Larhyss Journal, ISSN 1112-3680, n°55, Sept 2023, pp. 73-87

FLOOD HAZARD MAPPING OF LOWER DAMANGANGA RIVER BASIN USING MULTI-CRITERIA ANALYSIS AND GEOINFORMATICS APPROACH

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Research Article – Available at http://larhyss.net/ojs/index.php/larhyss/index
Received February 13, 2023, Received in revised form August 25, 2023, Accepted August 28, 2023

ABSTRACT

One of the most damaging natural disasters that occurs anywhere in the world is flooding. Flood hazard mapping is essential to determining the flood risk zone areas. In the present study, the analytical hierarchical process (AHP) and geographical information system (GIS) were used for flood hazard mapping of the lower Damanganga River basin from the Madhuban Dam to the Arabian Sea. The major factors affecting floods are hydrological characteristics, which are the combination of meteorological and basin characteristics. A total of seven parameters were selected, and

a thematic map for each parameter was prepared. AHP was used to find the weights of the selected parameters using a questionnaire survey. Thematic maps were then integrated with weighted parameters obtained to create the flood hazard map. The abovementioned study's findings show that approximately 32% of the total area in the lower Damanganga River basin is prone to high floods, whereas 33% of the total area is prone to moderate floods. This study will be helpful to policy makers for reducing the risk of flooding.

Keywords: Damanganga basin, AHP, Flood hazard mapping, GIS, Resources at LISS-III.

INTRODUCTION

One of the most harmful natural risks to communities and ecosystems beside rivers is flooding (Aroua, 2020; Hafnaoui et al., 2022). Floods can endanger human life, damage property, disrupt ship navigation, and damage infrastructure and companies. There are many different types of flooding, including flash floods, river floods, coastal floods, urban floods, and flooding caused by dam or reservoir openings or breaches. (Lad and Shah, 2021). Climate change has recently played a significant role in extreme flood events. In addition to climate, a region's altitudinal characteristics, slope (S), elevation (E), distance from the main river channel (DMR), rainfall (R), soil (SO), drainage density (DD), land use-land cover (LULC), and many other factors might affect whether a flood occurs. The assessment of flood hazards can be performed with the use of RS and GIS, which are highly thorough technologies (Bekhira et al., 2019; Hachemi and Benkhaled, 2016). Analyzing complicated choice issues, which frequently incorporate data and incomparable criteria, requires the use of multicriteria decision analysis (MCDA) approaches (Ghezelsofloo and Hajibigloo, n.d.). One well-known method in the area of MCDM technique is AHP (Saaty, 1980). One of the main problems with the AHP technique is that weights must be determined using expert knowledge, which might be viewed as a possible source of error (Rahmati et al., 2016).

Any region can experience the fatal occurrence of flood risk. Severe floods have already occurred in Gujarat's Lower Damanganga basin, which lies in the western Daman and Valsad districts. The Damanganga River in southern Gujarat was prone to unexpected floods in 1994, 1997, 2001, 2003, 2004, 2006, 2013, 2016 and 2019. However, accurate flood assessment is a challenging task, and due to a lack of data and other issues, critical evaluation of flood hazards is still absent in this area. (Das, 2018). As a result, the project work that is being presented here aims to evaluate a variety of influencing factors that contribute to the occurrence of floods and to identify key locations in the lower Damanganga basin that are vulnerable to flooding through an analytical hierarchy process and geospatial analysis.

Finding important or high-risk flood zone locations and assessing flood hazard areas throughout the lower Damanganga basin are the study's key goals. The resulting flood hazard map shows that 17.55 sq. km (5.16%) and 89.97 sq. km (26.45%), respectively, are in very high-risk and high-risk zones, with the bulk of these areas being categorized as residential and industrial areas. The finding indicates that Lower Damanganga is highly susceptible to floods.

STUDY AREA AND DATA COLLECTION

The lower Damanganga River basin is located in the section of Madhuban Dam to the Arabian Sea. The Indian Western Ghats contain the Damanganga Basin. The Sahyadri mountain ranges near the village of Ambegaon in the Nasik district of Maharashtra State are the source of the Damanganga River, which flows 131.30 kilometers before draining into the Arabian Sea at Daman. It travels 131.30 km before it drains into the Arabian Sea at Daman. The basin is located between 72º50' and 73º38' E longitude and 19º51' and 20º28' N latitude. The basin's entire drainage area is 2318 square kilometers. In the current study,a total length of 48.59 km was taken into account, which roughly spans 342.55 sq km.

Damanganga and its tributaries pass through the states of Maharashtra, Gujarat, the U.T. of Dadra and Nagar Haveli, and Daman. The catchment area of the river is fan shaped. Dawan, Shrimant, Val, Rayate, Lendi, Wagh, Sakartond, Piperiya, Dongarkhadi, Roshni, and Dudhni are some of the significant tributaries of the Damanganga River. A total of 2318 square kilometers make up the damanganga basin's drainage area, of which 59% are in Nashik, Maharashtra, 21% are in Valsad, Gujarat, and 20% are in the U.T. of Dadara and Nagar Haveli, as well as Daman. As shown in Fig. 1, we have considered a lower Damanganga basin that lies downstream of the Madhuban dam. The Madhuban Dam is situated in the Valsad district of Gujarat state approximately 40 kilometers upstream of the Damanganga River near Madhuban village in Dharampur Taluka.

The summers in the basin are hot and dry, with the exception of the southwest monsoon from June to September. The temperature is highest in May and lowest from December to January. The SW monsoon produces the majority of the rainfall in the region from June to October. This time period sees approximately 98% of the basin's annual rainfall. The basin receives, on average, approximately 2261 mm of rain annually. The relative humidity in the Damanganga basin varies from 65.5% to 91.9% depending on the season. During the monsoon season, humidity is at its highest, hovering between 91.9 and 81.8%. It falls off in November and December, which are the cold months.

Rock from the Deccan trap basalt made up the Damanganga basin's geology. In the upstream portions of the Damanganga basin, there is no industry. There are several industries in the lowerDamanganga reaches. There are 5105 small and medium-sized businesses operating in the basin. The only mining activity in the Damanganga basin is the excavation of boulders from the bed for the purpose of producing crushed stone aggregate. The upper portions of the Damanganga basin are steep and forested. There are no significant cities throughout its wholelength. Silvasa, Vapi, and Daman are all small towns that it travels through. The index map ofthe Damanganga River basin is shown in Fig. 1.

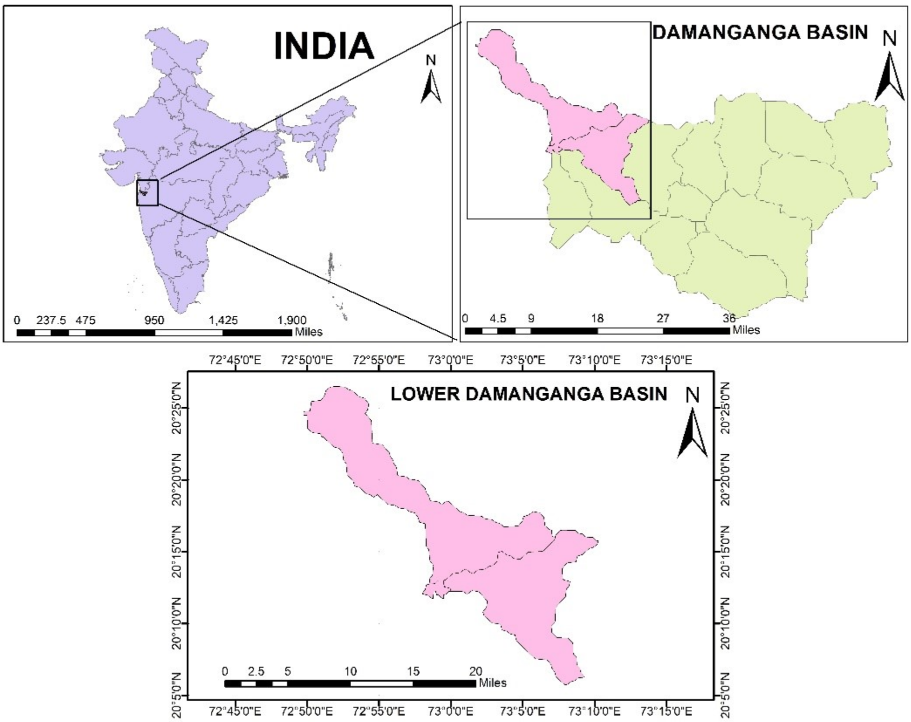

Figure 1: Index map of the Lower Damanganga Basin

Data collection

The 30 m resolution DEM was downloaded from the Bhuvan portal. The DEM was made using ArcGIS v10.3 for the preparation of elevationmap, slope map, drainage density map and distance from the main river map. The rainfall data were collected from the Indian Meteorological Department (IMD) for 2004. The land use/land cover data were collected from the ESRI Land use/Land cover data for 2021, and the soil data were collected from the FAO soils portal.

MATERIALS AND METHODS

The purpose of the study is to assess the flood hazard zone using AHP in the region that extends from Madhuban Dam to the Arabian Sea. Seven criteria were chosen, including slope, soil, elevation, rainfall, land use and land cover (LULC), drainage density, and distance from mainriver, based on various reviews of the literature and their significance. The thematic maps werecreated for each of the parameters in ArcGIS v10.3. Based on the opinion of experts, the weights of every parameter were determined. The experts were water resources engineers, assistant professors from the Indian Institute of Technology and National Institute of Technologyand researchers who work on flood analysis. A total of 67 forms were surveyed, and the consistency ratio (CR) for each was determined using AHP in an Excel sheet. Of these, 17 forms were rejected because their consistency ratios were greater than 0.1, and the remaining forms were processed to determine the individual weights of each parameter. The adopted methodology for this investigation is depicted in the flowchart below.

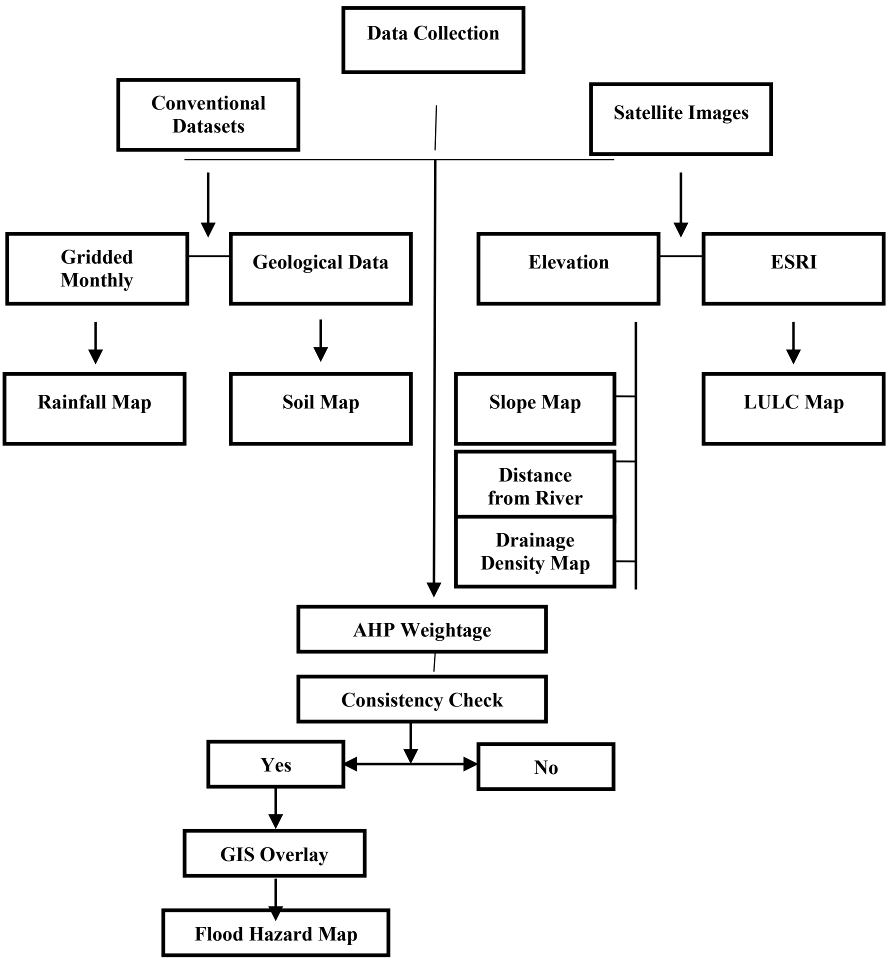

Figure 2: Flowchart of adopted methodology for this study

Overview of AHP

The AHP is an MCDM technique for complex structures in which several factors or criteria are taken into account when prioritizing and choosing alternatives. Thomas L. Saaty developed AHP in the 1970s, and it has since undergone extensive investigation. It is now used in collaborative, complicated decision-making scenarios when human perceptions, judgments, and outcomes have long-term repercussions (Bhushan and Rai, 2004).

The AHP technique is used for weighting parameters from its importance point of view. The first step in applying AHP is to arrange obstacles into a hierarchy of criteria so that they can be more quickly studied and contrasted independently. The decision makers can then compare the options pair-by-pair for each of the selected criteria after this logical hierarchy hasbeen built. Concrete information from the alternatives or human assessments may be used in this comparison as a source of related data (Saaty, 2008).

Flood hazard map

In the current study, the slope, soil, elevation, rainfall, land use and land cover (LULC), drainage density, and distance from the main river are taken into consideration when creating the map. Based on the literature review and their importance in the subject field, these characteristics were chosen. The next subsections outline the approach used to create thematic spatial datasets of the chosen parameters.

Elevation

In terms of flood area and flood depth, flood maps based on a DEM give stronger agreement with the baseline 1 m resolution map than the uniform DEM technique because of the intact riverbeds. The elevation of the lower Damanganga Basin varies from 1 to 726 meters, as shown in Fig. 3.

Slope

Slope is a key element in hydrological studies for regulating the flow of surface water. The length and steepness of the terrain have an impact on the discharge and flooding of a specific area. High or steep slopes increase the speed at which rainfall runoff occurs. Conversely, low or fat slopes result in waterlogging and high infiltration. Fig. 4 shows the classification of the slope map into mild, medium, high, and extremely high categories. The lower Damanganga River's source and the catchment area's outline were located on a steep section of the map. The slope was medium in the north, close to the Vapi district. However, there was mountainous terrain in the center of the research area.

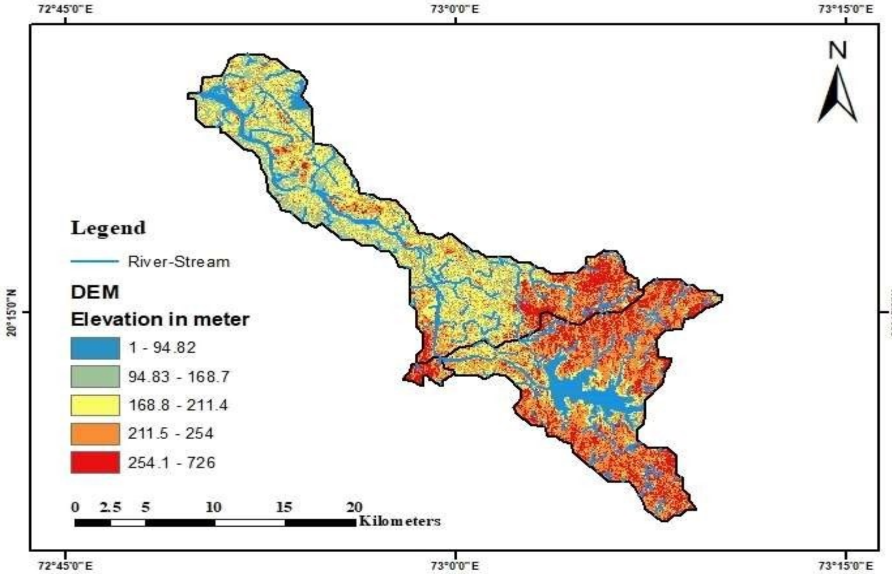

Figure 3: Elevation map of the Lower Damanganga Basin

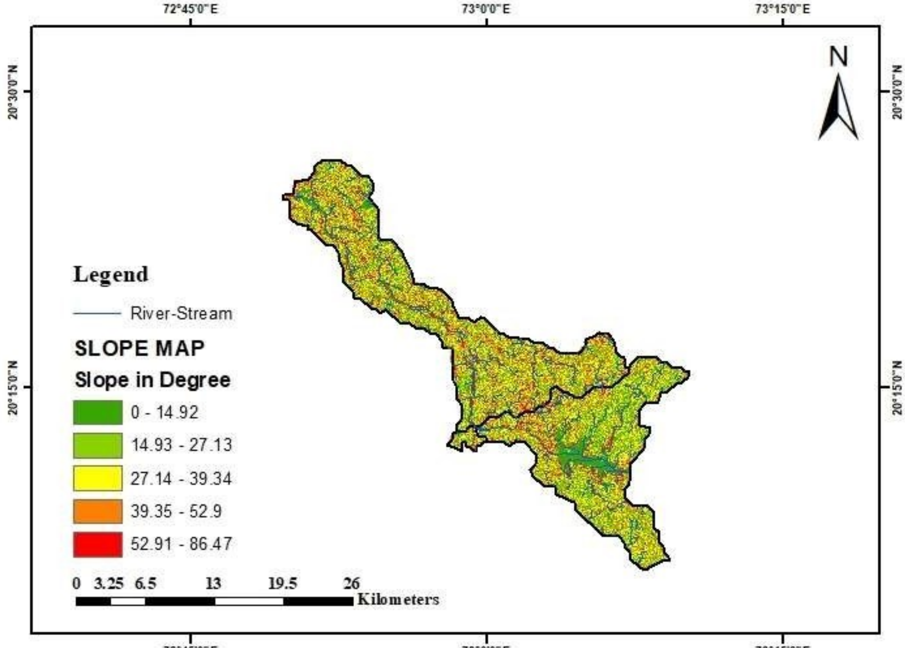

Figure 4: Slope map of the Lower Damanganga Basin

Rainfall

The flood hazard map primarily takes the amount of rainfall into account. A prolonged periodof heavy rainfall with a high intensity tends to produce greater runoff. As a result, the likelihoodof a flood rises as rainfall intensity does. In this study, there is much rainfall near the Madhuban Dam, which increases the likelihood that water will be released and cause floodingdownstream of the dam. The study area's developed rainfall map is shown in Fig. 5.

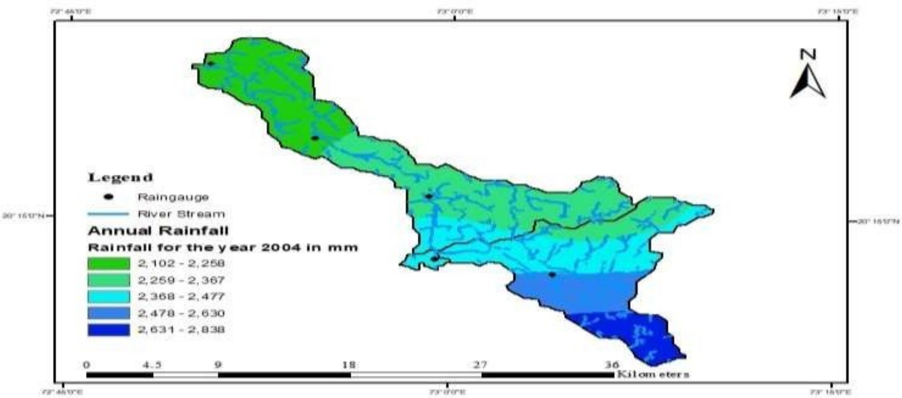

Figure 5: Rainfall map of the Lower Damanganga Basin

Land use – Land cover

Hydrological processes such as infiltration, interflow, base flow, evapotranspiration, and precipitation are impacted by LULC. Agricultural and urban areas, aquatic bodies, and arid land cover are more substantially impacted by floodwater than woodlands and grasslands because of higher runoff. Seven categories were used to categorize the map: water, built-up areas, crops, trees, vegetation that had been inundated, barren ground, and rangeland. The prepared LULC map is shown in Fig. 6.

Soil

Any region's susceptibility to flooding can be significantly influenced by its soil composition. When it rains, clay soil generates runoff at a higher rate than silty sandy soil. Taking into account the physical features of the soil in the research area, classes of soil maps were created. Clay and clay loam were separated into separate groups on the resultingmap. Fig. 7 shows the slope that has been prepared.

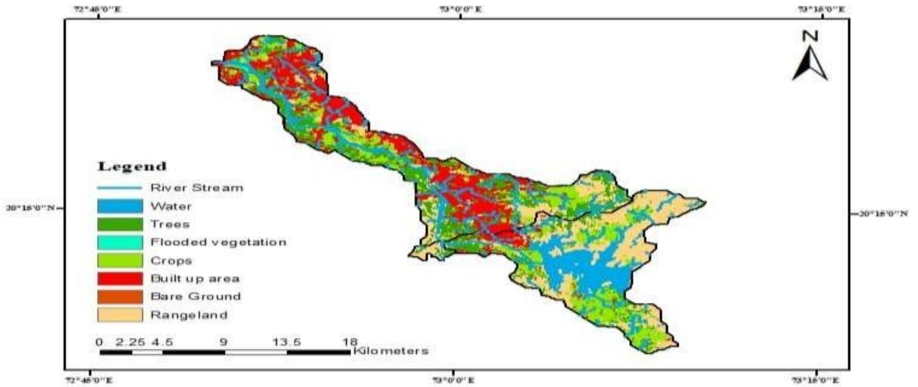

Figure 6: Land use – land cover map of the Lower Damanganga Basin

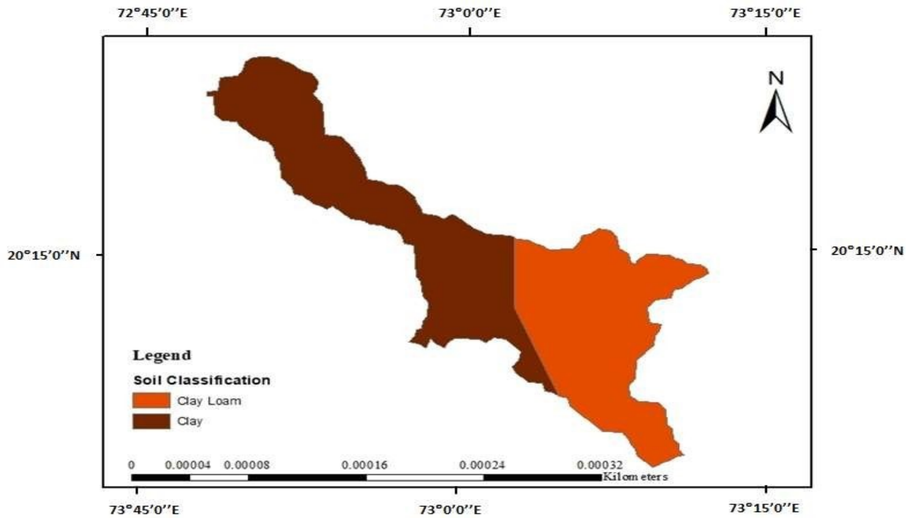

Figure 7: Soil map of the Lower Damanganga Basin

Distance from the main river

Since floods tend to concentrate along rivers, distance from the river is seen to be a crucial geomorphological component for effective flood mapping. As you get further from the main drainage system, the likelihood of flooding declines. The vulnerability to flooding decreases as the distance from the primary drainage network increases. Five groups were created based on the different intervals (Fig. 8): 0-1446 m, 1147-3253 m, 3254-5422 m, 5423-7952 m, and 7953-11520 m.

Drainage density

The sum of channel lengths per unit area is called drainage density. A mature channel system or systems are present if the drainage density is high. The coarser the drainage density is, the lower the value. This demonstrates impermeable geology or soil with little infiltration. From the catchment's edge, the surface runoff moves more quickly. Fig. 9 illustrates the calculated drainage density.

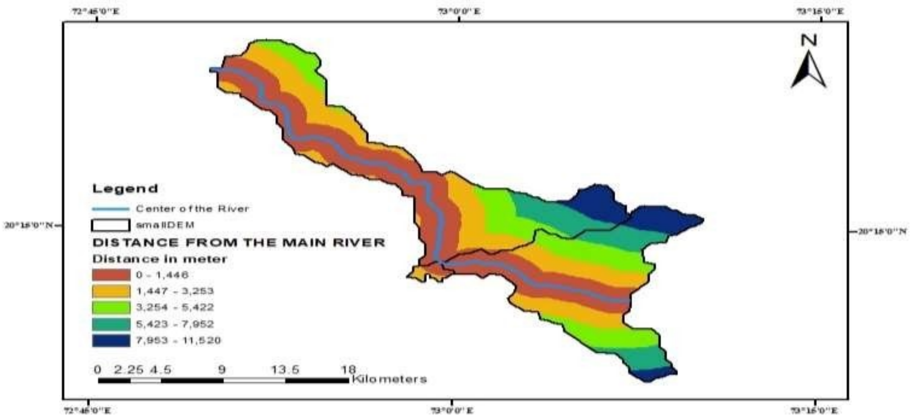

Figure 8: Distance from the main river map of the Lower Damanganga Basin

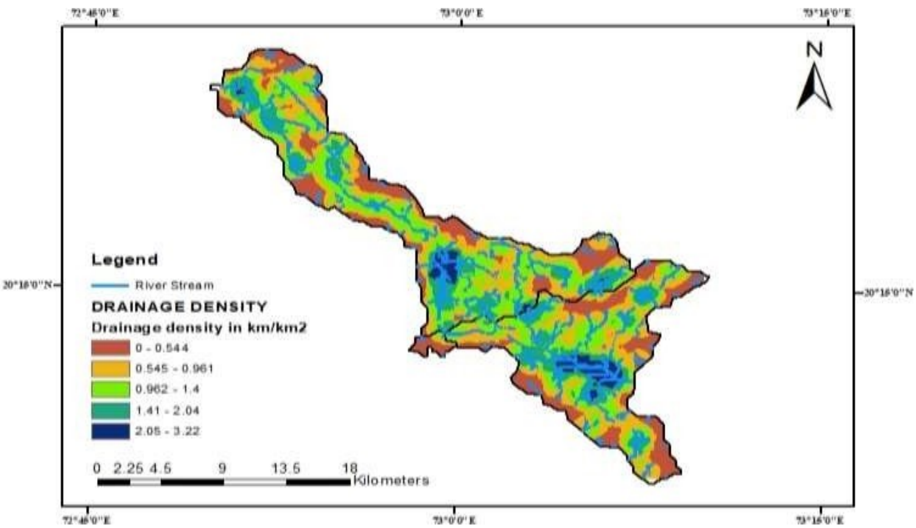

Figure 9: Drainage Density map of the Lower Damanganga Basin

RESULTS AND DISCUSSION

Table 1 describes the arithmetic means of all 50 responses in the form of pairwise comparisons,which are compiled into a single matrix, and Table 2 describes the assigned rank and weights for each parameter.

Table 1: Arithmetic mean values from the responses

Parameters	Slope	Elevation	Rainfall	Soil	Distance from Main River	Drainage Density	Landuse Landcover
Slope	1	1/3	1/5	5	1	1	5
Elevation	3	1	1	7	1	2	5
Rainfall	5	1	1	7	1	2	3
Soil	1/5	1/7	1/7	1	1/5	1/3	2
Distance from Main River	1	1	1	5	1	1	2
Drainage Density	1	1/2	1/2	3	1	1	5
Landuse Landcover	1/5	1/5	1/3	1/2	1/2	1/5	1

Table 2: Assigned rank and weights for each parameter

Factor	Class	Rating	Weight
Slope	0-14.92	1	0.131
	14.93-27.13	2	
	27.14-39.34	3	
	39.35-52.9	4	
	52.91-86.47	5	
Elevation in meter	1-94.82	1	0.235
	94.83-168.7	2	
	168.8-211.4	3	
	211.5-254	4	
	254.1-726	5	
Rainfall	2102-2258	5	0.248
	2259-2367	4	
	2368-2477	3	
	2478-2630	2	
	2631-2838	1	

Soil	Clay	1	0.041
	Clay-Loam	2	
Distance from Main River	0-1.446	1	0.162
	1.447-3.253	2	
	3.254-5.422	3	
	5.423-7.952	4	
	7.953-11.520	5	
Drainage Density	0-0.544	5	0.137
	0.545-0.961	4	
	0.962-1.404	3	
	1.405-2.036	2	
	2.037-3.225	1	
Landuse- Landcover	Water	1	0.046
	Crops	2	
	Trees	3	
	Flooded vegetation	4	
	Bare Ground	5	
	Built area	6	
	Rangeland	7	

The flood hazard map was created using weighted overlay analysis in GIS. The generated map gives us 5 categories: very high, high, medium, low and very low. Based onFig. 10, it can be shown that flood hazards lie in the moderate- to high-risk zone. Among 100%of the study area, 26.45% of the lower damanganaga was high risk, and the remaining 33.26% was moderate risk. Influence of parameters in ascending order is Rainfall > Elevation > Distance from Main River > Drainage Density > Slope > LULC > Soil

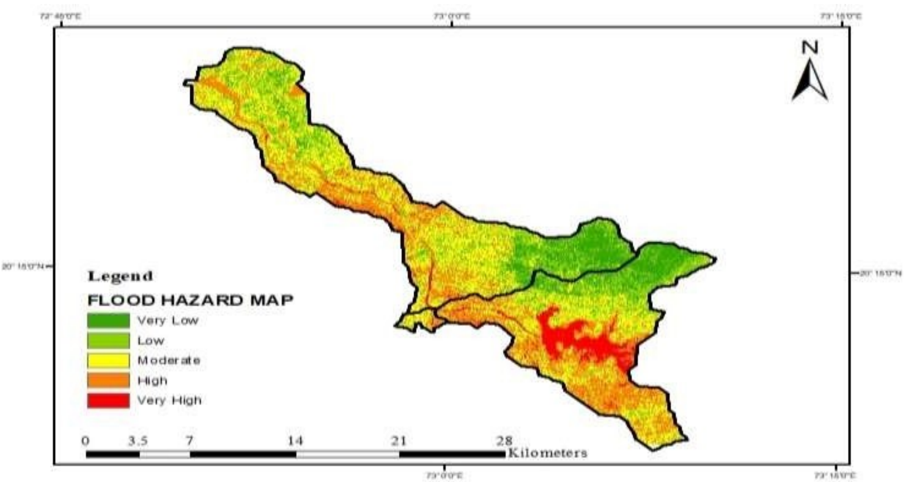

Figure 10: Flood hazard map of the Lower Damanganga Basin

CONCLUSION

The objective of the study is to assess the flood hazard area of the lower Damanganga basin using AHP and GIS. All seven parameter weights, elevation, slope, rainfall,drainage density, land use/land cover, soil and distance from the main river, were analyzed using the pairwise comparison method. The Flood Hazard Map can be created using GIS method, whichoffers an appropriate framework for integrating and analyzing all the elements. In the research area, rainfall, elevation, and distance from the main river were the three principal criteria that contributed to flooding. The resulting flood hazard map indicates that 17.55 sq. km (5.16%)were in the very high-risk zone and 89.97 sq. km (26.45%) were in the high-risk zone, out of which mostareas were in the residential and industrial categories. The obtained results show that Lower Damanganga is highly hazardous to floods. Moreover, AHP in combination with GIS provides a strategy that requires less time and money to assess the flood hazard zone.

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