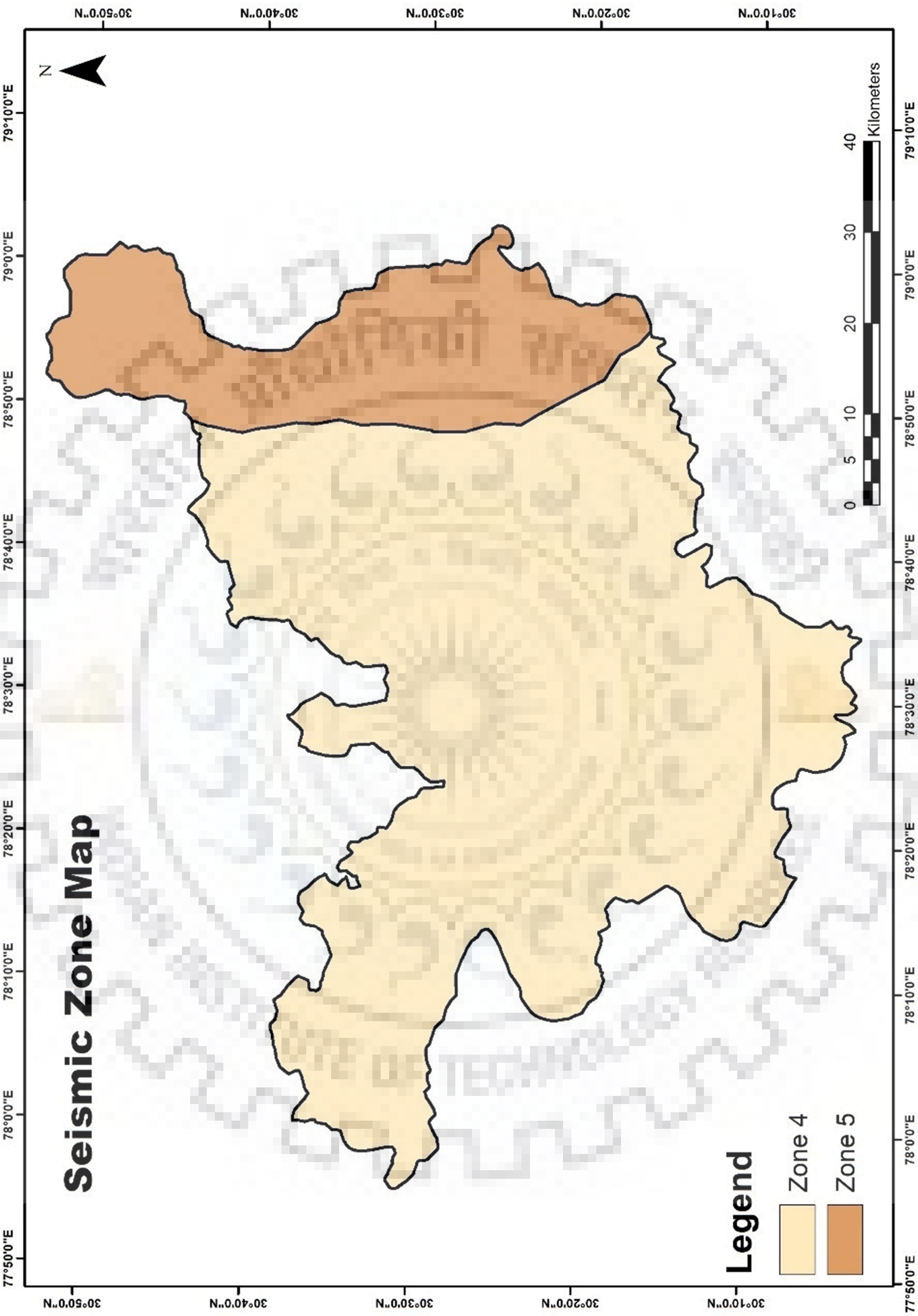


**Figure 4.13:** Tehri Garhwal Seismic Zone Map

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## 4.3 Weight of Various Classes:

The weight of the various classes have been decided on the Cosine Amplitude function derived for each class along with the various literature available in similar study areas. A correlation has been tried to be established amongst both while deciding the weightage values. This has been shown in the table

**Table 4.13:** Weightage Table

| FACTOR | CLASS | WEIGHT |
|---|---|---|
| SLOPE | 0-10 | 1 |
| | 10-20 | 2 |
| | 20-30 | 4 |
| | 30-40 | 9 |
| | >40 | 6 |
| ASPECT | Flat | 1 |
| | North | 1 |
| | Northeast | 2 |
| | East | 3 |
| | South East | 8 |
| | South | 8 |
| | Southwest | 9 |
| | West | 9 |
| | Northwest | 2 |
| | North | 1 |
| CURVATURE | Convex | 9 |
| | Concave | 9 |
| GEOLOGICAL | 'Bansi & Subathu Formations' | 0 |
| | Blaini Formation | 4 |

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| | | |
|---|---|---|
| | Chakrata Formation | 1 |
| | Chandpur Formation | 9 |
| | Debguru Porphyroid | 5 |
| | Deoban (Gangolihat) Formation | 1 |
| | Granite-Granodiorite & Augen Gneiss | 8 |
| | Joshimath Formation | 1 |
| | Krol Formation | 1 |
| | Mandhali (Sor + Thalkedar) Formation | 1 |
| | Nagthat - Berinag Formation | 2 |
| | Nathuakhan & Betalghat m. Bhatwari & Barkot units | 2 |
| | Rautgara Formation | 1 |
| | Saryu - Gumalikhet & Munsiari Formations | 1 |
| | Tal Formation | 1 |
| ROCK TYPE | Sedimentary And Metamorphic Rocks | 9 |
| | Hypabyssal And Volcanic Rocks | 1 |
| | Igneous_Plutonic_Acid_Rock | 1 |
| ROAD | 0-50 | 9 |
| | 50-100 | 1 |
| | 100-200 | 2 |
| | >200 | 1 |
| DRAINAGE | 0-50 | 3 |

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| | | |
|---|---|---|
| | 50-100 | 4 |
| | 100-200 | 9 |
| | >200 | 1 |
| LULC | Water | 0 |
| | Snow | 0 |
| | Vegetation | 1 |
| | Barren | 9 |
| | Built Up | 9 |
| RESERVOIR | 100 | 9 |
| | 200 | 8 |
| | 300 | 3 |
| | 400 | 1 |
| | 500 | 2 |
| | >500 | 1 |
| TECTONIC ARC | 250 | 5 |
| | 500 | 3 |
| | 1000 | 9 |
| | 2500 | 8 |
| | 5000 | 4 |
| | 10000 | 1 |
| SEISMIC ZONE | Zone4 | 8 |
| | Zone5 | 2 |

## 4.4 Result and Validation

The conventional method employed to segment the LSI values for the demarcation of various susceptibility zones is often subjective. Since, the variations in weights and the respective

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central tendencies in thematic data layers are often large and random, we employ in this particular study, a new probabilistic approach for such segmentation.

The LSI values were classified into five different classes with boundaries fixed at (μ - 1.5m℘), (μ + 1.5m℘),), (μ - 0.5m℘),) and (μ + 0.5m℘),) where m is a positive, non-zero value. The cumulative percentage of landslide occurrences in different susceptibility zones ranging from very high to very low can be plotted against the cumulative percentage of the area of the hazard zones based on a given LSZ map. The resultant curve, termed as the success rate curve in the literature (Chung and Fabbri 1999; Lu and An 1999; Lee et al. 2002b), can be used to select the appropriate value of m to decide the suitability of a particular LSZ map. Corresponding success rate curves were prepared for different m values like 0.7, 0.8, 1.0 and 1.1.

As seen from the graph below, that for the 10% of the area curve corresponding to m= 0.8 is showing the maximum landslide occurrences and therefore has the highest success rate.

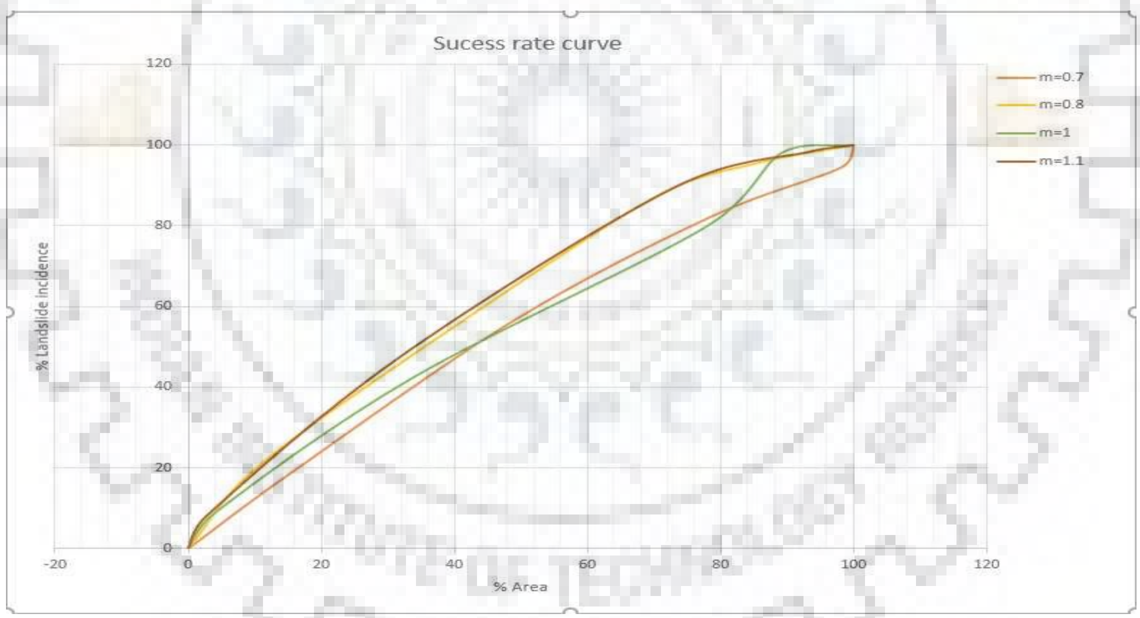


**Figure 4.14:** Success Rate Curve

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The corresponding details about various *m* values and its effect on the success rate curve has been shown in the table below.

**Table 4.14:** Success rate curve table for m=0.7

| CLASS | % AREA OF CLASS | % LANDSLIDE AREA |
|---|---|---|
| 28-44.5 | 1.94 | 3.29 |
| 44.5-51.1 | 19.61 | 5.70 |
| 51.1-57.7 | 29.60 | 17.38 |
| 57.7-64.2 | 33.44 | 35.10 |
| 64.2-86 | 15.41 | 38.53 |

**Table 4.15:** Success rate curve table for m=0.8

| CLASS | % AREA OF CLASS | % LANDSLIDE AREA |
|---|---|---|
| 28-43.1 | 14.66 | 2.70 |
| 53.1-50.6 | 15.13 | 3.85 |
| 50.6-58.1 | 33.66 | 26.85 |
| 58.1-65.6 | 26.13 | 29.36 |
| 65.6-86 | 10.43 | 37.25 |

`

**Table 4.16:** Success rate curve table for m=1.1

| CLASS | % AREA OF CLASS | % LANDSLIDE AREA (metre$^2$) |
|---|---|---|
| 28-38.9 | 6.81 | 0.89 |
| 38.9-49.2 | 20.11 | 4.12 |
| 49.2-59.5 | 41.37 | 30.17 |
| 59.5-69.9 | 28.96 | 50.46 |
| 69.9-86 | 2.75 | 14.36 |

The final Hazard map of Tehri Garhwal district, Uttrarakhand prepared is shown in the Figure 4.15

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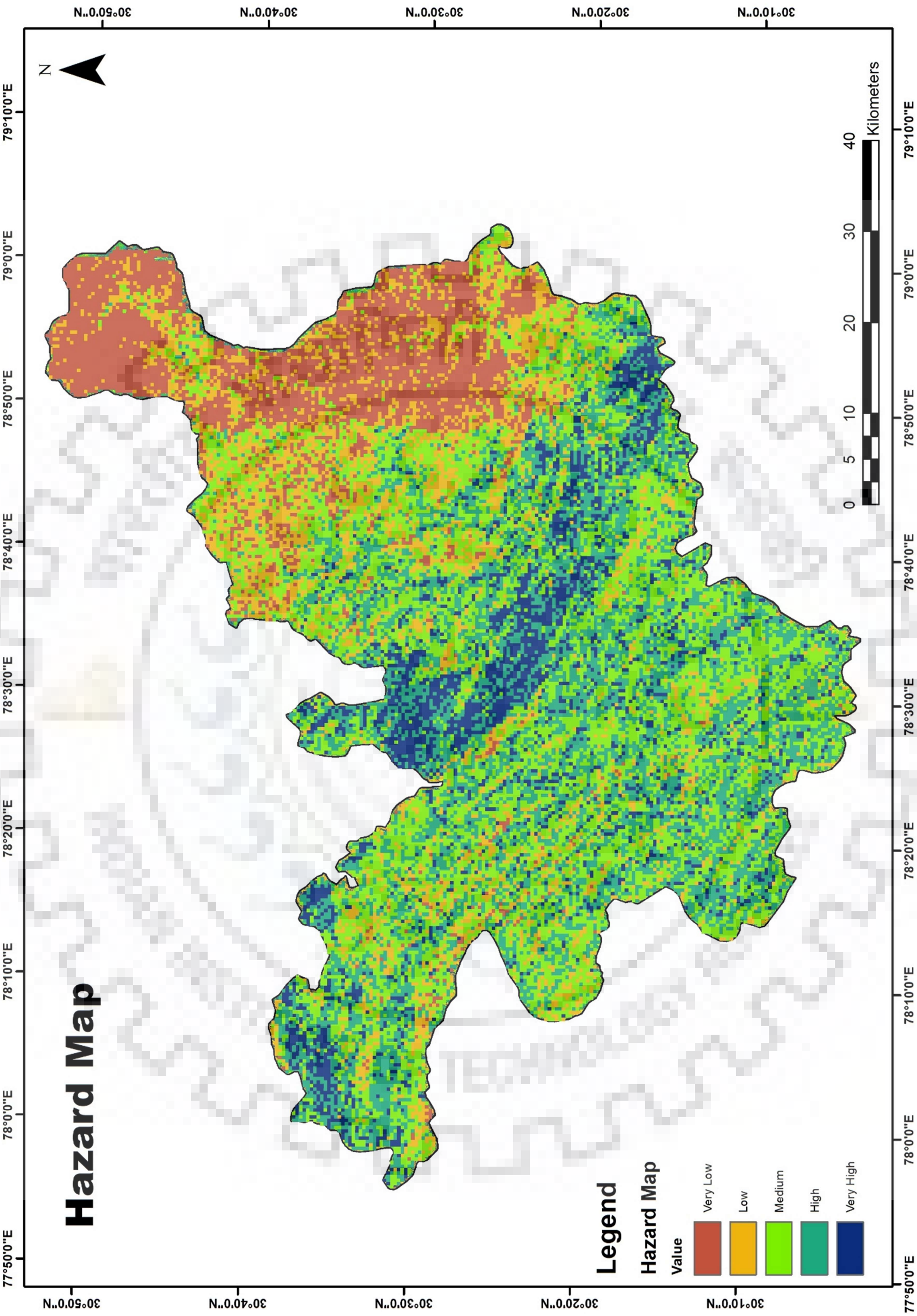


**Figure 4.15:** Tehri Garhwal Landslide Hazard Zonation Map

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Chapter 5

# Conclusion

Landslides are known to cause devastating damage to both property and life every year in hilly regions. In such areas, landslide susceptibility zonation is very essential to demarcate the landslide prone zones. Numerous techniques are in place for landslide hazard/susceptibility zonation. Among all these, the bivariate statistical methods are most suited for the regional-scale landslide susceptibility zonation. In this method, remote sensing and GIS techniques can be very useful in data acquisition, processing, analysis and management.

In the present study, Overlay method has been used to combine various causative factors. Weightage to various causative factors have been done using Cosine Amplitude values, where importance to area of landslide is given rather than incidences. Seismic parameters have also been incorporated based on their relative importance as a triggering factor. Finally, classification of area into various zones has been done on a more statistical based method rather than just on equal interval.

Understanding disaster risk is amongst the top priorities under the currently active Sendai Framework. For risk analysis, knowledge about the hazard is must. Landslide Hazard Zonation maps like these comes into picture over there and align themselves to the Sendai Framework.

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## References


Aleotti, Pietro, and R. Chowdhury. 1999. “Landslide Hazard Assessment: Summary Review and New Perspectives.” *Bulletin of Engineering Geology and the Environment* 58(1): 21–44.

Amirahmadi, A., M. Shiran, M. Zanganeh Asadi, and F. Keramati. 2017. “Landslide Susceptibility Zonation Using the Fuzzy Algebraic Operators in GIS, Iran.” *Journal of Materials and Environmental Science* 8(1): 50–59.

Articles, Original. 2005. “An Approach for GIS-Based Statistical Landslide Susceptibility Zonation — with a Case Study in the Himalayas.” (July 2004): 61–69.

DMMC. 2012. “State Disaster Management Action Plan for the State of Uttarakhand Disaster Mitigation & Management Centre Uttarakhand Secretariat.” http://dmmc.uk.gov.in/files/pdf/complete_sdmap.pdf.

Government, Of India. 2009. “National Disaster Management Guidelines: Management of Landslides and Snow Avalanches.” (June): 190.

Kanungo, D. P., Anindya Pain, and Shaifaly Sharma. 2013. “Finite Element Modeling Approach to Assess the Stability of Debris and Rock Slopes: A Case Study from the Indian Himalayas.” *Natural Hazards* 69(1): 1–24.

Kumar, Rohan, and R Anbalagan. 2015. “Landslide Susceptibility Zonation in Part of Tehri Reservoir Region Using Frequency Ratio , Fuzzy Logic and GIS.” (2): 431–48.

Maheswari, B K. “GIS BASED EARTHQUAKE INDUCED LANDSLIDE HAZARD ASSESSMENT OF CHAMOLI DISTRICT , UTTARAKHAND , INDIA.” : 1–16.

Marjanovi, Miloš, and Jan Caha. 2011. “Fuzzy Approach to to Landslide Susceptibility Zonation Fuzzy Approach Landslide Susceptibility Zonation.” : 181–95.

Marrapu, Balendra Mouli, and Ravi Sankar Jakka. 2014. “Landslide Hazard Zonation Methods: A Critical Review.” *International Journal of Civil Engineering Research* 5(3): 2278–3652. http://www.ripublication.com/ijcer.htm.

Novotný, Jan. 2013. “Varnes Landslide Classification (1978).” *Charles University in Prague, Faculty of Science, Czech Republic* (November): 25 p. URL http://www.geology.cz/projekt681900/vyuk.

Rautela, Piyoosh, and V C Thakur. 1999. “Landslide Hazard Zonation in Kaliganga and Madhyamaheshwar Valleys of Garhwal Himalaya: A GIS Based Approach.” *Himalafan Geology. Vo* 20(2): 31–44.

Reservoir, Tehri, and Rim Region. 2017. “Landslide Susceptibility Mapping Using Analytical Hierarchy Process ( AHP ) in Landslide Susceptibility Mapping Using Analytical Hierarchy Process ( AHP ) in Tehri Reservoir Rim Region , Uttarakhand.” (April 2016).

Sarkar, S., and D.P. Kanungo. 2004. “An Integrated Approach for Landslide Susceptibility Mapping Using Remote Sensing and GIS.” *Photogrammetric Engineering & Remote Sensing* 70(5): 617–25. http://openurl.ingenta.com/content/xref?genre=article&issn=0099-1112&volume=70&issue=5&spage=617.

Sassa, Kyoji, and Paolo Canuti. 2009. Thomson Reuters Foundation *Landslides - Disaster Risk Reduction*. http://www.trust.org/spotlight/Disaster-risk/?tab=briefing.

Uvaraj, S., and R. Neelakantan. 2018. “Fuzzy Logic Approach for Landslide Hazard Zonation Mapping Using GIS: A Case Study of Nilgiris.” *Modeling Earth Systems and Environment* 4(2): 685–98. http://link.springer.com/10.1007/s40808-018-0447-8.