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Research article

Geo-spatial based cyclone shelter suitability assessment using analytical hierarchy process (AHP) in the coastal region of Bangladesh

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A R T I C L E I N F O

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A B S T R A C T

The coastal district of Bangladesh is susceptible to cyclones, which cause significant damage to infrastructure, economy, and social structures every year. The importance of protecting lives and property in these vulnerable areas is a top priority, especially in times of cyclones and storm surges. Therefore, the identification of potentially suitable shelter locations is essential for disaster risk resilience planning and implementation in the coastal regions. In this context, our research focuses on Barguna, which has witnessed severe damage from previous cyclones over the last several decades. We aim to identify and map feasible cyclone shelter suitability by utilizing GIS, AHP, Hotspot Analysis, and Remote Sensing techniques. The use of advanced techniques enables a comprehensive assessment of multiple variables that influence shelter suitability, ensuring the selection of the most strategically significant locations. The goal is to enhance disaster preparedness and resilience in Barguna District, reducing the risk and vulnerability of its coastal communities to cyclones. Seven variables associated with cyclone hazards, such as elevation, slope, distance from roads and rivers, population density, land use, and cover, and proximity to healthcare facilities, are considered to identify the safest and most suitable cyclone shelter areas. The assessment of the appropriateness of shelter locations for the study area was facilitated by the collection of 181 GPS locations regarding existing cyclone shelters. The findings reveal that approximately 15.53 % (1956 ha) of the total land area is considered less suitable, 67.31 % (84763 ha) moderately suitable, 16.70 % (21024 ha) suitable, and 0.29 % (362 ha) highly suitable for optimal cyclone shelter establishment in the study area. This study has a major limitation due to the use of Landsat imagery, which may not always provide fully accurate image classification. To validate our methods, we collected existing cyclone shelter data and performed a pixel-based accuracy assessment, achieving high accuracy and confirming the reliability of our approach. This research addresses a critical gap in cyclone shelter planning, offering valuable insights for residents and decision-makers to mitigate cyclone risks not only in the Barguna

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district but also in similar coastal regions of Bangladesh. The framework developed in this study can aid non-government organizations and the government in determining the most appropriate locations to construct cyclone shelters to build a safer, more resilient future for the region, capable of withstanding the relentless threats posed by cyclones every year.

1. Introduction

Tropical cyclones have become a significant global threat, affecting approximately 22 million individuals and causing an average economic loss of around 29 billion (USD) annually [1]. It has been observed that the likelihood of more intense cyclones (categorized as 3 to 5 on the Saffir-Simpson scale) has been consistently rising by 2 %–15 % per decade, driven by the effects of global warming. As a result, these cyclones will likely occur more frequently and for a longer duration in most of the world basins [2–4]. The severity of storm surges and other natural disasters has been on the rise in recent years, with the main cause being the increasing vulnerability of urban societies. Consequently, experts suggest that governments should engage local experts and decision-makers to reduce risk and improve disaster resilience activities [5,6]. Moreover, the interest in "pre-disaster planning and risk reduction" is growing in both academic and practitioner communities. The Sendai Framework emphasizes the significance of "prevention, mitigation, and strengthening preparedness for response" for Disaster Risk Reduction among its significant objectives [7], echoing the key aim of the preceding Hyogo Framework of Action [8]. One crucial and effective strategy to strengthen preparedness for response is the identification and allocation of appropriate locations for emergency cyclone shelters before any disaster strikes to the local community [5, 9–14] which improves social resilience as well [5,15,16].

Bangladesh is located along the northern edge of the Bay of Bengal, and this location makes it particularly prone to tropical cyclones. As storms travel up the bay, the unique shape of the coastline and the shallow waters increase the winds and storm surges, putting the country's coast at significant risk [17–19]. Approximately 43.5 million people reside in coastal areas, with an average elevation of 1.0–1.5 m above sea level [20,21]. Over a million people have died in Bangladesh because of cyclonic events throughout history [17]. Previously, there wasn't enough built infrastructure, like climate-resilient houses and public cyclone shelters. People died while living in fragile homes and trying to survive by holding on to trees and swimming in storm surges [22]. Fortunately, now a days, there has been substantial development in building design and construction, an increase in income level and diversification, education, poverty reduction strategies, and a decreasing reliance on agriculture-based earning [23]. Moreover, disaster preparedness, evacuation, and response have been strengthened by a community-based approach that focuses on decentralizing disaster management and partnerships across different levels [24–27]. Consequently, there has been a significant reduction in the number of fatalities associated with tropical cyclones in Bangladesh. For instance, cyclone *Gorky* (Classified as Category 4) in 1991 and Cyclone *SIDR* in 2007 resulted in 147,000 and 4500 fatalities respectively. In contrast, cyclone *Mora* (Categorized as Category 1) in 2017, led to only 6 deaths. However, Numerous factors may still exacerbate vulnerability and lead to fatalities, including proximity to poorly fortified embankments, lack of awareness of warnings, and inadequate transportation routes that hinder mass movement. Additional risks involve limited access to cyclone shelters due to distance and insufficient numbers, lack of protective measures for vulnerable groups, community unawareness, failures in emergency communication, challenges in evacuating remote populations, and deficiencies in radio and mobile network coverage [22]. It is especially concerning that despite early warnings, many people do not evacuate when a cyclone is expected. Both the rate of evacuation and the percentage of the population seeking refuge in shelter facilities remain very low, not exceeding 20 % [28]. More specifically, the non-evacuation rates after the 1970 and 1991 cyclones were 99 % and 70 %, respectively [29]. Furthermore, there was an increasing trend of a significant portion of the local population not evacuating during the SIDR (2007), Aila (2009), and Mora (2017) cyclones with rates reaching 57 %, 74 %, and 78 % respectively [30–32]. While many people are willing to seek refuge in cyclone shelters, several critical factors contribute to non-evacuation trends. These include long distances to public shelters, inadequate or damaged road networks, obstructions such as fallen trees or flooding, slippery conditions due to rainfall, challenges for individuals with dependents, difficulties in transporting livestock, overcrowding in shelters, and insufficient healthcare facilities [23,28,30,33–36].

Despite the construction of approximately 6000 cyclone shelters nationwide, their distribution is uneven, leading to inadequate coverage for certain neighborhoods [17,37]. Several studies have been conducted in Bangladesh, targeting cyclone shelters from different perspectives, like non-evacuation. Parvin et al. [38] conducted a study to identify different factors related to evacuation in cyclone shelters that help the decision-making process. The study found some factors for non-evacuation in cyclone shelters in coastal Bangladesh, including cyclone warning content, timing of orders, road conditions, shelter distance, and individual evacuation decisions. The distance of cyclone shelters significantly influenced people's motivation to evacuate to these shelters. Those living within 1500m of cyclone shelters were more willing to take shelter than those living further away. Hayat et al. [39] presented a case study where they analyzed the accessibility condition of cyclone shelters. This study revealed that an inadequate number of cyclone shelters were identified in the Atulia Union of Satkhira District. The accessibility analysis revealed that some shelters are situated more than 1500 m away from settlements, which is affecting their accessibility to cyclone shelters. The condition of roads leading to shelters caused travel times to differ; for instance, shelters located on bricked or Kacha roads were more difficult to reach than those on Pucca roads. The study emphasized how important it is to use shortest-route maps to enhance disaster resilience. Uddin and Matin [40] discussed hazard zonation and shelter suitability mapping in Bangladesh using geospatial technology, emphasizing the importance of relocating people to safe shelters and the need for planning and prioritizing shelter construction for disaster risk mitigation. Chakma and Akihiko [41] examined the reasons and factors why people do not evacuate to cyclone shelters in any emergency period. The study identified several reasons for not evacuating cyclone shelters during cyclone Komen, such as the distance to the nearest shelter, limited shelter space, late evacuation orders, and underestimation of the cyclone's severity. Some people who weren't evacuated faced obstacles like bad road conditions, extreme weather, and poor road networks when attempting to reach cyclone shelters. Billah et al. [42] checked the existing cyclone evacuation route to cyclone shelters and they proposed the development of an evacuation route using shortest distance analysis to determine the most efficient paths to cyclone shelters. Coastal villages often have underdeveloped road networks, making evacuation difficult during cyclones due to road damage from storm surges, hindering access to safer locations. Amin et al. [43] evaluate the perceived status of cyclone shelter (CS) facilities in the south-central region of Bangladesh. Reasons for non-evacuation in cyclone shelters in coastal Bangladesh include a lack of connecting roads, concerns about women's security, and inadequate sanitation facilities as indicated by survey respondents. Approximately 56 % of people were not willing to go to cyclone shelters during disaster warnings due to the lack of connecting roads highlighting infrastructure challenges. Rendana et al. [44] wrote a paper where they focused on shelter suitability mapping using geospatial technique and AHP for sustainable urban management. This study uses several factors, such as elevation, distance from rivers, and distance to settlements, which play a crucial role in determining suitable locations for shelters. The elevation was identified as a significant factor contributing to inundation events in the study area, with slope being the highest contributor, followed by elevation, drainage density, and distance to the river. The inundation risk map revealed that areas located farther from the river and at higher elevations were less vulnerable to inundation compared to lower-elevation areas.

Mallick [45] wrote a paper that empirically analyzed the utilization of cyclone shelters within a selected study area along the southwest coastal region of the country. The study examines how the placement of cyclone shelters can affect social dynamics and power structures in coastal Bangladesh. The study area lacks sufficient cyclone shelters, and only a small percentage of the population has access to paved roads near their homes, which could have an effect on shelter-seeking behavior during cyclones. Islam et al. [33], conducted a research study analyzing cyclone risk assessment and the need assessment of cyclone shelters in the coastal regions at the Upazila level. The study developed a framework to aid government decision-making regarding the strategic allocation of future cyclone shelter construction, with an emphasis on location-specific requirements assessment. The coastal region of Bangladesh

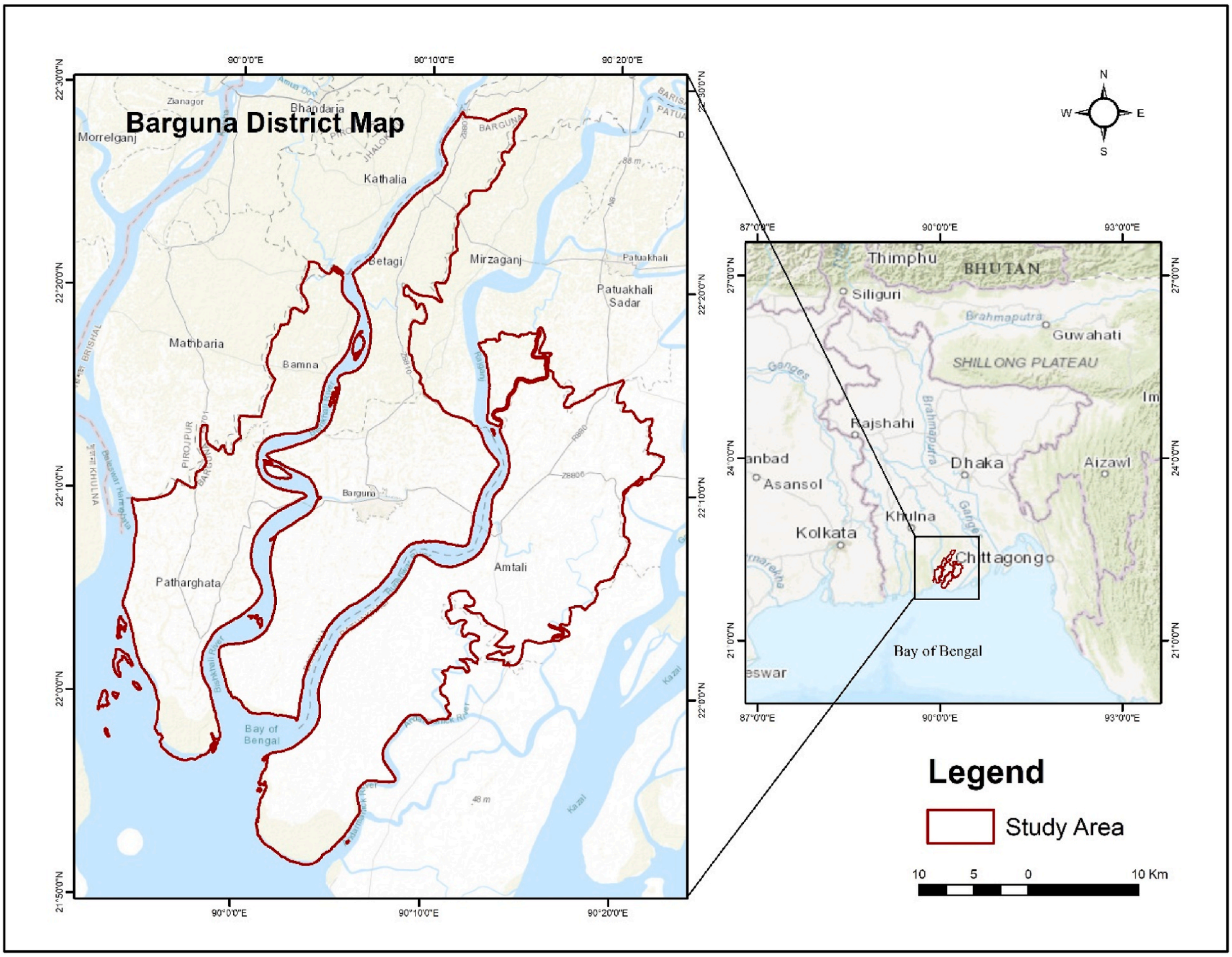

Fig. 1. Location map of the study area.

requires about 1800 cyclone shelters, as suggested by their research. Now the question arises as to which locations of cyclone shelters could ensure balanced distribution and effectively mitigate the death factors and non-evacuation issues mentioned earlier. This paper aims to identify suitable locations for cyclone shelters by integrating and examining all the criteria linked to the aforementioned non-evacuation and death factors using the analytical hierarchy process (AHP) with Geographic Information System (GIS) techniques. The findings of this paper may strengthen preparedness for response within the framework of the "Disaster Risk Reduction" strategy by allocating suitable sites for future CS and continuing the current progress of sustaining risk reduction efforts. It is important to consider factors like vulnerability to hazards, accessibility, and safety when deciding where to construct shelters. Therefore, the Multi-Criteria Decision-Making (MCDM) approach, which incorporates AHP and Geographic Information System (GIS) techniques, is a crucial element in this scenario. AHP has been proven effective in spatial planning, evaluating the suitability of a particular site, and natural hazard management. Furthermore, it serves as a practical tool for engineers, planners, and local authorities involved in complex decision-making [46,47]. Currently, AHP is extensively used along with the amalgam of GIS to identify appropriate sites for shelters [40,44,48] as well as address various location-based challenges [49–53]. Therefore, in this study, the Analytic Hierarchy Process (AHP), a tool for analyzing multiple criteria in decision-making, is selected to determine the relative importance of each criterion. Simultaneously, geospatial techniques facilitate the creation of a site-suitability map for cyclone shelters through the extraction and integration of various spatial layers.

2. Materials and methods

2.1. Description of the study area

Bangladesh has borders with India in the western, northern, and northeastern areas. Bangladesh is also connected by its south-eastern and southern borders with Myanmar and the Bay of Bengal. The geographical coordinates of the Bangladesh locations are between 20°34′ to 26°38′ north latitude and 88°01′ to 92°41′ east longitude. It is organized into 8 administrative divisions and 64 districts geographically, which extend across 148,460 square kilometers [54]. Among those 19 districts, which consist of 147 Upazilas, they are considered a coastal zone with an area of 47,201 km^2 which is 32 % of the country [55,56]. The selected study area is Barguna district which is situated in the southern coastal region of Bangladesh. It is located between 89°52′ and 90°22′ east longitudes and 21°48′ and 22°29′ north latitudes. (Fig. 1). Barguna district is comprised of a total area of 1939 km^2 and a total population of 10,10531 individuals [21]. It is divided into a total of 6 Upazila and 45 Union (lowest administrative units of Bangladesh government system). The Payra, Bishkhali, Baleshwar, and Haringhata rivers flow through it. The study area is recognized as one of the most hazardous regions in Bangladesh due to its proximity to the Bay of Bengal. This location makes it vulnerable to a range of coastal phenomena, including severe cyclones, riverbank erosion, flooding, and salinity intrusion [56,57]. The southern region of Bangladesh has been struck by cyclones that have killed thousands of people, including SIDR (2007), Aila (2009), Foni (2019), and Amphan (2020). In the study area, 7.8 % of general households live in pucca houses, 6.8 % in semi-pucca houses, 84.5 % in kutcha houses, and the remaining 0.9 % live in Jhupri [21]. Therefore, most of the infrastructure is highly vulnerable to catastrophic events such as cyclones. As a result, the majority of individuals depend on cyclone shelters to protect their lives and property in the event of a cyclone. The absence of suitable cyclone-resilient housing poses a severe danger to the lives of individuals in the study area during cyclonic events [22] and that's why the study area Barguna is chosen due to its extreme vulnerability to cyclones.

2.2. Methodology

2.2.1. Data collection and preparation

This research employed a GIS-based multi-criteria decision-making approach, integrating the Analytical Hierarchy Process (AHP) to identify and map suitable areas for cyclone shelters in the study region. Spatial data layers of seven key factors-elevation, slope, land use/land cover (LULC), proximity to rivers, proximity to roads, proximity to hospitals, and population density were prepared and analyzed. Data were sourced from both primary and secondary sources (Table 1) to ensure comprehensive coverage and accuracy. The Digital Elevation Model (DEM) data, with a 30-m resolution, was obtained from the U.S. Geological Survey (USGS) and used to create topography maps, analyzing elevation and slope. Road network data were sourced from the Local Government Engineering Department (LGED) website, specifically focusing on primary and secondary roads. Hospital location data were also gathered from LGED and

Table 1
Data source of the study.

Data	Source	Year
Study area	DIVA-GIS	N/A
Digital elevation model (DEM)	USGS (SRTM 1 arc-second Global)	2014
Major roads	LGED (Local Government Engineering Department, Bangladesh)	2023
Major River	HydroSHEDS (HydroRIVERS)	N/A
Slope	DEM (SRTM 1 arc-second Global)	2014
Land use & Land cover	USGS	2023
Hospital	LGED (Local Government Engineering Department) of Bangladesh).	2016/1999
Population	BBS (Bangladesh Bureau of Statistics)	2011
Cyclone Shelters (Latitude and Longitude)	Field Survey (GPS)	2023

supplemented with field survey data using GPS machines. For land use/land cover (LULC) mapping, Landsat 8 Operational Land Imager (OLI) data from 2023 were obtained from USGS, with a 30-m spatial resolution and less than 10 % cloud cover to ensure accuracy. River shapefiles were extracted from the HydroRIVERS dataset, while population density data were collected from the Bangladesh Bureau of Statistics. The location data for 181 cyclone shelters were gathered through field surveys using GPS coordinates. Subsequently, the population density was computed using Equation (1) shown below and then included in the attribute table.

$$\text{Population density} = \frac{\text{Total number of People}}{\text{Total Land Area}} \tag{1}$$

2.2.2. Data processing and analysis

Data processing was performed extensively using ArcGIS 10.8 software. The DEM data were utilized to create elevation and slope maps of the Barguna district. The road and river shapefiles were clipped to the study area boundary using ArcGIS software geoprocessing tools, and Euclidean distance analysis was conducted to classify the distances of roads, rivers, and hospitals. The LULC map

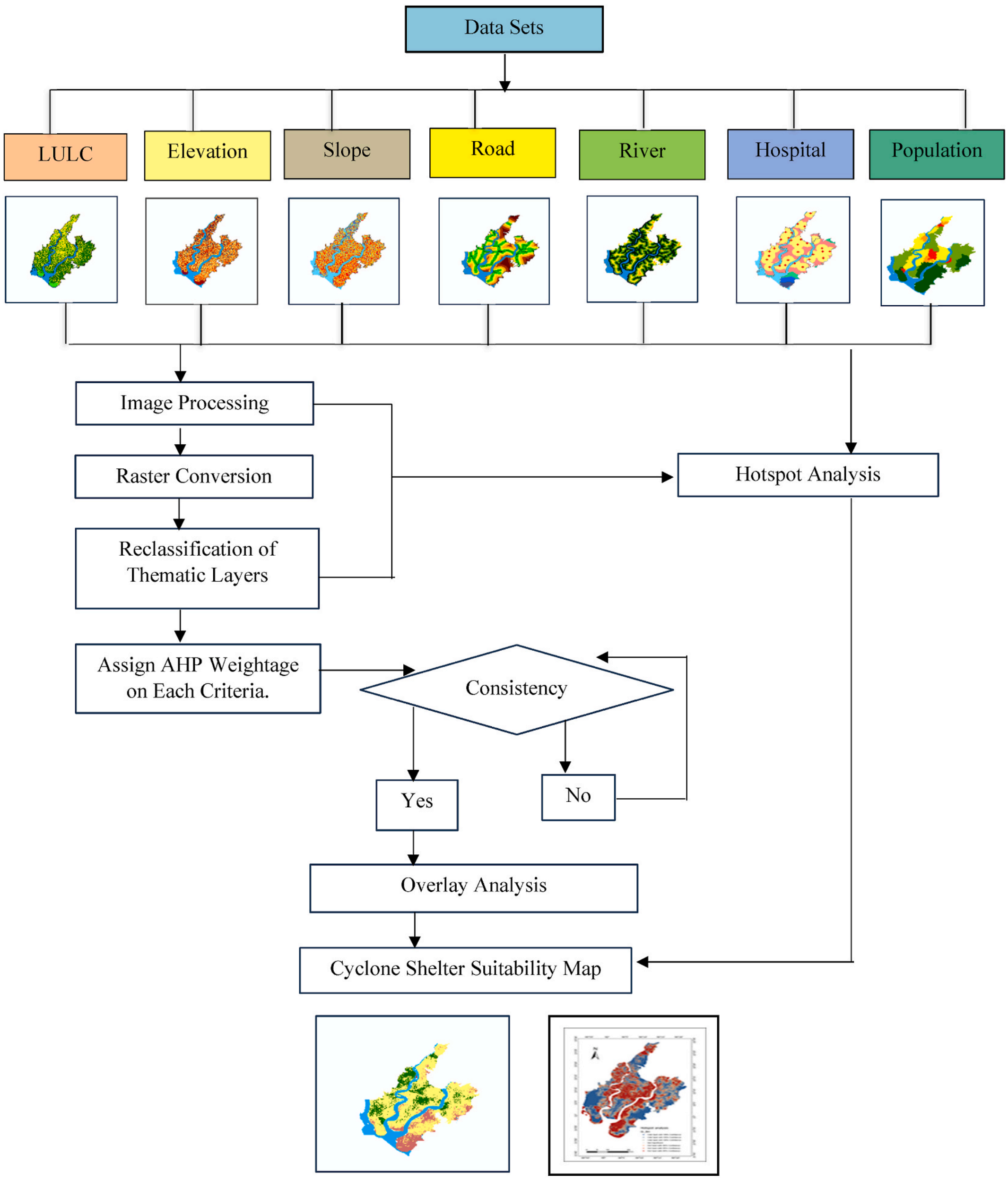

Fig. 2. Flowchart of Research methodology.

was created by merging Landsat image bands using the Composite Bands tool, then clipped to match the study boundary. The image was projected into the UTM Zone 46N to align with other spatial data. The stacked image was classified using the supervised classification maximum likelihood algorithm. This method was chosen because of its robust theoretical basis and its capability to classify image pixels into distinct classes by analyzing their spectral properties [58]. Afterward, five comprehensive LULC classes (water body, built-up area, vegetation, agriculture land, and barren land) were calculated based on interactive supervised classification. This classification allows us to evaluate the correctness of the land cover classification results generated from remote sensing data [59]. Approximately 100 ground-based training samples were created for each LULC class. Consequently, roughly 200 random points were selected as the ground truth point to compare it with the Google Earth Pro for accuracy assessment [60]. Finally, four distinct categories of calculations-user accuracy, producer accuracy, overall accuracy, and the kappa coefficient were employed to obtain precise accuracy values. User accuracy and producer accuracy are frequently used calculations to depict the respective class percentages within classified images [61]. The formulas for user accuracy (Equation (2)), overall accuracy (Equation (3)), producer accuracy (Equation (4)), and the Kappa coefficient (Equation (5)) were derived from this equation [62].

$$Users\ Accuracy = \frac{Number\ of\ Correctly\ Classified\ Pixels\ in\ each\ Category\ (Diagonal)}{Total\ number\ of\ Classified\ Pixels\ in\ that\ Category\ (The\ Row\ Total)} \times 100 \tag{2}$$

$$Producer\ Accuracy = \frac{Number\ of\ Correctly\ Classified\ Pixels\ in\ each\ Category\ (Diagonal)}{Total\ Number\ of\ Reference\ Pixels\ in\ that\ Category\ (The\ Column\ Total)} \times 100 \tag{3}$$

$$Overall\ Accuracy = \frac{Total\ Number\ of\ Correctly\ Classified\ Pixels\ (Diagonal)}{Total\ Number\ of\ Reference\ Pixels} \times 100 \tag{4}$$

$$\text{Kappa Coefficient}\ \left(\widehat{k}\right) = \frac{N\left(\sum_{i=1}^{r} x_{ii}\right) - \left(\sum_{i=1}^{r}(x_{i+} \cdot x_{+i}\right)}{N^2 - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})} \tag{5}$$

2.2.3. Cyclone shelter suitability analysis

Once all spatial layers were prepared, they were converted from vector to raster format. Each factor map was reclassified to a standardized scale from 1 (very low) to 5 (very high) using the reclassify tool in ArcGIS environment. The AHP model was then applied to assign relative weights to each factor. These weights were determined based on expert judgment and prior studies, reflecting the importance of each factor in determining cyclone shelter suitability. The final step involved integrating the reclassified layers through the weighted overlay method in ArcGIS to produce the final suitability map for cyclone shelters. This overlay highlighted areas of high suitability for cyclone shelters, offering crucial insights for disaster preparedness and mitigation strategies. All processing and map creation were conducted in ArcGIS 10.8, while Microsoft Excel 2019 was used for AHP analysis. The complete methodological framework employed in this study is illustrated in Fig. 2.

2.3. Analytical hierarchy process (AHP)

The Analytical Hierarchy Process (AHP) is a decision-making model that relies on a pairwise comparison matrix. It was first proposed by Myers and Alpert in 1968 and later developed by Saaty in 1977 [63–65]. The judgmental evaluation scale (Table 2) is used to compare criteria and determine their degree of dominance over the others in the AHP process [66–68]. In this research, AHP was used with geospatial methods to integrate different types of criteria for identifying suitable land for cyclone shelters in the study area. In our analysis of the AHP process, we are assisted by an expert from NGO personnel who are working in the development sector and government officials from LGED (Civil engineers) to aid in the assessment process. These experts provided invaluable insights and perspectives essential for evaluating the relative importance of factors involved in constructing suitable locations for cyclone shelters. Collaborating with experts allowed us to navigate the complex decision-making process inherent in AHP, ensuring a comprehensive and informed analysis. Various processes of the AHP methodology have been explored to determine weightage values for each criterion

Table 2
Analytical hierarchy process (AHP) evaluation scale by adopted from *Saaty, 1980.*

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent judgement	When compromise is required

Table 3
Random index (R.I) Value (Saaty, 1990).

n	1	2	3	4	5	6	7	8	9	10	11	12
(R. I)	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

and the consistency ratio (CR). Following Saaty's [69] recommendations, the study adopted a systematic approach to assign relative weights to each factor for cyclone shelters used in this study and we followed step-by-step procedures as outlined below.

1. Each factor was assigned a value ranging from 1 to 9 based on its relative importance in constructing the pairwise comparison matrix (Table 2). It is noted that on the scale utilized, 1 denotes equal importance, while 9 denotes extreme importance.
2. Subsequently, the normalized pairwise comparison matrix table was created by dividing each value in the column in the pairwise comparison matrix by the sum of the columns.
3. During the third stage, the weight of each factor was calculated by dividing the sum of each row in the normalized pairwise comparison matrix table by the number of seven factors in this study area.
4. Following the computation of weights for each cyclone shelter factor, the consistency check was conducted using equations (Equation (9)) to determine the correctness or consistency of the comparisons.
5. Finally, the consistency ratio (CR) was calculated using Equation (4) and if the consistency ratio (CR) exceeds or equals 0.10, it indicates an inconsistency in the pairwise comparison process, and it needs to be repeated until the CR value is below 0.10. If the determination of the consistency ratio (CR) is less than 0.10, it indicates that the pairwise comparison matrix has an acceptable consistency [69,70]. The following equations (6)–(9) were employed for AHP analysis and they are given bellows:

(I) To construct the decision matrix for each criterion.

	1	d_{11}	d_{12}	d_{13}	-	-	d_{1N}
	2	d_{21}	d_{22}	d_{23}	-	-	d_{2N}
DM X N =	*3*	d_{31}	d_{32}	d_{33}	-	-	d_{3N}
	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
	M	d_{M1}	d_{M2}	d_{M3}	-	-	d_{MN}

Attribute = 1 2 3 - - N.

(II) Geometric Mean (GM):

$$G.M = \left[\prod_{i=1}^{N} a_{ij}\right] 1/N \tag{6}$$

Where, G.M = To calculate the geometric mean (G.M) of the ith row.

(III) Normalized Weight:

$$W = \sum_{i=1}^{N} G.M \tag{7}$$

Where, W = To estimate the normalized weight of geometric mean of ith row.

(IV) The consistency ratio is explained as follows:

$$CR = \frac{CI}{RI} \tag{8}$$

Where, CR= Consistency Ratio,
RI= Random index.

(V) Consistency Index:

$$CI = \frac{(\lambda \max - n)}{(n - 1)} \tag{9}$$

Where, CI= Consistency Index.

λ_{max} = Maximum eigenvalue of the matrix
n = Dimension of the matrix.

2.4. Hotspots analysis for cyclone shelter suitability

A hotspot refers to a region exhibiting a higher concentration of events than would be anticipated under a random distribution. The Getis-Ord G_i^* statistic is an analytical tool that identifies seven distinct geographical patterns, along with corresponding confidence levels for either warm (hotspot) or cold (cold spot) conditions, expressed through the Gi Bin [71]. The Getis-Ord G_i^* analysis, developed from the study of point distributions or spatial clustering, enables the identification of these spatial patterns. The calculation of the G_i^* statistic follows the formulation provided in Equations (10)–(12).

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \overline{X} \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}{n-1}}} \tag{10}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\overline{X})^2} \tag{11}$$

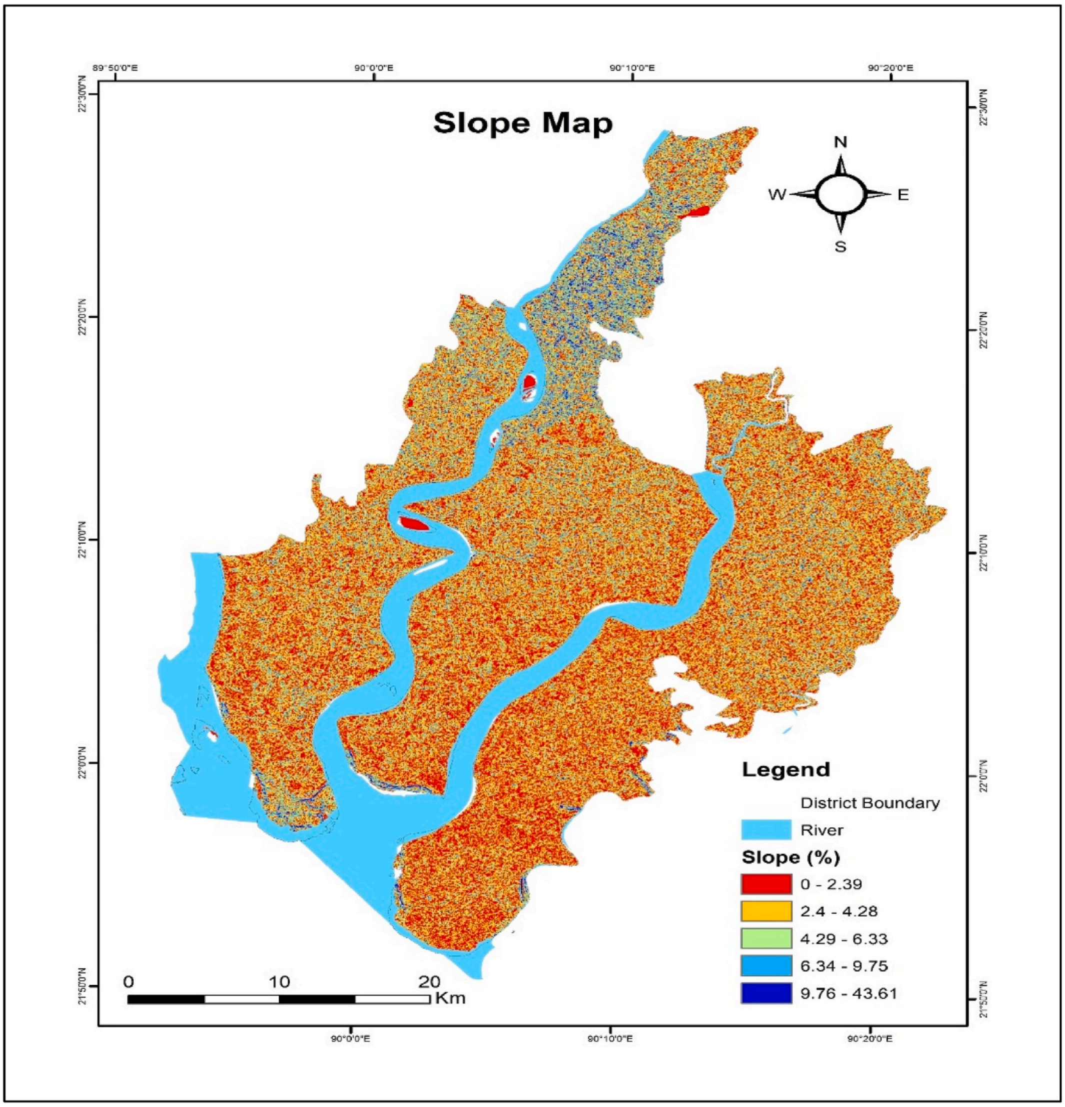

Fig. 3. Slope map of the study area.

$$\overline{X} = \frac{\Sigma_{j=1}^{n} x_j^2}{n} \tag{12}$$

where X_j represents the attribute value for feature j, $W_{i,j}$ denotes the spatial weight between features i and j, and n refers to the total number of features. The G_i^* statistic, represented as a z-score, serves to quantify the statistical significance of these spatial clusters.

3. Results

3.1. Slope

The slope is a distinct feature of the Earth's surface that is characterized primarily by its inclination towards a horizontal plane, which is a significant factor in choosing cyclone shelter locations [72]. Slope influences variety of geologic and geodynamic processes, such as surface flow velocity, soil moisture content, runoff infiltration rate, erosion potential, sedimentation quality, and so on [73–76]. The slope factor was derived from DEM data, and the slope map was generated using the ArcGIS software 10.8 including the slope tool. Cyclone shelters should be sited on a slope between 2 % and 5 %, not exceeding 7 % to ensure easy access for wheelchair users and efficient transportation of essential goods for local communities. The IFRC [77] have also emphasized the value of slopes in building suitable cyclone shelters. This research has identified five types of classes in the study area based on reclassification such as 0 %–2.41 % (Less suitable), 2.42%–4.17 % (Highly suitable), 4.18%–6.26 % (Suitable), 6.27%–9.47 % (Moderately suitable) and 9.48%–40.9 % (Not suitable). According to the reclassified slope map (Fig. 3), approximately 40.60 % (54370 ha) of the research area have

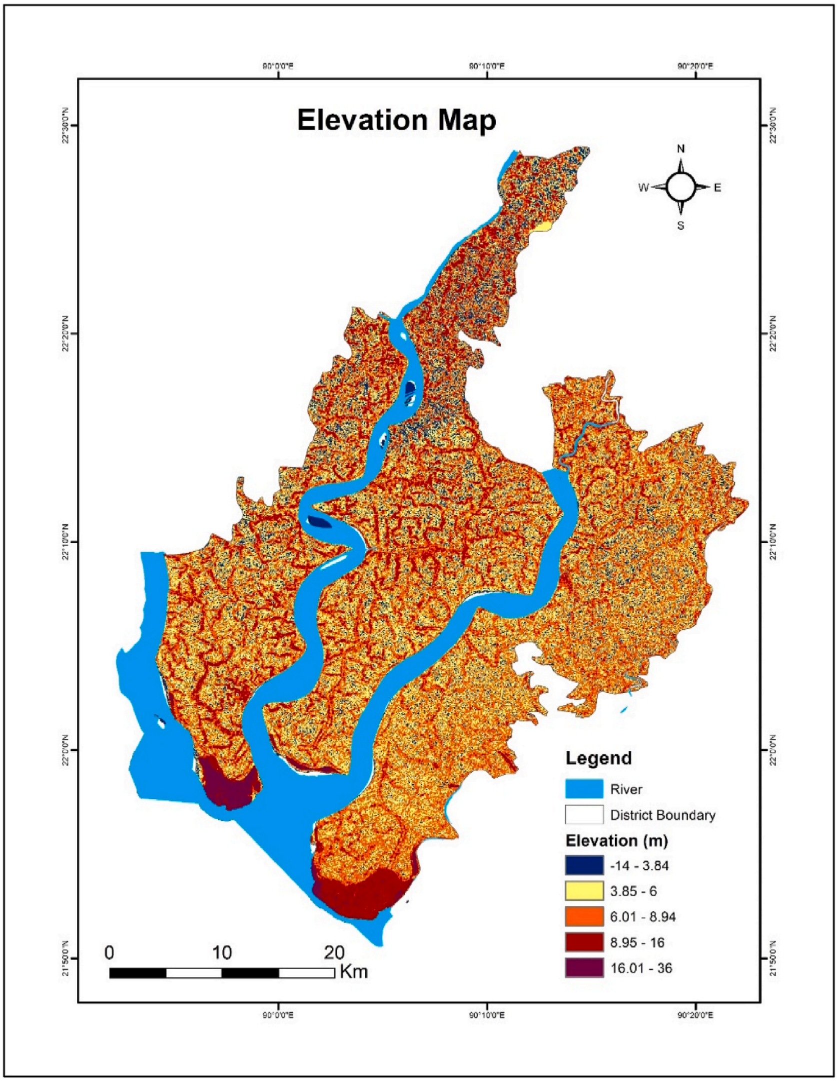

Fig. 4. Elevation map of the study area.

slopes ranging from 2.42 % to 4.17 % which are considered as highly suitable for existing or to construct future cyclone shelters. On the contrary, approximately 29.27 % (39,203 ha) of the study area exhibits less suitability, with only 21.58 % (28,896 ha) been deemed suitable and around 7.31 % (9789 ha) moderately suitable for cyclone shelter construction. Moreover, a small area of 1.24 % (1656 ha) is not suitable to construct cyclone shelters or which exist in those ranges, they are not favorable conditions in the study area of Barguna District.

3.2. Elevation

The coastal belt of Bangladesh is greatly benefited by the use of cyclone shelters to mitigate the devastating impact of cyclones. In cyclone-prone regions, shelters should be placed on elevated ground to reduce the risk of storm surges and flooding, particularly in coastal areas of Bangladesh. The ability of these shelters to withstand cyclonic winds and storm surges is directly influenced by the slope of the land on which they are situated. A gentle slope can facilitate proper drainage, prevent water accumulation around the shelter, and reduce the risk of structural damage from storm surge waters [75,78–80]. During cyclonic events, having an appropriately sloped terrain can assist in the smooth evacuation of residents and ensure the safety of local communities. The elevation map was created through ArcGIS software 10.8, and it ranges from −12 m to 32 m (Fig. 4). The map has been separated into five different categories according to their elevation intervals, which include: −12m–3.875m (Not suitable), 3.876m–5.945m (Less suitable), 5.946m–8.878m (Moderately suitable), 8.879m–15.95m (Suitable), 15.96–32 (Highly suitable). The investigation revealed that 62.01 % of the study areas were situated at an elevation range of −12 to 5.945 (84,045 ha). Additionally, 36.77 % of the regions (49,827 Ha) were found to be located at an elevation ranging from 5.945 to 15.95 m. Furthermore, 1.22 % of the areas (1655 ha) were situated at an elevation ranging from 15.96 to 32 m.

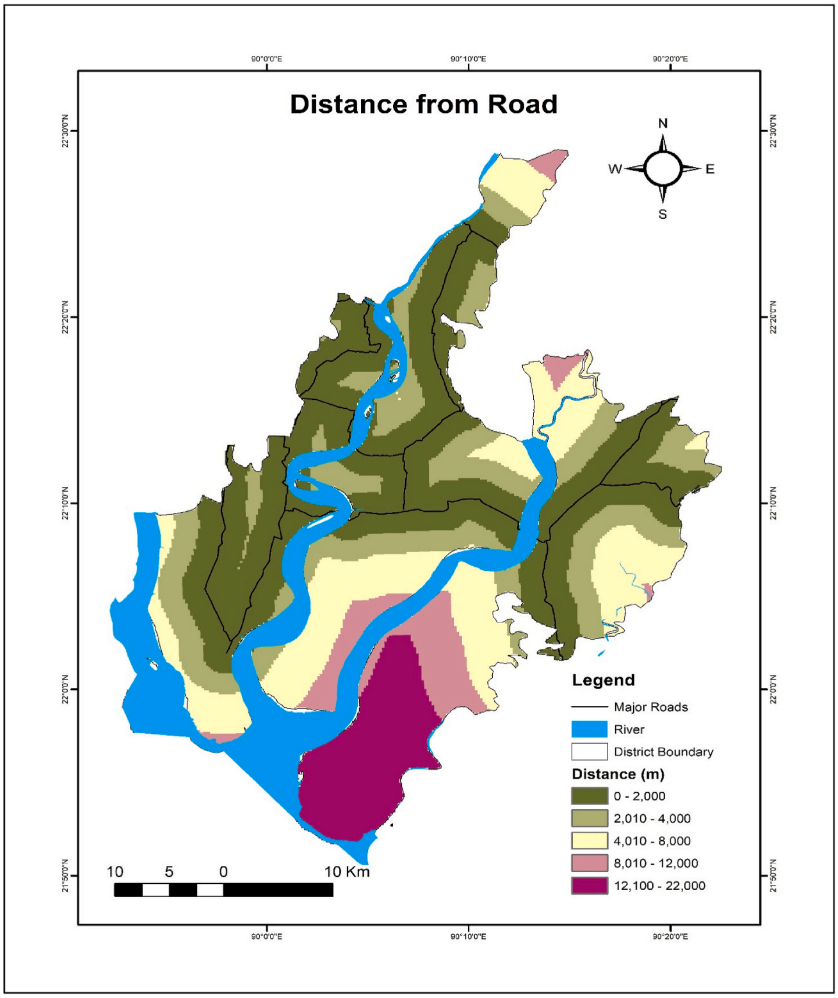

Fig. 5. Proximity of the cyclone shelter to road.

3.3. Proximity of the cyclone shelter to road

Road distance is crucial for cyclone shelter suitability since it impacts the time needed for evacuation shelters and the accessibility of the shelters for vulnerable populations. Until the water surge enters their courtyards, most Bangladeshi people do not go to shelters, which makes it challenging to walk more than 2 km. The majority of locals can only travel between 0.8 and 1 km to reach a shelter during a cyclone [81]. During past cyclones like SIDR, Gorky, and Aila, people were obstructed from going to shelters due to unleveled and undulating roads to the shelter, as well as surge water [29,30,34,38,82]. The World Bank-supported Multipurpose Disaster Shelter Project (MDSP) in Bangladesh has focused on constructing and improving existing disaster shelters, as well as building connecting roads and communication networks to ensure easy accessibility to the shelters [83]. Approximately 56 % of residents of the south-central region of Bangladesh were not willing to go to cyclone shelters during the disaster warning time simply due to the absence of a connecting road [43]. In this study, the Euclidean distance is used in ArcGIS 10.8.2 environment to determine the nearest road distance which is collected from LGED. Primary and secondary roads were considered to identify the suitable location for cyclone shelters. This research identified the road distance to cyclone shelters between 1 m and 1037 m as highly suitable (47,592 ha), between 1038 and 2333 m as suitable area (36,824 ha), and over 5617 m as unsuitable areas (9086 ha) for cyclone shelters (Fig. 5).

3.4. Proximity of the cyclone shelter to river

The design and placement of cyclone shelters in the study areas should take into account their proximity to rivers. Therefore, it is essential to consider the proximity of cyclone shelters to rivers to minimize exposure to storm surge waters and different types of hazards [84,85]. This is because the slope and elevation both rise with increasing distance [75,80]. Strategic placement of cyclone shelters away from rivers facilitates timely evacuation efforts and enhances overall resilience in vulnerable coastal regions of Bangladesh [86–90]. River-related data was taken from the HydroRIVERS data products of the website HydroSHED. The Euclidean

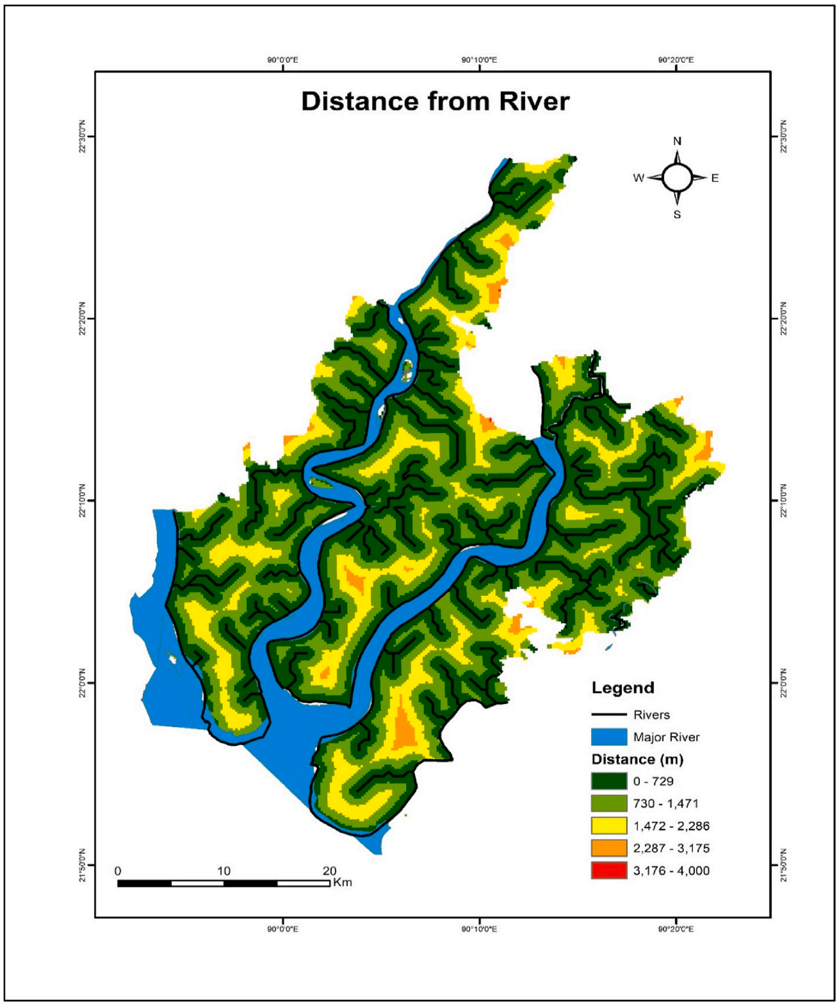

Fig. 6. Proximity of the cyclone shelter to river.

distance tool of ArcGIS software is employed in this research to determine the distance between the river and current cyclone shelters (Fig. 6). In the study area, regions situated at a distance of ranges 3921–6801 m from the river are classified as highly suitable areas (4382 ha) for the construction of cyclone shelters. On the other hand, locations located at distances of 2480m–3921m (43795.74 ha), 1440m–2480m (22450.39 ha), 640m–1440m (10449.12 ha) and less than 640 m (10449.12 ha) from the river are considered suitable (32.3 %), moderately suitable (16.6 %), less suitable (7.7 %) and not suitable (3.2 %) to cyclone shelters respectively.

3.5. Proximity of the cyclone shelter to hospital

During disasters, all of society is affected by physical trauma, water, and vector-borne infectious diseases, mental health effects, and more diseases [91]. In emergencies, disasters, and other crises, the lives and well-being of the affected population require healthcare facilities, particularly in time to build a resilient society. The hospital and clinic section provides quality healthcare to the local community that ensures universal health coverage [92]. In 1996 and 2006, the government of Bangladesh planned to open healthcare facilities so that villagers all over the country would receive basic healthcare rights at home in emergencies [93]. If healthcare facilities or hospitals are located near the cyclone shelters, community people can get timely medical services during the emergency period. The latitude and longitude of healthcare institutions were determined through a survey, and the ArcGIS Euclidean distance tool was utilized to determine the distance, similar to that of rivers and roads (Fig. 7). In the study area, five classifications were taken into account regarding the distance from the hospital such as highly suitable (1m–2,651m), suitable (2,652m - 4,740m), moderately suitable (4,741m - 8,276m), less suitable (8,277m - 13,580m) and not suitable (13,590m - 20,490m).

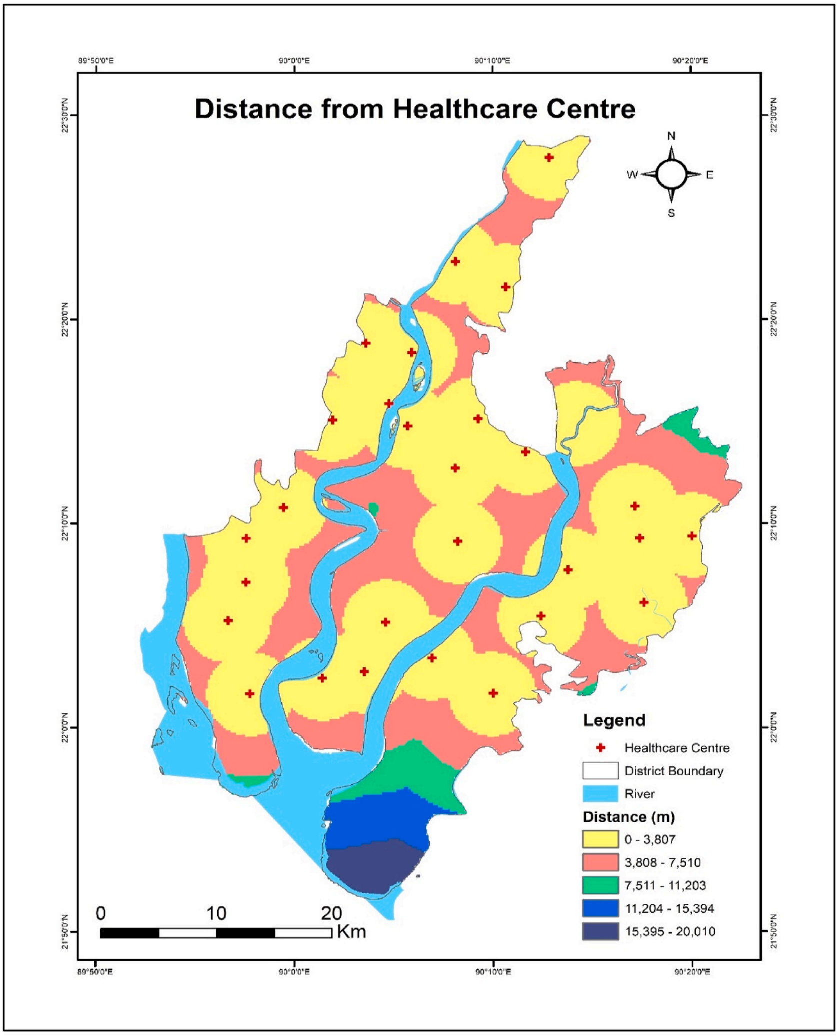

Fig. 7. Proximity of the cyclone shelter to hospital.

3.6. Land use and land cover

The use of land use and land cover is influential in determining suitable locations for cyclone shelters in the study area which are integral to environmental management and decision-making [94–96]. Areas with dense vegetation like mangrove forests or dense tree cover can act as natural buffers that reduce the impact of destructive cyclones and expert opinion has found that they are moderately suitable for constructing cyclone shelters. While agricultural lands are necessary for food security, it's important to consider their suitability for shelter placement. The Built-up areas, characterized by infrastructure and dense populations, may require enough shelters in those zones to ensure accessibility and minimize risks from cyclones. The lack of vegetation in barren land may result in limited protection against cyclonic winds and storm surges, making it highly desirable for shelter placement. When building multi-purpose shelters, preference should be given to open spaces in government and non-government schools, colleges, and madrasas, as long as these spaces aren't being used as playgrounds [97]. Additionally, water bodies like rivers is not suitable for the construction of cyclone shelters in the study area. It is imperative to integrate knowledge of land use and cover to identify the most optimal cyclone shelter locations in the study area. It will significantly enhance the effectiveness of these shelters in safeguarding vulnerable populations during cyclonic events. ArcMap 10.8. was used to extract the LULC map of the study area (Barguna) from the Landsat 8 image, which was collected from USGS (United States Geological Survey). The kappa coefficient of this LULC map is 80.25 % while the overall accuracy is 84.67 % (Table 4). The LULC map of the study area in this study is categorized as highly suitable (Barren land), suitable (built-up area), moderately suitable (vegetation), less suitable (agricultural land) and not suitable (waterbody) for constructing to cyclone shelters (Fig. 8). The suitable land use and land cover type is barren land (3563.28 ha), which encompasses approximately 2.26 % of the study area (Table 8). This land type is well-suited for the construction of cyclone shelters. On the other hand, the vegetation, agricultural land, built-up area and water body area are about 6.48 %, 45.43 %, 30.66 and 15.17 %, respectively.

3.7. Population density

Population density is a crucial consideration when building cyclone shelters. High population density areas are more susceptible to the devastating impacts of cyclones, which include increased risk of casualties, displacement, and infrastructure damage. Therefore, cyclone shelters need to be strategically located in densely populated areas to provide timely and accessible refuge for residents during cyclonic events. The shelters should be placed thoughtfully, close to vulnerable communities, ideally within 1.5 km, so people can reach them quickly in times of emergency. By being nearby, these shelters will allow individuals to seek safety quickly when disaster strikes [97]. By considering population density in the construction of cyclone shelters, the study area can enhance its resilience and mitigate the adverse effects of cyclones on its densely populated coastal communities. The population has been categorized into five distinct groups (Fig. 9) such as 256–552 per sq. km (Not suitable) 552–804 per sq. km (Less suitable), 804-1291 per sq. km (Moderately suitable), 1292–1987 per sq. km (Suitable) and 1988–2473 per sq. km (Highly suitable).

3.8. Analytical hierarchy process (AHP) analysis for cyclone shelter suitability

Following the reclassification of cyclone shelter suitability factors, an Analytical Hierarchy Process (AHP) analysis was conducted to determine the relative weights or influences of these factors for weighted overlay. This involved the development of a pairwise comparison matrix (Table 5), followed by the normalization of the comparisons and computation of factor weights (Table 6), all in accordance with the methodology outlined by Saaty (1987). Additionally, a consistency check of the comparisons was performed to ensure the reliability of the analysis. Table 7 and Fig. 11 represents the final weights assigned to each cyclone shelter suitability factor, indicating their respective estimated influences within the study area: elevation (17.61 %), land slope (7.1 %), distance from road (18.4 %), distance from rivers (6.1 %), population (24.2 %), land use and land cover (6.1 %), distance from the hospital (27.1 %). The Consistency Index (CI = 0.04) was computed using Eq. (9), employing the highest eigenvalue ($\lambda_{\max} = 7.532$) and the total number of factors (n = 07). Furthermore, the determination of the consistency ratio (CR = 0.06) was conducted using Equation (8). The CR ratio was calculated using a random index (Table 3) [65] of 1.32. The random index (RI) is subject to variation based on the number of factors involved, with different authors noting a value of 1.32 for seven factors [98–101]. With a calculated consistency ratio (CR) of 0.06 (6 %), the comparison is deemed acceptable for weighted overlay application, as it falls below the threshold of 0.1 (10 %).

3.9. Hotspot analysis for cyclone shelter suitability

The hotspot analysis for cyclone shelter suitability shows clear patterns of areas that are either more or less suitable for building shelters. Using the Getis-Ord Gi* statistic, the study mapped out these areas, classifying them as either cold spots, which have lower risk, or hot spots, which are higher risk to construct the cyclone shelters. These classifications were made with varying levels of confidence-99 %, 95 %, and 90 % giving a detailed view of where cyclone shelters might be most needed or least effective (Fig. 12). Hot

Table 4
Accuracy Assessment Calculations of the study area.

Year	Overall accuracy	Kappa coefficient
2023	84.67 %.	80.25 %

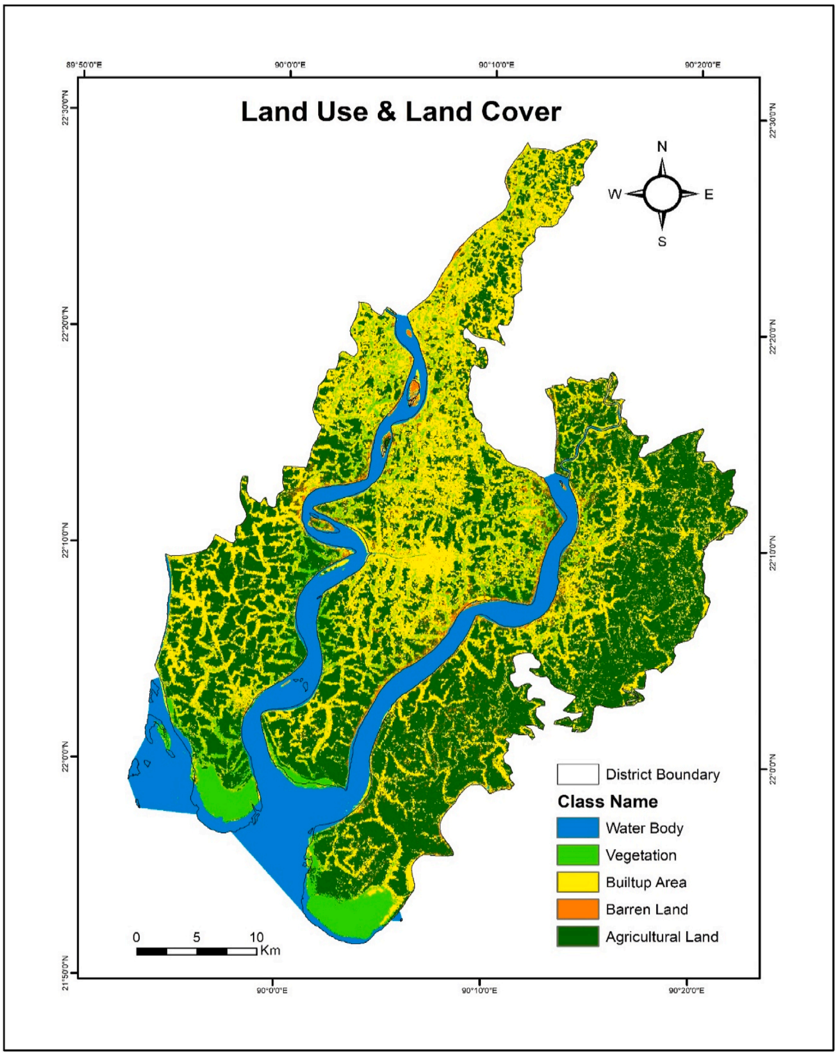

Fig. 8. Land Use and Land Cover of the study area.

spots are regions less suitable for cyclone shelters, often due to geographical or infrastructure challenges. Areas marked as Hot Spots with 99 % Confidence are particularly unsuitable, likely because they are in low-lying areas or far from key services like hospitals or roads. Even though Hot Spots with 95 % or 90 % Confidence are somewhat less certain, they still reflect significant limitations, often related to moderate distances from essential infrastructure or medical facilities. On the other hand, Cold spots highlight regions that are highly suitable for shelter placement. Areas classified as Cold Spots with 99 % Confidence are ideal locations, usually because they're close to major roads, hospitals, or situated on higher ground. These areas are strong candidates for cyclone shelters. Although Cold Spots with 95 % or 90 % Confidence are slightly less definitive, they still offer good potential for shelter development, providing moderately favorable conditions. Finally, some areas were classified as "not significant", meaning they didn't stand out as either particularly suitable or unsuitable for the construction of cyclone shelters in the study area. These regions will need further investigation before deciding whether they are good locations for shelters. This study utilizes the classification of cyclone shelter suitability that is presented in Table 9.

4. Discussion

The construction of cyclone shelters in vulnerable coastal regions is imperative for mitigating the devastating impacts of cyclonic events on human lives and infrastructure [102]. In the study area where cyclones are a recurrent threat [103], identifying suitable locations for cyclone shelters is essential for enhancing community resilience and reducing the risk of casualties and damage. In this study, we employed a comprehensive approach integrating seven factors to develop a cyclone shelter suitability map for the Barguna District. The factors to be considered in determining cyclone shelter suitability using multi-criteria decision-making (MCDM) approaches are not fixed and there is no universal guideline for selecting these factors [104]. Therefore, this study focused on factors

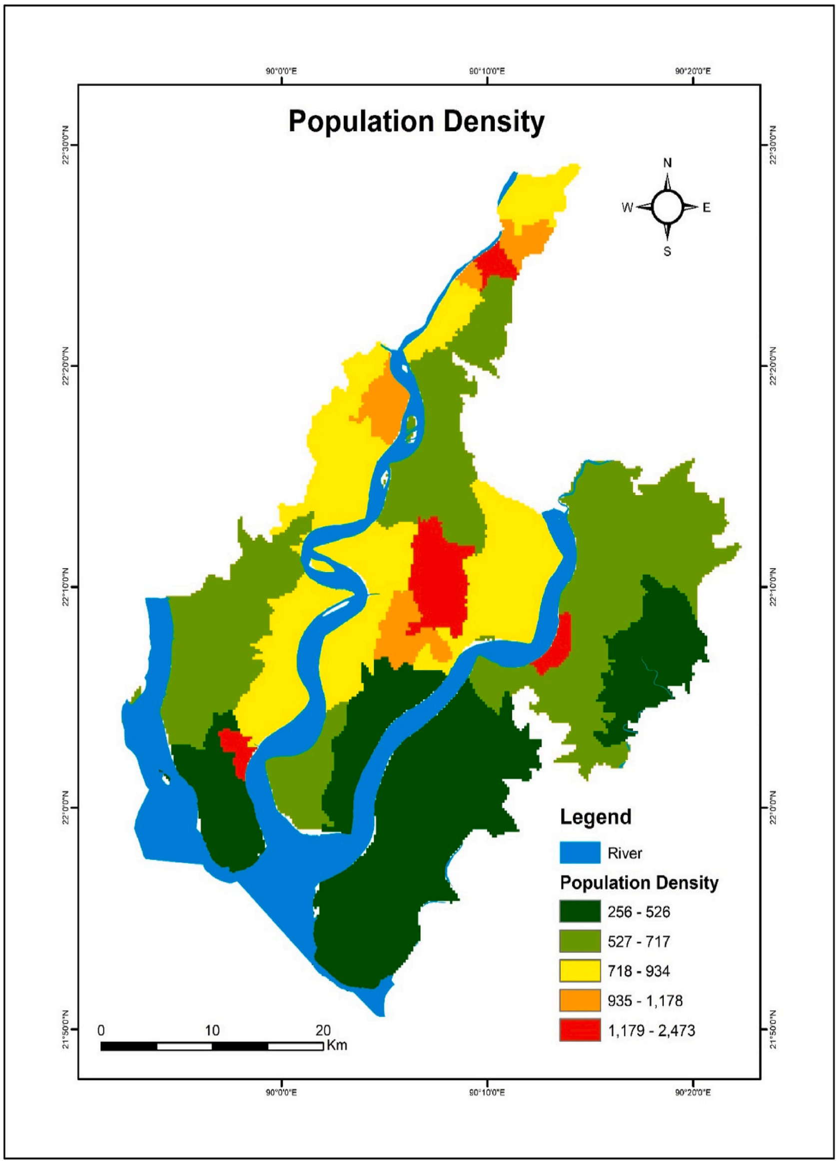

Fig. 9. Population density map of the study area.

Table 5
Pairwise comparison matrix for selected cyclone shelter suitability factors.

Criteria	Slope	Distance from road	Distance from river	Population	LULC	Hospital	Elevation	Normalized principal eigenvector
Slope	1	1/3	1	1/3	1	1/3	1	7.11 %
Distance from road	3	1	3	1	3	1	1	18.43 %
Distance from river	1	1/3	1	1/3	1	1/3	1/3	6.14 %
Population	3	1	3	1	3	1	5	24.21 %
LULC	1	1/3	1	1/3	1	1/3	1/3	6.14 %
Hospital	3	1	3	1	3	1	7	27.10 %
Elevation	1	1	3	1/5	3	1/7	1	10.88 %

including elevation, land slope, distance from roads and rivers, population density, land use and land cover, and distance from healthcare facilities, which were carefully considered to identify optimal locations for cyclone shelters. By integrating these factors, the research aimed to ensure the safety and well-being of coastal communities during cyclonic events which enhance community resilience in the Barguna District [105]. The application of weighted overlay integration prepared five distinct cyclone shelter suitability classes,

Table 6
Assigning a normalized weight and rating to each theme layer.

Criteria	Buffer zone (m)	Reclass	Rank	Suitability Class	Weight
Proximity to river *Locations closer to waterbodies are less desirable*	0–640.17	1	1	Not suitable	7
	640.18–1440.4	2	2	Less suitable	
	1440.5–2480.7	3	3	Moderately suitable	
	2480.8–3921	4	4	Suitable	
	3921.1–6801.8	5	5	Highly suitable	
Proximity to Road *(Locations closer to major transportation routes is more suitable)*	0–1037	1	5	Highly suitable	18
	1037.1–2333.3	2	4	Suitable	
	2333.4–3802.4	3	3	Moderately suitable	
	3802.5–5617.2	4	2	Less suitable	
	5617.3–11018	5	1	Not suitable	
Proximity to health care facilities *Locations closer to health facility are more desirable*	0 - 2651	1	5	Highly suitable	26
	2652 - 4740	2	4	Suitable	
	4741 - 8276	3	3	Moderately suitable	
	8277 - 13,580	4	2	Less suitable	
	13,590 - 20,490	5	1	Not suitable	
Total Population *(Higher populations are more desirable)*	256.2–551.8	1	1	Not suitable	24
	551.9–804	2	2	Less suitable	
	804.1–1291	3	3	Moderately suitable	
	1292 - 1987	4	4	Suitable	
	1988 - 2473	5	5	Highly suitable	
Slope *(Cyclone shelters should be located on a slope not exceeding 7 %, preferably between 2 % and 5 %. Slope gradient is important to ensure easy access for victims with wheelchair and for transporting goods)*	0–2.41	1	2	Less suitable	7
	2.42–4.17	2	5	Highly suitable	
	4.18–6.26	3	4	Suitable	
	6.27–9.47	4	3	Moderately suitable	
	9.48–40.9	5	1	Not suitable	
Elevation *Locations with lower elevation are less desirable*	−12–3.875	1	1	Not suitable	11
	3.876–5.945	2	2	Less suitable	
	5.946–8.878	3	3	Moderately suitable	
	8.879–15.95	4	4	Suitable	
	15.96–32	5	5	Highly suitable	
LULC	Vegetation	1	3	Moderately suitable	7
	Built-up Area	2	4	Suitable	
	Barren Land	3	5	Highly suitable	
	Agricultural Land	4	2	Less suitable	
	Water Body	5	1	Not suitable	

Table 7
The criteria weightage of cyclone shelters for the study area.

Criterion			Weights		+/−
1		Slope	7.1 %		1.7 %
2		Distance from road	18.4 %		4.8 %
3		Distance from river	6.1 %		1.6 %
4		Population	24.2 %		12.0 %
5		LULC	6.1 %		1.6 %
6		Hospital	27.1 %		19.5 %
7		Elevation	10.9 %		6.2 %
Result	**Eigenvalue**	Lambda:7.532	MRE: 43.9 %		
	Consistency Index: 0.04		GCI: 0.24	Psi: 3.8 %	**CR:** 0.06

providing valuable insights for decision-makers and planners in prioritizing shelter construction efforts and maximizing shelter effectiveness. There are 106,150.03 ha (84.21 %) of land in Barguna District that are suitable for shelter construction, including highly suitable (362.35 ha), suitable (21,024.47 ha), and moderately suitable (84,763.21 ha) land. Strategic selection of these lands is vital to maximize shelter effectiveness and protect coastal communities during cyclones (Fig. 10). However, it is important to acknowledge the challenges and limitations associated with identifying suitable locations for cyclone shelters. There is a high risk of shelter construction or potentially endangering existing shelters on the 19,775 ha (15.79 %) of lands that are not suitable (215 ha) or less suitable

Table 8
The area calculation of suitability for cyclone shelters in the study area.

Class	Area (ha)	Percentage (%)
Not suitable	214.60	0.17
Less suitable	19560.67	15.53
Moderately suitable	84763.21	67.31
Suitable	21024.47	16.70
Highly suitable	362.35	0.29

Table 9
Classification of cyclone shelter suitability based on Hotspot Analysis.

Hotspots	Zone
Hotspot 99 % Confidence	Extreme risk zone
Hotspot 95 % Confidence	Very risk zone
Hotspot 90 % Confidence	Moderately risk zone
Not Significant	Non-significant zone
Cold spot 99 % Confidence	Extremely safe zone
Cold spot 95 % Confidence	Very safe zone
Cold spot 90 % Confidence	Moderately safe zone

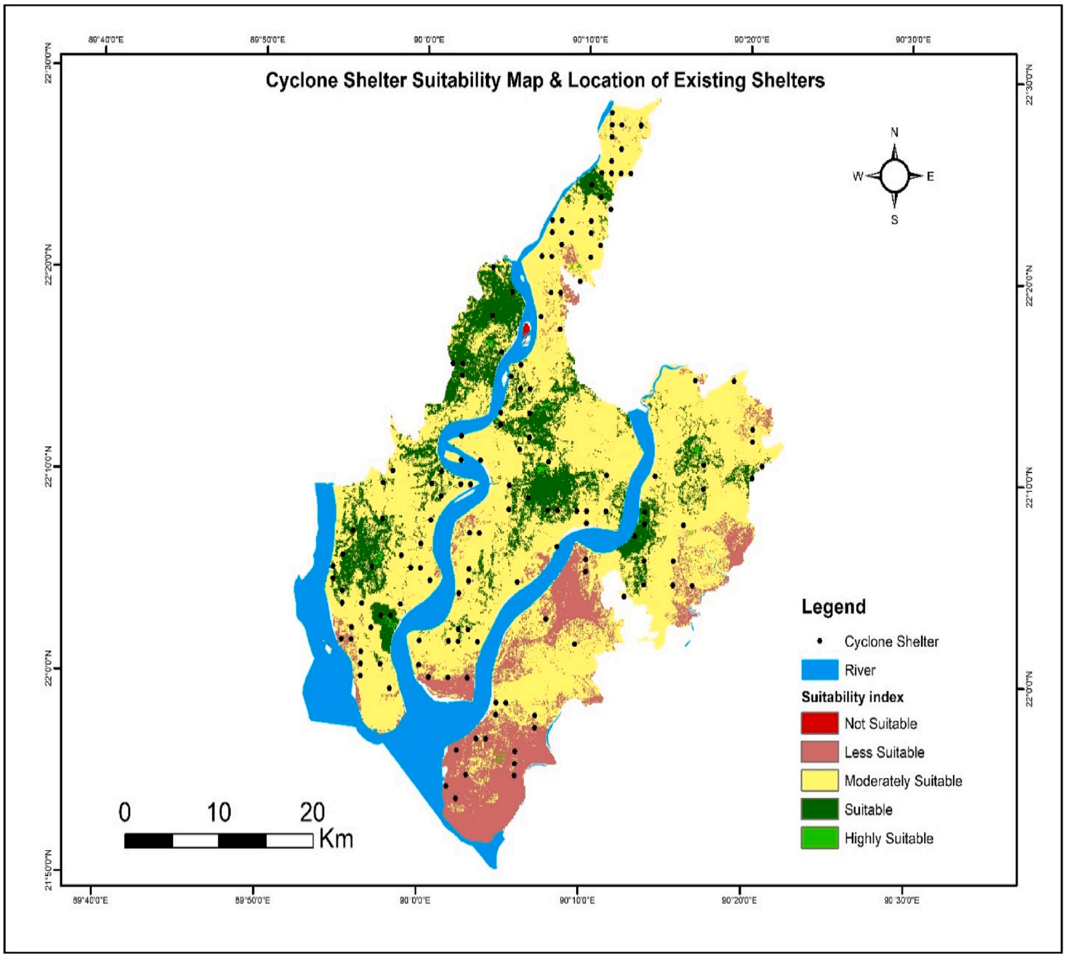

Fig. 10. The suitability of future cyclone shelters and the locations of existing shelters in Barguna District.

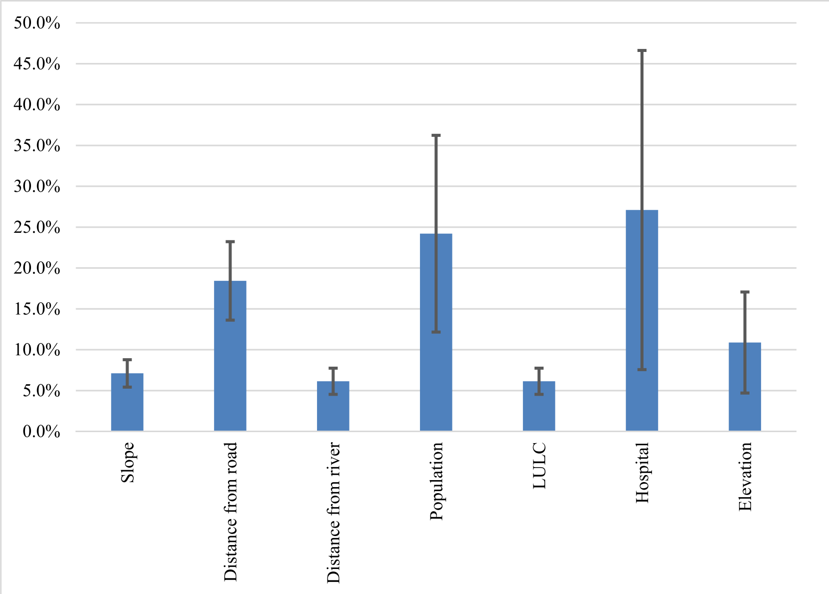

Fig. 11. AHP-based criteria weightage of cyclone shelter suitability for the study area.

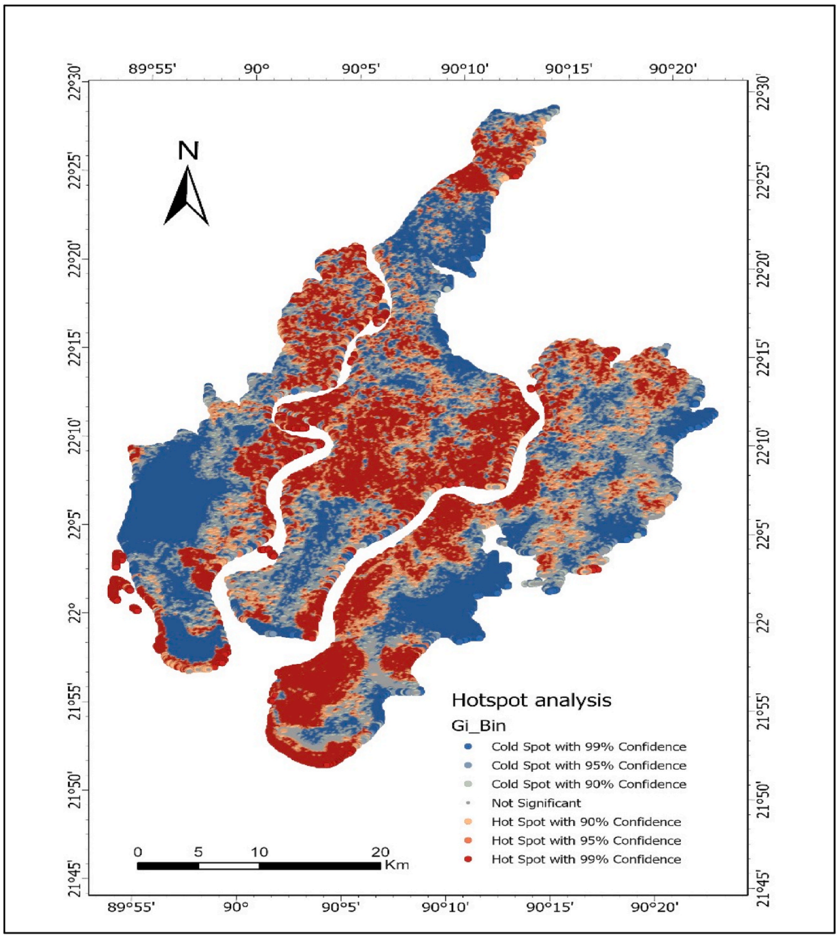

Fig. 12. Hotspot and Coldspot zones for cyclone shelter suitability based on hotspot analysis (Getis-Ord Gi*).

(1919561 ha). Different factors such as distance to hospitals, elevation, and proximity to river, distance from roads influence the suitability of these areas for shelter construction and must be considered in decision-making processes carefully. In contrast, the Hotspot analysis spatially categorizes the region into areas of high and low suitability, effectively illustrating where these influential factors converge. Hot spots identified through this analysis correspond to regions with optimal conditions for shelter placement, aligning with the high weights assigned in the AHP. Together, these methodologies enrich our understanding of cyclone shelter suitability by providing both a quantitative assessment of critical factors and a spatial representation of their impacts. This dual approach enables targeted interventions in high-suitability areas while acknowledging the limitations in less favorable regions, ultimately informing more effective disaster preparedness strategies.

The outcomes of the study hold relevance for directing resource allocation in rural planning efforts aimed at disaster management [102]. Concerns regarding disaster management in Bangladesh often revolve around the establishment of shelters in appropriate locations [106]. However, this crucial aspect is sometimes overlooked, resulting in the construction of shelters near influential elite villagers [40]. The establishment of cyclone shelters in coastal communities is not solely based on rights or demands but is influenced by the socio-political influence and affluence of local decision-makers [45]. In alignment with previous research by Paul [35] on cyclone Sidr, it was observed that approximately 17 % of individuals opted to return home due to overcrowding in cyclone shelters. Consistent with the findings of both Paul [35] and Mallick et al. [107], this study also highlights the deterrent effect of cyclone shelter distance and road conditions on evacuation decisions. Within the studied community, an estimated 55–65 % attributed their choice not to evacuate during Cyclone Aila to the challenges posed by distance and poor road conditions leading to cyclone shelters. Therefore, the roads leading to the shelters should be easy for everyone to use and connected not just to the main road but to all the surrounding local roads. If needed, the project for building the shelters should also cover the cost of these connecting roads. Moreover, the roads to the shelters must be safe and accessible for everyone, including women, children, the elderly, and people with disabilities. To make sure future cyclone shelters are built in the right places by various ministries, organizations, NGOs, and development partners, important factors like population density, access to roads, distance from existing shelters, and available land need to be carefully considered. This planning should use Geographic Information System (GIS) technology [97].

In the context of addressing these challenges, the integration of remote sensing, GIS techniques, and AHP emerges as a pivotal approach, offering unbiased scientific analysis to identify suitable locations for shelters [45]. Our study's findings, facilitating the visualization of sites with optimal potential for establishing such shelters, present a valuable contribution to this field. The findings presented in this study propose a mitigation approach for identifying optimal locations for cyclone shelters and contribute to the ongoing efforts to mitigate cyclone disaster loss and damages in the coastal districts of Bangladesh. Despite the valuable insights provided by this study on cyclone shelter suitability in Barguna District, several limitations warrant consideration. Firstly, the assessment mainly relied on available secondary data and methodologies, which may be subject to limitations in accuracy and comprehensiveness. Future research endeavors should aim to incorporate additional factors, such as climate change projections and community perceptions to enhance the robustness of shelter suitability assessments. Moreover, the dynamic nature of environmental and socio-economic factors underscores the need for ongoing monitoring and adaptive management strategies to ensure the relevance and effectiveness of shelter initiatives over time. Furthermore, while the study delineated suitability classes and highlighted strategic areas for shelter construction, the translation of these findings into actionable policies and interventions requires close collaboration with local stakeholders and policymakers. By engaging communities in decision-making processes and integrating local knowledge with scientific assessments, policymakers can foster more inclusive and contextually relevant approaches to cyclone preparedness and disaster resilience. Ultimately, the findings of this study provide a valuable foundation for guiding future research efforts and informing evidence-based policies aimed at enhancing cyclone preparedness and safeguarding vulnerable coastal communities. To ensure data quality and methodological robustness, the study implemented rigorous validation processes for remote sensing data and the multi-criteria decision analysis (MCDA) framework. The method of validation involved using the Analytical Hierarchy Process (AHP) for weighted overlay analysis, with consistency checks to assess reliability and robustness. Comparisons with ground truth data further validated the cyclone shelter suitability maps. Expert consultations enhanced the weighting process, contributing to the study's overall credibility and reliability [108].

5. Conclusion

Cyclones in Bangladesh are highly destructive phenomena that are impossible to prevent completely and they can be managed to mitigate the loss of life and resources by identifying the proper location of cyclone shelters. Cyclone shelters that are misplaced may result in higher casualties, infrastructure damage, and impeded evacuation, which can further enhance the impact of cyclonic events in the study area. Therefore, reliable information is essential for establishing an efficient and durable cyclone shelter that ensures safety during catastrophes. This study utilizes GIS-based multi-criteria decision-making alongside the analytical hierarchy process (AHP), which has been proven to be essential, economical, and highly effective in identifying and mapping areas for the suitable location of cyclone shelters, thus significantly improving cyclone risk management strategies in the coastal belt of Bangladesh. This research classifies the whole study area into five distinct zones and each characterized by varying degrees of suitability, ranging from not suitable to highly suitable.This paper states that approximately 1956 ha, 84763 ha, 21024 ha and 362 ha of the land area in Barguna district are regarded as less suitable (15.53 %), moderately suitable (67.31 %), suitable (16.70 %) and highly suitable (0.29 %) for the best zone of cyclone shelters construction. The unsuitable (215 ha) and less suitable (19561 ha) lands, totaling 19,775 ha (15.79 %), pose a high risk for shelter construction or potentially endanger existing shelters. The use of Hotspot and Cold Spot analysis, which uses 99 %, 95 %, and 90 % analysis, is effective in identifying significant clusters of high and low values within spatial data, which provide crucial insights for targeted decision-making. It assists in resource allocation, risk assessment, and strategic planning by revealing patterns of concentration. By continuing to use this analysis and validation, we can improve our understanding of spatial dynamics and achieve better results. The study's results are directly applicable to regional disaster risk management policies, providing actionable insights that can inform policy decisions and strategic planning. By identifying specific shelter construction sites, the research helps establish targeted investment strategies in disaster-prone areas, leading to improved preparedness and response capabilities at both local and regional levels. After modifying the essential criteria, data type and scale this verified approach can be applied in other similar environments for mapping to cyclone shelter suitable locations for different regions. The significant limitation of this research is the exclusion of climate change data in the analysis of cyclone shelter suitability. Future research should integrate climate change projections to ensure that the identified shelter locations remain effective and safe in the face of changing climate conditions.

CRediT authorship contribution statement

Irteja Hasan: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Md Omar Faruk:** Writing – original draft, Visualization, Software, Resources, Formal analysis. **Zarin Tasnim Katha:** Writing – original draft, Visualization, Software, Resources, Formal analysis. **Md Osman Goni:** Writing – original draft, Visualization, Software, Resources, Formal analysis. **Md Shafiqul Islam:** Writing – original draft, Visualization, Software, Resources, Formal analysis. **Tapas Ranjan Chakraborty:** Writing – review & editing, Validation, Investigation. **Sheikh Fahim Faysal Sowrav:** Validation, Investigation. **Md Shakhawat Hossain:** Resources.

Data availability statement

Data will be made available on request.

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.

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