



## Flood risk mapping of Khagrachhari district, Bangladesh: A GIS based approach

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### Abstract

One of the most destructive natural disasters that harm both natural and man-made features on the surface of the world are floods. Because of geographical location Bangladesh has faced flood every year. Khagrachhari District, which is in the south-eastern region of Bangladesh, is mainly a hilly region, is characterized by steep slope, regular monsoon rainfall and devastating flash flood. Slope, proximity (distance to river), soil type, drainage density, population density as well as low adaptive capacity in the district increase the flood risk. The primary goal of the study is to evaluate the flood risk in the Khagrachhari District using mainly secondary data with the help of remote sensing and geographic information system (GIS) techniques. This was accomplished by weighing the "vulnerability" and "hazard" elements that contribute to flooding individually at various degree levels. Using a raster calculator, the final vulnerability and hazard index was multiplied to create the risk map. Dighinala and Khagrachhari Sadar were found to be high risk of flooding. The rest of the Upazilas were found very low to moderate risk. Future land use and development activity should be done to reduce the risk of flooding using flood risk maps.

**Keywords:** Flood risk management, GIS, Khagrachhari, Hazard assessment

### Introduction

Floods are the most damaging natural disasters that affect both natural and artificial features on Earth's surface. Bangladesh is a component of the most active delta system in the world and the most dynamic hydrological system. The three major rivers' locations, topographies, and outflows influence the yearly hydrological cycle of the region. Rainfall and the monsoon have historically shaped the nation's economy, ecology, environment, and level of civilization. Bangladesh's location, topography, abundance of rivers, monsoon climate, and other factors make it extremely susceptible to flooding. Floods are a common occurrence, with the months of July and August seeing the worst flooding (Payudyal, 2002). The floods that occurred in 1954, 1955, 1974, 1987, 1988, 1998, 2004, 2007, 2014, and 2016 all resulted in significant property damage and fatalities. Up to 25% of the country's land area floods on average each year, with 68% or more of it being affected by the worst floods (Ali, *et al.*, 2019) [1]. Between August 5 and August 10, 2023, 2.4 million people were exposed in four seriously damaged districts: Chittagong, Bandarban, Rangamati, and Cox's Bazar, according to the UNOSAT Flood-AI Monitoring Dashboard. In Khagrachhari district, 15,000 persons (4,439 women and 5,940 children) were impacted.

Until recently, the design of flood defense systems involved defining an exceedance probability that the system could defend a given area against. Structures like dikes were intended to withstand floods up to a predetermined design flood, like a flood that occurs once every 100 years. The risk of flooding has not disappeared despite several management measures. This is because flood defenses do not provide total security. Consequently, the notion of the "flood control approach" is currently being questioned more and more, and numerous scholars have advocated for a more thorough design process known as "flood risk management" (Merz, *et*

*al.*, 2010) [20]. Flood risk management begins with risk assessment. Flood risk is a component of risk assessment that includes flood hazard (i.e., extreme events and their probability), vulnerability (i.e., elements at risk), and consequences (i.e., property damage) of flooding. However, these kinds of evaluation techniques are still uncommon in developing nations with serious flooding problems (like Bangladesh).

This study's goal is to assess the flood risk in Bangladesh's Khagrachhari district, which is home to the Chengi, Feni, and Maini rivers. In the study area, we do not introduce a novel approach to risk assessment for evaluating flood risk. Rather, we employ current statistical risk methods. The main objectives of this study are: (i) To create a composite hazard map, (ii) To create a composite vulnerability map, and (iii) To create a composite risk map.

### 1. Study Area

Khagrachhari is bordered with India on the north; Chittagong and Rangamati districts border it on the south; and Chittagong district and India border it on the west. It is located between longitudes 91°44' and 92°11' east and latitudes 22°38' and 23°44' north. The district covers 2,699.55 sq. km (1042.30 sq. miles) in total, of which 603.73 sq. km are covered by forests. The district is hilly. Folded sedimentary rocks make up this region's hills. The district of Khagrachhari spans 2699.55 square kilometres. The district consists of 8 Upazilas, 38 unions, 120 mauzas, 1706 villages (paras), 3 paurashavas, 27 wards and 155 mahallas. The Upazilas are Dighinala, Khagrachhari Sadar, Lakshmichari, Mahalchari, Manikchari, Matiranga, Panchari and Ramgarh. The annual average temperature of the district varies from maximum 34.6°C to minimum 13°C and the average annual rainfall of the district is 3031 mm. Chengi, Maini, Feni, and Lake Mataipukhuri (Debota pukur) are main rivers of this district.

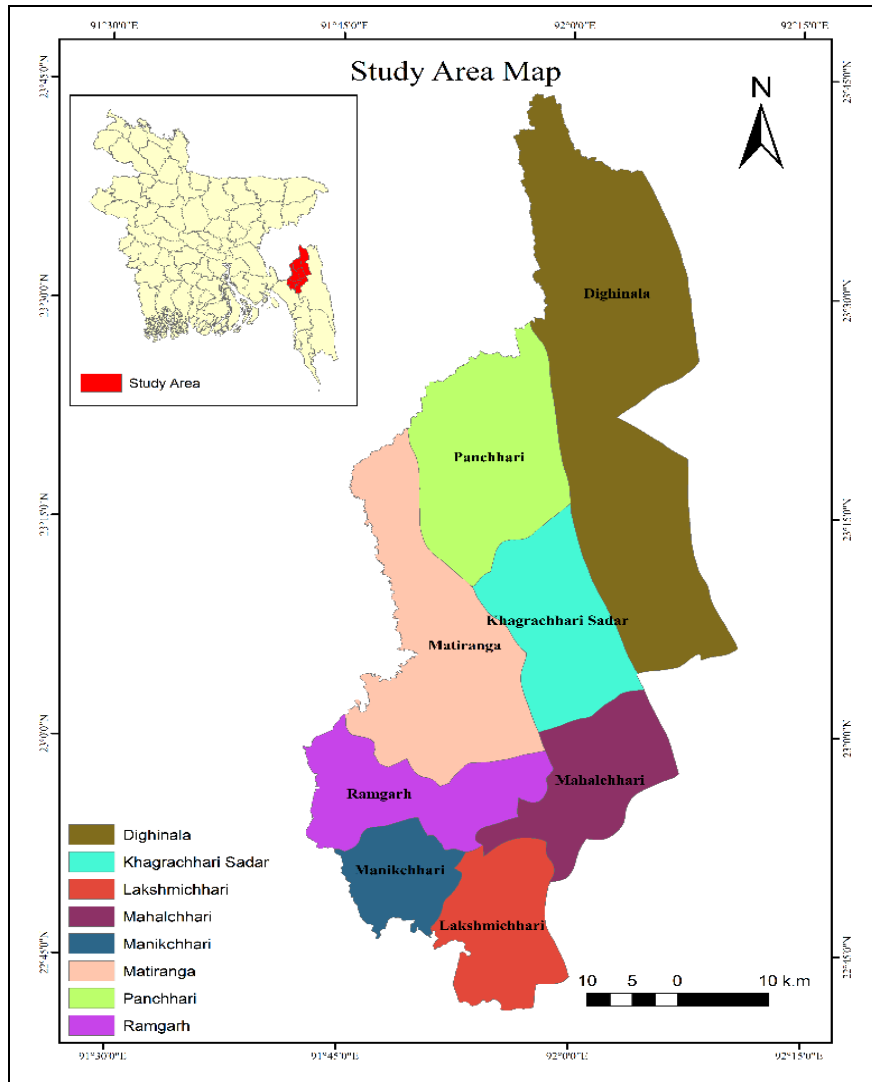


Fig 1: Map of Khagrachhari District, Bangladesh

**Material and Methods**

**1. Data Source**

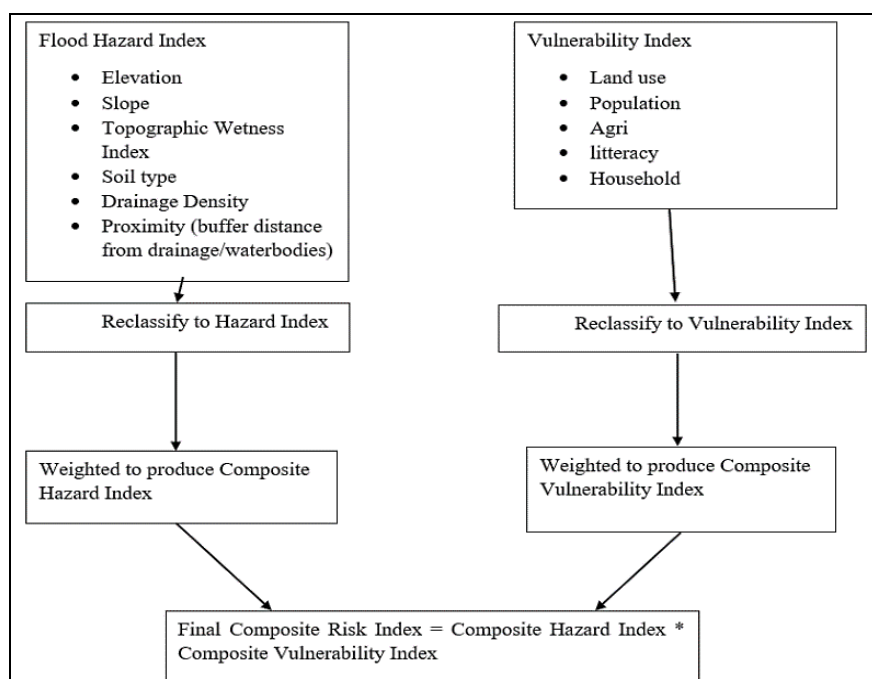


Fig 2: Concept frame of this study

Secondary data has been used for the analysis. The USGS provided the Landsat picture data and the ASTER GDEM 30-m resolution. The DEM was used to extract drainage density and slope related flood hazard factors, while Landsat 9 data that was 30 m spatial resolution was used to obtain land use and cover information. Rainfall data of 23-years (from 2000 to 2022) have been gathered from NASA Power Climate Data for return period and probability estimation. Soil data have also been gathered from FAO soil map, and census data have been obtained from Census Report 2011 by BBS (Bangladesh Bureau of Statistics) for population densities analysis.

**2. Methods of Data Analysis**

Arc-GIS 10.8 software was used to create LULC (Land use/Land cover) map, drainage density map, elevation map, proximity factor (Distance to stream), composite vulnerability index map and composite risk map. To generate lulc map supervised classification method is used with overall accuracy 87% and kappa coefficient 0.83. google earth image is used as ground truth to validate the LULC map. Other factors were classified following natural break method to determine the hazards, vulnerability, and risk index in ArcGIS. All factors are reclassified into five classes with varying degrees of flood risk (very high, high, moderate, low, and very low) (Díez-Herrero & Garrote, 2020) [6].

**Table 1:** Classified Index

Reclass Value	Index
1	Very low
2	Low
3	Moderate
4	High
5	Very high

Classification of population density, household numbers, agricultural land and literacy rate was done by using IDW method. The Weighted overly tool was used to prepare composite hazard index and composite vulnerability index map. A raster calculator was used to prepare a composite risk map for the defined area (Tien Bui, 2016) [26].

Composite Risk Index = Composite Hazard Index \* Composite Vulnerability Index (Ayenew & Kebede, 2023) [3]

Finally, the zonal statistic as table tool use to determine the risk index as upazilla wise. Here used the average reclassified value from zonal statistics to find out the risk index for each upazilla of Khagrachhari district (Pham, *et al.*, 2021) [23].

**Results and Discussions**

**1. Factors of Flood Hazard**

**1.1 Elevation**

In this study’s flood risk assessment, Elevation values are categorized into five distinct ranges. Areas with very low elevations (0 to 30 m) are closest to sea level or bodies of water. They are highly susceptible to flooding as even modest increases in water levels can lead to inundation. High-elevation areas (30 to 70 m) are less prone to flooding compared to lower elevations but can still be impacted by flooding during significant precipitation events. Moderate-elevation areas (70 to 160 m) may be susceptible to flooding under certain conditions, such as heavy and prolonged

rainfall. Areas with very high elevations (250 to 350m) are situated at the highest elevations and have the lowest flood risk. These locations are far less likely to experience flooding and are relatively safe from inundation under most circumstances.

**1.2 Slope**

Slope values are categorized into five distinct ranges. Areas with very high slope values (20.77-67.39) feature steep terrain. These areas are at a significantly reduced risk of flooding, as water is more likely to drain quickly and not accumulate. They are less prone to inundation during heavy rainfall or storm events. High slope areas are characterized by moderately steep terrain (13.73 to 20.76). While they have some natural drainage advantages, they may still experience localized flooding during intense precipitation or in low-lying portions. Low slope areas (4.51 to 8.63) have gentle terrain, which may lead to slower water drainage. Flooding in these regions is more likely, especially during prolonged heavy rainfall or snowmelt events. Very low slope areas (0-4.5) indicate nearly flat terrain, where water drainage is limited. These areas are at the highest risk of flooding, as water is likely to accumulate, and flood events can be widespread and persistent.

**1.3 Topographic Wetness Index (TWI)**

TWI values are categorized into five distinct ranges. Areas with very high TWI values (14.66 to 23.84) indicate locations with significant water accumulation potential. These regions tend to have low-lying terrain, flat areas, or saturated soils, making them highly susceptible to flooding. High TWI values (10.93 to 14.65) suggest areas with a considerable level of wetness, making them moderately prone to flooding. Moderate TWI values (8.2 to 10.92) represent flooding risk in these regions is moderate and typically depends on factors such as rainfall intensity, soil composition, and land cover. Low TWI values (6.21 to 8.19) indicate areas with limited wetness and are less prone to flooding. Very low TWI values (2.72 to 6.2) represent areas with minimal wetness, indicating a low risk of flooding. These areas are rarely affected by flooding and generally remain dry under most circumstances.

**1.4 Soil Type**

Soil Type is categorized into three distinct types. Areas with Ferric Acrisols are at a relatively low risk of flooding under normal conditions for their limited permeability and water-holding capacity. Areas with Dystric Cambisols typically have a moderate flood risk, as their ability to manage water is relatively neutral and contingent on factors such as precipitation intensity and land use practices. The "Water" category represents areas with high water content due to their proximity to water bodies, waterlogging, or other factors causing constant saturation. These areas are at the highest risk of flooding, as they lack the ability to absorb or retain additional water.

**1.5 Drainage Density**

Drainage density values are categorized into five distinct ranges. Areas with very high Drainage Density (58.73 to 73.41) values represent regions with an extensive and tightly knit network of streams and rivers. These areas are at a significantly heightened risk of flooding due to the efficient conveyance of water. High Drainage Density values indicate

a well-developed stream network and are moderately susceptible to flooding. Moderate Drainage Density values suggest a fairly developed river network but with less efficiency in water drainage. Low Drainage Density (14.71 to 29.36) values represent regions with a limited stream network. Flooding in such areas is less frequent, but when it occurs, it can be more severe due to the slower drainage capacity. Areas with very low Drainage Density (0 to 14.7) values have minimal river or stream presence and flooding in these areas is relatively rare.

### 1.6 Proximity

Areas with very high proximity to water bodies (0 to 5,500 m) are located within a short distance from rivers, lakes, or other bodies of water. These areas are at a significantly heightened risk of flooding, especially during periods of heavy rainfall or when water bodies overflow. High proximity areas (5,501 to 10,500 m) are reasonably close to water bodies, making them moderately susceptible to flooding. Low proximity areas are situated at a significant distance from water bodies, reducing their vulnerability to flooding. Areas with very low proximity (25,001 to 30,100 m) to water bodies are far removed from any significant bodies of water. These locations are at the lowest risk of flooding and typically remain dry under most circumstances.

From the processed map in figure-3, we find that, areas in the upazillas namely- Dighinala, Panchari, Khagrachari Sadar and Mohalchari got identified into the "Moderate to Very High Hazardous zones" in the Composite Hazard Index (22.76% to 16.69%). And surely the Hazard index factors are working behind this, like- the presence of rivers "Maini" and "Chengi" in those upazillas or their proximity. While upazillas of the south- Matiranga, Guimara, Ramgarh, Manikchari and Laxmichari falls into the "Low to Very Low" category of Composite Hazard Index (20.74% to 8.20%).

## 2. Factors of Flood Vulnerability

### 2.1 Land Use

With overall 87% accuracy, LULC vulnerability is categorized into five main categories, each representing different levels of susceptibility to flood risk.

- 1. Very High (Waterbodies):** 328.2 sq kilometer areas with waterbodies as the primary LULC category are at the highest risk. These areas are directly exposed to floodwater and are the most vulnerable to inundation.
- 2. High (Agricultural Land):** High vulnerability indicates that the primary land use of 780.7 sq kilometer area is for agriculture. These areas are susceptible to crop damage and economic losses during flooding.
- 3. Moderate (Settlement):** Moderate vulnerability suggests that the land is primarily used for settlements, with potential impacts on buildings and infrastructure during floods with an area of 255.7 sq kilometer.
- 4. Low (Vegetation):** 1079.1 sq kilometer areas with vegetation as the primary LULC category exhibit lower vulnerability. The presence of vegetation can mitigate flood impacts by absorbing water.

- 5. Very Low (Barren Land):** 410.4 sq kilometer barren land areas are the least vulnerable, with minimal risk of flood-related impacts due to their sparse land cover.

### 2.2 Population Density

A location with population density of only 120 to 170 people per square kilometer was designated as having "Very Low" population susceptibility to floods. The location with 171 to 220 people per square kilometer was designated as having "Low" population susceptibility to floods. The ranges of 221-270 people per square kilometer have been used to represent "moderate" population susceptibility to floods, which has a very large aerial area, but a low population density compared to the others. 'High' population susceptibility to flooding ranges from 271 to 320 people per square kilometer. 'Very high' population susceptibility to floods varies from 320-370 people per square kilometer.

### 2.3 Agricultural Land

It has been categorized into five value ranges, each reflecting different levels of susceptibility to flood risk. Areas with "Very Low" agricultural land susceptibility to floods only comprises 12095 acres to 18730 acres. Areas with land of 18730.5 acre to 25370 acre have been used to represent "low" agricultural land susceptibility to floods which indicates a reduced risk. 'Moderate' agricultural land susceptibility to flooding ranges from 25370.5 to 32010 acre indicating moderate level of risk. High vulnerability areas with substantial risk ranges from 32010.5 to 38650-acre agricultural land. "Very high" agricultural land susceptibility to floods varies from 38650.5 to 45290 acres. Areas falling into this range are extremely vulnerable. They are at a significantly increased risk of flood-induced damage, with potentially severe economic, social, and environmental consequences.

### 2.4 Literacy Rate

For vulnerability index determination, literacy rate vulnerability is categorized into five value ranges, each representing different levels of susceptibility to flood risk:

- 1. Very High (35.2-40.16):** Areas falling into this range exhibit the highest vulnerability. These areas have a lower literacy rate, which can hinder effective communication and response during floods.
- 2. High (40.17-45.1):** High vulnerability indicates a significant proportion of the population with limited literacy. These areas require substantial efforts to enhance education and flood awareness.
- 3. Moderate (45.11-50.1):** Moderate vulnerability suggests a mid-level of risk. While literacy rates are higher, there is still room for improvement in terms of flood preparedness.
- 4. Low (50.11-55.11):** Areas in the low vulnerability range a relatively higher literacy rate, enabling better flood risk understanding and response.
- 5. Very Low (55.11-60):** The very low vulnerability range signifies the lowest vulnerability. These areas boast a high literacy rate, contributing to enhanced flood resilience and effective community response.

**2.5 Household Number**

For vulnerability index determination, it is categorized into 5 distinct categories which are described below:

1. **Very High (23021-27250):** Areas in this range are at the highest risk level, with a substantial number of households exposed to potential flood impacts.
2. **High (18781-23020):** High vulnerability signifies a significant population at risk. While not as extreme as "very high," these areas require serious attention and planning to mitigate flood-related consequences.
3. **Moderate (14551-18780):** Moderate vulnerability suggests a mid-level of susceptibility.
4. **Low (10321-14550):** Areas in the low vulnerability range have a reduced risk, with fewer households at risk.
5. **Very Low (6085-10320):** This range indicates the lowest vulnerability. These areas have a relatively small number of households at risk, making them more resilient to flood events.

**2.6 Composite Vulnerability Index Map**

Khagrachari Sadar, Southern part of Dighinala and most of Matiranga falls into the category- "Very High" in the map of Composite Vulnerability index which is about 14.09% as shown in figure 4. Laxmichari and Panchari in the "Low to Very Low" category (19.88% to 7.02%) and the rests are in the category of "moderate to high" (30.01% to 29%). This implies most of Khagrachari to be in the danger zone.

**3. Risk Index Map**

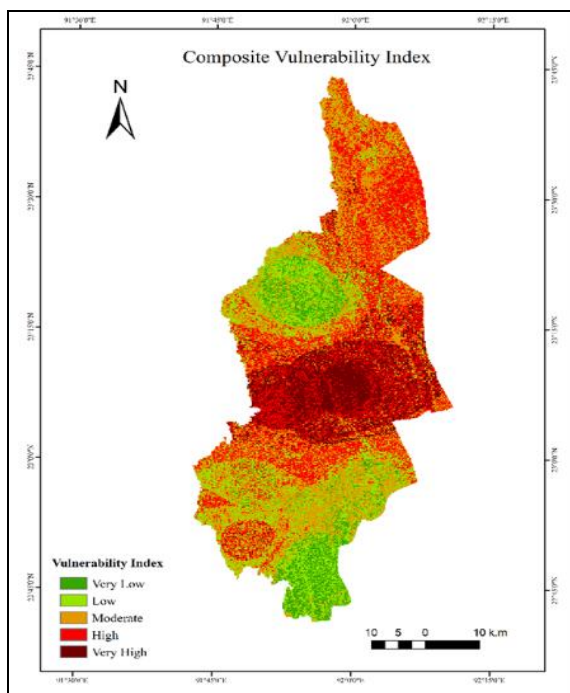
Finally, we can make some conclusions by analyzing the map shown in figures 5 and 6.

1. Khagrachari Sadar and Dighinala falls into the "Very High to High" zones, (19.82% - 12.86% area)
2. Panchari, Matiranga, Guimara and Mohalchari fall into the "Moderate" zones which is about 37.5% area.

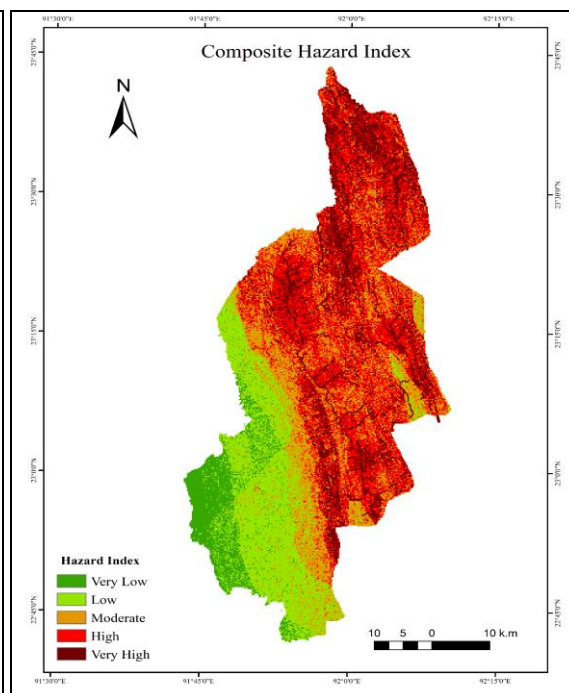
3. Ramgarh, Manikchari and Laxmichari in the "Low to Very Low" zones, in the Risk Index for Flood events. (11.38% to 18.45% area).

**Conclusion**

The study conducted a comprehensive assessment of flood risk in the Khagrachari District of Bangladesh. The analysis integrated various factors, including elevation, slope, topographic wetness index, soil type, drainage density, proximity to water bodies, rainfall patterns, land use, population density, literacy rates, and household numbers. These factors were categorized and weighted to create composite hazard and vulnerability indices. The results of the study revealed that Khagrachari Sadar and Dighinala are at a very high risk of flooding, with a significant portion of their areas falling into the "Very High to High" risk zones. On the other hand, areas such as Panchari, Matiranga, Guimara, and Mohalchari were categorized as having "Moderate" flood risk, covering a substantial portion of the district. Finally, Ramgarh, Manikchari, and Laxmichari were found to be in the "Low to Very Low" risk zones. This analysis provides valuable insights for flood risk management and land use planning in the Khagrachari District. It emphasizes the need for targeted measures to mitigate flood risks in the highly vulnerable areas, especially in Khagrachari Sadar and Dighinala. The study also highlights the importance of considering multiple factors in flood risk assessment, including socioeconomic and environmental aspects. Future land use and development activities in the district should take into account these risk maps to reduce vulnerability and enhance resilience to flooding. Moreover, ongoing monitoring and continuous updates of flood risk assessments are essential to adapt to changing environmental conditions and population dynamics. Overall, this study serves as a valuable resource for policymakers, local authorities, and disaster management agencies to make informed decisions in the context of flood risk reduction and disaster preparedness in the Khagrachari District of Bangladesh.



**Fig 3: Composite Hazard Index Map**



**Fig 4: Composite Vulnerability Index Map**

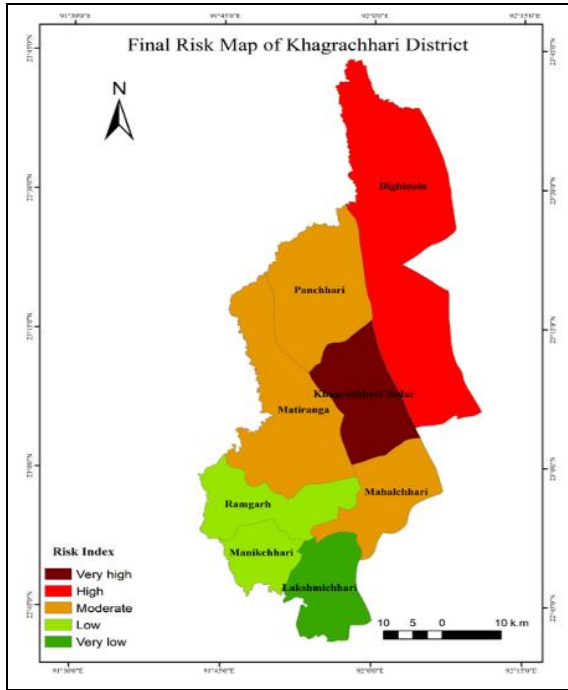


Fig 5: Composite Risk Index Map

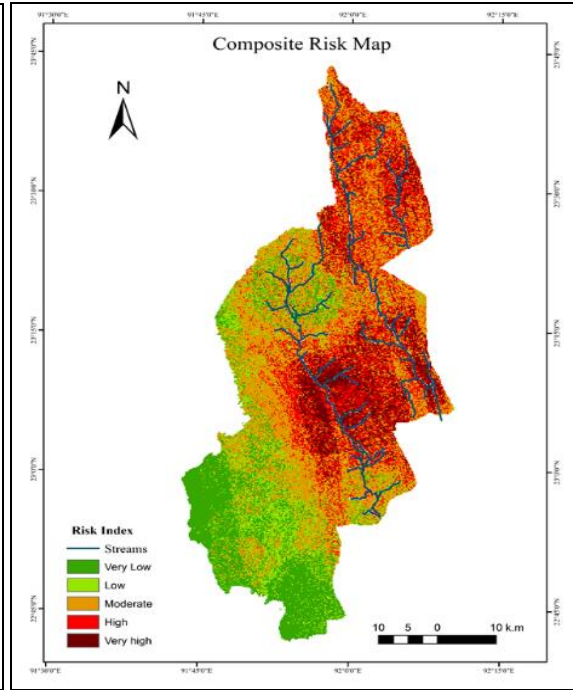


Fig 6: Final Risk Index Map

Table 3: Flood Hazard Factors, Ranges & Weightage in Flood Risk Assessment

Factor	Unit	Range	Susceptibility Class Ranges & Ratings	Weightage (%)	Total		
Elevation	meter	0-30	Very Low	15%	100%		
		30-70	Low				
		70-160	Moderate				
		160-250	High				
		250-503	Very High				
Slope	degree	0-4.5	Very Low	20%			
		4.51-8.63	Low				
		8.64-13.72	Moderate				
		13.73-20.76	High				
		20.77-67.39	Very High				
		TWI	level	2.72-6.2		Very Low	15%
				6.21-8.19		Low	
				8.2-10.92		Moderate	
10.93-14.65	High						
14.66-23.84	Very High						
Type		Ferric Acrisols	Low	10%			
		Dystric Cambisols	Moderate				
		Water	High				
Drainage Density	m/km <sup>2</sup>	0-14.70	Very Low	15%			
		14.71-29.36	Low				
		29.37-44.04	Moderate				
		44.05-58.72	High				
		58.73-73.71	Very High				
Proximity	meter	0-5,500	Very Low	25%			
		55,01-10,500	Low				
		10,5501-20,000	Moderate				
		20,001-25,000	High				
		25,001-30,100	Very High				

Table 4: Zonal statistic for each Upazila

Upazila	Majority Index	Mean Index	Risk Index
Dighinala	4	3.8	High
Khagrachhari Sadar	5	4.6	Very high
Lakshmichhari	1	1.4	Very low
Mahalchhari	3	3.0	Moderate
Manikchhari	2	1.7	Low
Matiranga	3	2.7	Moderate
Panchhari	3	2.8	Moderate
Ramgarh	1	1.7	Low

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