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Flood Susceptibility Mapping of Netrokona District Using a GIS-based multi-criteria Analysis

Neelo Sultana[1]
Bibi Hafsa[2]
Sabnam Jareen Laxmi[1]
Subrina Rahman Nijhum[1]
Mahib Reza[1]

Abstract: *Due to geographical location and physiographic conditions, i.e., low elevation, siltation of riverbed, monsoon dominated excessive rainfall at upstream Bangladesh faces most destructive flood events every year, especially Netrokona, a district of north-eastern Bangladesh. Such extreme events not only destroy property and assets but also endanger people's life and livelihoods. Existing research works have assessed flood risk using several methods but the dynamic interaction between human and climate as well as their inherent community knowledge is ignored. In this study, researchers aim to integrate those by developing a multi-criteria approach in order to mapping flood susceptibility of Netrokona. Subsequent studies lack precise and intricated mapping operations as well as susceptibility indexing that directs flood vulnerability analysis with a view to integrate mitigation strategies and planning. In this research, the socioeconomic factors, i.e., land use, population and drainage are integrated with physical factors, i.e., elevation, slope, rainfall, and drainage using Weighted Linear Combination (WLC) method. To enhance local relevance, the study incorporates expert input and participatory mapping. Weights were derived by the Analytical Hierarchy Process (AHP) using seven essential geographical criteria: elevation, slope, rainfall, soil type, drainage density, land use/cover, and historical flood data. Reliability was ensured through pairwise comparisons and consistency ratios. With zones ranging from extremely low to very high risk, a flood susceptibility index was created by integrating layers into a GIS environment. According to this study, 29.44% of the district is very to extremely susceptible to flooding, primarily along rivers and low-lying areas. This study aims to address these gaps by developing a Multi-Criteria Approach (MCA) for flood susceptibility mapping in Netrokona using Geographic Information Systems (GIS). The methodology employs the Weighted Linear Combination (WLC) method to integrate socioeconomic factors (such as land*

[1] Research Student, Department of Geography and Environment, Jahangirnagar University
[2] Associate Professor, Department of Geography and Environment, Jahangirnagar University. Email: hafsa@juniv.edu

use, population, and infrastructure) with physical factors (including elevation, slope, rainfall, and drainage). The resulting flood risk and social maps contribute significantly to integrated flood risk management in Bangladesh, supporting early warning systems, disaster resilience planning, and informed decision-making.

Keywords: Flood, Natural Hazard, Multi-criteria Analysis, Susceptibility map, Analytical Hierarchy Process.

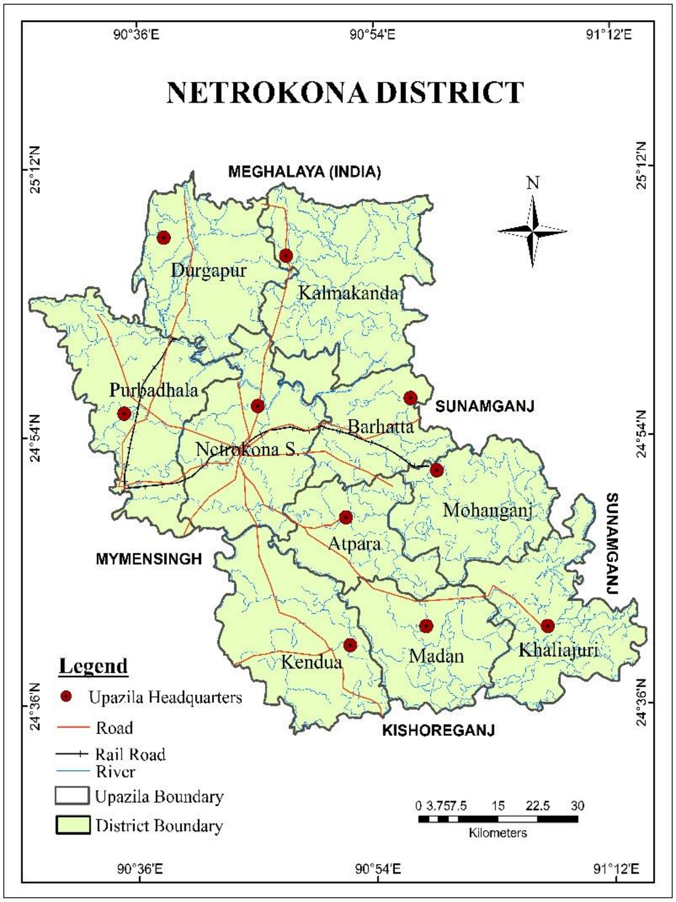
Introduction

Floods are a common and prominent natural hazard in Bangladesh (Kabir & Hossen, 2019). The floods that occurred in 1954, 1955, 1974, 1987, 1988, 1998, 2004, 2007, 2017, and 2019 all resulted in significant property damage and many fatalities (FFWC, 2020). One of the most destructive natural disasters, flooding poses a significant risk to infrastructure, human life, and the environment (Jerome G.F., 2021). Rapid urbanization, uncontrolled land use, and climate change have all contributed to a rise in its incidence and severity worldwide (Traore, et al., 2025). Due to its unique topography and hydrology, Bangladesh, a low-lying deltaic country, is particularly vulnerable, especially in the Netrokona District (Rahman M., et al., 2025). Netrokona frequently experiences floods caused by upstream waters and monsoon rains, as it is located in a floodplain traversed by rivers such as the Dhanu, Mogra, and Kangsha. Flood hazards are further increased by socioeconomic factors like poverty, a significant reliance on agriculture, crowded populations, and inadequate infrastructure (Winsemius et al., 2018). The problem is exacerbated by unplanned settlements in high-risk areas. In Bangladesh, field surveys and hydrological models are the primary methods used for traditional flood risk assessments. While these approaches are informative, they often lack real-time flexibility and fail to consider regional socioeconomic factors. Previous research that utilized methods like logistic regression, frequency ratio, and AHP has shown potential; however, it often overlooks community knowledge and the dynamic nature of human-climate interactions by treating flood risk as a static issue. Hazard does not affect the community in linear form, rather impacts in multi-various ways. Not every person in the community gets affected by hazard at the same intensity and magnitude. Socioeconomic factors draw variations among communities into different layers. For example, an educated person knows how to react during hazard period, but an uneducated person may react differently. To address such existing gaps, this study develops a comprehensive flood susceptibility map of Netrokona using a GIS-based Multi-Criteria Analysis (MCA). The GIS-based MCA approaches offer an efficient tool for risk assessment by considering all relevant hazard sources, thereby enhancing prediction accuracy to some extent (Sadeghi & Pouya, 2017; Tanavud, 2004). This method ensures both scientific rigor and local relevance by integrating socioeconomic factors (such as population density, land use, and infrastructure) with physical factors (including elevation, slope, and rainfall), complemented by participatory mapping and surveys. The theoretical framework is grounded in Integrated Flood Risk Management (IFRM) and Disaster Risk Reduction (DRR), which assign values to various criteria through the weighted linear combination (WLC) method. By incorporating community feedback and spatial analysis, this study provides an advanced and practical tool for flood management. Its aim is to enhance disaster preparedness, improve early warning systems, and facilitate targeted planning, ultimately making the community more resilient and flood aware. The broad aims of this research is to develop a GIS-based multi-criteria approach for flood susceptibility mapping in Netrokona district. It involves generating maps of flood-conditioning factors and applying the GIS-based approach to assess flood susceptibility. The study also identifies vulnerable sectors and elements to produce a comprehensive flood risk map.

Study Area

This study is based on Netrokona District, located in the north-central part of Bangladesh. Geographically, it lies between 90°00′E and 91°07′E longitudes and 24°34′ N and 25°12′ N north latitudes. The district is bordered by Kishoreganj to the south, Sunamganj District to the east, Mymensingh to the west, and the Indian state of Meghalaya to the north (BBS, 2015). The total area of the district is 2,744.28 km², with approximately 9.17 km² covered by forested land.

Being located at regions of multi-river intersections of Surma-Meghna River System, it's characterized as Low-lying floodplain constituted with flat alluvial plains, marshes, seasonally inundated haor wetlands, specially subtropical monsoon climatic condition, precisely, with hot, humid summers averaging between 25 to 35 degrees Celsius, and milder, drier winters ranging from 10 to 20 degrees Celsius, influences heavy rainfall during monsoon, have made this region prone to flooding (WARPO, 2004). While these floods are essential for agricultural and environmental restoration, they pose serious risks to infrastructure and populated areas. The general community structure of this district varies in terms of literacy, religion, economic activities, sex ratio. But the most attributive characteristic of the community is that about 40% of the population are literate, that indicates noticeable challenges of this community in development. Most of the population of the study area are engaged in primary economic activities, especially farming. It sums that the community structure is fragile, making high vulnerability to hazards, concisely flood. Map-1 mirrors the study area.



Map-1: Study Area

(Source: Authors, 2025)

Methodology

The process begins with the preparation and standardization of geographic data layers that influence flood susceptibility, which are then used to create maps of flood conditioning factors. Through a review of the literature and expert insights, several key conditioning elements are identified, including elevation, slope, land use and land cover (LULC), soil type, proximity to rivers, and precipitation. To ensure compatibility and spatial consistency, all datasets are projected into a standard coordinate reference system. ArcMap's 'Identify' and 'Statistics' tools are utilized to assess each layer's properties and value distribution. Following this, the 'Reclassify' tool in ArcToolbox is employed to reclassify each raster layer. To produce maps of flood conditioning factors, the first step involves preparing and standardizing the geographic data layers that affect flood susceptibility. Every layer was standardized for integration and projected onto a single coordinate system. To evaluate the relative importance of each factor, a pairwise comparison matrix was created using the Analytic Hierarchy Process (AHP) (Table 1). Factors were weighed according to Saaty's 1–9 scale (Table 2). The matrix was normalized, and the Consistency Ratio (CR) was maintained below 0.1 to ensure consistency before determining the weights. A standard scale (e.g., 1–10) was used to reclassify each raster layer based on its contribution to the risk of flooding. Using these classified layers and the determined weights, a weighted overlay analysis was performed in ArcGIS to produce a composite Flood Susceptibility Index (FSI). To ensure accuracy and reliability, the final map was cross-checked against historical flood data. Spatial data representing critical assets such as communities, agricultural areas, transit systems, and public infrastructure are overlaid on flood susceptibility outputs to analyze vulnerable sectors and elements. This flood susceptibility mapping helps create a comprehensive flood risk map, identifying high-risk areas and specific components most at risk of future flooding. By integrating socioeconomic factors, land use data, and vulnerability assessments, we can develop a thorough flood risk map. To ensure the model's accuracy and effectiveness for planning and risk management, we validate the results by comparing them with historical flood data and expert knowledge. Adjustments to weights or categorization schemes are made as needed to enhance the model's outputs. All methodological steps, including the decision-making process, criteria weighting, and GIS operations, are thoroughly documented to ensure transparency, reproducibility, and scientific integrity.

Data Source and Data Collection

To facilitate flood susceptibility mapping in the Netrokona District, this study utilized data from a range of reliable national and international sources. Meteorological data, including daily rainfall and temperature records from the past 30 years, was obtained from the Bangladesh Meteorological Department (BMD) to analyze seasonal flood patterns. Elevation data was sourced from NASA's Shuttle Radar Topography Mission (SRTM) via the USGS Earth Explorer platform. The necessary GeoTIFF tiles (90E25N and 91E25N) were downloaded and then mosaicked using QGIS to create a seamless elevation model. This model covers the geographic coordinates ranging from 24°54'N to 25°12'N and 90°36'E to 91°12'E. The Climatic Research Unit (CRU) at the University of East Anglia provided long-term climate data for the analysis. To evaluate historical rainfall variability, the CRU TS 4.01 dataset was downloaded, which contains monthly climate data from 1901 to the present, in NetCDF format and processed it accordingly. Additionally, to analyze flood exposure and accessibility, the information on land use and infrastructure, including roads, bridges, and settlement patterns were collected from the Local Government Engineering Department (LGED). Land use classification and seasonal change detection were conducted using high-resolution satellite data from Sentinel-2 and Landsat 8, which were obtained from the Copernicus Open Access Hub and USGS Earth Explorer. To enhance analysis, pre- and post-monsoon images with minimal cloud cover were selected. Once standardized to the WGS 84 coordinate system, each dataset was prepared for integration into a GIS-based system. The multi-criteria approach employed in this study allows for a comprehensive and geographically informed evaluation of flood risk based on these combined datasets.

Table 1: AHP model to identify significant factors.

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Elevation	Distance from river	A	1
1	3		Slope	A	5
1	4		Precipitation	B	1
1	5		LULC	A	4
1	6		Aspect	A	1
1	7		Drainage density	B	1
1	8			A	
2	3	Distance from river	Slope	A	5
2	4		Precipitation	B	1
2	5		LULC	A	3
2	6		Aspect	A	3
2	7		Drainage density	A	1
2	8			A	
3	4	Slope	Precipitation	B	5
3	5		LULC	B	1
3	6		Aspect	A	3
3	7		Drainage density	B	5
3	8			A	
4	5	Precipitation	LULC	A	4
4	6		Aspect	A	3
4	7		Drainage density	A	1
4	8			A	
5	6	LULC	Aspect	B	3
5	7		Drainage density	B	5
5	8			A	
6	7	Aspect	Drainage density	B	2
6	8			A	
7	8			A	

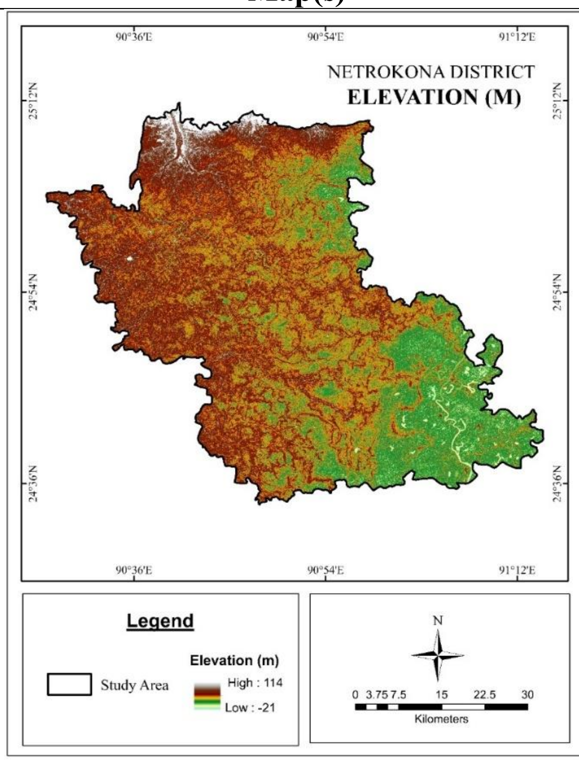
(Source: Authors, 2025)

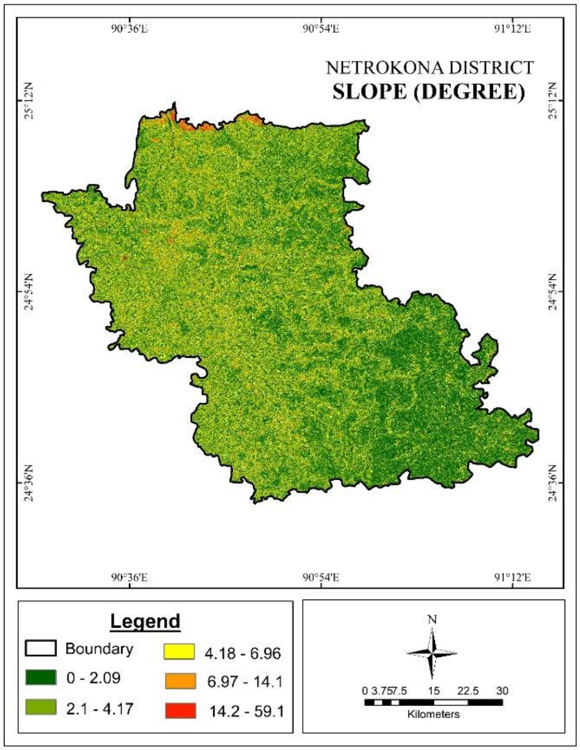
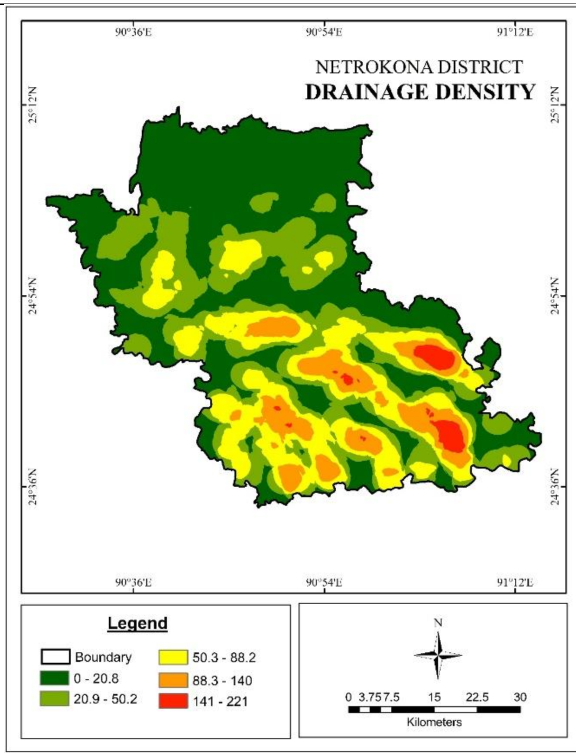
Table 2: Saaty's Scale for weighing factors.

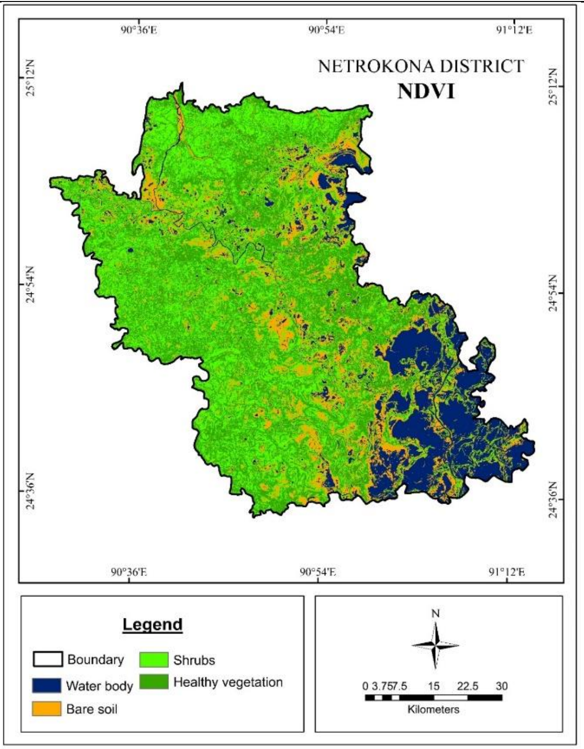
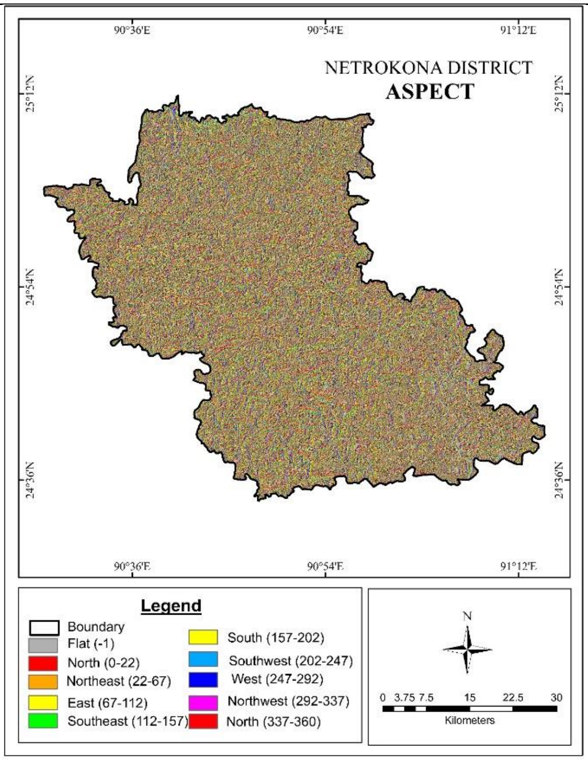
Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	who contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	**Intermediatory**	Can be used to express intermediate values

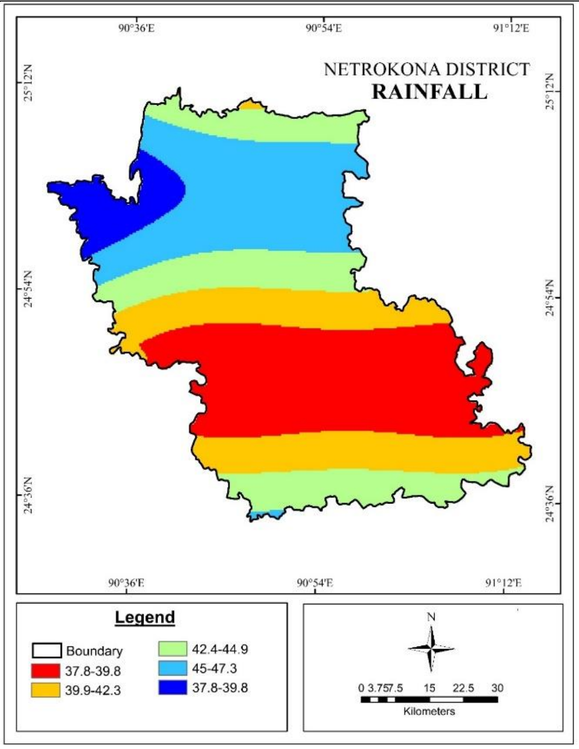
Results & Discussion: By completing the methods mentioned, the following results are found: (a) The mapping of conditioning factors of flood

Table 3: Factors of Flood

Factors	**Discussion**	**Map(s)**
Elevation	In Netrokona, elevation plays a crucial role in preventing flooding due to the area's low-lying topography, especially in the flood-prone Haor basin. With an average elevation of just 5 to 10 meters above sea level, the region is particularly vulnerable to flooding during the monsoon season, as water flows easily from the nearby Meghalaya Hills.	

Slope	The slope of the land has a minimal impact on flood conditions in the mostly flat and gently sloping region of Netrokona. Factors such as elevation and land use play a more significant role in flooding than slope does. Even though water from higher elevations tends to flow more rapidly and accumulate in lower areas like the Haor basin, effective drainage systems, reforestation, and other sustainable land-use practices can help manage water flow and reduce the risk of flooding.	
Drainage Density	The extensive network of rivers and canals in Netrokona plays a vital role in draining excess water, making drainage density crucial for flood prevention. However, challenges such as siltation, encroachment, and inadequate maintenance diminish the system's efficiency and heighten the risk of flooding.	

NDVI	Higher NDVI (Normalized Difference Vegetation Index) readings indicate dense vegetation, which helps minimize flooding by absorbing rainwater and stabilizing soil. Therefore, NDVI is a vital factor in flood prevention in Netrokona. However, due to increasing runoff and water accumulation caused by urbanization and deforestation, the NDVI has decreased, and flood risks have risen. To mitigate flooding, it is essential to restore and maintain vegetation.	
Aspect	Due to the level topography in Netrokona, the direction of slopes (aspect) has a reduced impact on flood susceptibility. Slopes facing south and southwest are more likely to experience higher rainfall and runoff because they are more exposed to monsoon winds, which increases their risk of flooding. In contrast, slopes facing northeast and northwest tend to receive less precipitation. However, in this predominantly flat region, changes in land use and elevation play a more significant role in	

<table>
<tr><td></td><td>flood risk than the slope's direction.</td><td></td></tr>
<tr><td>Rainfall</td><td>Rainfall plays a crucial role in flood conditions in Netrokona, where frequent flooding occurs due to heavy monsoon rains from June to September. The area's flat terrain, low elevation, and inadequate drainage infrastructure exacerbate waterlogging, intensifying the flooding problem. To mitigate risks, effective flood control measures are essential, especially considering the influence of regional weather patterns and rainfall variability on the severity of floods.</td><td>
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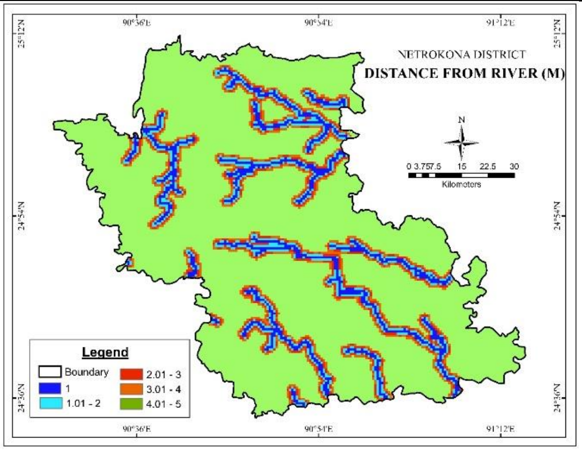
<tr><td>Distance from River</td><td>One of the primary factors influencing flood risk in Netrokona is the proximity to rivers. Areas near the Someshwari, Mogra, and Kangsha rivers are particularly vulnerable to flooding. These regions often experience prolonged flooding and suffer more severe impacts during heavy rainfall. To mitigate risks and enhance resilience in flood-prone areas, it is essential to implement effective flood management strategies, including flood control infrastructure, zoning regulations, and community preparedness.</td><td>
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(Source: Authors, 2025)

Flood Susceptibility

The Netrokona District flood hazard map highlights areas with varying levels of flood risk (Figure 2). The central and southeastern regions, particularly Kendua, Kalmakanda, and Durgapur, face extremely high flood dangers and are very susceptible to seasonal flooding. Additionally, Mohanganj, Atpara, and Khaliajuri are also at high risk due to their proximity to river systems and haor wetlands. Purbadhala and Netrokona Sadar are classified as moderate risk areas, indicating that localized flooding could still lead to significant problems. Madan and Barhatta, located in the west and northwest of Bangladesh, face low to extremely low flood hazards due to improved drainage systems and somewhat higher altitudes.

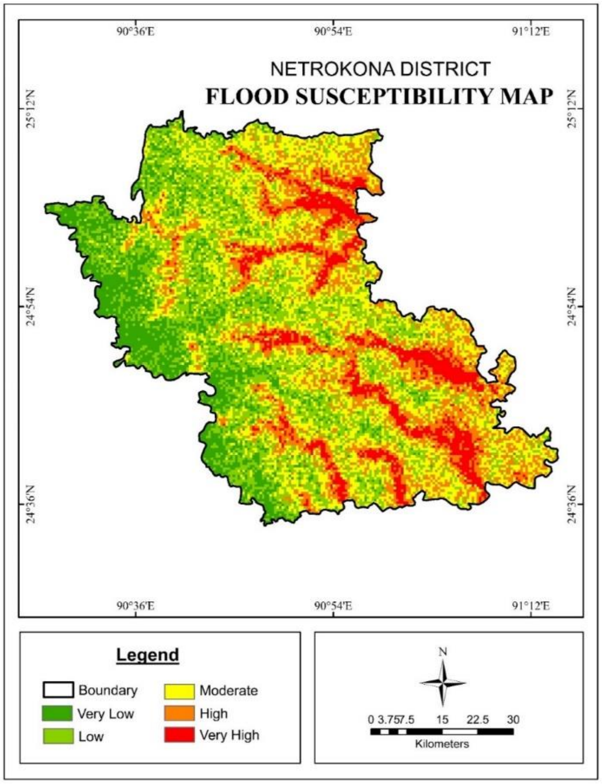

Figure 2: Flood Susceptibility Map of Netrokona District

(Source: Authors, 2025)

There is an urgent need for flood risk management, as shown by the flood susceptibility map of the Netrokona District, which indicates varied levels of risk in multiple areas. Approximately 29.43% of the district, or 843.2 square kilometers, is classified as having "Moderate" susceptibility. This indicates a considerable risk of flooding in these regions, which should be taken seriously in disaster preparedness. Additionally, the zones classified as 'High' and 'Very High' susceptibility together account for roughly 29.44% of the district. This means that nearly one-third of the district is vulnerable and likely requires strict flood control measures. Due to their susceptibility to frequent and potentially severe floods, these areas will benefit from targeted mitigation efforts. These efforts include reinforcing infrastructure, implementing community training programs, and ensuring robust emergency responses. In contrast, regions classified as "Very Low" and "Low" for flood vulnerability account for 41.13% of the district. Although these areas are not completely immune to flooding, they are significantly less vulnerable. This classification allows for the prioritized allocation of resources, focusing on preparedness and preventive measures rather than aggressive mitigation tactics.

Table 4: Flood Susceptibility by Area

Susceptibility	Area (Sq. km.)	Area (%)
Very Low	415.84	14.51%
Low	762.56	26.62%
Moderate	843.2	29.43%
High	585.28	20.43%
Very High	258.08	9.01%

(Source: Authors, 2025)

b) Vulnerable Factors and Risks

This map (Figure 3) captures all the physical and cultural elements of the Netrokona district. It offers a detailed overview of the area's infrastructure, services, and community distribution, illustrating how the region's natural features relate to human settlements. The Netrokona District social map is an essential tool for planning, development, and disaster relief, ensuring that resources are allocated effectively to meet the needs of the public.

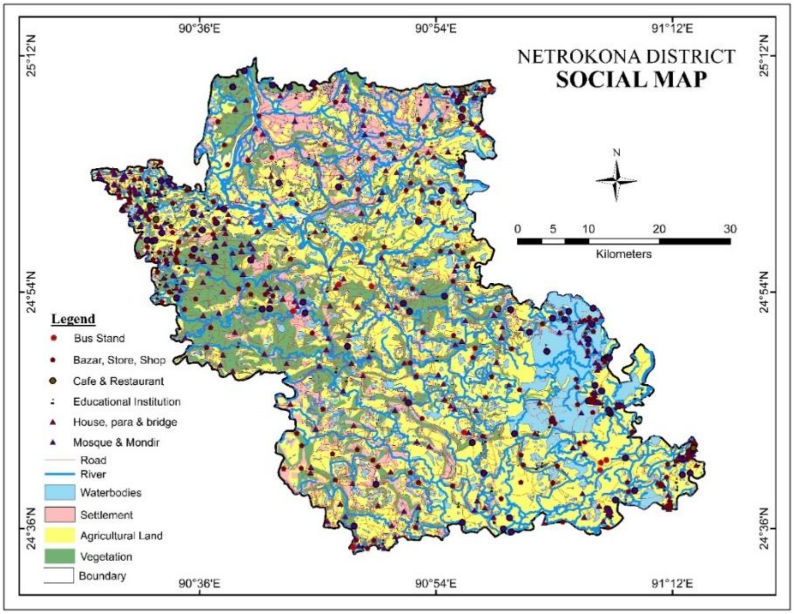

Figure 3: Social Map of Netrokona
(Source: Authors, 2025)

Flood events affect numbers of sectors both in individual and community level. It hampers day to day life of the population, destroying livelihoods. As mentioned earlier, the community's economy largely depends on primary economic activities, specifically farming, the flood effect deteriorates agriculture and fisheries sector along with infrastructure create harm to the community most.

Table 5 : Vulnerable sectors

Sectors	Elements	Flood
Agriculture	Aush	Yes
	Amon	No
	Boro	No
	Vegetables	No
Fisheries	Pond	Yes
Infrastructure	Roads	Yes
	House	Yes
	Institutions	Yes

(Source: Authors, 2025)

Flood events are seasonal, thus do not effect agricultural production at same rate in different production periods. Table shows that flood affects Aush production period but do not affect the other two periods, Amon and Boro. It does not hamper vegetable production as well because mostly winter is suitable for vegetable production. Flood overflows ponds and rivers thus fisheries get affected. Destructing infrastructures and flood causes serious damage at community level.

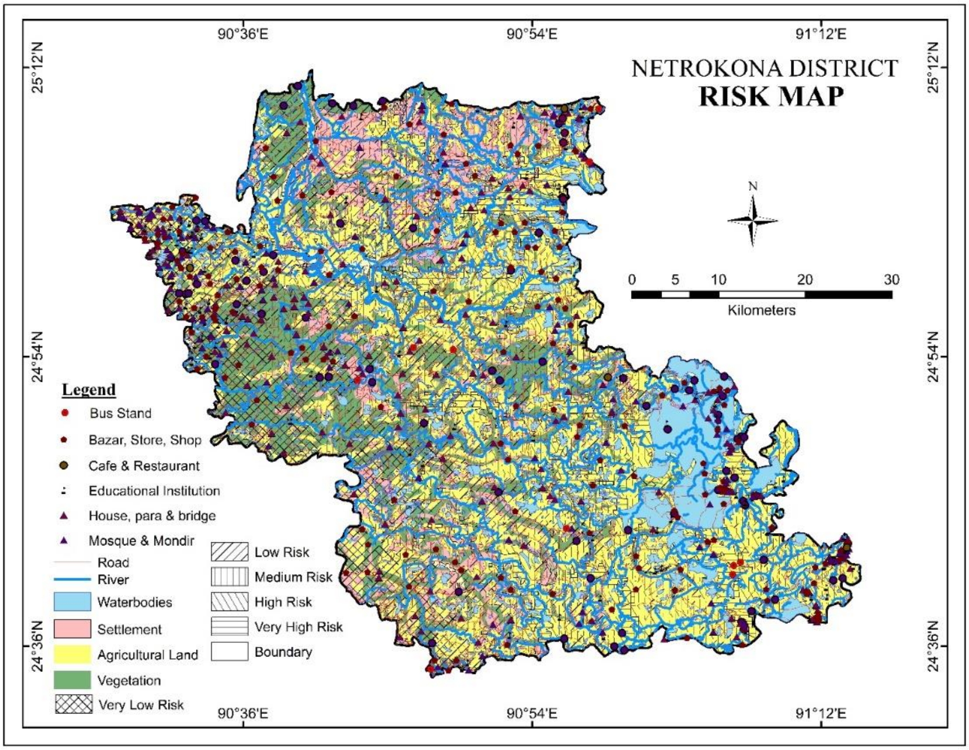

Figure 4 : Risk Map of Netrokona District

(Source: Authors, 2025)

Different levels of hazard exposure are illustrated on the Netrokona District Risk Map. The eastern and southeastern regions, particularly Khaliajuri, Mohanganj, and Kalmakanda, face an extremely high risk due to their expansive water bodies, haor wetlands, and frequent flooding. These areas are highly vulnerable because they contain essential infrastructure, including marketplaces, roads, bridges, and educational facilities. In the medium-risk areas of Netrokona Sadar, Atpara, and Kendua, agricultural land, bazaars, and densely populated communities are somewhat susceptible to seasonal flooding. Conversely, the western and northwest regions of Barhatta and Madan have low to very low risk due to improved drainage systems, increased vegetation, and higher elevation. To safeguard residents and support economic activities in high-risk areas, there is an urgent need for resilient infrastructure, effective flood mitigation strategies, and disaster preparedness measures, as highlighted on the map. The research considers various factors that influence flood susceptibility, such as land use, elevation, river networks, and rainfall patterns. To enhance disaster preparedness, it is crucial to focus on high-risk areas, especially those located in low-lying floodplains and coastal regions. Both rural districts like Netrokona and Sylhet, as well as urban areas like Dhaka and Chittagong, experience different types of flooding, including flash floods and riverine floods. By analyzing this data, authorities can improve emergency response plans, early warning systems, and infrastructure design to reduce flood damage and protect communities.

Conclusion

Hazard and its potentiality largely dependent on community structure and perception. Flood events happen every year spanning a particular region, concisely Sylhet. Recurrence of flood events creates internal resilience to the community, enlightening them regarding the possible reaction they should make, necessary preparations they should take and strategies they should follow during flood. Areas unprecedented to flood lack such community preparedness. It formulates that hazard has multi criterial dimensions. Understanding the impacts of any hazard is incomplete without integrating multi criterial concept into account, especially flood. Creating a flood risk map for the Netrokona district is essential for understanding and mitigating the impacts of floods on vulnerable areas and resources. This process underscores the significance of spatial analysis and data integration in identifying the infrastructure and locations most at risk, as well as in facilitating resource allocation and proactive planning. The map will highlight areas of high susceptibility, including residential neighborhoods, agricultural zones, critical infrastructure (such as roads, bridges, and power grids), and socioeconomic resources. Flood hazards pose a significant challenge for Netrokona, affecting various sectors of the community.

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