IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Flood Risk Mapping and Near Real-time Flooding Extent Assessment Using Remote Sensing and GIS: A Case Study on Morigaon & Nagaon District, Assam, India

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Abstract :

In Assam State, the districts of Morigaon and Nagaon have been severely affected by floods in recent years (2015,2021,2022). The major focus of the current study find out the causes of flood in the Morigaon and Nagaon district. These floods are primarily caused by heavy monsoon rains that lead to overflowing rivers and submerging large areas of land. The Brahmaputra River and its tributaries receive heavy rainfall during the monsoon season (June to September), causing water levels to rise rapidly. The Brahmaputra River and its tributaries carry a large amount of silt, which reduces the water-carrying capacity of the rivers, leading to frequent flooding. According to the study, it is helpful to determine the causes of flood and projected District growth and development so that District planning authorities may control the flood and development in accordance with the region's ecological or environmental carrying capacity.

Keywords : Flood Vulnerability Mapping Variables And Analysis, Elevation And Slope, Relative Relief, Soils, The Stream Network, Drainage Density, LULC, Ranking Of Flood Mapping Criteria.

1.1. INTRODUCTION :

Flood is a natural hazard where lands that are usually dry submerge under the overflow of water. Heavy rains can cause an overflow of water and can become a natural disaster if there is a great loss of people and property. Apart from heavy rain, multiple reasons can lead to a flood. Several types of floods occur but based on the geomorphology of a location, only a few may be experienced in that particular location. The following are the classifications that floods are generally grouped into and some of these flood classifications encompasses several flood sub types- Pluvial (Surface) Flooding, Riverine flooding, Groundwater flooding (Ground failures), Coastal flooding. This can lead to limiting the extent of flood damage if flood plains are reserved for uses that are less susceptible to damage from flooding such as parking lots, recreational areas, agricultural activities and etcetera.

1.2. OBJECTIVES : The present study focused on the following major objectives-

- To derive drainage patterns and watershed areas and model the areas and extent of possible inundation.
- To understand the causative factors and the dynamics of the perennial flooding of Morigaon and Nagaon.
- To examine the factors such as rainfall, drainage topography and land use for the flood risk assessment and determine their relative importance.

1.3. STUDY AREA : The district of Morigaon & Nagaon stands on the south bank of the mighty river Brahmaputra. The district lies between 25°12`0`` and 27°0`0`` North latitudes and 91°48`0`` and 94°12`0`` East longitudes. The district covers an area of 10,83,165 Bighas and 13 Lessas (1450.02 Sq. Kms). The greater part of the district is an alluvial plain, criss-crossed with numerous rivers and water ways and dotted with many beels and marshes. The mighty Brahmaputra flows along with the northern boundary of the district. Killing, Kollong and Kapili rivers flow through the southern part of of the district. The Killing meets the Kapili at the Matiparbat where from Kapili moves westward. The Kollong joins Kapili at the Jagi Dui Khuti Mukh and from here they jointly fall into the Brahmaputra. The general appearance of the district is extremely picturesque. On a clear day in the winter the view to the north is bounded by the blue ranges of the outer Himalayas, behind which snowy peaks glisten brightly in the sun, while to the west and the south of the district lie range upon range of lower hills, whose sides are covered with luxuriant vegetation of the tropical forest. There are three Reserved Forest constituted under Assam Forest Regulation Act, 1891. These are Sunaikuchi, Khulahat, and Bura Mayong. There is also one wildlife Sanctuary, named Pabitara, which is famous for the Indian one horned Rhinoceros.

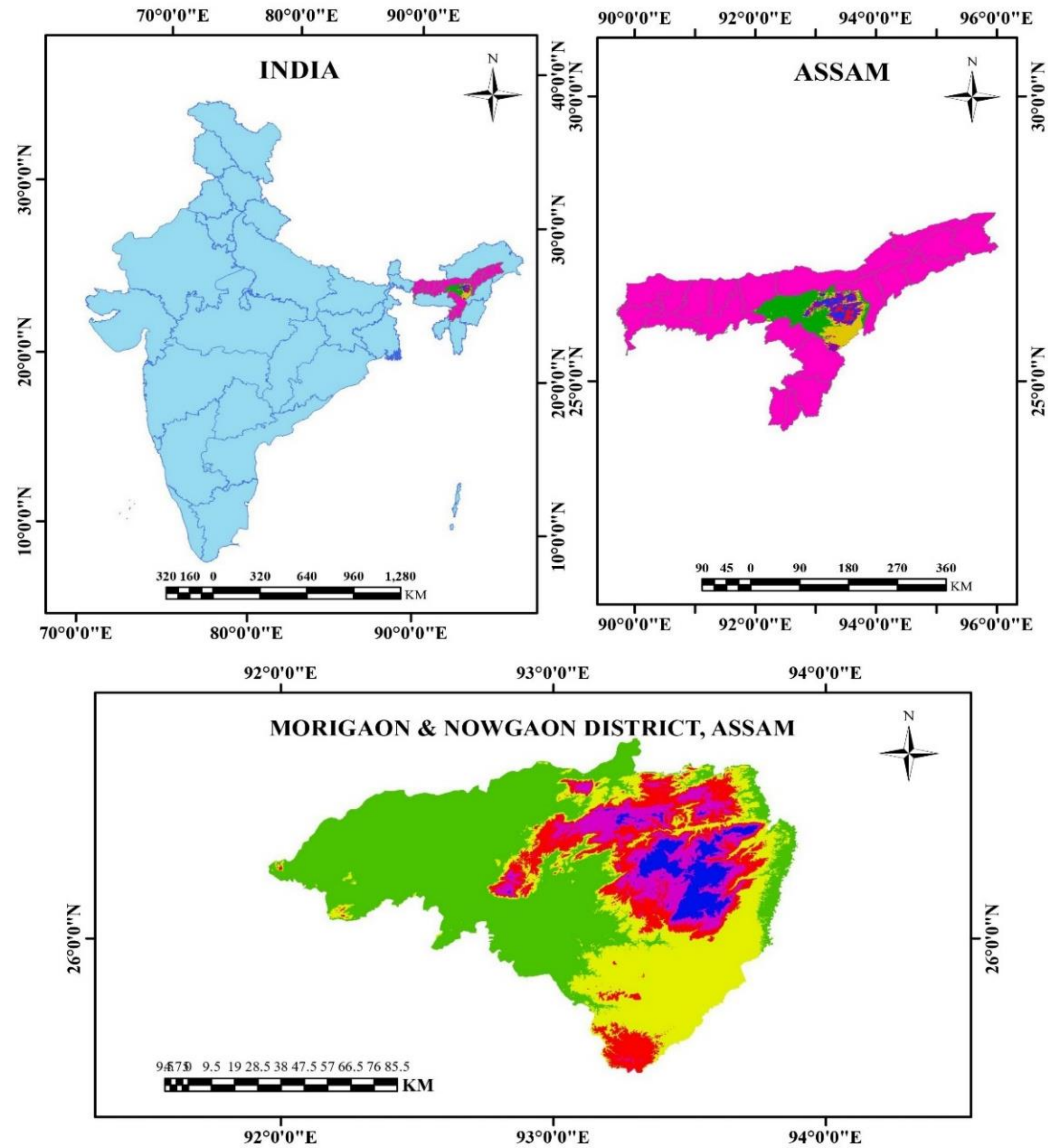


Figure 1.1: Location map of the study area

1.4. METHODOLOGY:

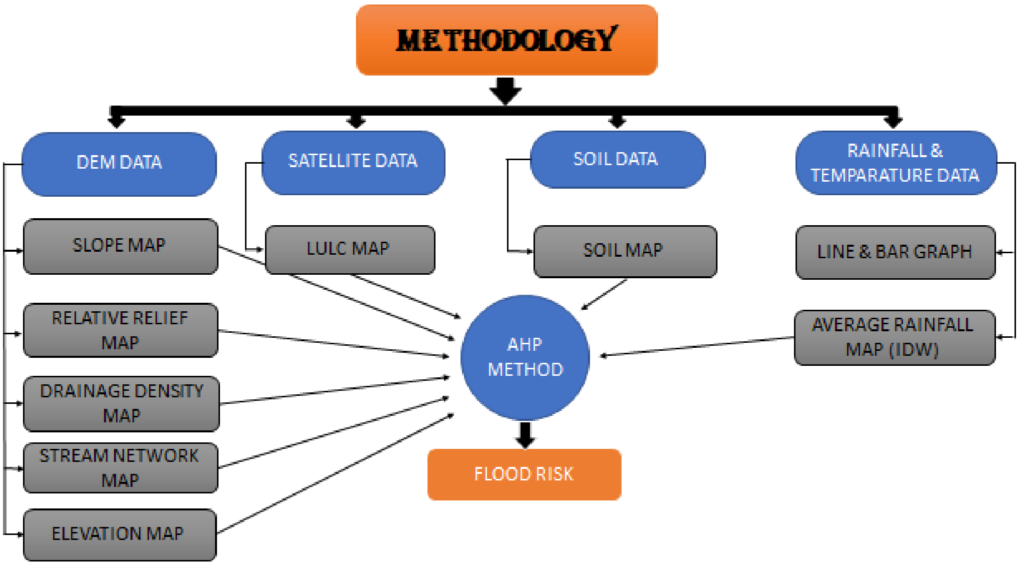
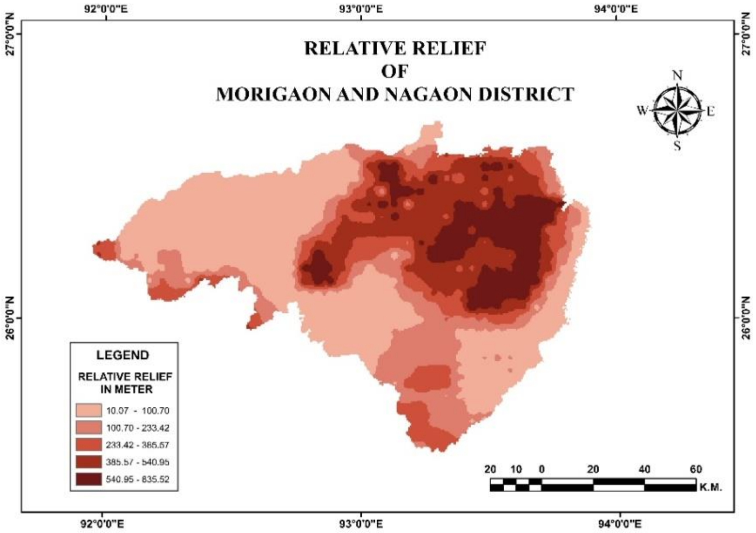


Table 1.1: Secondary Data source of this research

LAYOUT	DATA	WEBSITE
STUDY AREA	DEM DATA	Indian Geo Platform of ISRO (nrsc.gov.in)
ANNUAL AVERAGE RAINFALL	RAINFALL AND TEMPARETUR	Home | India Meteorological Department (imd.gov.in)
SLOPE MAP	DEM DATA	Indian Geo Platform of ISRO (nrsc.gov.in)
RELATIVE RELIEF	DEM DATA	Indian Geo Platform of ISRO (nrsc.gov.in)
DRAINAGE DENSITY	DEM DATA	Indian Geo Platform of ISRO (nrsc.gov.in)
LULC	SATELLITE DATA	EarthExplorer (usgs.gov)
STEAM ORDERING	DEM DATA	Indian Geo Platform of ISRO (nrsc.gov.in)
BAR GRAPH & LINE GRAPH	RAINFALL AND TEMPARETUR	Home | India Meteorological Department (imd.gov.in)
SOIL MAP	SOIL DATA	Statistics | Food and Agriculture Organization of the United Nations (fao.org)
GEOMORPHOLOGICAL MAP	GEOMORPHOLOGICA DATA	Indian Geo Platform of ISRO (nrsc.gov.in)
ELEVATION MAP	DEM DATA	Indian Geo Platform of ISRO (nrsc.gov.in)

1.5. RELATIVE RELIEF:



The Northern part covered by Low relative relief. Southern and middle portion covered by low relative relief zone. Highest relative relief zone is found eastern part of Nagaon District.

Figure 1.2: Relative Relief

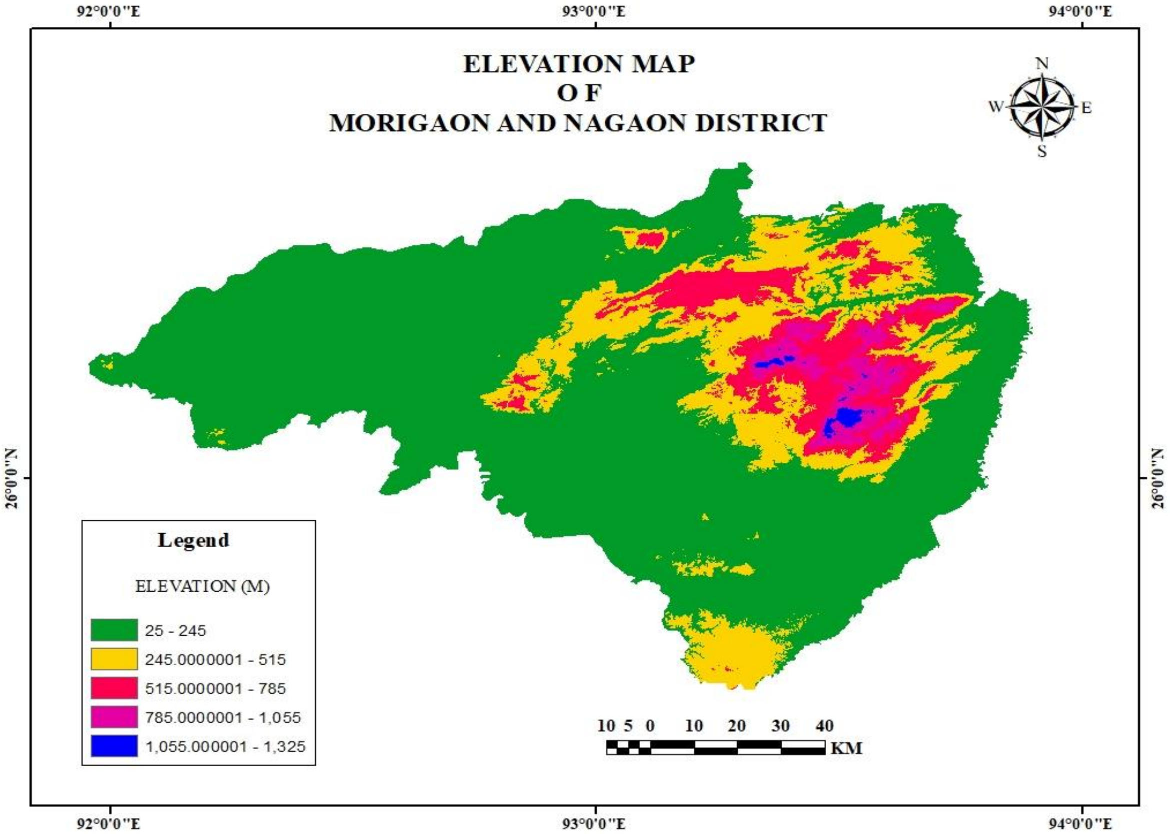


Fig-1.3: Elevation

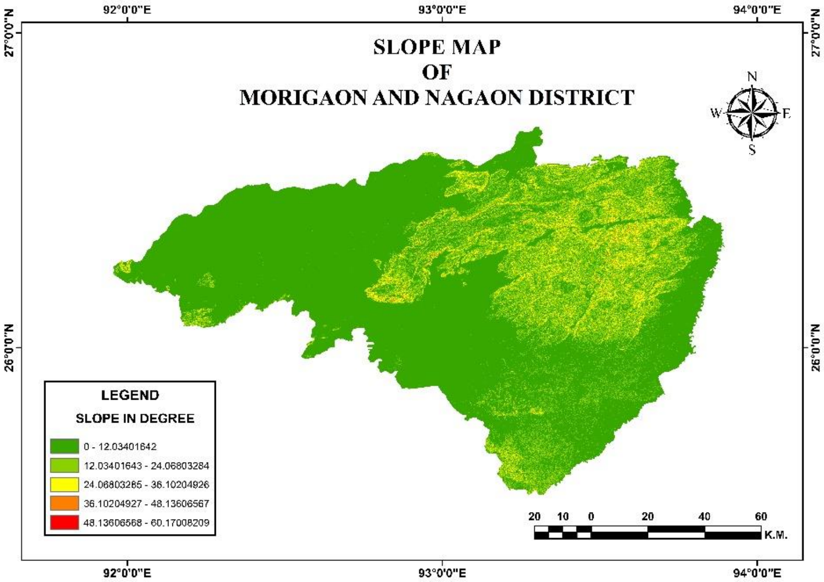


Figure 1.4: Slope Map

1.6. SLOPE:

Highest slope zone is shown Marigaon District. Rest part of map is occupied by Moderate zone. In this paper, the slope map was prepared using the digital elevation model (DEM) and slope generation tools in ArcGIS software.

The slope classes having less values was assigned higher rank due to almost flat terrain while the class having maximum results of the original and reclassified elevation and slope layers are presented in Figure 4. According to Figure 4 the entire study area lies in a moderately steep slope. This implies that slope may not be the predominant factor in ranking hazard and risk classes.

Table 1.2 Flow accumulation Ranking and Slope Ranking

FLOW ACCUMULATION	RANKING	Slope	Degree
24528 – 32408	Very High	0-12.03401642 (degree)	Very high
15378 – 24528	High	12.03401642-24.06803284 (degree)	High
6863 – 15378	Moderate	24.06803284-36.10204926	Moderate
1652 – 6863	Low	36.10204926-48.13606567	Low
0 – 1652	Very Low	48.13808568	Very Low

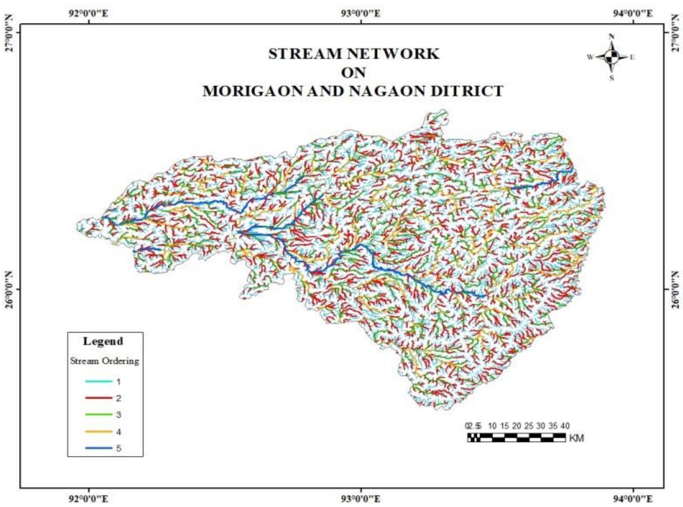


Figure 1.5: Stream Network.

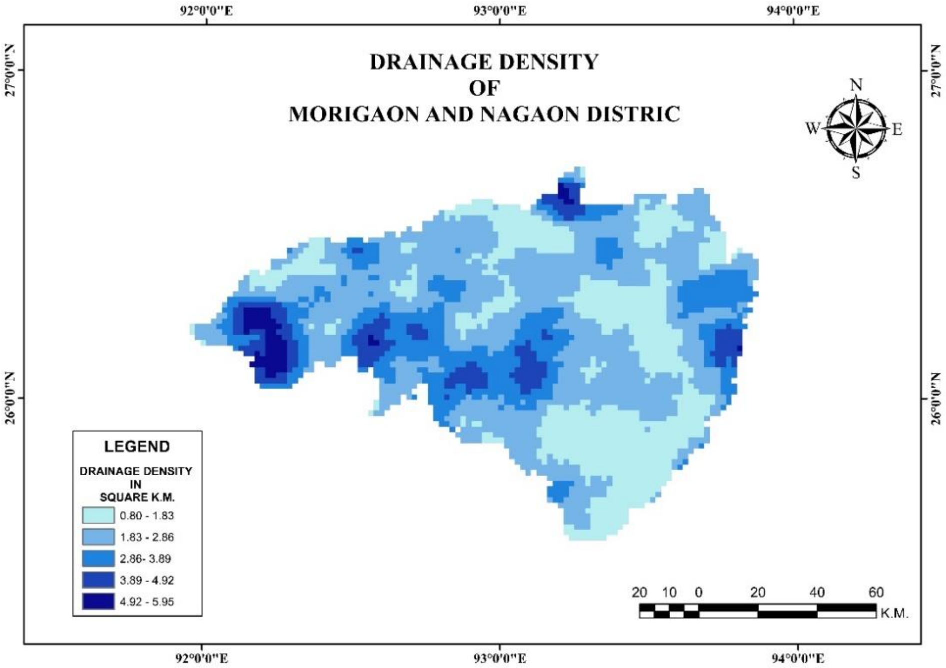
1.7. THE STREAM NETWORK

The stream network is derived from the CARTOSAT-1. **Figure 1.5** shows the conceptual overview of watershed and stream network delineation. Flow direction tool is then applied to compute the direction that water would flow for every cell and flow accumulation calculates the number of cells flowing into each cell of the filled DEM.

Areas with very high values may possibly be perennial streams or rivers, areas with lower values may be sporadic streams. The Basin tool finds its own pour points and creates watersheds for the whole map.

1.8. DRAINAGE DENSITY:

Drainage density map could be derived from the drainage map. i.e., drainage map is overlaid on watershed map to find out the ratio of total length of streams in the watershed to total area of watershed and is categorized. The drainage density of the watershed is calculated as: D LA = / , where, D = drainage density of watershed; L = total length of drainage channel in watershed (km); A = total area of watershed (km2). A watershed with adequate drainage runoff should have a drainage density ≥ 5, whilst the moderate and the poor ones have drainage density classes 1–5 (Figure 1.6)



Lowest drainage density is found southern and northern part of the map. Highest density is found western part of Morigaon District. In rest part of the map covered by moderate Drainage Density.

Figure 1.6: Drainage Density.

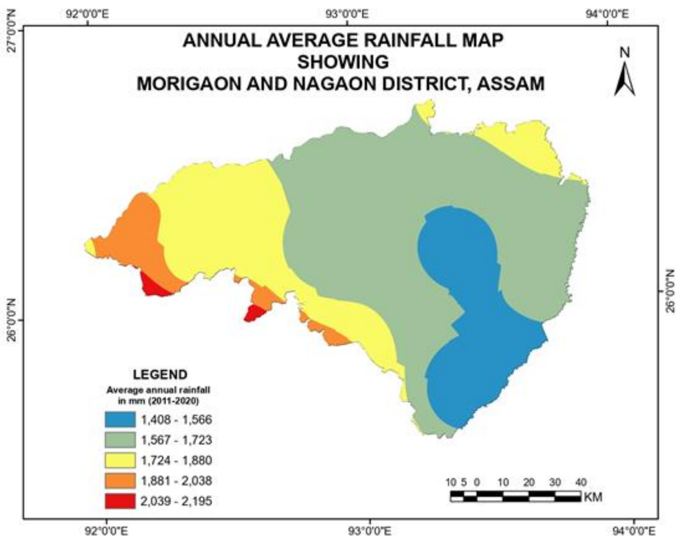


Figure 1.7: Annual Average Rainfall Map 2011-2020.

1.9. ANNUAL AVERAGE RAINFALL (2011-2020)

:Heavy rainfalls are one of the major causes of floods. Flooding occurs most commonly from heavy rainfall when natural watercourses do not have the capacity to convey excess water. Floods are associated with extremes in rainfall, any water that cannot immediately seep into the ground flows down slope as runoff.

The amount of runoff is related to the amount of rain a region experiences. The level of water in rivers or lakes rises due to heavy rainfalls. The water overflows to the areas adjoining to the rivers, lakes or dams, causing floods or deluge. In the study, it was observed that while the local rainfall is relevant for pluvial flooding, rainfall amounts on the upstream catchments contribute to flood hazard and risk caused by the rivers. Therefore both the local and upstream rainfalls were integrated in the analysis, due to the limited size of the study areas. A mean annual rainfall for eleven years (2001–2011) was considered and interpolated using Inverse Distance Weighting (IDW) to create a continuous raster rainfall data within and around municipality boundary. The resulting raster layer was finally reclassified into the five classes using an equal interval. The reclassified rainfall was given a value 1 for least rainfall to 5 for highest rainfall. Figure 1.7 shows the results of the raster rainfall layer, IDW interpolated data layer and the reclassified rainfall data. Highest rainfall is occurred southern part of the Marigaon District.Lowest rainfall is occurred south eastern past of Nagaon District (Figure 1.7).

1.10. SOIL MAP:

Soil textures have a great impact on flooding because sandy soil absorbs water soon and few runoffs occurs. On the other hand, the clay soils are less porous and hold water longer than sandy soils. This implies that areas characterized by clay soils are more affected The structure and infiltration capacity of soils will also have an important impact on the efficiency of the soil to act as a sponge and soak up water. Different types of soils have differing capacities. The chance of flood hazard increases with decrease in soil infiltration capacity, which causes increase in surface runoff. When water is supplied at a rate that exceeds the soil's infiltration capacity, it moves down slope as runoff on sloping land, and can lead to flooding.

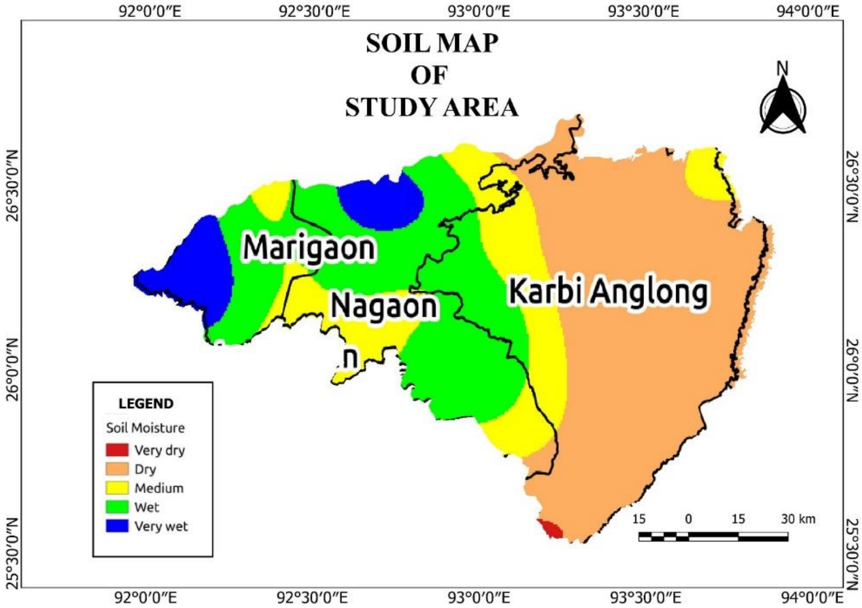


Figure 1.8: Soil Map.

1.11. GEOMORPHOLOGICAL MAP:

Geomorphic studies also conclude that the Brahmaputra is an antecedent river, older than the Himalayas, which has entrenched itself since they started rising. It often crosses higher altitudes in the Himalayas eroding at a greater pace than the increase in the height of the mountain range to sustain its flow. The height of the surrounding regions still increasing forming steep gorges in Arunachal.

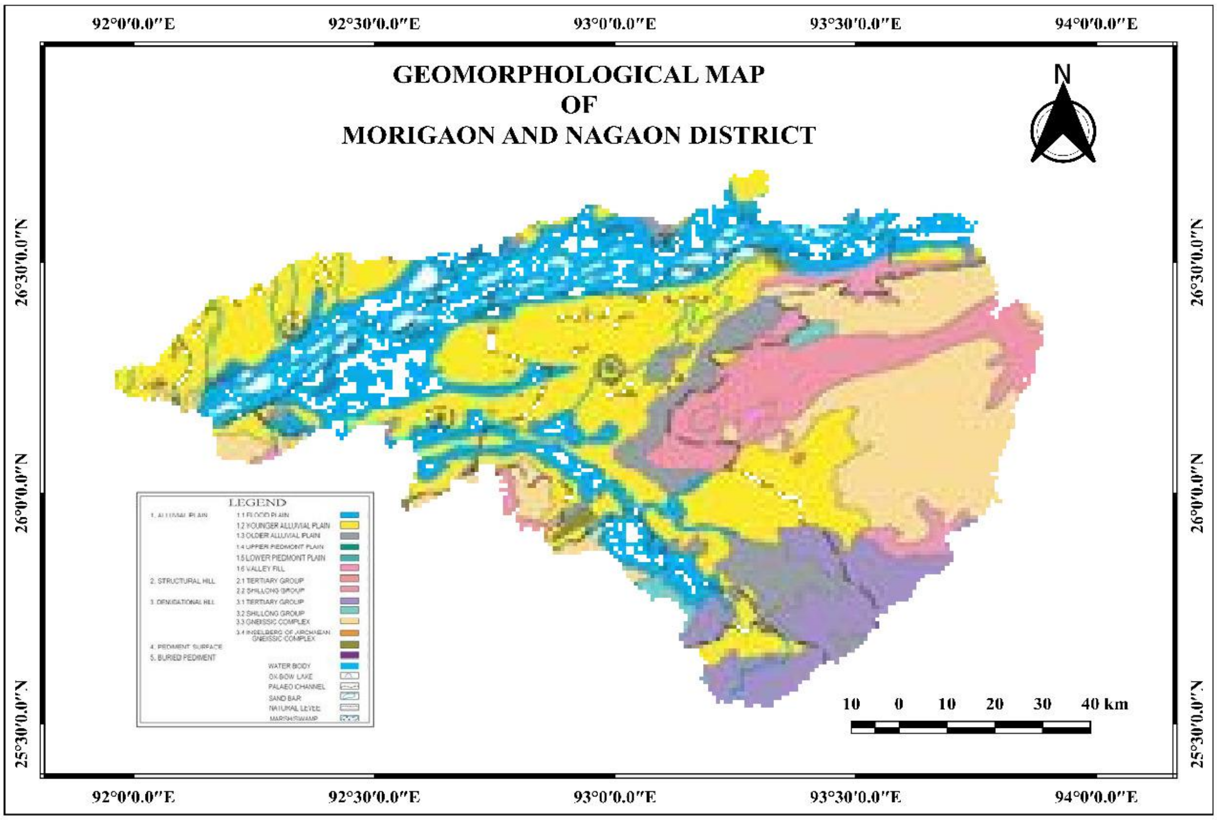


Figure 1.9: Geomorphological map.

1.12. LAND USE LAND COVER MAP:

The land-use Land-cover map of the study area is classified from a Landsat-8 OLI satellite imagery acquired on March 22, 2014. Iso cluster Unsupervised classification was carried out to generate the land use/cover map The created LULC map included five features namely; forest, water, urban, vegetation and bare ground. This is then reclassified for the overlay analysis. The urban land cover is deemed to be the cover highest prone to flooding because of all the impermeable surface and therefore assigned the rank of 'very high'. Vegetation and bare ground land covers are both deemed to be the next highest covers prone to flooding because of their compacted nature and are assigned the rank of 'high'. The forest and water land covers are assigned moderate and low rankings respectively. The LULC statistics (figure1.10) show that majority of the study area is covered by urban land.

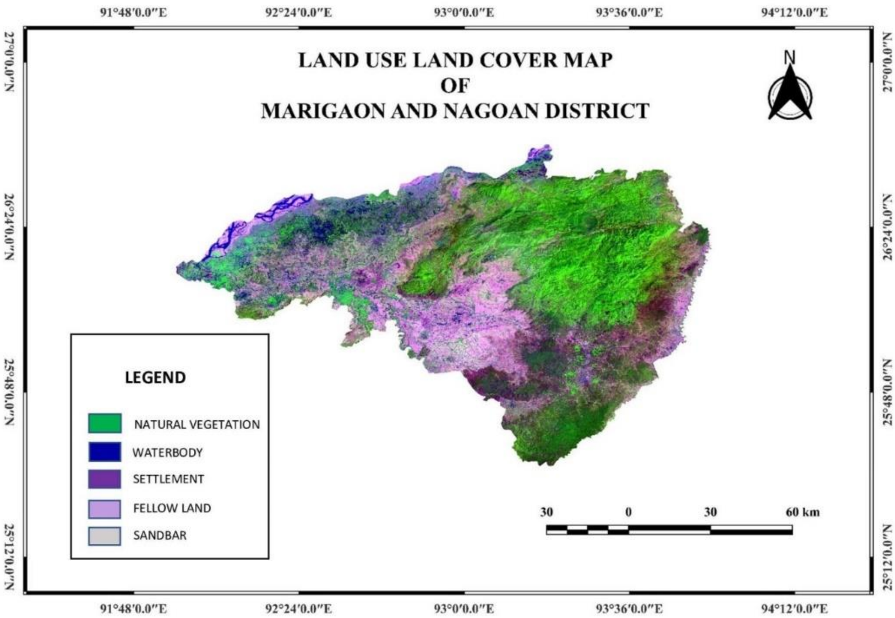


Figure 1.10: Land use and Land Cover map.

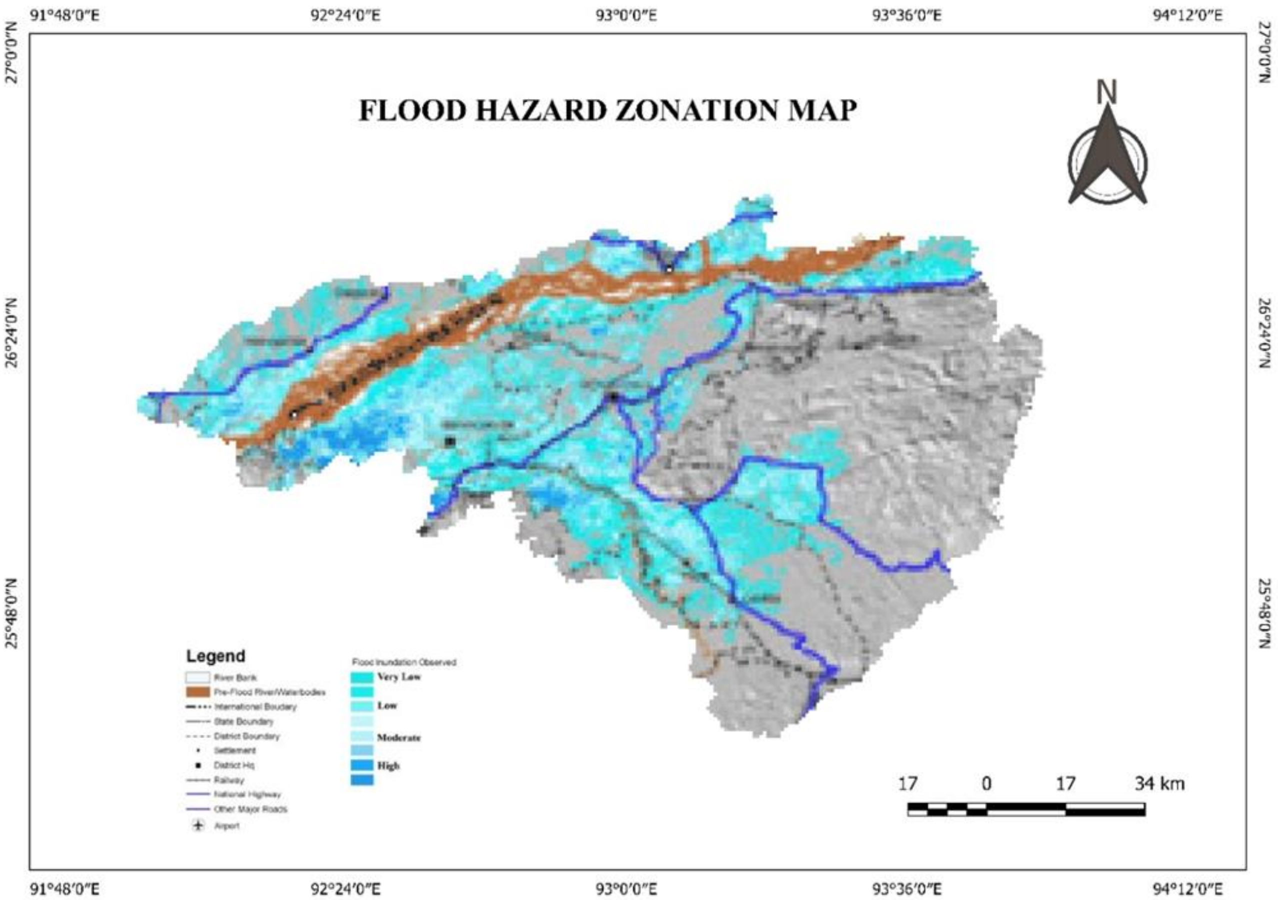


Figure 1.11: Flood Hazard Zonation Map.

1.13. RANKING OF FLOOD MAPPING CRITERIA :

The ranking and prioritization process is the main purpose of AHP based multi-criteria decision making. The quality of priority-setting directly influences the effectiveness of available resources which are, in most cases, the primary judgment of the decision maker. When making decisions, hydrologists and engineers frequently use heuristic and experiential judgments from the public who are the end-users. In this study, to determine the objectives and formulate the decision making process, sixteen experts comprising of four hydrologists, four engineers and eight end-users were asked to give their assessments and judgments regarding the variables related to flooding and their significances in terms of weights, out of the six factors analyzed. Experts or decision makers comprise of those with the technical skills and know-how for solving a given problem, while end-users are the public who are affected by the phenomenon and for this case study comprised of representatives from community leaders, area chief and sub-chief. Each of the expert participants assigned weights to the objective factors in three rounds, with each round using a different approach comprising of the following rounds:

Round 1: Assign each objective or factor a percentage to indicate the weight;

Round 2: Use round 1 to indicate the lowest importance, and assume the importance scale among the objectives is linear;

Round 3: The importance of objectives should be ranked using a 1 to 5 scale, with 1 representing the least important and 5 representing the most important.

In order to illustrate the significance of each factor as compared to the other criteria in resulting flood hazard, eigenvector is used to weight the standardized raster layers. The results of the pairwise comparison and ranking of the criterion are presented in Table 1. 3. Next, Table 1.4 shows the normalized matrix converted to percent contributions, from which the average priority vector (X) is derived.

The consistency check CI is determined from the matrix formulation (max AX X = λ); where (A) is the pairwise matrix and (X) is the eigenvector of weights. From the solution for max λ , the CI is obtained as in Equation.

Table 1.3. Ranking of flood causing criteria to obtain the pairwise comparison matrix.

Criteria	Rainfall	Drainage	Elevation	Slope	Soil	Land-use
Rainfall	1	1	2/3	1/2	2	2
Drainage	1	1	2/3	1/2	2	2
Elevation	1½	1½	1	3/4	3	3
Slope	2	2	1⅓	1	4	4
Soil	1/2	1/2	1/3	1/4	1	1
Land-use	1/2	1/2	1/3	1/4	1	1
Total	6½	6½	4⅓	3½	13	13

Table 1.4. Normalizing the criteria columns to obtain the normalized matrix :

Criteria	Rainfall	Drainage	Elevation	Slope	Soil	Land-use	Priority vector (x)	Percent (%)
Rainfall	2/13	2/13	2/13	2/13	2/13	2/13	0.1301	13%
Drainage	2/13	2/13	2/13	2/13	2/13	2/13	0.0814	8%
Elevation	3/13	3/13	3/13	3/13	3/13	3/13	0.0710	7%
Slope	4/13	4/13	4/13	4/13	4/13	4/13	0.1800	18%
Soil	1/13	1/13	1/13	1/13	1/13	1/13	0.2771	28%
Land-use	1/13	1/13	1/13	1/13	1/13	1/13	0.2604	26%
Total	1	1	1	1	1	1		100%

1.14. WEIGHTING AND RANKING OF THE MODEL INPUT FACTORS :

In the weight and ranking calculation step, the pairwise comparison matrix and the factor maps are used. The principal eigenvector of the pairwise comparison matrix is figured out to produce a best fit to the weight set. Weight values represent the priorities which are absolute numbers between zero and one. Using a weighted linear combination, it implies that the weights sum to 1. A summary of the flood causative factors or variables development showing the various factors, their respective weights and how they are ranked according to their influence to flood events in the study area is presented in Table 1.4. In Table 1.4, the sub- factors (j) are the ranges of decision factor (i) which contribute to the decision ranking values. Table 1.4 shows how the three-level hierarchical structure is decomposed, and how ranking decision is derived for the subsequent vulnerability and risk mapping. A higher weight value of the factors represents more priority or more impact than others within the study. From the factor weights found for this study area, it is clear that the soil cover, characterized by infiltration, have the highest weights, implying that they have more contribution to flooding in the area as compared to the other factors or elements. This factor not only affects the bare soil surfaces, but the general material the covers a given area.

From the flood vulnerability map, the whole study area can be considered as a flood plain as the terrain is fairly flat. The areas with moderate, high and very high floods are heavily populated urban areas where, in addition to residential properties, all the industries, markets and commercial activities are located. In the event of flooding, commercial activities grid to a halt and millions of dollars of property are lost. The conventional method of relocation of persons within flood plains cannot be applied here since it would imply the relocation of a population of over four million. Also since the raining season is just four months out of twelve, relocation seems unrealistic. This suggests that other ways of combatting the perennial flooding are needed. Recommendations for battling the situation are as follows

- **Land-use Controls:** More open spaces should be included in design of new settlements to aid in the reduction of water runoff. Porous materials that are stable and strong, but that still permit water to drain through can be used in the construction of driveways, sidewalks, parking lots and pathways.
- **Town Planning :** It is imperative that builders acquire building permits before buildings are erected. This will ensure that wetlands are not filled in and waterways and stream channels are not blocked.
- *Large scale afforestation*, range management and animal grazing controls to increase absorption and reduce rapid runoff.
- to make individuals aware of the existence and operation of *flood warning plans* and
- to encourage individuals to keep drainage ways clean and to report potential maintenance problems.

1.16. FINDINGS:

- The whole study area can be considered as a flood plain as the terrain is fairly flat.
- The areas with moderate, high and very high floods are heavily populated urban areas where, in addition to residential properties, all the industries, markets and commercial activities are located.
- The conventional method of relocation of persons within flood plains cannot be applied here since it would imply the relocation of a population of over four million. Also since the raining season is just four months out of twelve, relocation seems unrealistic.
- This suggests that other ways of combatting the perennial flooding are needed.

1.17. CONCLUSION:

The rapid urbanization of areas surrounding the Brahmaputra rivers has led to the construction of buildings and infrastructure in flood-prone areas, increasing the risk of damage and displacement. The destruction of natural habitats and forests in the catchment areas of the rivers has increased the risk of flooding. Flood risk mapping is an essential component for relevant land use planning in flood plain areas and it aids in the efforts of city planners and administrators to prioritize their mitigation or relief response. The basic notion of flood risk mapping undertaken in this project is to efficiently delineate flood prone areas in Assam. It is achieved through a multi criteria evaluation method within a GIS environment based overlay analysis. Whereas the radar analysis map shows the areas actually covered with flood waters, the MCA map gives an indication of the expected level of flood hazard but the radar analysis method is much effective when there is access to real time satellite imagery. The resulting map of MCA analysis can be used as a guide for decision makers and city planners for better land use planning and flood risk management. The accuracy and visualization of the MCA work presented can be further improved by using high resolution DEM data which will generate flood inundation map with high accuracy and extensive rainfall data for accurate flood prediction analysis.

Author contribution :

Conceptualization, methodology, writing – orginal draft, MM. The author has read and agreed to the publication.

Conflicts of interest: The author declare no conflict of interest.

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