ISSN2349-7831

International Journal of Recent Research in Social Sciences and Humanities (IJRRSSH)
Vol. 4, Issue 2, pp: (92-118), Month: April - June 2017, Available at: www.paperpublications.org

Monitoring and Assesment of Landslide from Agastmuni To Sonprayag

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Abstract: **The present work is concentrated on the landslides which are very common disaster in the Himalayan region. This specific research theme was attempted taking cues from preparation of a landslide inventory, damage assessment, hazard mapping and subsequently risk analysis. Moreover Landslide change detection of two event pre and post Digitized based on visual interpretation over LISS4 image.**

Landslide inventory, a catalogue of present and past landslides prepared by comparing pre and post Kedarnath disaster from a high resolution IRSP6 LISS4 image. Multiple landslides are identified and marked along the Mandakini River course in the inventory map. For susceptibility mapping eight data layers viz Geology, Geomorphology, Slope, Aspect, Distance to lineament, Soil type stream order, NDVI and LULC were created from different sources like SRTM DEM (30M), high resolution multispectral image, soil map etc. Then by weighted overlay in which weights are assigned to each layer according to their influence, susceptibility map is prepared. The statistics of the map indicate that 4% of the area is under high susceptible zone.

After that vulnerability and risk assessment analysis was carried out considering agriculture, built-up and road as important elements. According to the obtained vulnerability map only 7% of the area is under high vulnerability zone where most of the built-up and road is concentrated. The final map is the risk map which shows that only 3% of the total area is under high risk zone.

Keywords: **Landslide, Hazard Mapping, Susceptibility Map, Vulnerability Map, Risk Mapping.**

I. INTRODUCTION

Landslides are defined as the movement of a mass of rock, debris or earth down a slope under the action of gravity. These include mass movements of all kinds namely falling, sliding and flowing and often take place in combination with cloudburst, heavy rainfall, volcanic eruption, earthquakes, and floods majorly in high altitude regions. The factors controlling slope instability include geology, geomorphology and hydrology along with complex tectonics, geodynamics and meteo-climatic factors. Increased urbanization, accompanied by expansion of roads also creates an increasing pressure on the landscape, and leads to higher degrees of vulnerability. The destruction of forests and the vegetative cover that binds the top soil at an increasing pace and the conversion of forest land into agricultural and horticultural holdings also adds to the increasing landslide susceptibility of the terrain. A Hazard is a perceived natural event which has the potential to threaten both life and property-a disaster is the realization of this hazard '(Whittow,1980).Hazard is considered as disaster when there is huge destruction caused in the area and there is extreme loss of human life and property. Disasters can be induced by both human activities and natural events.(Goel,2007). There is an unexpected death of human beings, damage to building facilities, transportation facilities, etc. during these events. (Goel,2007). There has been observed increase in disasters during the percent time period as a result of expansion of urban activities, industrial growth, unplanned use of the land, and particularly due to activities in the risk/hazard prone zones.(Goel, 2007). Natural disasters are increasing now-a-days due to an imbalance in the natural equilibrium caused as a result of human activities in particular. (Goel,2007).

The incidence of disasters can be heard from different parts of globe. The commonly occurring hazards causing major disasters are tsunami, earthquakes, landslides, floods, droughts, cyclones, volcanic eruptions, etc. Developing countries like Asia are the hotspots of major disasters where there is variation in monsoon pattern resulting in flood and drought conditions, cyclone events in the coastal zones, seismically inactive Himalayan belt resulting in landslides and earthquakes. (Goel, 2007).

Landslides constitute one of the major damaging natural disasters in the worldoccursin high mountainous region in response to a wide variety of terrain conditions as well as triggering processes like heavy rainstorms, cloudbursts, earthquakes, and unsafe developmental activities. It is a common phenomenon especially in the lower Himalayas which is a tectonically fragile and sensitive mountainous terrain (**Ghosh&Suri., 2005).** Asia undergoes the maximum damages / losses due to landslides in general and the south Asian nations, in particular, are the worst sufferers. Furthermore, among the south Asian countries, India is one of the affected countries by landslides. In this particular zone, especially interaction between local geology and the long-term climatic conditions result in significantly different landforms with varying degree of susceptibility to land sliding (**Kuldeep et al., 2012).** Although landslides are local phenomenon, but the total loss of life and property due to this event is far greater than any other hazard. In India, approximately 15% of its territory is prone to various degrees of landslide hazard **(GSI, 2009),** frequently affecting the human life, livelihood, livestock, living places, structures, infrastructure, and natural resources in a big way. In addition to direct and indirect losses, landslides cause significant environmental damages, societal disruption and strategic concern. Statistically it has been estimated that annually on an average about 300 human lives are lost and approximately Rs.300 Cores are lost every year.

Landslides also known as landslips, in its firm sense is a geological phenomenon that includes a wide range of movement of a mass of rock, debris or earth down slope, due to gravitational pull, and in general are triggered by a variety of external factors such as intense rainfall, earthquake shaking, water level change, storm waves and rapid stream erosion etc. **(Dai et al., 2002).**Typically , pre-conditional factors build up specific sub-surface conditions that make the specific area/slope prone to failure , whereas the actual landslide often requires a trigger before being released. These triggering factors have an influence in increasing the shear stress and decreasing shear strength of slope forming materials beyond a threshold limit and cause failure. In addition to that due to the impact of rapid urbanization and human interventions in terms of developmental activities relating to expansion on unsafe locations, unscientific mining, unsafe construction of roads, dams and river training works together with growing population eventually create undesirable pressure over land especially in unstable slopes in hilly terrain, pose increasing risk to human lives, buildings, structures, infra-structures and environment. However changing climatic condition in the form of global warming, glacial melting, erratic and uneven rains, and extreme temperature conditions etc. are also extending these risks to even unexpected areas. Moreover large scale deforestation along with faulty management has led to increased vulnerability to landslides in many regions of the country. All the factors are responsible to increased intensity of landslides. In this regard it is mandatory to take national strategy for disaster management by the national disaster management authority through national disaster policy and guidelines on management of landslides. Having knowledge of the diversity of issues associated with national landslide problem inputs from a wide variety of stakeholders are essential. Hence, strengthening the process of landslide assessment, investigation, mapping and management is sure to have far reaching effects in reducing landslide losses. Now the main concern is the causes which may be considered to be factors that makes the slope unstable. The trigger is the single events that finally initiate the landslide. Thus, causes combine to make a slope vulnerable to failure, whilst the trigger finally initiates the movement. Landslide can have many causes. Usually, it is relatively easy to determine the trigger after the landslide has occurred (although it is generally very difficult to determine the exact nature of landslide triggers ahead of a movement event).Majority of cases, the main trigger of landslides is heavy or prolonged rainfall. Generally, this takes the form of either an exceptional short lived event, such as the passage of a tropical cyclone or even the rainfall associated with a particularly intense thunderstorm or of a long duration rainfall event with lower intensity, such as the cumulative effect of monsoon rainfall in South Asia. In the former case, it is usually necessary to have very high rainfall intensities, whereas in the latter the intensity of rainfall may be only moderate. In a general sense this phenomena increases the pore water pressure within the highly dissected rock mass and eventually initiates the slide. There are types of landslides based on the material or movement is given.

It is a matter of concern for the government and disaster management authorities at present to take necessary actions and measures for the mitigation of the problems which are caused as a result of the landslide events which area common phenomenon in the northern part of India in the Himalayan belt. Proper investigation has to be done in the landslide prone zones and according to the important steps are needed to be taken in order to reduce the effects which are caused by this event. Landslide assessment by inventories (past and current landslide occurrence), mapping of hazardous zone (delineating the areas where landslides may occur in the future) are essential before any mitigation and evaluating the associated risk to population, infrastructure and property. Knowledge of this particular issue is importance to land use planning, engineering design and civil protection program which aim to minimize human and material losses due to landslides. It is also evident that disaster prevention and mitigation strategies cannot be appropriately implemented without suitable landslide-related maps **(Herva´s et al., 2003).** Consequently, extensive landslide mapping program at adequate scales as well as the application of cost-effective methods and models for reliable and comparable landslide susceptibility is a much more needed issue in hazard and risk assessment and mapping. However these tasks needed extensive data collection and modeling work.

Susceptibility of landslide relates to the affinity or probability of the occurrence of the landslide events in a given area. (Fell et al., 2008). Susceptibility involves the zonation of the area on the basis of the relative weightage given to the factors responsible for causing landslide like slope, lithology, geomorphology, and other terrain factors .(Fell et al., 2008).

Vulnerability of elements at risk is an important issue in order to make risk zonation. One of the most useful definitions of risk is presented by Varnes (1984) as the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular damaging phenomenon for a given area and reference period. It is important to have an estimate of loss caused to the elements at risk post disaster so as to make a risk zonation map. (Varnes. 1984).

A number of approaches has been adopted for the landslide risk assessment (Bonnard et al. 2004; Lee and Jones 2004; Eberhardt et al. 2005; Glade et al. 2005).Here the main focus of the study is to make a landslide risk zonation map including the factors of susceptibility and the elements of vulnerability by applying the multi criteria decision making approach. (Eastman et al., 1993a; Eastman et al.1993b). The multi criteria decision making approach is based on the Analytical Hierarchy Process developed by Saaty in 2008. (Saaty, 2008). Based on the Saaty scale the AHP is used to get weights for the different parameters causing landslide and the different elements which are affected by landslides (Feizizadeh and Blaschke, 2011). The weights are then applied to the raster layers in order to generate the final output by using the Weighted Linear combination method in the GIS domain. (Ayalew et al., 2004). This method is based on the weightages given by the different experts(Ishizaka and Labib, 2009) who have worked on landslides and also those who have an idea about the conditions which will cause landslide to occur and the situations post landslides.

A. Problem Statement:

Since Himalaya is tectonically active zone, there are incidences of landslides every year. This region is not stable enough economically and thrives on tourism and pilgrimage. The whole economy of the region is dependent on tourism because of very high altitude, rugged terrain (relative relief around > 600m), less agricultural land, extreme environmental conditions and lesser amount of industrial development .Therefore the frequent landslides is the greatest threat for the economy of the mountains. The landslides becomes more aggravated especially during monsoon season though the main causative factors behind the instability of land surface are mainly geomorphologic and geological in nature. Frequent seismic events also play a major role in inducing such a large number of landslide since the investigated area holding number of faults especially surrounded by main central trust. The Garhwal Himalaya region has a history of landslides and frequently it suffers from this disaster .Some very well-known landslides are, in the year 1991 Uttarkashi earthquake caused numerous massive landslides, particularly on a 42 km road stretch between Uttarkashi and Bhatwari (Jain et al., 1992),in the year 1998 Malpa landslide in Uttarkashi killed 300 people including 60 pilgrims of Kailash-Manasarovar Yatra (The Hindu, 1998) .Landslides induced by earthquake shocks again spread devastation in the year 1999 in Chamoli district of Uttarakhand (Kimothei et al., 2005).Last but the most horrible and devastating one is the Kedarnath tragedy of June 2013 caused due to cloud burst induced heavy rainfall.

ISSN2349-7831

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Since this area is very much important from a tourism point of view and landslide events along the roads completely cut off the supply line of various dispersed hill stations. Thus it is necessary to have proper planning and measures to mitigate and reduce the disastrous impacts of landslides.

This small research is an attempt towards detecting the landslide susceptible and vulnerable area through mapping together with risk assessment.

(1) Concept of Landslide:

A landslide is the movement of a mass of rock, debris, or earth down a slope, under the influence of gravity (Cruden and Varnes, 1996). Varnes (1978) defined landslides as the downward and outward movement of slope forming materials composed of rocks, soils or artificial fills‖. The movement mainly occurs when the inter-granular movements exceeds the shear surface movement. (Varnes, 1978). This movement can be debris flow, rock fall, lateral spread, depending on the type of material which is predominant in that particular movement. (Varnes, 1978). There are many causes which triggers landslides like slope instability, low vegetation cover, increased soil moisture content, seismic movement, weathering, and presence of lineaments and faults.

(2) Landslide inventory:

Landslide inventory is the most important part in damage assessment as it gives the location of the landslides. Landslide inventory is the first step which is required for making susceptible map. The distribution of landslides, the types of mass movements, the areas where landslides have occurred, the date of incidence, the past and present movement of slides can all be inferred from the landslide inventory map. (Pašek, 1975; Hansen, 1984a; 1984b; McCalpin, 1984; Wieczorek, 1984; Guzzetti et al., 2000).Preparing landslide maps is important to document the extent of landslide phenomena in a region, to investigate the distribution, types, pattern, recurrence and statistics of slope failures, to determine landslide susceptibility hazard, vulnerability and risk, to study the evolution of landscapes dominated by mass-wasting processes‖.(Guzzetti et al., 2012). There are various methods of preparing a landslide map, the most widely accepted and conventional way is visual interpretation technique on very high resolution imagery like LISS4,Geoeye-1, quick bird, etc. The landslide areas can be further validated by field survey/investigation. Remote sensing technique along with GIS helps a great deal in making a landslide inventory map which is cross checked with field investigation for more accuracy.

Susceptibility mapping:

Landslide susceptibility mapping is basically an indirect method describes the degree of landslide susceptibility on the basis of multiple factors that state the occurrence of landslides which is being practiced by various scientists based on a number of factors like geology, slope classes, soil depth or land use etc. In the last four decades, several qualitative and quantitative studies have been carried out to prepare landslide hazard maps. Many different indirect methods have been applied, which can be subdivided into heuristic, statistical and deterministic approaches (**Soeters& Van Westen, 1996).** Since the susceptibility mapping involves handling, processing and interpreting a large amount of territorial data, thus, Geographical Information Systems (GIS) proved to be very important tool in susceptibility mapping and tremendously helped to prepare maps with greater efficiency and accuracy than before. (**Aleotti&Chowdhury, 1999; Ayalew et al., 2005).**

(Clerici et al., 2006) distinguished three distinct categories of methods for landslide susceptibility mapping: the deterministic (or engineering, or geotechnical), the heuristic (knowledge based indexing) and the statistical methods (based on landslide inventories).

Deterministic approaches, based on stability models, rely upon the understanding of the physical laws controlling slope instability (Okimura & Kawatani, 1987; Dunne, 1991; Montgomery & Dietrich, 1994; Dietrich et al., 1995; Terlien et al., 1995)ncan be very useful for mapping hazard at large scales. Deterministic landslide hazard maps normally provide the most detailed results, expressing the hazard in absolute values in the form of safety factors, or the probability of failure.

In the heuristic methods, the causative factors are ranked and weighted according to their assumed or expected importance in causing slope failures. Since the ranking and weighting rules are based on the experience of geoscientists involved, therefore this method requires a substantial degree of subjectivity.

The statistical methods are more objective and better suited for assessing land sliding probability, especially at medium scales. All the statistical methods, despite the methodological and operational differences, are based on the common assumption that slope failure in the future will be more likely to occur under those conditions which led to past and present instability **(Clerici et al., 2006).**

Risk mapping:

Landslide Risk Mapping not only considers the exposure (or elements at risk) and vulnerability but it also includes the susceptibility/hazard. (Jelínek, 2007).Risk mapping is an important component of hazard analysis. It includes both susceptibility and vulnerability assessment of elements (like settlement, road, and Landuse) taken under consideration for risk analysis. A number of landslide risk methods have been published recently which gives a good idea of making landslide risk mapping and assessment.(**e.g., Cruden and Fell1997; Guzzetti 2000;Dai etal.2002).** For small scale areas risk indexes has beendone. (**Davidson1997;Carreño etal.2007).**The landslide risk zonation done at small scale areas can help in giving the high risk areas more priority and thus the local authority can better take care of that and proper mitigation measures and management can be done.(**Abellaand Westen,2007).**

B. Causual Factors:

The force governing the dynamic landscape processes is the constant pull of gravity which makes all hill slopes susceptible to failure. Upon failure, the earth material moves down slope until slope stability is re-established. Besides gravity, geology, geomorphology, hydrology and anthropogenic factors contribute largely towards destabilization of slopes.

The USGS landslide group classifies the causal factors as follows:

1) Geological causes

a) Weak or sensitive materials

b) Weathered materials

c) Sheared, jointed, or fissured materials

d) Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth)

e) Contrast in permeability and/or stiffness of materials

2)Morphological causes

a) Tectonic or volcanic uplift

b) Glacial rebound

c) Fluvial, wave, or glacial erosion of slope toe or lateral margins

d) Subterranean erosion (solution, piping)

e) Deposition loading slope or its crest

f) Vegetation removal (by fire, drought)

g) Thawing

h) Freeze-and-thaw weathering

i) Shrink-and-swell weathering

3) Human causes

a) Excavation of slope or its toe

b) Loading of slope or its crest

c) Drawdown (of reservoirs)

d) Deforestation

e) Irrigation

f) Mining

g) Artificial vibration

h) Water leakage from utilities (Source: http://landslides.usgs.gov/)

C. Landslide monitoring and assessment:

landslide monitoring of two year pre event and post event to see changes after the kedarnath disaster. in 2011pre event there were only 150 landslides after the kedarnath disaster caused by cloud burst and heavy rainfall landslide increased It is observed after the Kedarnath tragedy, the chances of landslides occurrences in this region getting increased in comparison to the previous result. Simultaneously the vulnerable and risk zones are also increased than before. It may be the huge river cutting and soil erosion due to the massive outburst flood makes the slope more unstable, and finally makes this region more susceptible to landslide.

On the basis of various thematic layers viz. Geomorphology, LULC, Slope, Aspect, Distance to lineament etc. and together with landslide inventory, the susceptible map was accomplished using weighted overlay method. The weights were computed for every factor was added in order to discover susceptibility map. The final output map was normalized and classified into 3 classes. To validate the result of the study, inventory map was generated based on the pre and post event satellite imagery was to combine to the susceptibility mapping and ground truthing. This present study also encountered subsequent vulnerability and risk analysis with a quantitative approach. In this context build up areas of Gaurikund and Sonprayag, Ukhimath, Agastmuni region and the main connecting tracking route between Gaurikund to Ukhimath comes under high risk zone.

The present study is mainly focusing on to find out the landslide susceptible zone from Gaurikund, Sonprayag to Agastmuni region with vulnerability and risk analysis after the shaking Kedarnath disaster of June 2013 with the help of remote sensing and GIS technology. In modern days RS and GIS technology play a vital role in landslide hazard assessment and analysis. Again RS and GIS is also a very excellent tool for displaying the spatial distribution of landslides with their nature.

STUDY AREA:

Overview of Area:

It study about Uttarakhand state Rudraprayag district covers an area of about 2439 sq. km lies between latitude 30°19’ and 30°49’ North and longitude 78°49’ and 79°21’East , falling in the survey of India top sheet numbers 53J 53N. The district is bounded by Uttarkashi in north, Chamoli in the east, Tehri Garhwal in the west and Pauri in the south. Major part of it is under forest. Intermittent sparse patchy terraced cultivation is also practiced on fairly steep hill slopes whereas dry and wet cultivation are prevalent on the uplands and low-lying valleys respectively. The proper study area is situated on the Mandakini River basin. The district has network of roads of 1372 kms which connects its major towns to its head quarter. The only national highway is from Rishikesh to Badrinath, which runs parallel to river Ganga and Aleksandra. The road bifurcates from Rudraprayag and goes up to Gaurikund all along river Mandakini. Pathways, Kaccha road and tracks play an important role in providing movement facility and communication in the difficult hilly terrain of rural area of the district. Rail links are not available in the district.

Frequent slope failures are observed during monsoon majorly along National highway. . Landslides here are the outcome of intense rainfall, complex tectonic setting with unique geomorphology of steep slopes and dissected hills.

At an elevation of 1829 mts. and on the main Kedarnath route, Sonprayag lies at the confluence of river Basuki and Mandakini. The holy site of Sonprayag is of immense religious significance. It is said that a mere touch of the holy water of Sonprayag helps one to attain the “BaikunthDham”. Kedarnath is at a distance of 19 kms. From Sonprayag. Triyuginarayan, which is supposed to be the marriage place of Lord Shiva and Parvati, is at a distance of 14 kms. By bus and 5 kms. On foot from here **(http://rudraprayag.nic.in/pages/display/61-sonprayag**)

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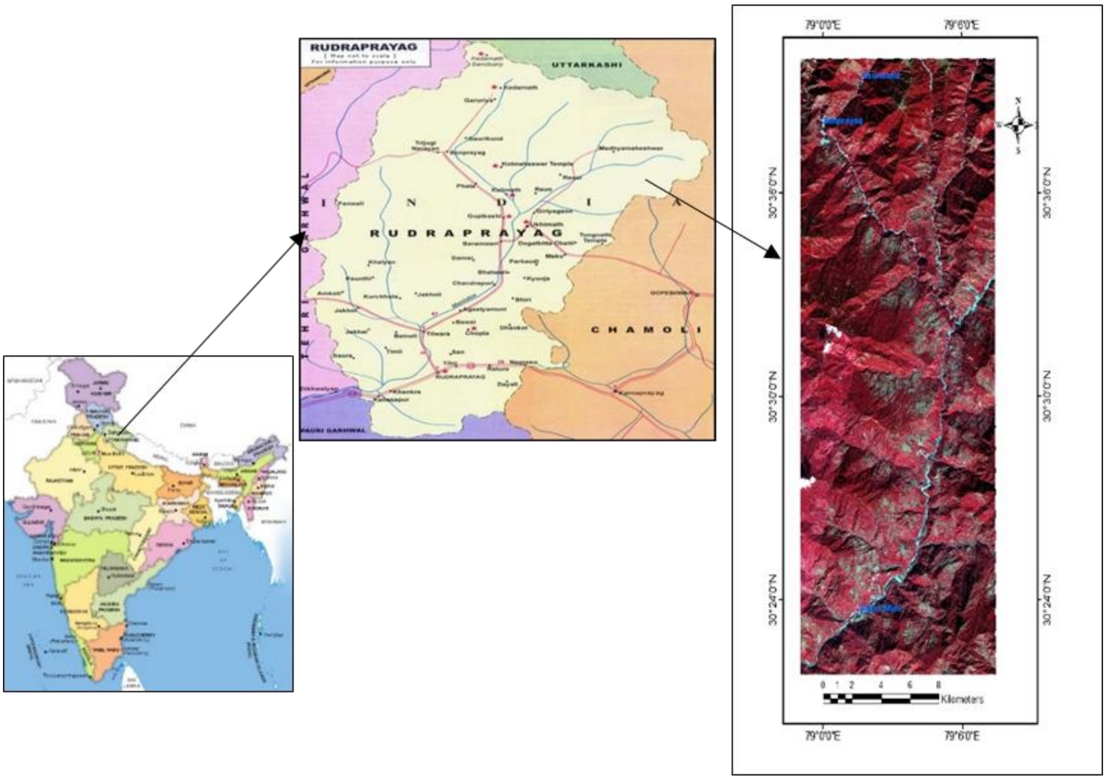

Geographical Extension:

30°3957.24N-30°2154.32N Latitude

78°5904.73E-79°0718.89E Longitude

Figure:1. Image and location of Study Area

Climate and Rainfall:

The climate varies from sub-tropical monsoon type (mild winter, hot summer) to tropical upland type (mild and dry winter, short warm summer). Some parts of the district is perennially under snow cover. Severe winter and higher rainfall are the characteristic features of the northern part. The year is divided into four seasons viz. the cold winter season, (December to February), the hot weather season (March to May), southwest monsoon season (June to September) followed by post monsoon season (October to November). In the lesser Himalayas maximum rainfall occurs in southern half which is about 70 to 80%. August is the rainiest month, it decreases rapidly after September and is least in November. About 17% of total annual rainfall occurs in winter season. The winter precipitation is in association with snowfall particularly at higher elevation. The precipitation during pre-monsoon which is about 7% of total annual rainfall and the post monsoon is frequently associated with thunderstorms. The overall average rainfall in the district is 1485mm, in the northern part at Ukhimath it is 1995mm.

D. Geomorphology:

Geomorphological Rudraprayag district is divided into two major units the high danudational mountain and the river valleys. Separated from Shiwalik by the Krol thrust is the Lesser Himalaya which characteristically wide and mature topography with gentle slopes and deeply**.**Dissected valleys suggestive of furiously Active River and streams. Denuded and rugged terrain of Lesser Himalaya are characterized by many transverse spurs emanating from the Great Himalaya.

E. Soil:

The soils have developed from the rocks like granite schist, slate, gneiss, phyllite, shale, slate etc. under cool and moist climate. The very steep to steep hills and glacio-fluvial valleys are dominantly occupied with very shallow to moderate excessively drained , sandy to loamy , neutral to slightly acidic with low available water capacity soil. Soil cover in terraces is generally very thin, cultivated areas with moderate slopes have relatively thicker soil cover and precipitous

ISSN2349-7831

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slope are generally without soil cover. In cliffs the soil exists along the cracks. Fine soil is found abundantly on moderate slopes, while coarse soil is abundant on steep slopes.

F. Geology of the Area:

The rock formations of this area belong to Lesser Himalaya some from Outer Lesser Himalaya and most are from Inner Lesser Himalaya. The overall geology of the Lesser Himalaya is given in the table below.

Table 1. Stratigraphic sequence of lesser Himalaya (by Valdiya)

	Outer Lesser Himalaya	Inner Lesser Himalaya
		Vaikrita Group(Early Precambrian) --------Vaikrita(Main Central) Thrust------
Almora Group	Gumlikhet Fm. ChampawatGranodiorite Saryu Fm.	Munsiari Fm.
Ramgarh Group	----------- Almora Thrust--------- DebguruPorphyroid Nathuakhan Fm.	------------Munsiari thrust------------ Barkot and Bhatwari units ---------Barkot-Bhatwari Thrust--------
Sirmur Group	-----------Ramgarh Thrust------------- Subathu Formation (Lower Eocene) Singtali Fm.(Palaeocene)	
Mussoorie Group	Tal Formation(Permian) Krol Formation Blaini Formation	Berinag Formation
Jaunsar Group	Nagthat Formation Chandpur Formation Mandhali Formation --------------Krol Thrust----------------- Subathu (Lower Eocene)	------------Berinag Thrust---------------
		MandhaliFormation (Upper riphean-Vendian)Tejam Group Deoban Formation(Upper-MidRiphean)
Damtha Group	Rautgara Formation Chakrata Formation	Rautgara Formation (Lower to Mid Riphean)

The following groups and formations are exposed in study area:

1. Jaunsar Group

-Berinag Formation: this comprises of huge massive, coarse grained to pebbly or even Boulder and usually silicate quartzarenite of white, pale purple and green color with metamorphosed amygdaloidal vesicular basalts and tuffites.

2. Ramgarh Group

This group comprises of quartz-porphyry and porphyritic granite suite occurring in a succession of phyllites, fine grained quartz wackes and metasilt stone and carbonaceous pyritous slates alternating with banded white blue marble.

3. Almora Group

This group basically consist of crystalline rocks. Important components of this group is types of schist, gneisses and metamorphic rocks,

ISSN2349-7831

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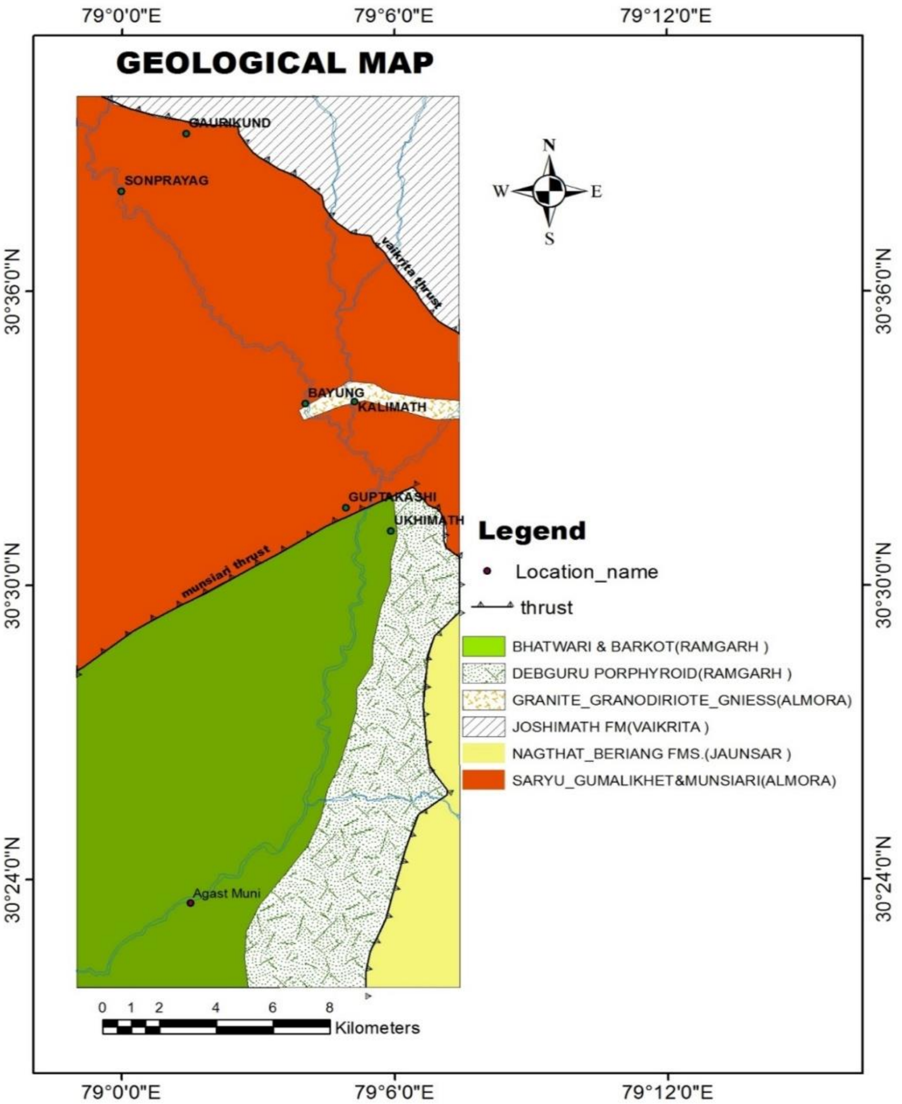
4. Vaikrita Group

This group comprises very coarse grained kyanite and locally sillimanite bearing garnet-muscovite-biotite psammitic gneiss inter bedded with garneti ferrous kyanite muscovite-biotite schist.



Source: Vaidya 1980

Figure 2.Geological map of the Study Area

G. 4. DATA SETS, MATERIAL & METHODOLOGY

H. Data Set Used:

1) Optical Data***:***

2) LISS-IV, resolution(5.6m)

3) SRTM DEM, resolution(30m)

4) Software Data used:

- Arc GIS
- Erdas Imagine
- ILWIS

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5) Ancillary Data used:

- Geological map(Vaidya 1980)
- Land use land cover map(IGBP)(2005)

I. Materials:

For any scientific research work some materials are needed which are to be processed to get desired result. So this project need many materials including the satellite images together with other ancillary data as well as ground truth data (field information). Various thematic layers were prepared to make input parameter for landslide inventory, susceptibility mapping, risk mapping and Landslide change detection with the help of Digitized based on visual interpretation over LISS4 image& various software's like ArcGIS 10.2.2, ERDAS IMAGINE 2013,

Table 2.Thematic layers and their source of generation

SL No	THEMATIC LAYERS	SOURCE
LANDSLIDE INVENTORY		
1	Landslide location map	Pre and Post LISS4 image.
SUSCEPTIBILITY MAPPING		
2	Slope	
3	Aspect	Generated form srtmDEM (30 m)
4	Geology	Geological map (Thakur)
5	Structural features (lineaments)	Imageenhancement (edge detection) IRS-P6 (LISS-4) image.
6	Drainage	Digitized over LISS4 image
7	Land use/Land cover	Digitized based on visual interpretation over LISS4 image
8	Mass Wasting	Digitized over LISS4 image
9	Soil Type	Soil Map
10	Vegetation	Supervised Classification (Maximum likelihood), (Validate with National Biodiversity map of India)
11	Geomorphology	Digitized based on literature survey
RISK MAPPING		
12	Settlement	Digitized over LISS4 multispectral image
13	Road	and Cartosat-1 cross checked with Google Earth
14	Agricultural field	
LANDSLIDE CHANGE DETECTION PRE AND POST DATA		
15	Landslide changes	Pre and post image liss4 2011and 2013) Digitalized over LISS4 image

J. Data Preparation for Landslide Inventory Mapping

For the preparation of landslide inventory map main focus is on very high resolution optical imagery for identification and mapping of landslides. This mapping is done by using high resolution Resource SAT LISS4 (5.8m) multispectral image for post disaster event dated (1.12.2013) and same for pre disaster event dated (17.12.2011) for identification of landslides. The resulted work is further validated through Google Earth temporal images. Since the study is not so large, the visual interpretation method gives good result.

K. Data Preparation for Susceptibility Mapping

For the preparation of landslide susceptibility map various the matic data layers (slope, aspect, geology, distance to linear features, Land use/Land cover, soil type, Drainage, vegetation, geomorphology, mass wasting) were generated in using ARC Map. Subsequently, all the vector layers, excluding the image processed map (slope, aspect), were converted into raster layers. A brief description of the same is given below:

❖ SRTMDEM (30M) resolution was used to derive topographic parameters that is slope and aspect.

❖ Lineament map was generated by spatial enhancement techniques mainly edge detection directional filters over IRS-LISS 4. Subsequently these linear features were rasterized and created buffer zones of 100m, 200m and 300m.

❖ Land use/Land cover was prepared through visual interpretation and digitized over LISS4 multispectral image. The resultant land use/ land cover was further verified with LULC map provided from Forestry Department.

❖ Soil map is prepared through digitization over Soil Map of Uttarakhand of National Bureau of Soil Survey and Land Use Planning

❖ Geology basically reflects the lithology means rock type which is one of the important influencing factor for landslide .Geology map is digitized over the Geological Map of Vaidya 1980.

❖ Geomorphology map is prepared by digitization over multispectral LISS4 image and further verified from the Geomorphological Map of Uttarakhand available on Bhuvan portal.

❖ Mass wasting layer is prepared by digitizing over multispectral LISS4 image.

L. Data preparation for risk map

Risk analysis of any hazard involves vulnerability assessment of elements, therefore vulnerable elements e.g. settlements, roads and agricultural lands were taken in consideration for risk analysis. All the risk element data layers regarding vulnerability assessment were created using LISS4 multispectral imagery and Google Earth image by digitization after that buffer zones are prepared for road and settlements. Afterward, all the vector layers were converted to raster map and reclassified. Then by using weighted overlay tool in ARC.

Vulnerability map is obtained by using these layers. Finally the susceptibility and vulnerability maps are crossed using raster calculator to get risk map.

M. Landslide change detection

Change detection procedure intend to find and interpret the alterations of objects or phenomenon between the different acquiring times. When using multi temporal landslide data, the value of an image pixel or object at a time can be compared with the value of the corresponding image pixel or object at another time in order to determine the degree of change. Many different procedures have been developed depending on the spatial, spectral and temporal resolution of the available imagery and computer capacities in regard to digital image processing. At the same time the variety of change detection applications has increased whereas the first change detection studies particularly focused on large scale and possibly long term changes of land use and land cover i.e. vegetation, forest, agriculture, urban areas. Now the change detection techniques have broadened the influence area and have found increased applications in landslide mapping and inventory preparations.

Landslide inventories, are prerequisite for landslide hazard and risk assessment, so far for many parts of the world such multi temporal landslide inventories are largely missing because the preparation relies mainly on the time consuming and resource intensive conventional methods, i.e. visual interpretation of optical data aided by comprehensive field surveys. Against this the long time archives' of satellite remote sensing data and high resolution satellite imageries open up new opportunities for analyses of landslide occurrence at a regional scale. Thus change detection techniques are now been employed for mapping and zonation of landslides, several approaches based on automated multisensory pre-processing and multi-temporal change detection methods. Change detection requires precise spatial alignment of the whole database which is a pre-requisite. An approach for landslide mapping using change detection based on analysis of temporal NDVI trajectories was developed for mapping landslide (Behling, 2014). The NDVI trajectories are obtained for every pixel across the analyzed time span. NDVI trajectories represent specific temporal footprints of vegetation changes. They allow for automatic identification of landslide events due to landslide specific footprints represented by short term vegetation cover, destruction as well as longer term vegetation rates as the effects of landslides related disturbance and dislocation of soil in combination with DEM derivatives example slope, stream order etc. thus enabling automated object based identification of landslides of different sizes shapes and is suitable for mapping spatio- temporal landslide activities under varying natural conditions.

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Other change detection approach involves object oriented approach (OAA). OAA, which is based on image segmentation and subsequent classification of derived image primitives, represent a more advantageous approach for analyzing high resolution data, because image pixels can be meaningfully grouped into networked homogenous objects and noise can be consequently reduced. Moreover, OOA offers a potentially automated approach for landslide mapping, with a consideration of spectral, morphological and contextual; landslide features supported by expert knowledge. Thus allowing a cognitive approach that is comparable to visual image analysis. So far few studies have used OOA for landslide mapping. Although automated detection of landslides using low resolution imagery have been carried out by Barlow et.al. Using Landsat (ETM+) images. The methodology was further improved by the use of higher resolution SPOT-5 data as well as an inclusion of more robust geomorphic variables. Also Martha et all integrated spectral spatial and morphometric features to successfully recognize and classify five different types of landslides in different terrain in the high Himalayas. These studies show the increasing utility and potential of OOA in detecting and mapping landslides.

N. Methodology

First purpose of the research is to prepare landslide inventory map which is done by the visual interpretation of multispectral LISS 4 image. All landslides from Gaurikund, Sonprayag to Agastmuni were identified and marked in the inventory map. This inventory is used further for the preparation of susceptibility & vulnerability map.

For the preparation of vulnerability and susceptibility weighted overlay method is used in which each layer is given influence value plus weightage is given to each class of all layers.

After the calculation of weights from above formula the thematic layers are reclassified in this basis and added in Arc GIS through weighted overlay. After this addition final susceptibility map is obtained. Similarly by weighted overlay vulnerability map is also prepared. Finally the susceptibility map and vulnerability map is crossed in GIS environment through raster calculator to get the final risk map.

O. Weighted overlay for landslide susceptibility mapping

The Spatial prediction of landslide is termed as landslide susceptibility, which is a function of landslide and landslide related internal factors. The aim is to identify places of landslide occurrence over a region on the basis of a set of internal causative factors. This is specifically known as landslide susceptibility zonation (LSZ), which can formally be defined as the division of land surface into near-homogeneous zones and then ranking these according to the degrees of actual or potential hazard due to landslides (Kunango.D.P., 2009).

Thus the primary objective is to produce the Landslide Susceptibility Map for Alaknanda valley so that appropriate landslide disaster risk reduction strategies can be developed by demarcation of high risk zones. The flow chart of the methodology adopted is listed:

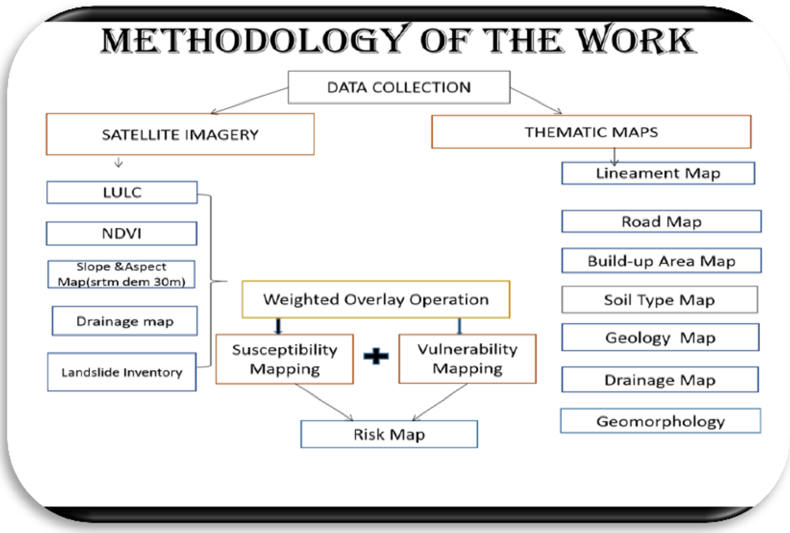

Figure: 3. Flow chart illustrating entire methodology involves susceptibility mapping and subsequently assimilation with vulnerability map for final risk assessment

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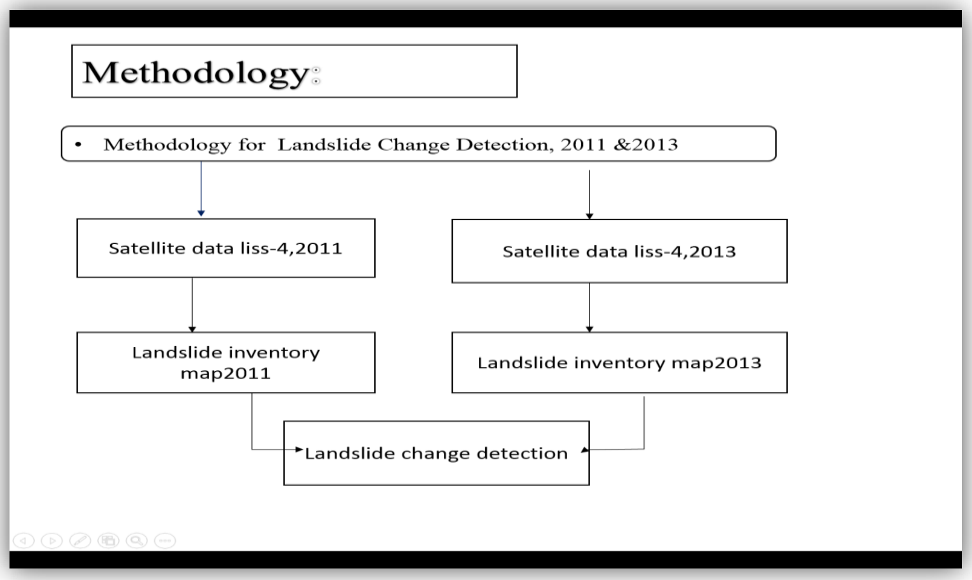

Figure: 4.Flow chart illustrate methodology of landslide change detection

P. 5. RESULTS AND DISCUSSION

Q. Landslide Inventory:

The landslides have caused major damage in the study area. In the landslide inventory, a total of 390 landslides have been detected and mapped in the image (Figure 5.1). The landslides are found to be scattered throughout the study area. The common type of landslides are debris flows, rock slides, earth slides and very few are found to be rotational slides. Most of the landslides are found to be situated near the steep slope. From the inventory map it is evident that most of the landslides are located on western side of the river. The dispersion of the landslides indicates that landslides are frequent in the area. The landslide have caused major damage in the study area. High-resolution satellite imagery (LISS4 5.8m resolution) & (Google earth geo-eye data) were used for landslide detection. To identify the conditions where the landslide originated, the upper edge of the landslide main scarp was assumed as the slope failure and therefore the landslide origin (Clerici, 2002).it is frequently known, that in a landslide it is two different zones, depletion zone (upper part of landslide), where a landslide is originated, and accumulation zone (lower part of landslide), which is affected by from the upper zone. The landslides are found to be scattered throughout the study area.

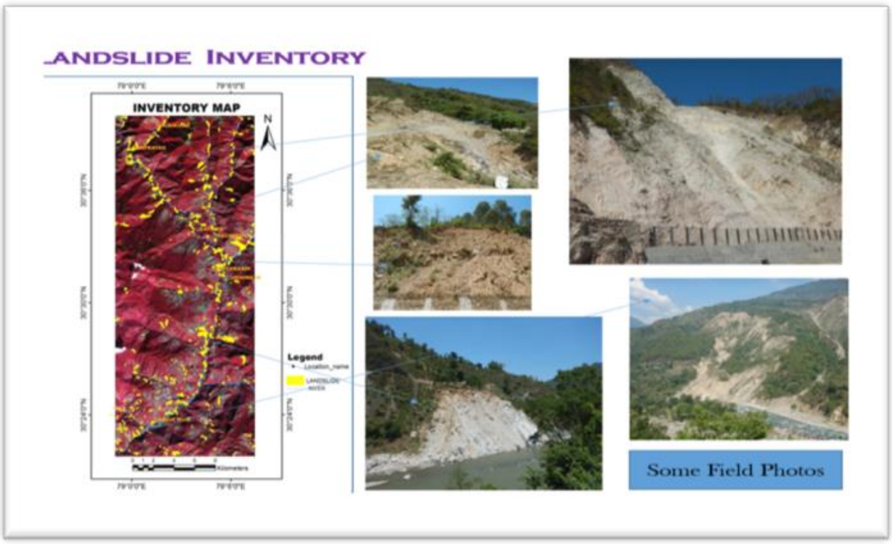

Figure:5. Thematic Layer of Landslide Inventory Map

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R. Landslide Susceptibility Map:

Susceptibility map is the representation of area into different classes ranked according to how they are prone to landslide.

1) Topographic Factors:

Topographic parameters basically include slope and aspect map of the are generated from the dem. Slope is an important parameter for the assessment of landslide, slope map used have 5 classes that are 0-15°, 15-25°, 25-35°, 35-45°, 45-75°. It is known that movement is always from high to low that is down the slope. Most of the study have slope greater than 15° and it is well known that in Himalayas most of the landslide occur at slopes ranging between 25-55°. Most of the landslide in the study area is concentrated in the area having slope ranging between 35-75°. The influence of slope steepness on landslide occurrence is the easiest factor to understand. Generally, steeper slopes have a greater chance of land sliding. This does not prevent failures from occurring on gentler slopes. Other factors may make a gentle slope especially sensitive to failure, and thus in this situation could be determined to have a relatively high hazard potential.

The aspect map of the area indicates the direction of the slope and this layer is classified into 4 classes NE, SE, NW and SW. The distribution of aspect is quite homogenous. The distribution of landslide is more or less equal in all classes of aspect.

Table 3.statistics of aspect map

ID	CLASS	AREA (in sq.km.)	Area (in %)
1	NE	125.2089	27.622263
2	SE	120.6209	26.610107
3	NW	103.3919	22.809227
4	SW	104.0681	22.958403

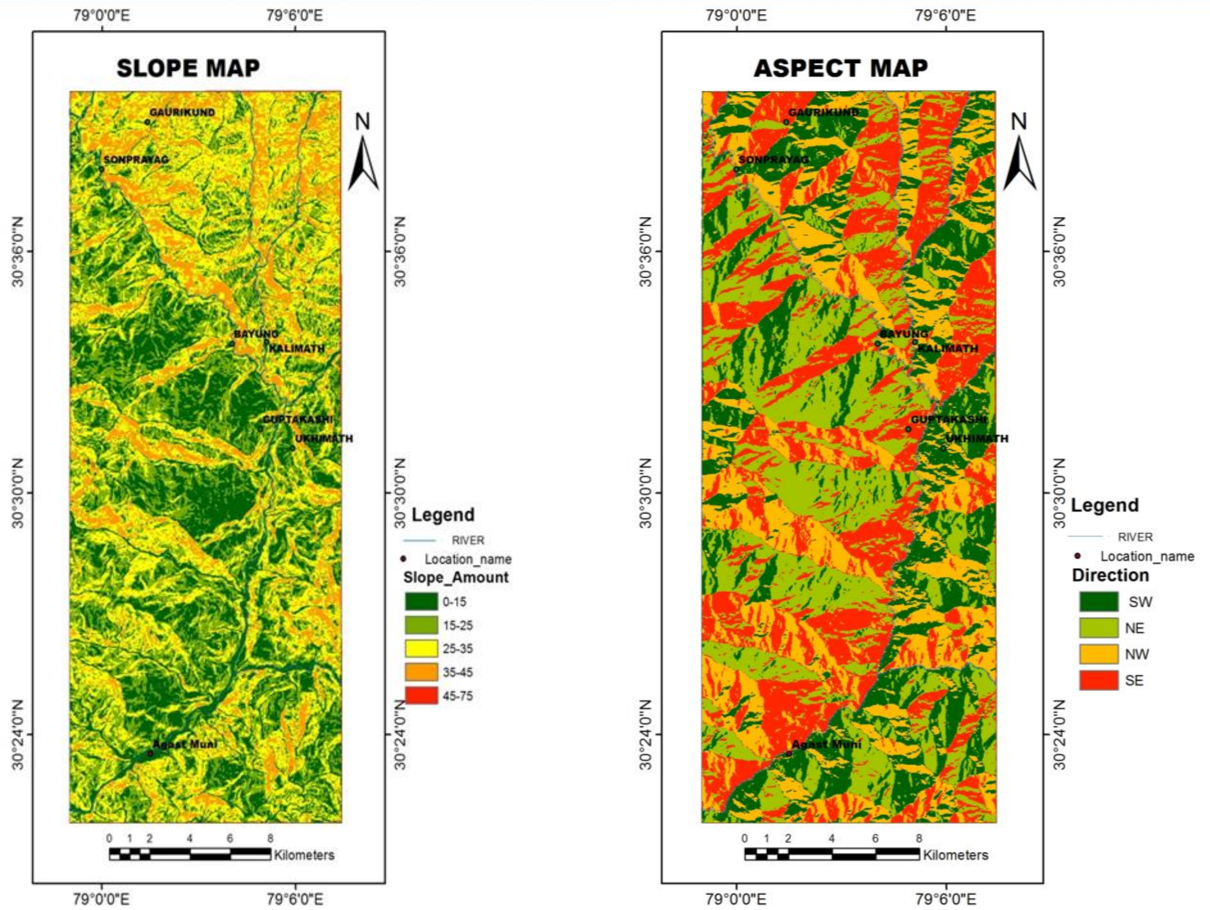

Figure: 6.Thematic Layers of Slope and Aspect

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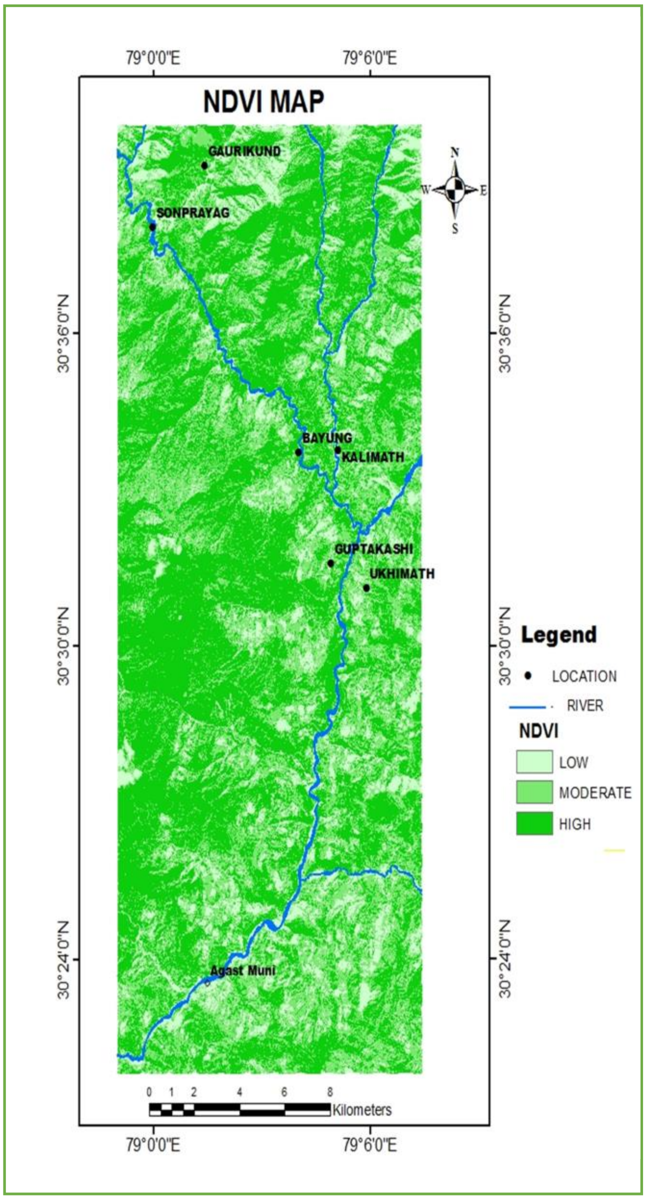
2) Vegetation and Land Use & Land Cover:

The NDVI map indicates the vegetation type of the area higher the value higher is the vegetation. After crossing of this layer with landslide indicates that most of the landslide are in areas of comparably less

vegetation. Most of the slopes in higher altitudes are apparently barren with some shrubs, rhododendrons, mosses, lichens and some windflowers. Terrace farming is common and potatoes, pulses and barely are mainly grown.In LULC map there are many classes but broad classes are forest , crop land, barren land , fallow land, grass land and water body. On crossing this layer with landslide it is seen that very less landslides are there in forest and water body class while highly concentrated in fallow land and crop land.



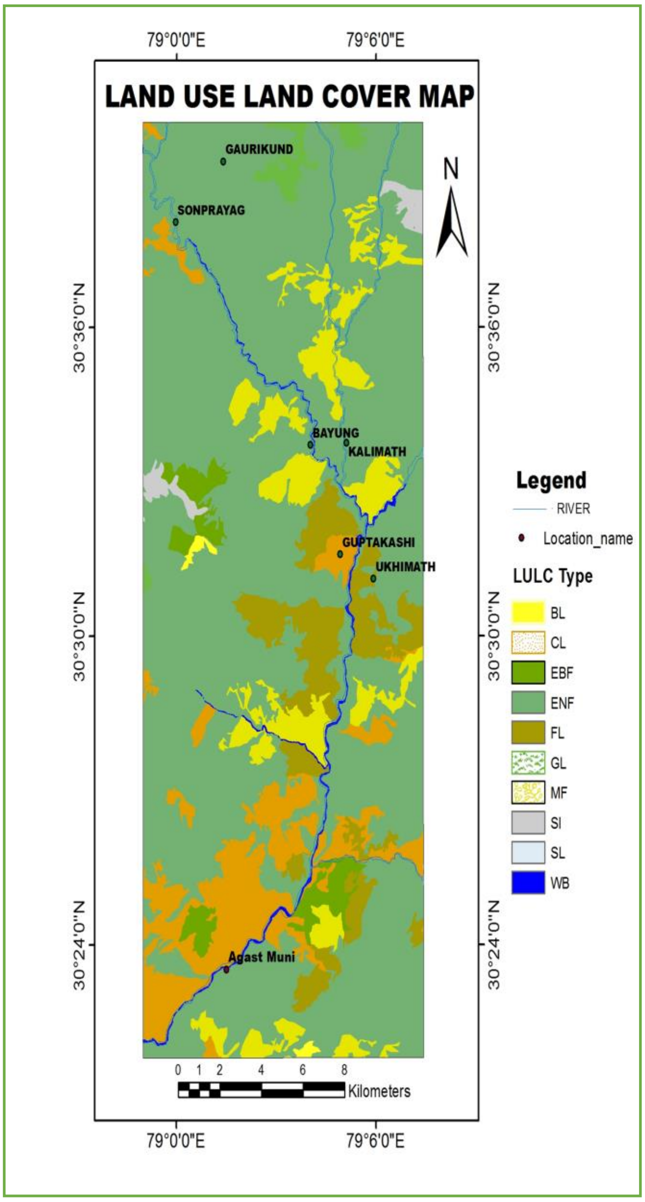


Figure 7.Thematic Layers of NDVI Map and LULC Map

3) Linear Features (Lineaments):

Observed Tectonic structures like faults and thrusts are associated with extensive fractures and steep relief variations. It is seen from that the probability of landslide increases towards these lineaments. The area is full of lineaments including four major thrusts Berinag Thrust, Bhatwari Thrust, Munsiari Thrust and Vaikrita (Main Central) Thrust. Other major

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lineaments are along the Mandakini River. Lineament map are classified into three classes based on the buffer distance (100m, 200m and 300m) and it is that landslide are mostly concentrated in the 100m buffer zone. So it is concluded that as the buffer distance increases the probability of landslide decreases.

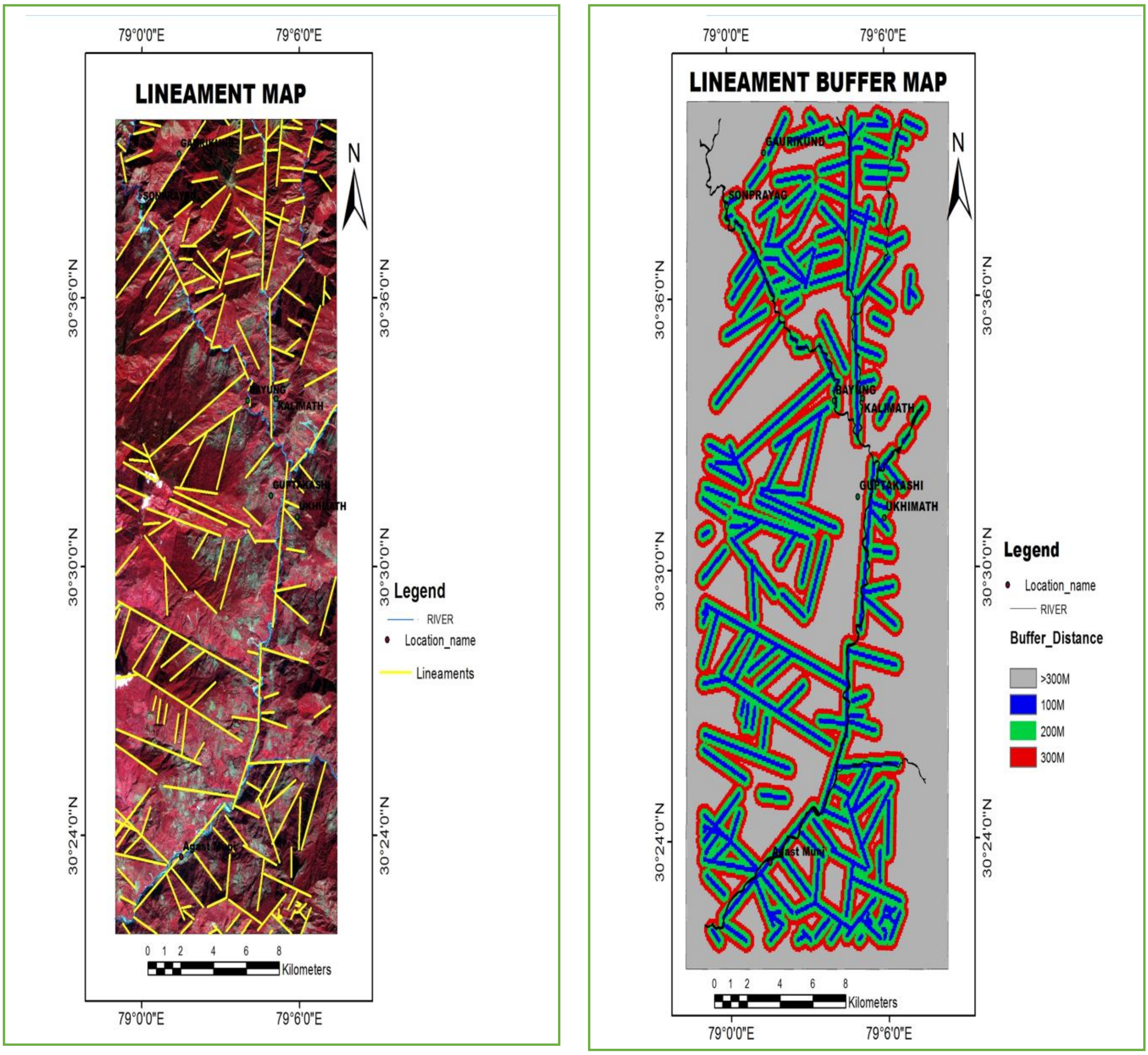

Figure:8. Lineament map and Lineament buffer map

4) Soil Type & Curvature Map:

Soil type is also an influencing factor for landslide but in study area its influence is not much. Four types of soil are delineated in the study are i.e.Typic Haplustalls, Typicustipsamments, Fluventic Eutroc hreptusand Lithic Udorthents from the soil map (National Bureau of Soil Survey and Land Use Planning, ICAR). Fluventic Eutrochreptus and Lithic Udorthents are dominant class means covering most of the area. But if landslide distribution is calculated then most of the landslide will come under rest of the two classes.

The curvature is a technique to measure morphological characteristics of the topography. A positive of curvature indicates that the surface is convexity of any area and a negative curvature indicates that the surface is upward concavity. A value of zero indicates the surface is plane. The positive and negative value of curvature are more chances to occur in landslide area.

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Table 4. Table of curvature map

ID	CLASS	AREA (in sq.km.)	No. of Pixcels
1	CONVEX	90.8883	908883
2	FLAT	301.2594	301259
3	CONCAVE	61.2427	612427

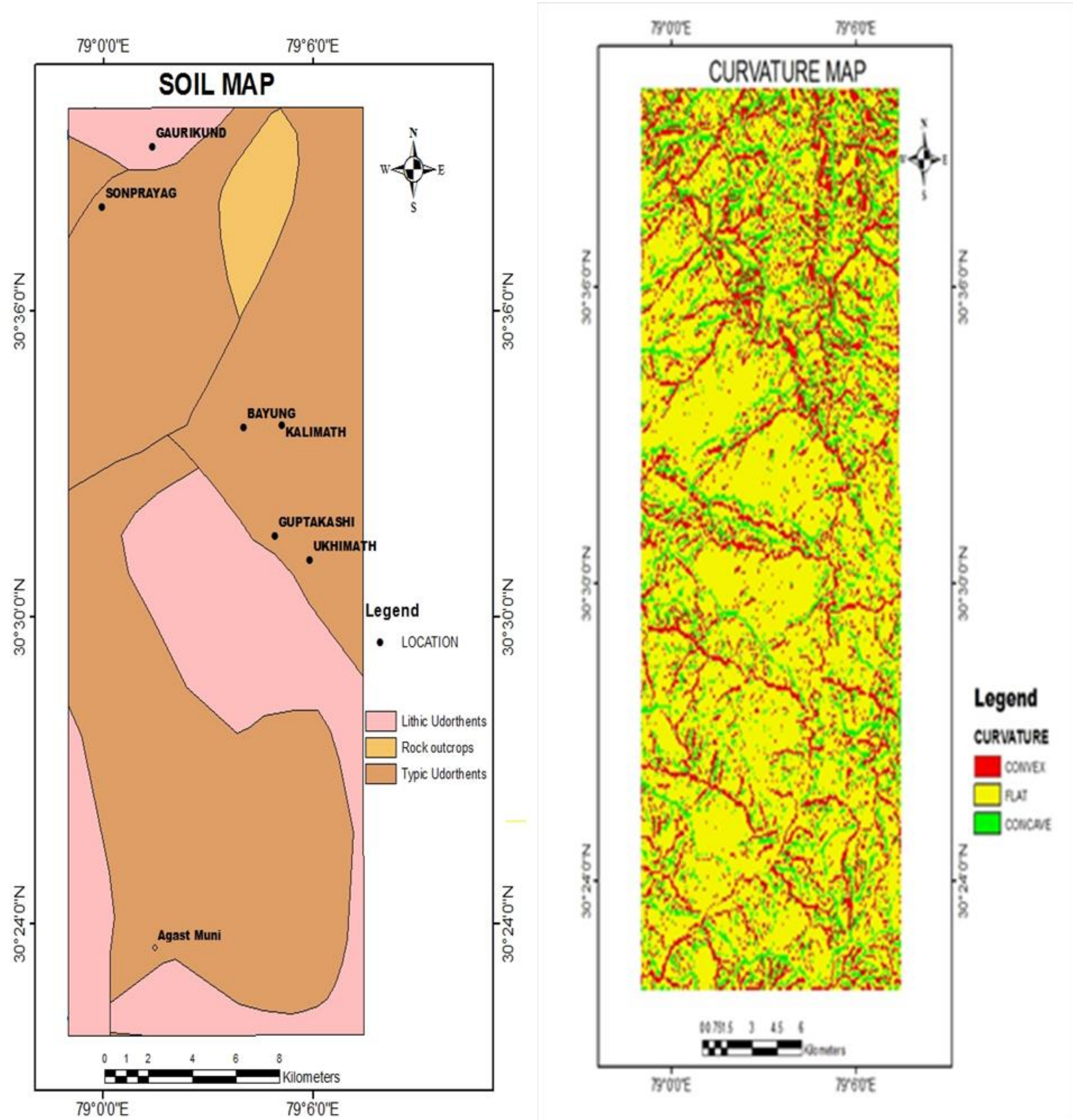

Figure 9.Thematic Layers of Curvature Map and Soil Type Map

5) Geomorphology:

Morphological set-up of an area depicts by geomorphology which may give a clue for the future landslide. In the study area, gently sloping and undulated land surfaces clearly predominating eight major units like densely highly dissected hill, less vegetated highly dissected hill moderately dissected hill, alluvium plain, flood plain, channel and braided bars and active river channel. 90% of the area is covered with highly dissected hills and landslides are also concentrated in that class very few are there in flood plain and river.

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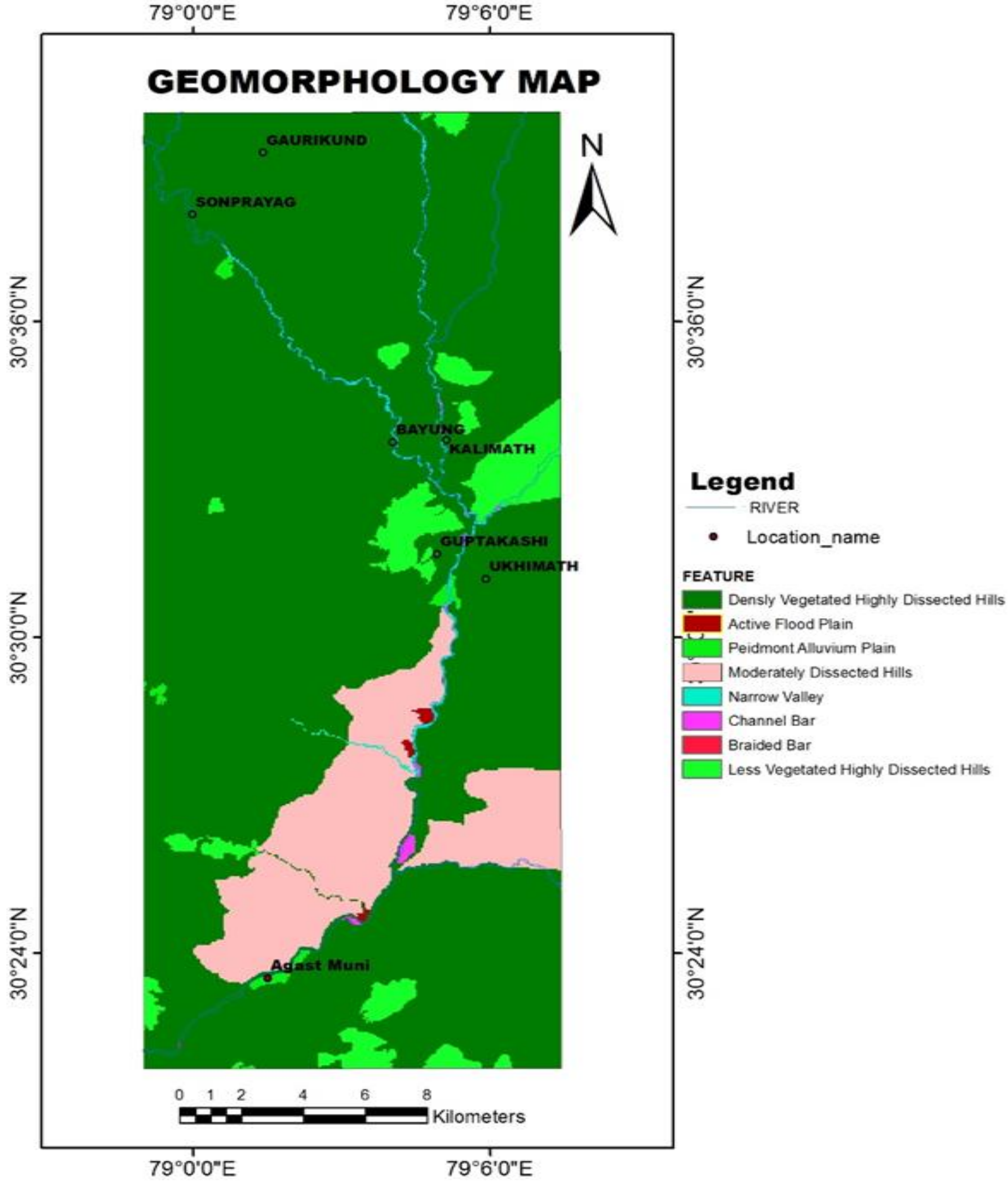

Figure 10.Thematic Layers of Geomorphology Map

Table5.Geomorphology Statistics

ID	Class	Area(sq.km)	%percentage
1	Densely Vegetated Highly Dissected Hills	374.56	82.66
2	Active Flood Plain	0.5324	0.117486
3	Piedmont Alluvium Plain	1.5416	0.340187
4	Moderately Dissected Hills	50.5715	11.159698
5	Narrow Valley	2.3947	0.528442
6	Channel Bar	0.6557	0.144694
7	Braided Bar	0.0328	0.007238
8	Less Vegetated Highly Dissected Hills	22.866	5.045879

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S. Landslide Susceptibility Analysis:

The landslide susceptibility map was prepared through weighted overlay method. The total area is 453 sq. km and number of pixels are 75738. Most of the pixels lie in low susceptible zone and least in high susceptible zone. Out of the 100% area 62% area is low susceptible , 34% is under moderate zone and 4% is high susceptible.

Table 6.Statistics of Landslide Susceptibility Map

Susceptibility Class	No. of pixels	Area (Sq.km)	Percentage of area(%)
Low	276610	276	62
Moderate	155099	155	34
High	195313	19	4

Area along the course of Mandakini River is highly susceptible, it is because of the undercutting of slope by the river which makes the slope unstable especially during floods. Also from the map it can be observed that as we move upstream from Ukhimath area is more susceptible because most part is under high susceptible zone.

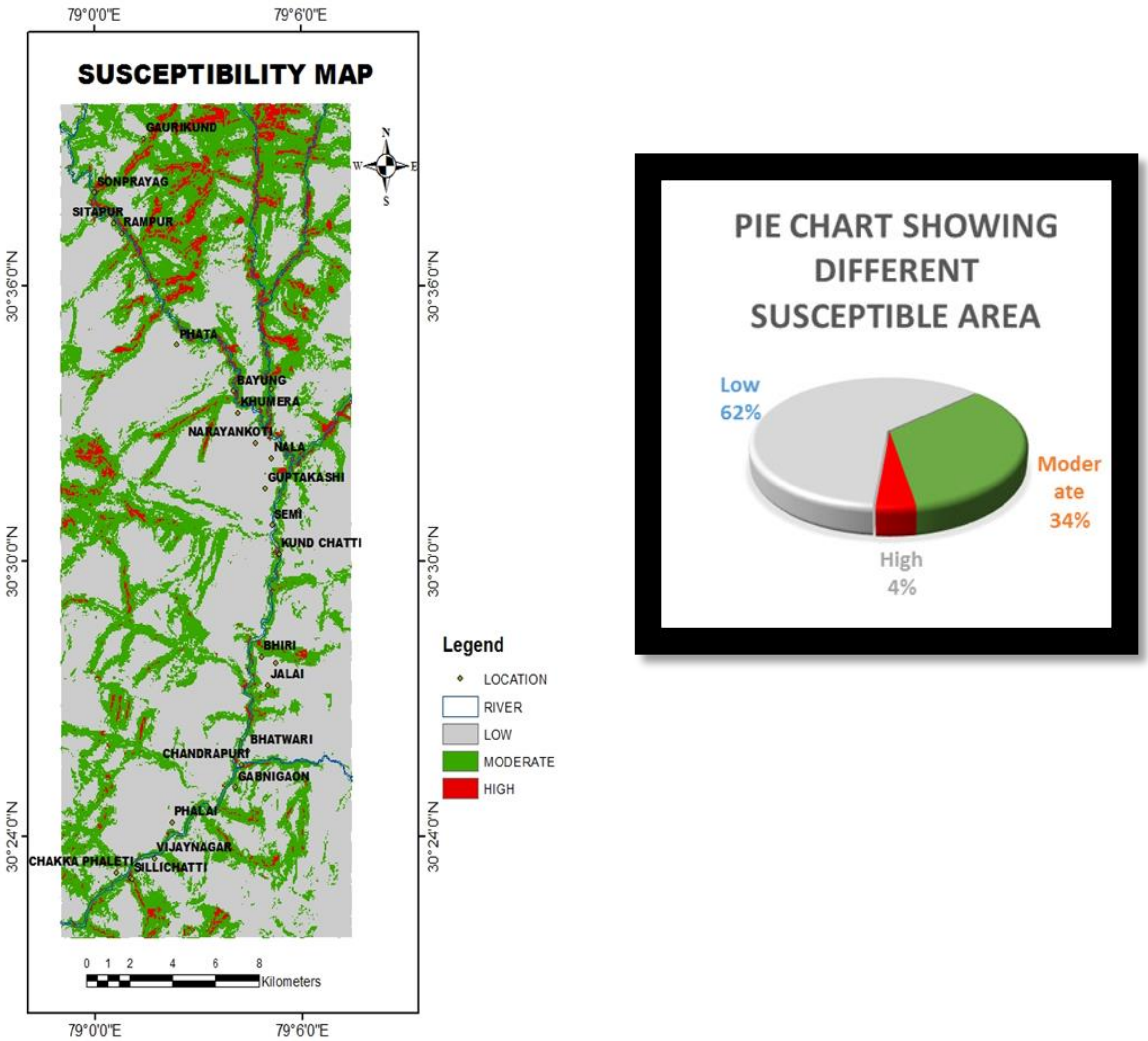

Figure 2 (a)Susceptibility Map of Study Area and (b) Pie Chart of Susceptibility

T. Vulnerability Assessment:

Vulnerability infers to the loss of life, infrastructure and property because of the landslide. This map was derived by adding the three thematic layers that are road, built-up and land cover (especially agriculture). The total number of pixels

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in the map is 86051, out of these maximum number of pixels are in very less vulnerable zone and least number in very high vulnerable zone.

Table 7. Statistics of Vulnerability Map

Vulnerable Classes	No. of Pixels	Area(Sq. km)	Percentage
low	303323	303	67
moderate	113969	113	26
high	353552	35	7

This map infers that the areas under built-up, agriculture and near road are very high to high variable. As the distance increases from road built up etc. vulnerability is less. Out of total area 7% area approximately 35 sq. km area is located in high vulnerable zone. Rest of the area which are dominated by dissected hills are less susceptible because of the absence of settlements and roads.

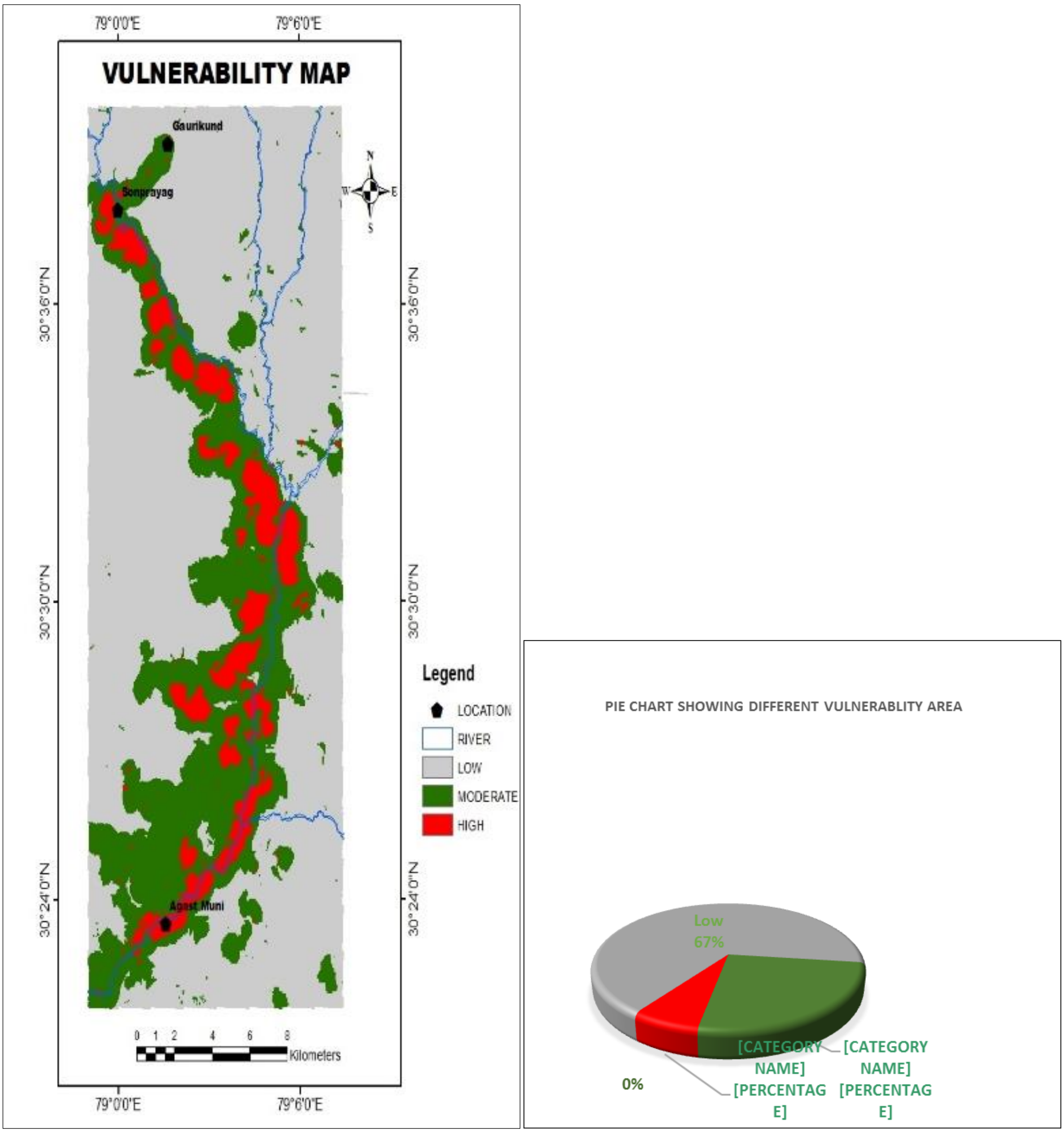

Figure 3.Pie Chart of distribution of vulnerable zone and Vulnerability Map

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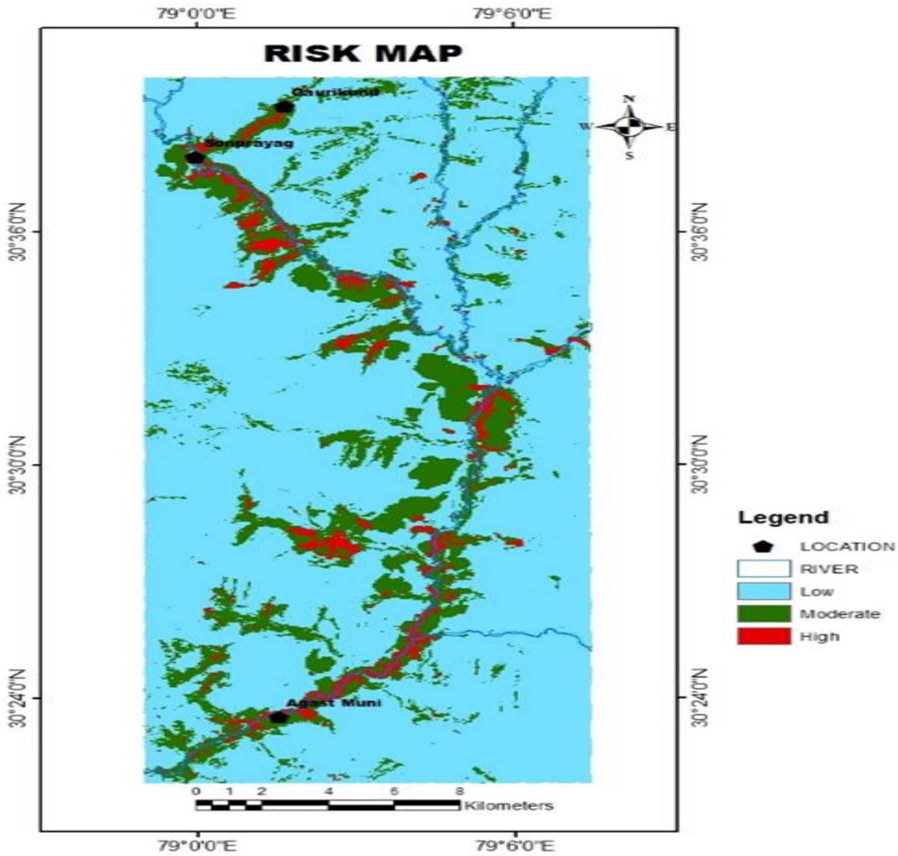
U. Risk Assessment:

Risk is the product of susceptibility and vulnerability means risk map was derived by crossing the susceptibility and vulnerability map. The total number of pixels in the layer is 75809 out of which maximum are under low risk zone. Most part of study area is under low to moderate risk only 4% is under high risk. Ukhimath, Sonprayag and Gaurikund are in high risk zone.

Table 8.Statistics of Risk Analysis

Risk class	No. of Pixels	Area(Sq. km)	Percentage (%)
Low	47878	405	63
Moderate	23242	197	31
High	4689	40	4



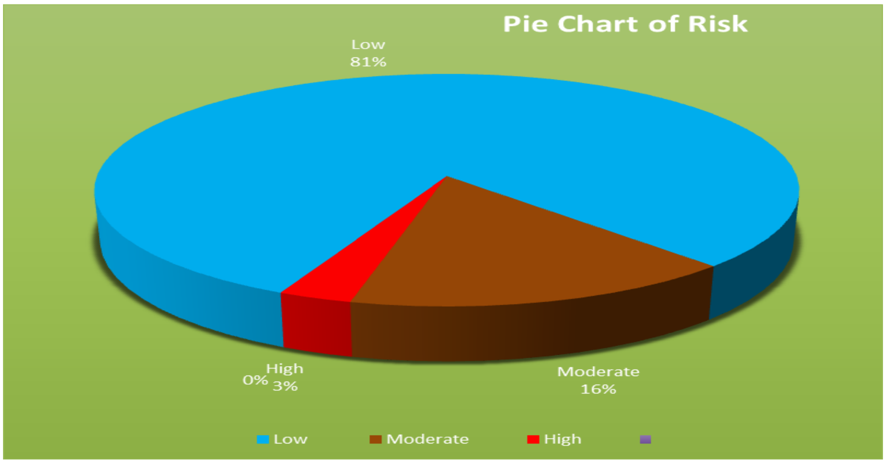


Figure 4. Pie Chart of Risk and Risk Map

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V. Landslide change detection:

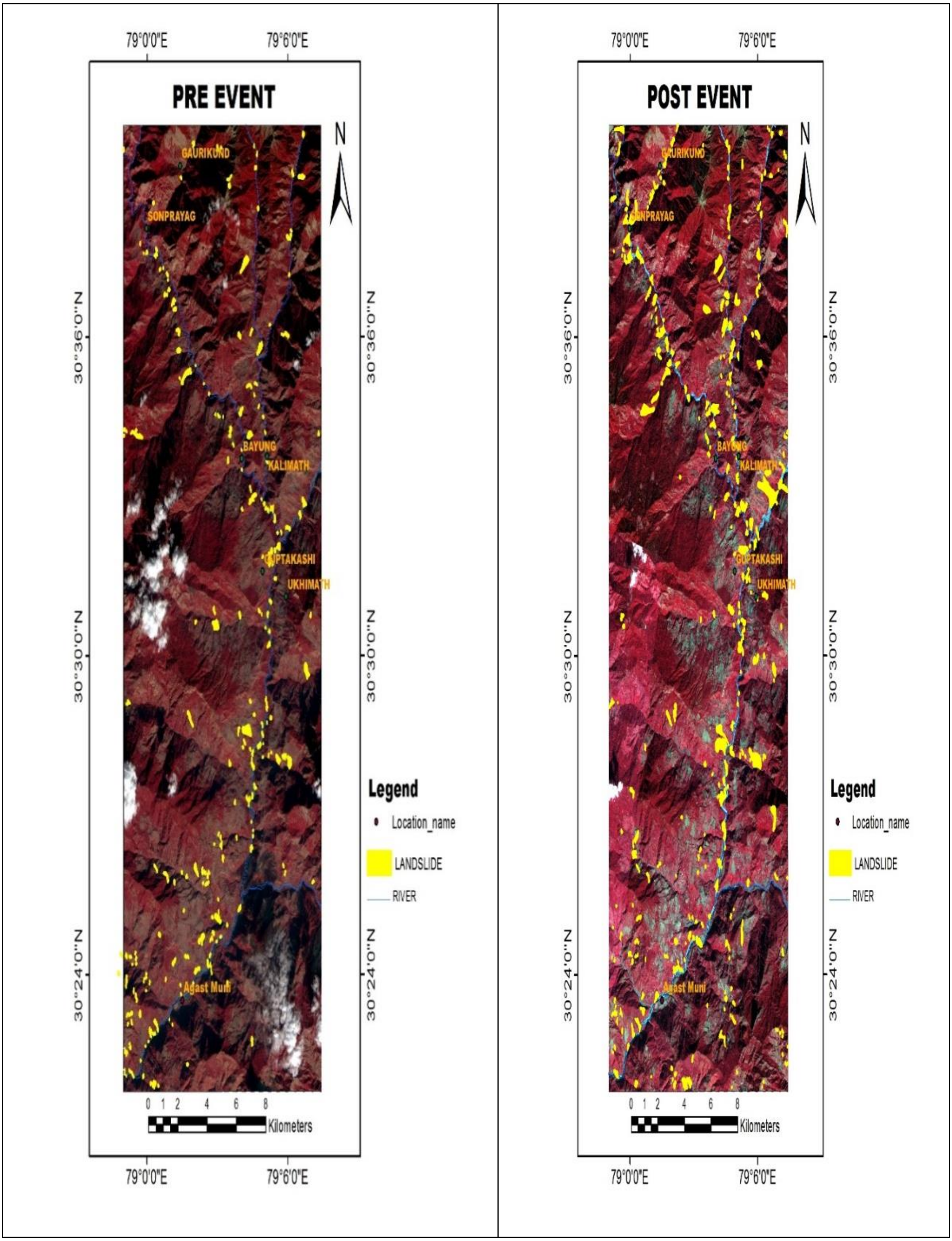

Figure 14.Landslide pre_event and post_event combine Map

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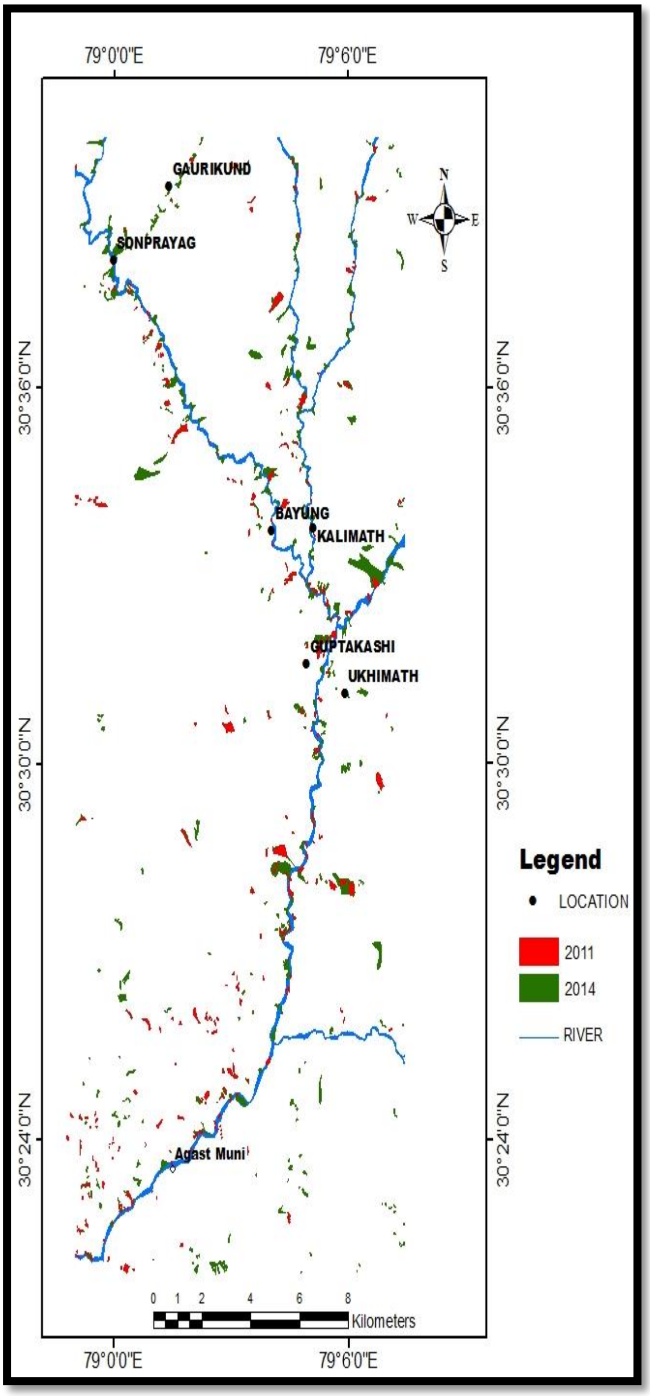

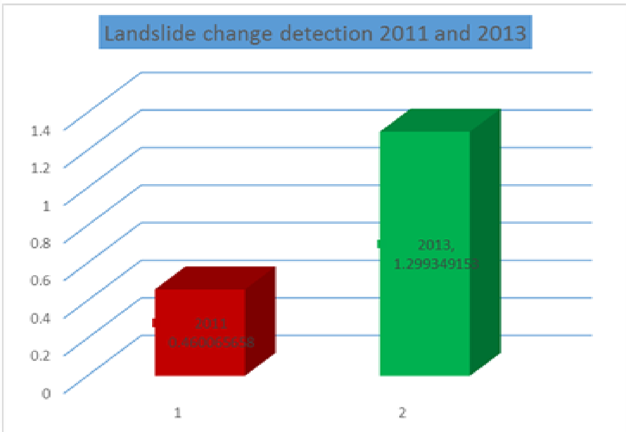

Figure 5.Landslide pre_event and post_event combine Map (b) Landslide pre_event and post_event affected percentage Diagram

Landslide change detection on the basis of digitized landslides over liss-4 satellite image and cross checked with the help of google earth ,pre event 2011 dec data and post event 2013 dec data after kedarnath to see what changes come out.total study area from gaurikund to sonprayag to agastmuni 453.87 (sq.km) pre event landslide affected total area 2.0881, and post event landslide after kedarnath igot increased so the affected area 5.897.after it to calculate percentage of pre event and post event affected area divided by total study area respectively,total percentage of pre event 0.46 and after kedarnath disaster it was increased so 1.2 percentage,than post event percentage minus by pre event there was 0.74 percentage difference.percentage (diagrame figure 5) showing

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Table 9. Landslide pre_event and post_event table

Total Study Area (sq.km)	453.87	Percentage
Pre-event affected area 2011 (sq.km)	2.0881	0.46
Post-event affected area 2013 (sq.km)	5.897	1.2

III. CONCLUSION

Being a tectonically active zone, Himalaya possesses high probability of occurrence of devastating landslide every year in Uttarakhand, eventually causes loss of life as well as huge property. Present study is focused on mapping of landslide including susceptibility and risk map using remote sensing and Gis technique. Remote sensing helps in identifying and locating landslides through satellite imagery while GIS gives information related to area, count, sum, etc. of the different thematic layers along with their spatial location.

The IRS P6 LISS 4 imagery has greatly helped in the study. Nearly 290 landslides have been delineated from the high resolution multispectral imagery. A high resolution image is very useful in preparation of inventory map and further in susceptibility & vulnerability map, hence in hazard assessment.

On the basis of the weight ages and calculation, it can inferred that geology was the predominant factor in causing landslide. Then the next highest average was obtained for Slope then lineament followed by Geomorphology. Then others factors were given importance.

The percentage of low susceptible zone is maximum nearly 62% while in case of vulnerability most of the area is within very less to moderately vulnerable zone hence after combination of two risk is determined and only 4% area is under high risk zone.

So, following are the brief conclusion of this research work:

- High resolution imagery can efficiently be used for assessment of risk and damage, thereby helping mitigation
- Slope, geology and lineaments are found to be more influencing for landslide hazard in the study area.
- The most high risk areas are confined along the river
- Less than 1800m altitudinal zone is mostly affected during kedarnath disaster.
- Landslide hazard risk map is evident that lower part of ukhimath, guptkashi,narankoti,phata,sonprayag,gaurikund&

along the river of Madhmashawar ganga & kaliganga fall high to very high risk zone

❖ The minimum size of the landslide that can be detected using this method depends upon the resolution of the satellite data. However, using 5.8 m resolution data, a landslide of 452 sq. km was detected.

ACKNOWLEDGEMENT

My deepest gratitude goes to my respected supervisor and co-supervisor, Mrs. Richa Upadhyay Sharma Scientist "SD", Geosciences and Geo-hazard Department and Dr. ShovanLalChattoraj Scientist "SD" Geosciences and Geo-hazards Dept**.**Indian Institute of Remote Sensing (IIRS).They are always available as an active support and assistance throughout this project work. I thank them for their advice, guidance, patience and encouragement they showed to me. I have learned a lot from them above all the essence of a scientific research and critical comments.

I feel indebted to Dr. P.K. Champati ray, Scientist "SG", Head, Geosciences and Geo-hazards Department for his constant help, cooperation and supervision all through the course.

I would like to express my heartfelt gratitude and thankfulness to Dr. R.S. Chatterjee, Scientist SG Indian Institute of Remote Sensing, Course coordinator, Geosciences Department for his constant support and encouragement throughout the course at Geosciences Department, IIRS.

I owe my gratitude to Mr. Suresh Kannujiya Scientist "SC", Geosciences and Geo-hazard Department for his help and support.

I avail this opportunity to express my profound sense of reverence and humble gratitude to Dr. Senthil Kumar, Director, IIRS, and Dr. S.P.S Kushwaha, Dean (Academic), IIRS for their support to stay at beautiful and homely campus of IIRS in Dehradun.

My Special thanks to all JRFs and M.tech seniors Bhavana Ghildiyal, Somalin Nath, Bipin Kumar, Gopal Sharma, ShailajaThapa, Rohit Kumar, Vivek Senger, Shobhna Lakhera and Sumi Kala who gave me support and ideas throughout the Project work.

I cannot forget my friends Nazia khan ,Fakhr Un Nisha, Deepmala Gupta and Nida plus all my friends and classmates who have always been remained supportive during my course work. My sincere thanks to them for their encouragement and cooperation.

I would love to express my sincere gratitude to my parents Ayyub Ahmad Mother Sanjeeda Begum and my brother Dr. Tanveer and sisters Fahmida, Asba, Farha, Qudsi for their continuous support and encouragement and love and concern are always overwhelming and led me to a great accomplishment.

Last but not least to Ashish Dhiman (Tech-Asst) and Ms. Ramandeep Kaur who has been very active in providing necessary logistics that make my project smoother.

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ISSN2349-7831

International Journal of Recent Research in Social Sciences and Humanities (IJRRSSH)
Vol. 4, Issue 2, pp: (92-118), Month: April - June 2017, Available at: www.paperpublications.org

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