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INTEGRATED HYDROLOGICAL MODELLING OVER UPSTREAM CATCHMENTS OF HIMALAYAN RIVERS AND ASSESSMENT OF EXTREME HYDROLOGICAL EVENTS

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INTRODUCTION

- Flood is an overflow of water that submerges land that is usually dry. Flash flooding is characterized by an intense, high velocity torrent of water that occurs in an existing river channel with little to no notice. Flooding that begins within 6 hours, and often within 3 hours, of the heavy rainfall (or other causes.
- The Himalayan Rivers induce major floods, that are mainly caused in the Ganges-Brahmaputra-Meghna basin which carries 60% of the total river flow of the country. The flows of the Ganges, Brahmaputra are highly seasonal, and heavily influenced by monsoon rainfall. As a result, these rivers swell to their banks and often overflow during the monsoon months.
- These early monsoons have brought misery in the life of the people in Uttarakhand, which is part of Himalayan Rivers. Flash floods effects most of the areas in the downstream portion of Alakanda River and Bhagirathi River. Many towns getted flood along the bank of these rivers.

AIM AND OBJECTIVE

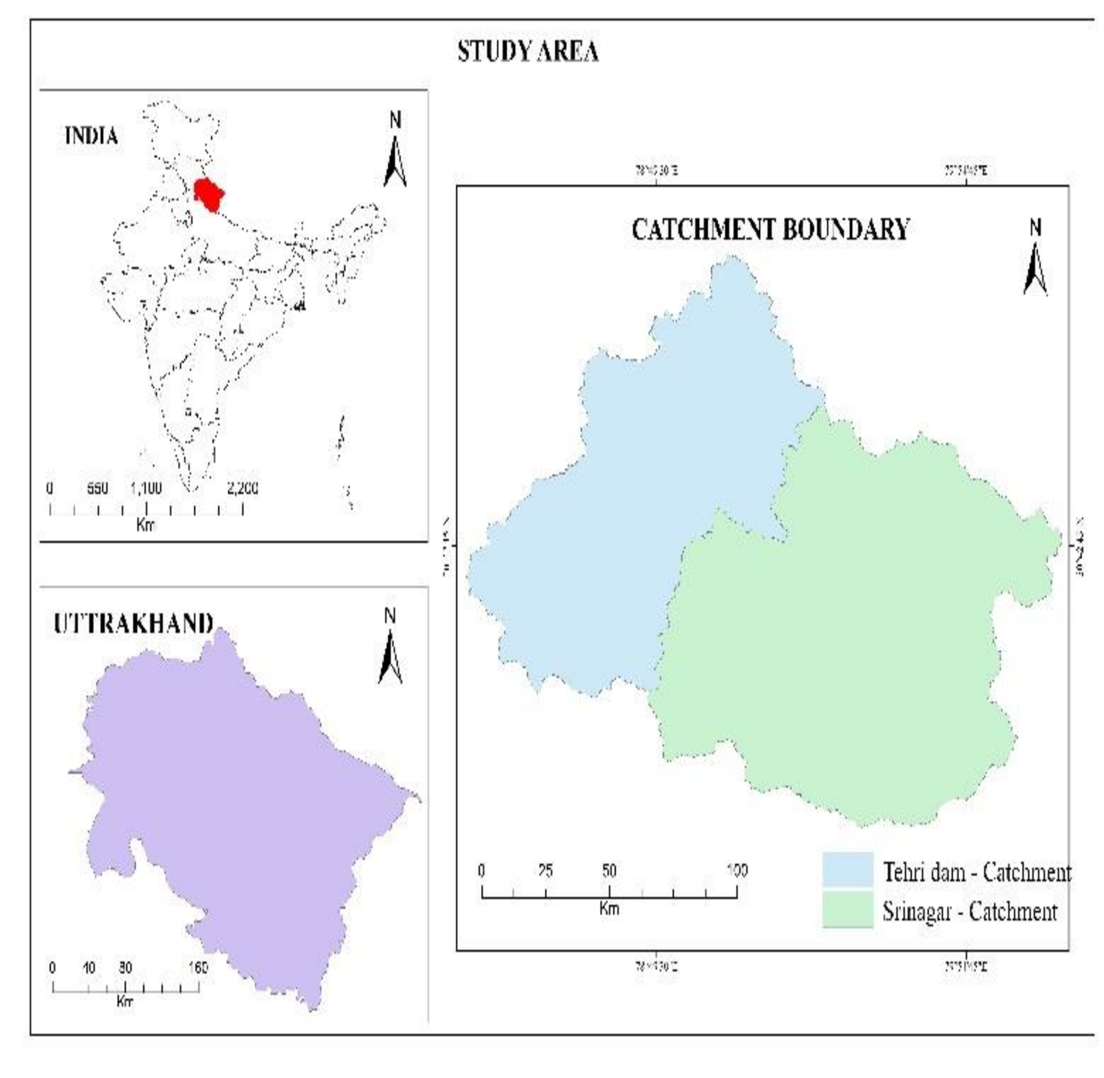
AIM

To assess the flood vulnerability map on the Uttarakhand catchments which are more vulnerable along Bhagirathi and Alaknanda River.

OBJECTIVE

- To create morphometry parameters to analyse the flood vulnerability in the two catchments using DEM.
- To analyse the discharge and rainfall data from SAC HYDRO MODEL for extreme weather events.
- To use the geological layer obtained from NRDB (Natural Resource DataBase) to analyze flood vulnerability.
- To combine these morphometry parameters, discharge, rainfall and geology layers and weighted by Analytical Hierarchy Process (AHP) techniques.

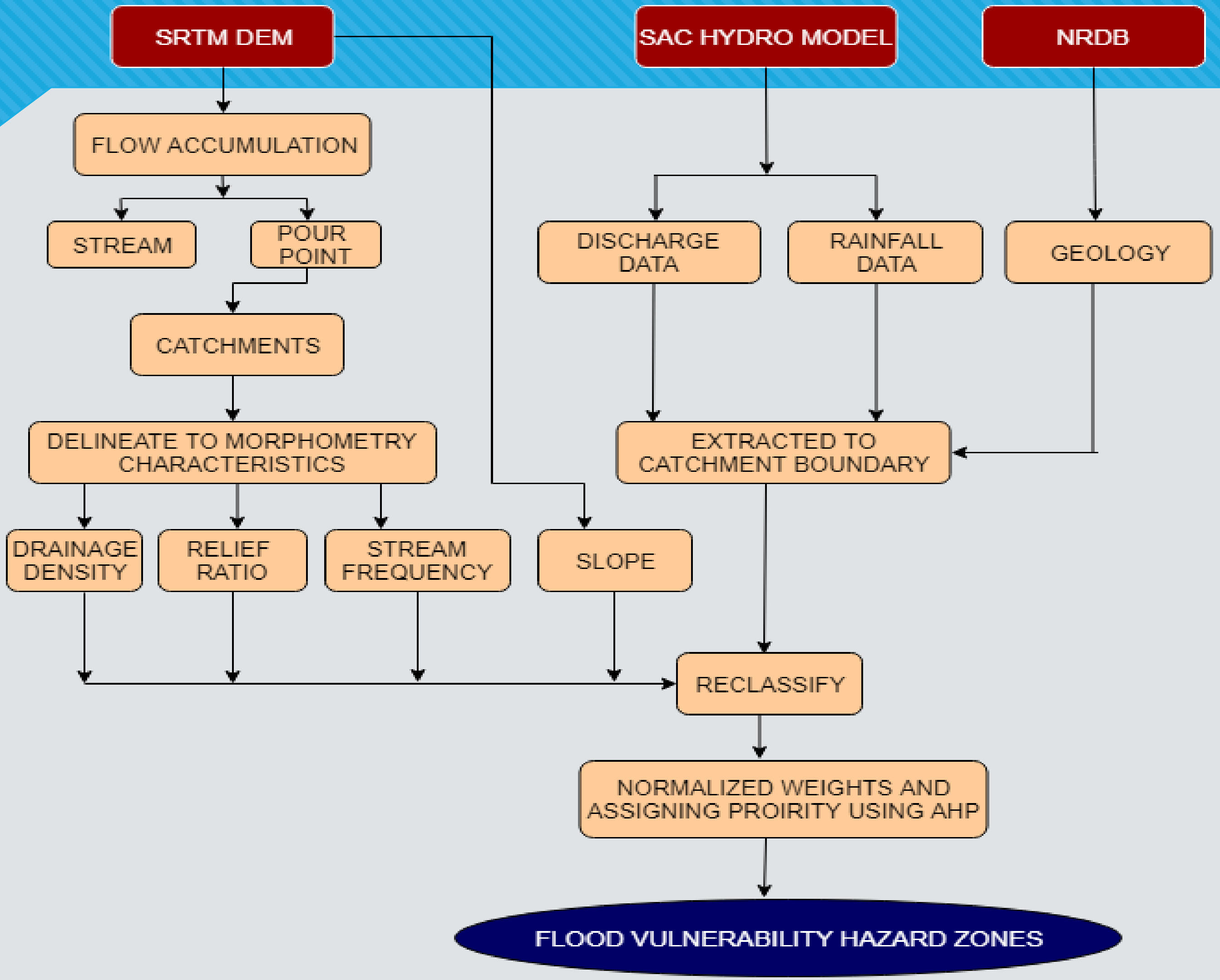
STUDY AREA



The **Tehri Dam** is one of the five biggest dams (260.5 m high) of the world and the biggest in Asia. It is located deep in the Garhwal hills of Uttarakhand state across the river Bhagirathi about 1.5 km downstream the confluence of the river Bhagirathi and Bhilangana. Tehri Hydro Development Corporation (THDC) was formed in 1988 to manage the dam. If the dam fails, it can crash the densely populated valleys of Rishikesh, hardwar, Meerut, Bijnor etc. within hours.

The **Srinagar Catchment** which has river Alaknanda is the major tributary of the Ganga river basin, which also includes other rivers such as Bhagirathi, Pindar and Dhauliganga. The river Alaknanda originates in the glacial region (Alkapuri glacier) of Himalaya in Chamoli district of Uttarakhand and enters district Pauri Garhwal.At present two Hydroelectric projects i.e. Srinagar (330 MW) and Vishnuprayag (400 MW) are under construction on river Alaknanda while five more projects on this river have been identified in the district Chamoli.

METHODOLOGY



DATA SOURCE

DATA	DATA SOURCE	RESOLUTION
DEM (SRTM)	Earthexplorer.usgs.gov.in	30m
DHM (Simulated data)	SAC HYDRO MODEL	5km x 5km
GEOLOGY	NATURAL RESOURCE DATABASE	1:250000

SOFTWARE USED

ARCGIS 10.5

SNAP

MS OFFICE 2016

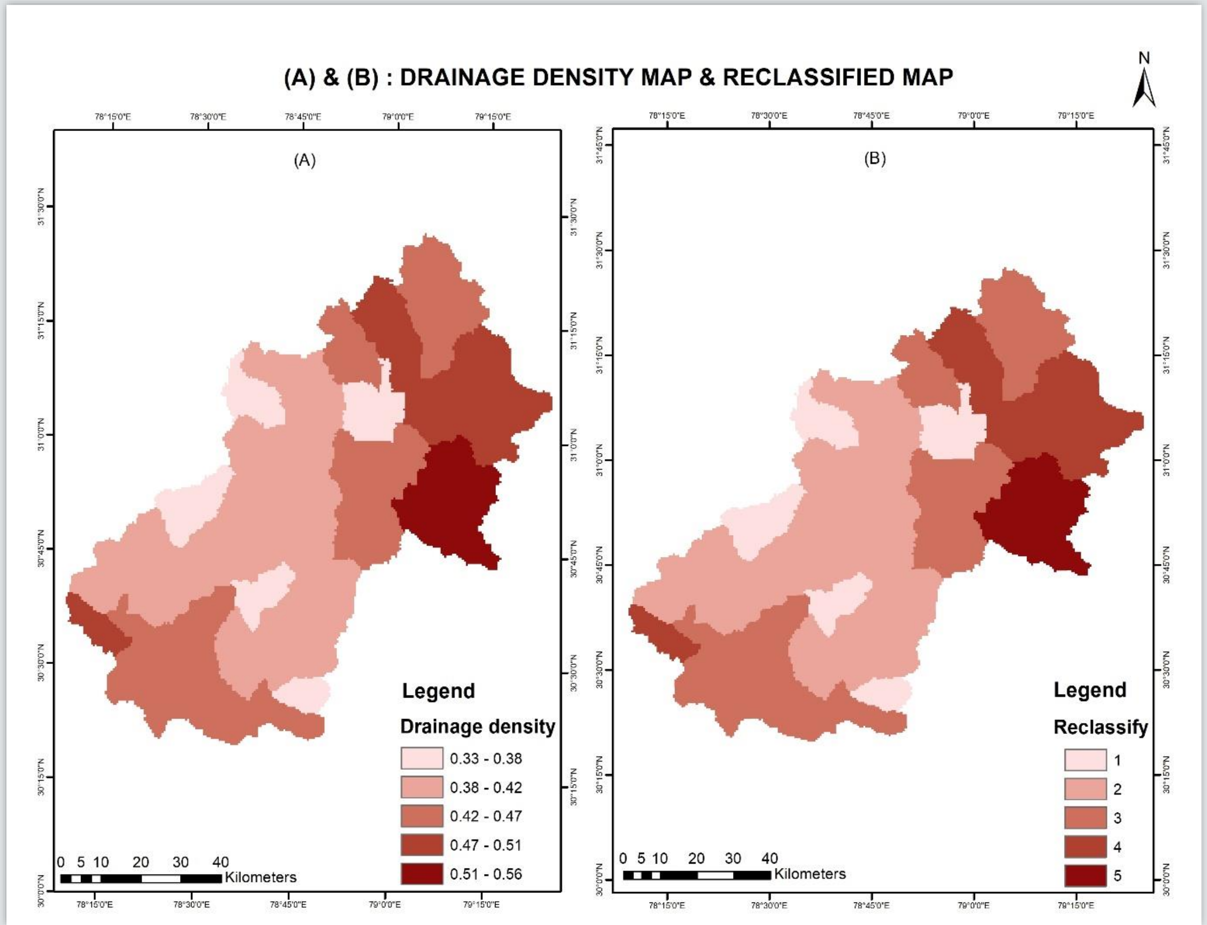
MORPHOMETRY PARAMETERS

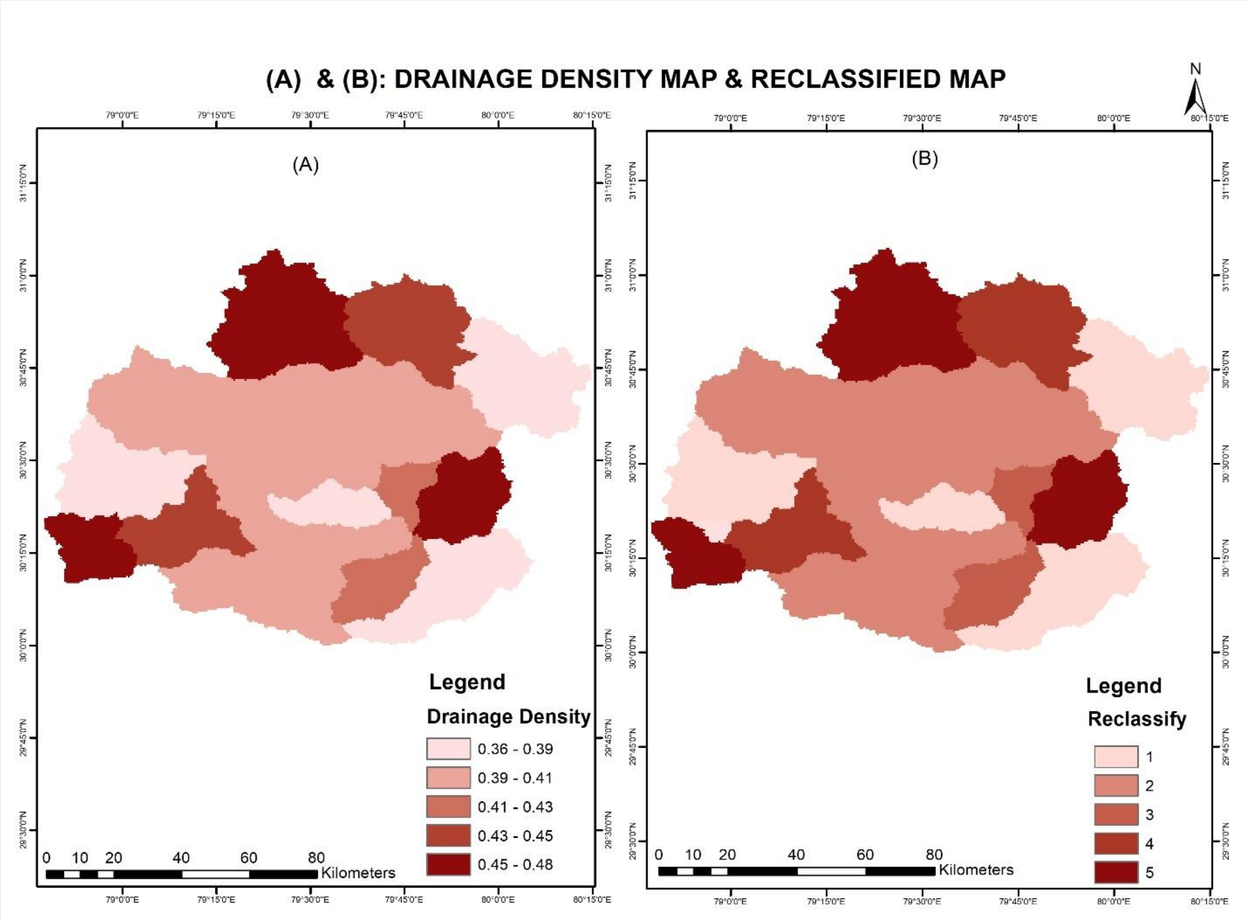
The two catchment morphometric parameters were inferred by using the linear, areal and relief characteristics. In this study, drainage density, relief ratio, and stream frequency are assessed to achieve the vulnerability assessment of two catchments [9]. The following table is used to calculate the catchment morphometry response.

PARAMETER	FORMULA	DERIVATION PROCEDURE
DRAINAGE DENSITY	$Dd = \sum L / A$	where, Dd=drainage density, ∑L = total no. of stream length, A= area of basin
RELIEF RATIO	$Rh = R / Lb$	Where,Rh=relief ratio, R=basin relief, Lb=length of basin
STREAM FREQUENCY	$Fs = Nu / A$	Where, Fs=stream frequency, Nu= total no. stream in that basin, A=basin area

DRAINAGE DENSITY

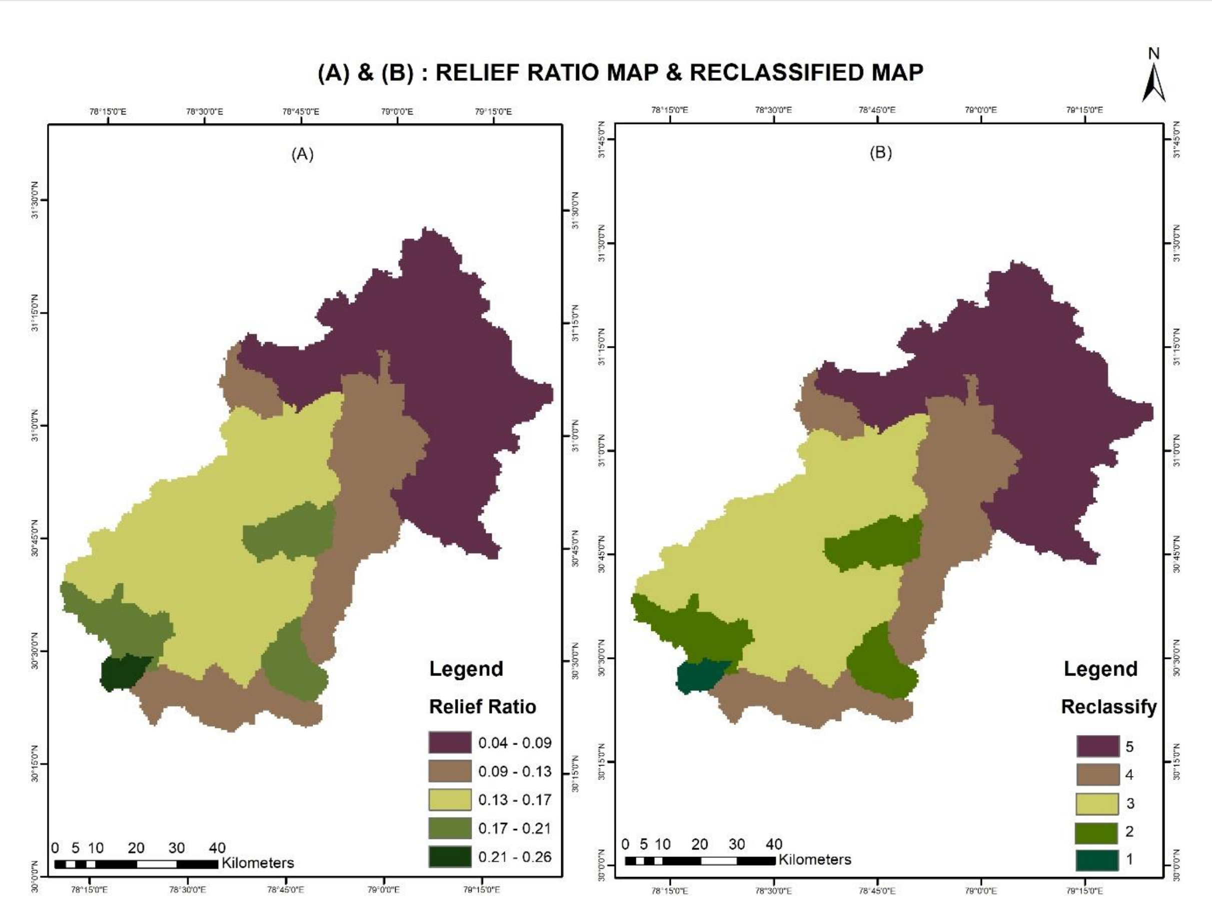
Drainage Density (Dd) is the total length of stream in the watershed to the area of that watershed. If Dd is high in the watershed, it has more run-off and less infiltration rate. If Dd is low, it has less run-off and more infiltration rate.

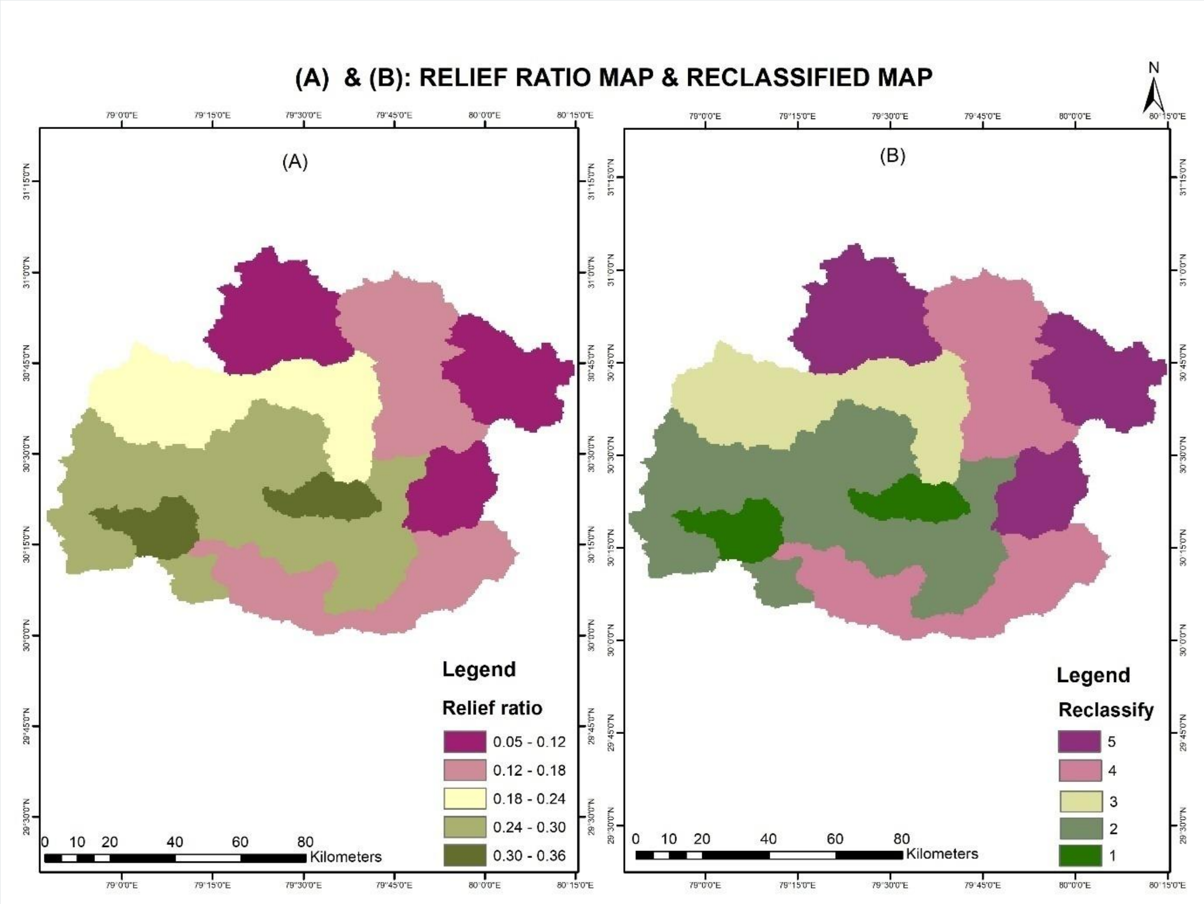




RELIEF RATIO

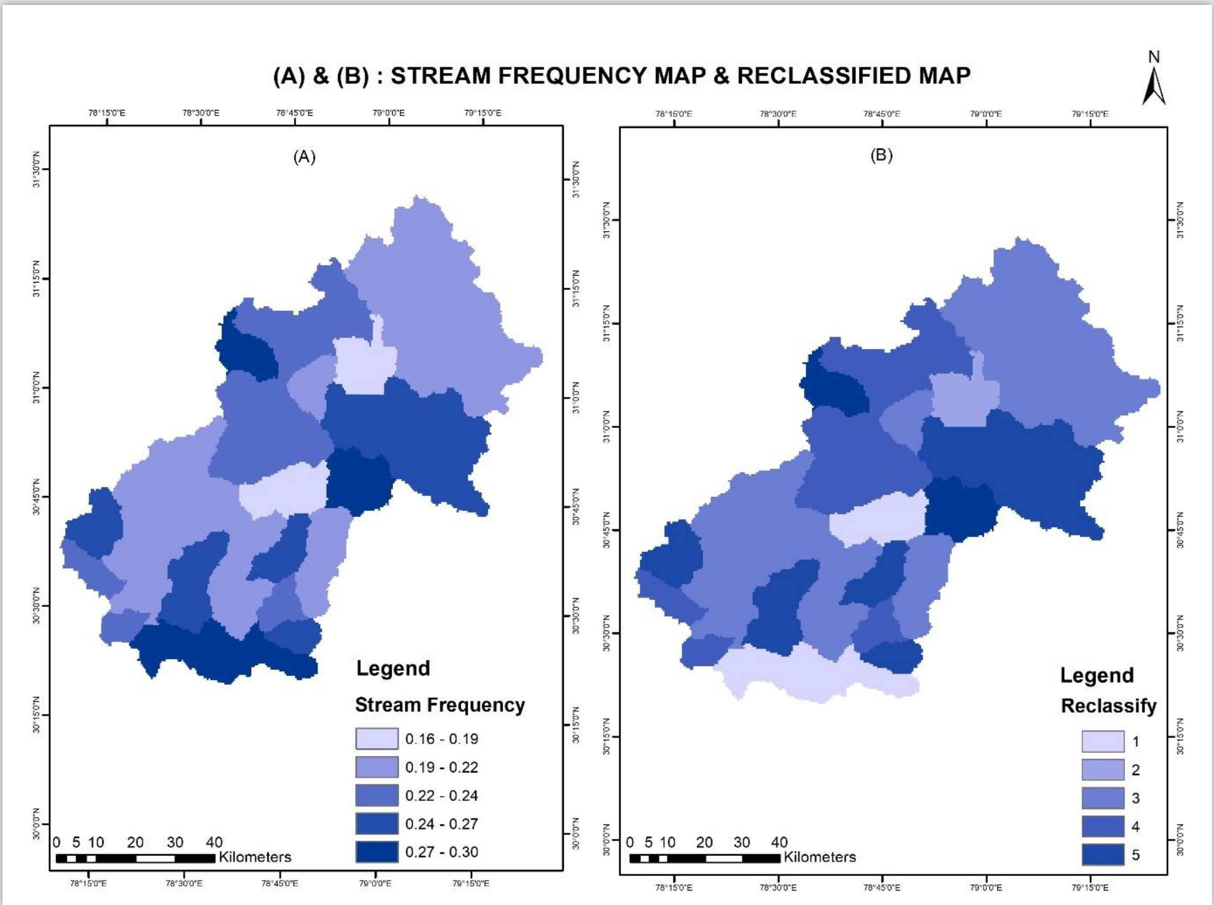
- Relief ratio (Rh) ratio between total relief(R) of the watershed and its longest dimension parallel to principle drainage line(Lb). It indicates steepness of drainage basin showing the effect of intensity of degradation processes operating on slope of the watershed.

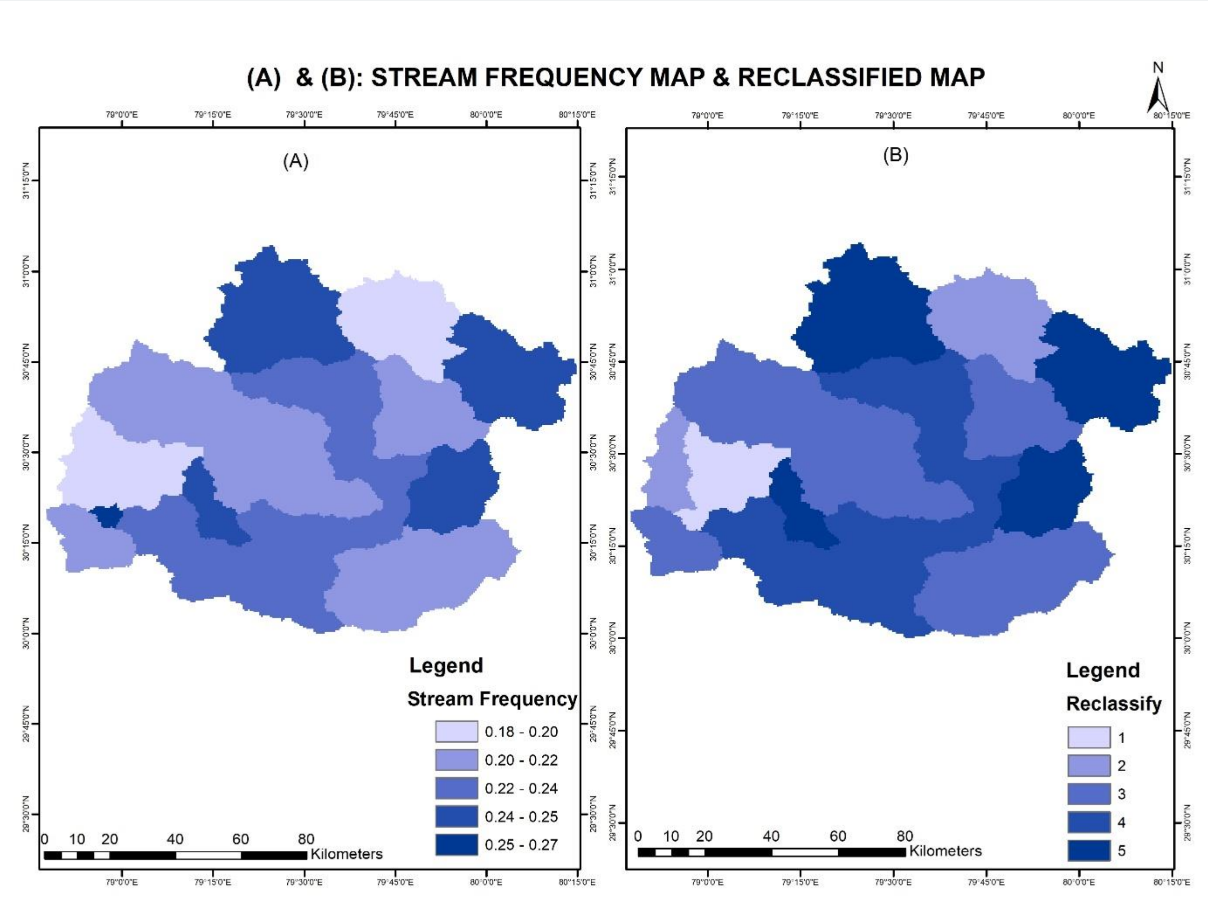




STREAM FREQUENCY

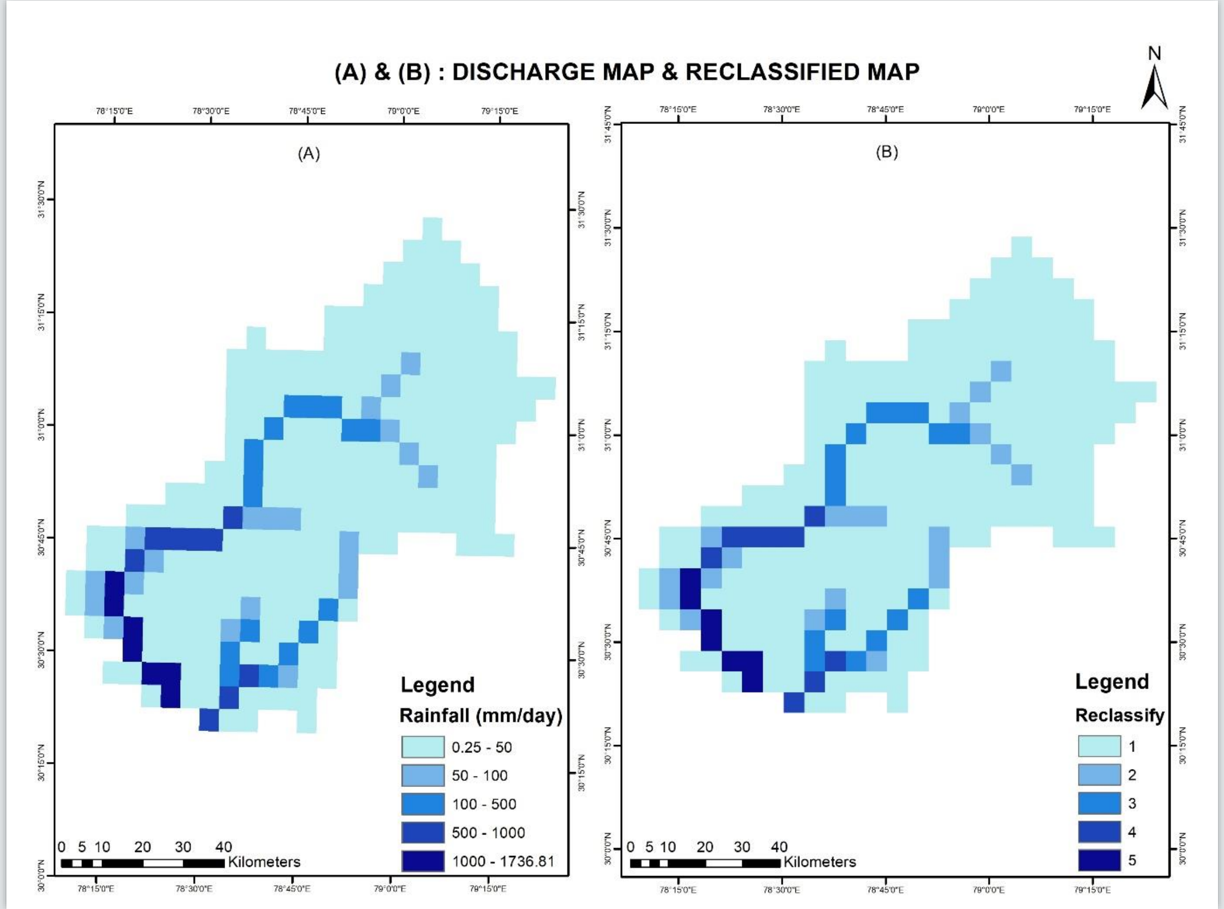
Stream frequency (Fs) ratio of the total no. streams in a basin to that of basin area. It is a measure of closeness of drainage. If drainage frequency is more, there will be more surface runoff. If drainage frequency is less, less surface run-off in the watershed.

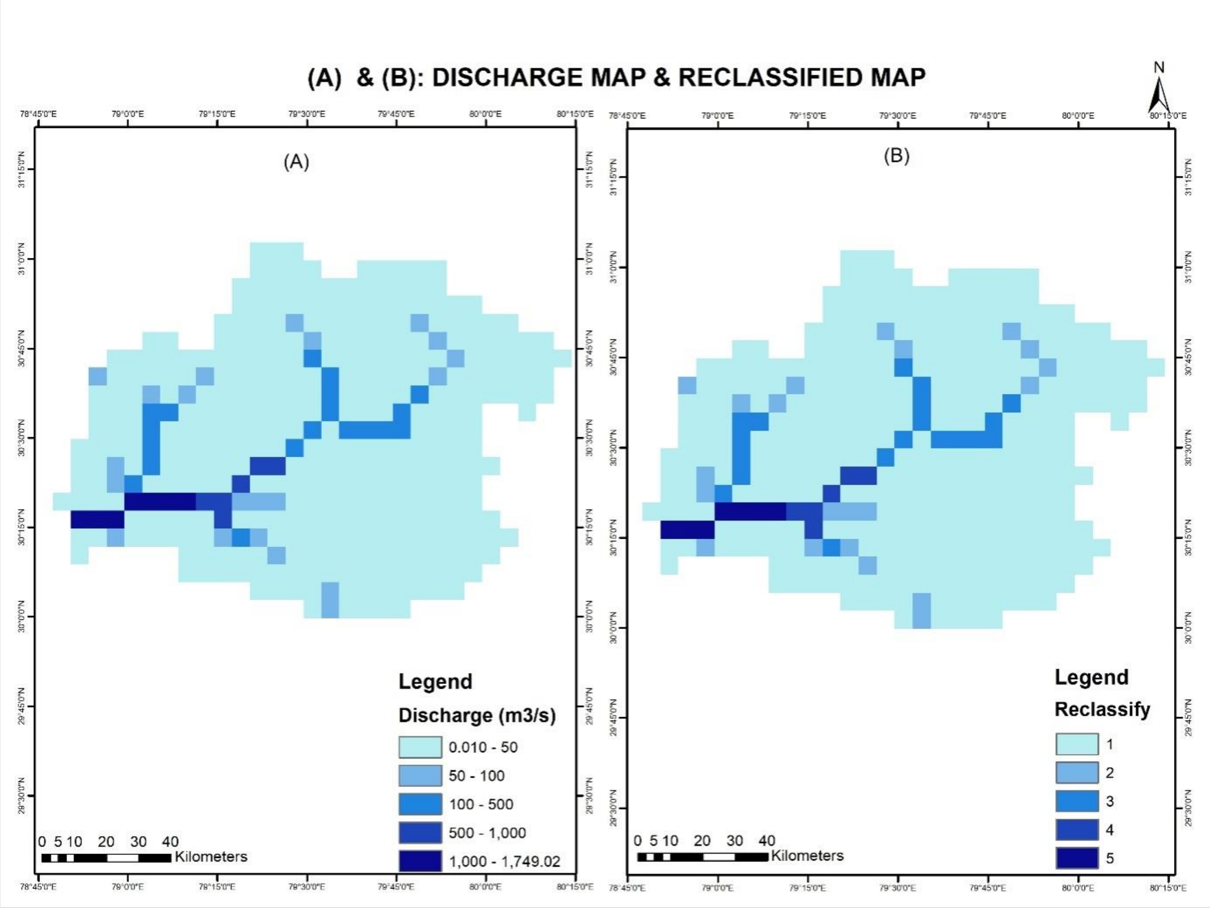




DISCHARGE

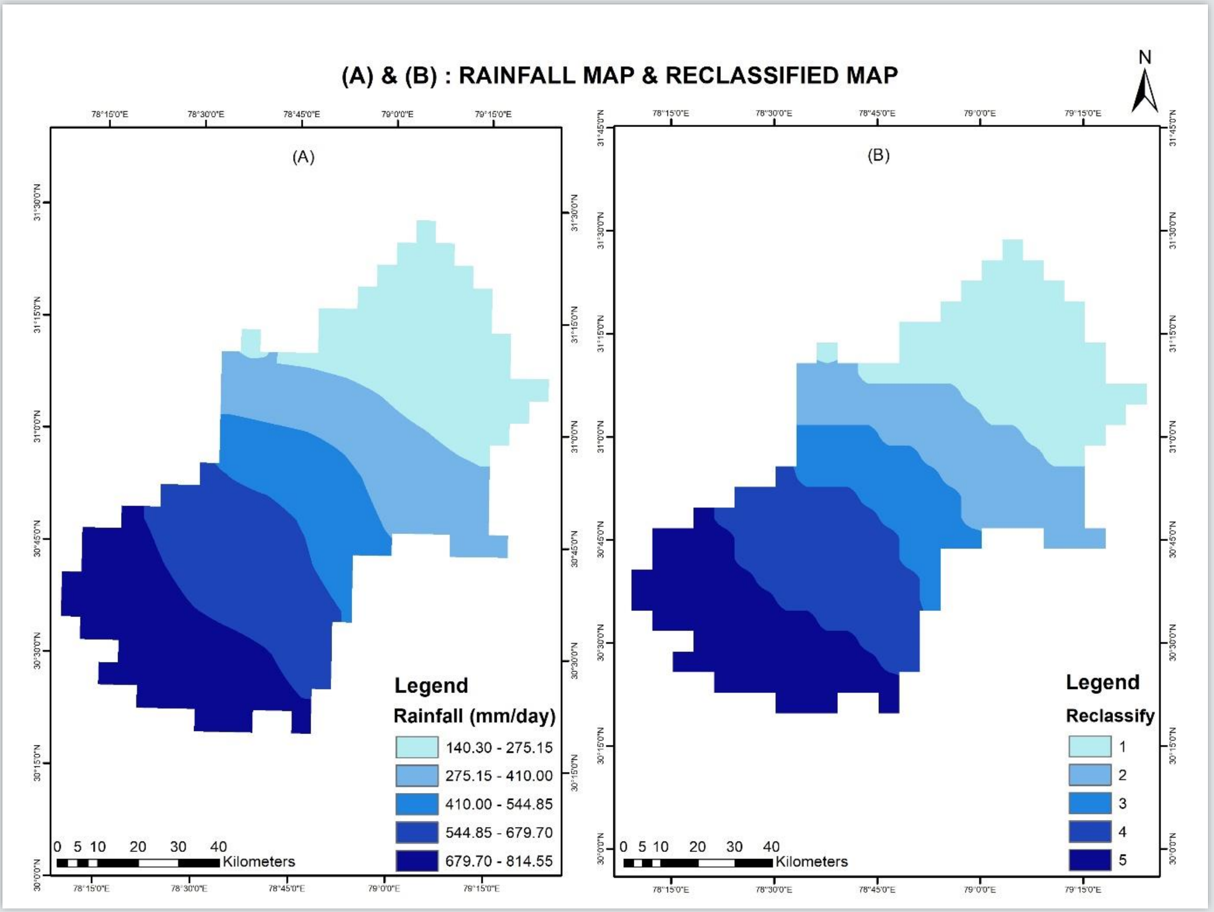
Discharge data calculated for the peak flow rates of the extreme weather events. Three events were recorded as the flash floods in the river valley along the both catchments. The average data can be taken to estimate the flood vulnerable areas in these catchments.

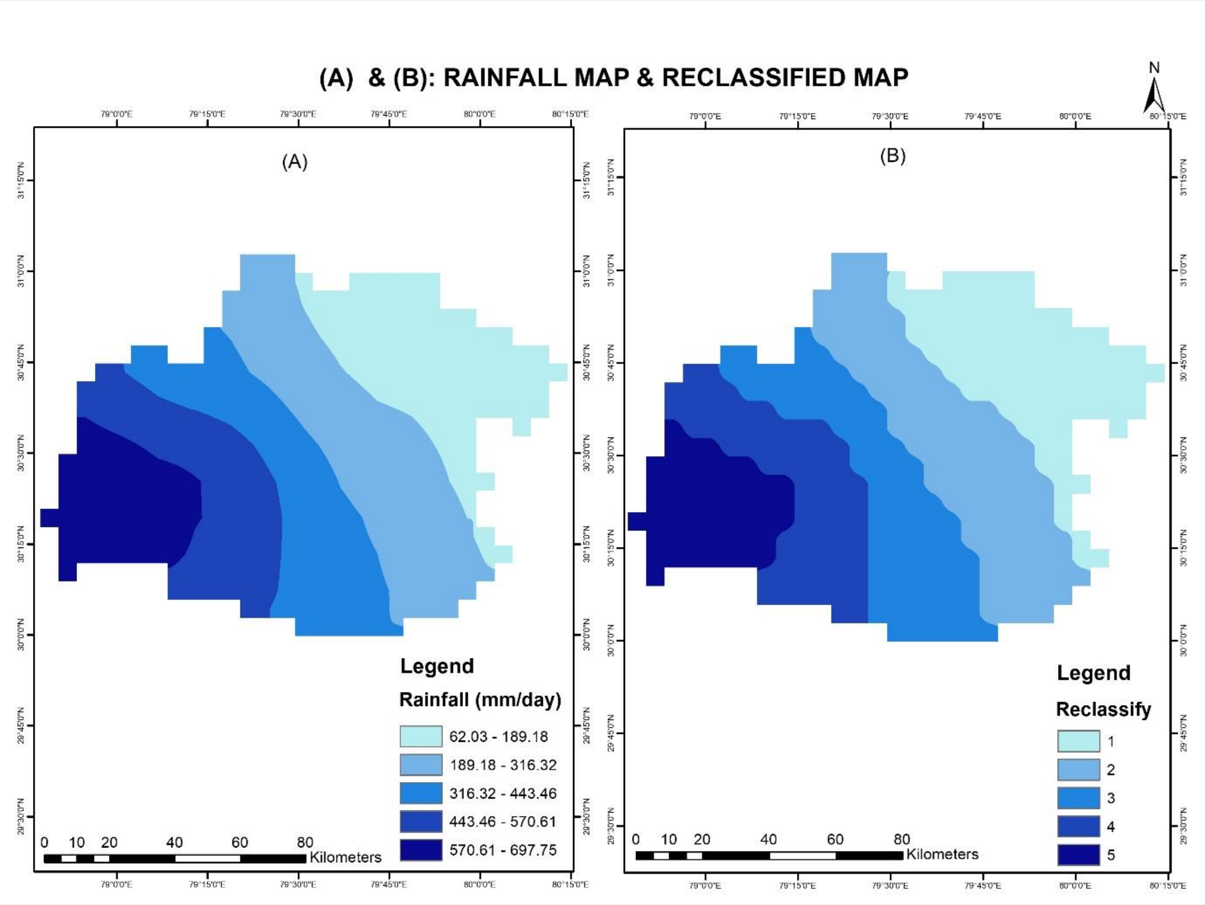




RAINFALL

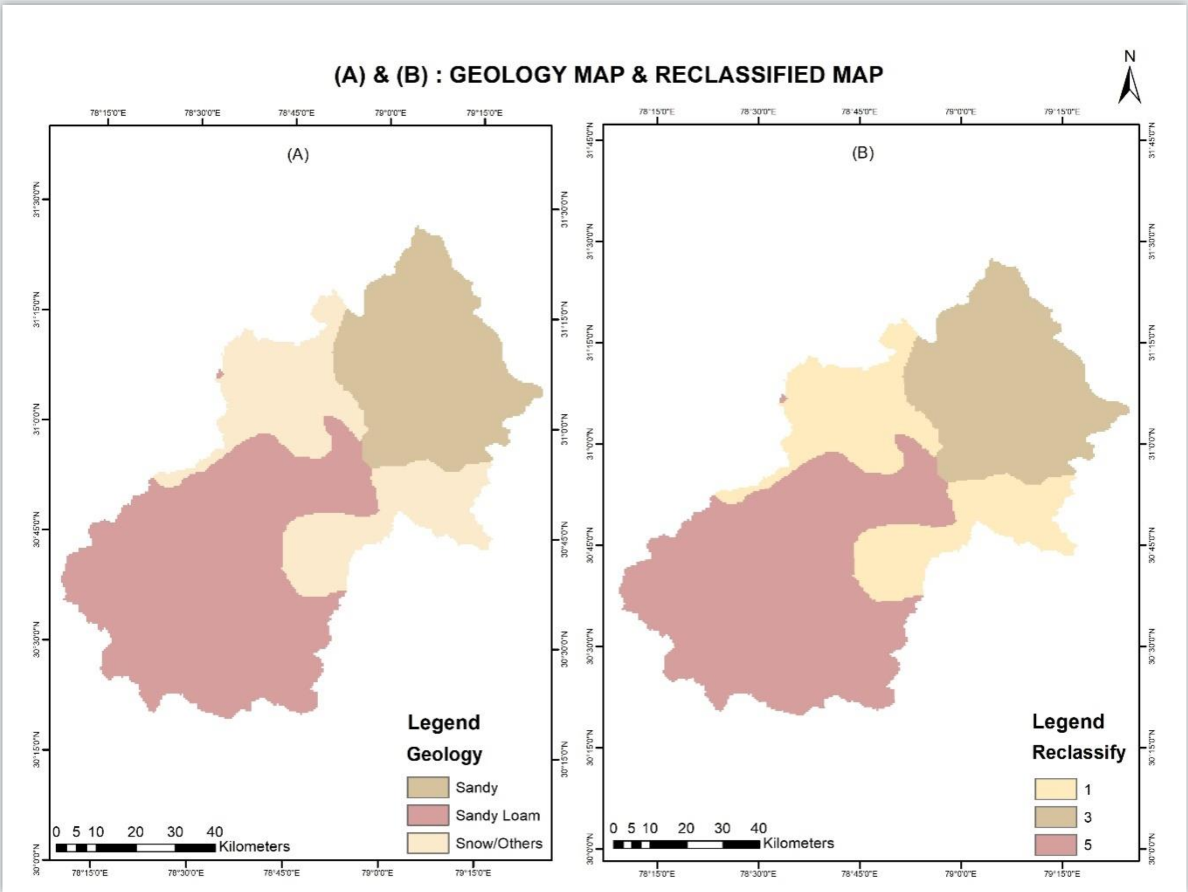
Rainfall data can be analysed for the monsoon period of these extreme weather events. The image shows the rainfall varies from low to high at the downstream rivers.

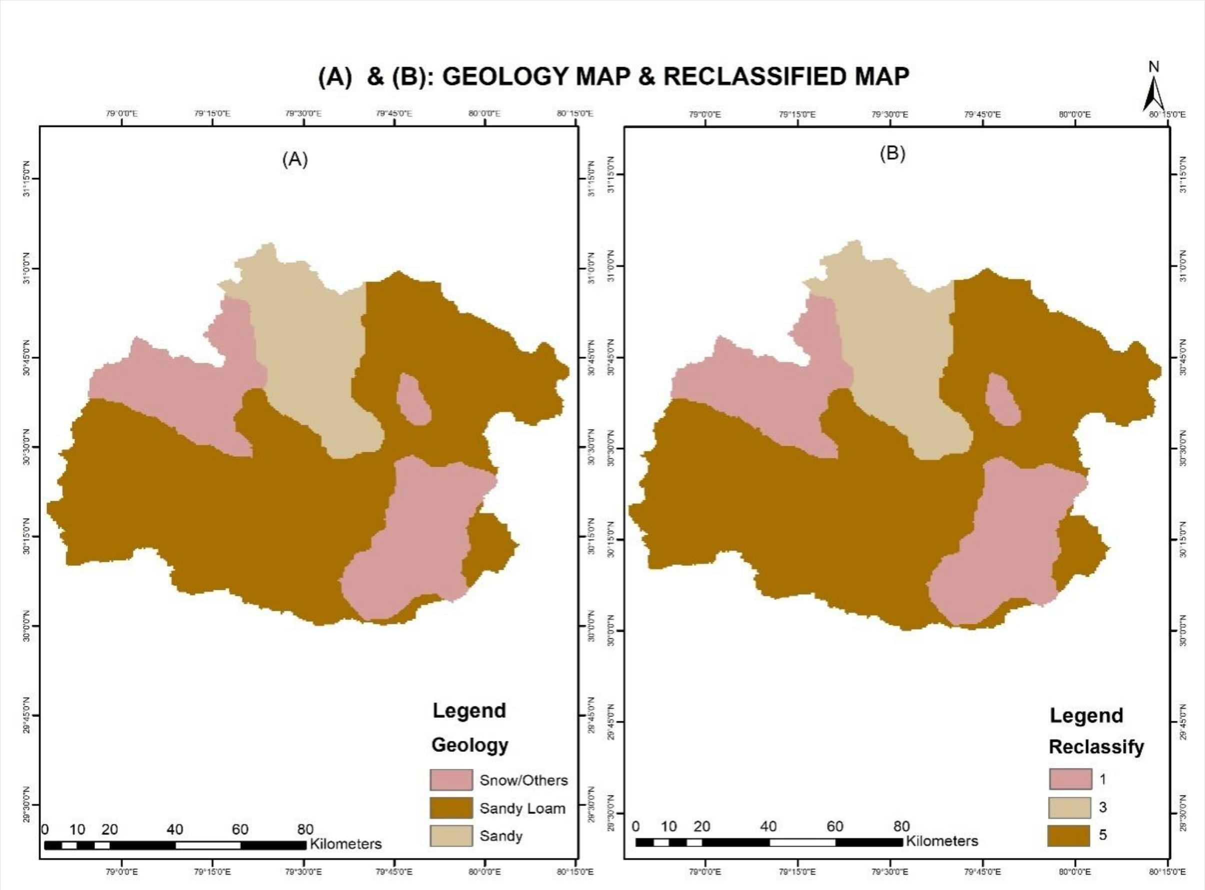




GEOLOGY

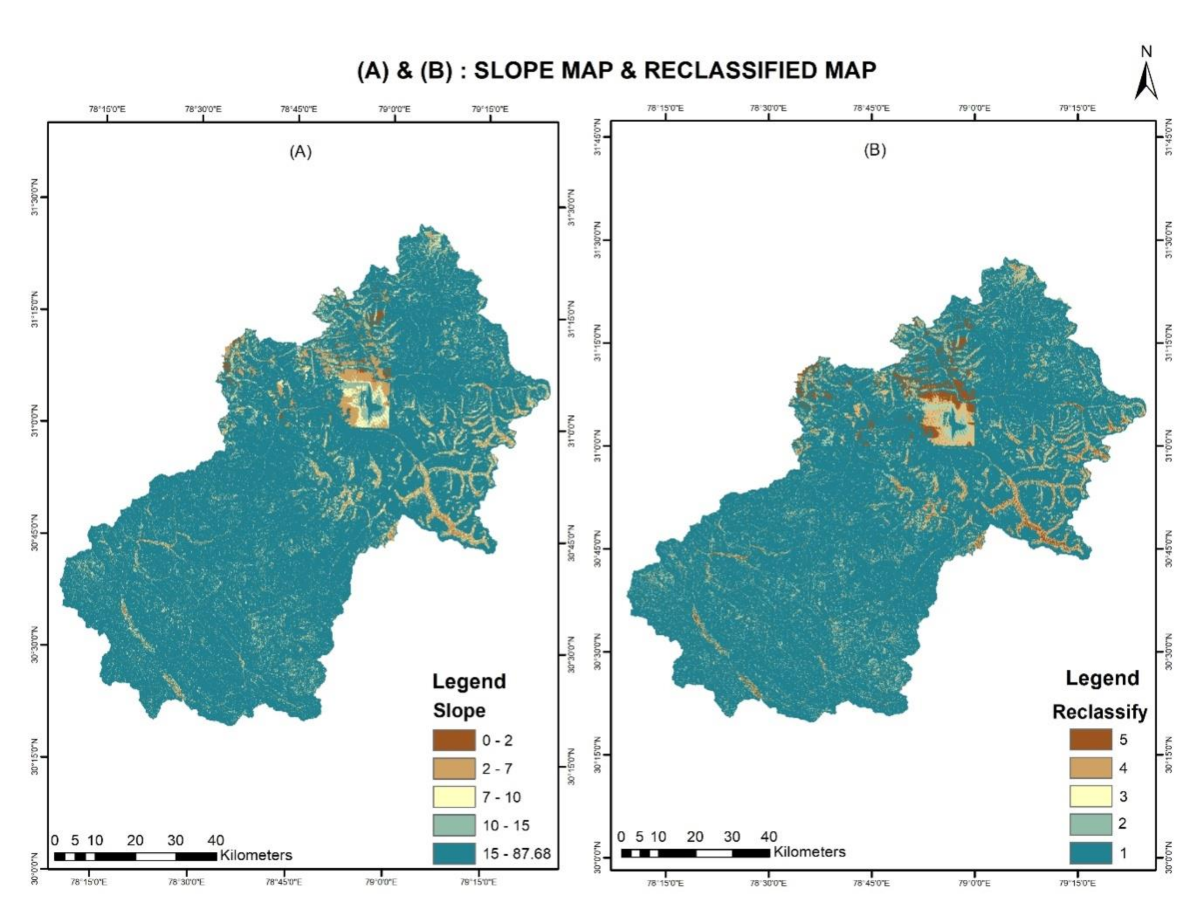
Geology map showing three layers: sandy loam, sandy and snow. Sandy (coarse texture) which have high permeable for water disposal and low erosive. Sandy loam (medium texture) have moderately vulnerable when water comes. Snow layer which may effect of ice melting.

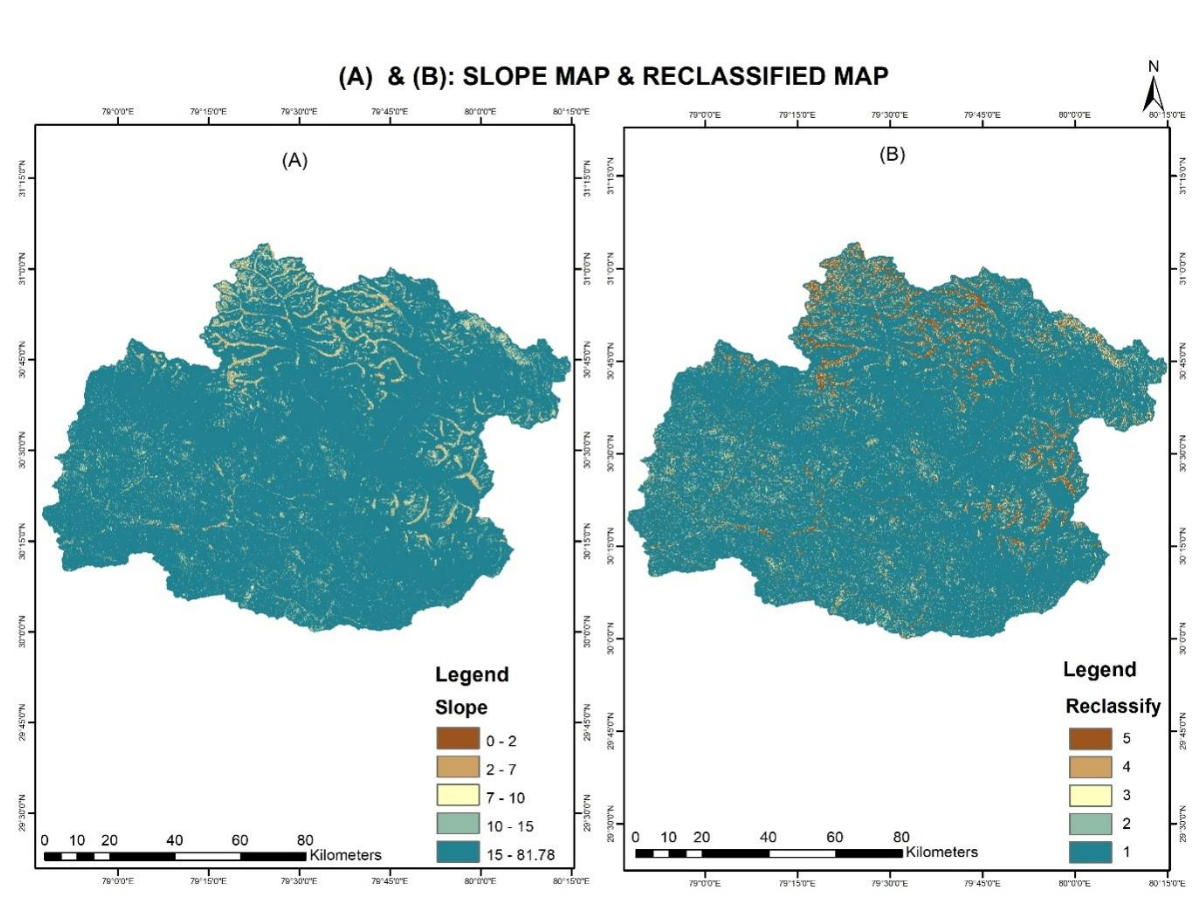




SLOPE

Slope is the ratio of steepness or the degree of inclination of a feature relative to the horizontal plane. Gradient, grade, incline and pitch are used interchangeable with slope. The low value of slope are in the river valley area which are having very high vulnerable for flooding.





PAIR-WISE COMPARISON MATRIX FOR MULTI-CRITERIA AND ITS CONSISTENCY

Parameters	C1	C2	C3	C4	C5	C6	C7	mean	Weight in (%)
C1	0.53	0.72	0.64	0.42	0.48	0.36	0.33	0.50	50
C2	0.07	0.09	0.16	0.17	0.14	0.18	0.17	0.14	14
C3	0.07	0.05	0.08	0.17	0.14	0.18	0.21	0.13	13
C4	0.11	0.05	0.04	0.08	0.10	0.09	0.08	0.08	8
C5	0.08	0.05	0.04	0.06	0.07	0.09	0.08	0.07	7
C6	0.09	0.03	0.03	0.06	0.05	0.06	0.08	0.06	6
C7	0.07	0.02	0.02	0.04	0.03	0.03	0.04	0.04	4

ANALYTICAL HIERARCHY PROCESS (AHP) TECHNIQUE

AHP is a decision-making technique utilized for solving complex problems, with many parameters of interrelated objectives or concerned criteria. The level of parametersis not equal; some parameters are dominant over others. Different weights can be generate the difference in the level of susceptibility. It is based on ranking from the experts, literature reviews and previous study. The AHP pairwise have to be consistent with all pairwise comparisons. The main equipment of AHP is a functional hierarchy with the main input of human perception. The output of AHP has to be consistent for all the pairwise comparisons measured by consistency Index (CI) and Consistency Ratio(CR). The CI follow by Saaty's equation.

$$CR = CI / CR$$

AHP CALCULATING EQUATIONS

Where,

$$CI = (\lambda max - n) / (n-1)$$

CI: Consistency Index. λmax : the largest eigenvalues of the "n" order matrix. The largest eigenvalue is obtained by summing the result of multiplication of the number of columns by eigen vector. The limit of inconsistency is measured by using Consistency Ratio (CR), is compared between Consistency Index(CI) and random generated value (RI).

Table: Random Index of Consistency (RI)

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

MULTI-CRITERIA DECISION ANALYSIS FOR TEHRI DAM AND SRINAGAR CATCHMENT

FACTOR	Tehri Dam Catchment		Srinagar Catchment		WEIGHT
	CRITERIA	INDEX	CRITERIA	INDEX	
Discharge (m3/S)	0.01-50	0.05	0.25-50	0.05	50%
	50-100	0.09	50-100	0.10	
	100-500	0.16	100-500	0.13	
	500-1000	0.26	500-1000	0.28	
	1000-1749.02	0.45	1000-1736.81	0.44	
Rainfall (mm/day)	62-189	0.04	140.3-275.15	0.05	14%
	189-316	0.09	275.15-410	0.11	
	316-443	0.15	410-544.85	0.16	
	443-570	0.31	544.85-679.7	0.29	
	570-697	0.40	679.7-814.5	0.40	
Slope (%)	0-2	0.43	0-2	0.45	13%
	2-7	0.28	2-7	0.27	
	7-10	0.15	7-10	0.15	
	10-15	0.09	10-15	0.09	
	15-81.76	0.05	15-87.56	0.05	
Drainage Density	0.36-0.39	0.05	0.34-0.38	0.05	8%
	0.39-0.41	0.10	0.38-0.43	0.12	
	0.41-0.43	0.18	0.43-0.47	0.15	
	0.43-0.45	0.24	0.47-0.52	0.26	
	0.45-0.48	0.43	0.52-0.56	0.42	
Geology	Sandy Loam	0.66	Sandy	0.66	7%
	Sandy	0.22	Sandy Loam	0.22	
	Snow/ others	0.12	Snow/ others	0.12	
Relief Ratio	0.05-0.12	0.43	0.04-0.09	0.43	6%
	0.12-0.18	0.29	0.09-0.13	0.28	
	0.18-0.24	0.15	0.13-0.17	0.16	
	0.24-0.30	0.08	0.17-0.21	0.08	
	0.30-0.36	0.05	0.21-0.26	0.05	
Stream Frequency	0.18-0.20	0.05	0.16-0.19	0.05	4%
	0.20-0.22	0.10	0.19-0.22	0.10	
	0.22-0.24	0.19	0.22-0.25	0.19	
	0.24-0.25	0.26	0.25-0.27	0.25	
	0.25-0.27	0.41	0.27-0.30	0.40	

FLOOD VULNERABILITY HAZARD ZONE MAP

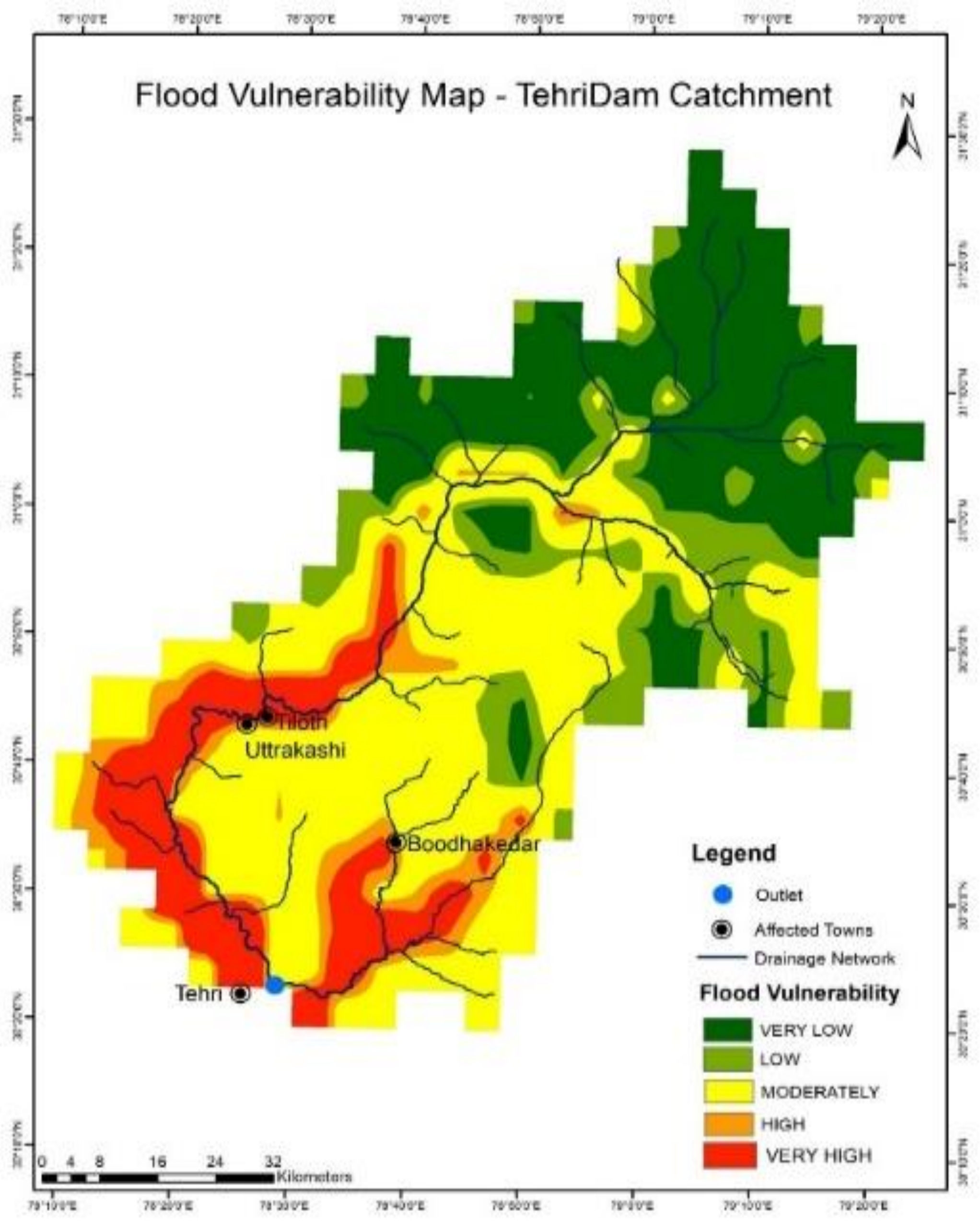
For every parameter, the ranges are classified and the index value is assigned based on the vulnerability characters. Every layer is Reclassified with their range value and multiplied their index value with range value and again layers were get Reclassified with the index value. Once the weight in each factor was determined, the multi-criteria analysis was performed to produce a flood-vulnerable area by using the GIS approach. To compute the vulnerable area, a weight linear combination was applied as shown in equation:

Z = (50 x Discharge) + (14 x Rainfall) + (13 x Slope) + (8 x Drainage density) + (7 x Geology) + (6 x Relief ratio) + (4 x Stream Frequency)

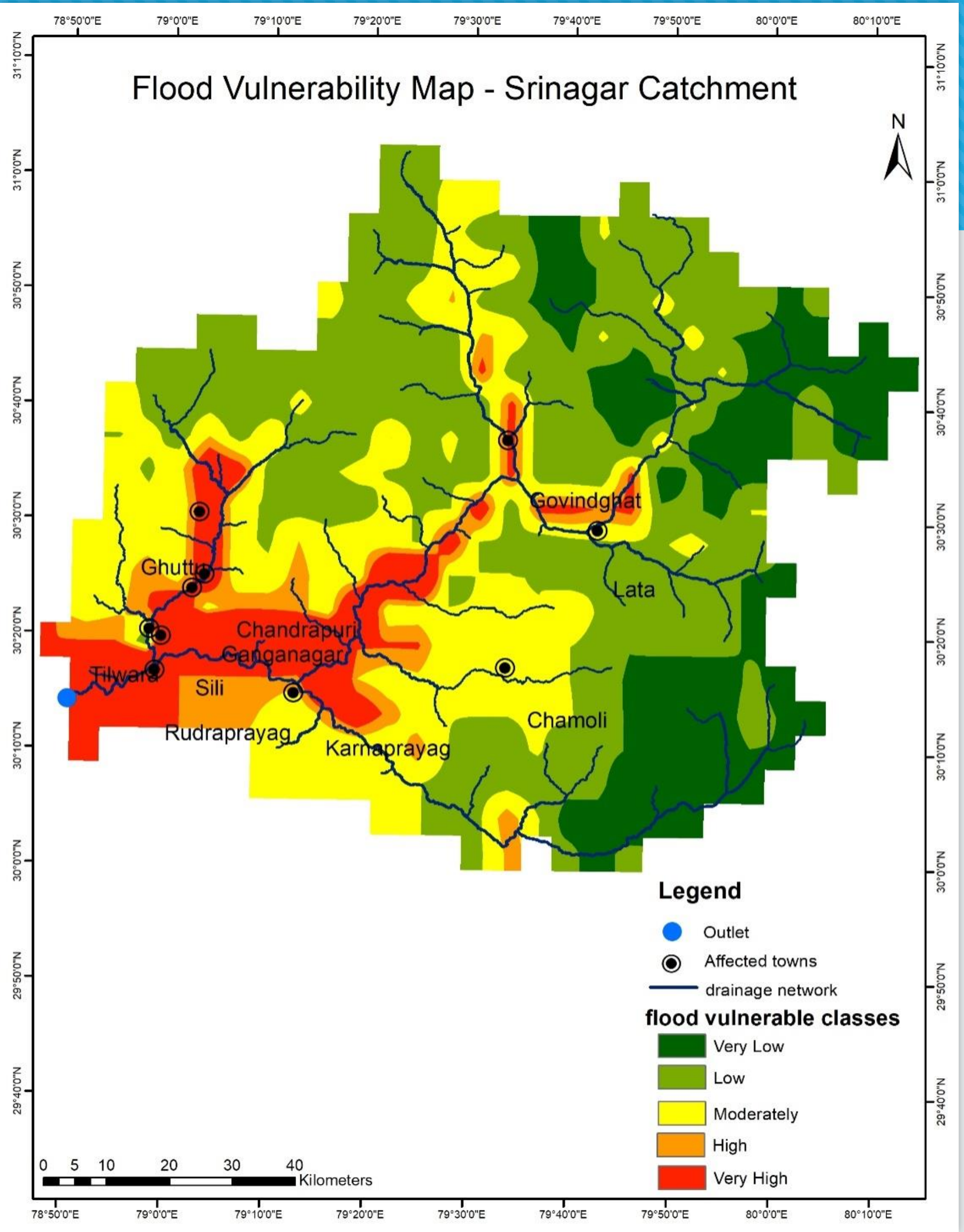
The final vulnerable map output has been represented with a graduated scale of a color map indicating the flood vulnerability. The vulnerability of flood areas is categorized into 5 (five) criteria, namely

- Very high vulnerable,
- High vulnerable,
- Moderate vulnerable,
- Low vulnerable, and
- Very low vulnerable.

FLOOD MAP



Flood Vulnerability Map - TehriDam Catchment
N
Tiloth
Uttrakashi
Boodhakedar
Tehri
Legend
Outlet
Affected Towns
Drainage Network
Flood Vulnerability
VERY LOW
LOW
MODERATELY
HIGH
VERY HIGH
0 4 8 16 24 32
Kilometers



Flood Vulnerability Map - Srinagar Catchment
N
Govindghat
Ghuttu
Lata
Chandrapuri
Ganganagar
Tilwara
Sili
Rudraprayag
Karnaprayag
Chamoli
Legend
Outlet
Affected towns
drainage network
flood vulnerable classes
Very Low
Low
Moderately
High
Very High
0 5 10 20 30 40
Kilometers

AREA ESTIMATION OF FLOOD HAZARD

The above flood vulnerability hazard map shows the range of vulnerable and area which are very highly prone to the flash floods are assessed under the red zone. Mostly, it is seen clearly that, very high to highly prone areas are very close to the river Bhagirathi and the river Bhilanganga. The sudden flash flood causes a dramatic increase in river water level and creating a hazard to the people belonging to the river line liable livelihood. The vulnerability area is calculated and showed in the following table .

Table Area Calculation for the study area Catchments

Vulnerable Class	**Tehri Dam Catchment**		**Srinagar Catchment**	
	Area (in sq.km) Total area=7294.78	**Area (in %)**	**Area (in sq.km) Total area=10554**	**Area (in %)**
Very Low	2000.24	30%	1775.52	18%
Low	800.1	12%	3875.47	40%
Moderate	2775.34	41%	2450.30	25%
High	425.05	6%	525.06	5%
Very High	750.09	11%	1050.13	11%

CONCLUSION

The assessment of flash flood hazard zone map is necessary for very high prone areas where the extreme weather events often happening. The final priority assessing map shows the clear cut decision on where the flash flood can make a vigorous effect at the sudden cause of time. The systematic approach of AHP helps to determine various Criteria analysis made at one time to produce the output results. In addition, Consistency Ration of the pair-wise comparison matrix is 0.06, acceptable at the thumb-rule set. Although very high prone area shows less percentage calculation, the place where they are estimated is very close to the river line level. These catchments show very high vulnerable in the downstream region where the floods are accumulated and discharged.

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Dano Umar Lawal; Abdul-Nasir Matori; Ahmad Mustafa Hashim; Khamaruzaman Wan Yusof; Imtiaz Ahmed ChandioDetectingflood-susceptible areas using GIS-based analytic hierarchy process