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RESEARCH ARTICLE

MASS MOVEMENT VULNERABILITY ASSESSMENT OF UTTRAKHAND AND SIKKIM, INDIA USING GEOSPATIAL TECHNOLOGY

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ABSTRACT

Mass movement is a major problem in mountainous regions of India. Mass movements cause road blockage, causality and property loss which affects the economic development of that region. The use of Remote Sensing and Geographical Informatics System (GIS) can be highly useful for prediction of mass movement in vulnerable regions and it is also time and cost effective. This information can be used by natural hazard planners and decision makers for proper management of mass movement related hazards. In this paper a comparison between Uttrakhand and Sikkim state of India is studied in terms of its vulnerability for mass movement using the Analytical Hierarchy Process (AHP). Parameters which trigger the occurrence of mass movement such as rainfall, slope angle, aspect, geology, landuse landcover (LULC), proximity to drainage and road network was considered in this study. The results show that Analytical Hierarchy Process (AHP) is a good tool for remote prediction of mass movement. In this study Sikkim shows more vulnerability for mass movement then Uttrakhand.

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INTRODUCTION

Mass movement is a natural hazard event in which downslope movement of soil, rock, and organic materials occurs due to various processes. The materials may possibly shift by falling, toppling, sliding, spreading, flowing etc (Lynn, 2004). Mass movements can damage a nation to achieve its developmental goals because history shows mass movement produced multiple losses of life, property, resources and ecosystems in the region which affect the economic development. The unscientific developmental practices, forest degradation, deforestation, increase pressure of tourism, waste disposal has contributed the region under vulnerable zones for mass movement. In this study various mass movement influencing parameters such as slope angle, aspect ratio, landuse landcover (LULC), geology, drainage and roadways are analyzed for Uttrakhand and Sikkim region. These parameters are used in GIS platform for prediction of mass movement in this region. The Analytical hierarchy Process (AHP) was implemented for this task. Analytical hierarchy Process (AHP) engages building a hierarchy of decision parameters. These parameters are used for making judgments between probable pairs in a matrix for giving each parameter an influence factor. Analytical hierarchy Process (AHP) is supported by three ideology i.e. decomposition, comparative judgment and synthesis of priorities (Malczewski, 1999). The main objective of the study is to identify the vulnerable zones for occurrence of mass movement. In this study, the combination of GIS and remote sensing technology is implemented to derive a mass movement susceptibility map for Uttrakhand and Sikkim region, India. The analytical hierarchy Process (AHP) with Geographical information system (GIS) was employed to identify the areas which are more vulnerable for mass movement in both the states of India i.e. Uttrakhand and Sikkim.

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Study Area

Uttrakhand and Sikkim are the states of Indian Himalayan region (Fig. 1). Uttrakhand extends between 28.7156° N to 31.4722° N latitude and 77.56224°E to 81.02874° E Longitude whereas Sikkim extends between 27.08161°N to 28.13096°N latitude and 88.00914° E to 88.92237° E longitude. Uttrakhand covers around 53,483 sq km of area whereas Sikkim is a small state which covers only 7069 sq km in area. The elevation of Uttrakhand ranges between 140 to 7800 m whereas elevation of Sikkim lies between 150 to 8400m. These two states are known for its rich spiritual and religious tourism, ecological diversity and cultural prosperity. These regions are also known for occurrence of mass movement because of its topographical characteristics. These regions are also tectonically active (EERI, 2012) which makes it more vulnerable for mass movement occurrence.

exposure of sun light to the slope surface which influences the weathering process in that area. Meteorological events for instance the rainfall direction, quantity of sunshine, regional morphologic arrangement etc, affect the slope stability (Mohammadi, 2008; Pourghasemi *et al*., 2012).

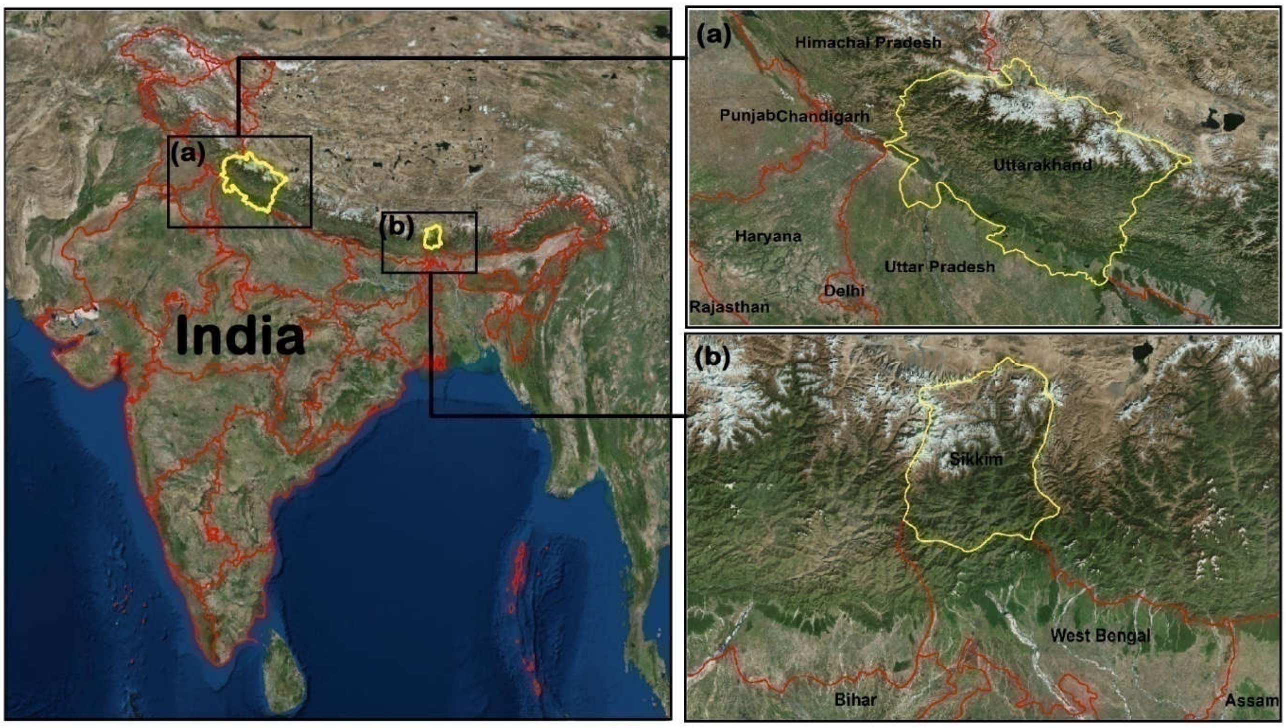


Fig. 1. Study Area Uttrakhand and Sikkim (a) State boundary of Uttrakhand covering 53,483 sq km of total area (b) State boundary of Sikkim covering 7069 sq km of total area

Geo-environmental parameters

Slope Angle

Slope angle is the most important driving forces for mass movement triggering. Researcher have found that every increase in slope of 1 degree, the initial factor of safety against mass movement triggering is reduced by 2.32% for a given soil material (Rahardjo *et al*., 2007). The area having slope angle between an inclination of 30° and 40° have highest chance of occurrence of mass movement. The steepest class has lower chance of mass movement due to the reason of mass wasting in the past, which degraded the soil and left more stable exposed bedrock (Meinhardt *et al*., 2015). It is found that the slope angle between 14° or less the cases of mass movement never happened. slope angle between 15° to 19° have some cases occurred, mass movement occurs usually in the slope angle between 20° to 40°. Slope angle between 41° to 60° have rare cases and at 60° to 90° mass movement never occurred. (Jackson *et al*., 2008)

Aspect

Aspect is the primary change in direction of a DEM, which is expressed in degrees ranging from 0 to 359.9 in clockwise direction from north (SPR 740 report, 2015). The exposure to sunlight, weathering differences, soil moisture, and drying winds all affects the stability of slope in an area (Chalkias *et al*., 2014). The direction of the slope also plays a major role for instability of slope. The direction of slope restricts the direct

Geology

The geological map provides information on the lithological and structural setting of the area. Mass movement is controlled by the lithological properties of land surface different lithological characters have different impacts on the occurrence of mass movement. The erodibility of rock to the processes of weathering and erosion has been is the major factors for classification of lithology into different subcategories, for instance hard rock such as quartzite, limestone and igneous rocks which are massive and resistant to erosion, these types of rock generally form steep slopes. Other rocks such as terrigenous sedimentary rocks are more vulnerable to occurrence of mass movement. Phyllites and schists are rocks which are well known for their flaky mineral quality; therefore these rocks are wreathed quickly leads to surface instability (Anbalgan, 1992).This type of weak rocks in an area which indicates the high chance of occurrence of mass movement. Areas having genesis soil type also experience a good chance of occurrence of mass movement whereas older alluvium is well compacted and has high shearing resistance.
Discontinuities in the rocks such as bedding, joints, foliations, faults and thrusts is also a good geologic indicator for occurrence of mass movement. Slope Stability of an area is highly influenced by the disposition of structural discontinuities with relation to the slope inclination and direction. The areas are more vulnerable for mass movement where there is more discontinuity of two discontinuities which tends to be parallel to the slope (Carrara *et al*., 1991; Anbalgan, 1992). The slope's permeability and strength of soil

and rock, jointing, structure, inter bedding, subsurface lithology, geologic variability and interfaces between soil layers all play a role in the type and size of mass movement. Therefore, grouping the lithologic properties properly is significant in providing data for mass movement vulnerability mapping (Pourghasemi *et al*., 2012).

Landuse landcover

Forest areas decrease the chance of occurrence of mass movement. The roots of Forests trap the soil material and reduce the movement of soil mass. Barren areas are more vulnerable for the occurrence of mass movement than the forest areas. Barren areas have low vegetation which leads to high exposure to sunlight influencing the weathering process in that area (Pourghasemi *et al*., 2012). Many researches conclude interesting fact that degraded forests have less increase in occurrence of mass movement whereas agricultural areas showed increase in occurrence of mass movement due to anthropogenic activities, low vegetation cover during no crop periods and high sheet erosion during heavy rainfall periods (Rail *et al*., 2014).

Drainage

Drainage is also an important parameter to determine the occurrence of mass movement. The areas which have good density of drainage have more chance of mass movement due to the moisture availability (Lynn, 2008). Areas near to the stream have more potential to erode the surface materials then the area which are far from streams.

Roadways

The Areas which are close to the roads are more likely the areas where mass movement is common. The slope is normalized during the construction of road, the slope become unstable due to negative effects of excavation (Chalkias *et al*., 2014). The transportation process in the roads creates vibration to the nearby areas which may cause instability in the sloppy regions.

Rainfall

Heavy and prolonged rainfall can create unstable condition and is a frequent trigger of mass movement. Mass movement are extensive in regions where the conditions are together like steep slopes, weak soil, weathered and is saturated due to heavy rainfall (Final Report SPR 740, 2015). Areas which have good degree of slope and saturated with heavy rainfall it means it have a good chance of occurrence of mass movement. The friction between the bedrock and the overlying sediment caused due to concentration of water in a region with combination of effect of gravity drive the debris to slide downward (Suzen *et al*., 2004). Continued rainfall over long time spans leads to weathering and weakening of rock or soil.

Materials Used

Open source data from Landsat 7 ETM+ sensor of the year 2003 was used in this study. This data are downloaded from the USGS earth explorer website. Landsat 7 has 8 bands ranging from various frequencies in the electro- magnetic spectrum. In this study visible band such as band1 blue (0.45-0.52 µm), band2 green (0.52-0.60 µm), band3 red (0.63-0.69 µm) and Infrared band such as band4 NIR bands (0.77-0.90µm) (NASA, 2016) are used for extraction of various landuse landcover related information. Landsat 7 has default 30m spatial resolution, this data was fused to 15 meter spatial resolution for detail information extraction using the PAN bands provided with the raw data in band 8. For Elevation related study Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) scenes acquired between March 2000 and August 2010 are used with 30m spatial resolution. Geological map of 1:50000 scale for Uttrakhand and Sikkim was obtained from Geological Survey of India for geological related analysis. Rainfall related data are obtained from Indian Meteorological Department (IMD) website. District wise rainfall statistic data for 5 year (2011-2015) was obtained from Indian Meteorological Department (IMD) Customized Rainfall Information System (CRIS) website for input in Analytical Hierarchy Process (AHP) (Table 1).

Table 1. Various data used in the study

S.No.	Data	Version	Period	Specification	Source
1.	Landsat	7	2003	30m Spatial Resolution	USGS Earth Explorer
2.	Geological Data	---	---	1:50000 scale	GSI
3.	DEM	V2	2011	30m Spatial Resolution	USGS Earth Explorer
4.	Rainfall	---	2010-14	District wise	IMD

Methodology

In this study to generate the potential zones which are vulnerable areas for mass movement occurrence Analytical Hierarchy Process (AHP) are used. Analytical Hierarchy Process (AHP) is a mathematical algorithm which is highly proficient for decision making. Analytical Hierarchy Process (AHP) uses pair-wise evaluation and experts judgments to obtain priority scales (Saaty, 2008).

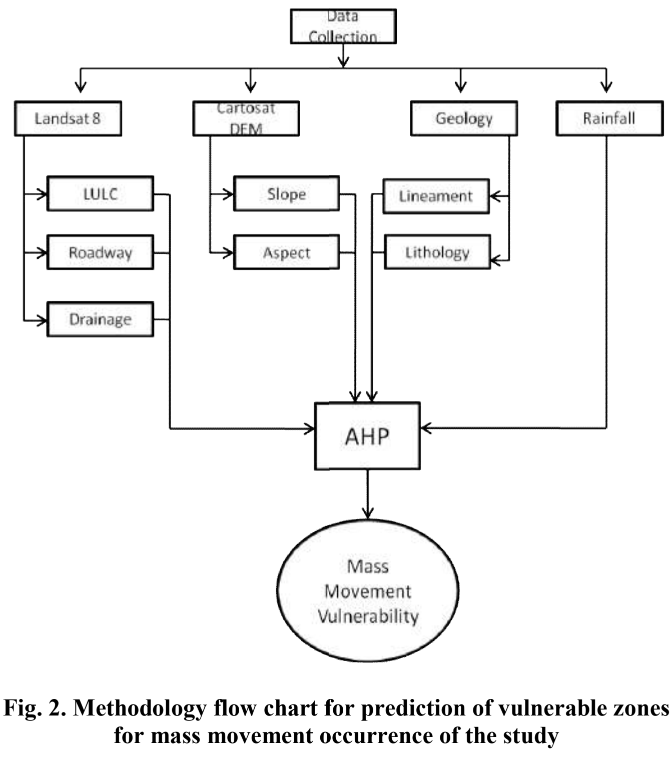


Fig. 2. Methodology flow chart for prediction of vulnerable zones for mass movement occurrence of the study

Landuse landcover (LULC) preparation

LULC map of Uttrakhand and Sikkim was prepared using the Landsat 7 ETM+ data (Fig. 3). For input in Analytical Hierarchy Process (AHP) supervised classification was implemented for generation LULC map of Uttrakhand and Sikkim. A negligible strip error was recognized in the supervised classification due to unavailability of cloud free data of the Uttrakhand study area. The classification of the areas was classified into 5 classes such as Barren, Snow, Scrub, Forest, Water body. For input in Analytical Hierarchy Process (AHP) it is required to assign the factors of influence. The factors were assigned according to the potential of the classes for occurring mass movement. The factors should range between 1 and 9. 1 means the least vulnerable factor for mass movement occurrence while 9 means the most vulnerable factor for mass movement occurrence. Example, Barren land has the maximum chance of mass movement so it will be give the highest value whereas areas which are densely covered with plant and trees such as dense forest areas have the lowest chance of mass movement occurrence (Table 2).

Table 2. Factor value assigned to Landuse landcover for mass movement occurrence

S.No	Class	Factor
1	Forest	1
2	Scrub	2
3	Waterbody	3
4	Snow	4
5	Barren	5

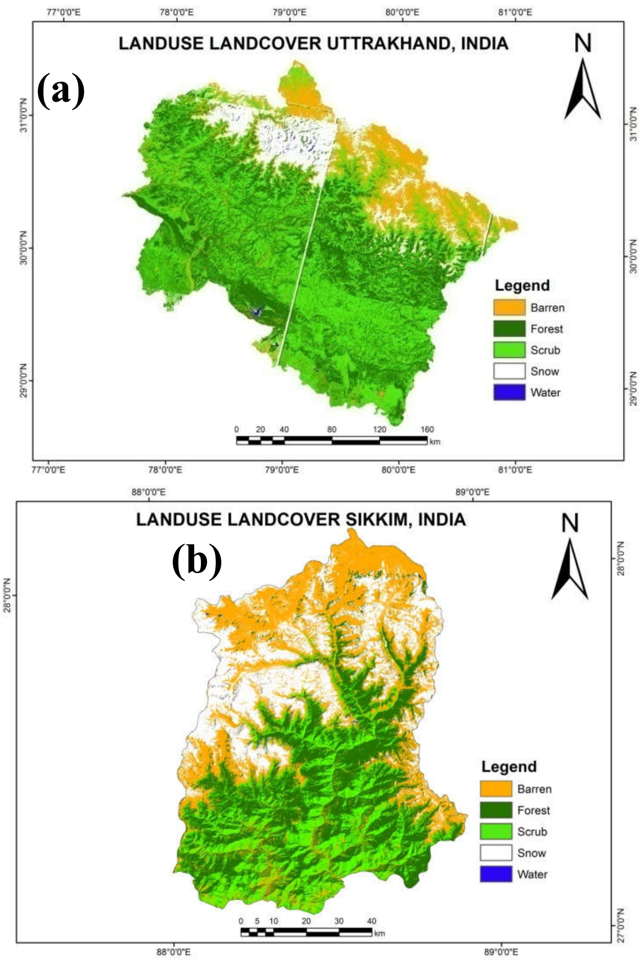


Fig. 3. Landuse Landcover (LULC) map of (a) Uttrakhand and (b) Sikkim prepared for input in Analytical Hierarchy Process (AHP)

The AHP accept only the raster data format to its execution and it is necessary to keep all geometric data similar with other input data such as cell size and the projection.

Topographical data preparation

For generation of slope angle and aspect direction of Uttrakhand and Sikkim USGS ASTER GDEM data is used in the GIS platform. Slope angle was generated and reclassified into 9 equal interval classes. These classes are further assigned the mass movement occurrence factor from low elevation angle to high elevation angle i.e. 1-9 (Fig. 4).

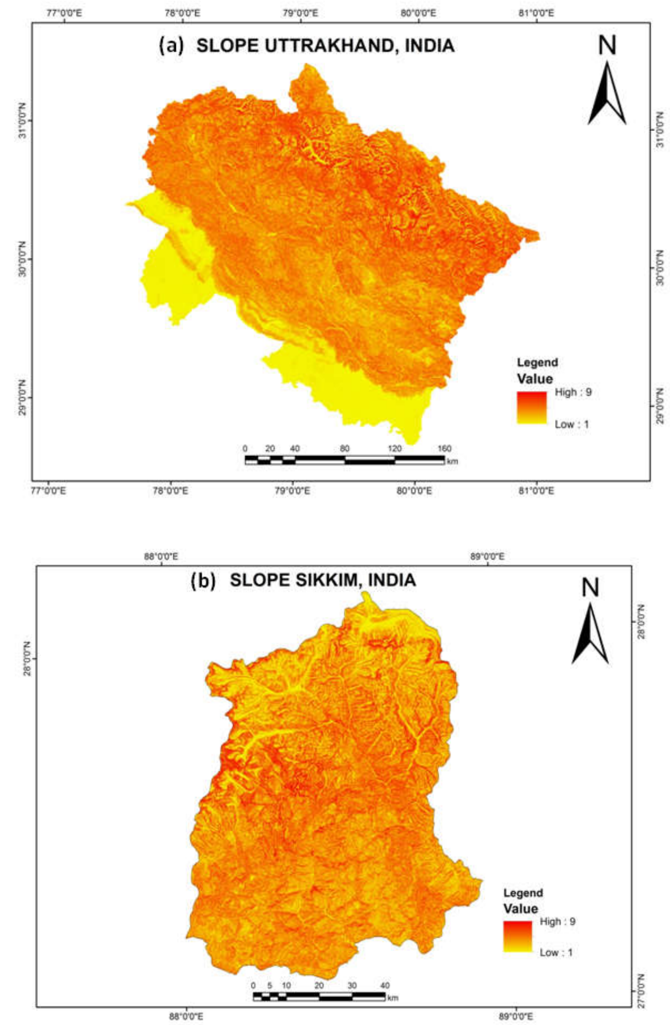


Fig. 4. Slope angle factor map of (a) Uttrakhand and (b) Sikkim generated using Digital Elevation Model (DEM) data

DEM data is also used to generate the aspect direction. Aspect direction is also an important parameter for identification of mass movement in any area. Aspect direction defines which region will face more concentration of sunlight and rainfall, which boosts the weathering process. Aspect direction is generated using the spatial analyst tool. The resultant represents the slope direction from -1^{o} to 359^{o}. This direction was equally classified into 9 directions and the factor value was assigned between 1 and 9 (Fig. 5). The study area is in the northern hemisphere therefore it can be assume that the aspect direction more than120^{o} from the north have the maximum influence of sunlight and the region experience more weathering process. It can be given the highest factor value whereas direction between 340^{o} to 40^{o} will be given the lowest factor because the region experience low sun rays.

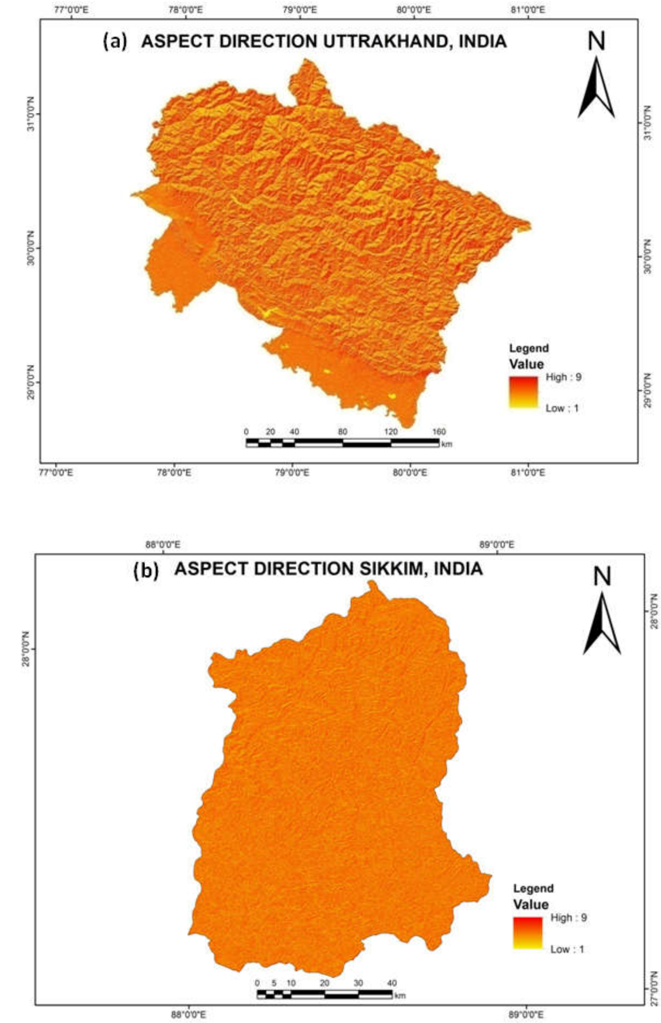
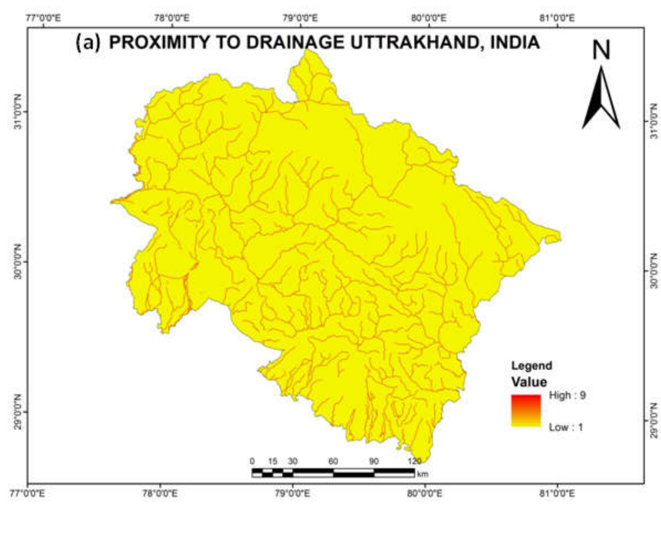


Fig. 5. Aspect direction factor map of (a) Uttrakhand and (b) Sikkim generated using Digital Elevation Model (DEM) data.

4.3. Proximity to Drainage

Drainage is extracted using the manual digitizing process. In case of drainage a nearness to drainage map have been generated for input in AHP. The regions which are away from the river have less chances of occurrence of mass movement whereas the areas which are more near to the river.



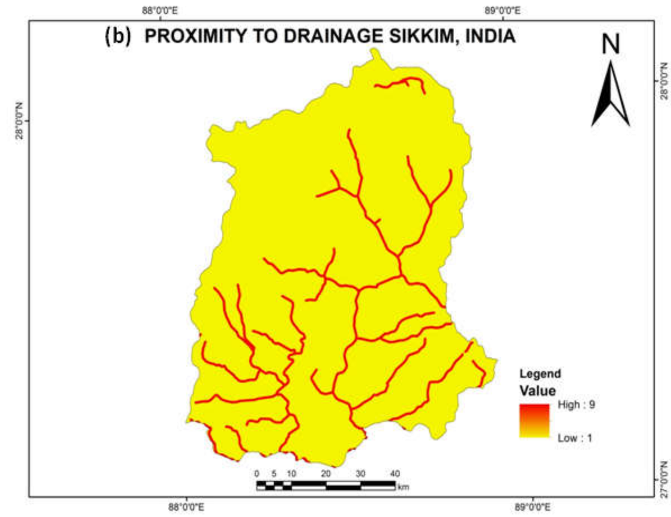
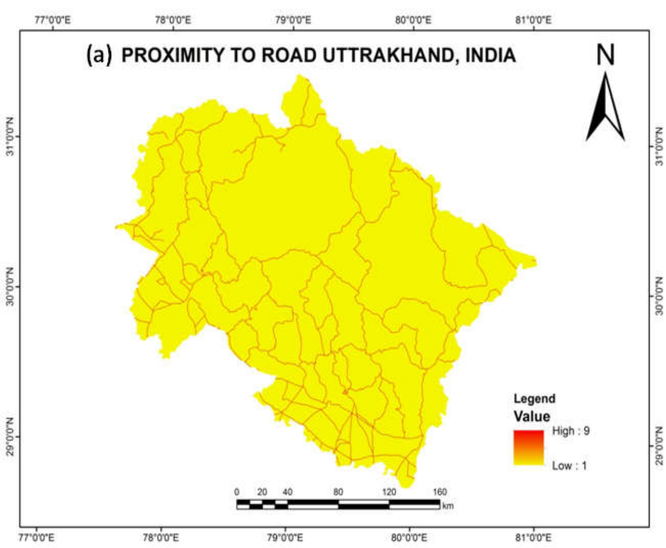


Fig. 6. Proximity to drainage factor map of (a) Uttrakhand and (b) Sikkim for input in Analytical Hierarchy Process (AHP)

Also the maximum influence distance of a river is estimated up to the distance of 500 meter. In this study a multi buffer analysis technique have been used. A 50 meter multiple buffers were created up to 450 meter. And factors from 1 to 9 were assigned in farthest to the nearest region (Fig. 6).

Proximity to Roadway

For study of potential vulnerable areas for mass movement we have considered the road parameter. Road is also an important influencing factor in many terms such as many heavy vehicles pass which generates vibration on the surface, roads provides accessibility for economic growth which results in deforestation and finally results in mass movement prone region. The cutting and drilling for construction of roads in mountainous areas are highly vulnerable for mass movement. For input in AHP Proximity to roadway map have been generated which indicates the region which are nearer to the road have the highest chance of mass movement and the region which are far it has low chance of mass movement and accordingly the factor value have be assigned (Fig. 7).



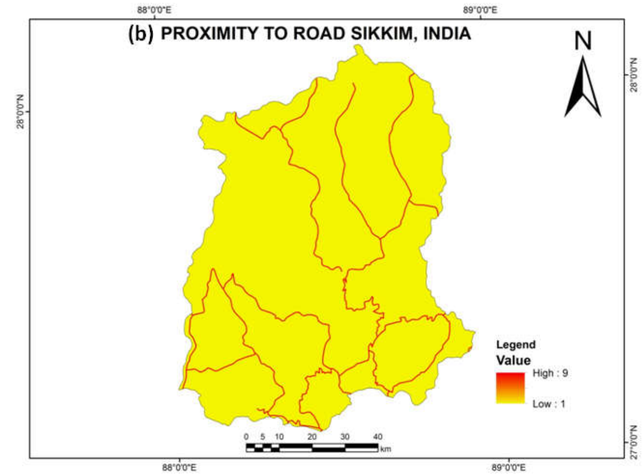


Fig. 7. Proximity to roadways factor map of (a) Uttrakhand and (b) Sikkim for input in Analytical Hierarchy Process (AHP)

Geology

Geological factor is an important factor for predicting the mass movement of any area. In this study geological data from Geological Survey of India (GSI) was used and manually digitized for input of geological configuration of Uttrakhand and Sikkim. Lithology of the study area was considered for input in the AHP process (Fig. 8). Lithological configuration of the study areas is assigned the influencing factor. The Leucogranite of the region have been given the lowest factor for mass movement occurrence. Orthogniess are given the highest factor because this geological configuration is more Vulnerable for mass movement occurrence.

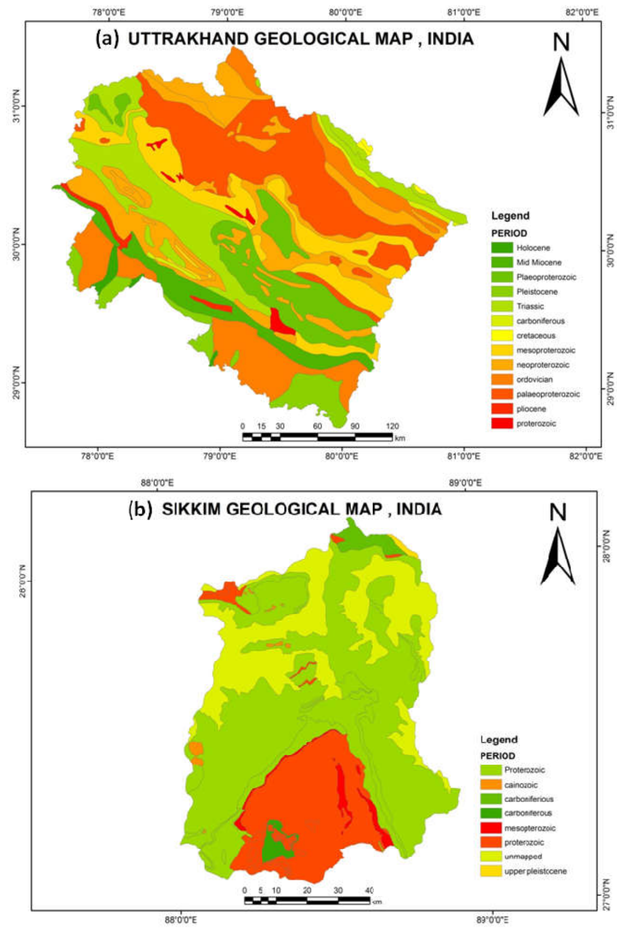


Fig. 8. Geological map of (a) Uttrakhand and (b) Sikkim for input in Analytical Hierarchy Process (AHP)

Rainfall

District wise monthly average rainfall data of Uttrakhand and Sikkim is obtained from Indian Meteorological Department (IMD) for the year 2010 to 2014. Average rainfall for 5 year of particular district was calculated using statistical tools (Table 3) and the factors for mass movement occurrence was assigned (Fig. 9). It is observed that Sikkim have high amount of average rainfall of about 1224mm at north district of Sikkim.

Table 3. Average rainfall of Uttrakhand and Sikkim

Uttrakhand			Sikkim		
District	5 Year Average Rainfall	Factor	District	5 Year Average Rainfall	Factor
Almora	465.525	1	East	1075.792	8
Bageshwar	652.9104	3	North	1224.45	9
Chamoli	631.3583	3	South	828.4644	5
Champawat	702.6875	4	West	869.8291	6
Dehradun	967.3917	7			
Haridwar	528.7333	2			
Nainital	840.9083	5			
Puri Garhwal	81.09167	1			
Pithoragarh	687.05	4			
Rudraprayag	665.2	3			
Uddham Ngr	561.8083	2			
Uttarkashi	748.2167	4			

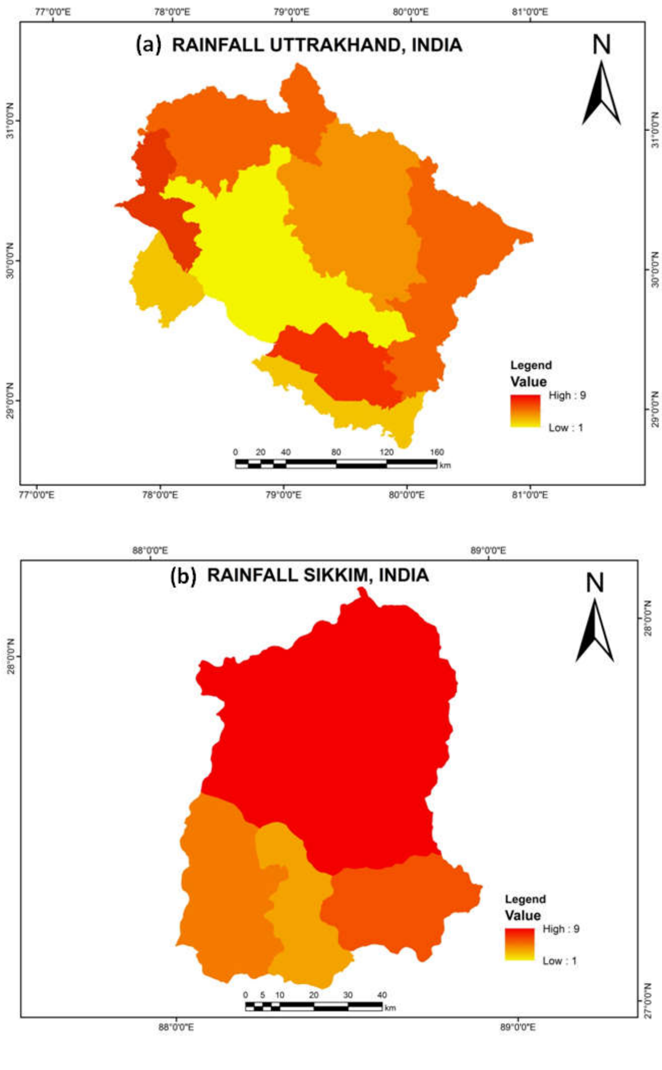


Fig. 9. Rainfall factor map of (a) Uttrakhand and (b) Sikkim for input in Analytical Hierarchy Process (AHP)

RESULTS AND DISCUSSION

In this study Analytical Hierarchy Process (AHP) was successfully applied for identifying the areas which are vulnerable for occurrence of mass movement for the area namely Uttrakhand and Sikkim. The result generated from AHP is categorized into level of vulnerability i.e. Low (1-2), Moderate (3-4), High (5-6) and Very high (7-8) (Table 4).

Table 4. Vulnerability categorized into low, moderate, high and very high

AHP Value	Vulnerability Level
1-2	Low
3-4	Moderate
5-6	High
7-8	Very High

The slope factor is given high factor in this study because greater part of these regions consists of undulated terrain. The results shows that majority of the region in both region Uttrakhand and Sikkim falls under moderate vulnerable zone for mass movement occurrence as shown in the bar graph (Fig. 10).

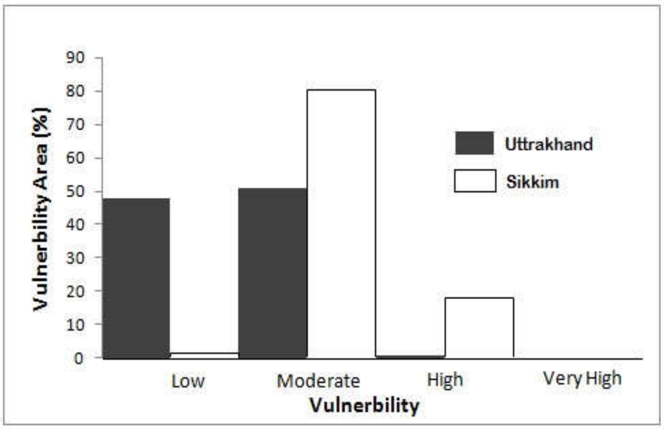


Fig. 10. Bar graph showing vulnerbility area in percent and level of vulnerability of Uttrakhand and Sikkim

The result demonstrate that about 48% of area of Uttrakhand falls under low range of occurence of mass movement. Uttrakhand has 51% of area under moderate range and 1% of total area under high range of occurence of mass movement. The Region near Didihati 29.945 N latitude and 80.508 E longitude at Uttrakhand indicated very high chance of occurence of mass movement. The region near Gangotri and Kedarnath also shows very high range of occurence of mass movement (Fig. 11). The result of Sikkim indicated that 86% of the total area falls under moderate range of occurence of mass movement, 17% in high range and around 1% in low range of occurence of mass movement. The results also shows that 1% of area of Sikkim falls in very high range. Very high ranges mostly falls in the North district of Sikkim. The region near Sakyong 27. 628 N latitude and 88.377 E longitude are very high zones of occurence of mass movement whereas other regions such as Jongsong Peak in north western Sikkim international border 27.941 N latitude and 88.208 E longitude, region near Ravangla, region near Sangkalang and lachung also falls under very high zones of occurence of mass movement (Fig 12).

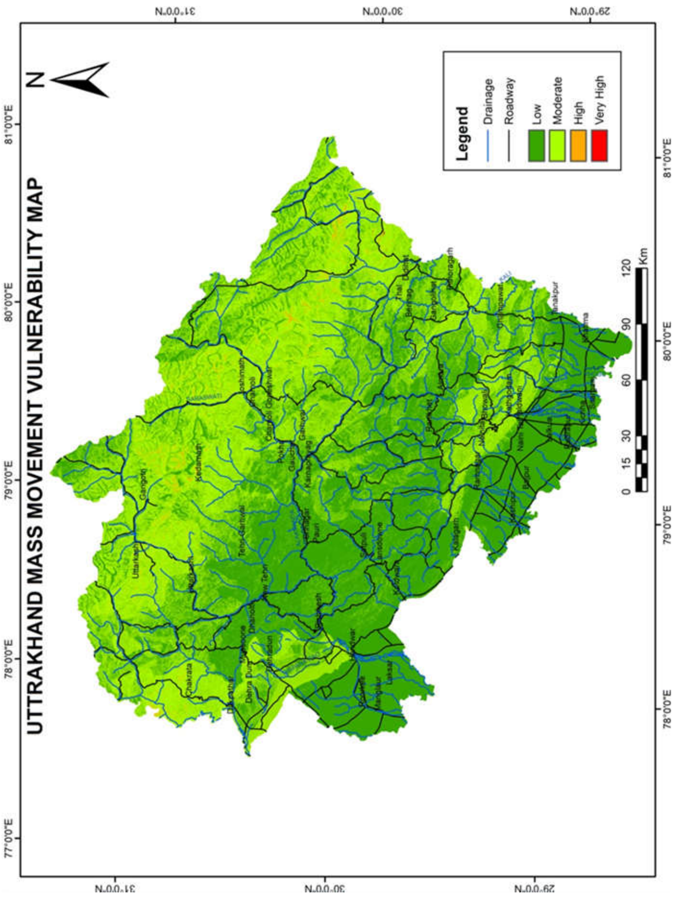


Fig. 11. Mass movement vulnerability map of Uttrakhand

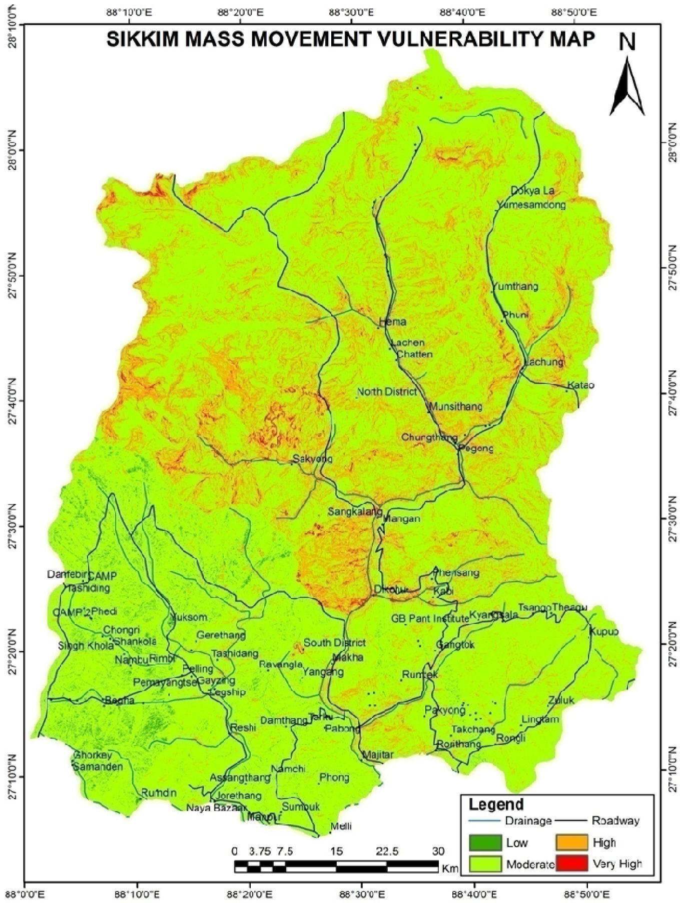


Fig. 12. Mass movement vulnerability map of Sikkim

Conclussion

Mass movement in an area is governed by many spatial parameters. In this study seven important parameters are incorporated for analysis of occurrence of mass movement in Uttrakhand and Sikkim region namely slope, rainfall, geology, drainage, roadway, landuse landcover (LULC) and aspect. These parameters can be easily acquired from geological maps, topographic maps, Digital Elevation Model (DEM), and satellite imagery and used as input in Geographical Information System (GIS) platform to predict vulnerable zones of mass movement, time and cost effectively. The result indicated Sikkim is more vulnerable for occurrence of mass movement with compared to Uttrakhand. It may be due to good amount of rainfall and the undulating topographical configuration experienced by Sikkim region which triggers the mass movement. Some areas near Sakyong in Sikkim illustrates very high chances of occurrence of mass movement. Reports from other sources also indicated that this region is vulnerable for instance the recent event of Dzongu landslide near Sakyong in North Sikkim which dumpped huge amount of debris in Kanka river and formed a landslide lake on august 2016, arising a risk of catastrophic flood due to sudden landslide dam break, this incidence is also reported by National Remote Sensing Center (NRSC). From the study it is found that Analytical Hierarchy Process (AHP) model with combination of Geographical Information System (GIS) is an excellent tool for prediction of mass movement, which can help decision makers for hazard management and early determination of safety measures.

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