Paper ID: CE 0300

Vulnerability Assessment of Cyclone by Using ArcGIS: A Case Study of Chittagong District

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Abstract

Cyclones were a frequent natural calamity in Bangladesh and often led to considerable harm to both human lives and property. This research aimed to assess the vulnerability of cyclones in Bangladesh by employing GIS technology, remote sensing, and the AHP method. It focused on estimating the at-risk population and economic losses in vulnerable regions during cyclones. Furthermore, the study evaluated the adequacy of existing cyclone shelters and their capacity to house the vulnerable population. The primary objective was to identify susceptible areas through data collection on historical cyclone occurrences, population density, cyclone shelter locations, DEM, and Slope. GIS technology was utilized to analyze this data and determine areas of vulnerability, as well as the availability and accessibility of cyclone shelters. The research revealed that approximately 46% (3076 km2) of the total area fell inside the high to very-high-risk zone. This zone included the western and northwestern regions, namely Sandwip, Anowara, Chakaria, Banskhali, Chittagong Sadar, Kutubdia, and Mirsharai. Around 24% (1937 km2) of the total area was moderately threatened, while 30% (2548 km2) exhibited low vulnerability to tropical cyclones. The findings were then contributed to actionable recommendations for mitigating the risks associated with cyclone-vulnerable areas. These recommendations were based on a combination of best practices from disaster management, urban planning, and climate adaptation strategies. The outcomes of this study could serve as a foundation for authorities dealing with cyclone impacts to create and implement effective strategies and plans for mitigating these effects.

Keywords: *Cyclone; Vulnerability assessments; GIS; Wind speed, Risk map, Chittagong district.*

1 Introduction

In recent times, there has been a concerning rise in the frequency and severity of natural disasters worldwide, which pose significant dangers to human lives, infrastructure, and the environment. Among these calamitous occurrences, cyclones have emerged as a recurrent and highly destructive phenomenon, particularly in coastal areas. Tropical cyclones are recognized as one of the most lethal climate-related hazards globally (Bakkensen and Mendelsohn, 2019), resulting in loss of life. Due to its geographical location, Bangladesh holds the fifth position among the countries most impacted by natural disasters. It is vital to comprehend and evaluate a region's susceptibility to cyclones for effective disaster management and mitigation strategies. The assessment of vulnerability offers valuable insights into the susceptibility of diverse regions, populations, and infrastructure to cyclone impacts. This process helps identify high-risk areas and aids policymakers and stakeholders in developing appropriate measures to minimize vulnerability, improve resilience, and safeguard lives and assets (Hoque, M. A. A., Pradhan, B., Ahmed, N., & Roy, S.,2019). Efficiently mapping the risk posed by tropical cyclones can be achieved by utilizing satellite remote sensing and spatial analysis (Phumbabai and Ramalingam, 2013). Geographic Information Systems (GIS) have revolutionized spatial data analysis and visualization, becoming indispensable tools for disaster management and risk evaluation. In this regard, the powerful GIS software ArcGIS provides a wide range of capabilities for spatial analysis, mapping, and modeling, Empowering researchers and decision-makers to effectively study and mitigate the consequences of natural disasters. The process of risk mapping involves using spatial analysis techniques to assess vulnerability and exposure to risk factors (Dewan, 2013b; 2014), hazards (Rashid, 2013), and mitigation capacity (Hoque et al., 2018a). While the Analytic Hierarchy Process (AHP) has been employed in only a few studies to map tropical cyclone risk this paper aims to comprehensively assess cyclone vulnerability using ArcGIS as an analytical and mapping tool, with a specific focus on the Chittagong District in Bangladesh. This district holds significance not only as a major coastal region but also due to its dense population. Thus, understanding its vulnerability to cyclones is essential for designing targeted interventions and policies to mitigate potential risks and enhance resilience. In summary, this paper provide decision-makers, urban planners, and disaster management authorities with valuable insights and tools to make informed choices when addressing cyclone vulnerability. By combining the power of GIS technology with comprehensive data analysis, the research seeks to contribute to the development of more resilient and sustainable communities in the face of cyclone-related challenges.

2 Methodology

2.1 Study Area

The research region covers a land area of 5,283 square kilometers and is home to a total population of 7,616,352 individuals. The density of the population is recorded at 1,400 individuals per square kilometer. Chattogram shares its borders with Feni district and Tripura state in India to the north, Cox's Bazar district to the south, and Bandarban, Rangamati, and Kagrachari districts to the east. Additionally, its boundaries include Noakhali district and the Bay of Bengal to the west.

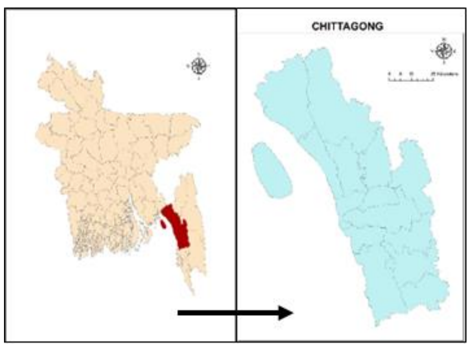

Figure 4. Study area: Chittagong district

2.2 Method and material

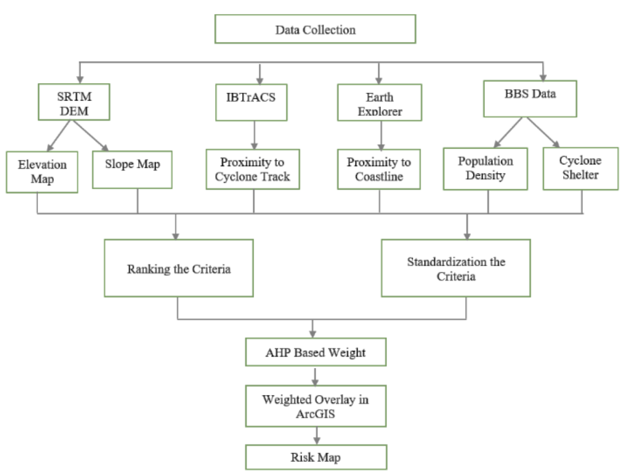

Figure 5. Methodological framework

2.3 Dataset and sources

Table 1 In this research, a range of dynamic measures related to three different risk factors were chosen to evaluate the risks associated with tropical cyclones. These chosen measures were derived from a diverse array of data origins, spanning from local to global government and private entities, along with numerous on-site inquiries. Geospatial methods were employed to incorporate these identified measures.

TYPE OF DATA	SOURCES	TIME PERIOD	OUTPUT
DEM at 10m spatial resolution	USGS Earth explorer	2020	Elevation, slope
Landsat 8 (30m resolution)	USGS Earth explorer	2020	Land use and Land cover
Cyclone track	International Best Track Archive for Climate Stewardship (IBTrACS)	1980-2018	Proximity to cyclone track
Population	BBS	2023	Population Census 2023
Number of cyclone shelter	MoDMR	2018	Number of cyclone shelter

2.4 Factors used in vulnerability and exposure cartography

Hoque et al. (2018a) introduced six criteria to assess susceptibility and exposure to tropical cyclones. These criteria encompassed population density as a measure of exposure, alongside elevation, slope, proximity to the coast, cyclone path, and the count of cyclone shelters as determinants of vulnerability. When evaluating an area's vulnerability to tropical cyclones, the factors of elevation and slope play significant roles. As per Rao et al. (2013), higher altitudes and steeper slopes are less prone to impact than low-lying and flat terrains. The Survey of Bangladesh (SOB) supplied a (DEM) digital elevation model at a 10-meter resolution (1:25000 scale), constructed from topographic sheets, for use in this research.

2.5. Alternative ranking and standardization of criteria layers

Each spatial criterion was assigned a risk rating and ranked on a 5-point scale, considering their contribution to risk and adhering to AHP guidelines. To aid analysis, vector data was transformed into 10-meter pixel raster layers using the weighted overlay technique. Standardization was achieved through the utilization of a linear scale conversion, which harmonized all rating values to a uniform spectrum spanning from 0-1.

Formula: P = (X - Minimum) / (Maximum - Minimum) (1).

2.6 Weighting the criteria using AHP

For this investigation, the criteria employed in constructing a risk map were weighted using the Analytic Hierarchy Process (AHP) decision-making algorithm. Four experts and a user, all possessing relevant expertise in coastal research and cyclone factors, collaborated to generate pairwise comparison matrices for each risk component, based on Saaty's "scale of relative importance" (2008). Each risk component was assigned a total score of 1. The experts' and user's comparison consistency was gauged using the consistency ratio (CR). The CR is deemed acceptable if it equals or falls below 0.1. An equation was utilized to compute the CR.

Formula: CR= consistency Index/Random Index (2)

2.7 Risk assessment

By employing the weighted overlay methodology, indicators pertaining to susceptibility and exposure, danger, and capability for mitigation were developed, directed by their corresponding criteria importance. These indicators were subsequently employed to produce visual representations, showcasing varying degrees of susceptibility and exposure, danger, and mitigation capacity, organized into distinct tiers of five divisions. A consolidated risk gauge was devised utilizing Formula (1) and standardized using Formula (2), yielding outcomes spanning from 0 to 1. Subsequent to this process, a risk chart was generated, classifying risk index figures into five distinct risk classifications.

3. Results and Discussion:

3.1. vulnerability and exposure map

The distance from the coastline and the trajectory of the cyclone plays a crucial role when assessing the likelihood of cyclone occurrence. Regions situated in close proximity to the coast and along the predicted path of cyclones are more susceptible to the impacts of these tropical storms compared to those located farther away. In the study, the researchers used Google Earth Pro to measure the distance between various parts of the study zone and the shoreline. To gather data on how close these areas were to cyclone paths, approximately 30 historical cyclone tracks from 1968 to 2018 were identified within the research region. This data was obtained from the International Best Track Archive for Climate Stewardship (IBTrACS) database (Knapp et al., 2010), and it helped create a spatial layer indicating the proximity to cyclone paths.

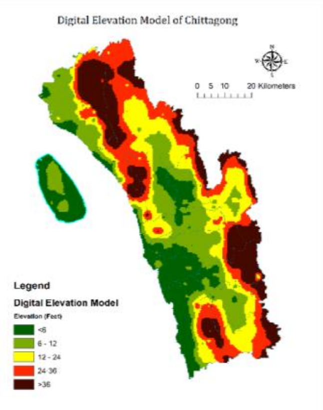

Figure 3(a). Elevation Map

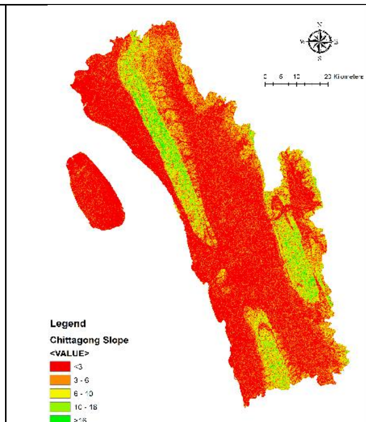

Figure 6(b.) Slope Map

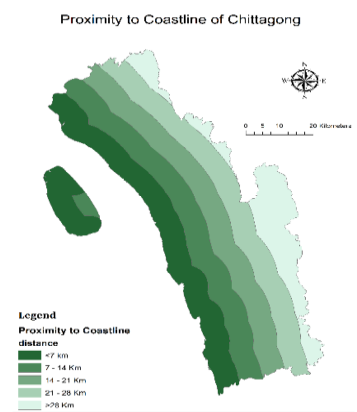

Figure 3(c.) Coastline Map

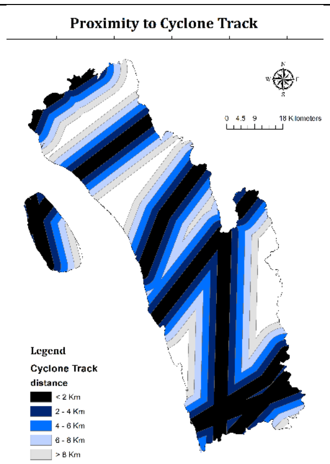

Figure 3(d). Cyclone Track Map

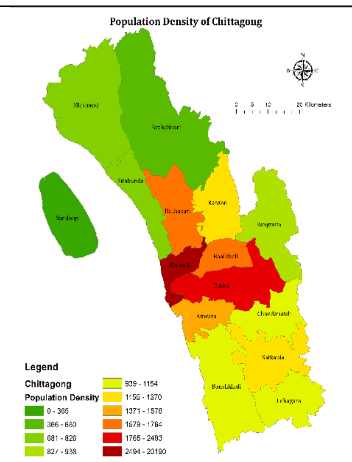

Figure 3(e). Population Density Map

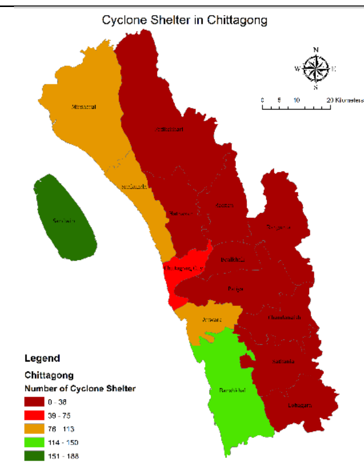

Figure 3(f). Cyclone Shelter

3.2 Risk mapping

Validating the precision of spatial risk assessment outcomes is complex due to the absence of well-defined validation methods in existing literature (Roy and Blaschke, 2013). In this investigation, a qualitative validation strategy was utilized. Physically visiting the study region, insights were gathered from approximately 70 individuals from the local community, as well as experts and decision-makers, regarding the risk assessment results produced by the software. Thorough firsthand observations were carried out to authenticate the assigned risk levels for specific areas on the map. Moreover, informal conversations with local residents were employed to gather historical data about instances of tropical cyclones and their consequences.

Table 2 Assessment of the relative importance of the following criteria in determining cyclone risk

Criteria	Low Risk (1)	Moderate (2)	High (3)	Very High (4)
Elevation (m)	Above 36	12-36	6-12	Below 6
Slope (%)	Above 16	10-16	6-10	Below 10
Coastline Proximity (km)	Above 28	14-28	7-14	Below 7
Cyclone Track Proximity (km)	Above 8	4-8	2-4	Below 2
Population Density (sq.km)	Below 365	365-1371	1371-2494	Above 2494
Cyclone Shelter	Above 150	114-150	38-114	Below 38

Table 3 Attributing numerical values to criteria weights and determining uniformity ratios using matrices of pairwise comparisons

Factor	Criteria	Weightiness
Vulnerability and Exposure	Elevation(m)	0.17
	Slope (%)	0.10
	Proximity to cyclone track(km)	0.23
	Proximity to coastline(km)	0.25
	Population density(sq.km)	0.10
	Cyclone shelter	0.15
Consistency Ratio		0.05

3.3 Risk Map:

The vulnerability and exposure map reveals that a significant portion of the surveyed area, approximately 46% or 3076 km2, encompassing regions such as Sandwip, Anowara, Chakaria, Kutubdia. Chittagong Sadar, Mirsharai, and Banskhali in the western and northwestern sectors, is confronted with an elevated susceptibility to the impacts of

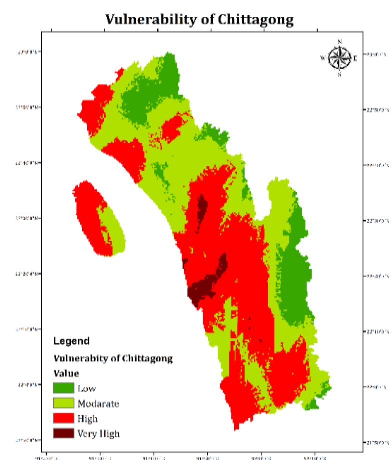

Figure 4. Risk map of the study area: Vulnerability & Exposure

tropical cyclones ranging from high to very high. This increased vulnerability is ascribed to several factors, encompassing proximity to cyclone trajectories and shorelines, reduced altitudes, gradual inclinations, concentrated population densities, and distinct land cover categories. These areas are prone to substantial economic damages due to the destructive impact of tropical cyclones. The agricultural sector losses also negatively affect the local economy.Covering an area of approximately 24% (1935 km2) in the study region, a moderate level of vulnerability is observed, leading to certain degrees of damage to both infrastructure and agriculture. Although these areas are less vulnerable compared to the highly vulnerable zones, they still undergo economic losses that impact local communities, businesses, and the overall economy. The remaining 30% (2548 km2) of the total study area, situated mostly in the eastern and northeastern parts, demonstrates very low to low vulnerability. This is due to factors such as higher elevations, steep slopes, low population densities, and greater distance from coastlines, all of which contribute to minimal economic losses. While there might be indirect effects such as disruptions in supply chains or temporary power outages, the overall economic repercussions are less severe in these regions. Comprehending these patterns of vulnerability is essential for prioritizing actions related to mitigation and preparedness.

4. Conclusion:

This research endeavor involved creating an all-encompassing map that assesses the risk posed by tropical cyclones in the eastern coastal area of Bangladesh. The map's development utilized remote sensing and Geographic Information System (GIS) techniques. By undergoing validation, the resulting risk map accurately identified regions at high risk, including Sandwip, Patiya, Chakaria, and specific sections of Chittagong Sadar and Hathazari. These areas are particularly susceptible to both primary and secondary impacts caused by cyclones. The study's findings offer essential insights that can guide the implementation of proactive strategies to mitigate risks within the identified zones. The primary goal is to protect human lives and valuable resources.

In light of the vulnerability of cyclone-prone areas identified through GIS analysis in Chittagong district, several key recommendations can enhance resilience. Establish community-centered early warning systems to ensure timely alerts. Develop and communicate clear evacuation plans, focusing on accessible routes and cyclone-resistant shelters. Strengthen local capacity through training sessions on disaster preparedness, first aid, and essential survival skills. Advocate for enforced building codes that prioritize cyclone-resistant structures and sustainable land-use practices. Foster collaborative partnerships among local authorities, NGOs, and communities to ensure effective disaster response coordination. Lastly, encourage ongoing public awareness campaigns to educate residents about cyclone risks and encourage proactive engagement in mitigation efforts. These combined measures will empower vulnerable areas to mitigate cyclone impacts and safeguard lives and livelihoods.

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