

FLOOD SUSCEPTIBILITY ASSESSMENT IN SOUTHWEST COASTAL REGION OF BANGLADESH USING AN AHP-GIS BASED APPROACH

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Abstract

Floods are one of the deadliest types of natural calamity that result in huge loss of lives and causes significant economic and property damages. Flood hazards are expected to persist in future, posing severe threats to humanity. As climate change continues, the severity and frequency of floods has become a major concern in many areas of the world. Bangladesh, being located in a low-lying topography, has been facing flood disasters over the years like many other nations around the world. Particularly, the southwest coastal region of the country is one of the most susceptible areas to floods. Flood management, control and prevention measures are crucial to minimize the likelihood of damage to agriculture, infrastructure and other natural resources. Flood mitigation efforts and early warning systems may depend heavily on the flood vulnerability assessment. Therefore, the objective of the current study is to identify the flood susceptible zones in the six administrative districts covering Khulna, Satkhira, Pirojpur, Bagerhat, Jhalokati, and Barguna in the southwest coastal region of Bangladesh. Flood-susceptible zones are determined using a multi-criteria decision technique that has adopted an integrated geographic information system (GIS) and analytical hierarchical process (AHP) based approach. Ten different flooding causative factors including elevation, topographic wetness index, land use/land cover, slope, soil type, distance from the main river, surface runoff, geology, soil drainage, and soil texture are used to identify flood susceptible zones. The flood susceptible areas with very low, low, moderate, high risk attributes, and river regions are found to be 318 km² (2%), 1553 km² (10%), 3556 km² (23%), 7190 km² (47%), and 2784 km² (18%), respectively. It is expected that the flood-prone zones identified by this study will be used to undertake immediate countermeasure for reducing flood-related losses.

Keywords

Flood Susceptibility; AHP-GIS; Coastal Region; NDVI; Multi-Criteria Decision Technique

1. Introduction

Floods are one of the most damaging natural catastrophes among all other natural disasters. It destroys infrastructure for communication and property and results in a major loss of human and cattle lives and destroys agricultural products, farmland and important properties [1]. Waterlogging and flooding are caused by sudden, broad, and continuous rainfall [2]. Future flood risks are anticipated to persist, and as climate change progresses, the severity and frequency of floods will become a problem in many regions of the world. Bangladesh, having low-lying land like many other countries of the world, has been facing flooding disasters over the years. One of Bangladesh's most seriously flood-prone regions is the southwest coastal region. Some major flood events in Bangladesh occurred in 1988, 1998, 2004, 2007, and 2014. During these occurrences, there has been a major loss of property and a fatality [3]. Floods are created by the rapid accumulation of flows from upstream and release of runoff waters to downstream as a result of extremely heavy rainfall. Discharges quickly reach a peak and then drop off just as swiftly. The breakdown of drainage management systems and major rivers are the causes of severe flood occurrences. Failure of drainage management systems and major rivers are the causes of these flood occurrences [4]. To minimize the likelihood of damage to infrastructure, agriculture, and other natural resources, flood control and prevention measures are required. Therefore, assessing flood susceptibility is crucial for future early warning systems and flood mitigation [5]. Water logging and flooding are caused by sudden, broad, and continuous rainfall. Numerous studies employ a variety of comprehensive approaches for mapping flood susceptibility, including the multi-criteria decision support approach (MCDA), analytical hierarchy process (AHP), weights of evidence (WoE), frequency ratio (FR) model, artificial neural networks (ANN) and so on [2]. The AHP method has received the most attention, has been used to develop a unique framework for making decisions regarding flood susceptibility mapping. In AHP, distinct flood vulnerability criteria are prioritized according to the impact of those parameters using various considerations. The chosen

methodological framework formulates each criterion's cumulative character, which is useful for generating flood data that are subject to the spatial scale, at local, regional, and national levels [6]. An effective way to give people the chance to analyze, acquire, store, combine, manipulate, retrieve, and display possible threat regions is through the use of geographic information systems (GIS) and remote sensing (RS) [7]. The objectives of the current study are to prepare maps of factors that are responsible to flood susceptible zone as well as to detect the flood susceptible areas in the southwest coastline of Bangladesh.

2. Description of the Study Area

Six administrative districts namely Khulna, Satkhira, Pirojpur, Bagerhat, Jhalokati, and Barguna located in the southwest coastline of Bangladesh are selected for the current study. The location of the study area is illustrated in Fig. 1. The total area of the study area is 15402 km². The geographical location of the area is between 88° 52' and 90° 23' east longitudes and between 21° 38' and 23° 1' north latitudes. The study area is bounded by West Bengal, India on the east side, and the Bay of Bengal on the south side. On the west side there are Barishal and Patuakhali districts and on the north side Jessore, Narail, and Gopalganj districts. The annual rainfall of the study area barriers between 1380mm to 2950mm with a mean of 2165mm. Most of the rainfall occurs from May to September. The average temperature of the region varies between 15.5°C to 36.2°C. Where the warmest month is April and the coldest month is January [8]. The study area has a large portion of Sundarban, a mangrove forest that is among the biggest in the world. This is a beautiful example of how people may live in harmony with both land and aquatic flora and fauna. This forest has remained largely unmodified due to the great commitment of the government under various preservation measures. Although the recorded net decline of mangrove forest is not particularly high, the changing pattern indicates that turnover due to erosion, aggradation, reforestation, and deforestation was significantly bigger than the net change. Both human and natural elements that cause the forest's degeneration pose a threat to it, especially illnesses like top-dying and overuse of its resources. [9]

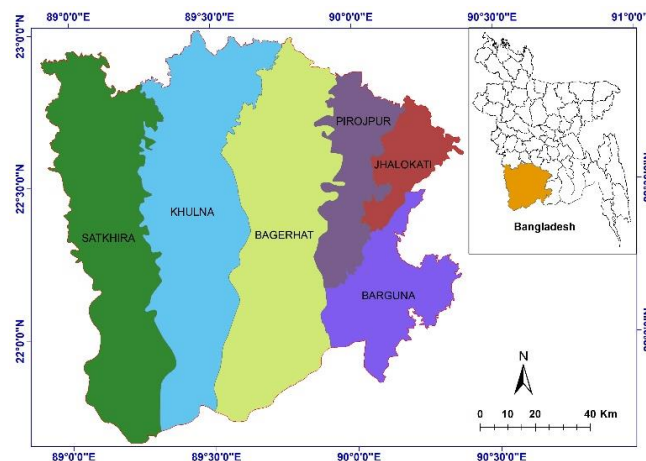


Fig. 1: Study Area Map

3. Methodology

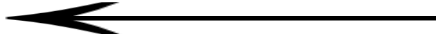

The development of numerous conceptual frameworks, which identify numerous indications and so implicitly demonstrate the complexity of vulnerability assessment, is a distinctive feature of the science of flood and water logging vulnerability assessment [10]. The current study is based on an integrated AHP and GIS-based approach. The RS data are adopted and processed in the ArcGIS platform for flood susceptibility mapping. The process of flood susceptibility mapping starts with the collection of maps for different flood-influencing factors. Ten flood influencing factors, namely rainfall, land use/land cover (LULC), topographic wetness index (TWI), elevation, slope, distance from the river, normalized difference vegetation index (NDVI), drainage density, distance from the road, and soil type are used in the current study. The source of the collected data is presented in Table 1. After the collection of data from different sources, thematic map of each factor is prepared by processing the collected maps in the GIS environment. ArcGIS software is used for processing and analysis of data and generation of thematic layers of the aforementioned impacting factors. The thematic map of different factors is then classified into different sub-classes depending on their effects on flood susceptibility. After the preparation of thematic maps for the factors, AHP technique is used to assign weightage to the sub-categories of the impacting factors. AHP is one of the most widely adopted multi-criteria decision analysis (MCDA) techniques. The technique is adopted by many researchers worldwide for ranking the priority-based factors [2, 6, 11–13].

Table 1: Sources of Flood Susceptibility Factors.

Factors	Source	Resolution
DEM	US Geological Survey (USGS) Shuttle Radar Topography Mission (SRTM) data	30m x 30m
Elevation, Slope, TWI, Drainage density	Generated from the DEM	30m x 30m
LULC	Landsat 8 satellite image, USGS online portal.	30m x 30m
NDVI	USGS	30m x 30m
Soil type, Distance from main river, Distance from road,	Bangladesh Agricultural Research Council (BARC)	
Rainfall	Bangladesh Meteorological Department (BMD)	

In AHP, the priority or weighting of the factors is determined using a pairwise comparison matrix. A linear scale of 1 to 9 based on Saaty [14] is used to assign score for building pair-wise comparison matrix. In the Saaty's linear scale, 1 denotes equal importance whereas 9 designate extremely more important, and 1/9 indicates extremely less important. The meaning of each score is tabulated in Table 2.

Table 2: Saaty's Linear Scale

Decrease in row importance over Column				Equal	Increase in row importance over Column			
				=				
1/9	1/7	1/5	1/3	1	3	5	7	9

The pairwise comparison matrix of different factors is tabulated in Table 3. Based on the importance determined by the pairwise comparison matrix (i.e., AHP analysis), each factor's priority is determined. According to the Saaty approach [14], a perfect pairwise comparison matrix should have a consistency less than 10%. In this experiment, the consistency is found to be 8.96%, which justifies the use of the pairwise comparison matrix. Next, the sub-categories of each factor are assigned with weight based on the ranking priority, which is presented in Table 4. Finally, the weighted overlay analysis of the factors is performed in ArcGIS platform based on the assigned weightage to achieve the flood susceptibility map.

Table 3: Pair-wise comparison matrix based on flood susceptibility.

	TWI	EL	Slope	RF	LULC	DD	NDVI	DRi	DRo	ST
TWI	1	1	1	1	3	3	3	1	3	5
EL	1	1	1	1	2	5	4	1	3	5
Slope	1	1	1	1	3	5	3	1/2	3	3
RF	1	1	1	1	3	3	2	2	4	5
LULC	1/3	1/2	1/3	1/3	1	3	1	1/3	3	1
DD	1/3	1/5	1/5	1/3	1/3	1	3	1/3	1	3
NDVI	1/3	1/4	1/3	1/2	1	1/3	1	1/5	5	5
DRi	1	1	2	1/2	3	3	5	1	3	3
DRo	1/3	1/3	1/3	1/4	1/3	1	1/5	1/3	1	1/3
ST	1/5	1/5	1/3	1/5	1	1/3	1/5	1/3	3	1

Note: EL = Elevation, TWI = Topographic Wetness Index, LULC = Land Use/Land Cover, RF = Rainfall, DD = Drainage Density, DRi = Distance from Major River, NDVI = Normalized Difference Vegetation Index, Dro = Distance from Road, and ST = Soil Type

4. Results and Discussion

4.1. Analysis of Influencing Factors

This study attempts to locate the flood susceptible zone in the southwest coastal region of Bangladesh. Among so many hydrological factors based on analysis ten major influencing factors are selected. They are land use/

land cover (LULC), topographic wetness index (TWI), slope, elevation, rainfall, drainage density, distance from the river, normalized difference vegetation index (NDVI), distance from the road, and soil type. The factors are then subdivided into different classes and assigned a weight based on AHP to obtain the reclassified flood susceptibility influencing factors. The area covered by each of the regions along with the weightage assigned to the subclass is presented in Table 4. The spatial analysis of the factors responsible for flood susceptibility is detailed in the following sub-sections.

Table 4: Assigned Weight to Different Layers.

Layer	Sub Class	Area (sq. km)	Rank	Individual weight	Weight	Layer	Sub Class	Area (sq. km)	Rank	Individual Weight	Weight
TWI	< 8.4	6101	1	3	14	Distance From Main River (m)	< 2015	7589	5	15	15
	8.4 - 11	3193	2	6			2015 - 6000	5272	4	12	
	12 - 13	3038	3	9			6000 - 9500	1395	3	9	
	14 - 16	2574	4	12			9500 - 17000	848	2	6	
	>16	495	5	14			> 17000	298	1	3	
Elevation (m)	< 2	3535	5	15	15	Distance From Road (m)	<12010	11821	5	4	4
	2 - 6	6235	4	12			12010 - 24021	1348	4	4	
	6 - 10	3882	3	9			24021 - 36031	1077	3	3	
	10 - 14	1473	2	6			36031 - 48042	837	2	2	
	> 14	277	1	3			> 48042	319	1	1	
Slope (% Rise)	< 1.4	4594	5	14	14	Soil Type	Alluvium	307	4	4	4
	1.4 - 3.8	6653	4	12			Floodplain Soils	8063	3	2	
	3.8 - 6.6	3147	3	9			Acid Sulphate Soils	339	3	2	
	6.6 - 11.5	868	2	6			Peat (Organic)	510	2	1	
	> 11.5	140	1	3			Sundarbans	4316	5	4	
Rainfall (mm)	< 1510	118	1	4	16		Waterbodies	1785	5	4	7
	1510 - 1740	2466	2	7				Urban	81	1	
	1740 - 1975	2941	3	10		< 0		2363	5	7	
	1975 - 2215	4466	4	13		0 - 0.15		2411	4	5	
	> 2215	5411	5	16		0.15 - 0.30		7035	3	3	
LULC	Water	36150	5	6	6	NDVI	> 0.30	3593	2	2	5
	Trees	56610	2	3			< 0.67	2669	5	5	
	Vegetation	1498	1	2			0.67 - 1.34	7110	4	4	
	Crops	46565	4	5			1.34 - 2.01	4569	3	3	
	Built Area	9125	1	2			2.01 - 2.68	969	2	2	
	Bare Ground	70	2	3			> 2.68	84	1	1	
	Rangeland	384	2	3							

Note: Here, the interpretation of Rank is 1 = Very Low, 2 = Low, 3 = Moderate, 4 = High and 5 = Very High

TWI: TWI is a wetness index, which is employed to evaluate the topographic management of hydrological processes. The index is a feature of each slope and the region upstream that contributes in a direction orthogonal to the waft direction [15]. From the AHP result, it secured the fourth position among the factors. The index is derived using DEM via several steps. The maps are divided into five subclasses. Fig. 2(a) shows the TWI categorized map for the research area.

Elevation: The elevation is also a strong factor regarding flood susceptibility mapping. It denotes the contour of a location. The higher value means the upper place where the chances of logging are low and the lower value indicates the lower region where the chances of water logging are higher. Therefore, it has an inverse relation with flood susceptibility. From the AHP result, it achieved the second position among the factors. The index is derived using DEM. Fig. 2(b) presents the classified elevation map for the research area.

Slope: The slope is also considered as a strong factor regarding flood susceptibility mapping. It denotes elevation in a detailed level. The higher value means the upper place where the chances of logging are low and the lower value indicates the lower region where the chances of water logging are higher. Therefore, it has an inverse relation with flood susceptibility [16]. From the AHP result, it achieved the fifth position among the factors. The index is derived using DEM. Fig. 2(c) shows the classified map of slope for the research area.

Rainfall: One of the most important factors that cause flood is Rainfall. It is an indication of the availability of water. Rainfall has a proportional relationship with flood susceptibility. From the AHP result, it achieved the first position among the factors. The collected rainfall records from BMD were used to derive the rainfall zone using IDW in the GIS domain. The maps are divided into five subclasses. Fig. 2(d) displays the classified map of rainfall for the research area.

LULC: The Landsat-8 satellite image, which is obtained from the USGS Earth Explorer at 30m resolution, is the source of the LULC map. The satellite image is used to derive a map of the land use and land cover using the supervised classification method. The derived map identifies various land uses that have varying degrees of potential for groundwater recharge. From the AHP result, it achieved the seventh position among the factors. Fig. 2(e) shows the classified map of LULC for the research area.

Drainage Density: Another influencing factor responsible for flood susceptibility is the drainage density. It shows where the storm drainage channels are concerning one another. Higher drainage density denotes that the speed and water get the advantage in early removal from a region. Lower density means there is a lack of flow path for water to be drained out. Therefore, it has an inverse relation with flood susceptibility. From the AHP result, it achieved the fifth position among the factors. The index is derived using DEM. The classified map of Fig. 2(f) presents the classified map of the Drainage Density for the research area.

NDVI: A well-known and often used index is NDVI. It is a significant vegetation index that is frequently used in studies on climatic and environmental change on a worldwide scale. The vegetation's sensitivity to the environment has been found to be a powerful defense against natural disasters, as it not only influences the ecological balance and climate [17]. From the AHP result, it achieved the sixth position among the factors. The index is derived using the near and far infrared band of the Landsat 8 satellite image. Fig. 2(g) displays the NDVI map for the research area.

Distance to Major River: Another mighty factor used in floor susceptibility analysis is the distance from the river map. It indicates the path for water to be drained out from a region. A higher distance indicates a higher time to discharge. Hence, there is a peak of water and hence flood occurs. On the contrary, the lower distance indicates less time for water to be drained out i.e., a lower probability to flood. Therefore, it has an inverse relation with flood susceptibility. From the AHP result, it achieved the second position among the factors. The index is derived using the river map. Fig. 2(h) presents the classified distance to the river map of the study area.

Distance to Road: A tiny factor for flood susceptibility is Distance from the road map. This factor denotes the availability of a road network where many of the road work as a dam or water barrier for a region. There it has an inverse relation with flood susceptibility. From the AHP result, it achieved the tenth position among the factors. The index is derived using the road map. Fig. 2(i) provides the classified distance to the road map for the research area.

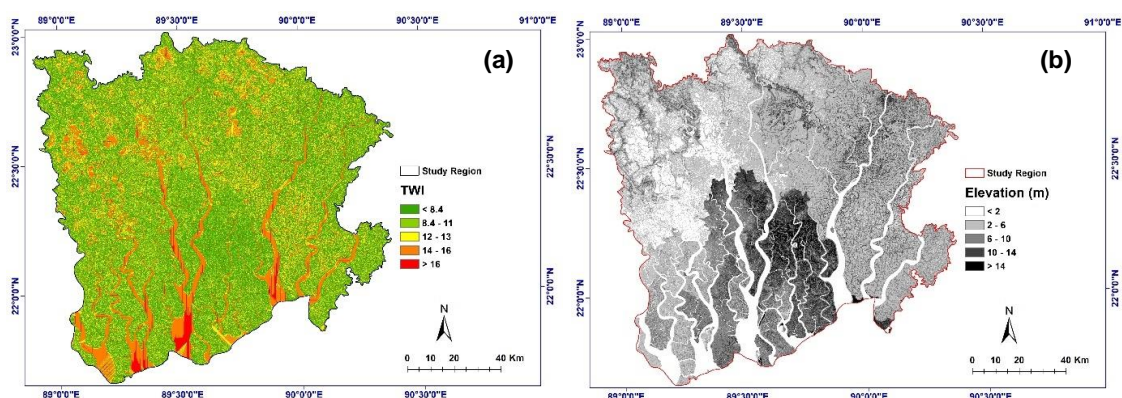


Fig. 2: Thematic maps of the study area (a) Topographic wetness index (TWI), (b) Elevation

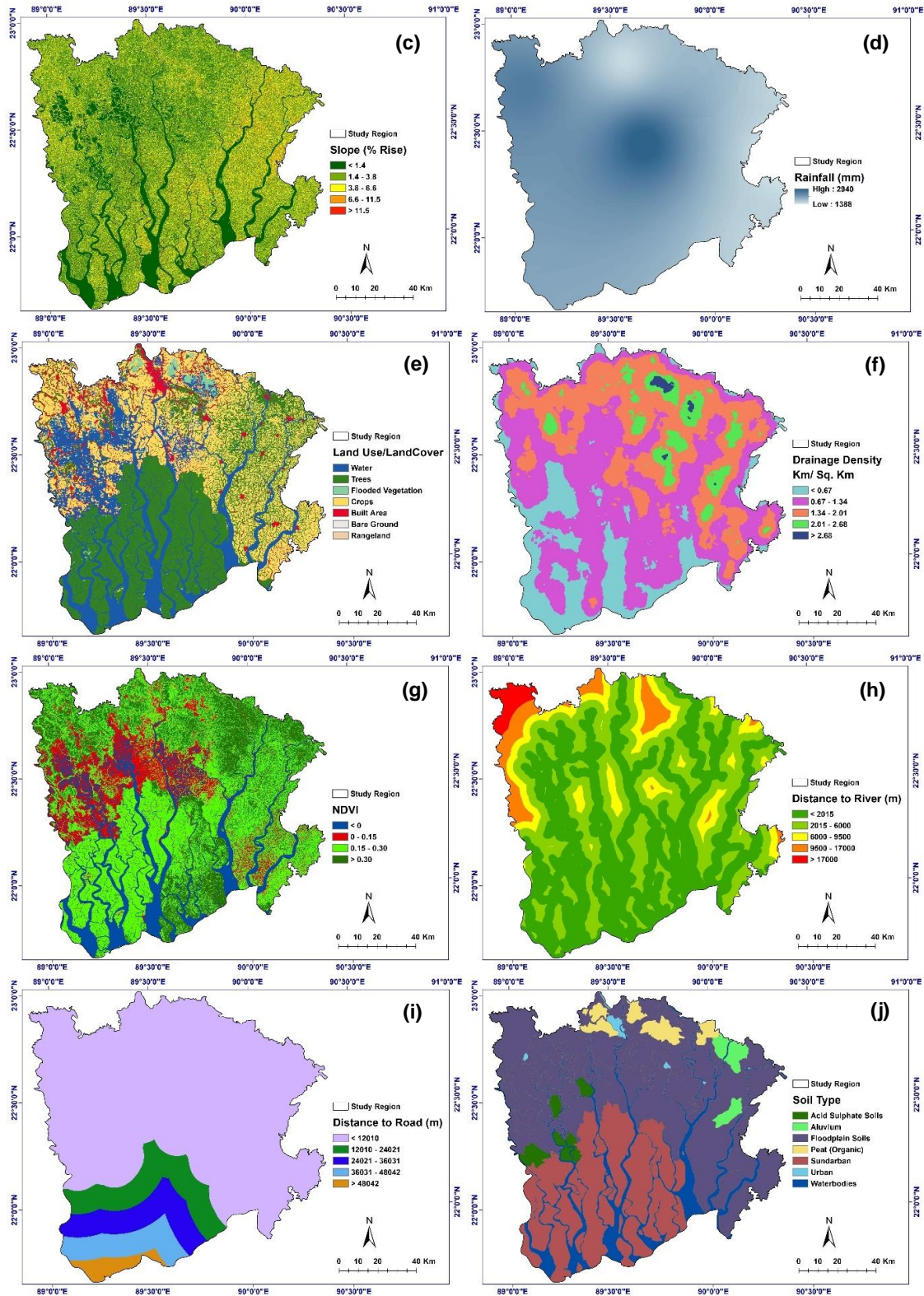


Fig. 2 (continued): Thematic maps of the study area (c) Slope, (d) Rainfall, (e) LULC, (f) Drainage density, (g) NDVI, (h) Distance to major river, (i) Distance to road, and (j) Soil type

Soil Type: Another less influencing factor for flood susceptibility is soil type. It is commonly acknowledged that different soil types affect groundwater recharge in different ways. For instance, less clay soil results in a higher rate of recharge [18]. From the AHP result, this factor gets the ninth position among the factors. Fig. 2(j) shows the classified soil type for the research area.

4.2. Assessment of Flood Susceptibility

The aforementioned influencing factor using the weightage obtained by AHP analysis was overlaid using the weighted overlay analysis using the ArcGIS platform for the derivation of flood susceptibility map. The map is then divided into four regions, which are categorized as very low, low, moderate, and high risk areas. Another portion that is subtracted from the map is the river region. The map of flood susceptibility is presented in Fig. 3. The area extended by each region is 318 km², 1553 km², 3556 km², 7190 km², and 2784 km² for very low, low, moderate, high risk, and river regions, respectively. The percentage of the total area covered by this region is 2%, 10%, 23%, 47%, and 18% and their corresponding classifications are very low, low, moderate, high risk, and river regions, respectively.

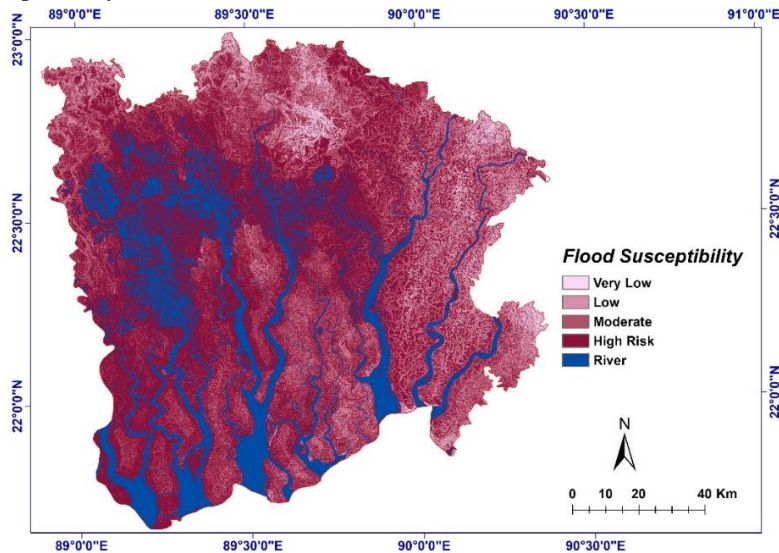


Fig. 3: Flood susceptibility map of the study area

Furthermore, it is seen from the current study that Khulna district has a higher risk of flood compared to other regions. The lower-risk region covers the upper part of the Bagerhat district along with, the Pirojpur, Jhalokati district. The influence of TWI is shown clearly in the final output that higher TWI in the upper part has a lower risk. Furthermore, the most dominating factor in the study is the elevation. The final output has a clear similarity with the different elevation regions where the relationship is proportional. The lower risk region is shown in the moderate slope area. The middle of the Bagerhat district has shown a higher risk where the main culprit is rainfall is higher in this region. The LULC does not have enough significance in the final output as there a majority part is covered with the Sundarbans. Though the AHP result gives drainage density a lower ranking compared to other factors, the higher drainage density region exhibits a lower risk of floods. In addition to this, NDVI of less than 0.15 is responsible for higher risk of flood. Though distance to the river factor is an important factor, it does not demonstrate enough influence on the flood susceptibility. It also found that the flood plain soil is responsible for causing comparatively higher flood susceptibility. Lower risk is seen near the areas having peat soil but the overall influence of soil type is lower in the flood susceptible map of the study area.

5. Conclusions

The current study focuses on the quantitative assessment of flood susceptibility in the southwest coastline of Bangladesh. The most widely used multi-criteria decision analysis techniques namely, AHP integrated with GIS are adopted in the current study using the remote sensing data and information to determine the flood susceptible zones. Several influencing factors for floods are selected namely elevation, topographic wetness index, rainfall, slope, drainage density, land use/land cover, distance from the river, NDVI, distance from the road, and soil type. Based on the results of the current study, the following conclusions can be drawn:

- The area extended by the region is 318 Km², 1553 Km², 3556 Km², 7190 Km², and 2784 Km² for very low, low, moderate, high risk, and river regions, respectively. The percentage of the total area covered by this region is 2%, 10%, 23%, 47%, and 18% for the very low, low, moderate, high risk, and river regions, respectively.
- It is found from the current study that Khulna district has a higher risk of flood compared to other regions. The lower-risk region covers the upper part of the Bagerhat district along with, the Pirojpur, Jhalokati district.

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