Assessment of Physical Accessibility to Cyclone Shelters in the Exposed Coastal Area of Bangladesh by using Geospatial Approach

Asib Ahmed[1]*, Zannatul Ferdous[1], Md. Humayun Kabir[1], Obaidur Rahman[2], Rezwan Ahmed[1] and Md. Abu Ryhan[1]

[1]Department of Geography and Environment, University of Dhaka, Dhaka 1000, Bangladesh
[2]Department of Geography, University of Utah, USA

Manuscript received: 11 September 2024; accepted for publication: 04 December 2024

ABSTRACT: The geographical positioning of coastal Bangladesh makes it more exposed to cyclonic events. Building cyclone shelters is a vital strategy for reducing the risk of natural hazards in the coastal area of Bangladesh. But often they are not easily accessible and well facilitated. This paper aims to assess the accessibility of current cyclone shelters in six upazilas of the coastal region of Bangladesh. AccessMod 5 tool was used to simulate travel time to cyclone shelters, providing insights into shelter accessibility and aiding in identifying areas requiring infrastructural improvements. Referral analysis was used to calculate optimal routes and travel times between starting points and cyclone shelters and zonal statistics to assess areas or populations within specific travel times to shelters. The coverage analysis for the study area was carried out to shed light on the existing coverage of cyclone shelters across its districts. Cyclone shelters in the southeast of the study area have longer travel times due to limited road accessibility; which makes delays for 30 to 60 minutes. People can reach cyclone shelters within 30 minutes in Char Fassion. In comparison, Barguna Sadar poses challenges, especially within the one-hour criterion. While some unions show reasonable accessibility metrics, others, particularly in the southeast, highlight the urgent need for infrastructure and strategic improvements to ensure optimal cyclone shelter accessibility.

Keywords: Coastal Area; Cyclone; Cyclone Shelter; Vulnerability; Accessibility; AccessMod

INTRODUCTION

Climate change has been exacerbating multidimensional vulnerabilities in coastal Bangladesh, making it crucial that people understand how it affects coastal living (Ahsan et al., 2024). Tropical cyclones have emerged to be an alarming global concern, affecting around 22 million people and leading to an average annual economic loss of about USD 29 billion (Hasan et al., 2024; Geiger et. al., 2018). There is a chance of more powerful cyclones increasing gradually by 2% to 15% every decade, mainly due to the adverse effects of global warming (Sugi, 2016). Establishing a network of cyclone shelters is a pivotal strategy to mitigate cyclone risks in coastal areas (Miyaji et al., 2020). The effectiveness of these shelters in reducing coastal disaster impacts hinges on enhancing their physical accessibility (Faruk et al., 2018; Shahin et al., 2020). Yet, accessing these shelters poses significant challenges, especially for vulnerable groups. The shelters' locations greatly affect their usage, as distant shelters may deter potential users (Hayat et. al., 2021). Although placing shelters near every community may not be economically viable, ensuring physical accessibility including road networks, proximity and availability of transport (Roy et al., 2015). Identifying vulnerable populations and improving their access to shelters is crucial to minimize travel times as well as possible loss.

Bangladesh's geographical features and high population density make it particularly prone to climate-related disturbances (MoEFCC, 2022). The southern part of the country faces numerous climate challenges such as cyclones, storm surges, salinity intrusion, drought, coastal flooding, heavy rainfall and sea-level rise (Chowdhury et al., 2024; GED, 2018). Despite the country's proactive measures, there's a noticeable gap in disaster preparedness, leading to significant losses in human lives, livestock, and economic assets (Alam and Rabbani, 2007). The coastal belt, which houses 28% of the population across 19 districts and 147 Upazilas, is especially at risk of cyclonic damage and flooding due to its location (Alam et. al., 2017). The entire area

*Corresponding author: Asib Ahmed
Email: asib01geo@du.ac.bd

DOI: https://doi.org/10.3329/dujees.v13i2.79455

experiences severe cyclonic events roughly every five years (Paul et al., 2023). Despite national efforts to reduce these impacts, the current measures are often insufficient (Pechdin et. al., 2023). The focus must be on improving shelter accessibility for the most vulnerable communities. Over 2,500 cyclone shelters exist within this coastal region, but their accessibility is inadequate, and the infrastructure to combat cyclone threats needs enhancement (Faruk et al., 2018).

In coastal areas of Bangladesh, some research has been conducted (e.g., Hasan et al., 2024; Akon and Mia, 2024; Chowdhury et al., 2024; Arif et al., 2023; Islam et al., 2021) which are related to the overall condition of accessibility of cyclone shelters. As per the Cyclone Shelter Construction, Maintenance, and Management Policy 2011, shelter needs to be located within 1500 meters from the housing, but it has been found that nine shelters of Atulia Union, Satkhira, Bangladesh, are located more than 1500 meters away from the settlements, which are deviatory from the policy (Hayat et el., 2021). For that, inhabitants in remote catchment areas do not have shelters nearer to them. Cyclone shelters which are located on Kutcha Road, take longer to travel (more than 30 minutes) compared to Pucca Roads. According to Faruk et. al. (2018), among the 10 cyclone shelters of Nilganj and Tiakhali union of Patuakhali district, only six (06) shelters are easily accessible and have the best pattern for minimizing impacts of the cyclonic event during an emergency period. Moreover, Billah et al. (2018) reported that only about 12% of people in the Mirzaganj Union of Patuakhali district can get shelter by using evacuation routes that are shortest in distance and time.

Recent research by Faruk et al. (2018) has identified the scope for assessing the accessibility in Bangladesh's coastal region calls for a broader analysis that includes demographic and socio-economic factors. Hossain and Rahman (2018) suggest using GIS-based network analysis to map out cyclone shelter service areas, an area yet to be fully explored. Shahin et al. (2020) and Mallick (2014) argue for incorporating sustainable development into shelter management. Quader and Mahbub (2012) and Mahmood et al. (2014) note the absence of empirical studies on the strategic placement of shelters, which is vital for effective evacuation. Dhakal and Mahmood (2014) discuss the misalignment of international aid with shelter construction and management, highlighting a need for insight into their long-term impact. These findings point to the need for a holistic approach to improve the accessibility and functionality of cyclone shelters, especially given the increasing climate threats. Therefore, this study aimed to assess the physical accessibility of cyclone shelters in the exposed coastal area of Bangladesh. The study also visualized the present status of physical accessibility of the exposed coastal area. This study will allow decision-makers to identify gaps in infrastructure, ensuring that vulnerable populations are adequately served with accessible evacuation routes and shelters. Besides, local governments can prioritize resources, improve emergency preparedness, and foster community awareness and engagement based on the outputs.

Materials and Methods

Study Area

The coastal zone of Bangladesh is divided into three zones based on its geographical characteristics: the eastern zone, central zone, and western zone (Sarkar et al., 2024). The present study selected a total number of six upazilas in the central coastal zone (i.e., Barguna Sadar, Patharghata, Amtali, Kala Para, Galachipa, and Char Fasson) from three districts (i.e., Barguna, Patuakhali, and Bhola) (Fig. 1). More than 1.1 million people live in these three districts (BBS, 2024) and are highly exposed to extreme events such as cyclones, salinity intrusion, storm surges and floods (Chowdhury et al., 2024). The area features a predominantly flat topography, making it susceptible to flooding and salinity intrusion (Baten et al., 2015).

Study Workflow

Some major physical criteria (i.e., administrative zones, transportation networks, distances between home and shelters, travelling mode to go to shelters, traveling speed, and the capacity of shelters to accommodate people) were considered for analyzing the accessibility of cyclone shelters in the study area. A thorough field work was performed for questionnaire survey, Focus Group Discussion (FGD) and key Informants Interview (KII) to evaluate inhabitants' experiences about the accessibility of the cyclone shelters. The findings from these methods were analysed and compared with the results obtained from the model to validate the accuracy.

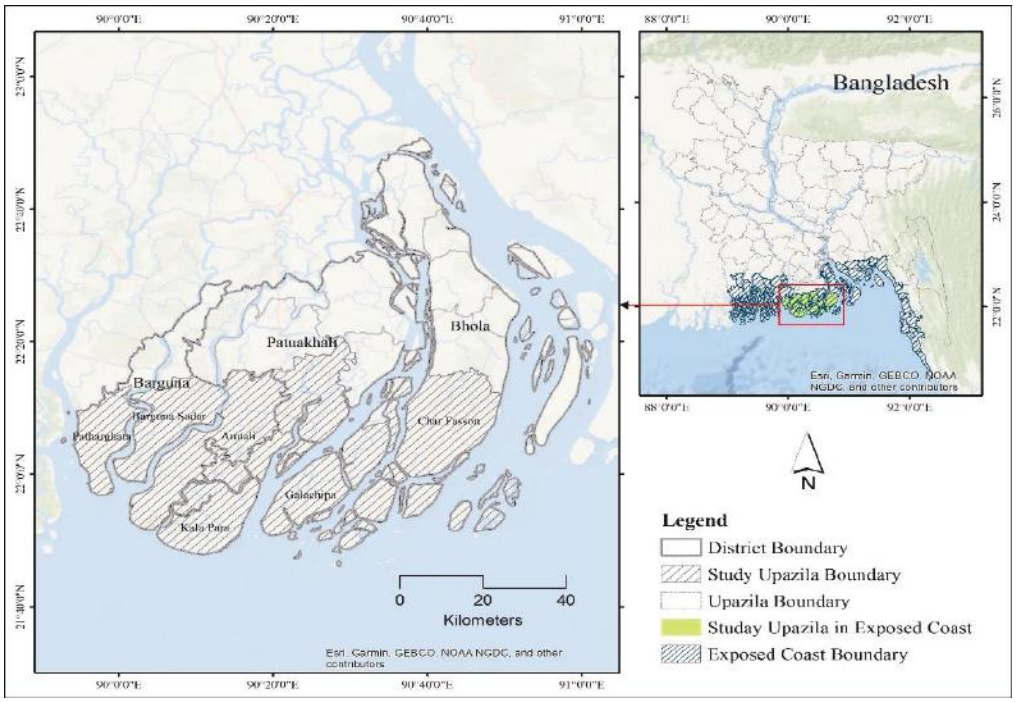

Figure 1: Locations of the Study in the Coastal Area of Bangladesh

The workflow included the steps shown below in Figure 2. In the initial phase, ArcGIS desktop was used to assess physical accessibility. It combines spatial layers that include cyclone shelters, road infrastructure, and other geographically important features like rivers and water bodies. This study utilizes the following datasets for a detailed analysis of the area's physical accessibility (Table 1: Data sources used in the study).

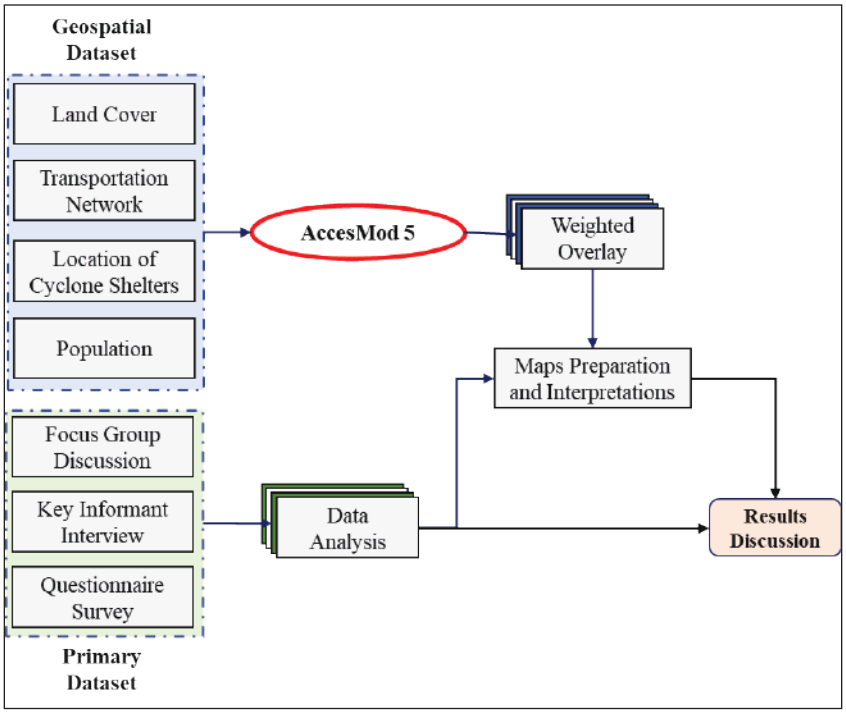

Figure 2: Methodological Workflow Followed for the Study

Table 1: Data Used in the Study

Dataset	Description	Sources
Land Cover Data	Identified land usage of the studied Upazilas. The classification includes waterbodies, agricultural tracts, barren land, vegetative zones, and urbanized regions.	EAS Sentinel 2A images (10-meter resolution)
Transportation Network	Detailed road networks and aquatic pathways data.	Roads and Highways Department (RHD)
Location of Cyclone Shelters	Adopted a two-pronged approach. Conducted field visits to physically verify shelter locations. Used analytical capabilities of GIS and Remote Sensing (RS) techniques.	Field visits and Local Government Engineering Department (LGED)
Population Data	Compiled a union-specific population dataset. Aimed at discerning the most populated unions within the study's purview.	World Pop and BBS datasets

The AccessMod 5 tool was used in this study to achieve the aim of the study. Additionally, the tool was employed to assess the spatial accessibility of existing health services, as developed by the World Health Organization (WHO). AccessMod uses a least-cost path algorithm to simulate the travel time needed to reach the destination (i.e., cyclone shelter) from any given location. This method operates on an impedance surface raster, which is created by combining various spatial information that includes elevation, land cover, road networks, riverine structures, and other relevant barriers (Ebener et. al., 2019). This tool is utilized not only to identify the physical proximity of existing services to their intended users but also to estimate the percentage of the population that, despite being within reach, might be underserved due to capacity constraints, both structural and non-structural.

The study used an automated workflow to refine population distributions by addressing barriers using AccessMod. This process relied on GIS tools to adjust the population distribution grid sourced from WorldPop, ensuring no individuals were allocated within "barriers". Initially, a temporary copy of the administrative boundaries' shapefile was created, which then underwent a masking process to derive a 'partial' population grid, obscuring the population on barriers. This involved integrating data values from the comprehensive (un-masked) and partial (barrier-masked) populations within each sub-national division. By calculating a ratio between these population datasets, population values were adjusted to achieve a proportional representation in correspondence with sub-national boundaries. This ensured that the redistributed population maintained congruence with the original dataset while obviating the barriers. Furthermore, assessing cyclone shelter accessibility within this region requires consideration of geographical attributes, transportation infrastructure, availability of shelters, and community challenges (equation 1).

$$Accessibility\ Score = \frac{Total\ Shelter}{Number\ of\ Accessible\ Shelters} \times Transportation\ Efficacy \times Community\ Barriers\ Coefficient \quad \text{(i)}$$

The capacity of the shelter and the accessibility score of the shelter are also considered by using the following formula (equation 2). Here, the total capacity of the shelter refers to the maximum number of individuals that the shelter can accommodate at any given time. The duration of shelter usability indicates the number of days in a year when the shelters are operational, considering factors such as maintenance and usage outside of cyclone periods.

$$Maximum\ Population\ Coverage\ of\ a\ Shelter =$$

$$(TotalCapacityoftheShelter)$$

$$\times\ (Duration\ of\ Shelter\ Usability\ in\ days/year) \quad \text{(ii)}$$

For these formulas (equation 1 and 2), the following factors were considered:

- A lack in the quantity and capacity of shelters, especially in areas with high population density
- The existence of numerous unpaved transportation paths, reduces their utility during cyclone events
- The presence of trees with shallow roots further obstructs evacuation processes
- Gaps in coordination between government and non-government organizations form obstacles to shelter access

Following this, a friction surface was developed that reflects the travel conditions based on various terrains and their influence on speed of movement in different directions, such as from north to south or east to west Next, a dataset pinpointing the locations of the existing cyclone shelters was integrated. Isotropic and anisotropic models were utilized to consider the constraints introduced by the terrain and other geographical features, including the Digital Elevation Model (DEM), in the computation of the cumulative travel time required to reach each shelter. These algorithms yield a detailed output, illustrating the areas where the time required to reach the shelters is significant.

The resultant analysis, visually depicted through maps such as friction and cumulative travel time maps, offers valuable insights into the accessibility of shelters during cyclonic events, aiding in identifying areas that may need infrastructural or logistical enhancements. Cyclone shelters were subsequently classified based on parameters specified by the user. These classifications can be based on specific values related to the shelter facility data. Alternatively, shelters could be ranked based on the total population within their catchment areas, considering specific travel times. Another sorting criterion could be the population contained within a user-defined radius around the shelter. Following these criteria, a geographical coverage analysis was conducted using the 'r.walk' algorithm from GRASS. This algorithm not only defines the catchment area but also produces a cumulative time distribution grid, highlighting the travel time metrics for various population subsets. A key part of the methodology involves aligning the shelter's capacity with the distribution of the population in the catchment area. A set of rules was established to guide this alignment process. In cases where a shelter's capacity is significantly less than the minimum cumulative population reachable within a short travel window (e.g., one minute), only the population within that time limit is considered, effectively eliminating any remaining capacity. On the other hand, if a shelter has a capacity that exceeds the maximum cumulative population reachable within the user-defined travel limit, the model calculates the excess capacity by comparing the shelter's capacity with the maximum accessible population. In situations where the shelter's ideal capacity matches the cumulative population for a specific travel period, the value of the remaining population is reset to zero until that time mark is reached. A more complex scenario occurs when the shelter's capacity fluctuates between the two extremes of minimum and maximum cumulative population metrics. In this case, the algorithm identifies the exact travel point at which the cumulative population exceeds the shelter's capacity. Based on this point, adjustments are made to the remaining population metrics.

Referral analysis, is designed to calculate the best routes between two distinct sets of locations. This is accomplished by starting with two sets of locations, one representing the starting point (the "From" set) and the other representing cyclone shelters (the "To" set). For each starting location, the optimal distances and travel times to all shelters were calculated, and tabulated. Besides, zonal statistics was used for a deeper understanding of the area or population covered within a specified travel time to the shelters. To carry this out, three layers were selected: population distribution, a pre-established travel time distribution, and zone boundaries. A maximum travel time is set as a filter, and cells from the travel time distribution that fall within this parameter are selected and converted into a raster mask. This mask, when overlaid on the population distribution, indicates the population that can be reached within the specified travel time. By including zone boundaries, the covered population of each zone can be determined, with the accessibility percentage being calculated as the ratio of the population within the travel time to the total population, multiplied by 100 (equation 3). It calculates the percentage of the population in a zone that can reach

a cyclone shelter within a specified travel time.

$$Accessibility\ Percentage = \frac{Population\ \ Travel\ Time}{Total\ \ Population} \times 100 \quad \text{(iii)}$$

The raster generated from this provides a solid basis for understanding the accessibility of cyclone shelters, which is a key aspect of disaster response and planning. A scaling-up analysis was then conducted to pinpoint the most appropriate locations for shelter centers, considering a network scale. This process amalgamates multiple variables to create a comprehensive map that illustrates the suitability of different areas, using an additive model approach. The first step is to identify exclusion zones. These zones mark areas that are not suitable for building cyclone shelters. They could be informed by various vector or raster datasets, such as regions susceptible to high flooding, areas with unstable land structures, or ecologically sensitive territories. A significant feature allows for the creation of buffer zones, ensuring that new shelters are not located too close to existing ones, thereby maximizing the reach and utility of the shelter. Once the exclusion zones are established, the focus shifts to assessing the suitability of areas outside these zones. Suitability is determined based on several factors: the population density within a certain radius, with priority given to areas with a higher population density that need quick access to shelters; proximity to critical infrastructure such as main roads or elevated terrains to ensure efficient evacuation routes; considerations of travel time to ensure that residents can reach shelters quickly in emergencies; and other crucial criteria for cyclone shelter placement, which can be encapsulated using generic priority maps. To measure the suitability, the following mathematical formula was used (Ebener et. al., 2019) (equation 4):

$$r = [0, 10000]$$

$$X = \frac{(X - Xmin) \times (rmax - rmin)}{Xmax - Xmin} + rmin \quad \text{(iv)}$$

$$S = \Sigma \frac{wi * Xi}{\Sigma wi}$$

Where:

r is the default suitability range

X is the standardized factor

S is the overall suitability

w represents the weights assigned to each factor

X_i represents individual factors

Once the initial setup is complete and the model is validated, the algorithm begins an iterative process. Each exclusion rule is applied to create a map of potential shelter locations. The methodology then focuses on the most suitable location for the establishment of a new cyclone shelter, marking its coverage area. This iterative process ends when any user-defined parameters, such as a specific coverage percentage or a desired number of shelters, are achieved.

After the initial study and analysis, questionnaire survey of 150 local individuals in the six Upazilas and KII of local governance and administrative figures (06), including the Upazila Chairman, heads of Union Parishads, and representatives from the Department of Disaster Management and Relief (DDMR) were conducted to gain insights on the geographical placement of cyclone shelters, the state of road connectivity, common transportation choices, and the challenges faced in enhancing and maintaining the accessibility of these vital shelters. Additionally, 06 FGD were conduction in six upazila with the local community.

RESULTS OF THE STUDY

The accompanying map outlines the accessibility of the designated cyclone shelters, with the transportation network being a crucial factor in assessing the feasibility of reaching these shelters. Notably, most of the cyclone centers across the six unions are not connected by paved roads.

By using AccessMod's coverage analysis, which is based on travel time and population metrics, the area's most vulnerable in terms of accessibility to cyclone shelters have been identified. The coverage analysis for the study area was carried out to shed light on the existing coverage of cyclone shelters across its districts. The cyclone shelters in the south-east have longer travel times (more than 30 minutes) according to the maps, due to limited road accessibility. Char Fassion shows relatively good accessibility where most of the people can reach the cyclone shelter within thirty minutes, while Barguna Sadar poses challenges, especially within the one-hour criterion. While some unions show reasonable accessibility metrics, others, particularly in the southeast, highlight the urgent need for infrastructure and strategic improvements to ensure optimal cyclone shelter accessibility (Fig. 5).

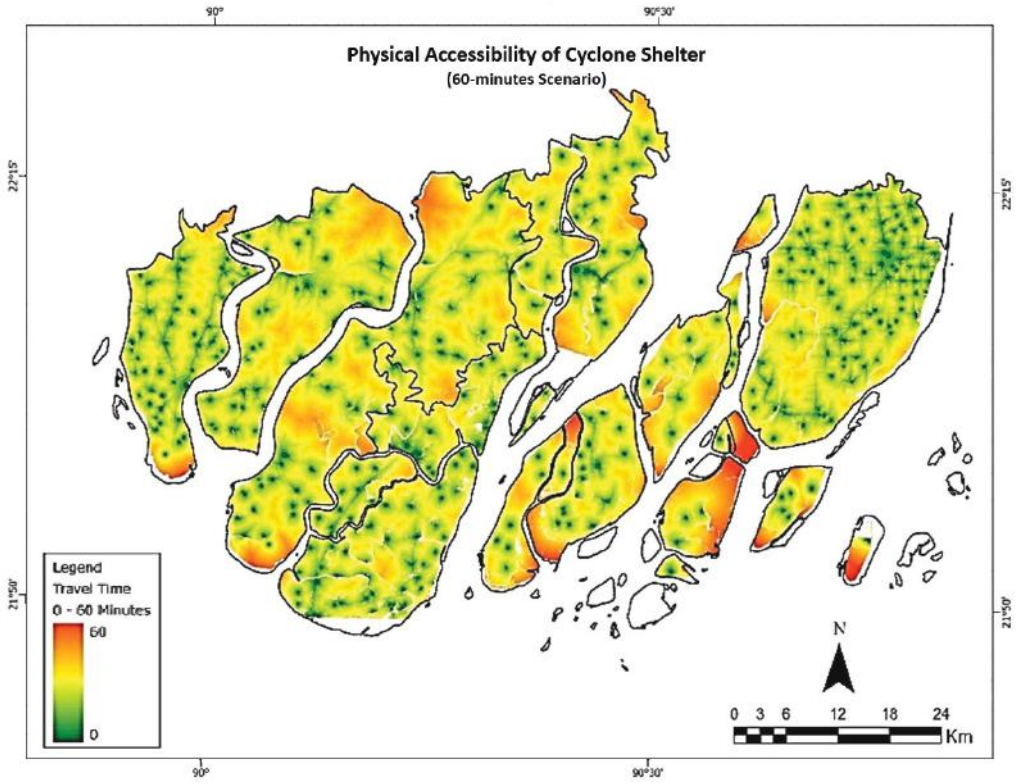

Figure 3: Physical Accessibility to Cyclone Shelters Under 60-Minute Scenario

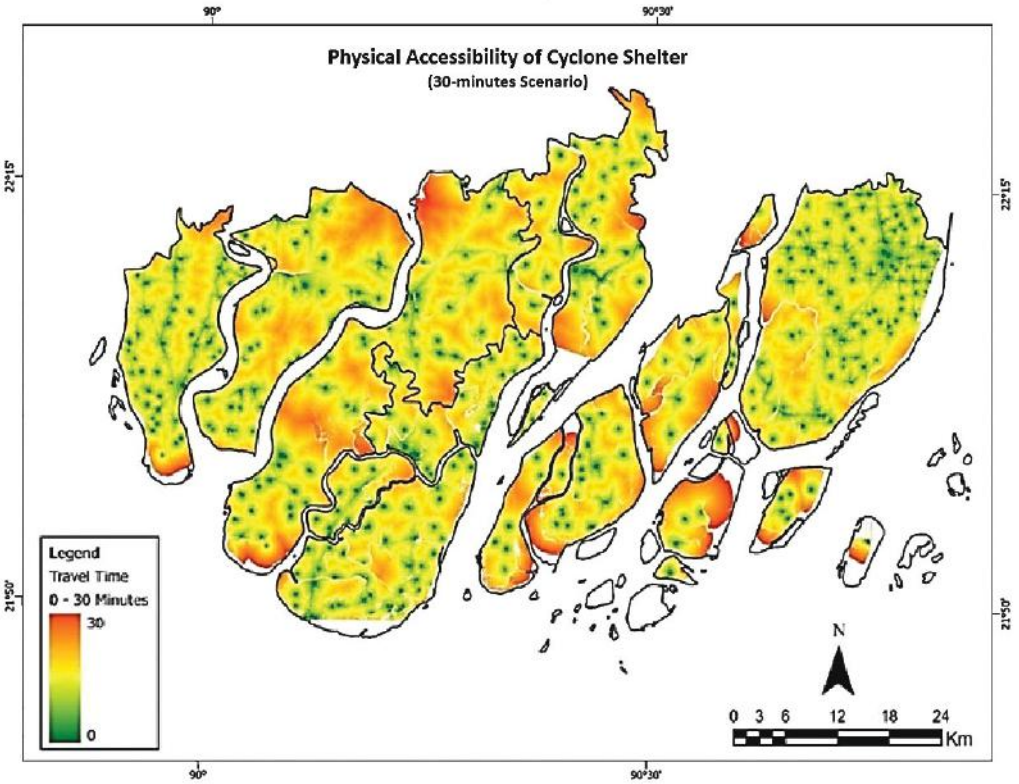

Figure 4: Physical Accessibility to Cyclone Shelters Under 30-Minute Scenario

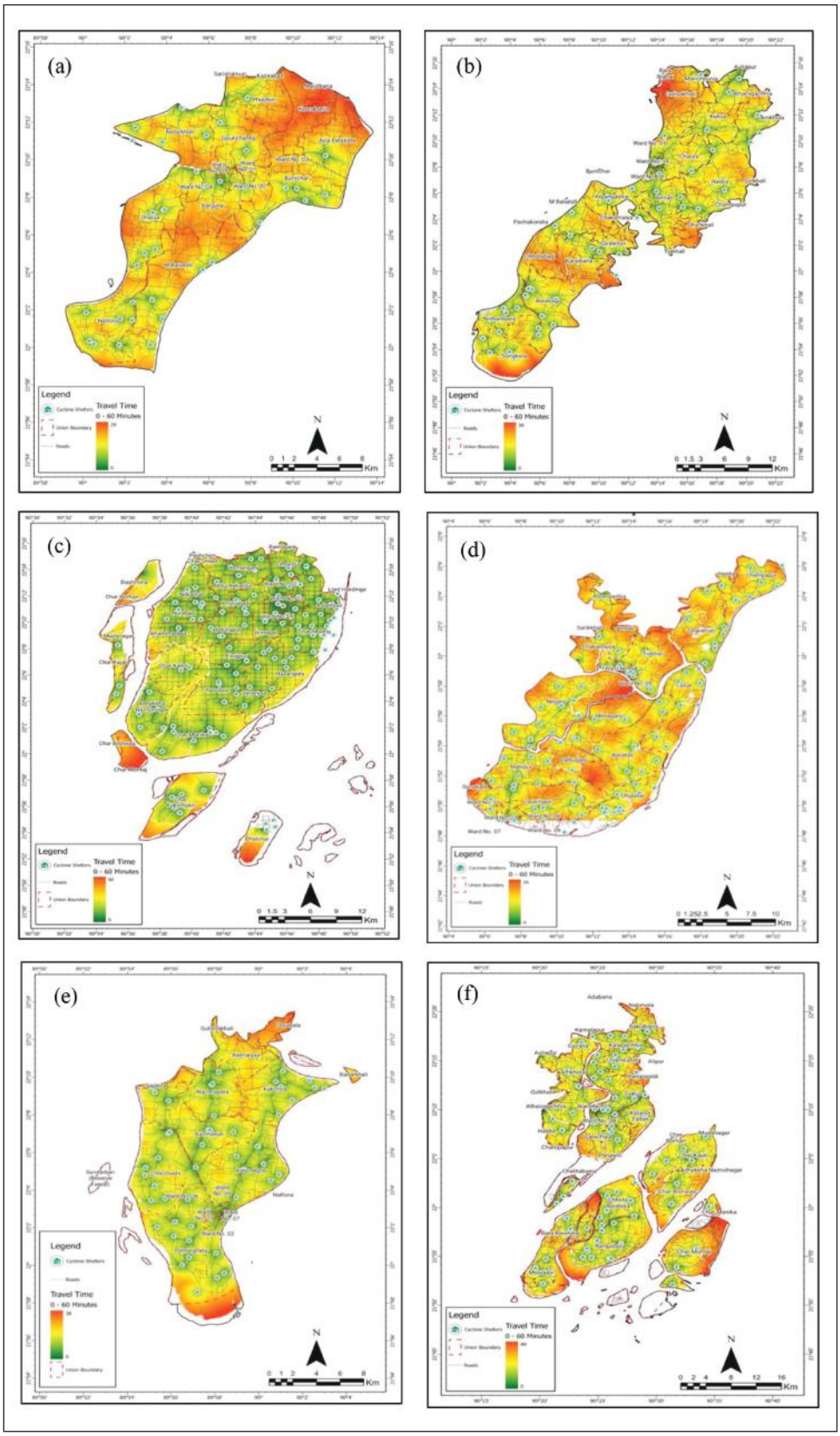

Figure 5: Physical Accessibility to Cyclone Shelters in Different Upazilas (a) Barguna Sadar, (b) Amtali, (c) Char Fassion, (d) Kalapara, (e) Patharghata, and (f) Galachipa

This research revealed significant challenges in physical accessibility and a lack of essential amenities during weather adversities. The union's freshwater resources are insufficient to meet the demands during disaster scenarios. Insights from the FGD and KII conducted within these unions underscore the community's urgent need for additional cyclone shelters and deep tube wells to cater to such a large population during cyclonic events or storm surges. The FGD on cyclone shelter accessibility in the study area identified significant barriers, notably communication challenges during cyclone events (Fig. 6).

Many respondents reported inadequate cyclone information and emphasized the need for improved communication from both governmental and non-governmental entities. While many rely on television for cyclone forecasts, power outages during disasters hinder electronic media access. Local authorities resort to hand mics for alerts, but reaching remote areas is problematic due to adverse weather and suboptimal transportation conditions. To validate the result, three cyclone shelters from each upazila were selected. Travel times to the nearest cyclone shelters were recorded. The result shows a strong positive correlation between the predicted and observed travel times with minor deviations. This deviation occurred due to variation in road quality, physical barriers and temporal variations in travel conditions.

Figure 6: Unimproved and Deteriorated Roads in the Study Area (Upper Left: Flimsy Bridge at Arpangashia, Upper Right: Dilapidated Brick Paved Road in Naltona, Lower Left: Broken Guard Rail on a Buckling Bridge at Char Kalmi, Lower Right: Makeshift Bridge at Naltona Near Bishkhali River

DISCUSSION

A thorough understanding of these geographical factors including proximity to rivers and the Bay of Bengal, prevalence of farming landscapes, and heighten the risk of cyclones etc. are crucial for effective disaster readiness and response in the area. The distribution of elevation differences across the landscape is not

evenly spread. The local governing body, responsible for the supervision and improvement of these road networks, admits that progress in this area has been slow. A noticeable lack of cooperative collaboration between government agencies and non-governmental organizations active in the region has hindered the development and maintenance of these transportation infrastructures. As a result, the continuously deteriorating condition of these roads intensifies vulnerabilities during cyclonic disturbances and related tidal surges. The degraded state of these transportation networks has had severe consequences, posing considerable risks to individuals traveling between locations during cyclonic events or subsequent storm surges. The power of strong winds can easily uproot trees with shallow root systems along these routes, increasing dangers and potentially leading to fatalities. There is a pressing need to improve the road conditions to ensure both the safety and efficiency of evacuations related to cyclones. This requires enhanced coordination and synergy among government bodies, non-governmental organizations, and local communities, with an emphasis on prioritizing the creation and maintenance of sturdy transportation infrastructure. Through such joint efforts, problems related to mobility during cyclonic incidents can be significantly reduced.

The findings from FGD, questionnaire survey and Key Informants Interview highlighted a significant coordination deficit between governmental and non-governmental entities, for instance, according to demographic data for Patharghata union, only five cyclone shelters serve a population exceeding thirty thousand individuals.

It was revealed from the focus group discussion that the populace's reluctance was a significant impediment to the utilization of cyclone shelters. Several factors contribute to this hesitancy: a subset of the population tends to dismiss cyclone warnings, opting to remain with their primary income sources, such as livestock. Furthermore, specific demographics, including individuals with disabilities, the elderly, and pregnant women, face challenges accessing these shelters. Predominantly, security concerns, particularly the potential loss of possessions and valuables during cyclonic events, deter individuals from seeking refuge. Women, in particular, express reservations due to the potential loss of ornaments, livestock, and produce. Despite these challenges, local governmental bodies actively strive to facilitate the evacuation of residents to cyclone shelters, recognizing the imminent threats posed by cyclones. Collaborative efforts with non-governmental organizations and volunteers aim to alleviate these concerns and ensure timely evacuation. Addressing these barriers is paramount for both governmental and non-governmental entities to safeguard lives and assets during cyclonic events. The FGD highlighted the extended travel time to cyclone shelters as a significant impediment to their accessibility. Participants indicated that the nearest cyclone shelters are considerably distant from their residences, necessitating extended durations to access . Compounding this challenge, the infrastructural pathways to these shelters often bear the brunt of prior cyclonic events, exacerbating the difficulty of travel. The scarcity of transportation amenities during disaster epochs further obliges individuals to traverse extensive distances to these shelters. Based on participant feedback, the predominant mode of transit to these shelters is pedestrian, as the prevailing transportation infrastructure becomes untenable for vehicular movement. Both local authorities, represented by the union chairman, and NGO representatives corroborated that such challenges are exacerbated during cyclonic events in regions such as Char Fassion.

In the study, participants were queried about their preferred mode of transportation to the nearest cyclone shelter. The data revealed that a predominant portion of the respondent's resort to walking. During cyclonic events, the local transportation infrastructure becomes compromised. Respondents highlighted that thoroughfares leading to the shelters often suffer damage from intense winds and substantial rainfall, rendering them impassable for vehicles. This challenge is further magnified by the insufficiency of transportation amenities during such disaster periods, compelling individuals to traverse significant distances on foot to access cyclone shelters. Local authorities, such as the union parishad, and NGO employees have also confirmed this situation in KIIs. People revealed that the situation in various unions worsens whenever a cyclone disaster occurs. The dearth of transportation infrastructure makes it difficult to evacuate people to the cyclone shelter in a timely manner, putting lives at risk. A primary issue is the vulnerability of short-rooted trees, which, due to their superficial root systems, are susceptible to the cyclone's potent winds and torrential rains. Additionally, damages to the protective barrage, which shields their dwellings from post-cyclonic tidal surges, emerge as a significant concern. The annual onslaught of hail during cyclonic events further exacerbates their plight, inflicting

substantial harm to crops and livestock. Notwithstanding these adversities, concerted efforts by local administrative bodies and non-governmental organizations are underway to alleviate the disaster-induced ramifications on the denizens of the study area. The collected data suggests that the existing cyclone shelters within the study area are inadequately equipped to accommodate the requisite number of evacuees during a disaster. Each shelter room can house on average 25 to 30 individuals, a figure substantially below the necessary capacity. This limitation results in overcrowding, posing particular challenges for women and children. Compounding these spatial constraints, the shelters are deficient in essential amenities, including food, potable water, and medical facilities. Respondents highlighted the scarcity of sustenance and clean water provisions. The absence of sanitary latrines further compromises hygiene standards, elevating potential health hazards. Women, in particular, grapple with concerns regarding the security of their belongings and valuables. Collectively, these suboptimal conditions render the cyclone shelters less conducive for habitation during natural calamities. The procured data also elucidates that the local governing body, tasked with orchestrating evacuations during cyclonic events, has instituted several amenities for the impacted populace within the study domain. Notably, the provision of shelter for both residents and their livestock emerged as a pivotal service rendered by the local administration. This authority also ensures the distribution of food and potable water, offers primary healthcare services, and prioritizes the well-being of vulnerable groups such as pregnant women, children, and the elderly. Furthermore, they facilitate transportation from high-risk zones to cyclone shelters. The data underscores the local government's endeavours to heighten public awareness regarding the imperativeness of timely relocations to cyclone shelters during such events. Cumulatively, the local government's interventions play an instrumental role in attenuating the repercussions of cyclones on both inhabitants and infrastructure within the surveyed region.

LIMITATIONS

This study on the physical accessibility of cyclone shelters in coastal Bangladesh presents valuable insights but also has several notable shortcomings. Firstly, the study primarily focuses on physical accessibility but does not adequately address other critical factors such as social, economic, and cultural barriers that affect shelter utilization. Secondly, it lacks detailed information on the conditions of existing shelters. Understanding the state of these shelters is crucial for assessing their effectiveness during emergencies. Thirdly, it lacks comprehensive community feedback on the result. Finally, we emphasized immediate infrastructural needs but did not propose long-term strategies for sustainable development and resilience building.

CONCLUSIONS

Undoubtedly, the study area faces significant challenges regarding the physical accessibility of cyclone shelters due to its location in the vulnerable coastal belt of Bangladesh. The combination of geographical complexities, infrastructural limitations, and community barriers exaggerates the vulnerability. Besides, its proximity to major waterbodies like the Bay of Bengal and rivers such as Bishkhali and Baleshwari, along with environmental factors like shallow-rooted trees and substandard road networks, exacerbate the risks during cyclonic disturbances. A key finding of this study is the glaring insufficiency of cyclone shelters in terms of their number and capacity, leading to overcrowding and compromised safety standards. This issue is further compounded by the lack of essential amenities, which are crucial for the well-being of evacuees, particularly vulnerable groups like women, children, and the elderly. The poor condition of the road infrastructure further intensifies the accessibility challenges. The frequent uprooting of shallow-rooted trees during cyclonic events and the poor condition of roads pose significant evacuation impediments, thereby increasing the risk for the populace. A noticeable gap in collaborative efforts among governmental bodies, disaster management entities, and non-governmental organizations has been identified as a major bottleneck. This lack of synergy hinders infrastructural development, maintenance, and the delivery of essential services during critical times. Specific regions, such as the Char Fassion union, with pronounced vulnerabilities, emerge as areas requiring urgent interventions. To safeguard the lives and livelihoods of the residents, there is an urgent need for a holistic approach. This approach should encompass infrastructural enhancements, strategic planning, community engagement, and robust inter-agency collaboration. Addressing these issues can substantially enhance the resilience and safety of inhabitants during cyclonic disturbances.

REFERENCES

Ahsan, M.N., Khatun, F., Abedin, N., Oni, F.A., Alam, M.I., Khatun, A., 2024. Adapting to adversity: unraveling the nexus between vulnerability and well-being in coastal Bangladesh. International Journal of Disaster Risk Reduction 112, pp.104798–104798. doi:https://doi.org/10.1016/j.ijdrr.2024.104798.

Akon, M. S., Mia, M. J., 2024. Performance of JICA funded cyclone shelter in the coastal areas of Bangladesh: An empirical analysis from Pirojpur district. Progress in Disaster Science 23, 100342–100342. doi:https://doi.org/10.1016/j.pdisas.2024.100342.

Alam, M., Rabbani, M.D.G., 2007. Vulnerabilities and responses to climate change for Dhaka. Environment and Urbanization 19(1), 81–97. doi:https://doi.org/10.1177/0956247807076911.

Alam, M.R., Kaish, A.B.M.A., Zain, M.F.M., Dev, S.K., Mahzabin, M.S., 2017. Vulnerability assessment and construction recommendations of local houses in the cyclone prone coastal areas of Bangladesh. International Journal of Disaster Risk Reduction 21, 118–130. doi:https://doi.org/10.1016/j.ijdrr.2016.10.010.

Arif, M.S.I., Mahdi, I., Rafi, M.A., Khan, S.J., Rahman, M.M., 2023. Cyclone exposure mapping in coastal Bangladesh: A multi-criteria decision analysis. Heliyon [online] 9(10), p.e21259. doi:https://doi.org/10.1016/j.heliyon.2023.e21259.

Bangladesh Bureau of Statistics (BBS), 2024. Population and housing census 2022, National report (volume I), ministry of planning, government of the people's republic of Bangladesh, Dhaka, Bangladesh, ISBN 978-984-475-201-6

Baten, M.A., Seal, L., Lisa, K.S., 2015. Salinity intrusion in interior coast of Bangladesh: Challenges to agriculture in south-central coastal zone. American Journal of Climate Change [online] 04(03), 248–262. doi:https://doi.org/10.4236/ajcc.2015.43020.

Billah, M., Sarker, S., Ansary, M.A., 2018. Cyclone evacuation route identification using GIS for coastal communities in Mirzaganj union, Patuakhali, Bangladesh. doi: https://doi.org/10.20944/preprints201810.0344.v1.

Chowdhury, K.J., Ali, M.R., Chowdhury, M.A., Islam, S.L.U., 2024. Climate change induced risks assessment of a coastal area: A 'socioeconomic and livelihood vulnerability index' based study in coastal Bangladesh. Natural Hazards Research doi:https://doi.org/10.1016/j.nhres.2024.06.005.

Dhakal, S.P., Mahmood, M.N., 2014. International aid and cyclone shelters in Bangladesh: adaptation or maladaptation? contemporary south asia 22(3), 290–304. doi:https://doi.org/10.1080/09584935.2014.931356.

Ebener, S., Stenberg, K., Brun, M., Monet, J.P., Ray, N., Sobel, H.L., Roos, N., Gault, P., Conlon, C.M., Bailey, P., Moran, A.C., Ouedraogo, L., Kitong, J., Ko, E., Sanon, D., Jega, F., Azogu, O., Ouedraogo, B., Osakwe, C., Chanza, H., 2019. Proposing standardised geographical indicators of physical access to emergency obstetric and newborn care Iin low-income and middle-income countries. BMJ Global Health 4(5), e000778–e000778. doi:https://doi.org/10.1136/bmjgh-2018-000778.

Faruk, M., Ashraf, S.A., Ferdaus, M., 2018. An analysis of inclusiveness and accessibility of cyclone shelters, Bangladesh. Procedia Engineering [online] 212, 1099–1106. doi:https://doi.org/10.1016/j.proeng.2018.01.142.

Geiger, T., Frieler, K., Bresch, D.N., 2018. A global historical data set of tropical cyclone exposure (TCE-DAT). Earth System Science Data 10(1), 185–194. doi:https://doi.org/10.5194/essd-10-185-2018.

General Economics Division (GED), 2018. Bangladesh delta plan 2100: Bangladesh in the 21st century. Dhaka: Bangladesh Planning Commission, Government of the People's Republic of Bangladesh. Retrieved from: www.plancomm.gov.bd, Accessed on: 20 October, 2023.

Hasan, I., Faruk, M.O., Katha, Z.T., Goni, M.O., Islam, M.S., Chakraborty, T.R., Sheikh., Hossain, M.S., 2024. Geo-spatial based cyclone shelter suitability assessment using analytical hierarchy process (AHP) in the coastal region of Bangladesh. Heliyon [online] 10(21), e39831–e39831. doi:https://doi.org/10.1016/j.heliyon.2024.e39831.

Hayat, T., Kamal, A.M., Hossain, M.S., Zaman, S., Hossain, B.R., Chakraborty, T.R., 2021. Accessibility analysis of cyclone shelters: A case study for Atulia

union, Satkhira, Bangladesh. Journal of the Asiatic Society of Bangladesh, Science 46(2), 163–178. doi:https://doi.org/10.3329/jasbs.v46i2.54412.

Hossain, K.T., Rahman, M.H., 2018. Delineating the service area of cyclone shelter and vulnerable households using network analyst tool: A case study on Southkhali union of Bagerhat district, Bangladesh. Journal of the Asiatic Society of Bangladesh, Science 44(2), 137–148. doi:https://doi.org/10.3329/jasbs.v44i2.46556.

Islam, M.T., Charlesworth, M., Aurangojeb, M., Hemstock, S., Sikder, S.K., Hassan, M.S., Dev, P.K., Hossain, M.Z., 2021. Revisiting disaster preparedness in coastal communities since 1970s in Bangladesh with an emphasis on the case of tropical cyclone amphan in may 2020. International Journal of Disaster Risk Reduction 58, 102175. doi:https://doi.org/10.1016/j.ijdrr.2021.102175.

Mahmood, M.N., Dhakal, S.P., Keast, R., 2014. The state of multi-purpose cyclone shelters in Bangladesh. Facilities 32(9/10), 522–532. doi:https://doi.org/10.1108/f-10-2012-0082.

Mallick, B., 2014. Cyclone shelters and their locational suitability: An empirical analysis from coastal Bangladesh. Disasters 38(3), 654–671. doi:https://doi.org/10.1111/disa.12062.

Miyaji, M., Okazaki, K., Ochiai, C., 2020. A study on the use of cyclone shelters in Bangladesh. Japan Architectural Review 3(4), 590–600. doi:https://doi.org/10.1002/2475-8876.12177.

MoEFCC, 2022. National adaptation plan of Bangladesh (2023-2050), ministry of environment, forest and climate change, government of the people's republic of Bangladesh, Available At: https://moef.portal.gov.bd/sites/default/files/files/moef.portal.gov.bd/npfblock/903c6d55_3fa3_4d24_a4e1_0611eaa3cb69/National%20Adaptation%20Plan%20of%20Bangladesh%20%282023-2050%29%20%281%29.pdf [Accessed 10 October, 2023].

Paul, G.C., Raju, I., Hossain, M.Z., Tauhida, N., Nuruzzaman, M., Khatun, M.R., Ali, M.E., 2023. Estimating water levels caused by a tropical storm along the Bangladesh coast: A numerical approach. Heliyon 9(10), e19901–e19901. doi:https://doi.org/10.1016/j.heliyon.2023.e19901.

Pechdin, W., Nghia, B.P.Q., 2023. Building community resilience to coastal disasters: A case study of cyclone sidr in Bangladesh 2007. Journal of Social Policy, Social Change and Development [online] 1, 39–46. Available at: https://so10.tci-thaijo.org/index.php/journalspsd/article/view/540 [Accessed 6 October, 2023].

Quader, M. A., Mahbub, A., 2012. Location analysis of cyclone shelters in the coastal belt of Bangladesh. Journal of Science, Jagannath University ISSN 2224-1698, 1(1), 97-106.

Roy, C., Sarkar, S.K., Åberg, J., Kovordanyi, R., 2015. The current cyclone early warning system in Bangladesh: Providers' and Receivers' views. International Journal of Disaster Risk Reduction 12, 285–299. doi:https://doi.org/10.1016/j.ijdrr.2015.02.004.

Sarkar, S.K., Rudra, R.R., Santo, M.H., 2024. Cyclone vulnerability assessment in the coastal districts of Bangladesh. Heliyon [online] 10(1), e23555–e23555. doi:https://doi.org/10.1016/j.heliyon.2023.e23555.

Shahin, M., Billah, M., Islam, M.M., Parvez, A., Zaman, A.K.M.M., 2020. Cyclone shelters need sustainable development. International Journal of Disaster Resilience in the Built Environment 11(5), 659–678. doi:https://doi.org/10.1108/ijdrbe-12-2015-0061.

Sugi, M., Murakami, H., Yoshida, K., 2016. Projection of future changes in the frequency of intense tropical cyclones. Climate Dynamics [online] 49(1-2), 619–632. doi:https://doi.org/10.1007/s00382-016-3361-7.