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RESEARCH ARTICLE

FLOOD-HAZARD MAPPING IN A REGIONAL SCALE – WAY FORWARD TO THE FUTURE HAZARD ATLAS IN BANGLADESH

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ABSTRACT

Flood causes substantial economic loss and hindrance to development activities in many developing countries of the world. Bangladesh, a developing country in South-east Asia is ranked as the world's ninth-most disaster-prone country by the World Risk Report, 2018 because of its high exposure to multiple hazards and less coping and adaptive capacities. The country is recurrently hit by flood hazard almost every year. Being a densely populated country with the fragile economic condition, Bangladesh urgently needs to focus on future flood-risk reduction with more effective measures in order to sustain the development milestone achieved till now. Flood hazard mapping, an initial phase of risk understanding (i.e., perception and knowledge), is often considered to be an indispensable component of flood-risk reduction strategies. In line with the contention, the present study aimed towards flood hazard mapping in Bangladesh where flood prone northeastern part of the country is taken as a case area. Multi-criteria evaluation technique (MCE) for hazard mapping has been employed where elevation, slope, distance from river, land use and landcover (LULC), precipitation, flow length, and population density were taken as the causative factors. Each factor, as well as their subclasses, were assigned with pertinent weight values based on expert knowledge by analytical hierarchy process (AHP)and subsequently integrated into geographic information system (GIS) platform. According to the final flood-susceptibility map, ~4241 km^2 (~ 20% of the total area) area is categorized as the highest flood potential zone which encompasses mostly the southern part of the study area, including Gazipur, Narsingdi, and Brahmanbaria districts. In contrast, low flood potential zone covers ~9362 Km^2 (~43% of the total area) area covering the northwestern and southwestern parts (e.g., Mymensing and Tangail districts) of the study region. Besides, a considerable portion of the study region, mostly in the western part (e.g., Sunamganj and Kishoreganj districts) is categorized as moderate flood potential zone encompassing ~7823 km^2 (~ 35% of the study area) area. Population density, distance to river and topographic characteristics are found as the most influencing factors for the mapping of flood-risk zones in the current study. This type of assessment in a regional scale may serve as a guide to the relevant stakeholders to formulate flood hazard atlas and minimize the adverse impact of the future flood in Bangladesh.

KEYWORDS

Flood, Northeastern Bangladesh, AHP, GIS, and Hazard Map atlas

1. INTRODUCTION

Flooding, one of the most common hydro-meteorological phenomena, inflicts harmful impacts on society from the dawn of civilization [1]. Flood may occur in various way. The most prevalent ones are an overflow of rivers/streams, excessive rain, breach in flood-protection structures and rapid melting of ice in the mountains. Except for flash flooding, which is restricted to foothills, most floods take hours to days to develop. In the past, highly destructive flooding events have taken place once in a century, however, global climate change, those high-magnitude hundred-year floods have been occurring worldwide with alarming regularity over the last few decades [2].

Globally, flood is regarded as one of the most destructive hazards due to its negative impact on human life, surrounding environments and economy [3]. For instance, the Yellow River valley in China experienced some of the world's worst floods during the last century; millions of people have perished in or been impoverished by floods [4]. Economic loss due to flood is common in many developed countries in the world, even in the United States, despite advanced flood mitigation and prediction, floods cause ~ US$6 billion worth of damage every year. A study by the Organization for Economic Cooperation and Development found that coastal flooding results in some US$3 trillion worth damage worldwide [5]. In contrast to the experience of developed nation in flood, the impact scenarios (e.g., flood causalities and damage) are more alarming in the developing nations due to their inadequate risk reduction measures against flood disaster [6].

Bangladesh, a developing nation in the southeast Asian region, situated in the confluence of mighty Ganges-Brahmaputra-Meghna river system, experiences flooding every year during the monsoon season from June to September. Excessive rainfall and upstream water discharge during rainy

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season eventually causes overflow of the river systems in Bengal basin and severely affects the cropland, settlements and transportation system of Bangladesh [7]. Physiographically, landmass of Bangladesh exhibits flood plains that renders the nation at risk of periodic flooding. Three mighty rivers, the Brahmaputra, Ganges and Meghna and their tributaries and distributaries contribute to the genesis of flood plain in their respective catchment areas and floods of varying magnitude occur on a regular basis due to low elevated flood plains within these catchments [8-11]. In the last 100 years, floods resulted over 50,000 people deaths, left nearly 32 million homeless and affected more than 300 million people in Bangladesh [12]. Each year ~ 26,000 km^2 (around 20% of the country) is flooded and during the severe floods, the affected area may exceed 68% of the country [13]. For example, the 1998 flood alone killed more than 3,500 people and destroyed crops and infrastructure worth more than US$2 billion [14].

Floods cannot be controlled entirely but increasing attention to flood regulation by the identification of risky areas can be an effective approach to minimize losses [15]. Permanent protection from flooding by building reinforced-concrete defenses, raised houses and roads above flood level have been the traditional practice for quite a while [16]. Although this has proven effective, flood protection by structural means alone may not be sufficient or economically feasible. Along with flood-prevention structures, non-structural flood control is also very useful in managing floods and minimizing flood damage [17]. For example, flood hazard mapping for the identification of risky zones is extremely useful in the development of automated methods for quantifying the spatial variation in flood susceptibility and has been widely used in supporting surface-water modelling and flood-hazard exposure [18-24].

Flood hazard map in the form of a flood atlas is popular in various part of the world [25]. Hazard Atlas generally provide information on the current situation of a particular hazard for a country in terms of vulnerability and risk. Though new, it is worth mentioning that Bangladesh attempted an atlas on the seismic hazards. The prime focus of the atlas was to disseminate earthquake history of the country, vulnerability and risk with respect to papulation, infrastructure, building stock, and emergency facilities in six major cities, as well as potential damage and loss assessment [26]. Compare to earthquake, flooding is more recurring phenomena in Bangladesh, however, no such attempt was observed in the existing disaster management policy in Bangladesh to develop a flood hazard atlas. High frequency of floods in Bangladesh over the last years urge an indispensable need to provide accurate and extensive information to the people at threat to minimize future damages. Hence, a flood zonation map can be a useful tool for identification of risky areas and will provide valuable information to local community through hazard atlas [27].

Currently, spatial technique, exclusively in GIS platform has grasp the attention among hazard mapping personals [28]. In a GIS environment, quantitative approaches, including the idea of ranking and weighting methods, are frequently employed MCE –purpose of the decision-making tool, eventually compare and rank alternatives and to evaluate their consequences according to given criteria. For example, the analytic hierarchy process (AHP) has widely been employed in many decision-making process in disaster managed domain particularly hazard and vulnerability mapping where GIS integrate the data and execute final result [29-32]. The use of GIS and MCE has been successful in the analysis of natural hazards [33,34]. For instances, some researchers used an integrated approach of MCE with GIS for urban flood mapping [35]. Other researchers determined the risk zone for flooding in Terengganu, Malaysia [36]. In other hand, the researchers used a multicriteria approach for flood-risk mapping of the Mulde River, Germany [37]. Additionally researchers developed a GIS-based spatial multicriteria method for flood-risk assessment in the Dongting Lake Region, Hunan, central China [38].

In recent times, remote sensing and GIS tools have been used for the creation of national-level flood-hazard maps of Bangladesh [39,40]. Hydrologic information has been integrated with population density and other socio-economic data to identify priority zones for instigating flood-prevention measures [41]. Several studies on flood hazard zonation using MCE in Bangladesh and adjacent areas have also been undertaken from different perspectives [42,43]. Other researchers evaluated flood hazard for land-use planning in greater Dhaka, Bangladesh using remote-sensing and GIS techniques [44]. Akiko determined flood-vulnerable areas in Bangladesh using a spatial MCE [45]. Rahman and Saha selected the Bogra district of Bangladesh for determining flood zonation in a GIS environment using AHP [42]. Despite a number of GIS based research on flood hazard in Bangladesh, majority are conducted in local scale with diverse motivation and scope, however, none of these researches acknowledge and/or comprehend the urgency of a regional flood hazard mapping for a comprehensive flood disaster management in Bangladesh.

Thus, this study, though deployed a common MCE technique in GIS environment, is particularly intended to focus on a regional scale flood hazard mapping (up to upazila level) in northeastern part of Bangladesh. The prime objective of this study, evading the complex modeling techniques, is to use the widely accepted causative attributes of flood hazard mapping and to acknowledge the implication of flood hazard atlas creation in Bangladesh. This particular approach of hazard mapping, if publicize through an atlas, will ease the decision-making process in future risk reduciton in the northeasterm part of bangladesh.

2. STUDY AREA

The northeastern part of Bangladesh was selected for the study; it covers eight districts, Brahmanbaria, Gazipur, Narsingdi, Netrokona, Kishoreganj, Mymensingh, Tangail and Sunamganj (Figure 1). The approximate surface area of the study region is ~12,298 km^2 and the total population ~12 million, with the average household size 5.3 [46]. Nearly half the population is involved in rice production and fishing. Due to the frequency of natural disasters and adverse weather due to climate change, they are therefore highly vulnerable to flooding. Less industrial activities present in the area however, infrastructural development is increasing now a day, with changing patterns of land use across the area [47].

The region has characterized by a diverse geomorphological setting, with elevated topography of Plio-Miocene hills along the border [48]. At the center, there is a vast low-lying flood basin, locally called known as Haor Basin. The basin covers an area of ~ 4505 km^2 and goes underwater for several months each year due to episodic flooding.

The northeastern part of Bangladesh falls under monsoon climatic zone, with an annual average maximum temperature of 23°C (Aug–Oct) and an average minimum temperature of 7°C (Jan) [49]. Flash flooding is common in this region, which occurs frequently from month May to the middle of October. The network of rivers, streams and channels overflows and fills the haors in the early part of the rainy season. Floodwaters in the study area, mainly in the Sunamganj and Netrakona districts, recently created huge shortages in the local economy. Large-scale floods frequently occur and cause huge economic loss in this region, as is evident from the historical flood records of 1988, 1992 and 1998 [50].

Figure 1: The study area, covering the northeastern part of Bangladesh.

3. MATERIALS AND METHODS

3.1 Data

After reviewing existing literatures on flood hazard mapping, the spatial data used in this study were obtained from open-source spatial databases (Table 1**)**. A simplified methodological flowchart (Figure 2) shows the spatial operations in a GIS environment. The topographic attributes such as slope and flow accumulation were created using SRTM DEM (earthexplorer.usgs.gov/). For a detailed land-use/land-cover (LULC) map, a recent multispectral satellite image (Landsat 8), dated January 2018, was obtained from the same source as the DEM data. Yearly average rainfall data from the available rainfall stations in the study area were sourced from the Bangladesh Meteorological Department (BMD). Upazila population data were extracted from the latest population census [46].

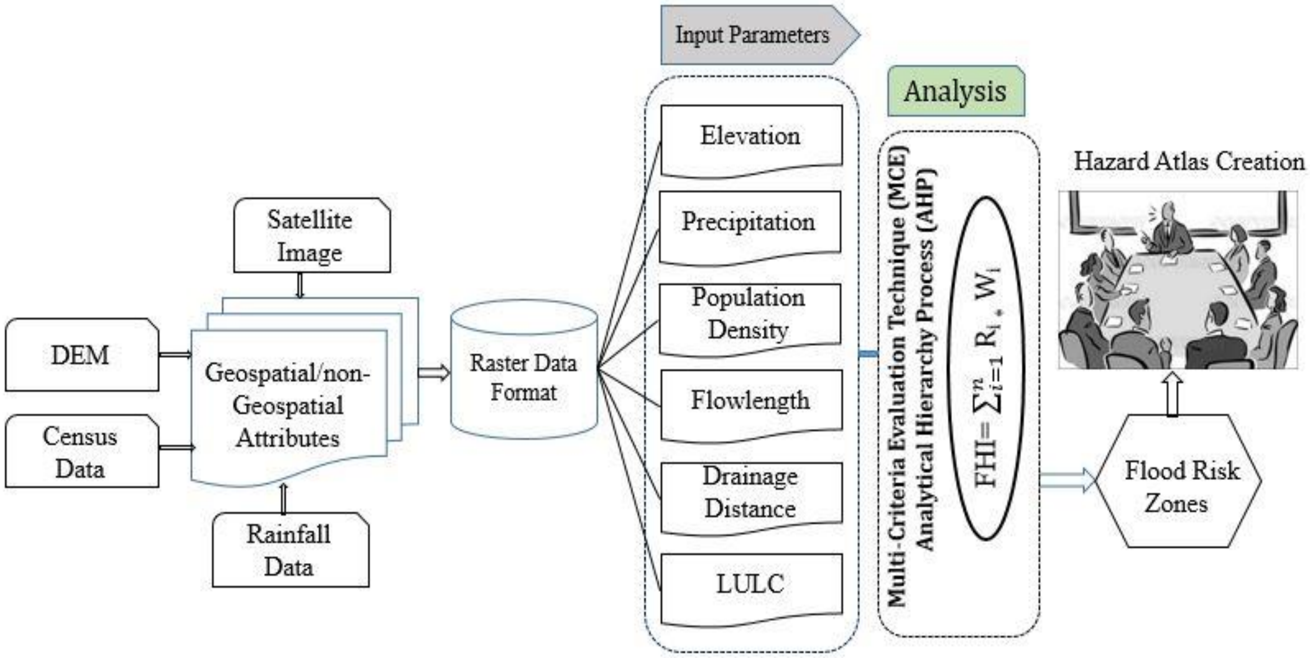

Figure 2: Methodological framework for the flood-hazard zonation.

Table 1: Spatial data used in the study

Parameter	Spatial Technique	Data Source	Justification
Elevation	Layer tinting of elevation raster	Shuttle Radar Topography Mission (SRTM) 30m digital elevation model (DEM) from Earth Explorer earthexplorer.usgs.gov/	[51, 52]
Flowlength	Spatial hydrologic analysis and flow-direction function. Spatial hydrologic analysis and flowlength		
Drainage distance	Spatial hydrologic analysis and Euclidean distance function		[43, 53]
Land-use/land-cover (LULC)	Unsupervised-classification techniques in ERDAS Imagine (version 14)	Landsat 8 OLI & TIRS (18 November 2014) Earth Explorer earthexplorer.usgs.gov/	[54, 55]
Rainfall (precipitation)	Spatial statistics and Inverse Distance Weighted (IDW) method	Bangladesh Meteorological Department (BMD)	[56]
Population density	Conversion of upazila polygon (containing population density field) to raster using conversion tool	Census Report [46]	[42, 54]

3.2 Data Preparation

The creation of spatial data involves multiple steps and needs expertise in geospatial data handling. In the present analysis, Digital Elevation Model (DEM) was the key to produce elevation, flow length and drainage distance raster. An elevation map was created from DEM using the natural break classification techniques in ArcGIS version 10.3. Hydrology tools in the same software were used for flow accumulation. Prior to extraction of all these DEM-derived data, a median filter function was run over the entire DEM to minimize/remove artifacts. For LULC mapping, supervised classification technique was employed in this study. Reasonable accuracy was achieved by using 100 random ground control points (GCP) from Google Earth. The accuracy assessment was satisfied, with ~75% of the GCP matched exactly on the classified map. Two image-enhancement techniques (histogram equalization and contrast stretching) were applied prior to the final image classification. The final LULC map has six distinct classes: Water; Vegetation; Agriculture; Barren Land; Swamp; and Settlement. For the rainfall-distribution mapping, the inverse-distance-weighted (IDW) interpolation technique was used. Rainfall was divided into five classes by means of natural break classification techniques. A new field in the vector file rainfall point map was created using spatial interpolation in the GIS environment from the location coordinates of the rainfall stations. Each thematic layer was put into one of five classes on the basis of its effect on flooding. For the population-density mapping, an

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administrative vector file was created from the LGED hardcopy upazila maps. The feature class containing the input field of population density converted to a raster dataset using conversion tool in GIS.

3.3 Analytical Model

MCE was used to determine the vulnerable areas in the present study. AHP technique was used for the determination of weights of the individual parameters (Table 2) [30]. The AHP empowers decision makers to find out a solution that best outfits their wide-ranges of goals [57]. This mathematical decision-making method lessens the complexity of the decision problem into a series of pairwise comparisons among competing attributes [58]. This is very helpful for decision makers when they find it hard to determine relative importance of weights for complex multi-attribute problems [59,60]. Here, the Pairwise Comparison Method was used in first defining the weights for the criteria. This method allows assessment of two criteria at a time.

Table 2: Scale of relative importance [29,30].

Intensity of Importance	Definition	Intensity of Importance	Definition
1	Equal importance	6	Strong plus
2	Weak importance	7	Demonstrated importance
3	Moderate importance	8	Very strong
4	Moderate plus	9	Extreme importance
5	Strong importance		

AHP uses several equations to ascertain the weight of individual criteria. principal eigenvalue (PEV) is calculated by the following equation:

$$\text{PEV}= 11/n \textstyle\sum_{i=1}^{n} Xi/Ci$$

Here, n= number of criteria; Xi= consistency vector and Ci= consistency of the weight values

Then, the consistency index (CI) can be calculated from the PEV value by the equation;

$$CI = (PEV - n)/(n - 1)$$

Finally, to ensure the consistency of the pairwise comparison matrix, the consistency decision must be cross-checked for the suitable value of n by CR [61].

$$CR = CI/RI$$

where RI is the random consistency index. A composite map of flooding risk was prepared using the raster calculator from the equation (weights in Table 3 and Table 4):

Flood Hazard Index (FHI) = W_P × Precipitation raster + W_{LULC} × LULC raster + W_D× Drainage distance raster + W_F × Flow length raster + W_E × Elevation raster + W_{PD} × Population density raster. Here, W= AHP weight for individual parameter (values were inputted from Table 4).

4. RESULTS AND DISCUSSION

In this study, different parameters were considered for their individual impacts on flood risk. The relative importance of individual layers and their sub-classes used in this study are discussed in the following sections.

4.1 Elevation

There is considerable variation in elevation over the study area. In general, the eastern part has lower elevation than the western part. On the basis of flood hazard due to elevation, the study area was divided into five categories. The lowest areas (eastern part of the study area) have the highest susceptibility to flooding and are in Category 1. The five categories are (with total areas): 1 very high susceptibility (299 km^2); 2 high susceptibility (1610 km^2); 3 moderate susceptibility (5250 km^2); 4 low susceptibility (8147 km^2); and 5 very low susceptibility (6138 km^2).

4.2 Rainfall (precipitation)

Rainfall is one of the most important factors influencing flood severity [62]. Areas with low annual precipitation, less than 1800 mm, are in Category 5 and cover approximately 43% of the study area (9090 km^2), while the northwestern part of the study area (1818 km^2), with very high annual precipitation (3200–3700 mm), is in Category 1.

4.3 Population density

Population density has a significant impact on flooding. Population density ranges from 0-437 per km^2 (Category 5) to 2550–5276 per km^2 (Category 1). Population density is highest in the south and southeastern part of the study area (the Gazipur Sadar Upazila of the Gazipur district) whereas the northeastern part (the Khaliajuri Upazila of Netrokona) has the lowest population density. Places with high population density are more prone to flooding.

4.4 Flowlength

Flowlength is the upstream or downstream distance, or weighted distance, along the flow path for each cell of the raster. Regions with long flowlengths had lower flood depths, and so were less susceptible to flooding. In contrast, areas with shorter flowlengths had higher flood depths, and were more often flooded. The shortest flow lengths (<4419 m) were recorded in the northeastern part of the study area, corresponding to a high risk of flooding. The remaining area (~97% of the study region, 20,904 km^2) had longer flowlengths (>50,675 m), and hence are less likely to flood.

4.5 Drainage distance

In a flood-susceptibility study, the distance of an area from major rivers is very significant. In general, areas near a river are more often flooded than areas far away from a river. Places adjacent to a river are inundated once the flow in the river overtops its banks. Drainage distances ranged from 0 m to 11,008 m. The minimum average distance (<1036 m) was recorded in the eastern part of the study area, indicating a greater likelihood of flooding; this area lies between major rivers and the sea. The maximum average drainage distance was recorded in the western part of the study area, indicating this region is less prone to flooding.

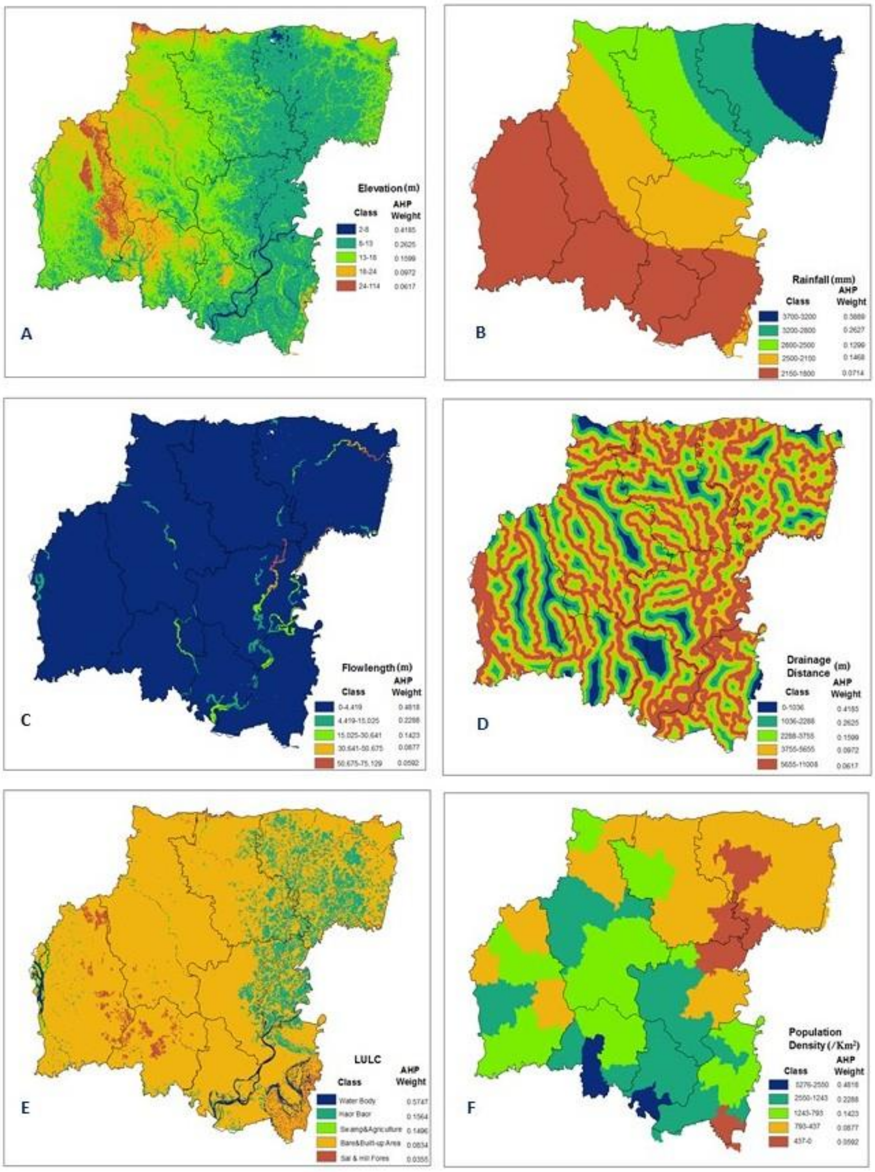

Figure 3: Reclassified maps: (**A**) Elevation (m); (**B**) Precipitation (mm); (**C**) Flowlength (m); (**D**) Drainage distance (m); (**E**) Land-use/Land-cover (LULC); (**F**) Population density (/km^2)

4.6 Land use and land cover (LULC)

Land-use types were assigned to five different categories depending on the flood susceptibility (see Table 3). The risk of flooding is highest near water bodies (rivers, lakes and haors); hence these areas were categorized as very high or high susceptibility. Built-up areas and forests were categorized as low or very low susceptibility. High-risk zones comprise about 450 km^2 in the eastern part of the study area (Figure 3).

The flood hazard index (FHI) map assigns different levels of flood hazard to the different upazilas in the study area after values for the relative importance of each of the factors discussed above (Table 4) are assigned. The pairwise comparison matrix of the flood-hazard parameters was calculated using AHP after reclassification of all parameters to compute the weights. All the parameters used in this research are thus combined to produce the flood-hazard map, with the FHI ranging from 0.05 to 0.31. We have shown five hazard classes on the final hazard map: very low (0.05 – 0.10); low (0.10 – 0.13); moderate (0.13 – 0.17); high (0.17 – 0.22); and very high (0.22 – 0.31).

About 20% of the total study area (~4241 km^2), mostly in the north-eastern and south-eastern parts, is in the high hazard category (Table 6), with some small scattered patches also evident in the east-central part (Fig. 4). These high flood-hazard zones cover parts of the Gazipur sadar, Narsingdi sadar, Tahirpur upazila of Sunamgonj and Tarail upazila of Kishoreganj district (Table 5). The Gazipur Sadar and Narsingdi sadar upazila are high hazard zones due to their high population density. The Tahirpur and Tarail Upazila are the most flood-prone areas.

An area of 7823 km^2, approximately 36% of the total study area, has a moderate flood-hazard, so that the high and moderate flood hazard zones together cover about 56% of the total area. The moderate flood-hazard zones are in a little away from the rivers located in the eastern part of the study area and include depressed areas (haors) such as those in the Sunamganj Kishoreganj and Netrakona districts. All the upazila in the Kishoreganj district, except Bajitpur and Katiadi (are in high hazard zone), are in the moderate hazard zone. The Kaliganj upazila of Gazipur (~81 km^2), Nabinagar, Kasnba and Akhaura upazila of Brahmanbaria (~360 km^2), Tahirpur and Dowarabazar Upazila of the Sunamganj district (~1500 km^2) and Delduar, Basail upazila of Tangail district (~189 km^2) are recognized to be in the moderate flood hazard zone (Figure 4).

The low flood hazard zones are about 43% of the study area covering~9362 Km^2. The northwestern and southwestern parts of the study area come under these categories. These areas are away from the rivers, their elevation is higher than other areas, and so they are the least vulnerable to flood. All the upazila of the Mymensing and Tangail districts, except Trishal and Mymensing sadar in Mymensing and Nagarpur, Delduar and Basail in Tangail, are in one of these categories.

Table 3: AHP values for individual parameters. The numbers in the left-hand column are category numbers. Category 1 corresponds to 'very high susceptibility', Category 5 to 'very low susceptibility'. The relevant range of the parameter (type for LULC) for each category is given at the end of each section in the table. Priority: numbers associated with the nodes of an AHP hierarchy; PEV: principal eigenvalue; CR: consistency ratio.

Elevation (m)	**Pairwise Comparison Matrix**						**Weight**	**PEV**	**CR**	**Area**	
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**Priority** (%)				km²	%
[1]	1	2	2	3	4	41.9	0.4185	5.068	0.015	299	1.4
[2]	1/2	1	1	2	3	26.3	0.2625			1610	7.5
[3]	1/3	1/2	1/2	1	2	16.0	0.1599			5250	24.5
[4]	1/4	1/3	1/3	1/2	1	9.7	0.0972			8147	38.0
[5]	1/5	1/4	1/4	1/3	1/2	6.2	0.0617			6138	28.6
Category: [1] 3–8m; **[2]** 8–12m; **[3]** 12–17m; **[4]** 17–24m; **[5]** 24–114m											
Population density (/km²)	**Pairwise Comparison Matrix**						**Weight**	**PEV**	**CR**	**Area**	
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**Priority** (%)				km²	%
[1]	1	1/2	1/3	1/4	1/5	5.9	0.0592	5.132	0.029	1591	7.4
[2]	2	1	1/2	1/3	1/4	8.8	0.0877			7681	35.8
[3]	3	2	1	1/2	1/3	14.2	0.1423			6113	28.5
[4]	4	3	2	1	1/2	22.9	0.2288			5507	25.7
[5]	5	5	4	3	1	48.2	0.4818			552	2.6
Category: [5] 0–437/km²; **[4]** 437–793/km²; **[3]** 793–1243/km²; **[2]** 1243–2550/km²; **[1]** 2550–5276/km²											
Flowlength (m)	**Pairwise Comparison Matrix**						**Weight**	**PEV**	**CR**	**Area**	
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**Priority** (%)				km²	(%)
[1]	1	3	4	5	6	49.2	0.0590	5.089	0.020	45	0.2
[2]	1/3	1	2	3	4	22.7	0.0777			44	0.2
[3]	1/4	1/2	1	2	3	14.2	0.1523			156	0.8
[4]	1/5	1/3	1/2	1	1	7.6	0.2188			295	1.4
[5]	1/6	1/4	1/3	1/2	1	6.4	0.4828			20904	97.5
Category: [1] 0–4419m; **[2]** 4419–15025m; **[3]** 15025–30641m; **[4]** 30641–50675m; **[5]** 50675–75129m											
Rainfall (mm)	**Pairwise Comparison Matrix**						**Weight**	**PEV**	**CR**	**Area**	
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**Priority** (%)				km²	(%)
[1]	1	1/2	1/3	1/3	1/4	7.1	0.0714	5.222	0.049	9090	42.4
[2]	2	1	2	1/3	1/3	14.7	0.1468			3544	16.5
[3]	3	1/2	1	1/2	1/3	13	0.1299			4531	21.1
[4]	3	3	2	1	1/2	26.3	0.2627			2461	11.5
[5]	4	3	3	2	1	38.9	0.3889			1818	8.5
Category: [5] 1800–2150; **[4]** 2150–2500; **[3]** 2500–2800; **[2]** 2800–3200; **[1]** 3200–3700											
Drainage distance (m)	**Pairwise Comparison Matrix**						**Weight**	**PEV**	**CR**	**Area**	
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**Priority** (%)				km²	(%)
[1]	1	2	3	4	5	41.9	0.4185	5.068	0.015	965	4.5
[2]	1/2	1	2	3	4	26.3	0.2625			2570	12.0
[3]	1/3	1/2	1	2	3	16	0.1599			4380	20.4
[4]	1/4	1/3	1/2	1	1	9.7	0.0972			6171	28.8
[5]	1/5	1/4	1/3	1/2	1	6.2	0.0617			7358	34.3
Category: [1] 0–1036m; **[2]** 1036–2288m; [3] 2288–3755m; **[4]** 3755–5655m; **[5]** 5655–11008m											
LULC	**Pairwise Comparison Matrix**						**Weight**	**PEV**	**CR**	**Area**	
	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**Priority** (%)				km²	%
[1]	1	2	3	4	5	57.5	0.5747	10.62	0.041	488	3.0
[2]	1/2	1	2	3	4	15.6	0.1564			2266	10.0
[3]	1/3	1/2	1	2	3	15	0.1496			18095	83.7
[4]	1/4	1/3	1/2	1	1	8.3	0.0834			124	0.7
[5]	1/5	1/4	1/3	1/2	1	3.5	0.0355			471	2.7
Category: [1] Water body; **[2]** Haor; **[3]** Swamp forest or agriculture; **[4]** Bare land or built-up area; **[5]** Forest.											

Table 4: AHP parameter values used in this study. Priority: numbers associated with the nodes of an AHP hierarchy; PEV: principal eigenvalue; CR: consistency ratio. Number of comparisons: pairwise comparisons with the other parameters and with itself.

Parameter*	**Pairwise Comparison Matrix**								**Weight**	**PEV**	**CR**	**Number of comparisons**
	[1]	**[2]**	**[3]**	**[4]**	**[5**	**[6]**	**Priority** (%)	**Rank**				
[1]	1	1/3	1/2	2	3	4	17.2	3	0.1715	6.156	0.025	15
[2]	3	1	2	3	4	5	36.1	1	0.3607			
[3]	2	1/2	1	2	3	4	22.8	2	0.2276			
[4]	1/2	1/3	1/2	1	2	3	11.9	4	0.1185			
[5]	1/3	1/4	1/3	1/2	1	2	7.3	5	0.0734			
[6]	1/4	1/5	1/4	1/3	1/2	1	4.8	6	0.0481			
* [1] Population density; [2] Elevation; [3] LULC; [4] Rainfall; [5] Drainage distance; [6] Flowlength.												

Table 5: Area Statistics of Flood Hazard Zonation in the study area

Hazard Class	Area (Km²)	Area (%)
Low	9362.16	43.68
Moderate	7823.08	36.51
High	4241.29	19.98

The flood hazard index map (Figure 4) shows the flood-risk zones classified into three categories. The statistics of the flood hazard index map from AHP are given in Table 4.

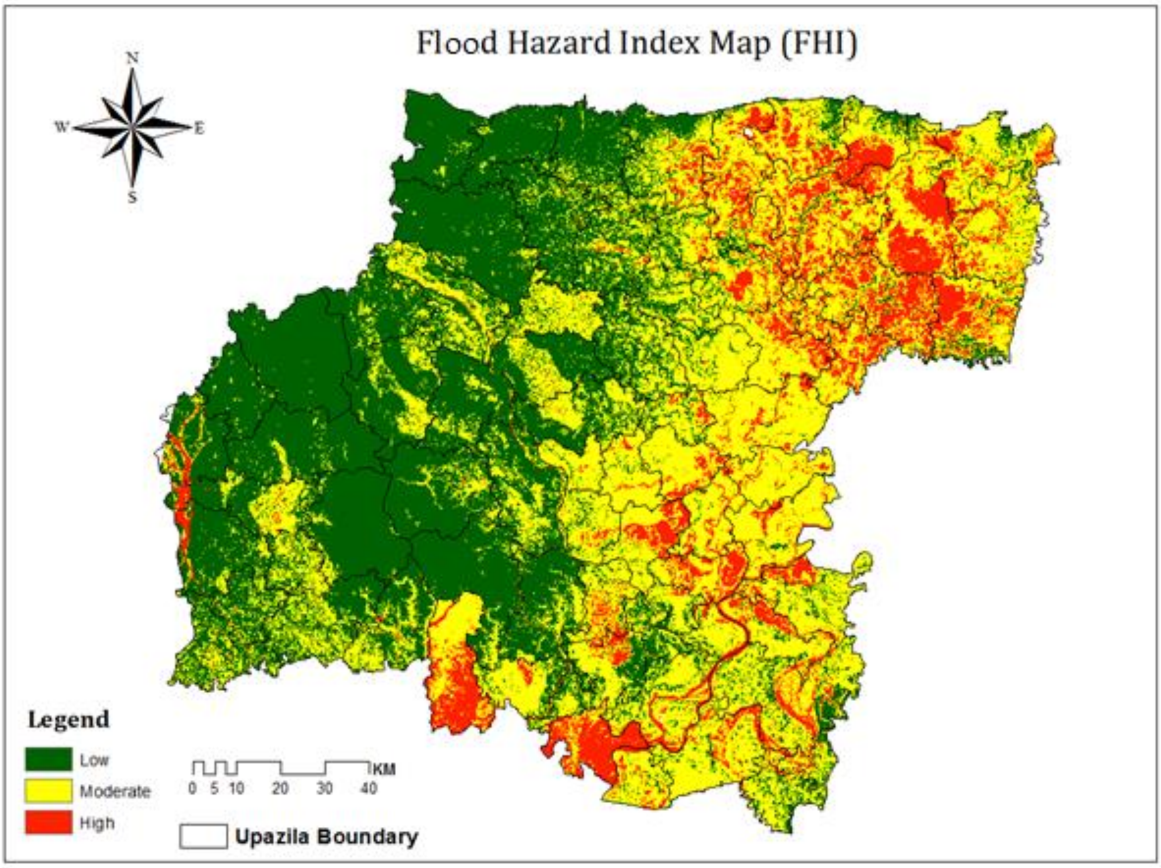

Figure 4: Flood Hazard Index (FHI) map showing flood-risk zones in the study area.

Table 6: Flood hazard zones by upazila.

		Low		**Moderate**		**High**	
District	**Upazila**	**Area (km²)**	**(%)**	**Area (km²)**	**(%)**	**Area (km²)**	**(%)**
Tangail	Basail	50	31.4	109	68.5	0	0
	Bhuapur	160	64.5	50	20.1	38	15.3
	Delduar	80	44.6	80	44.6	19	10.6
	Ghatail	440	97.1	10	2.2	3	0.6
	Gopalpur	189	84.7	30	13.4	4	1.7
	Kalihati	240	79.4	40	13.2	22	7.2
	Madhupur	512	99.0	5	0.9	0	0
	Mirzapur	160	43.7	206	56.2	0	0
	Nagarpur	95	37.5	150	59.2	8	3.1
	Sakhipur	432	97.7	10	2.2	0	0
	Tangail S.	270	85.7	30	9.5	15	4.7
Gazipur	Gazipur S.	5	1.4	160	46.3	175	50.7
	Kaliakair	150	48.7	150	48.7	8	2.5
	Kaliganj	60	29.8	81	40.2	60	29.8
	Kapasia	210	58.4	147	40.9	2	0.5
	Sreepur	300	64.3	165	35.4	1	0.2
Narshingdi	Belabo	55	47.8	55	47.8	5	4.3
	Manohardi	45	23.3	100	51.8	47	24.3
	Narsingdi S.	1	0.4	22	10.3	190	89.2
	Palash	45	48.9	46	50.0	1	1.0

	Raipur	45	13.8	260	80.0	20	6.1
	Shibpur	80	35.3	80	35.3	66	29.2
Brahmanbaria	Akhaura	20	22.9	50	57.4	17	19.5
	Bancharampur	25	12.2	150	73.5	29	14.2
	Brahmanbaria S.	130	23.9	280	51.5	133	24.4
	Kasba	110	50.2	100	45.6	9	4.1
	Nabinagar	36	10.4	210	60.6	100	28.9
	Nasirnagar	29	9.3	195	63.1	85	27.5
	Sarail	30	14.4	95	45.8	80	38.6
Kishoreganj	Astagram	30	10.0	178	59.7	90	30.2
	Bajitpur	10	5.4	50	27.1	124	67.3
	Bhairab	10	8.5	70	59.8	37	31.6
	Hossainpur	45	38.4	47	40.1	25	21.3
	Itna	20	5.2	260	68.4	100	26.3
	Karimganj	58	29.2	72	36.3	68	34.3
	Katiadi	45	20.4	45	20.4	130	59.0
	Kishoreganj S.	40	22.4	95	53.3	43	24.1
	Kuliarchar	40	40.0	40	40.0	20	20.0
	Mithamain	5	2.3	140	65.1	70	32.5
	Nikli	5	2.5	115	58.9	75	38.4
	Pakundia	75	43.5	79	45.4	30	17.2
	Tarail	28	20.0	85	60.7	27	19.2
Mymensing	Bhaluka	305	70.2	99	22.8	30	6.9
	Dhobaura	240	87.5	34	12.4	0	0
	Gaffargaon	190	47.7	198	49.7	10	2.5
	Gauripur	185	82.9	28	12.5	10	4.4
	Haluaghat	280	93.0	21	6.9	0	0
	Phulpur	270	88.5	30	9.8	5	1.6
	Muktagachha	197	63.1	105	33.6	10	3.2
	Mymensingh S.	240	63.1	100	26.3	40	10.5
	Nandail	150	46.2	150	46.2	24	7.4
	Ishwarganj	105	53.8	80	41.0	10	5.1
	Phulbari	284	70.4	103	25.5	16	3.9
	Trishal	200	5.9	105	31.1	27	8.0
Sunamganj	Chhatak	26	6.3	185	45.0	200	48.6
	Derai	20	4.8	80	19.4	312	75.7
	Dharampasha	40	8.8	260	57.7	150	33.3
	Dowarabazar	30	8.5	219	62.7	100	28.6
	Jagannathpur	72	19.3	160	43.0	140	37.6
	Jamalganj	46	10.3	100	22.4	300	67.2
	Sullah	20	7.6	120	46.1	125	48.0
	Sunamganj S.	30	5.9	70	13.9	401	80.0
	Tahirpur	18	5.8	150	48.7	140	45.4
	Bishwamvarpur	14	7.1	85	43.5	96	49.2
Netrakona	Madan	30	12.6	187	78.9	20	8.4
	Mohanganj	103	40.7	100	39.5	50	19.7
	Kendua	165	19.7	150	44.7	20	5.9
	Khaliajuri	45	15.6	117	40.7	125	43.5
	Kalmakanda	107	27.8	193	50.2	84	21.8
	Durgapur	197	68.4	91	31.5	0	0
	Barhatta	175	79.9	25	11.4	19	8.6
	Atpara	100	51.2	90	46.1	5	2.5
	Purbadhala	210	60.0	90	25.7	50	14.2
	Netrokona S.	150	47.7	150	47.7	14	4.4

5. IMPLICATIONS AND LIMITATIONS OF THE STUDY

Natural disasters are posing a threat to economic development continuously in recent times [63]. Clear concepts on the geographic patterns, causes, and effects of local hazards are crucial for serving peoples in future responding to the risk [64-66]. Regrettably, it is often hard to find comprehensive sources of data about local hazards. Several countries in the world, as for example India have come up a long way in plummeting the disaster risk. Understanding disaster risk and its potential impact on human lives and livelihoods including social, economic, and environmental assets made it easier to reduce the losses [27]. Timely, accurate, and comprehensible information on disaster risk and losses ought to be integral to both public and private investment planning decisions. “World Atlas of Natural Disasters Risk” is now a blessing to enhance understanding of hazard, vulnerability, risk, and exposure. Atlas contains the spatial distribution of disaster risk in many parts of the world. Online hazards atlas is a essential tool for awareness buildup, education and important decision-making process [67,68].

Assessment of flood hazard maps and web mapping services as information tools in flood risk management is a significant approach for the preparation online and print hazard atlas. In the present study, a comprehensive flood hazard index map has been prepared up to a upazila level where hazard potential could be assessed for local hazard mitigation and prevention. The information and results outlined in this research will serve enormous wealthy of information for the creation of regional online and print flood hazard atlas in Bangladesh [69]. We believe outcomes of the present study along with the other existing flood hazard maps in Bangladesh will contribute significantly in flood atlas preparation in a regional scale.

Apart from the advantage and implication of this study, we want to mention some of the limitations related regarding mapping to the theme. Distinct LULC classes could be identified and feed into the flood hazard modeling. Since the area is relatively flat, high resolution DEM may provide exact topographic characteristics of the study region. Mouza wise village data, if utilized could have been a realistic depiction of exiting population. To overcome these limiation, future work could be implemented through the usage of high-resolution satellite imagery as well as DEM. In addition, ground truth data may be added for LULC accuracy assessment. Flood vulnerability assessment on human properties (settlements and other infrastructure) may lifted the advantage to the future planning in this region.

6. CONCLUSIONS

MCE technique proved to be an effective tool for the creation of hazard index in the study area. The flood risk potential in different parts of the study area and their underlying causes might be discernable from the resulted map. MCE aided flood susceptibility analysis has revealed that ~ 55% (~ 12,064 Km^2) of the study area falls under moderate to high risk zone. Northeastern part of the study found as more susceptible to flooding whilst western part has low risk potential. Population density seems to be the most significant contributor to flooding hazard, as indicated by the high flood susceptibility in places with high population density. Several other parameters viz., LULC, elevation, and precipitation, also have significant impacts on final hazard map. This study should provide a more interactive, meaningful and detailed flood-risk assessment for the relevant decision makers and flood managers at all levels to understand the factors triggering flood inundation. We expect that this study will be able to serve as a prototype to develop a nation-wide flood hazards atlas. This work was done solely in a GIS environment, with very little input from field data. Supplementary information on and an analysis of the field conditions, hydrological status and characteristics of flood-prevention structures are necessary to substantiate the findings yielded from this study, as well as for a comprehensive flood-risk assessment. In order to determine the extent and severity of flood impact in any specific part of the study area in a more quantitative manner, a comprehensive study needs to gather all relevant information from all available sources.

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