Flood Assessment and Hazard Mapping Using Remote Sensing & GIS Techniques for Chamoli District, Uttarakhand

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Abstract: ***Understanding of rainfall is an important issue for Uttarakhand, India which having varied topography and due to that extreme rainfall causes quick runoff which warns structural and functional safety of large structures and other natural resources. In this study the attempt has been made to understand the Flood hazard index of the Chamoli district. Chamoli being the highly flood prone region of the state was selected as the study region. The study area lies between 30 - 31° N latitude and 79 - 80° E longitude. The satellite data was ortho - rectified and the study area was extracted using district boundary. The vegetation type/land use map was prepared using on - screen visual interpretation technique. The multi - flood time series dataset was used for preparation of Digital Elevation Model. Geographical Information System was used for identification of flood prone areas which were classified with zone - wise. A flood frequency map was developed using the multi - date Landsat satellite imagery. The classified vegetation type/land use map from 2010 - 2019 was overlaid to find out the frequency of the flood. Flood affected areas were classified into very low, low, medium, high, very high and extremely high based on vulnerability to the potential of flood hazard. The areas were further categorized, based on the vulnerability of flood viz; extremely high (6) very high (5), high (4), medium (3), low (2) and very low (1) respectively.***

1. Objectives

- To understand the flood hazards in historical context and trends in Chamoli region.
- To describe the geo - climatic and socio - economic profile of the study area
- To understand impacts of floods on life and property and to know the major contributors to the flood
- To develop flood hazard and risk assessment for conservation planning and management in the Himalayan regions.

2. Introduction

Flood is a major environmental problem in India as it has devastating effects on life and property. Flooding is an overflowing of water onto land that is normally dry. Floods can happen during heavy rains, when ocean waves come on shore, when snow melts quickly, or when dams or levees break. They are the most common and widespread of all weather - related natural disasters. Apparently, this is, for the large part, due to the heavy rainfall for long days on the upstream highlands. The rain has caused most rivers to swell and overflow of their courses, submerging the surrounding, flat fields or floodplains, which are mostly located in the outlying pastoralist regions of the country. In the period 1994 - 2004, Asia accounted for one third of 1, 562 flood disaster worldwide and nearly 60, 000 people were killed due to the flood. Every year, flood disaster results in tremendous losses and social disruption across the world. Statistically, 2.8 billion people have been affected (Doocy S, et al., 2013) with an average of more than 80 million affected each year across the globe in the last 30 years (Bhatt, et al., 2014). The repercussions include 4.5 million homeless, 540, 000 deaths, 360, 000 injuries and millions unrecorded (Doocy, et al., 2013). Economic loss for the last thirty years amounts to more than $11 billion. Between 1994 and 2004, Asia has seen approximately 1, 500 flood disasters (Bhatt, et al., 2014). The state of Uttarakhand, which is located at the foothills of Himalayas, with China and Nepal as its neighboring countries, is severely prone to floods and flash floods. Furthermore, flash floods often trigger landslides, and mudslides in regions that are geologically unstable. Some of the major events that have occurred in the last 30 years are Malpa flood and landslide of 1998 in Pithiragarh, Rudraprayag flood in 2001, Tehri flood of 2002 and Varunavat flood of 2003 (Pande, 2010). In June 2013, people of Uttarakhand witnessed one of the worst flash floods seen in over a century. More than 6, 000 people died, which is the highest for that year (Wake, Bronwyn, 2013), and thousands more were affected (Cho, et al., 2016). Geographic Information System (GIS) is a computer based system that provides the capabilities for input, data management, data storage and retrieval, manipulation, analysis and output to handle spatial data. GIS provides a broad range of tools for determining areas affected by flood and for forecasting areas that are likely to be flooded due to rise in water level in a river. The main benefit of GIS for flood management and planning is that, it generates visualization of flood prone areas that creates potential to further analysis the product to estimate probable damage due to flood. GIS has been extensively used to assemble information from different spatial data, aerial photographs, satellite images and Digital Elevation Model (DEM). Flood hazard mapping is a vital component for appropriate land use planning in flood prone areas. It creates rapidly accessible charts and maps, which facilitate the administrators and policy makers to identify areas of risk and prioritize their mitigation and response efforts. The regulation of flood hazard areas coupled with enactment and enforcement of flood hazard zone could prevent damage of life and property from flood in short term as well as in long term. The objective of this study is to delineate and identify flood hazard and risk assessment at landscape level using Landsat 8 image of Chamoli dristrict, Uttarakhand, India.

3. Study Area

A. Chamoli district is the second largest district of Uttarakhand state of India. The administrative headquarters of the district is Gopeshwar. It covers total geographical area of 8030 km^2. The study area lies between 30 - 31° N latitude and 79 - 80° E longitude and 44R UTM ZONE. It is bounded by the Tibet region to the north and by the Uttarakhand districts of Pithoragarh and Bageshwar to the east, Almora to the south, Garhwal to the southwest, Rudraprayag to the west, and Uttarkashi to the northwest. Administratively the district is divided into six tehsils namely viz; Joshimath, Chamoli, Karnaprayag, Pokhari, Gairsain and Tharali. Entire area is mountainous with agrarian economy. There are 1146 villages and 663 gram panchayat on recorded. District population of the study area (Census 2011) is 391605, where there are 193991 males and 197614 females. The population density is 42 persons/km^2 and the overall literacy rate is 76.23%. Administratively it is divided into ten tehsils viz; Chamoli, Joshimath, Dasoli, Pokhari, Ghat, Karnaprayag, Tharali, Narayanbagar, Dewal and Gairsain. The elevation of the district ranges from 800 - 8000 m. The climate of the district is depends on the altitude. The winter season is from November to March. As most of the region is situated on the southern slopes of the outer Himalaya, monsoon currents can enter through the valley, the rainfall being heaviest in the monsoon from June to September. The rainfall occurs during June to September when 70 to 80 percent of the annual precipitation is accounted for in the southern half of the district and 55 to 65 percent in the northern half. The major river in the study area is Alaknanda and Ramganga. The tributaries in the study area are: Dhauli Ganga, Birhi Ganga, Nandakini and Pindar etc. Agriculture is the main occupation in the study area, but the agricultural activities are restricted to river terraces, gentle hill slopes, and intermontae valleys. The major crops are: rice, wheat, potato, pulses, millets, seasonal vegetables and fruits respectively. The sources of irrigation are springs, gad, gadheras and rivers. The spring water which flows through the gads and gadheras, is diverted to small canals and guls by the minor irrigation department.

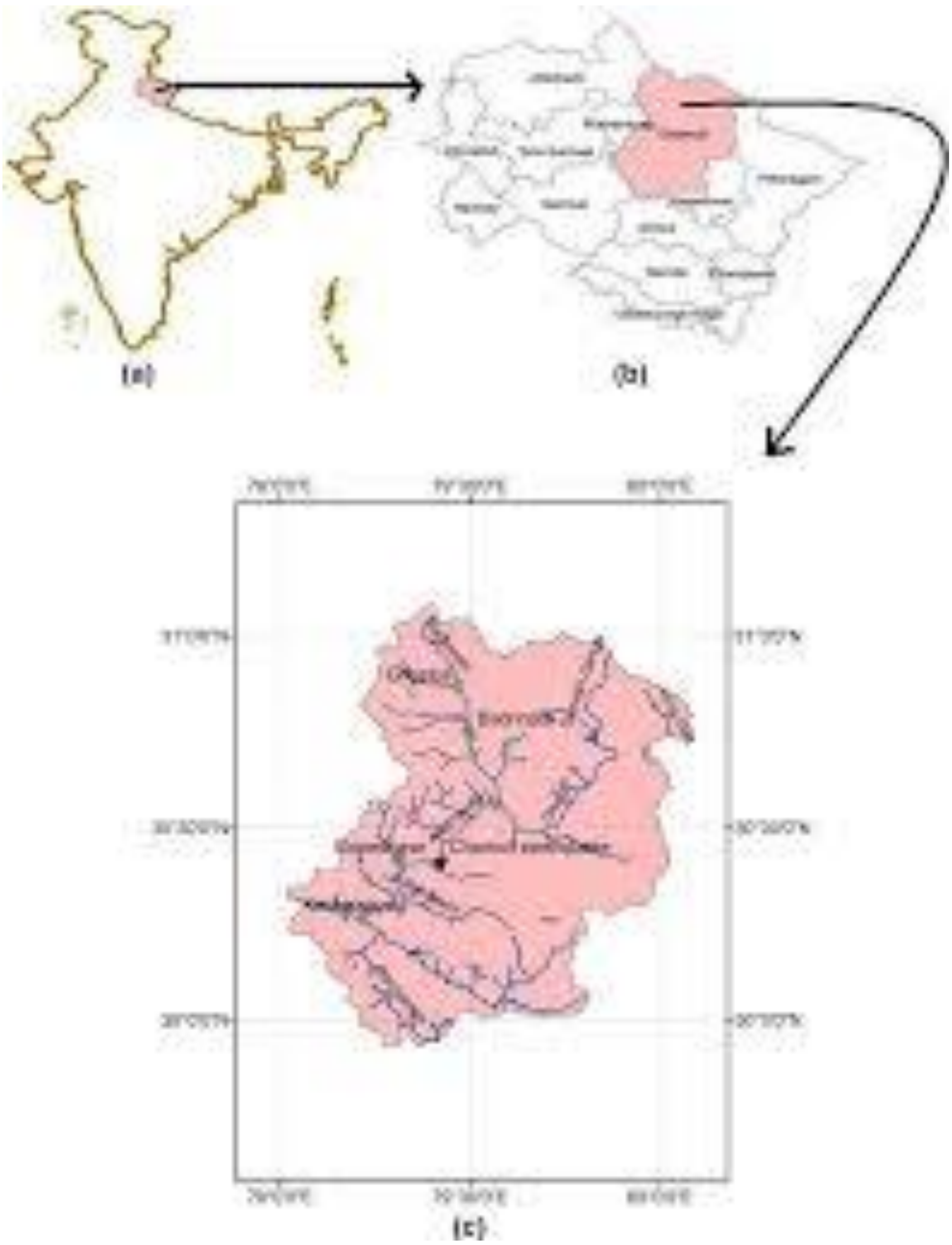

Figure: Chamoli district, Uttarakhand

4. Methodology

Data used:
Conceptually, hazard, related to flood events, is characterized by the law of probability that considers factors related to natural phenomena, like hydrological and meteorological activities for a region. Vulnerability determines the damage sustained by the socioeconomic factors like demography for the region due to the disaster caused by the above factors. Risk, for a region, is determined as a product of hazard and vulnerability (Gilard, 2016). Therefore, to compute flood risk, flood hazard and vulnerability assessments must be first carried out. The datasets used for hazard and vulnerability assessments are described below:

For hazard assessment various datasets such as Slope, Aspect, Hillshade, Contour, Precipitation were used. The Precipitation raster dataset from 2010 - 2019 was obtained from NASA's Giovanni website. Shuttle Radar Topography Mission (SRTM) 30 m resolution Digital Elevation Model (DEM) data was obtained from USGS's EarthData website. A total of 7 DEM raster tiles were obtained to cover the entire study area. Geology, Geomorphology, Fault, Roads, Rivers, Lithology datasets were obtained from BHUKOSH.

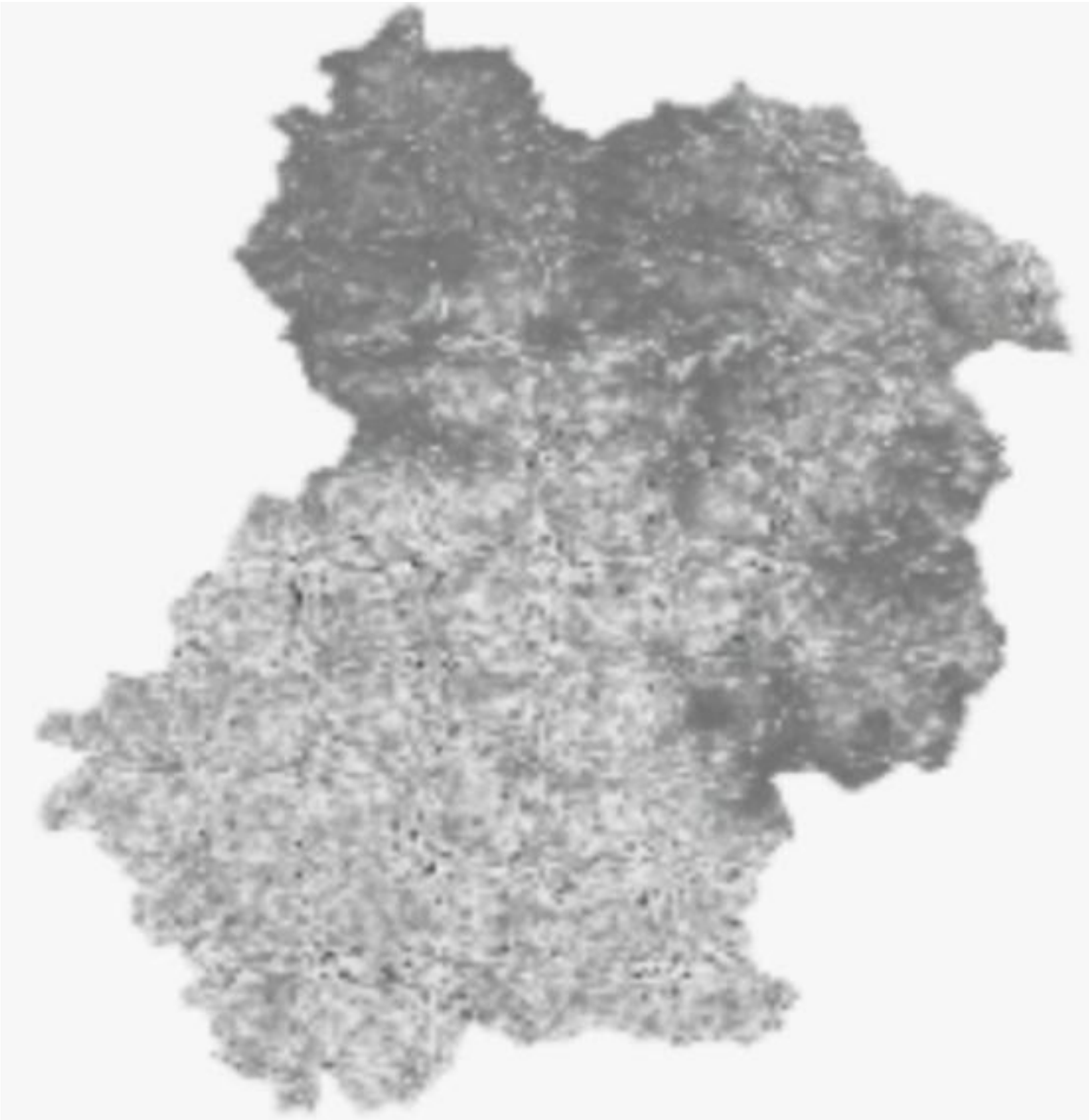

Figure: DEM image Chamoli

Method:
There are a lot of methods for flood risk analysis – quantitative, semi - quantitative and qualitative. For a large region like Chamoli, that is challenged by its terrain, remoteness, and lack of sufficient data, a more qualitative approach is appropriate, like the indicator - based approach. This method utilizes the indicators of hazard and vulnerabilities to assess the risk of the study area (Van Westen, 2016). Multi - Criteria analysis is a popular indicator - based approach that is used to carry out a holistic assessment of the indicators or variables to compute risk analysis by using remotely sensed data where quantitative ground data is lacking. Multi - Criteria Analysis (MCA) is a decision - making method for solving complex problems that involve multiple variables, high degree of uncertainty, many alternatives and scientific and socioeconomic challenges.

The Landsat - 8 image of 2019 which was obtained from the USGS was cropped using the map of the study area obtained from Diva - Gis with the help of the 'Clip' option from the arctool box. The DEM inage of the study area was used to create various datasets such as the Slope, Aspect, Hillshade and Contour. The district boundary of The study area which was obtained from Diva - Gis was clipped with various other datasets such as Roads, Faults, Rivers to identify the routed and regions through which they are flowing. The Geology, Lithology, Geomorphology, of the study area was drawn using the datasets obtained from the Bhukosh and was then 'Merged' with the DEM image with the help of the Arctool box.

Flash floods mostly occurs in complex terrain by orographic precipitation, which occurs by the influence of mountains or sometimes by hurricanes and tropical systems (Azmeri, et al., 2016; Hill and Firoz, 2010; Nation Research Council, 2005). Most flash floods are mainly triggered by high intense rainfall. However, there are other hydrological factors that also contribute to the cause. River channels, terrain slope, soil type and moisture, vegetation, landuse, snow melt and lake breach are some of them (Azmiri, etal., 2016; Bhambri, et al., 2016. Hill and Firoz, 2010; Martha, et al., 2015, National Research Council, 2005; Ray, et al., 2016). Azmeri, et al, 2016, Bonacci, O., et al, 2006, Kazakis, et al, 2015, Matori, et al, 2014, Strudevant - Rees, et al., 2001 have all considered intense rainfall as the main cause for floods in their research. Cloudburst, Snow/glacier melt and intense rainfall are the main causes for the floods to occur in the Chamoli region. As a result it was important to obtain the precipitation data along with the slope, river, road datasets. Hence, the precipitation data for year 2010 - 2019 obtained from the Giovanni website was merged using IDM tool with the district dataset to create the rainfall precipitation map. Finally, flood risk map is generated using 'Reclassify' followed by the 'Weighted sum' tool, as product of flood hazard and vulnerability assessment results (LULC, Road density, Fault).

Data Preparation

Precipitaion index map

TRMM Accumulated Precipitation of 10 years - - >Project to WGS 1984 UT resolution - - > Reclassify to 5 Quantile Classes - - > Precipitation Index Map.

River Map

Stream Network Vector Data - - > Create River Density using Line Density tool - - > Bilinear Interpolation. Rescale image to 30m. spatial resolution - - > Reclassify to 5 Quantile classes - - > River density map.

Slope Map

7 Digital Elevation SRTM satellite Images - - > Mosaic 7 Raster Images - - > Project to WGS 1984 UTM 44 N - - > Interpolate using cubic convolution - - > Derive slope - - > Reclassify to 5 Quantile classes - - > Slope map.

Road density Map

Road Network Data - - > Create Road Density using line density tool - - > Resample and Rescale to 30 m spatial resolution - - > Reclassify to 5 Quantile classes - - > Road density map.

5. Results

A total of 10 maps were generated from all the workflows in ArcGIS. They are as follows:

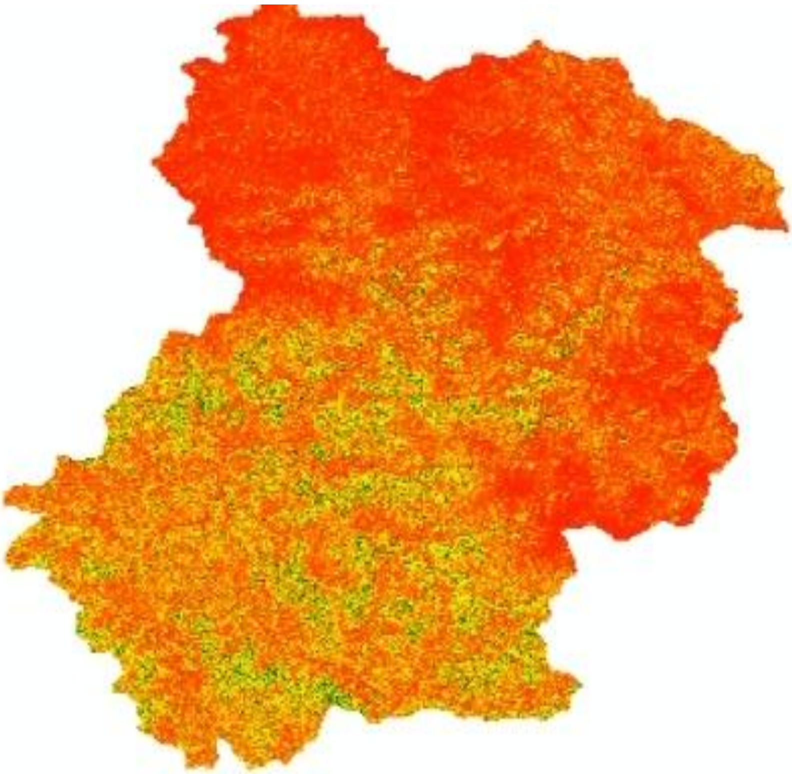

Figure: Slope, Chamoli.

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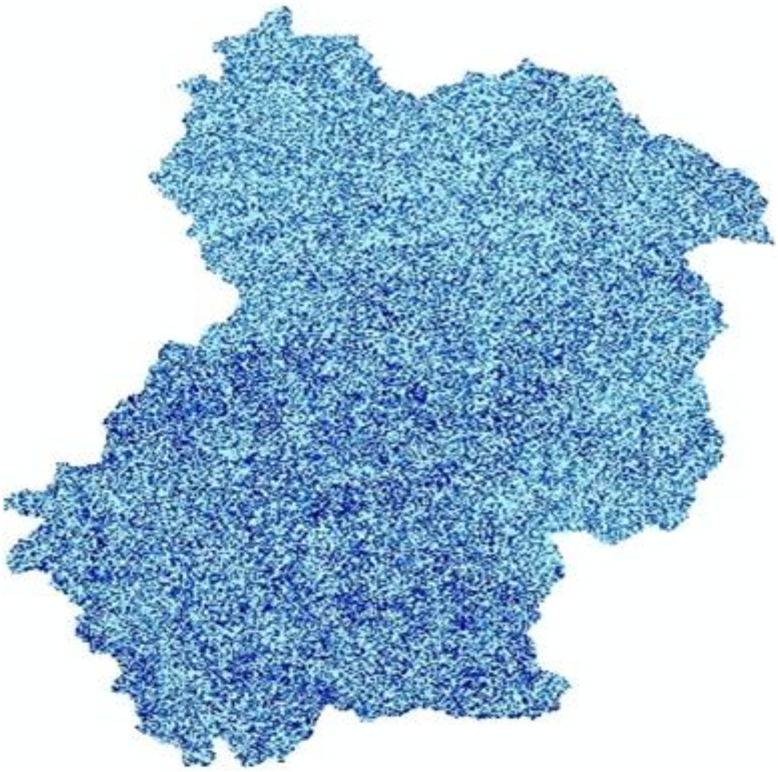

Figure: Hillshade Chamoli.

Figure: Geology

Figure: River

Figure: Geomorphology

Figure: Faults

Figure: Lithology

Figure: Contour

Figure: Roads

Figure: Aspect

Chamoli district comprises of high hills and mountains with very narrow valleys, deep gorges having very high gradient. The Northern, Northwestern, Eastern and Northeastern part of the district comprises of Tethyan Himalaya withsnow covered throughout the year. The tract of Chamoli district consists of outward succession of ridges viz. Greater Himalaya and Lesser himalaya of decreasing height. The hills possess very little level land. The soils have developed from rocks like granite, schist, gneiss, shales, slate, etc. under cool and dry climate.

Very steep to steep hills and glaciofluvial valleys are dominantly occupied with very shallow to moderately shallow, excessively drained, sandy - skeletal to loamy - skeletal, neutral to slightly acidic with low available water capacity soils. They have been classified as Lithic/Typic Cryorthents.

Geology of the study area: Chamoli district is mainly composed of highly compressed and altered rocks like granite, phyllites, quartzite, etc and a major part of it is under forest. Geologically the area belong to the Lesser Himalayas and lies in a tectonic fore deep. The Lesser Himalayas are comprised of fanglomerates followed by bedded quartzites, slates, phyllites and low - grade schists. The rock types are ranging from green schist to lower amphibolite facies.

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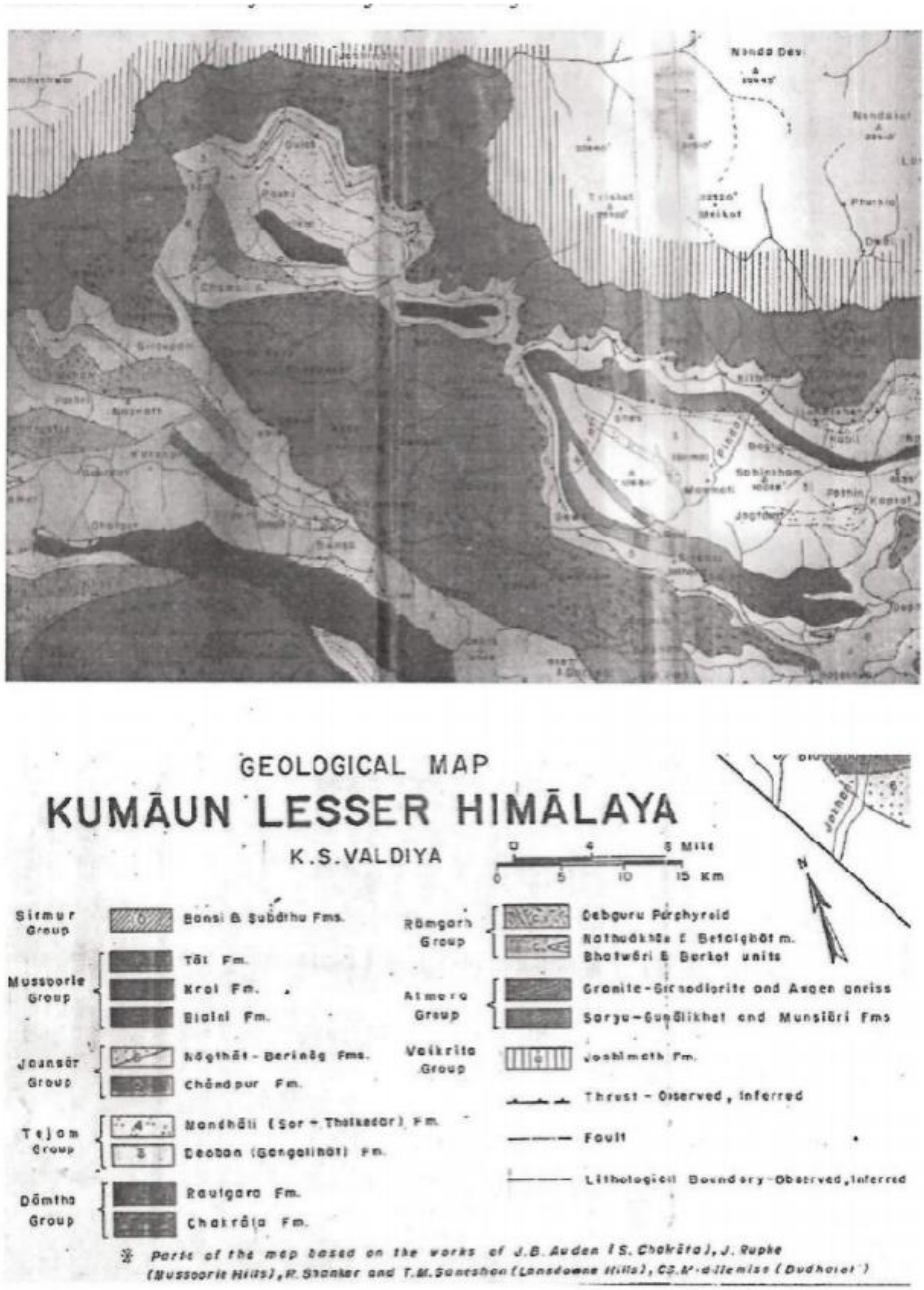

Rivers - The streams within the study area form certain patterns depending on the slope of the land, underlying rock structure as well as the climatic conditions of the area. Alaknanda, Pinder, Nandakini, Dhuliganga and Birhiganga the main river passes through the area which originates from the central crytalline zone defined by high mountain ranges which is covered by glaciers. Most of the streams have originated from the higher altitudes and flow down by cutting deep gorges in lower altitude where they ultimately join with the main river Alaknanda.

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River map of Chamoli District

Roads - The Chamoli district is well connected through road network, since air and rail connectivity in uttarakhand is limited. Road network is the best and easily available option for transport. The only national highway is from Rishikesh to Badrinath, which runs parallel to river Ganga and Alakhnanda. Pathways, Katccha roads and tracks play an important role in providing movement facility and communication in the difficult hilly terrain of rural area of the district.

Location of Chamoli District

There are various Faults seen in Gopeshwar, Chamoli and Bairagna. Cracks were also observed in asphalt roads at several locations. Severe ground deformations result in landslides at various places, in the southern, and northwestern region. The Himalaya Range has been undergoing crustal shortening along the 2, 400 km long northern edge of the Indian Plate which resulted in the formation of several thrust faults including the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT). The MCT consists of three sub - thrusts: MCT I, MCT II and MCT III. Many earthquakes have occurred along these thrust faults. It is thought that the Chamoli earthquake in 1999 was associated with these fault systems.

Months	Rainfall (mm)
January	213.75
February	749.90
March	462.60
April	38.40
May	23.40
June	956.60
July	2235
August	1436.80
September	177.94
October	67.80
November	2.80
December	17
Average Annual	6399.99

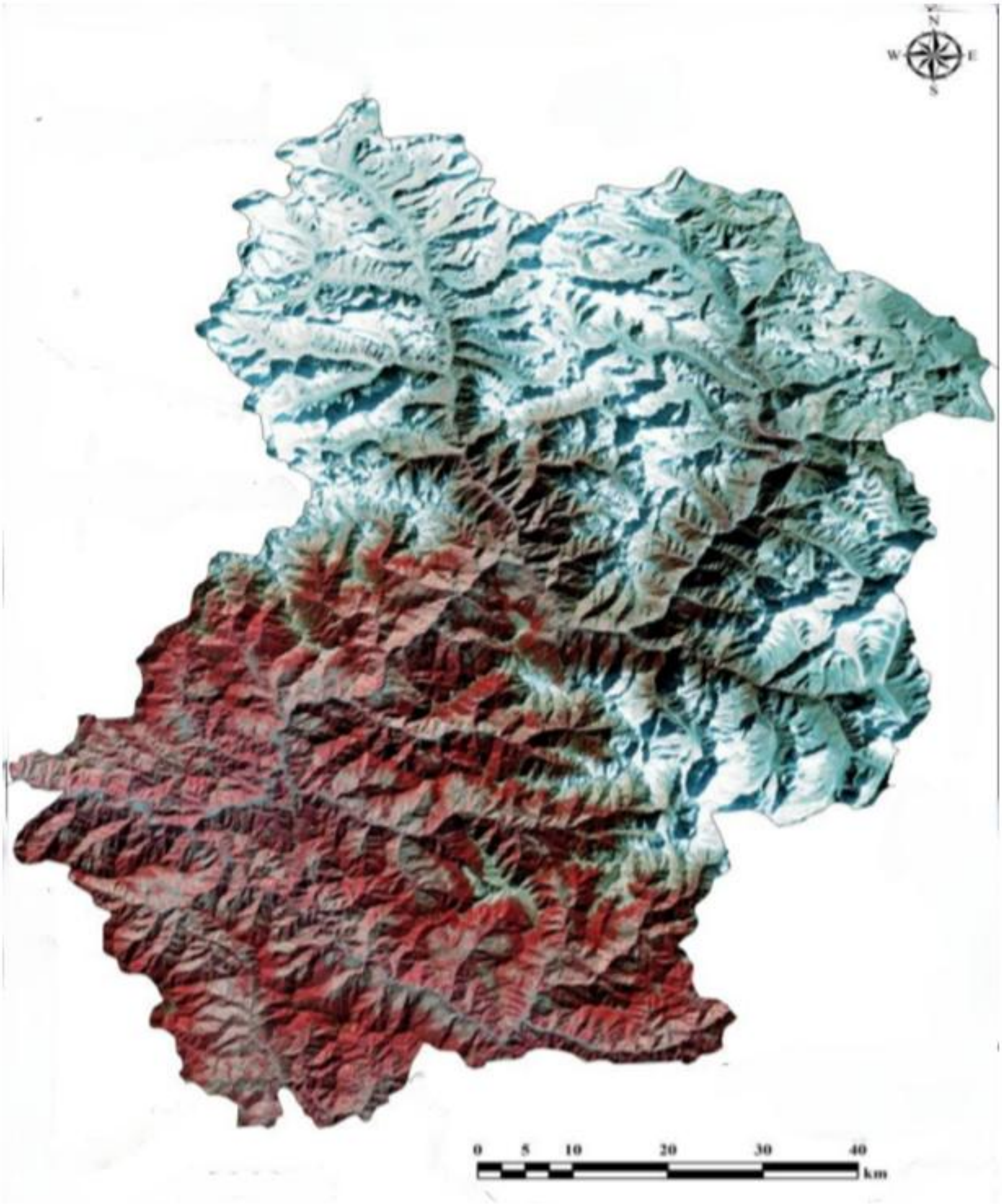

Figure: Landsat MSS False Color Composite

SR. NO.	Vegetation type/ Landuse	Area (sq km)	Area %
1	Forest	2712	33.77
2	Scrub	217	2.7
3	Agriculture	1537	19.14
4	Barren land	476	5.93
5	Snow	1040	12.95
6	Waterbody	1026	12.78
7	Settlement	1022	12.73
Total		8030	100

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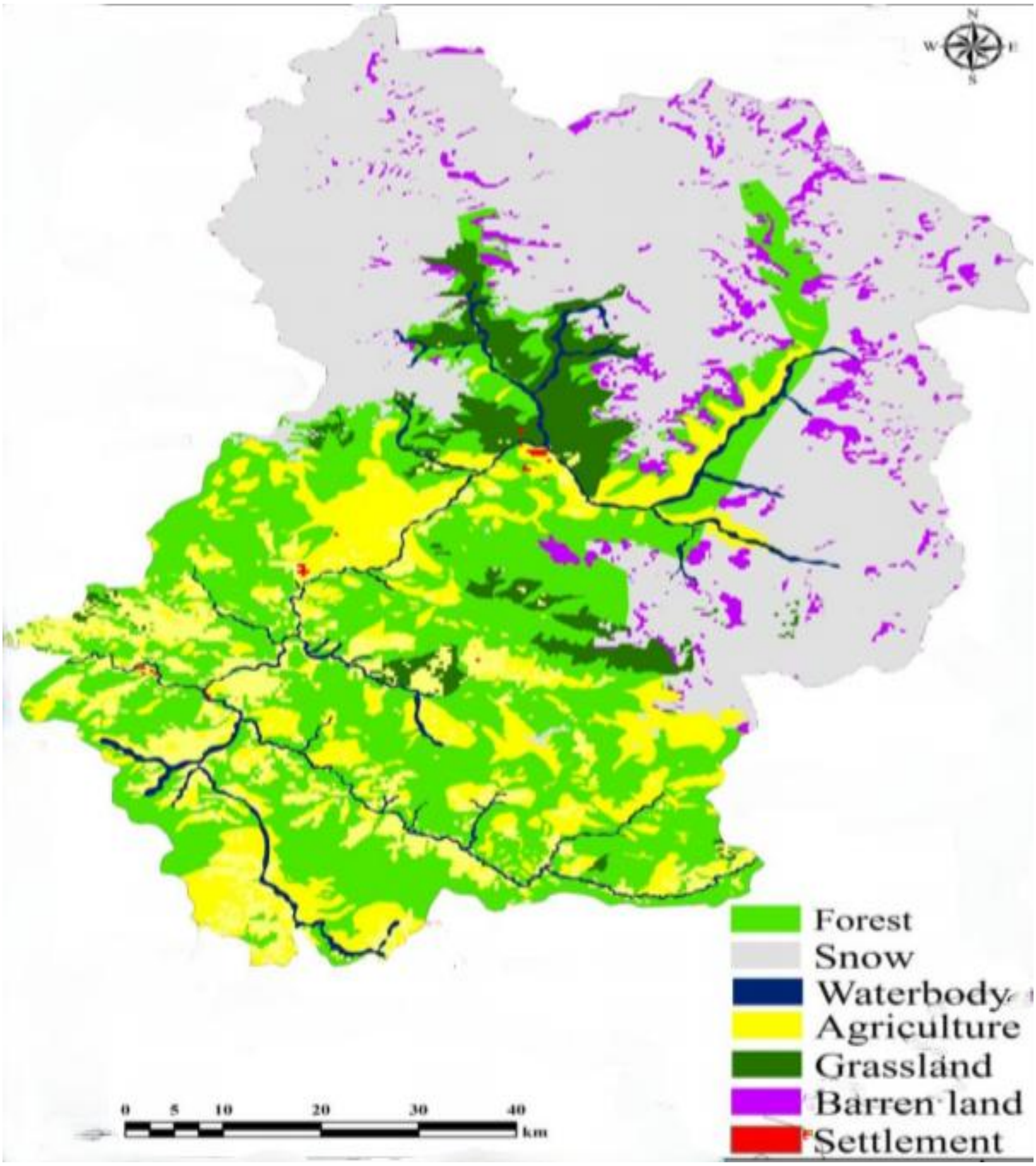

Figure: LULC map

The vegetation type/land use map is prime input for flood hazard and risk assessment at landscape level. The vegetation type/land use map was prepared using Landsat satellite data using on - screen visual interpretation techniques. The vegetation type/land use map was categorized in eight classes viz; forest, scrub, agriculture, barren land, snow, waterbody and settlement respectively. The maximum area is covered by forest 2712.00 km2 (33.77 %) followed by agriculture 1537.00 km2 (19.14 %), snow 1040.00 km2 (12.95 %) and water body 1026.00 km2 (12.78 %) respectively. The flood frequency map was generated from 2010 to 2019 using Landsat series data set was used. Based on these dataset a flood hazard and risk assessment map was developed. The high soil erosion was found in the upstream sediments and dissolved substances cumulatively in river load deposited in the river channels and on adjacent flood plains in downstream of the major rivers. As per field observation, sediments deposited in Alaknanda, Bhagirathi river and its tributaries have changed the rivers gradient, cross sectional area, velocity and intensity of water flow and discharge of rivers. Therefore, overflow of rivers occurred and flooded the nearby areas. The cross sectional area of these rivers is decreasing from time to time as a result of sediment deposition. In some areas the depth of Alaknanda river decreased to 35 - 11 m. Some agricultural land crops and settlement have been buried by the deposited sediments. Over all, the river channels depth and width increased and the water discharging capacity of the major rivers and their tributaries gets minimized which leads to overflow of water and flood consecutively.

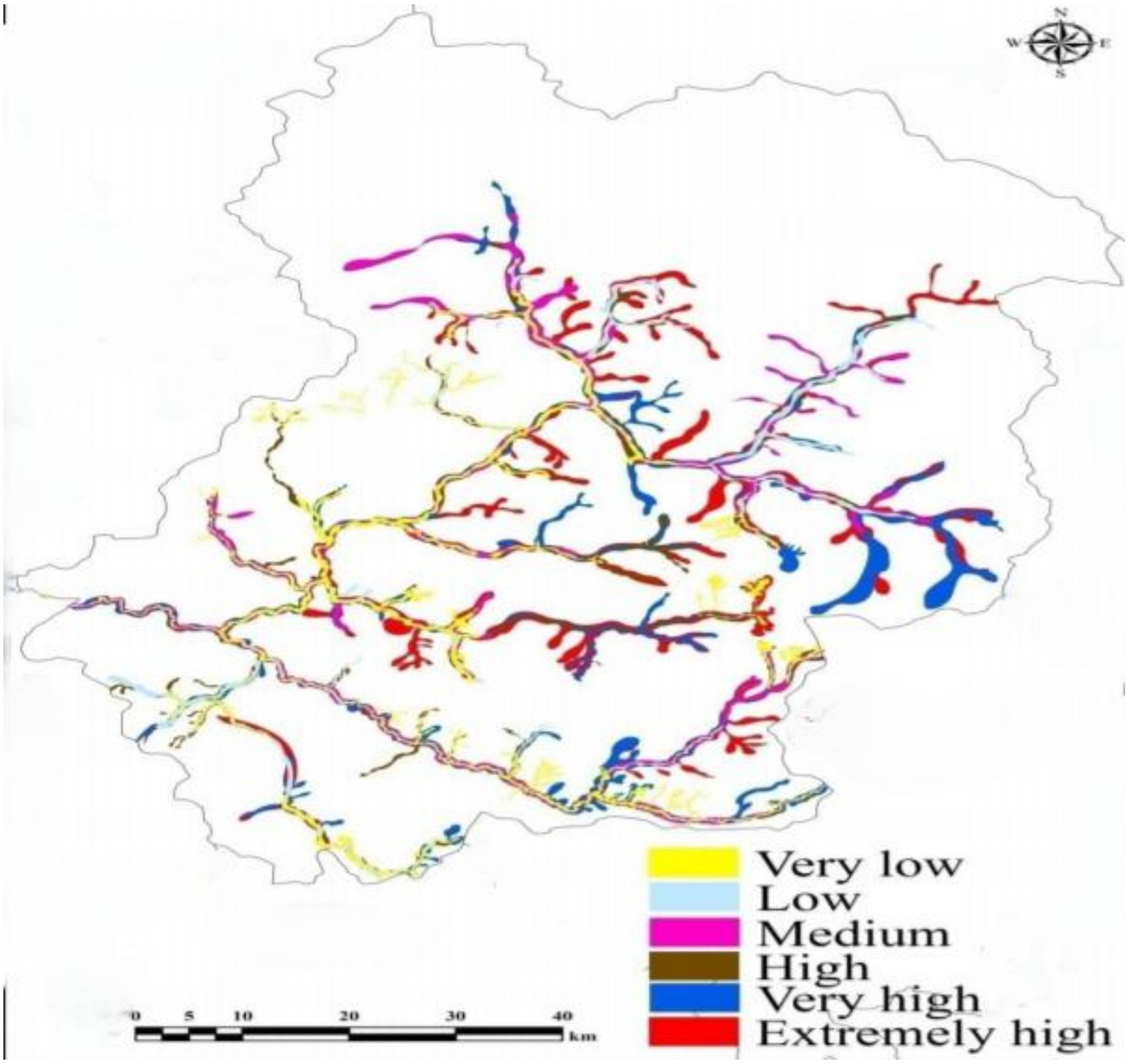

Figure: Flood Hazard Index Map

Larger part of the study area is situated on the southern slopes of the outer himalayas, being situated at the outer parts of himalayas, the entire region has lots of steep valleys. Hence, various issues such as glacier breaks, overflowing rivers cause flooding in many parts of the district. Recently, huge flooding took place on 7th February, due to the breaking off of the Nanda devi glacier which released the water trapped behind the ice, causing a glacial lake outburst flood. Hence, various methods should be taken into consideration such as building dams in the paraglacial zone, i. e. river valleys in which the floor is higher than 7, 000 feet.

6. Summary

Chamoli is a land of steep Himalayan mountains, dense perennial river networks, home to a host of pilgrim and tourist places, attracting thousands of people from across the world. The region is situated in a seismic active zone, and the recent urbanization has made the state more unstable. The district is also known for adverse weather conditions, which receives high intense rainfall and frequent cloudbursts. All these factors are responsible for the district being prone to flood disasters.

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