Heliyon 9 (2023) e21259

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Cyclone exposure mapping in coastal Bangladesh: A multi-criteria decision analysis

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A R T I C L E I N F O

Keywords:
Cyclone exposure map
Analytical hierarchy process
Coastal Bangladesh

A B S T R A C T

Owing to its geographical location, Bangladesh is highly exposed to natural disasters: the northern part is at risk of floods, while the southern part suffers from cyclones, storm surges, and salinity intrusion. This study aims to quantify the exposure to cyclones in Taltali, a southern coastal upazila of Bangladesh. To quantify the exposure, the study used 6 criteria, including elevation, slope, proximity to major water bodies, population density, proximity to cyclone tracks and land use and land cover, and produced maps focusing on each criterion. The overall exposure map was also created to observe the whole scenario of the upazila. All the analysis was done in a GIS environment using the Analytic Hierarchy Process (AHP) method. The individual criterion map represents the status of the study area in different classes. And the overall exposure map revealed that about 60 % of the study area was quantified as very highly exposed to cyclones, including 4 unions- Barabagi, Chhota Bagi, Karaibaria, Pancha Koralia and 6 Rakhain paras- Taltali, Monukhe, Momeshi, Agathakur, Saton, and Sawdagar. In numerical terms, about 8032 ha and 178 ha of land are counted as highly and moderately exposed to cyclones, respectively. Among the seven unions, the maximum area of the Barabagi and Chhota Bagi was found to be very highly exposed, followed by Panchakoralia and Karaibaria. Data from our previous study also validated the results of this study. Despite having some limitations, the study can be used to develop the capacity of the community to respond to cyclones. And the national and international communities can use the results to formulate policies regarding disaster risk reduction and risk mitigation.

1. Introduction

Bangladesh is a low-lying country [1,2], with 720 km of coastline [3–5]. Consequently, natural disasters pose the greatest threat to this nation, especially to the people in the southern coastal region [6–8]. Moreover, the coastal area of Bangladesh is often adversely affected by cyclones during monsoons due to the prevailing environmental and atmospheric conditions [9–11]. As a result, the coastal region experiences an estimated 16 tropical cyclones per year, with a more significant occurrence [12]. The development of tropical cyclones is influenced by a variety of factors. They work together to create favorable conditions for the emergence and development of these extreme weather occurrences [13]. Increased sea surface temperatures constitute an optimal setting for the maturity and

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https://doi.org/10.1016/j.heliyon.2023.e21259
Received 25 May 2023; Received in revised form 17 October 2023; Accepted 18 October 2023
Available online 19 October 2023

increased amplification of tropical cyclones [14]. This helps to intensify cyclone activity and raise the possibility of stronger storm surges [15]. Moreover, the formation of low-pressure systems in the Bay of Bengal triggers tropical cyclones [16]. They have an enormous effect on coastal areas because they are frequently selected as their sites of frequent landfall [17]. The addition of low vertical wind shear facilitates cyclone intensification [18,19]. In contrast, strong vertical wind shear prevents tropical cyclones from worsening and developing as much as they might typically [20]. In addition, cyclones sustain their potency through the provision of heat from profound, warm oceanic waters [21]. The presence of high ocean heat content intricately and positively influences the connection with hurricanes and tropical cyclones [22]. Besides, climate change has recently emerged as an additional contributory factor, augmenting both the impact and frequency of storms [23]. For instance, its connection to climate change has a complex effect on increased ocean heat content, leading to increased tropical cyclones [22]. Thus, extreme tropical cyclones pose consequences for Bangladesh's coastal regions as a result of climate change [24]. Several studies have already looked into how Bangladesh has been affected by climate change in terms of the vulnerability of tropical cyclones [25–27]. The increased frequency of cyclones driven by climate change, agricultural productivity in Bangladesh's coastal regions has decreased due to crop damage [25,28]. The resulting loss of life and property, as well as the threat to development activities, is inevitably pinned on climate change [29].

Tropical cyclones are the deadliest natural hazards that are associated with substantial rainfall, winds with high velocity and rises in water levels during storm surges. These are the defining characteristics of the weather situation. That brings catastrophic impacts, including losses of life and damage to properties and the environment [30–33]. Despite their devastating effects, Bangladesh has been the site of some of the most catastrophic cyclones in the world, such as the events of 1584, 1737, 1942, 1876, 1897, and 1970 [30,34]. Several destructive cyclones have struck Bangladesh, resulting in significant human and property losses, as documented in historical records [6,30,35]. The country's deadliest cyclone occurred on April 29, 1991, and was followed by another devastating cyclone in 2007 [30,35,36]. These events have had a lasting impact on coastal communities, exploiting the vulnerability of the region to cyclones. Furthermore, cyclones have affected Bangladesh more severely than any other country in the world, with over 40 % of cyclones resulting in over 5000 deaths occurring in Bangladesh [37]. Many coastal regions around the world frequently experience tropical cyclones and their effects, thus posing significant threats to vulnerable communities [38]. Additionally, over the past 200 years, 1.9 million people have perished worldwide as a result of cyclones [39,40]. Moreover, in Bangladesh, six cyclones at the beginning of the 1960s caused the deaths of over 50,000 people [41]. This country encountered a devastating experience when a single cyclone in 1970 resulted in over 300,000 fatalities, marking it as the highest death count from a single cyclone globally [7,42,43]. However, in recent years, Bangladesh has been able to reduce the number of fatalities caused by cyclones [43]. Between 1970 and 2019, tropical cyclones were responsible for worldwide damages of about USD 1965 billion [12]. But Bangladesh is yet to reduce its exposure to property damage and loss. Cyclone Sidr caused extensive damage in this country, with nearly 4406 fatalities and over 55,009 people injured. This event affected an average of 27 million people, resulted in the destruction of over 500,000 houses, and caused severe damage to around 900,000 houses, leading to losses of USD 839 million, which accounted for over 50 % of the total loss incurred across all sectors.

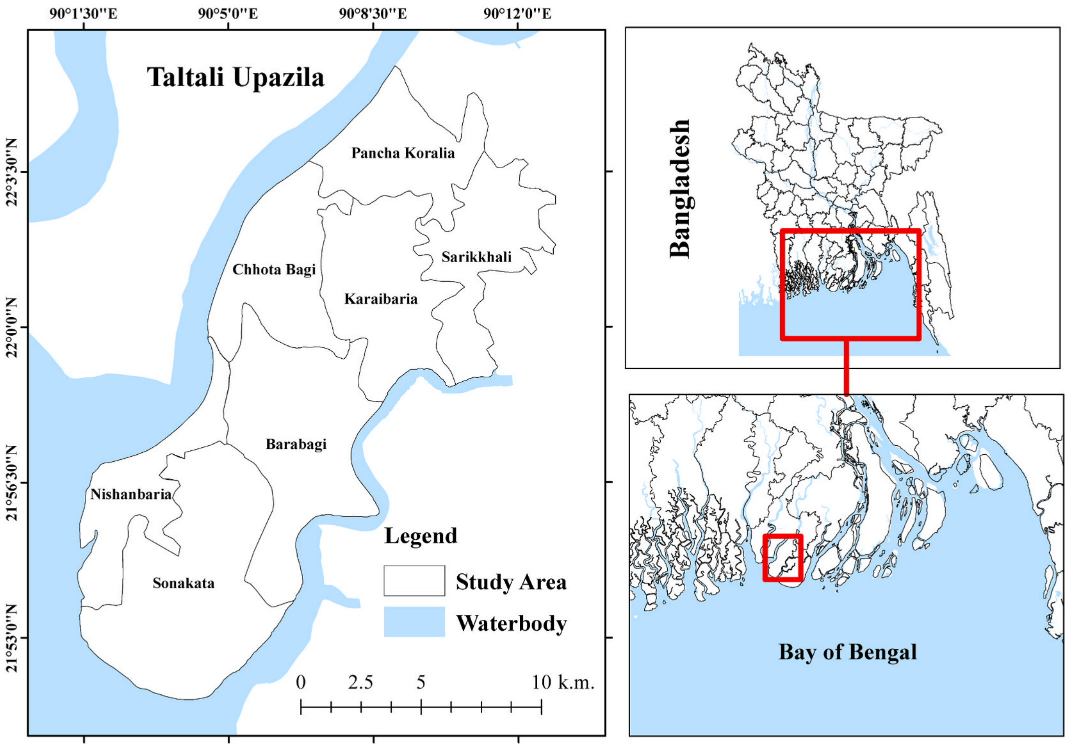

Fig. 1. Study area, Taltali Upazila of Barguna district in Bangladesh.

In May of 2020, Bangladesh was struck by Cyclone Amphan, which caused significant damage to the country's infrastructure. The cyclone resulted in the loss of 22 lives and damaged 149,000 ha of crops. The fisheries sector suffered a loss of USD 3.83 million due to the disaster. Moreover, the cyclone caused extensive destruction to infrastructure, including the demolishment of 55,667 houses, 150 km of embankments and 200 bridges and culverts across the affected areas [42]. Assessing risks has become a top priority for strengthening communities and preventing disasters. It is widely recognized that risk assessment is a critical measure for enhancing community resilience [44,45]. As noted by Ref. [30], risk assessment is a method that is constituted by the potential role of hazards, vulnerability and exposure to determine the possibility of a system being adversely affected by a disaster in the future. The three factors of hazard, vulnerability and exposure are united in the concept of disaster risk. A hazard is characterized by the nature, intensity, and frequency of a natural process that can lead to a disaster. Moreover, exposure refers to the spatial context that indicates the possibility of people and assets being affected by a specific hazard in a particular location. Additionally, understanding vulnerability is critical for identifying the conditions that can turn a hazard into a disaster.

This research paper aims to assess cyclone exposure in Taltali upazila. Moreover, it will contribute valuable insights into the southern coastal exposure status of the concerned area. The specific objective of the study includes: 1) to prepare the maps of criteria of exposure; and 2) to form a risk map by weighing the criteria map to perform GIS-based multicriteria decision analysis. These specific objectives elucidated how the selected criteria-elevation, slope, proximity to major water bodies, population density, proximity to cyclone tracks and land use and land cover-influence the exposure of the Rakhain community due to cyclones.

Efficient planning and management of natural disasters are necessary to save lives and reduce economic loss [46]. The Multi-Criteria Decision-Making (MCDM) techniques prove to be valuable in spatial planning and natural hazard management, serving as a practical tool for engineers, planners, and local authorities [47]. While employing a multi-hazard map, planners may encounter challenges in deciphering the problems due to hazards, leading to potential confusion in decision-making. In contrast, opting for a single-hazard map provides a clearer and more focused perspective, facilitating more effective planning and risk mitigation strategies [46]. For the purpose of determining suitability for land use development, planners continue to rely heavily on reliable information on the spatial pattern of natural disasters [48,49]. Therefore, it is very important to incorporate predictive maps for natural hazards into the land use planning phase [46].

2. Study area

Low-lying Taltali Upazila (333.83 square kilometers), is located in the Barguna district of coastal Bangladesh (Fig. 1). To its west lies Barguna Sadar and the Buriswar river, while to the east is the Andharmanik river and Kolapara Upazila in Patuakhali. The area is flanked by the Tengrabil forest and the Bay of Bengal to the south, and by the Kachupatra river, Panchkoralia river, and Amtali Upazila to the north. It is geographically located between 22.0237° N and 90.1308° E.

The study area Taltali (Fig. 1) is distinguished by its funnel-shaped structure next to the Bay of Bengal, resembling the Meghna estuary, and embodies a micro-to meso-tidal coastal environment [50]. Taltali is made up of the Meghna estuarine floodplain [16]. Given the characteristics of this region, a rise in sea level could exacerbate the overall risk, possibly amplifying the potential for heightened storm surge hazards as well [51]. The intensive agricultural use of deltaic floodplains increased the risk of cyclones due to crop damage [52]. Tengrabil forest, mainly a mangrove forest with an eco-park covering specific areas, densely envelopes Taltali's entire southern part [53]. This ecological fortress serves as a strong green barrier, providing a formidable defense against the effects of cyclones [54]. Taltali has a long history of cyclones. For example, Cyclone Yass (2021), and Mahasen (2013) damaged people and their assets in Barguna [55,56]. Only cyclone Mahasen affected about 60 % of the people in Barguna, and 7 people died. In addition, about 57 % of agricultural land and about 7000 houses were entirely damaged in this district [56]. Not only that, Barguna was also affected in 2007, 1970, 1965, 1935, and more [29,57]. Also revealed in the report, Barguna is very exposed to natural disasters like cyclones, floods, storm surges, river erosion, drought, etc. [58]. Moreover, climate change enhanced the intensity of storm surges [59,60].

Taltali Upazila is a rural area with a population of 88,004 and a population density of 433 people per square kilometer [61]. Taltali comprises seven unions: Sonakata, Nishanbaria, Barabagi, Chhotabagi, Sarikkhali, Karaibaria, and Panchakoralia. Among them, except Sarikkhali, all the unions were at risk of cyclones [58]. In addition, Taltali Upazila is the largest habitat of the Rakhain community among all upazila in Barguna. The last census of the country reported 1059 Rakhain people in this district, of whom 998 were reported in Taltali upazila [61]. Apart from this district, they also settled in Cox's Bazar and Patuakhali. Mainly, their ancestors are from the Arakan region of Myanmar, and from there they migrated to this country owing to the genocide of 1784 [62]. They used to speak Arakanese, but most of them now speak Bengali. They are practicing Buddhism. When they migrated to Taltali, this area was untouched; they cleared the forest, built their loft house to protect themselves from animal attack, and cultivated land as a livelihood [63]. About 144 paras were in this upazila in the year 1948, however, among them, only 26 are now existing [64]. But the field survey that was conducted in January 2022 found only 13 paras. This ethnic population is declining rapidly due to the persecution and land grabbing of local influential people [64]. Also, devastating cyclones in the southern coastal zone influence them to migrate [63]. This study also focused on this ethnic community.

3. Materials and methods

3.1. Datasets and sources

A region's exposure can be determined by a number of different dynamic components; six of these components were selected for this study after reviewing the relevant literature in order to determine the exposure [30,59,65–67]. Afterward, the chosen components were mapped using ArcGIS 10.8, and Table 1 provides an overview of the properties of the datasets.

3.2. Criteria for exposure assessment and mapping

The likelihood of being affected by cyclones is influenced by a number of dynamic factors, of which six were chosen for the purpose of this research: elevation, slope, proximity to a major water body, proximity to the previous cyclone track, land use and land cover, and population density.

The elevation and slope of a location are two factors that may be used to determine whether or not it is exposed to the destructive power of a cyclone's storm surge. A region that has both a high elevation and a steep slope is considered to be extremely exposed, while a region that has both a low elevation and a gentle slope is considered to be less exposed [30,60,67–69]. This research made use of a digital elevation model (DEM) with a spatial resolution of 10 m, which was obtained from the Survey of Bangladesh. In this study, the elevation map was divided into five categories: (i) < 1 m; (ii) 1 m–2 m; (iii) 2 m–3 m; (iv) 3 m–4 m; and (v) > 4 m (Fig. 2A). Additionally, there were five categories in which the slope is divided: (i) < 0.11, (ii) 0.11–0.22, (iii) 0.22–0.59, (iv) 0.59–2.91, and (v) > 2.91 (Fig. 2B). According to this classification, about 86 and 85% of the Taltali upazila have an elevation of less than 1 m and a slope of less than 0.11 percentile, respectively (Fig. 2 A, B). This implies that the area is very highly exposed. The rest of Taltali is situated in highly exposed locations.

In addition, cyclones may have a significant negative influence on human life as well as property that is situated close to a major water body or the shore. Also, areas close to the path of the preceding storm were shown to have a greater risk of exposure in earlier research [30,59,65,67]. Using data from the International Best Track Archive for Climate Stewardship (IBTrACS) spanning the years 1968–2019, this research identified locations that were in close proximity to the course taken by the preceding cyclone (Fig. 2E) [70]. Five classes were used to categorize the distance to the coast: (i) 0–5 k m, (ii) 5–10 k m, (iii) 10–15 k m, (iv) 15–20 k m, and (v) 20–25 k m (Fig. 2C). Distances to previous cyclone tracks were also divided into five categories, including (I) < 2 k m, (ii) 2–4 k m, (iii) 4–6 k m, (iv) 6–8 k m, and (v) > 8 k m (Fig. 2E). According to the findings of the proximity analysis, about 90 % of the research area was determined to be very highly exposed, which meant that it was located within 0–5 km of a major waterbody, while the remaining 10 % was found to be located within 5–10 km (Fig. 2C). Apart from that, it was observed that 82 % of Taltali was very highly exposed in reference to the paths of prior cyclones, while another 17 % was identified to be within 2–4 km of a cyclone path (Fig. 2E).

In determining whether or not a region is exposed to cyclones, land use and land cover are also significant factors [30,66,67,71]. According to earlier research, exposure varies depending on the land cover. Some forms of land cover are more prone to suffering damage and loss as a result of cyclones. In our study, we focused on three distinct land cover classes: (1) built-up and bare land; (2) water; and (3) vegetation. The order of precedence for classes is as follows: 1 > 2 > 3. The Sentinel-2 images were used for maximum likelihood classifier analysis to determine these classes [59]. The findings indicate that the majority of the land in Taltali is vulnerable to the effects of cyclones and the associated losses (Fig. 2F). Accuracy assessment was done by following the [59,66] method, and overall accuracy and kappa values were respectively 92.37 % and 91.13 %.

Population density and geographical variation, which affect vulnerability, are also major elements. Population data from the 2011 housing census in Bangladesh was used to create a population density map for this research. The population density map was categorized into five classes: (I) 125–170, (ii) 171–207, (iii) 208–265, (iv) 266–321; and (v) 322–474 (Fig. 2D). According to the study, Chhota Bagi and Barabagi, which together make up nearly 31 % of the upazila, are the two unions in Taltali with the highest population density (Fig. 2D). Moreover, 47 % of additional places are classified as very susceptible.

3.3. Ranking the criteria

Using a scale from one to five, where one represents a very highly exposed area and five represents a very low exposed area (Table 2), each of the criterion layers were given a ranking out of one to five. The order of the alternatives was determined by following the rules for AHP and exposure in that order.

Table 1
Datasets overview.

Types of Data	Source of Data	Period	Output of Mapping	Web Links
Digital Elevation Model (DEM) (10 m)	Survey of Bangladesh (SOB)	2014	Elevation, slope	http://www.sob.gov.bd
Waterbody	Bangladesh Agricultural Research Council	2015	Proximity to major waterbody	http://apps.barc.gov.bd/maps
Cyclone track	International Best Track Archive (IBTrACS)	1960–2019	Proximity to cyclone track	https://www.ncei.noaa.gov
Sentinel 2 (10 m)	Earthdata - NASA	2023	Land use and land cover	https://search.earthdata.nasa.gov
Population	Bangladesh Bureau of Statistics	Population Census 2011	Population density	https://bbs.portal.gov.bd

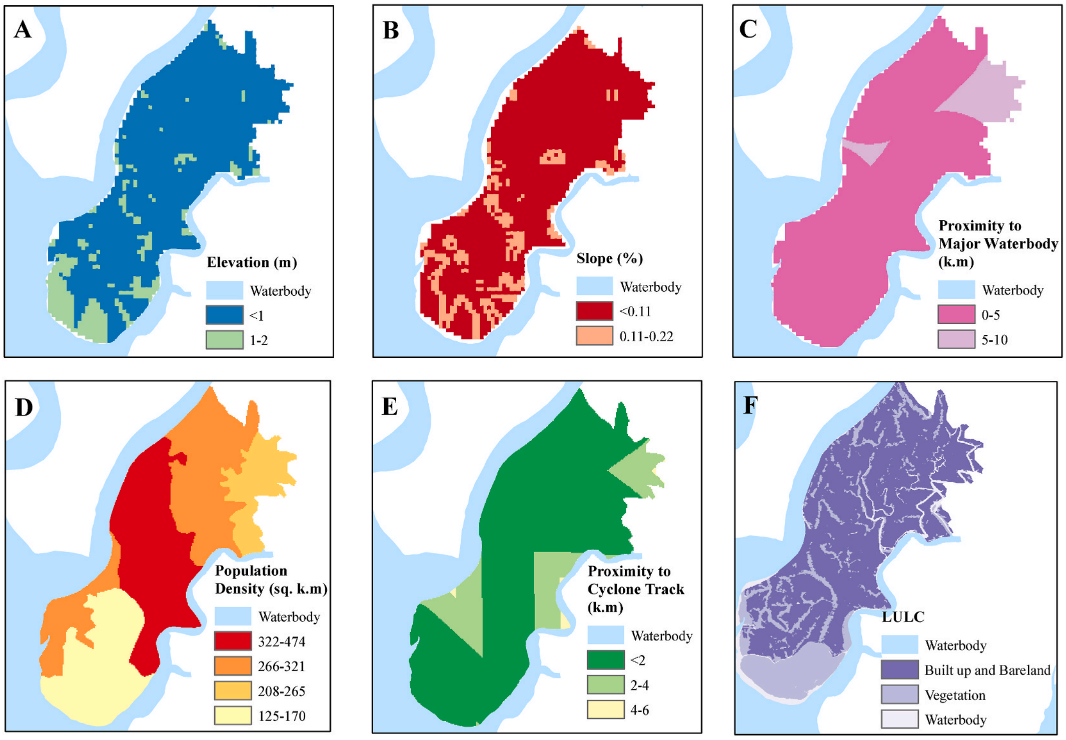

Fig. 2. Criteria of exposure: (A) Elevation (B) slope (C) proximity to major waterbody (D) population density (E) proximity to cyclone track (F) land use and land cover.

3.4. Weighting the criteria using AHP

The Analytic Hierarchy Process, or AHP for short, is a method of making decisions according to multiple factors that was established by Saaty, 2008. For the purpose of doing an analysis of the risks posed by potential disasters, this approach may be utilized to hypothesize the relevant components. The AHP was combined with GIS in a significant number of earlier research studies in order to solve disaster management problems (risk, exposure, and susceptibility), map potential erosion areas, and select sustainable landfill sites [30,59,65–67,72–74].

The AHP methodology was utilized in this study for the purpose of weighing the criteria. The data from the four different experts was used to build a pairwise comparison matrix. Each of the professionals has relevant experience as well as an understanding of disaster management and the area under study. They ranked the factors in order of importance using a scale that ranged from one to nine points (Table 3), which was developed from Ref. [75].

To demonstrate that the opinions of the specialists are reliable, a consistency check of the pairwise matrix was carried out using equation (1). The study maintained an acceptable level of consistency ratio (CR), which is less than 0.1; the CR was 0.055 in this study.

$$CR = \frac{CI}{RI} \tag{1}$$

Where CI refers to the Consistency Index, while RI stands for the Random Index.

Random Index (RI) is a fixed number which is increased with the increase of criteria. The table of RI is given in Table 4. And Consistency Index (CI) was calculated using equation (2).

Table 2
Ranking of the spatial layers based on the contribution to cyclone exposure.

Criteria	Ranking				
	Very High	High	Moderate	Low	Very Low
Elevation (m)	<1	1–2	2–3	3–4	>4
Slope (%)	<0.11	0.11–0.22	0.22–0.59	0.59–2.91	>2.91
Proximity to a major waterbody (km)	0–5	5–10	10–15	15–20	20–25
Proximity to cyclone track (km)	<2	2–4	4–6	6–8	>8
Land use and land cover	Built-up, bare land	Vegetation	Waterbody	–	–
Population density	322–474	266–321	208–265	171–207	125–170

Table 3
Level of importance, adopted from Ref. [75].

Level of Importance	Definition	Description
1	Equal Importance	Both criteria have equal influence
3	Moderate Importance	Influence of one criterion is slightly high over another
5	Strong Importance	Influence of one criterion is strongly high over another
7	Very Strong Importance	Influence of one criterion is very strongly high over another
9	Extreme Importance	one criterion is influencing another
2,4,6,8	Intermediate value between two adjacent judgements	In case of compromise is needed

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

Where λ_{max} means the highest eigenvalue of the matrix and n is the matrix order.

The final weight of the criteria is given in Table 5. All five criteria layers were converted into a 10-m-pixel raster to apply the raster-based weighted overlay technique. Finally, the exposure map is categorized into five classes: very highly exposed, highly exposed, moderately exposed, low exposed, and very low exposed.

3.5. Validation method

Validating the findings of the research that used spatial analysis is challenging. In the present research, a qualitative validation strategy was used following the methods of [59,65,76]. Previous research, government documents and reports from humanitarian organizations were used to validate the result [29,55,56,58,61,77,78].

4. Result

Using AHP and GIS, the research's exposure assessment technique generated six criterion maps and an overall exposure map of the study region. These maps were divided into five groups, ranging in exposure level from very high to very low.

According to the findings, the center and northwestern parts of the research areas were discovered to be very highly exposed, while the southern portion and certain north-eastern portions were revealed to be situated in highly exposed locations. Additionally, certain Sonakata Union locations showed signs of moderate exposure. In terms of numbers, around 12155.52 ha, which account for 59.68 % of the Taltali upazila, were identified as being very highly exposed, while another area including approximately 8032.18 ha, which counts for 39.43 %, was evaluated as highly exposed (Figs. 3 and 4). Also, it was revealed that 178.68 ha of land were exposed to moderate levels of risk.

Barabagi, one of Taltali's seven unions, contributed the most to the very high exposure, with 32.67 %; this was followed by Karaibaria (23.02 %), Chhotabagi (19.88 %), and Pancha Koralia (16.90 %). In each of these unions, a very high level was found for each of the six criteria. For instance, it was observed that the population density of Barabagi and Chhotabagi was between 322 and 474 people, which corresponds to a level of exposure that is considered very high.

In addition, it was noted that elevation, slope, proximity to major waterbodies and cyclone tracks, as well as land use and land cover, were all elements that played in the phenomenon. Nevertheless, in terms of highly exposed locations, the biggest contribution came from Sonakata (59.48 %), followed by Sarikkhali (26.34 %), and Nishanbaria (9.29 %). The key elements that contributed to the exposure were the high population density, the storm's path, and the relative proximity to major bodies of water. Lastly, the Sonakata Union had 172.93 ha of the total 178.68 ha that were classified as having moderate exposure.

Regarding the Rakhain minority, they are residing in a cluster habitat referred to as "Para". We conducted interviews and collected the latitude and longitude of ten paras in an earlier study [77]. In this research, we used those latitudes and longitudes to determine where they fell on the exposure scale, ranging from very high to very low.

Among them, six paras, including Taltali, Monukhe, Momeshi, Agathakur, Saton, and Sawdagar, were found to have very high exposure. Nonetheless, Kabiraj para, Namishi para, Ankujon para, and Lau para were found to be the most vulnerable to the cyclone (Fig. 5).

5. Discussion

Exposure assessment of natural hazards using the geospatial method has been done previously in Bangladesh; however, a study focusing on the ethnic minority population is rare. The present study assessed exposure to the deadliest natural hazard, a cyclone, with

Table 4
Random Index table.

Random Index (RI)															
n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Table 5
Weight of criteria derived from matrices.

Criteria	Weight
Elevation	0.06
Slope	0.04
Proximity to a major waterbody	0.16
Proximity to cyclone track	0.32
Land use and land cover	0.13
Population density	0.29

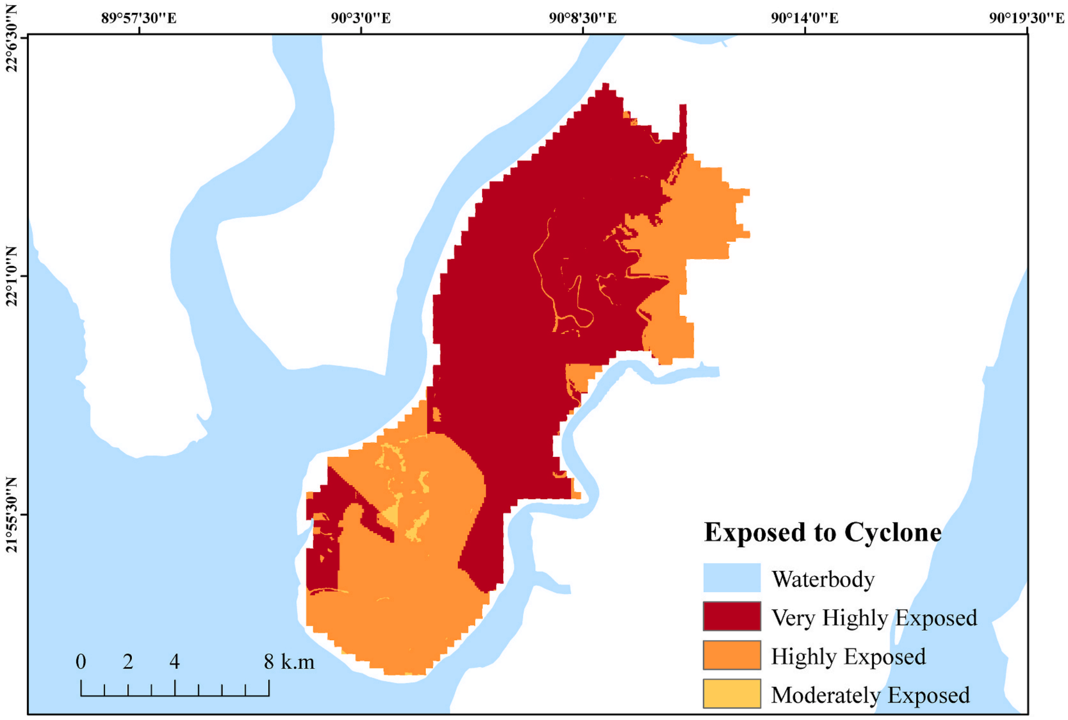

Fig. 3. Exposure to cyclone of Taltali upazila.

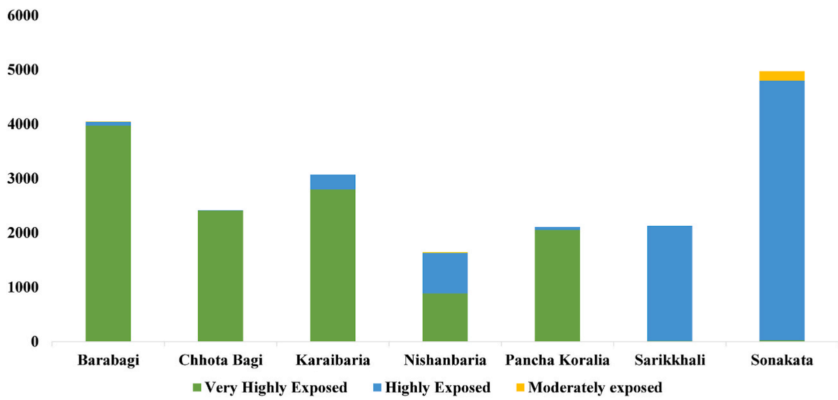

Fig. 4. Unionwise exposed area in hectares.

which coastal people are struggling almost every year [29,55–58,77–83]. In this study, six criteria—elevation, slope, proximity to a major water body, proximity to the previous cyclone track, land use and land cover, and population density—were used to assess coastal exposure to cyclones (Fig. 2). These criteria have been used in numerous earlier studies to assess exposure and vulnerability to

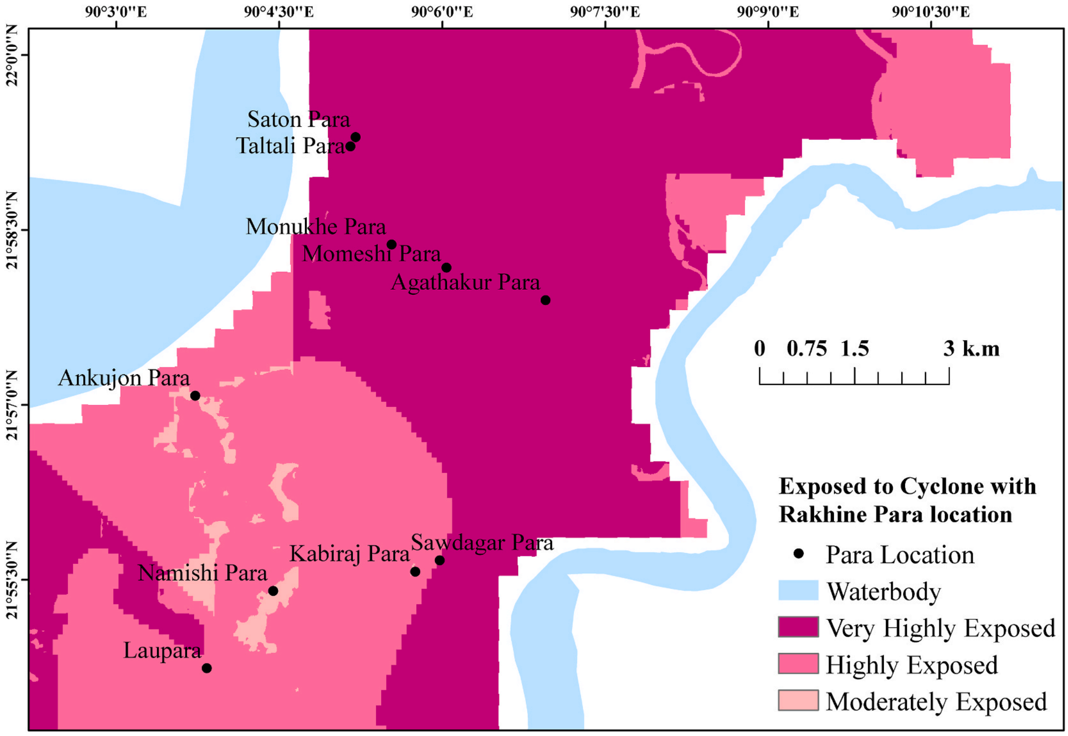

Fig. 5. Rakhain Para exposure to cyclone of Taltali upazila.

natural hazards [30,46,59,60,65–69,71,84–88].

Approximately 60 % of the study area showed a classification as very highly exposed to cyclones, mostly located in the north-western part. The proximity of the Buriswar River may be attributed to its susceptibility to the impacts of cyclones. The closeness of the Bay of Bengal, located just 20 km away, increases the possibility of being affected by storm surges and flooding. Related to this, a noteworthy finding emerges from the previous studies on multihazard assessments: the closer a region is to major water bodies, the greater the susceptibility to flooding [30,84,87,88]. Hence, a viable solution could be embankment construction along the coastline, functioning as a safeguard against the peril of saline water inundation during cyclonic events [89–91]. Well-documented negative effects of saline water on human health, local ecosystems, and agricultural land highlight the need for immediate intervention. However, the construction of embankments must be accompanied by the establishment of a robust and integrated drainage system for rainwater; otherwise, the residents' area would get flooded with rainwater.

As an important factor, land use and land cover play a pivotal role in shaping cyclone susceptibility [30,59,68,84,86,88]. The transformation of land from its natural state to a settlement area, characterized by the replacement of vegetation with man-made structures such as buildings, roads, and bridges, increases the area's vulnerability to natural hazards. Additionally, the situation is made worse by the frequent rainfall during cyclonic events because the concrete surface, made by removing the natural vegetated area, hinders the infiltration rate. The present study also observed a strong connection between exposure level and land use pattern. Also, human density has an influence on this matter [30,67]. From the outcomes of the analysis, it is evident that the very highly exposed zone is mostly covered by either human settlements or agricultural land. The central and western regions, encompassing two unions—Barabagi and Chhota Bagi—are notable for having dense populations ranging from 322 to 474 people in a 1-km radius. This densely populated zone is also home to Rakhine communities, including Saton, Taltali, Monukhe, Momeshi, Agathakur, and Sawdagar Para. Collectively, the convergence of these factors-land use and land cover patterns and population density-renders the sustainability of natural hazards, for instance, cyclones, in this region. However, the southern part is observed to be less exposed than other regions despite being very close to major water bodies because of the Tengrabil forest. Expert opinion on this study also suggests that vegetation plays a crucial role in this matter. The coastal forest acts as a natural buffer, mitigating the potential impacts of natural hazards [91].

Furthermore, the research also discussed the physical attributes of the study area—specifically, elevation and slope—as pivotal components in assessing cyclone exposure. The slope angle influences the velocity of the runoff rainwater, which affects the flood occurrence during a cyclone. Previous studies found a dynamic relationship between slope angle and the possibility of flooding in an area: when the angle of the slope increases, the possibility of flooding decreases. The continuous flow of rainfall-derived water during a cyclone from higher elevations to lower flatlands underscores the importance of elevation in flood control strategies. It is assumed that households situated at higher elevations are inherently less susceptible to the adverse effects of storm surges. Thus, it is recommended to build a household in the highlands along with a row of trees that should act as a natural shield. And houses could be built in a zig-zag pattern to avoid being directly impacted by a cyclone [89].

The analysis results of the study provide the current status of the cyclone vulnerability of each union of the Taltali upazila. And the map shows the spatial distribution of vulnerability. Detailed driving factors were also observed on each criterion map. All of this provides insights to the government, stakeholders, policymakers, and planners to formulate effective measures and strategies to mitigate the impact of cyclones in this region.

An extensive review of the existing literature was employed in this study to validate the findings. According to the literature, Barguna is one of the most exposed and vulnerable districts in the coastal region. Due to its location, it faces hazards such as cyclones, floods, storm surges, river erosion, drought, etc. at different times of the year and throughout the year [58]. The recent cyclone, Cyclone Yass, traversed the west coast of Bangladesh and Barguna was one of the most damaged districts [55]. Apart from that, about 59 % of the Barguna population, 57 % of the agricultural land and 7 people died during the cyclone Mahasen in 2013. Also, about 6856 houses were entirely destroyed [56]. Prior to Mahasen, Sidr, a cyclone of category 4, that struck the southern region of Bangladesh in 2007 and caused major human, economic, and environmental losses. Particularly in Barguna, where 44.5 % (1334 people) of all deaths occurred and about 95,412 houses were fully and partially damaged. In addition, almost 1120 square kilometers of the area were destroyed and 60–70 % of the crops were lost [29,57]. Along with this, Barguna was also affected by severe cyclones in 1935, 1965, and 1970 [57]. The Atlas for Barguna has identified cyclones as the most devastating disaster, with bores and floods following closely behind. In Taltali upazila, there are a total of 29 cyclone shelters available during cyclones and they have a combined capacity of 26, 100. But the total population is 334,491. Also, six unions of Taltali are marked very susceptible to cyclones [58,61]. Also, our previous study conducted on Rakhain people found storm surges are responsible for damaging households' dwellings [77]. The academic expert also affirmed the research area's significant vulnerability to natural hazards.

6. Conclusions and limitations of the study

A detailed cyclone exposure map for the Taltali upazila on the coast was developed in this research. Each spatial criteria layer was created using GIS and remote sensing, and six criteria were considered overall. The AHP method was taken into account while developing the exposure map. Literature, field data, and academic expert opinion were also used in the validation process. Barabagi, Karaibaria, Chhotabagi, and Pancha Koralia, constituting 59.68 % of the research area, were found to be areas of very high exposure. Taltali, Monukhe, Momeshi, Agathakur, Saton, and Sawdagar para, six Rakhain paras, were also observed in this class. In addition, it was determined that 4 Rakhain paras of Taltali and over 8032 ha of land are very vulnerable to cyclones.

This research had several shortcomings, any of which might have affected the findings of the study. First of all, the facts on the country's population were obtained from the census that took place in 2011, which was the most recent census; nevertheless, the current reality would be different. The spatial data that was used in this study came from a variety of sources, and the quality of the data is another matter of concern. In addition, high-resolution satellite data do very well in this kind of study; however, since this sort of research is costly, the data that is publicly accessible was used instead. Also, the expert opinion of the AHP approach could be varied depending on who the researcher is. As a consequence of this, the findings of the research would turn out differently. The validation process itself is another shortcoming of the research; nevertheless, quantitative validation may be able to provide more precise findings. Apart from that, the nature of any natural disaster is dynamic. Its impacts could also vary depending on their type, the time, or the circumstances. So, it is challenging to provide an accurate assessment of the exposure using the previous data.

Notwithstanding the limitations that were noted, the results of the research may assist public and private authorities in the development of mitigation measures and coping capabilities that can lessen the effect of cyclones. In addition, local authorities will be able to use the research as a reference throughout the stages of response and recovery after a cyclone, as well as during the process of establishing comprehensive strategies, plans, and regulations.

Funding

The research has not received any funding.

Data availability

The Data of this research will be made available on request.

CRediT authorship contribution statement

Md Saidul Islam Arif: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Ibnul Mahdi:** Writing – original draft, Validation, Software, Investigation, Data curation. **Md Adil Rafi:** Resources, Investigation. **Saadmaan Jubayer Khan:** Writing – review & editing, Supervision. **Md Mostafizur Rahman:** Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

For allowing this study to proceed, the authors are indebted to the Department of Disaster Management & Resilience of Bangladesh University of Professionals.

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