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Assessing Flood Vulnerability at Chilmari Upazilla in Bangladesh through GIS and AHP Approaches

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Abstract

Flooding is a major threat in Bangladesh's northwestern region of Kurigram, destroying crops, homes, and infrastructures. So, flood risk assessment is of great importance here as a prerequisite of flood management programs. Chilmari, one of the nine upazilas of Kurigram district, is situated in the Brahmaputra river basin and very often affected by flood because of onrush of water from upstream and incessant rainfall. This study's primary goal is to create and evaluate a methodology for identifying and preparing for floods by delineating flood hazard zones in Chilmari upazilla. After examining relevant literature, six indicators and indexes were utilized to analyze flood susceptibility in the study region, including slope, rainfall, land use land cover, normalized difference vegetation index, topographic wetness index and elevation. Satellite data were used in GIS and then to AHP to obtain the results. A final flood hazard map has been created as an outcome of this research, which shows major water bodies, very high, high, moderate, low and very low flood risk areas cover 7.06%, 18.09%, 24.50%, 22.41%, 18.27% and 9.66% of the study area respectively. Thus, the research could aid in the creation of a preparedness system that would reduce wealth and property loss in Bangladesh's most vulnerable Chilmari region.

Keywords: *Flood risk; Vulnerability; Satellite Data; AHP; GIS*

1 Introduction

Unusual climatic variations have been reported all across the world in recent decades. Natural risks caused by climate change could affect any location on Earth (Sami et al., 2013; Zinat et al., 2020). In the changing environment of climate, preparedness to avoid loss from hydro-meteorological disasters, notably from flood, is regarded as a significant challenge for humanity, and it must be researched at both the global and local levels (Sami et al., 2013; Danumah et al., 2016). Bangladesh is a South Asian country bordered by India and Myanmar (Burma) and located at the confluence of three main rivers: the Ganges, Brahmaputra, and Meghna. As a result, it is prone to flooding on a regular basis, making it one of the world's most flood prone countries. In this study, we attempted to demonstrate how GIS (Geographic Information System) and AHP (Analytical Hierarchy Process) might benefit in flood vulnerability assessment in a specific region of Bangladesh. To study flood prone areas, GIS may integrate diverse data layers such as topography, land use, and precipitation. AHP is a multicriteria decision-making (MCDM) strategy that can be used to prioritize susceptible areas based on infrastructure, population, and flood history. They work together to improve understanding and enable effective flood risk management planning.

2 Study Area

From historical floods, previous research works, various news sources and opinions of local residents, it has been observed that Chilmari upazilla of Kurigram district is the most vulnerable zone to flood due to its topography, geographical location and socioeconomic infrastructures. So, we selected Chilmari upazilla as our study area and its location map is shown in Figure 1. Chilmari upazilla of Kurigram district has an area of 224.97 square kilometers and is located between 25°26' and 25°40' north latitudes and 89°38' and 89°48' east longitudes. It is flanked on the north by Ulipur upazilla, on the south by Char Rajibpur and Sundarganj upazilas, on the east by

Raumari and Char Rajibpur upazilas, and on the west by Sundarganj and Ulipur upazilas

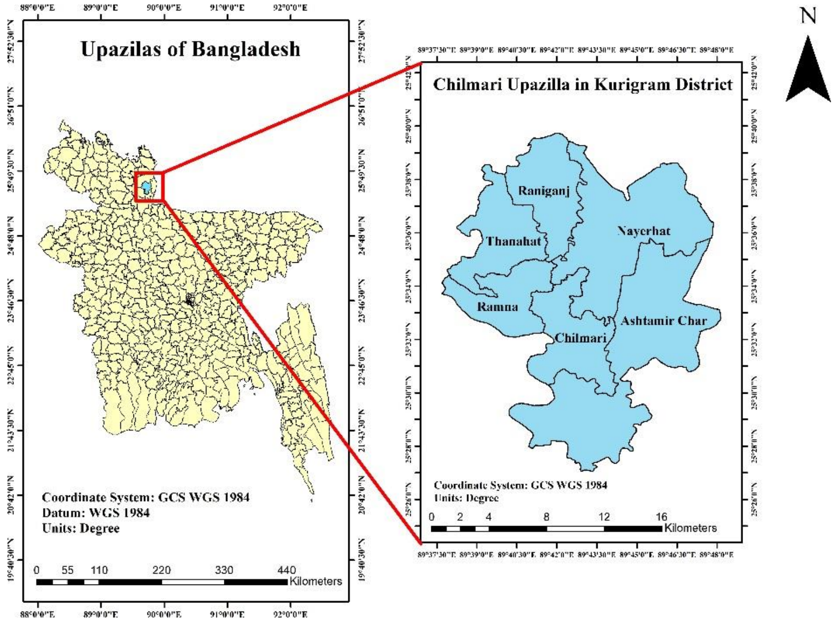

Figure 1. Map of the Study Area

2.1 Flood Inducing Factors

The goal of flood vulnerability assessment is to determine the likelihood and severity of a flood hazard happening over time (Baky et al., 2019; Hoque et al., 2019; Mundhe, 2019). The present research has been carried out to framework the AHP model coupled with GIS using ArcGIS 10.7.1. Six flood influencing parameters have been taken into consideration here, namely:

Topographic Wetness Index (TWI): It is a metric used to estimate a landscape's wetness or moisture conditions based on topographic parameters such as slope, aspect, and flow accumulation. It is a widely used method for describing the state of wetness at the catchment level (Grabs et al., 2009). The TWI forecasts the possibility for water accumulation and flow, both of which can lead to flood formation. High TWI readings indicate locations prone to water saturation, rendering them more vulnerable to floods during heavy rainfall or snowmelt occurrences.

Elevation: The height or altitude of a location above sea level is referred to as elevation. It is significant in determining the likelihood of floods. Flooding is more likely in locations with lower elevations because water naturally flows downhill. Higher elevation regions, on the other hand, are less prone to floods since water naturally drains away more quickly.

3 Data, Materials and Methodology

Slope: The steepness or inclination of the land's surface is referred to as the slope. It influences flood potential by influencing water flow speed and direction. Water movement can be accelerated on steeper slopes, increasing the risk of erosion and flash flooding. On the other hand, water drains more slowly on gentle slopes, causing threats of prolonged flooding.

Precipitation: The process through which water vapor condenses and falls to the Earth's surface as rain, snow, sleet, or hail is referred to as precipitation. Heavy or persistent precipitation can overrun the capacity of rivers, streams, and drainage systems, resulting in excessive water accumulation and floods in surrounding areas. Also, unexpected rains (both in amount and schedule) can cause a flood crisis (Das, 2018).

Land Use Land Cover (LULC): It refers to the physical and functional characteristics of the Earth's surface, including vegetation, urban areas, water bodies, and agricultural land. Different forms of land cover have different effects on the occurrence of flood risks (Romero et al., 2012) by influencing water infiltration, runoff, and flow, affecting flood severity and duration.

Normalized Difference Vegetation Index (NDVI): It is a remote sensing-based measure of the health and density of vegetation. It is often used to obtain biophysical components from vegetation cover (Jiang et al., 2006; Gandhi et al., 2015). NDVI can have an indirect impact on flood potential because thick vegetation absorbs and slows rainfall, reducing surface runoff and lowering flood risk.

3.2. Materials

Geographic Information System (GIS): It is a spatial data gathering, analysis, and visualization technique. GIS integrates several data layers (e.g., elevation, land use, hydrology) in flood risk assessment to model and analyze flood-prone areas, identify susceptible assets, and support decision-making for mitigating measures and emergency preparation

Analytical Hierarchy Process (AHP): The most reliable and flexible multi-criteria mathematical approach, AHP, was used in our current study to map the flood vulnerable zone (Chen et al., 2011; Dandapat and Panda, 2017). It was first proposed by Saaty in 1977 and the further development regarding various parameters like consistency checking (consistency ratio must be below 0.1 or 10%) has increased its acceptance (Saaty, 1980). In flood vulnerability zoning, AHP can be used to prioritize and weight factors. It aids in the creation of effective and scientifically informed flood risk zones by taking into account factors such as land use, elevation, proximity to rivers, and infrastructure susceptibility. Two important features related to this technique, i.e., AHP scale and random index values for various sizes of matrices are shown in Table 1 and Table 2 respectively.

Table 1: AHP Scale (Saaty, 1980)

AHP Scale	1	3	5	7	9	2,4,6,8
Preferences	Equal Importance	Moderate Importance	Strong Importance	Very Strong Importance	Extreme Importance	Values in Between

Table 2: Random Index (RI) Values (Saaty, 1980)

Size of Matrix (n)	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.3 Data

We needed various datasets while conducting the study, their names along with sources are presented in Table 3.

Table 3: Datasets used in this study

Sl.	Datasets	Description	Resolution	Source
1	Digital Elevation Model (DEM)/ Elevation	ASTER	30 m	USGS Earth Explorer https://earthexplorer.usgs.gov
2	LANDSAT-9	Downloaded	30 m	USGS Earth Explorer https://earthexplorer.usgs.gov
3	Precipitation	Interpolation Method		Climatic Research Unit https://crudata.uea.ac.uk
4	Slope	SRTM GL1	30 m	Open Topography https://www.opentopography.org
5	TWI	GIS Steps	30 m	DEM
6	LULC, NDVI	GIS Steps	30 m	LANDSAT-9 Band Images

3.4 Methodology Described in a Flowchart

To achieve the goals of the study, we needed to follow a certain set of steps. The methodology we used is described as a flowchart in Figure 2.

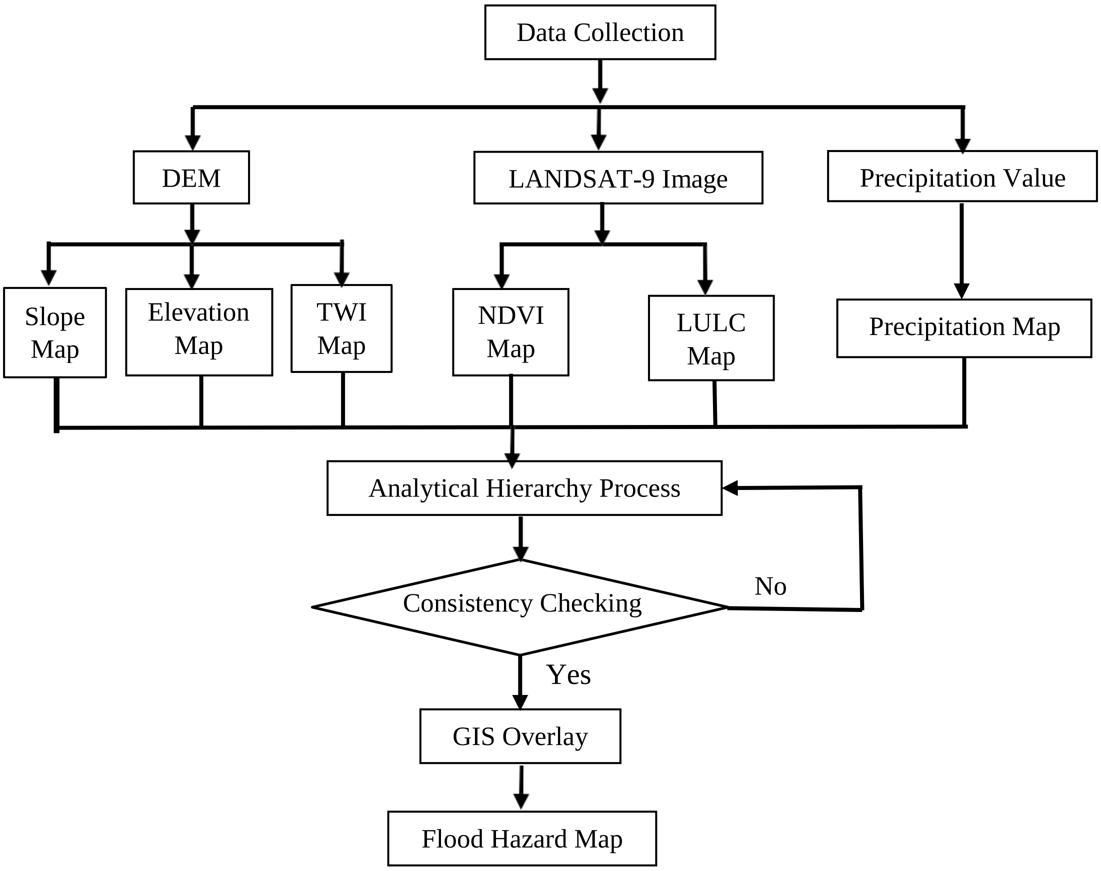

Figure 2. Flowchart of Methodology

4 Result and Discussion

Various thematic maps have been prepared using GIS software. These maps are shown in Figure 3-8 in the following part of the study. Then priorities of these flood inducing factors have been selected by analyzing previous research works, personal judgement and expert opinion. With these listings of priorities, a 6×6 pairwise comparison matrix was formed as shown in Table 4. Then sequentially normalized pairwise comparison matrix, criteria weights, consistency, weighted sum value, λ, λ_{max}, consistency index and finally consistency ratio were determined.

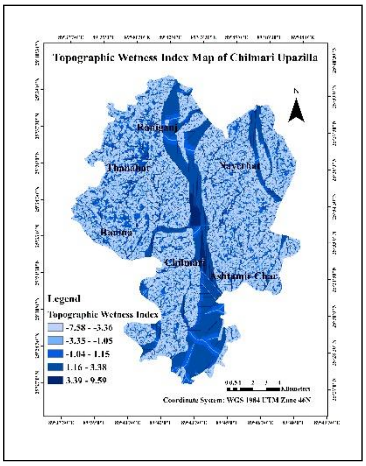

Figure 3. TWI Map

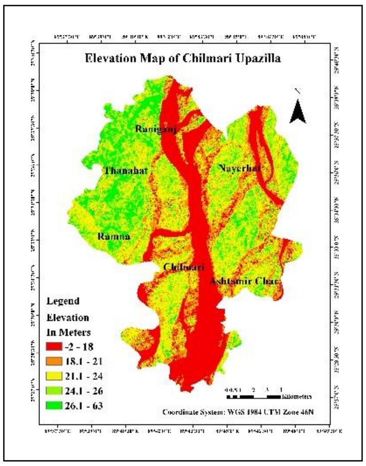

Figure 4. Elevation Map

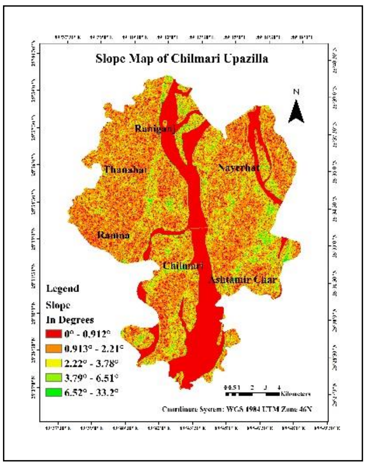

Figure 5. Slope Map

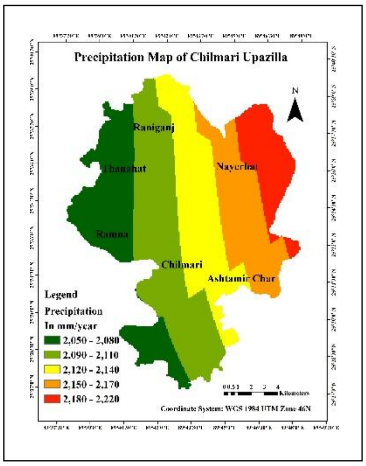

Figure 6. Precipitation Map

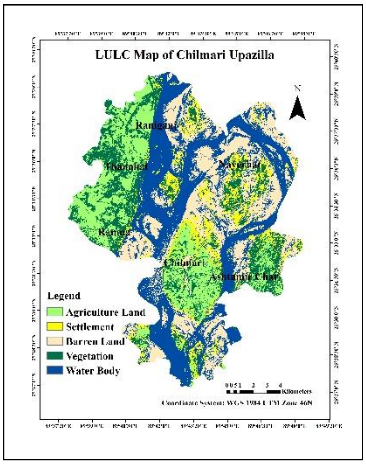

Figure 7. LULC Map

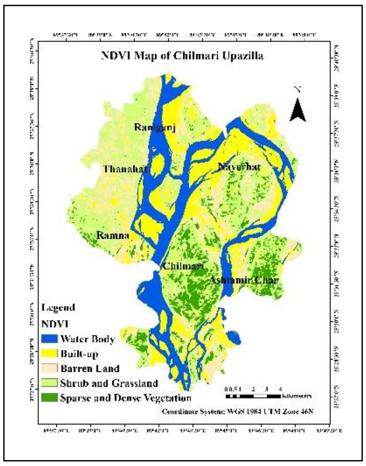

Figure 8. NDVI Map

Table 4: 6×6 Pairwise Comparison Matrix

	TWI	Elevation	Slope	Precipitation	LULC	NDVI
TWI	1	1	1	1	3	1
Elevation	1	1	1	1	2	1
Slope	1	1	1	1	3	1
Precipitation	1	1	1	1	5	1
LULC	0.33	0.50	0.33	0.20	1	0.17
NDVI	1	1	1	1	6	1

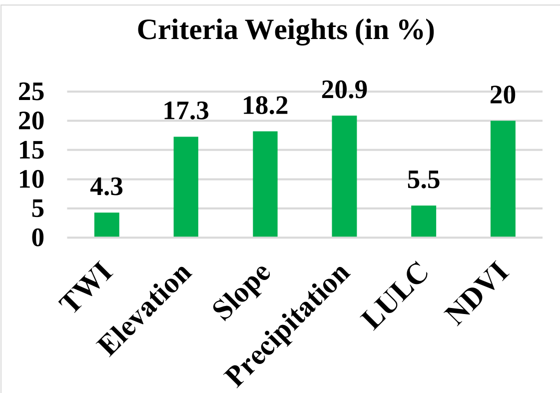

Figure 9. Graph Showing Criteria Weights

Figure 9 shows the weights of the flood inducing parameters considered. Consistency Ratio (CR) has been found 1.8%, which is satisfactory. Using this weightage, weighted overlay was done in ArcGIS with reclassified thematic maps and hence the final flood hazard zoning map has been prepared that is shown in Figure 10. The area percentages covered by various hazard zones is shown in Figure 11, which was calculated by GIS field calculator.

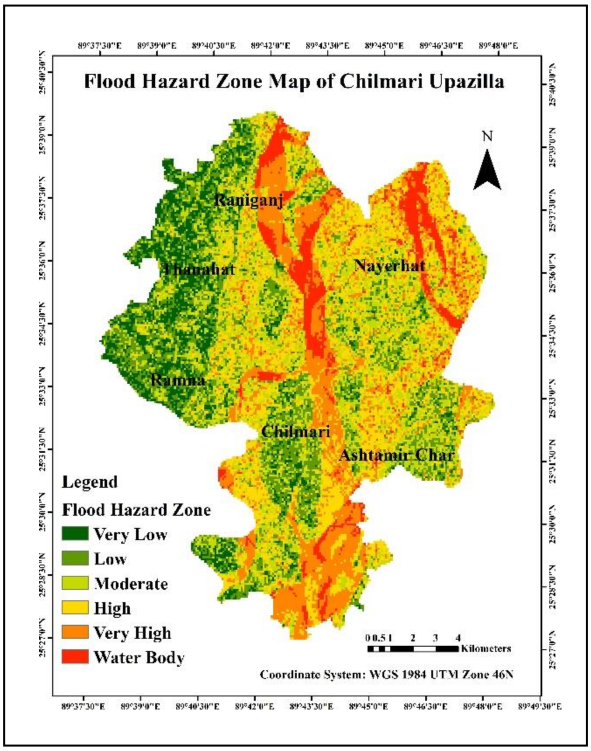

Figure 10. Flood Hazard Zone Map of Study Area

The flood hazard zoning map of Chilmari upazilla of Kurigram district shows us that the region is quite vulnerable to flood and supposedly flood occurs very often here causing massive tangible and intangible losses. This zonation can be useful in detailed area planning, selection of shelter location and crop patterns. Preventive and precautionary steps taken by several authorities can be planned and implemented following this hazard map.

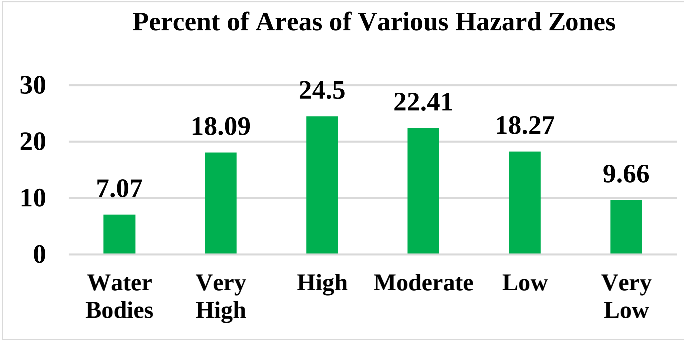

Figure 11: Percent of Areas Covered by Various Flood Hazard Zones

5 Conclusion

Flooding is a natural hazard that stances a risk on the lives of people and also on physical structures in the affected areas. With the help of spatial assessment and geographic information system (GIS), the flood risk occurrence can be better understood. This study focused on AHP, to create flood susceptibility maps by using six geo-climatic factors. GIS is used as an essential tool that helped in identifying flood hazard zones and evaluating the effects of flood in the respective zone to reduce flood risk. The final output map shows the flood hazard zone of the Chilmari region. This research could be used in the northwestern region of Bangladesh for manipulating, managing, and lowering the damage of flash flooding. Finally, the flood preparedness program in the previously discussed region (also in other areas) should be based on detailed and knowledgeable planning.

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