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Flood Hazard Zonation of Bhagirathi River Basin using Multi-Criteria Decision-Analysis in Uttarakhand, India

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ABSTRACT: Uttarakhand is the alpine Himalayan state which are highly vulnerable for natural disaster, every year during monsoon floods claim number of casualty in terms of human property and infrastructure loss. Flood hazard zoning is important to map the extent of flooding which is helpful in case of planning any activities nearby river banks and valley portion of the river. The Bhagirathi River basin of Garhwal Himalaya is highly susceptible to flood hazards. A GIS-based Multi-Criteria Decision-Analysis (GIS-MCDA) has been implemented for the first time in Bhagirathi River basin using four physical parameters like land-use land-cover, elevation, slope, and distance to river. It was observed by the spatial analysis that the risk is very high up to 350 m distance along both sides of the river terraces. The results estimated that 16.7% area (1028.3 km^2) of the Bhagirathi River basin is vulnerable for flood hazards, 46323 population and 9753 households of 96 villages were identified as hotspots for flood hazard. A total of 160 km of the road length is found under high to a very high category of the risk. This study would be very helpful to reduce the losses of life, property, and infrastructure during floods in the future, the outcomes of the study can be used as a ready reference to support the management and mitigation of rescue and rehabilitation policies of the banks of river Bhagirathi.

Keywords: Remote Sensing, Flood damages, Mapping of hazard and risk, GIS, Bhagirathi River basin, Vulnerability.

Abbreviations: GIS, Geographical Information System; MCDA, Multi Criteria Decision Analysis; UNDP, United Nation Development Programme; ICIMOD, International Centre for Integrated Mountain Development; MOEF & CC, Minatory of Environment, Forest & Climate Change; MNWDI, Modified Normalized Difference Water Index; NDWI, Normalized Difference Water Index.

I. INTRODUCTION

Regional climatic conditions have a major effect on the mountainous glacial environment. Flash floods are one of the biggest hazards related to the changing climate and natural disasters in the world [1]. They are the major sources of destruction to mankind lies in plains and river valleys [2]. One-third of the total land area, including 82% of the total world population of 90 nations is directly prone to catastrophic flooding [3-6]. Similarly, one-eighth of India's total geographical (40.0 million hectares) area is prone to floods [7-9]. However, the area under the risk of floods is increasing extensively in India with a rate of 0.014 million hectares annually under the changing climatic scenarios [10]. Over a period of five decades (1953-2007), there was an increase of 7.5 million-hectare area is getting affected by the floods.

In India, about 30 million individuals are under the threat of floods and contributed annually one-fifth (more than 1,500 individuals) of the world death count because of floods. The majority of flood events in India occur during the monsoon period because of the high spatial and temporal variations in the precipitation. Furthermore, the reducing capability of rivers to hold the large volume of water under heavy siltation may change the direction of river flow. Glacial and cloud outbursts aggravate common issues related to the increased incidences of floods.

The Indian Himalayas are one of the most vulnerable for flooding due to change in climatic conditions and human interference. A number of studies have indicated that the rate of progressive warming of higher altitude region of the Himalaya is much higher than the rate of average global warming (0.09°C per year). For the eastern Himalayas, the warming trend ranges from 0.1°C to 0.06°C per year [11-16].

Climate change is directly related to extreme weather changes in Himalayas as intense unpredicted rainfall that is leading to flash flood, cloud burst, mass movement and debris flow [17].

According to the Indian Institute of Tropical Meteorology (IITM), the recent rainfall pattern of the country shows an increase in precipitation rate. The hilly regions like

Uttarakhand and Himachal Pradesh received maximum precipitation in Northwest monsoon (July-September), which commonly causes natural calamities like cloud burst that led to flash floods almost every year. In the Himalayan region of India, the Bhagirathi River basin is highly susceptible to flood hazard, the major incidents were reported in years of 1978, 1980, 2000, 2009, 2012 and 2013, which caused widespread damage in the river basin [18]. The Bhagirathi River originates at Gaumukh (~ 4000 m) from the Gangotri glacier of Himalaya in the Uttarkashi district of Uttarakhand state [19]. The river flows around 205 km from its origin to merge with the Alaknanda River at Devprayag (elevation 830m asl) being named as river Ganga thereafter. The Bhagirathi River basin is spread over 6170.82 km^2 within Garhwal Himalaya. Because of active tectonics and fragile geomorphic condition, the basin area is highly vulnerable to natural hazards and in consequence, during monsoon season the hydrologic process enhances the frequency of natural calamities.

Floods in the Bhagirathi river basin can be classified into two categories with flash flood and rapid flood. The flash floods occur due to extreme downpour whereas and the rapid floods occur due to continuous downpour for several days [20]. Flood hazard mapping of this area is important to prevent and plan the risk with the help of various high-end computer programming where disaster can be predicted with high accuracy [21, 22]. Hence, there is a need for flood zonation of this river basin to understand the threat of lives and socio-economic losses. For flood zonation, the GIS-based analysis is widely used due to its multidimensional spatial phenomena. It manages a large volume of spatial data very effectively [23-26].

MCDA is a significant tool for mapping of flood risk/hazard zones in a river basin. This method is helpful particularly for flood management plans of remote settlements and population within the river basin [27].

The study is focused to determine the spatial extent of flood hazard zones in the Bhagirathi River basin as well as in identifying the settlements at greater risk during flood events. The MCDA used to determine the spatial extent of flood, and the GIS overlay analyses are used to identify settlement under flood influence [28]. The analyses are based on four spatial parameters as the distance to a river, land-use land-cover, slope, and elevation. The results identifies the hotspots areas under flood hazards including population, number of villages, households, educational institutions, hospitals, road network, and bridges. The outcomes of this study will help policy makers, scientists and local administration to take on-time preventive measures and decision making to save total loss.

II. MATERIALS AND METHODS

Study Area: The study area spread over Uttarkashi and Tehri Garhwal districts, Uttarakhand and some part of Kinnaur district, Himachal Pradesh. The geographic extent of Bhagirathi River basin is 30°16′ to 31°10′ North and 78°11′ to 79°17′ East, the basin is at the North West region of Uttarakhand state (Fig. 1).

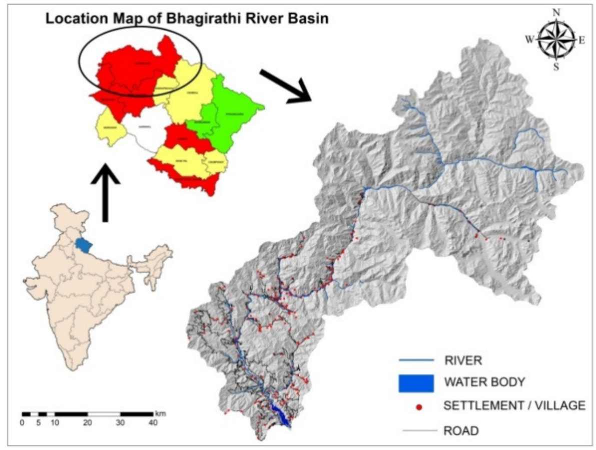

Fig. 1. Location map of Bhagirathi River basin showing water bodies, river, settlement, and roads.

The total area of the Bhagirathi basin is about 6170.82 km^2.Physiographically it is the part of Garhwal Himalaya and falls under the lower to higher Himalayan zone. The climate of the study area is sub-tropical with the seasonal monsoon period of July to September, August as the wettest month during monsoon. As per the thematic layer of census of India, 2011, a total of 690 villages fall under the study area that covers the total population of 332541 individuals and 59115 households. The road network within the basin area includes both state and national highways covering a total length of 224.6 km.

GIS-based multi-criteria decision analysis (GIS-MCDA) approach: In past studies, the impact of a natural hazard on socioeconomic parameters was done using various statistical tools. GIS-based multi-criteria decision approach method has been used the first time in the Bhagirathi River basin by using four factors like land-use land-cover, elevation, slope, and distance from the river. The factors like hierarchical model structure and criteria weights, the application of the GIS-MCDA tool overcome the hindrance of various factors mentioned in the past studies [29]. For social and economic vulnerability assessment towards flood risk, there is a limited scope available for the application of spatial MCDA [30-32]. In this study, proximity analyses of GIS tools were used to create a distance buffer from the main stream.

The topographic inputs like slope and elevation were derived (Table 1) from 1 arc-second Digital Elevation Model (DEM) of Shuttle Radar Topography Mission.

A preliminary exercise was carried out for the selection of technology and assessment of flood hazards. After successful analysis of several natural hazards [33-35] and geo-environmental studies, the combination of multi-criteria decision analysis (MCDA) along with GIS has to be found the most appropriate fundamental tool for assessing the vulnerability and flood hazard due to accuracy and flexibility for decision-making.

Table 1: Data used for flood risk hazard zonation in the Bhagirathi River basin.

Data	Derived Maps	Sources
LANDSAT-8, OLI	Land-use Land Cover Distance to river	8 May 2015 and 21 April 2016 https://earthexplorer.usgs.gov/
SRTM DEM 1 arc-second (30 m)	Elevation Slope	11 February 2000 https://earthexplorer.usgs.gov/
Village/ Settlement /Population/ Roads	690 point locations, 224 Km road, & 84 Bridge locations	Census of 2011/Google Map http://www.censusindia.gov.in/2011census/dchb/DCHB.html
Historical flood Events	Location	literature review

The adoption of methodology for evaluating the flood hazard is a fundamental step, it is important to identify basic factors that are responsible for flooding in order to create a reliable vulnerable flood map [36-39]. Before performing the analysis, the secondary data was collected from different sources. The methodology framework is shown in through Fig. 2.

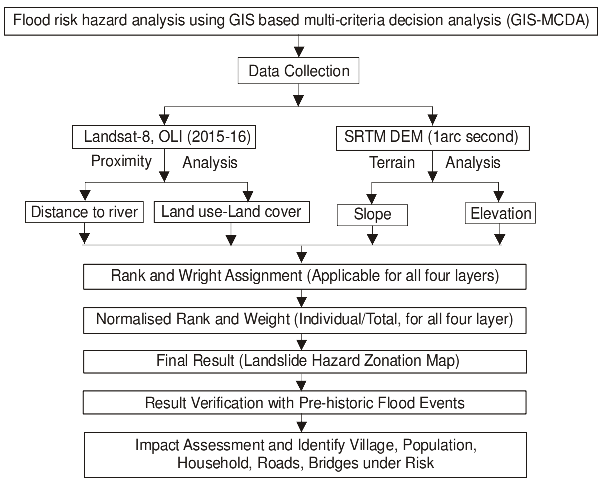

Fig. 2. Flow diagram of methodology used for GIS-MCDA based flood hazard zonation mapping.

Criteria Selected for Flood Vulnerability Mapping

(a) Distance to River: The impact of the flood is more on the river terraces/flood plains along the main river stream [40].

For this study, the river channel was delineated by the visual image interpretation of remote sensing data. A digital band combination of near-infrared (NIR), Green and Blue bands of LANDSAT-8, OLI (Path/Row of 146/38 and 146/39, 15 m panchromatic resolution) optical satellite remote sensing imagery of 8th May 2015 and 21st April 2016 were also used [41] (Fig. 3).

The simple Normalized Difference Water Index, (NDWI) does not differentiate shallow parts of the water (Eqn. 1), therefore to delineate the whole water body the Modified Normalized Difference Water Index, (MNDWI) were used (Eqn. 2).

The combination of NDVI and MNDWI is very useful to extract "maximum water body" (Eqn. 3) from the digital imageries [42].

$$NDWI = (Green - NIR)/(Green + NIR) \quad (1)$$

$$MNDWI = (Blue - NIR)/(Blue + NIR) \quad (2)$$

The Index is used (I)

$$(I) = NDWI + MNDWI \quad (3)$$

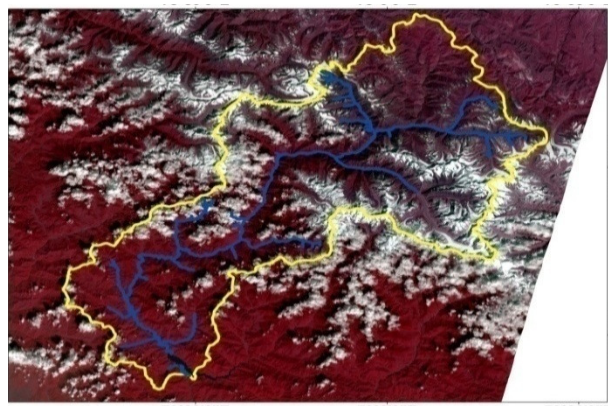

Fig. 3. Overlay of Bhagirathi River basin boundary on LANDSAT-8, FCC of 8th May 2015.

After delineation of river channel form satellite imagery through visual image interpretation, a GIS-based proximity analysis was done to find out the distance from the river to most affected areas during floods. The effect of flood is more visible up to the distance of 2000 meters from the main river stream showing more vulnerability towards floods, therefore the study area is classified into nine different classes of specific intervals of distance (Table 2).

Table 2: Proximity distance class distribution of Bhagirathi River basin.

Range of Proximity Distance from River (m)	Area (km^2)	Area (%)
< 50	103.8	1.7
50-150	102.8	1.7
150-350	198.0	3.2
350-600	237.6	3.9
600-900	274.1	4.4
900-1250	308.0	5.0
1250-1650	337.6	5.5
1650-2000	284.9	4.6
> 2000	4324.1	70.1
Total	**6170.8**	**100**

The range of nine thematic classes are 0 to 50, 50-150, 150-350, 350-600, 600-900, 900-1250, 1250-1650, 1650-2000, and more than 2000 m has been presented through Fig. 4.

(b) Land-use Land-cover: Land use and land cover are the most important factor for flood vulnerability study. The water infiltration and the surface runoff are controlled by the density of vegetation cover and forest cover. The areas of high forest density and high vegetation density are less susceptible because of the high infiltration rate. Surface runoff is very high in urban and agricultural areas as compared to the forest areas [43].

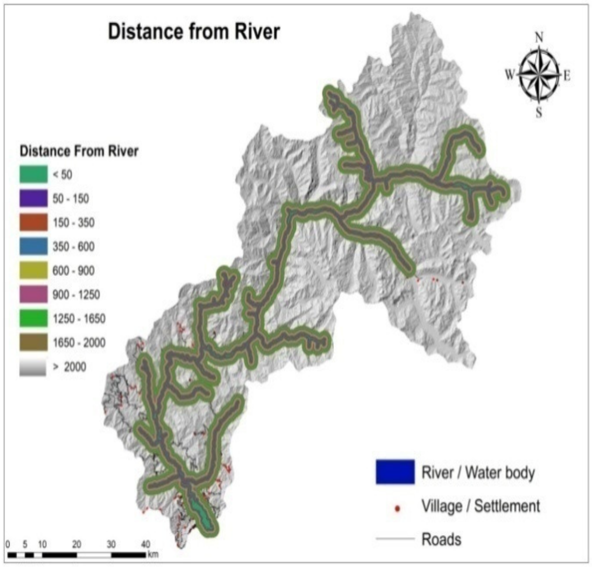

Fig. 4. Proximity distance from the river channel.

The land-use land-cover map of the study area has been derived from optical Landsat-8 (LOI) satellite remote sensing imageries of 2015-16 (Fig. 5). There are nine classes for land-use land-cover mapping using supervised classification in ERDAS Imagine image processing software (Table 3).

Table 3: Land use/Land cover classes under the different characteristics of the Bhagirathi River basin.

Land-use Land-Cover Class	Area (km^2)	Area (%)
River/ Stream/ Canals/Lake/Ponds	44.4	0.7
Urban/Rural	3.1	0.1
Cropland	367.4	6.0
Fallow land	100.7	1.6
Scrub land	37.6	0.6
Evergreen/ Semi-evergreen Grassland/Grazing Land	2338.9	37.9
Deciduous	93.2	1.5
Scrub Forest	47.2	0.8
Snow /Glaciers & Barren Rocky	3138.3	50.9
Total	**6170.8**	**100**

(c) Elevation: Elevation map of the study area is derived from the 30 m digital elevation model (DEM) of SRTM. The maximum and minimum elevation of the Bhagirathi River basin is 6757 m and 545 m asl respectively (Fig. 6).

(d) Slope: The Bhagirathi River originated from the snout (Gaumukh) of Gangotri glacier at a height of about 4000 m asl. The whole glaciated area is barren rocky, devoid of vegetation and covered with snowfields throughout the year. Between 3000 to 4000 m elevation, the valley is filled with glacier derbies that have very few and sparse alpine type vegetation. The steep valley was observed between the elevation of 2000 to 3000 m with tremendous gorges and steep to a dizzy height.

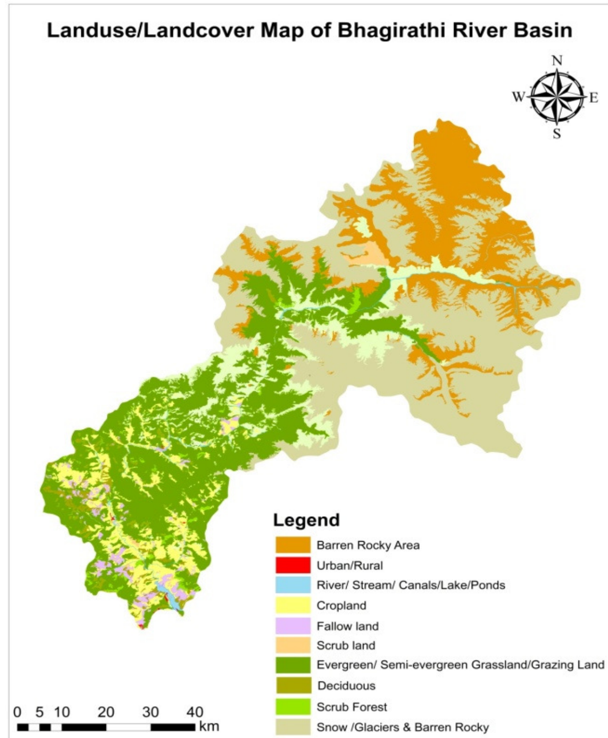

Fig. 5. Land-use Land-cover map of Bhagirathi River basin derived through Landsat-8 satellite imagery of the year 2015-16.

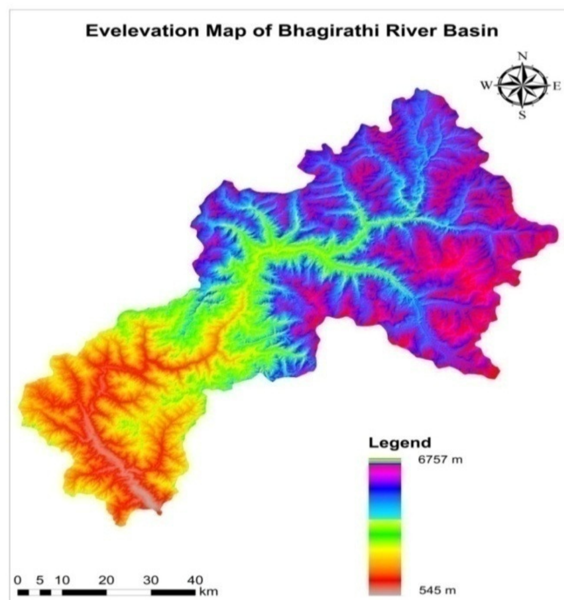

Fig. 6. Elevation map of the Bhagirathi River basin in meter above sea level.

This area is also extremely rugged and full of forests. The river terraces, agriculture, and forest were seen at the elevation of 1000 to 2000 m. The slope map of the river basin area is derived from the one arc second SRTM DEM. The study area shows a wide variety of average slope from 3° to 69° with a mean of 32° (Fig. 7).

For the analysis of the flood damage risk using GIS-MCDA, the elevation and slope maps were classified into nine classes (Table 4 and 5). It may be noted that each criterion has own significance in the special analysis.

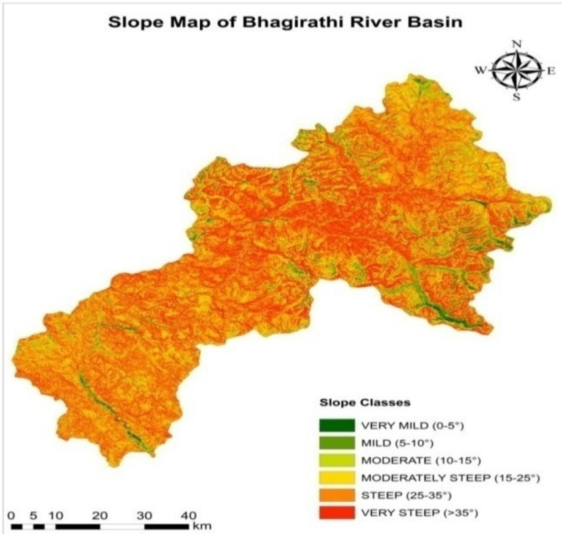

Fig. 7. Slope map of Bhagirathi River basin represented in the range of degree.

Table 4: Slope classes and its area characteristics of the Bhagirathi River basin.

Slope Class(degree)	Area (km^2)	Area (%)
< 2	7.4	0.1
2-3	19.1	0.3
3-4	32.2	0.5
4-5	38.5	0.6
5-6	49.9	0.8
6-10	346.9	5.6
10-15	488.1	7.9
15-20	635.9	10.3
> 20	4552.9	73.8

Table 5: Elevation classes and its area characteristics in the Bhagirathi River basin.

Elevation Class (meter)	Area (km^2)	Area (%)
<545	1.9	0.0
545-565	2.3	0.0
565-585	3.6	0.1
585-605	2.8	0.1
605-725	23.8	0.4
725-825	66.0	1.1
825-925	431.8	7.0
925-1025	1161.9	18.8
> 1025	4476.8	72.6
Total	**6170.8**	**100**

III. RESULTS AND DISCUSSION

Zonation and ranking of area: The most important criterion "distance to the river" shows that the most affected area is near the main river course including river banks, river terraces, and flood plains. Depending on the physiography of the Bhagirathi River basin 2000 m distance both sides from the main river course has been considered as flood risk zone.

Out of the total basin, 29.9% (1846.7 km^2) area is falling under flood risk zone covering up to 2000 m distance on both sides of the river. The slope plays an important role in flood hazard mapping in alpine areas.

The movement of water is very slow on the flat and low gradient slopes and it accumulates for a longer time. About 26.2% (1617.9 km^2) area of the basin slope is falling in the range between 0°-20° slopes. Land use of the Bhagirathi River basin shows that the human activity is comparatively more frequent in these three classes, therefore the most susceptible land use classes for floods are, (1) River/Stream/Canals/Lake/Ponds (2) Urban/Rural (3) Cropland. About 6.7% (414.9 km^2) of the basin area is covered by these vulnerable classes.

The surface elevation plays an important role to identify the flood damage risk zone, with this analysis the impact of flood damage has been taken from 545 m to 1025 m asl. Total 27.5 % (1161.9 km^2) areas are falling under the risk zone (Table 6).

Table 6: Criteria wise risk percentage and associated area for flood vulnerability of Bhagirathi River basin.

Criteria	Vulnerable class under flood risk	Area under risk (%)	Area under risk area (km^2)
Distance to river	2000 m distance from both side of the river stream	29.9	1846.7
Slope	0 to 20°slope	26.2	1617.9
Land use/land cover	River / Stream / Canals/Lake/Ponds, Urban/Rural, Cropland	6.7	414.9
Elevation	545 m to 1025 m asl	27.5	1161.9

To finalise the analysis, Rank (R) and Weight (W) for each responsible criteria were assigned. For this study there are four criteria that have been selected for flood risk vulnerable mapping, the criteria are the distance to the river, land-use/land-cover, elevation, and slope. All the criteria parameters were classified into a scale of 1 to 9 as per user-defined rank under the geospatial environment. High rank (9) assigned for high-risk class and low rank (1) is assigned for no-risk class [44-46].

After assigning ranks for all four thematic layers, the sum weight (W) of 10 was assigned after dividing all four parameters as per the priority of importance. Weight 4 assigned "distance to the river" due to its importance as compared to the other three. As per the importance, the weight for slope (3) elevation (2) and Land-Use/Land cover (1) were assigned for assessment of vulnerability.

After assigning Rank (R) and weight (W), the Normalized rating index (NRI) and Normalized weight index (NWI) were calculated using the raster tool in ArcGIS. NRI is the value of total Rank dividing with individual Rank, whereas NWI was calculated using total weight dividing with individual weight (Table 7).

The GIS layer integration of NRI and NWI was done using weighted sum overlay analysis of spatial analysis tool extension of ArcGIS.

Table 7: Criteria wise Normalised Rank Index (NRI) & Normalised Weight Index (NWI) calculation for thematic classes.

Criterion	Thematic Layer Category Class	Rank (r)	NRI r/R	Weight (w)	NWI w/1
Proximity form River (Meter)	< 50	9	0.20	4	0.4
	50-150	8	0.18		
	150-350	7	0.16		
	350-600	6	0.13		
	600-900	5	0.11		
	900-1250	4	0.09		
	1250-1650	3	0.07		
	1650-2000	2	0.04		
	> 2000	1	0.02		
	Total (R)	**45**	**1.00**		
Slope (Degree)	< 2	9	0.20	3	0.3
	2-3	8	0.18		
	3-4	7	0.16		
	4-5	6	0.13		
	5-6	5	0.11		
	6-10	4	0.09		
	10-15	3	0.07		
	15-20	2	0.04		
	> 20	1	0.02		
	Total (R)	**45**	**1.00**		
Elevation (meters)	<545	9	0.20	2	0.2
	545-565	8	0.18		
	565-585	7	0.16		
	585-605	6	0.13		
	605-725	5	0.11		
	725-825	4	0.09		
	825-925	3	0.07		
	925-1025	2	0.04		
	> 1025	1	0.02		
	Total (R)	**45**	**1.00**		
Land Use/Land Cover (Km^2)	River/ Stream/ Canals/Lake/Ponds	9	0.20	1	0.1
	Urban/Rural	8	0.18		
	Cropland	7	0.16		
	Fallow land	6	0.13		
	Scrub land	5	0.11		
	Evergreen/ Semi-evergreen Grassland/Grazing Land	4	0.09		
	Deciduous	3	0.07		
	Scrub Forest	2	0.04		
	Snow /Glaciers & Barren Rocky	1	0.02		
	Total (R)	**45**	**1.00**		

Identification of Flood vulnerability: Based on the various indicators, flood damage risk index map has been prepared through ArcGIS by using the weighted value (Table 7) of each parameter. In the flood index map, the range of vulnerability was from 0.013 to 0.168, which means the lower value (0.013). Represents the low-risk zone whereas the higher value (0.168) represented the high risk (Fig. 8).

Further, the flood risk index map of the study area was classified into five categories using natural break classification method in ArcGIS, the classes were very high risk (0.0133-0.049), high risk (0.049-0.074), medium risk (0.074-0.093), low risk (0.093-0.112) and no risk (0.113-0.168). The category wise risk map is shown in Fig. 9.

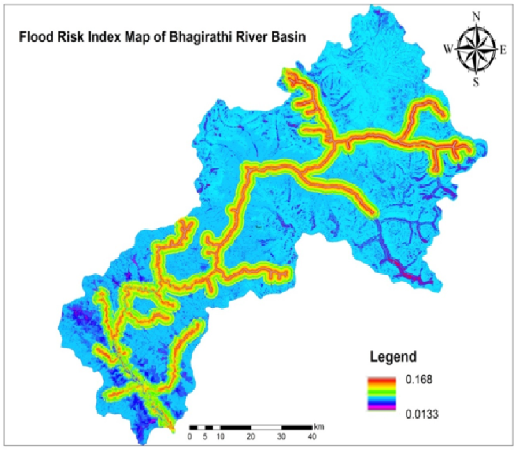

Fig. 8. Flood risk index map of Bhagirathi River basin showing high and low index values.

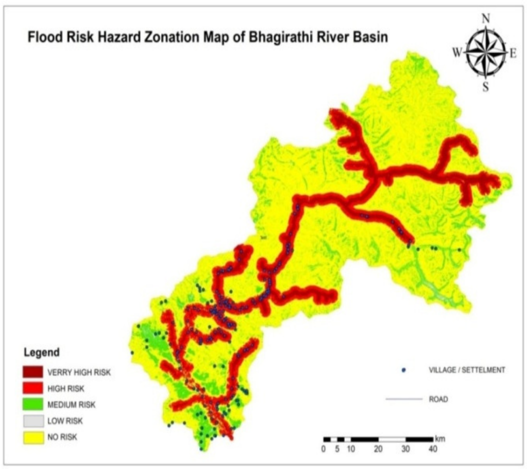

Fig. 9. Flood risk hazard map showing hotspot areas of Bhagirathi River basin.

It has been observed that the area lying near to the river channel is prone to very high flood risk and as we move forward away from the river channel the risk decreases gradually. During the assessment, it was observed that 1028.28 km^2 (16.7%) of basin area comes under flood vulnerable zone. The very high-risk zone lies up to 350 m on both sides of the river channel which covers 91.27 km^2 (1.5 %) area of the complete river basin. The high-risk zone, moderately risk and low risk occupies 183.0 km^2 (3.0%), 382.62 km^2 (6.2%) and 371.39 km^2 (6.0%) area of river basin respectively. The details about the flood damage risk vulnerable area are given in Table 8.

Extent of socio-economic loss: As per the Census of India 2011, a thematic layer of 690 villages was generated for the Bhagirathi River basin. The thematic layers were superimposed on the flood risk vulnerability map. It was found that 23 villages come under very high-risk zone followed by 73 villages under the high-risk zone, 109 villages under moderate, 275 under the low risk and 210 villages under no risk (Table 8).

In terms of human threats and infrastructure, a total of 224400 individuals and 41638 households of 480 villages falls under the flood vulnerable zone in different categories.

A total of 9625 individuals and 2036 households of 23 villages fall under the very high-risk flood hazard zone whereas 36698 individuals and 7717 households of 73 villages are under the high-risk zone. However, 77033 individuals and 11293 households of 109 villages are falling under the moderate risk zone while 101044 individuals and 20592 households of 275 villages lie under low-risk flood hazard zone. The majority of the road i.e. 94.36 km lies under a very high-risk zone followed by high risk (65.68 km), moderate risk (2.06 km) and low risk (58.18 km). It was also found that a total of 81 bridges is lying under a moderate flood risk zone to a very high flood risk zone in the study (Table 8).

The findings of this study were further revalidated through ground-truthing and secondary data available in official records of Uttarakhand state Govt. It was verified that the overall 2100 km length of national highway and 1600 km of state highways have been damaged due to natural hazards in the Garhwal region of Uttarakhand throughout the year. The final GIS-MCDA based flood risk hazard map was also verified through the available literature (Fig. 10) related to four extreme historical flood events i.e. Bhagirathi flood in (1978), Gyansu Nala flash flood (1980), Uttarkashi flood (1991), Asi-Ganga flood (2012), [47-49]. In (2013), the Mandakini, Alakananda, Bhagirathi and other river basins have experienced the flash flood, making a loss of 580 individuals and overall 900000 individuals were affected by the flood in Uttarakhand (Government of Uttarakhand 2013). It may be noted that 41638 households, 220.28 km roads, and 84 bridges are under the threat of floods in this study.

Table 8: final flood risk hazard area and its impact on village/settlement and roads (hotspots) of the Bhagirathi River basin.

Flood Hazard Class	Area (km^2)	Area (%)	Number of Villages (Census 2011)	Vulnerable Population (Census 2011)	Vulnerable Households (Census 2011)	Length of Roads in km	No of Bridge
Very High Risk	91.3	1.5	23	9625	2036	94.4	42
High RISK	183.0	3.0	73	36698	7717	65.7	31
Moderate Risk	382.6	6.2	109	77033	11293	2.1	8
Low Risk	371.4	6.0	275	101044	20592	58.2	3
No Risk	5142.5	83.3	210	108141	17477	4.3	0
Total	**6170.8**	**100**	**690**	**332541**	**59115**	**224.6**	**84**

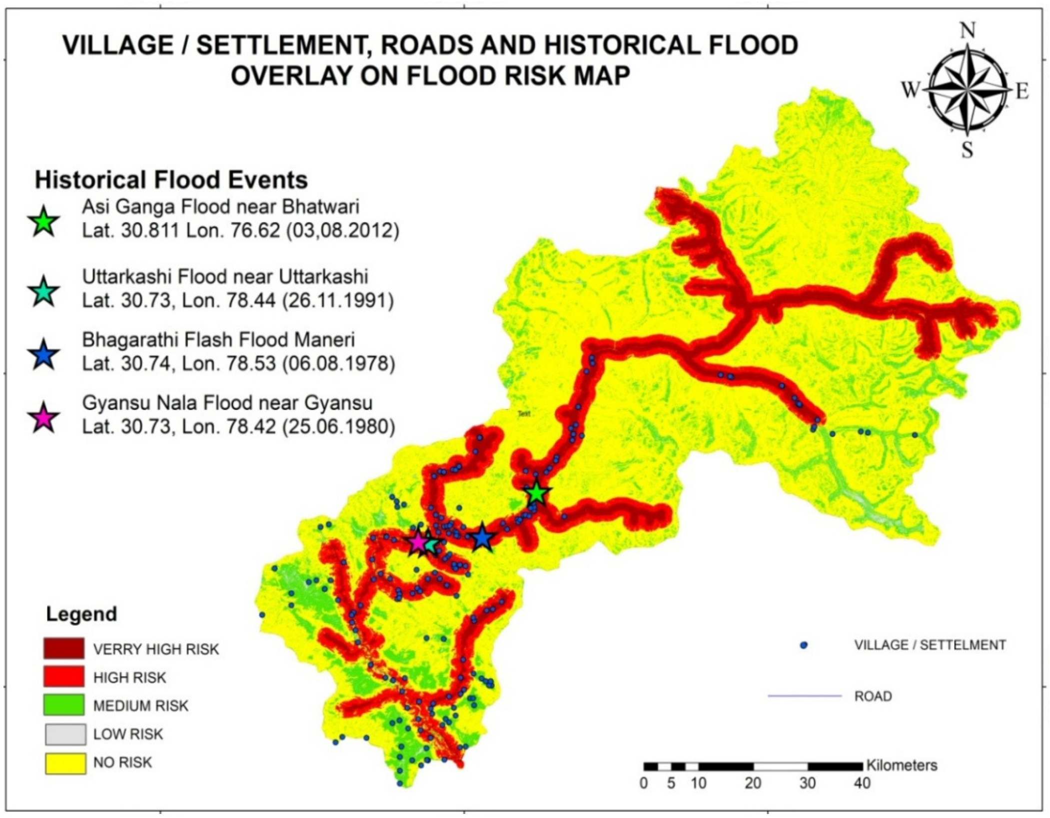

Fig. 10. Historic flood locations overlay on Flood Risk hazard impact zonation map of Bhagirathi River Basin.

If flood event prevails, the total financial burden overcomes the extent of damages caused by the floods will be approximately Rs. 124.08 billion INR for the rehabilitation of houses, reconstruction/maintenance of roads and bridges.

IV. CONCLUSION

The Indian Himalayan region is one of the most vulnerable flood zones under the varying climatic conditions. The study on the Bhagirathi River basin revealed that this location is highly vulnerable for flood as a natural hazard. An innovative approach, a GIS-based MCDA technique has been used first time in this basin to carry out the flood extent estimation and preparation of flood zonation map where four important factors like land-use land-cover, elevation, slope, and distance were considered. It was observed that the risk is very high up to 350 m distance along both sides of river banks which covers 91.3 km^2 area of the complete river basin. It may be noted that 1028.3 km^2 of basin area falls under flood vulnerable zone. The high-risk zone, moderate risk, and low risk occupy 183.0 km^2, 382.7 km^2, and 371.4 km^2 area respectively. Within this flood vulnerable area, there are 23 villages under very high-risk zone followed by 73 villages under the high-risk zone, 109 villages under moderate, 275 villages under the low risk while 210 villages under no risk. In terms of socio-economic losses, a total of 224,400 individuals and 41,638 households of 480 villages are under the flood vulnerable area falling indifferent categories.

The majority of the road segments (i.e. 94.4 km) fall under a very high-risk zone followed by high risk (65.7 km), moderate risk (2.06 km) and low risk (58.2 km). It was also found that a total of 81 bridges are lying under a moderate flood risk zone to a very high flood risk zone.

V. FUTURE SCOPE

The different natural hazards have damaged in terms of life and property and seriously impacted the socio-economic status of the region in the past as reported in the records of Uttarakhand state as well as the different works of literature. This research output will be useful in the policy and planning for the preparedness, mitigation, and management for rescue and rehabilitation of the flood-affected population.

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REFERENCES

[1]. Rao, K. D., Rao, V. V., Dadhwal, V. K., & Diwakar, P. G. (2014). Kedarnath flash floods: a hydrological and hydraulic simulation study. *Current Science*, 598-603.

[2]. Kundzewicz, Z. W. (2002). Non-structural flood protection and sustainability. *Water International*, *27*(1), 3-13.

[3]. UNDP, (2004). Reducing disaster risk: a challenge for development. United Nations Development Programme, Bureau for Crisis Prevention and Recovery, New York, 146.

[4]. Dilley, M., Chen, R. S., Deichmann, U., Lerner-Lam, A. L., & Arnold, M. (2005). Natural disaster hotspots: a global risk analysis. World Bank Disaster Risk Management Series, *5*, 1-132.doi: 10.1007/978-3-322-82113-3_1

[5]. Adhikari, P., Hong, Y., Douglas, K. R., Kirschbaum, D. B., Gourley, J., Adler, R., & Brakenridge, G. R. (2010). A digitized global flood inventory (1998–2008): compilation and preliminary results. *Natural Hazards*, *55*(2), 405-422.

[6]. Kumar, R., Singh, R. D., & Sharma, K. D. (2005). Water resources in India. *Curr Sci. 89*, 794-811.

[7]. Gupta, S., Javed, A., & Datt, D. (2003). Economics of flood protection in India. In *Flood Problem and Management in South Asia*, *28,* 199-210. Springer, Dordrecht.

[8]. Mohapatra, P. K., & Singh, R. D. (2003). Flood management in India. In *Flood Problem and Management in South Asia*, *28,* 131-143. Springer, Dordrecht.

[9]. Roy, P. S., Bhanumurthy, V., Murthy, C. S., & Chand, T. K. (2008). Space for disaster management: lessons and perspectives. *J South Asia Disaster Stud*, *1*, 157-177.

[10]. Kumar, M. (2013). A geographical study of floods and flood management in India (Doctoral dissertation, MPhil dissertation, Department of Geography, Kurukshetra University, Kurukshetra, India).

[11]. Shrestha, A. B., Wake, C. P., Mayewski, P. A., & Dibb, J. E. (1999). Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94. *Journal of climate*, *12*(9), 2775-2786.

[12]. Shrestha, A. B., & Devkota, L. P. (2010). *Climate change in the Eastern Himalayas: observed trends and model projections*. International Centre for Integrated Mountain Development (ICIMOD).

[13]. Benn, D. I., Bolch, T., Hands, K., Gulley, J., Luckman, A., Nicholson, L. I., & Wiseman, S. (2012). Response of debris-covered glaciers in the Mount Everest region to recent warming, and implications for outburst flood hazards. *Earth-Science Reviews*, *114*(1-2), 156-174.

[14]. Change, C. (2010). India: A 4x4 Assessment—A Sectoral and Regional Analysis for 2030 s. *Indian Network for Climate Change Assessment, Ministry of Environment and Forests, Government of India*.

[15]. Sharma, A. (2017). Understanding Sustainable Approach on Eco-Design in Cold Climate – A Case Study. *International Journal on Emerging Technologies,* (Special Issue-ICTOAD-2017), *8*(1): 1-5.

[16]. Sharma, S. (2018). A brief Insight in to Impact of Temperature rise due to Climate Change on Soil Microflora. *International Journal of Theoretical & Applied Sciences, 10*(1): 41-45.

[17]. Eriksson, M., Xu, J., Shrestha, A. B., Vaidya, R. A., Santosh, N., & Sandström, K. (2009). *The changing Himalayas: impact of climate change on water resources and livelihoods in the greater Himalayas*. International centre for integrated mountain development (ICIMOD).

[18]. Chaudhuri, C., Tripathi, S., Srivastava, R., Misra., A. (2015). Observation- and numerical-analysis-based dynamics of the Uttarkashi cloudburst. Ann. Geophys., *33*: 671–686.

[19]. Srivastava, D. (2012). Status report on Gangotri glacier. *Science and Engineering Research Board, Department of Science and Technology, New Delhi, Himalayan Glaciology Technical Report*, *3*, 21-25.

[20]. Djordjević, S., Vojinović, Z., Dawson, R., & Savić, D. A. (2014). Uncertainties in flood modelling in urban areas. In *Applied uncertainty analysis for flood risk management*, pp. 297-334.

[21]. Bhatt, C. M., Rao, G. S., Manjushree, P., & Bhanumurthy, V. (2010). Space based disaster management of 2008 Kosi floods, North Bihar, India. *Journal of the Indian Society of Remote Sensing*, *38*(1), 99-108.

[22]. Büchele, B., Kreibich, H., Kron, A., Thieken, A., Ihringer, J., Oberle, P., & Nestmann, F. (2006). Flood-risk mapping: contributions towards an enhanced assessment of extreme events and associated risks. *Natural Hazards and Earth System Science*, *6*(4), 485-503.

[23]. Zerger, A. (2002). Examining GIS decision utility for natural hazard risk modelling. *Environmental modelling & software*, *17*(3), 287-294.

[24]. Bathrellos, G. D., Skilodimou, H. D., Chousianitis, K., Youssef, A. M., & Pradhan, B. (2017). Suitability estimation for urban development using multi-hazard assessment map. *Science of the Total Environment*, *575*, 119-134.

[25]. Tehrany, M. S., Pradhan, B., & Jebur, M. N. (2013). Spatial prediction of flood susceptible areas using rule based decision tree (DT) and a novel ensemble bivariate and multivariate statistical models in GIS. *Journal of Hydrology*, *504*, 69-79.

[26]. Malczewski, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature. *International journal of geographical information science*, *20*(7), 703-726.

[27]. Fernández, D. S., & Lutz, M. A. (2010). Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. *Engineering Geology*, *111*(1-4), 90-98.

[28]. Samanta, S., & Koloa, C. (2014). Modelling coastal flood hazard using ArcGIS spatial analysis tools and satellite image. *Int. J. Sci. Res*, *3*, 961-967.

[29]. Kuhlicke, C., Scolobig, A., Tapsell, S., Steinführer, A., & De Marchi, B. (2011). Contextualizing social vulnerability: findings from case studies across Europe. *Natural Hazards*, *58*(2), 789-810.

[30]. Kienberger, S., Lang, S., & Zeil, P. (2009). Spatial vulnerability units--expert-based spatial modelling of socio-economic vulnerability in the Salzach catchment, Austria. *Natural Hazards & Earth System Sciences*, *9*(3), 767-778.

[31]. Scheuer, S., Haase, D., & Meyer, V. (2011). Exploring multicriteria flood vulnerability by integrating economic, social and ecological dimensions of flood risk and coping capacity: from a starting point view towards an end point view of vulnerability. *Natural Hazards*, *58*(2), 731-751.

[32]. Farr, T. G., & Kobrick, M. (2000). Shuttle Radar Topography Mission produces a wealth of data. *Eos, Transactions American Geophysical Union*, *81*(48), 583-585.

[33]. Rashed, T., & Weeks, J. (2003). Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas. *International Journal of Geographical Information Science*, *17*(6), 547-576.

[34]. Gamper, C. D., Thöni, M., & Weck-Hannemann, H. (2006). A conceptual approach to the use of Cost Benefit and Multi Criteria Analysis in natural hazard management. *Natural Hazards and Earth System Science*, *6*(2), 293-302.

[35]. Gigović, L., Pamučar, D., Lukić, D., & Marković, S. (2016). GIS-Fuzzy DEMATEL MCDA model for the evaluation of the sites for ecotourism development: A case study of "Dunavski ključ" region, Serbia. *Land Use Policy*, *58*, 348-365.

[36]. Kia, M. B., Pirasteh, S., Pradhan, B., Mahmud, A. R., Sulaiman, W. N. A., & Moradi, A. (2012). An artificial neural network model for flood simulation using GIS: Johor River Basin, Malaysia. *Environmental Earth Sciences*, *67*(1), 251-264.

[37]. Yang, W., Sun, X., Deng, W., Zhang, C., & Liao, Q. (2016). Fourier locally linear soft constrained MACE for facial landmark localization. *CAAI Transactions on Intelligence Technology*, *1*(3), 241-248.

[38]. Bathrellos, G. D., Karymbalis, E., Skilodimou, H. D., Gaki-Papanastassiou, K., & Baltas, E. A. (2016). Urban flood hazard assessment in the basin of Athens Metropolitan city, Greece. *Environmental Earth Sciences*, *75*(4), 319-332.

[39]. Dai, F. C., Lee, C. F., & Zhang, X. H. (2001). GIS-based geo-environmental evaluation for urban land-use planning: a case study. *Engineering geology*, *61*(4), 257-271.

[40]. Fernández, D.S., & Lutz, M.A. (2006). Urbanflood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. *Engineering geology, 111*, 1-4.

[41]. Mishra, K., & Prasad, P. (2015). Automatic extraction of water bodies from Lands at imagery using perceptron model. *Journal of Computational Environmental Sciences*, 1-9.

[42]. Xu, H. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International journal of remote sensing*, *27*(14), 3025-3033.

[43]. Norman, L. M., Huth, H., Levick, L., Shea Burns, I., Phillip Guertin, D., Lara-Valencia, F., & Semmens, D. (2010). Flood hazard awareness and hydrologic modelling at Ambos Nogales, United States–Mexico border. *Journal of Flood Risk Management*, *3*(2), 151-165.

[44]. Michael, E. A., & Samanta, S. (2016). Landslide vulnerability mapping (LVM) using weighted linear combination (WLC) model through remote sensing and GIS techniques. *Modeling Earth Systems and Environment*, *2*(2), 88-102.

[45]. Kolat, Ç., Doyuran, V., Ayday, C., & Süzen, M. L. (2006). Preparation of a geotechnical microzonation model using Geographical Information Systems based on Multicriteria Decision Analysis. *Engineering geology*, *87*(3-4), 241-255.

[46]. Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. Mc Graw-Hill: New York, NY, USA.

[47]. JRDNA August (2013). India, Uttarakhand Disaster June 2013, https://www.adb.org/sites/default/files/linked-documents/47229-001-sd-01.pdf.

[48]. Faisal, A. F., & Faisal, N. A. (2015). Freezing Point Prediction of Minimally Processed Food with Different Sucrose Content*, Biological Forum – An International Journal* (Special Issue 2015), *7*(2), 15-19.

[49]. Upadhyay, K. K., Pandey, A. C., & Manzoor, J. (2017). Impact of Dyes on the Chemistry of Water and its Implications: A Review. *Bio-Bulletin, 3*(1), 01-07.

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