Scientific Research Publishing

American Journal of Climate Change, 2024, 13, 611-646
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

# Climate Change Impact on Cyclone Shelter Management over Noakhali Region, Bangladesh

**Nahid Sultana[1], Naheed Farhana[2]**

[1]Department of Geography and Environment, University of Dhaka, Dhaka, Bangladesh
[2]Department of Public Health, North South University, Dhaka, Bangladesh
Email: nahidsultana2610@gmail.com; Naheedfarhana1984@gmail.com

**How to cite this paper:** Sultana, N., & Farhana, N. (2024). Climate Change Impact on Cyclone Shelter Management over Noakhali Region, Bangladesh. *American Journal of Climate Change, 13,* 611-646.
https://doi.org/10.4236/ajcc.2024.134028

**Received:** September 17, 2024
**Accepted:** November 18, 2024
**Published:** November 21, 2024



## Abstract

Bangladesh, due to its unique location and geography, is one of the country's most at risk from natural disasters, particularly cyclones. The coastal region, especially the Noakhali area, faces constant threats from these powerful storms, with climate change making the situation even worse by increasing both their frequency and intensity. This paper explores how climate change is impacting cyclone shelter management in the Noakhali region, which includes the districts of Noakhali, Feni, and Lakshmipur. While these shelters have saved countless lives, many are now in poor condition, suffering from lack of maintenance and infrastructure that isn't built to withstand the evolving risks brought by climate change. The study identifies key challenges, such as the need for better upkeep, stronger infrastructure, and new designs that can handle the demands of a changing climate. It also highlights the importance of adapting our disaster management strategies to ensure that shelters remain a safe haven for vulnerable communities during future cyclones.

## Keywords

Climate Change, Cyclone Shelter Management, Noakhali Region, Cyclones, Coastal Vulnerability, Disaster Risk Reduction, Bangladesh, Tidal Surges, Cyclone Frequency, Sidr and Aila, Infrastructure Resilience, Coastal Management, Humanitarian Response, Geophysical Conditions

## 1. Introduction

Bangladesh, a low-lying and densely populated country, is highly vulnerable to natural disasters due to its geographical location. It sits at the apex of the Bay of Bengal, where the triangular funnel shape amplifies the intensity of cyclones and

storm surges. Cyclones are a frequent and devastating occurrence in the region, causing significant loss of life and property. Historical data show that cyclones like the 1970 Bhola cyclone and the 1991 cyclone claimed the lives of over 300,000 and 138,000 people respectively. However, with advancements in disaster preparedness and cyclone shelter infrastructure, the human toll has drastically decreased in recent events, such as Cyclone Sidr in 2007 and Cyclone Aila in 2009 (Islam et al., 2021).

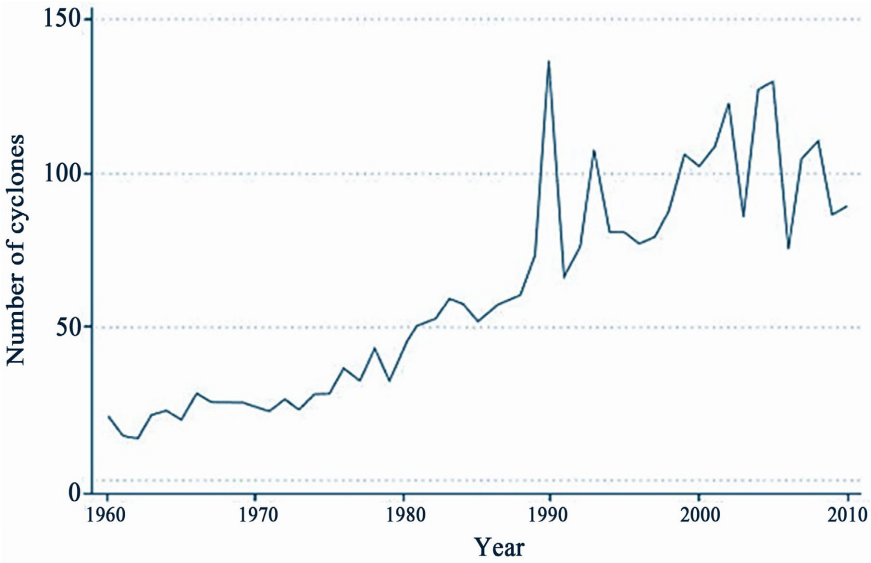


Figure 1. Frequency of world cyclones.

Climate change is exacerbating the frequency and severity of tropical cyclones in Bangladesh, posing additional challenges for disaster management. The Noakhali region, consisting of Noakhali, Feni, and Lakshmipur districts, is particularly vulnerable due to its coastal location and socio-economic conditions. Despite the significant progress in cyclone shelter construction, many shelters suffer from inadequate maintenance, posing risks to the vulnerable coastal population. Poor structural integrity, insufficient access to resources, and outdated designs are just a few issues plaguing existing cyclone shelters. Shown in Figure 1.

This study seeks to assess the impact of climate change on cyclone shelter management in the Noakhali region, with a focus on understanding the effectiveness of current infrastructure, identifying areas for improvement, and recommending strategies to enhance cyclone shelter resilience under changing climatic conditions. Given the increasing risks posed by more frequent and intense cyclones, robust shelter management strategies are critical for reducing casualties and safeguarding livelihoods.

This report is made to analyze the climate change impact on Cyclone Shelter management over Noakhali region which includes Noakhali, Feni and Lakshmipur district as shown in Figure 2.

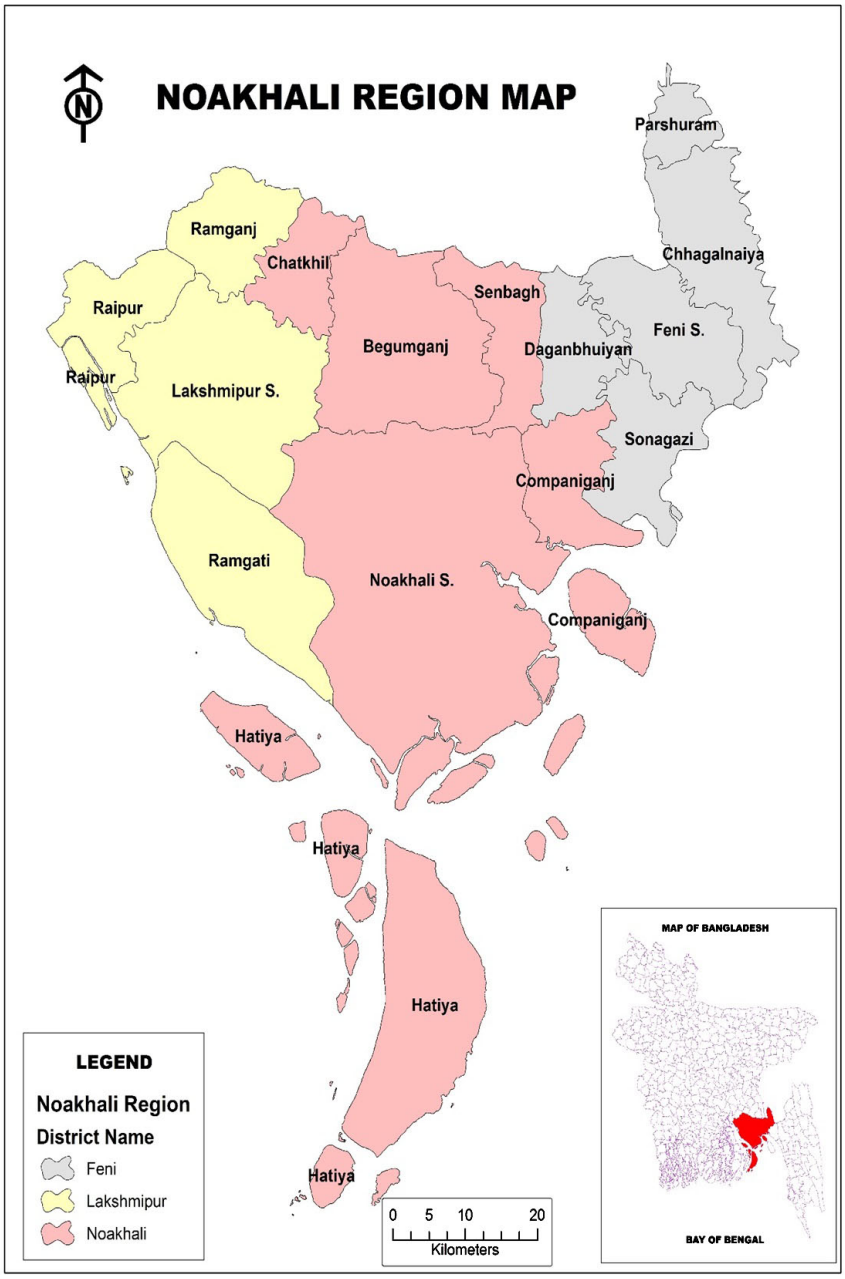


Figure 2. Regional map of Noakhali region.

## 2. Objectives

The objectives of the study are-

1) To assess the current condition of cyclone shelters in the Noakhali region with a focus on structural integrity, maintenance practices, and capacity to withstand climate-induced disasters.

2) To evaluate the impact of climate change on the effectiveness of cyclone shelter management, particularly in terms of increased cyclone frequency, intensity, and associated risks such as rising sea levels and storm surges.

3) To analyze the challenges in maintaining and operating cyclone shelters in

the face of climate change, including resource limitations, infrastructure amenabilities, and local management practices.

4) To explore community preparedness and response strategies in relation to cyclone shelter usage during extreme weather events exacerbated by climate change.

5) To recommend strategies for enhancing the resilience of cyclone shelters in the Noakhali region, incorporating climate-resilient designs, better management practices, and sustainable maintenance protocols.

### 2.1. Background of the Study

Bangladesh, situated at the northern tip of the Bay of Bengal, is one of the most vulnerable countries to natural disasters, particularly cyclones. Its geographic and topographic features make it a hotbed for tropical storms, which cause widespread devastation, particularly in the coastal regions. Historically, cyclones like the 1970 Bhola cyclone and the 1991 cyclone resulted in hundreds of thousands of deaths and immense destruction of property. Over time, the country has made significant progress in disaster management through government-led and international interventions, notably the construction of cyclone shelters in vulnerable areas (Hossain et al., 2011). These shelters have played a crucial role in reducing the human toll during more recent cyclones, where fatalities dropped drastically due to better preparedness and shelter availability.

However, climate change poses new and growing challenges for disaster management in Bangladesh. The frequency and intensity of cyclones in the Bay of Bengal are projected to increase, driven by rising sea surface temperatures and changing weather patterns. This creates an urgent need to reassess the infrastructure and management of cyclone shelters, particularly in highly vulnerable regions like Noakhali. The Noakhali region, which includes Noakhali, Feni, and Lakshmipur districts, is home to millions of people living in coastal and low-lying areas. These communities are directly exposed to the increasing risk of severe cyclones, storm surges, and flooding exacerbated by climate change.

Cyclone shelters, originally designed to provide refuge during storms, are increasingly under pressure from both environmental and human factors. Many shelters suffer from poor maintenance, inadequate facilities, and designs that do not account for the future impacts of climate change. The rising sea levels, more intense storm surges, and extreme weather conditions are expected to test the limits of these structures. Despite progress in disaster risk reduction, the current management practices for these shelters are not sufficient to address the evolving challenges brought by climate change.

This study aims to analyze the current state of cyclone shelter management in the Noakhali region and assess how climate change impacts the sustainability and effectiveness of these critical infrastructures (Mohapatra et al., 2022). It also seeks to identify the gaps in shelter maintenance, design, and usage, and recommend strategies to improve resilience and ensure that shelters continue to serve as life-

saving havens in the face of future climate-induced disasters.

### 2.2. Importance of the Study-

Preparing for natural disasters is essential in low-lying Bangladesh, which has hundreds of rivers and sits on the edge of the Bay of Bengal. This makes it especially vulnerable to cyclones and floods, which happen nearly every year. In May 2017, Cyclone Mahasen hit coastal areas with a glancing blow but left 17 dead and 1.2 million people with losses and damages. Cyclones can happen in the spring and fall, during two cyclone seasons that last several months. As the world's most densely populated country with 152 million people packed into a smaller space, natural disasters here can be devastating. (Kabir et al., 2016)

Most poor, rural people in cyclone-prone areas live in flimsy homes made of thatch or tin roofs, and mud walls and floors. In most natural disasters, the common loss of affected people is their poorly made houses. These houses cannot withstand any storm and as a result cannot save any life during the disasters. The disaster shelters are multi-purpose in a simple, yet innovative way. They serve as primary schools throughout the year. They also function as community centers.

A considerable number of shelters are in a vulnerable condition as most are damaged due to lack of day-to-day maintenance and other reasons such as river bank erosion, poor quality of construction materials, less consideration given to potential high wind speed at construction, etc. Currently, people of cyclone affected areas take shelter without considering the vulnerability of the buildings and at the same time they are in fear of the shelters collapsing on top of them during the event. This fear discourages them from taking shelter in these structures. According to the structural strength analysis of the 2,583 cyclone shelters conducted by CEGIS, around 3% (81) of shelters are vulnerable to tsunami, around 8% (208) to cyclone and around 72.8% (1,881) to earthquakes (Mohapatra et al., 2022).

Over the years, investments in cyclone preparedness and flood management helped save lives, reduce economic losses, and protect developmental gains. To maintain the service condition of the disaster shelters, it is mandatory to find out the effect of climate change on these structures as well as other conditions that may influence the service conditions. There is no doubt that existing and new shelters are vital for mitigating or minimizing the casualties of vulnerable populations in the event of natural disasters.

### 2.3. Socio-Economic Condition of Noakhali Region

While analyzing the socio-economic condition of the Noakhali region, it is important to assess the distinctive characteristics of the population in respect to their socio-economic profile, specifically considering factors such as literacy level, employment patterns, occupation, income level, etc. (Rahman et al., 2022).

The people of this region speak in an informal Bangla dialect. Linguistically, it is connected to the districts of Noakhali, Feni, and Lakshmipur, as well as the southern parts of the district of Comilla and Mirsarai Upazila of Chittagong

district. Indian nationals of Tripura State also speak this simplified Bangla dialect. The Noakhali dialect does not have any recognized grammar recording, and it is not formally used in public, in courts, or in the legislature, unlike standard Bangla. It remains primarily the language of the Greater Noakhali region of Bangladesh.

**Noakhali District:** Noakhali District: The deltaic Noakhali District, situated at the fringe of the Bay of Bengal, is bordered by Comilla District to the north, Feni and Chittagong Districts to the east, the Bay of Bengal to the south, and Bhola and Lakshmipur Districts to the west. It lies between 22˚07' and 23˚08' north latitudes and between 90˚53' and 91˚27' east longitudes. The district consists of 9 Upazilas, 91 unions, 946 mauzas, 987 villages, 8 paurashavas, 72 wards, and 123 mahallas. The Upazilas are Noakhali Sadar, Begumganj, Chatkhil, Companiganj, Hatiya, Senbagh, Kabirhat, Sonaimuri, and Subarnachar (see Figure 3).

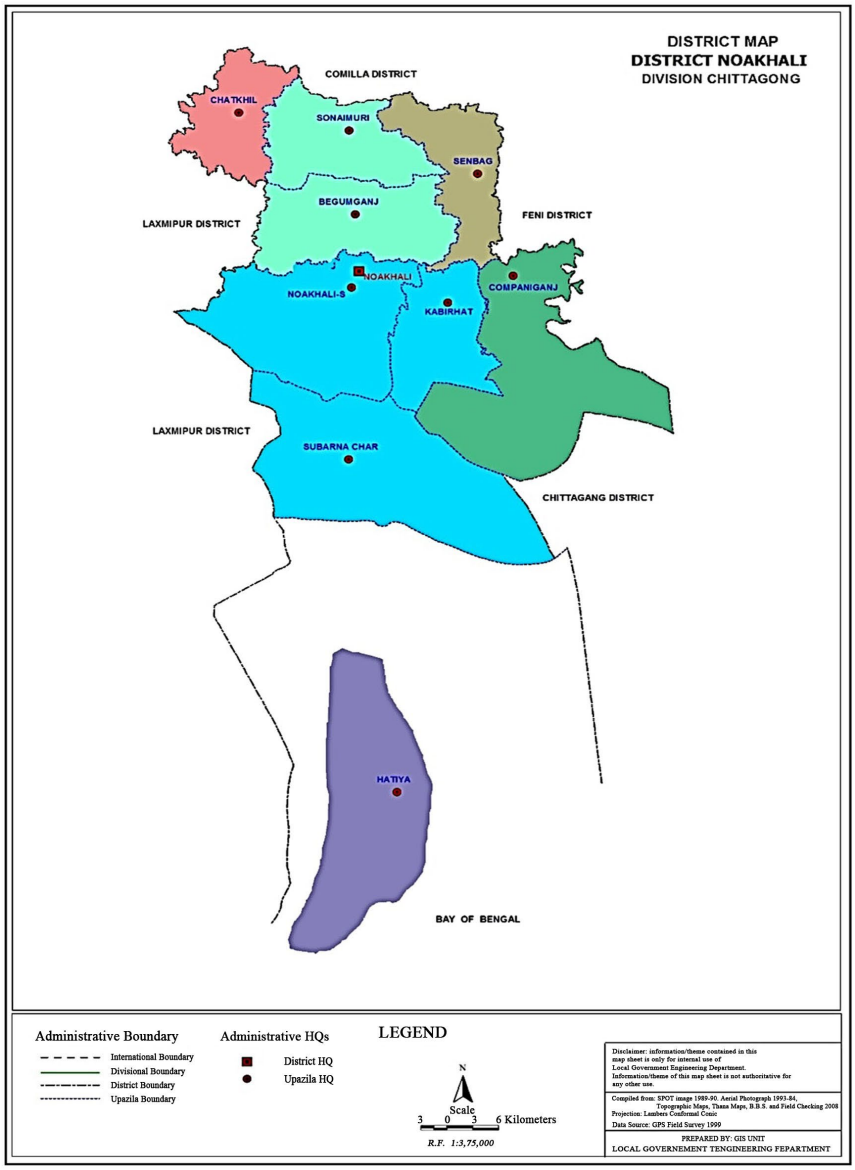


Figure 3. District Map of Noakhali.

**Feni District:** Feni, formerly a subdivision of Noakhali District, was upgraded to a district on March 1, 1984. Bordered by Comilla District and India to the north, India and Chittagong District to the east, Chittagong and Noakhali Districts to the south, and Noakhali District to the west, Feni District lies between 22˚44' and 23˚17' north latitudes and between 91˚15' and 91˚35' east longitudes. According to Bangladesh Bank, it is ranked second nationally in terms of gross national income (GNI) and wealth (Islam et al., 2021). The district comprises 6 Upazilas, 43 unions, 552 mauzas, 571 villages, 5 paurashavas, 54 wards, and 83 mahallas. The Upazilas include Chhagalnaiya, Daganbhuiyan, Feni Sadar, Parshuram, Fulgazi, and Sonagazi (see Figure 4).

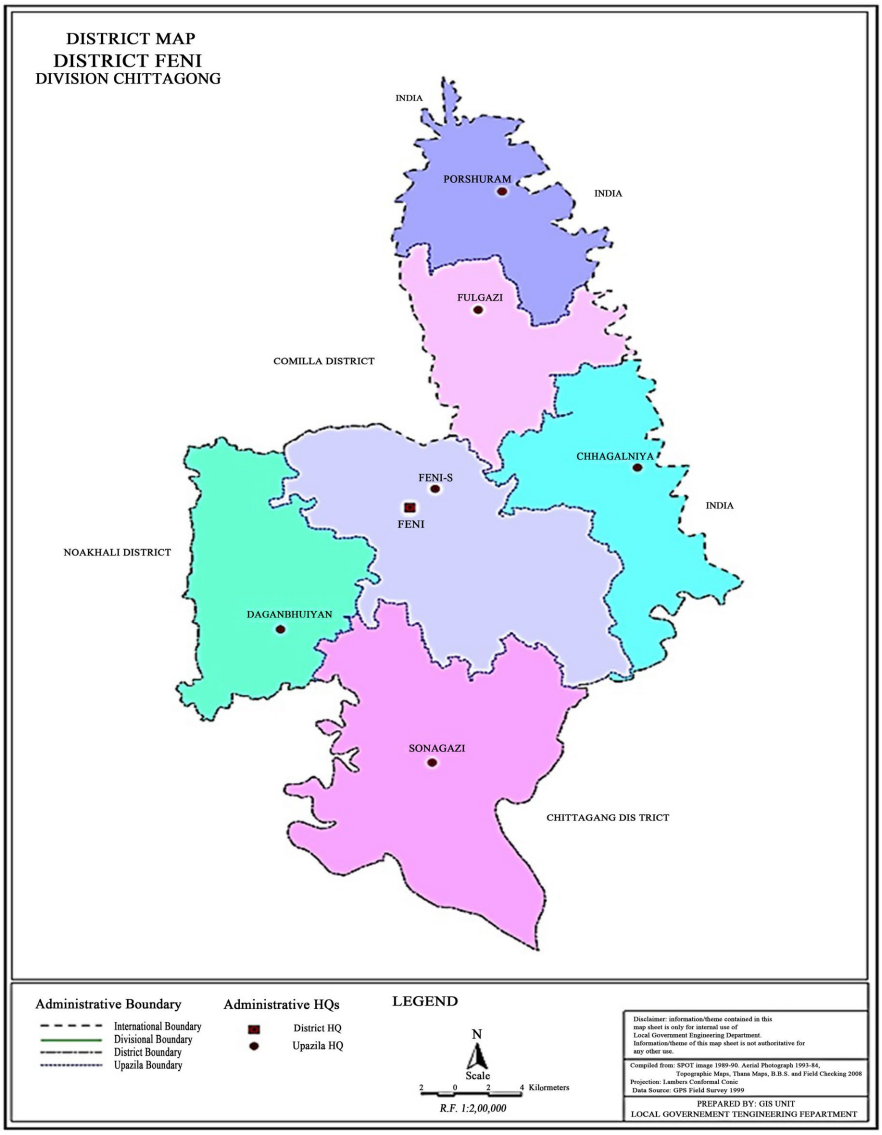


Figure 4. District Map of Feni.

**Lakshmipur District:** Originally part of Noakhali District, Lakshmipur was elevated to a district in 1983. It is bordered by Chandpur District to the north,

Noakhali District to the east, Bhola District to the south, and Barisal and Bhola Districts to the west, lying between 22˚30' and 23˚10' north latitude and between 90˚38' and 90˚01' east longitudes. The district consists of 5 Upazilas, 58 unions, 447 mauzas, 539 villages, 4 paurashavas, 39 wards, and 69 mahallas. The Upazilas are Lakshmipur Sadar, Roypur, Ramganj, Ramgati, and Kamalnagar. With the Meghna River flowing through it, Lakshmipur is particularly vulnerable to flooding, cyclones, and storm surges. Cyclones Aila and Sidr caused significant damage to all four Upazilas in 2007 and 2009 (see **Figure 5**) (Dasgupta et al., 2013).

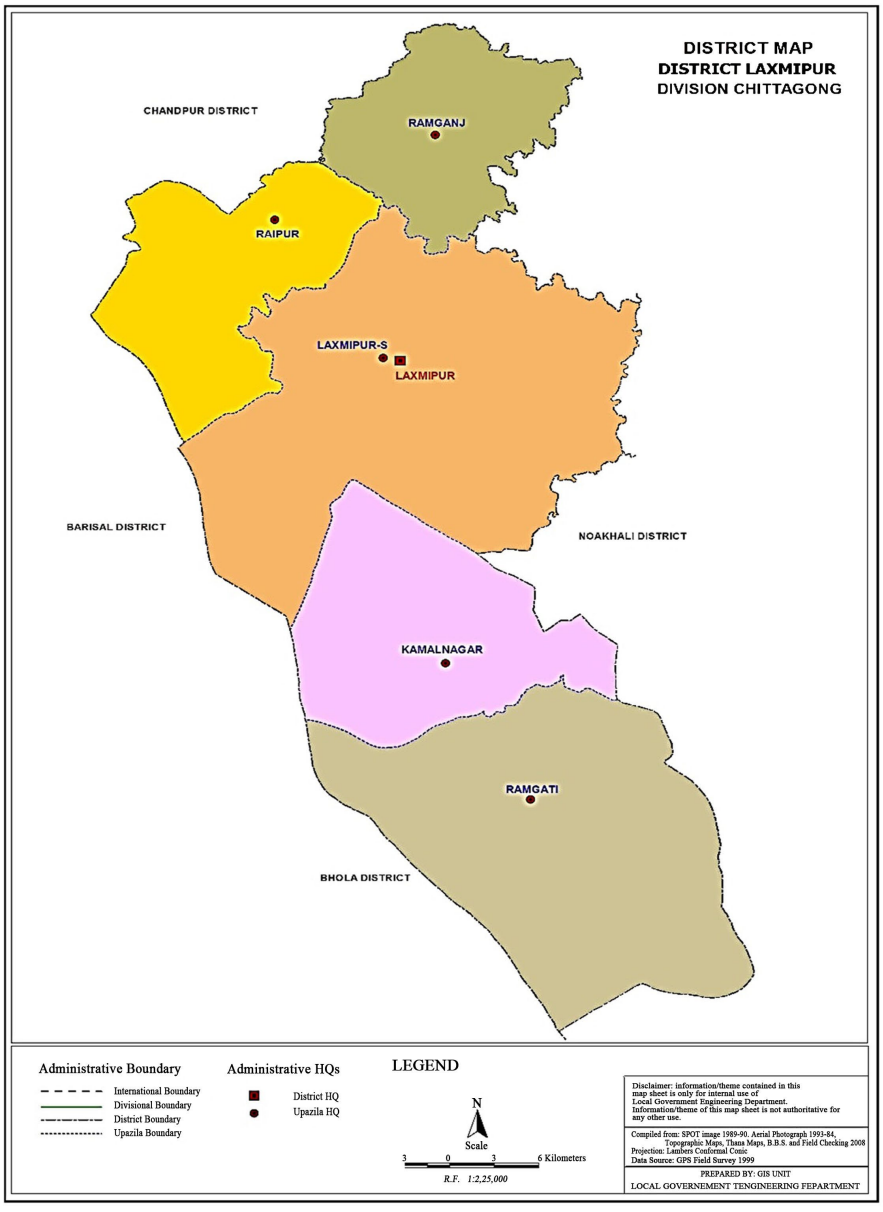


**Figure 5.** District Map of Lakshmipur.

The socio-Economic Conditions of the three districts of the Noakhali region are given in the following table:

Table 1. Socio-economic condition of Noakhali Region.

| Parameters | Noakhali District | Feni District | Lakshmipur District |
|---|---|---|---|
| Area (sq. km.) | 3685.87 | 990.36 | 1440.39 |
| Population (Male: Female) | 3318083 (92:100) | 1437371 (93:100) | 1729188 (92:100) |
| Population Density/sq. km | 897 | 1451 | 1200 |
| Annual Growth Rate (%) | 1.86 | 1.46 | 1.48 |
| Religion | Muslims: 95.42%, Hindus: 4.52%, Buddhists: 0.03%, Christian: 0.02% | Muslims: 89.65%, Hindus: 10.32%, Buddhists: 0.013%, Christian: 0.002% | Muslims: 92.11%, Hindus: 3.52%, Buddhists: 0.04%, Christian: 0.04% |
| Literacy Rate (Male: Female) | 69.57% (72.40:67.6) | 59.60% (61.10:58.30) | 49.40% (48.90:49.80) |
| Economy | Agriculture: 30% Non-Agriculture:3.43% Industry: 0.84%, Others: 55.11% | Agriculture: 31.51% Non-Agriculture:2.57% Industry: 0.98%, Others: 64.94% | Agriculture: 447.51% Non-Agriculture:3.19% Industry: 0.85%, Others: 48.45% |
| Main River | Bamni, Meghna | Feni, Muhuri | Meghna, Dakatia, Katakhali, Rahmathkhali, Bhulua |
| Annual Avg. Temperature (˚C) | 34.3 - 14.4 | 34.3 - 14.4 | 34.3 - 14.4 |
| Agriculture | Rice, Wheat, Vegetables, Spices, Betel leaves | Rice, Vegetables, Spices, Oilseeds, Maize | Wheat, Mustard oil, Chili, Potato, Soybean, Sugarcane |

*According to 2015 census (Bangladesh Sample Vital Statistics 2015/BBS/SID/Ministry of planning)

## 2.4. Climate Condition of Noakhali Region

Noakhali District: The climate is tropical in Noakhali district. Noakhali has significant rainfall most months, with a short dry season. In Noakhali, the average annual temperature is 25.6˚C. The highest being in May at around 28.60˚C, and the January being the coldest month with 19.50˚C, as seen in the Temperature Graph for Noakhali District in Figure 6 below.

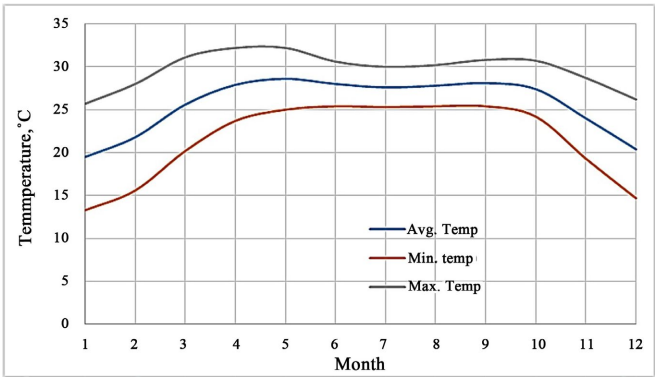


Figure 6. Temperature graph of Noakhali District.

In Noakhali, the driest month is January, with only 8 mm of precipitation, as shown in Figure 7 below. In July, the precipitation reaches its peak due to increased rainfall in the monsoon season, with an average of 671 mm. About 2980 mm of precipitation falls annually.

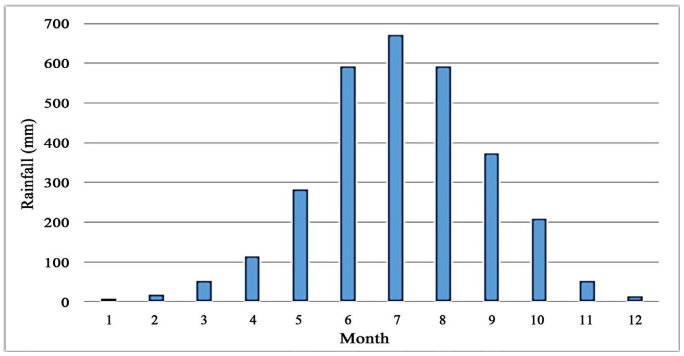


Figure 7. Rainfall bar chart of Noakhali District.

The precipitation varies 663 mm between the driest month and the wettest month. The variation in annual temperature is around 9.1˚C.

Feni District: Feni has a tropical climate which includes significant rainfall in most months of the year. The short dry season has little effect on the overall climate. The average temperature in Feni is 25.6˚C. The warmest month of the year is May, with an average temperature of 28.4˚C shown in Figure 8 below. January has the lowest average temperature of the year which is 19.5˚C.

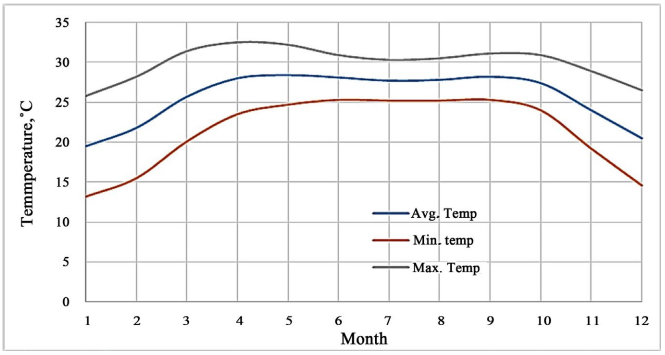


Figure 8. Temperature graph of Feni District.

In Feni, the driest month is December, with 4 mm of rainfall shown in Figure 9 below. With an average of 570 mm, the most precipitation falls in the month July due to the increased rainfall. The average annual rainfall is 2673 mm.

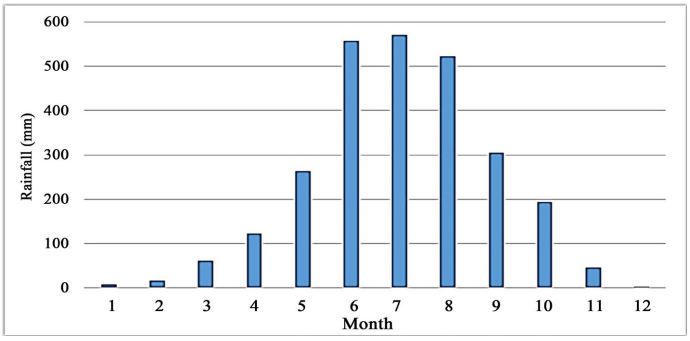


Figure 9. Rainfall bar chart of Feni District.

Lakshmipur District: The climate is tropical in Lakshmipur district. During most months of the year, there is significant rainfall in Lakshmipur. There is only a short dry season. In Lakshmipur, the average annual temperature is 25.7˚C. The average annual rainfall is 2547 mm.

With an average of 29.1˚C shown in Figure 10, May is the warmest month. In January, the average temperature is 19.3˚C. It is the lowest average temperature of the whole year.

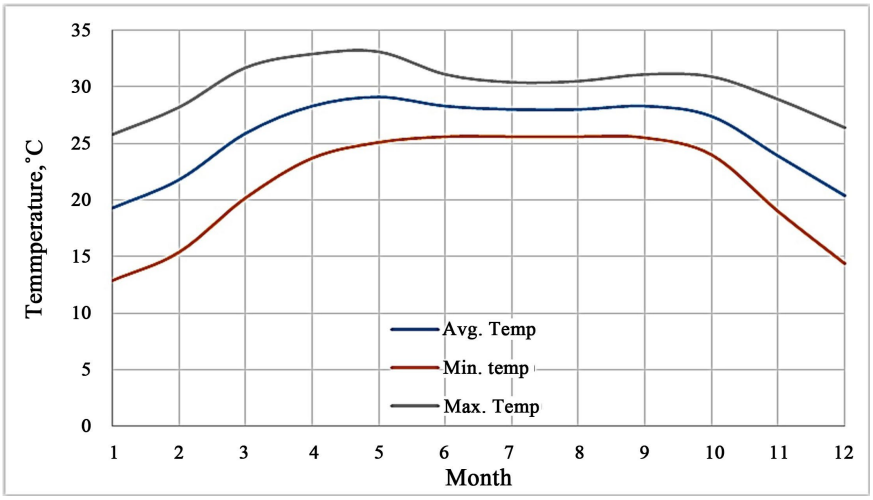


Figure 10. Temperature graph of Lakshmipur District.

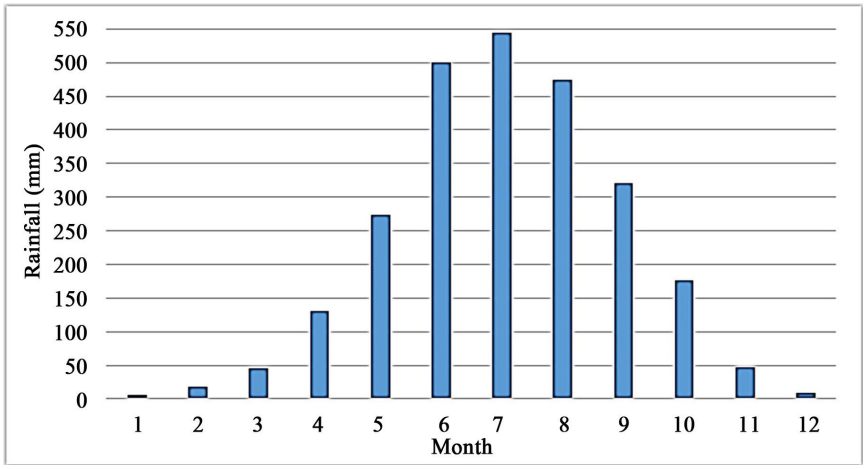


Figure 11. Rainfall bar chart of Lakshmipur District.

The driest month is January. There is only 6 mm of precipitation in January. Most precipitation falls in July, with an average of 545 mm shown in Figure 11.

## 2.5. Risk Related to Cyclone over Noakhali Region

Bangladesh is positioned with the Bay of Bengal and the North Indian Ocean to the south and the Himalayas to the north. The coastal area of Bangladesh is different from rest of the country for its unique geophysical characteristics which is

almost exposed to the Bay of Bengal. The area is very productive for some important agricultural products. Most of the coastal areas are very vulnerable to cyclone and flood.

Bangladesh has a 711 km long coastline that consists of a vast network of river systems draining the vast flow of the Ganges-Brahmaputra-Meghna River system (Hossain et al., 2011). The coastal zone covered by the lowest landmass, is a part of the delta of the Himalayan drainage ecosystem. The coastal zone covers 19 out of 64 districts facing, or in proximity to, the Bay of Bengal, encompassing 6153 thanas (sub-districts, formerly called Upazilas) and the EEZ. Coastal Districts spread from Satkhira on the Indian border on the west to Cox's Bazar on the Myanmar border to the eastern part of the country. Although the zone constitutes 32 percent of the area, 28 percent of the population of Bangladesh live in this zone (Rashida et al., 2022).

Bangladesh suffers from cyclones almost every year, in early summer, during April-May, and late rainy season, from October to November. There have been 154 cyclones, including 43 severe cyclonic storms, 43 cyclonic storms, 68 tropical depressions during the period from 1877 to 1995. Since 1995, five severe cyclones hit coast of Bangladesh in May 1997, September 1997, May 1998, November 2007 and May 2009. The cyclone Sidr in 2007 and Aila in 2009 devastated almost all the coastal districts and caused huge property and livelihood losses.

On average, a severe cyclone storm strikes Bangladesh every three years. UNDP has identified Bangladesh to be the most vulnerable country in the world to tropical cyclones (Chowdhooree & Mallick, 2022).

The Cyclone Sidr was the second natural disaster to affect Bangladesh in twelve months. Monsoon floods had previously caused extensive agricultural production losses and destruction of physical assets, totaling nearly USD1.1 billion. The occurrence of these events in close succession is a reminder of the country's extreme vulnerability to frequent hydro-meteorological hazards.

The category 4 Cyclone Sidr struck the south west coast with winds up to 240 km/hr, accompanied by tidal waves up to 5 meters high and surges up to 6 meters in some areas, breaching coastal and river embankments, flooding low-lying areas and causing extensive physical destruction. The damages and losses from Cyclone Sidr were severe on four south western districts, and moderate on eight other districts, total amounting to around USD1.7 billion.

However, it has been observed that the number of deaths that occurred due to Cyclone Sidr was only about 3400, which was very much less than the number of deaths due to previous Cyclones of the same strength. Improved disaster prevention measures, including improved forecasting and warning systems, coastal forestation works, cyclone shelters and embankments, are credited with lower casualty rates than what would have been expected, given the severity of the storm (Mohapatra et al., 2022).

**Table 2** shows the details of cyclones Bangladesh experienced during the last 35 years.

Table 2. Major cyclones which influenced on Noakhali region during 1983-2016.

| Date | Land fall | Max. Wind Speed in km/h | Storm Surge height in meters | Affected Area | Damage occurred |
|---|---|---|---|---|---|
| 14 - 15/10/83 | Near estuary of Feni River | 93 | N/A | Chittagong, Noakhali& Offshore islands | Severe Cyclonic Storm. 43 persons killed 6 fishing boats and a trawler lost. 150 fishermen and 100 fishing boats missing and 20% aman crop destroyed |
| 5 - 9/11/83 | Cox's Bazar | 136 | 1.52 | Chittagong, Cox's Bazar, Noakhali, Patuakhali & Barisal | Severe Cyclonic Storm. 300 fishermen killed 50 boats missing and 2000 houses destroyed. |
| 24 - 25/05/85 | Near estuary of Feni River | 153 | 4.5 | Cox's Bazar, Chittagong, Noakhali& Offshore islands | Severe Cyclonic Storm. 11,069 persons killed. 94,379 houses damaged. 135,033 livestock lost. 74 km road damaged |
| 08 - 09/11/86 | Patuakhali Coast | 110 | 1 | Barisal, Patuakhali, Noakhali, offshore islands | Cyclonic Storm 14 persons killed. 97,200 ha paddy fields damaged School, Mosques, houses warehouse damaged |
| 25 - 29/04/91 | Cox's Bazar | 225 | 5 - 8 | Cox's Bazar, Chittagong, Noakhali, Patuakhali & Barisal | The great cyclone of 1991. 15,000 persons killed and the 70,000 cattle killed. Property damage estimated at BDT60 billion. |
| 31/05/91 | Near Meghna estuary | 110 | 1.9 | Barisal, Patuakhali, Noakhali, Chittagong & offshore islands | Cyclonic Storm. Cattle perished; boats lost. |
| 29/04 - 03/05/94 | Cox's Bazar | 210 | N/A | Cox's Bazar, Chittagong's offshore islands | Severe Cyclonic Storm. 400 persons killed and 8,000 cattle lost |
| 21 - 25/11/95 | Cox's Bazar | 210 | N/A | Offshore islands | Severe Cyclonic Storm. 650 persons died and 17,000 cattle perished. |
| 16 - 19/05/97 | Sitakunda | 225 | 3 | Bhola, Noakhali, Chittagong, Cox's Bazar, offshore islands | Severe Cyclonic Storm. 126 people died |
| 25 - 27/09/97 | Sitakunda | 150 | 2 - 3 | Bhola, Noakhali, Chittagong, Cox's Bazar, offshore islands | Severe Cyclonic Storm. |
| 16 - 20/05/98 | Sitakunda | 150 | 2 - 3 | Noakhali, Chittagong, Cox's Bazar, offshore islands | |
| 19 - 22/11/98 | Sitakunda | 90 | 2 - 3 | Offshore islands of Chittagong, Cox's Bazar, Noakhali and Bhola | |

Continued

| | | | | | |
|---|---|---|---|---|---|
| 15 - 17/11/07 | South west coast | 240 | 6 | 12 Districts in the South west | **Severe Cyclone Storm Sidr. 3000 persons killed. Immense damage to property about USD 1.7 billion including one million houses-** |
| 27 - 29/05/09 | | | | | Severe Cyclonic Storm. 15 districts affected. 150 persons killed 2 lac houses and 3 lac acres of cultivated land destroyed. |

As per the Cyclone Risk map produced by the SPARRSO in Figure 12 below, the lower stretch of Noakhali region is a high-risk area, marked by red color. Wind speed in the marked area is 260 km/hr and surge above 1 m. The middle stretch of Noakhali falls into the Risk area where wind speed varies from 240 km/hr to 260 km/hr and Surge is below 1m. The top part of the region falls into the High wind Area with wind speed varying from 200 km/hr to 240 km/hr.

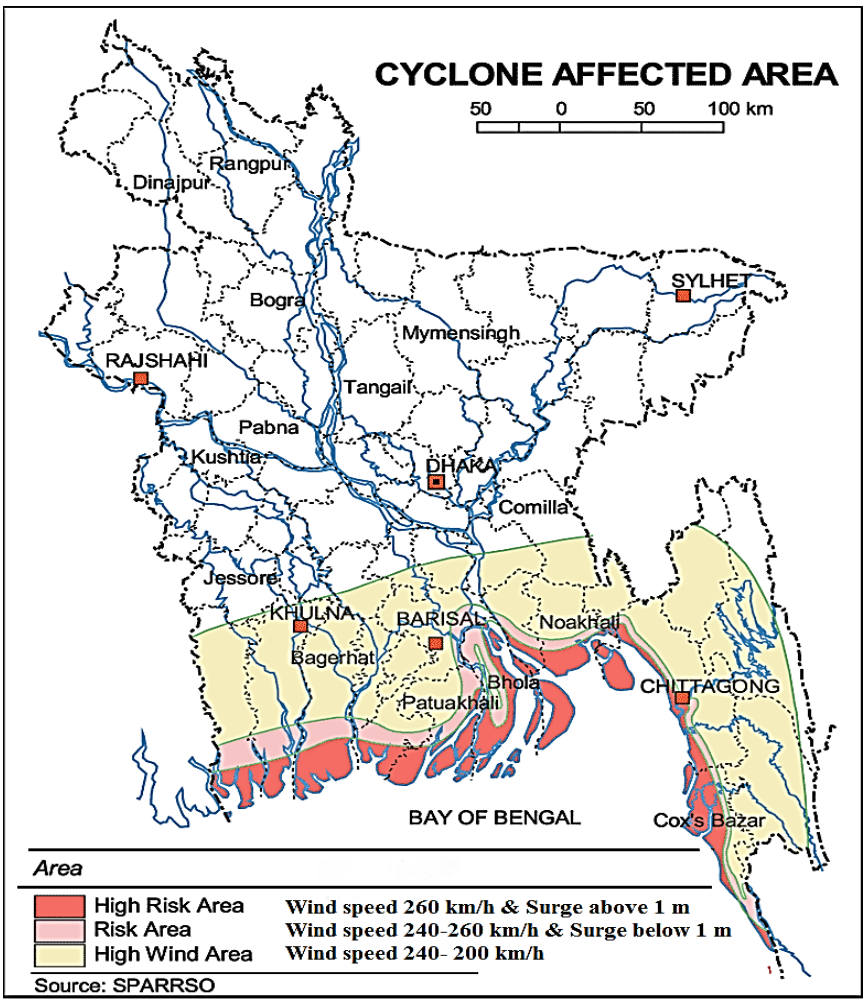


Figure 12. Cyclone Risk Map of Bangladesh. Source: SPARRSO.

### 2.6. Status of Cyclone Risk Management over Noakhali Region

Bangladesh is one of the most natural disaster-prone countries. Over the last 40 years many cyclones have affected the country accompanied with loss of lives and property. Global climate change will make the country even more vulnerable to cyclones and floods. For low-lying countries as Bangladesh, it is very important to adapt to climate change, to reduce impacts, which may lead to increased human misery, social injustice, and damaged ecosystems. The poor people have the least capacity to absorb shocks and adapt to the adverse impacts of climate change. Thus, the poor are the most vulnerable to climate change impacts and disaster risks (Mallick, 2014).

Initiatives at central and local governmental, nongovernmental and community levels seem to be key for success in minimizing cyclone-related mortalit

Adaptive measures are necessary to reduce people's vulnerability to flooding. The construction of shelters at a household scale saves lives and properties, as shown during the last decade. Adaptation should reduce risk and vulnerability from extreme events: cyclones and storm surges and impacts of climate change. Adaptive measures should be geared to increase resilience and provide security in terms of food, water, and energy supply, as well as safeguard livelihoods and social coherence (Karim & Mimura, 2008).

Adaptive measures such as the construction of (multi-purpose) shelters and measures at a household scale, are important to save lives, property and livelihood. Followings are some good examples to adapt to manage the cyclone risk:

Increasing Shelter Program: The first purpose-built cyclone structures were built in 1960s. Since the Great Bhola Cyclone of 1970, Bangladesh embarked on program to build concrete cyclone shelters. However, these efforts were insufficient and in 1991 more than 140,000 people died from another tropical cyclone. After this cyclone, the Bangladesh government with the support of different foreign agencies, have been building multi-purpose cyclone shelters so that these can also be used as primary schools during normal period of time. According to Local Government Engineering Department, in 2006 there were about 2500 cyclone shelters in the country (Islam, 2021). Bangladesh has developed a GIS-based information system for all existing cyclone shelters. Quite a number of cyclone shelters have been neglected, others have been abandoned altogether (Saha & Khan, 2014).

Need of More shelters: As the shelters can accommodate only 27% of the population at risk, 2000 more cyclone shelters are planned to be built soon in the low-lying coastal districts. Construction of new cyclone shelters has started under different donor-funded programs. One of the largest programs for disaster shelters in the country is the World Bank-financed Multipurpose Disaster Shelter Project (MDSP).

Measures to mitigate the risk. As a disaster-prone country, twelve districts of the coastal area are highly vulnerable to cyclone and storm surge. Bangladesh government has taken five measures to mitigate the risk of cyclone:

1) Vulnerability and Risk analysis.

2) Deposit early and essential relief materials to the vulnerable area.

3) Information management.

4) Early preparedness in the local area: The effective early warning system provided by the government in advance of Cyclone Sidr in 2007 enabled the successful evacuation of coastal communities resulting in fewer than expected deaths.

5) Resource collection.

Dissemination of early warning: Cyclone preparedness has improved following the launch of the Cyclone Preparedness Program by the Bangladesh Red Crescent Society in 1970. The program's goal is to minimize the loss of lives and property in cyclonic disasters by strengthening and developing disaster preparedness and response capacity in coastal communities, and by increasing the effectiveness of volunteers.

The program's activities include:

1) Disseminating cyclone warning signals issued by the Bangladesh Meteorological Department through an extensive telecommunication network;

2) Providing and assisting in first aid, rescue, relief and rehabilitation operations; and

3) Coordinating and building community capacity, disaster management and development activities.

The Bangladesh Disaster Management Bureau also issues cyclone alerts through the national media as soon as a cyclone is detected by environmental satellites. The Bangladesh Meteorological Department has three radar stations in Dhaka, Khepupara and Cox's Bazar that transmit minute-by-minute weather updates. The Department also receives information from the National Oceanic and Atmospheric Administration in the United States of America (USA) and from a Japanese satellite via the Bangladesh Space Research and Remote Sensing Organization.

Preparing the local population: Taking the following steps can prepare the local people better for upcoming cyclone:

1) Warning of cyclones are needed to broadcast among the locals of coastal area to warn

2) them long before the cyclone season.

3) Aware the locals about the cyclones and its effects.

4) Inspire the locals to listen to the radio (All Radio stations give weather warnings).

5) Inspire the locals to keep monitoring the warnings. This will help them to prepare for a

6) cyclone emergency.

7) Motivate the locals to pass the information to others.

8) Inspire the locals to ignore rumors and discourage from spreading them; this will help to avoid panic situations.

9) Motivate the locals to believe in the official information.

10) Make the locals to stay alert for the next 24 hours as a cyclone alert means that the

11) danger is within 24 hours.

Coastal greenbelt: Coastal Greenbelt is a measure to prevent coastal erosion and reduce other natural hazards by planting trees and creating forests along the coasts. The south and eastern coasts of Bangladesh face tidal surges and erosion every year. Planting along roads and embankments contributes to the establishment of a greenbelt and plays a role in coastal protection. The coastal areas of Bangladesh are prone to severe damage from cyclones. In 1991, a devastating cyclone with winds exceeding 200 kilometers (km) per hour and a tidal surge of 6 meters (m) struck Bangladesh. About 140,000 lives and about $240 million worth of public infrastructure alone were lost. This and previous cyclones proved that dense forest cover along the coastline, particularly wide belts of mangrove plantations such as those found in the Sundarbans (a large natural mangrove area in the southwestern part of Bangladesh) and other coastal areas, are an effective buffer against the impacts of cyclone. After the cyclone, the government of Bangladesh took up an afforestation project to establish a greenbelt in the coastal regions of the country.

Embankment: Apart from early warning systems, other measures such as coastal embankments, have contributed to reducing death rates in Bangladesh.

Tools up gradation: As the development of the world's coastlines continues to accelerate, organizations need robust tools that can help them manage their tropical cyclone risk.

Experiences from other countries: By examining the impacts of and responses to cyclones in other countries, we can improve our understanding of effective strategies for preventing the loss of life. Cuba has significantly improved its pre- and post-cyclone early warning and evacuation systems and health services and has introduced a cyclone preparedness Program for primary school children. Universal education and the eradication of illiteracy are important to improve awareness of the risks associated with hurricanes and the understanding of government warnings. Cuba also has a population with a very high level of civil participation and a comprehensive primary health care system (Sarker & Azam, 2013).

Empowering the community Community-based initiatives empower the communities to build on their existing local knowledge and provide confidence to the most vulnerable people to explore the long-term benefits of investing small amounts on flood-resistant construction towards making safer homes.

### 2.7. Status of Cyclone Shelter Management over Noakhali Region

Due to geographic location and geophysical conditions, Bangladesh is one of the most disaster-prone countries in the world. The location of the off-shore islands and the triangular funnel shape of the Bay of Bengal have made the coastal areas susceptible to cyclone and tidal surges. In addition to the plenteous loss of assets and properties, more than 3 lakhs and 1.38 lakhs people were died in the devastating

cyclones of 1970 and 1991 respectively. Although the loss of properties had been very severe in the cyclone SIDR of 2007 and AILA of 2009 (Rahman et al., 2022), but loss of human lives was reduced to 3406 and 190 respectively due to effective disaster risk reduction and preparedness programs conducted by the Government. Out of 35 million people in 700-kilometer-long stretched coastal areas of Bangladesh, 7 million lives in high disaster risk. With the objectives of protecting the lives and properties of the people from the devastating cyclones like Sidr and Aila, the Government and the non-government organizations, different development partner countries and organizations have constructed a number of cyclone shelters and constructions of more shelters are still going on.

**Figure 13.** A Cyclone Shelter in Parshuram Upazila of Feni District.

All multistoried buildings in the coastal area are constructed and to be constructed in the future by the government and non-government organizations, and also the similar commercial buildings owned by private individuals, will be used as cyclone shelters during cyclones. In case of use of commercial buildings owned by non-government organizations or individuals, the concerned Upazila Nirbahi Officer (UNO) will execute a Memorandum of Understanding (MoU) with the owners of the buildings on behalf of the government.

The buildings owned by the Government and the non-government organizations in the coastal areas are using as cyclone shelters. The structural designs and the amenities of those shelters are different. Due to poor maintenance, a number of those shelters have already become unsuitable for use. At one side, the proper use and maintenance of these shelters cannot be ensured and on the other hand, the development partner countries and organizations have been expressing their concerns on the use, maintenance and management of those shelters. Apart from this, there is no specific allotment provision in the national budget for restoration and maintenance of cyclone shelters.

Although the Physical Infrastructure Division of the Planning Commission

prepared a guideline in this respect in 1996, but that simply inadequate to meet the present requirement. As long time has passed in the meantime, there is an imperative for amendment, modifications and developing a policy for construction, maintenance and governance of cyclone shelters.

Addressing all the hazards revised "Standing Orders on Disaster" was published in April, 2010 from the then Disaster Management Bureau under the Disaster Management & Relief Division as per the decision and approval of the meeting of the National Disaster Management Council, chaired by the Hon'ble Prime Minister. According to this Standing Orders on Disaster, Ministry of Disaster Management & Relief is coordinating all activities related to disaster risk reduction, preparedness, humanitarian assistance during disasters and post-disaster rehabilitation. Since the construction of cyclone shelters is included in disaster risk reduction and preparedness Program and the shelters ensure the security of the people during disaster, naturally the responsibilities for coordination of construction, maintenance and use of cyclone shelters fall on the Ministry of Disaster Management and Relief. Under the stated circumstances, and in consideration of all the issues, "Cyclone Shelter Construction, Maintenance and Management Policy 2011" has been formulated by the Ministry of Disaster Management and Relief. The government hopes that from now onwards, if this policy is followed, then it will be possible to ensure proper use of the multi-purpose cyclone shelters that have already been constructed, under construction and to be constructed in the coastal areas (Sarker & Azam, 2013).

**Cyclone Shelter Management-**

Construction of Shelters: A cyclone shelter is basically a solid building, an elevated construction that provides security from the cyclones and associated storm surges. The foundations are such that they dissipate energy from upcoming cyclonic storm surges from the sea or from riverine floods. Above the foundation, at some meters from the ground, one or more floors are constructed to provide shelter. Sometimes they are built in a semi pyramidal shape to withstand the storm surges better.

Access Friendly Shelter: Each shelter is designed to serve approximately 2000 people and also to function as schools. Access ways are major issues. Studies have shown that unless a cyclone shelter is within 1.5 km of a house, it may be too distant. The local people, afraid for theft, postpone their withdrawal to the shelter to the eleventh hour. Moreover, women going at the last moment in case shelters are lacking proper women toilets and are therefore disproportionate victim of last-minute drowning. New generation of shelters are better equipped within access point and gender-friendly use.

Responsibility of Local community: The local beneficiary communities have to be involved at the time of construction of the shelters so that, later, they can take responsibility of its management. If the organization constructing the multi-purpose cyclone shelter is its user, then the responsibility of the management of the shelter will also fall on them. The responsibility of management of the multi-

purpose cyclone shelters in educational institutions will fall on the relevant management committee of the governing body of the institutions under the control of the Ministry of Education and the Ministry of Primary and Mass Education. If the organization/institution constructing the cyclone shelter surrenders its ownership after the construction, in that case the ownership will be entrusted to the Ministry Disaster Management and Relief. In such case, according to the instructions given by the Ministry of Disaster Management and Relief the concerned Upazila Disaster Management Committee shall take over the control of these shelters and ensure its regular management, maintenance and use through Union Disaster Management Committee (Shahin et al., 2020).

Responsibilities of Local Disaster Management Committee: As per the Standing Orders on Disaster (SOD) 2010, the responsibility for ensuring proper management of all cyclone shelters located in a particular District is vested with the District Disaster Management Committee. On behalf of the District Disaster Management Committee, the Deputy Commissioner shall ensure proper sanitation, the safe drinking water and sufficient lighting facilities in all the cyclone shelters in the district with the help of the Upazila and Union Disaster Management Committees.

Responsibility of Deputy Commissioner: As the Chairperson of the District Disaster Management Committee, the Deputy Commissioner shall act as the source for collection and storage of relevant information concerning all cyclone shelters of the district under his jurisdiction. The Deputy Commissioners shall prepare a database on the basis of such information and arrange for its dissemination through their respective district website.

Cyclone Shelter Management Committee: To ensure proper management and use of the cyclone shelters which do not fall under the control of school, college, madrasa, mosque, temple or any other organization, the following 07 (seven) member "Cyclone Shelter Management Committee" shall be responsible for managing affairs of each of the cyclone shelter and earthen kills in line with the National Plan for Disaster Management 2010-2015:

1) Union Parishad Member of the concerned Ward - Chairperson
2) Headmaster of the local Primary School- Member
3) Chairperson/Imam/Religious Leader of local religious institution - Member
4) Female member of the concerned Ward - Member
5) A representative of the Cyclone Preparedness Program - Member
6) A representative of the Private organization/NGO -Member
7) A member of the Union Disaster Management Committee- Member Secretary

The concerned Upazila Nirbahi Officer shall select the members of the Cyclone Shelter Management Committee and also determine the tenure (duration of office) of the Committee.

**Scope of Work for the Cyclone Shelter Management Committee**

1) To open the cyclone shelter, with necessary provision for safe drinking water

and sanitation, immediately after the announcement of warning signal 04 by the Bangladesh Meteorological Department.

2) To bring the vulnerable communities to the cyclone shelter immediately after the issuance of evacuation order by the competent authority.

3) To ensure vacating the shelter through facilitating the return of all the concerned to their respective houses following instructions issued by the competent authority to vacate the shelter.

4) To complete the overall cleanliness and repair (if required) of the cyclone halter after it is vacated by the people.

5) To carry out the responsibilities properly for "use of the cyclone shelters in normal time" as and when such responsibilities are entrusted upon it by the Upazila or the Union Disaster Management Committee in accordance with the provisions of clause 10 of this policy.

**Ensuring the essential facilities at the cyclone shelters**

In addition to providing shelter to the vulnerable communities during disaster, the issues of sufficient light, safe water, food, toilet and sanitation at the cyclone shelters have to be kept under consideration. During the time of construction of cyclone shelter, RAMP facilities have to be kept to ensure easy access of women, children, aged, severely ill and people with disabilities. In addition to separate toilet facilities for the pregnant, separate room has to be kept for women. The facility for light has to be kept on top of the roof of the buildings so that the shelter becomes visible during disasters, especially in heavy rain and storms at night. For that, solar panel should be arranged in every shelter. The water in the coastal areas is saline in nature. So, the rain water harvesting arrangement has to be considered to ensure provision of safe drinking water at the cyclone shelters. The cyclone shelters should be of three stories in which arrangement should be made for keeping the cattle on the first floor with RAMP facilities for easy access (Mallick, 2014).

**Maintenance of the List of Cyclone Shelters**

1) The Ministry of Disaster Management and Relief shall act as the depository of all relevant information in respect of cyclone shelters and keep the Cabinet Division informed about it.

2) The Deputy Commissioner: The responsible Deputy Commissioner shall send the list of the cyclone shelters and all other information related to overall management to the relevant Ministries and the Ministry of Disaster Management and Relief on a regular basis.

3) Upazila Nirbahi Officer: The concerned Upazila Nirbahi Officer shall identify, earmark and declare all Government, Non-Government, privately owned commercial buildings as "cyclone shelter" which are considered suitable for use as shelters. He shall maintain a list of all such buildings and send a copy of the list to the concerned Deputy Commissioner.

All information related to cyclone shelters throughout the country shall be posted in the website of the Ministry of Disaster Management and Relief and the website of Department of Disaster Management for information of all concerned.

**Repair, Maintenance, Abandoning and Sale of Cyclone Shelters**

1) The responsibility for maintenance and repair of the cyclone shelters, which are built and used by individuals and non-government organizations for other purposes such as schools, community centers, etc. shall lie with the respective individuals and organizations (Mallick, 2014).

2) The cyclone shelters whose ownership shall be transferred by the constructing organizations to the Government immediately after construction, the responsibility for their maintenance, repair and rehabilitation shall vest with the Upazila Disaster Management Committee under approval of the Ministry of Disaster Management and Relief.

3) The Ministry of Disaster Management and Relief shall allocate required fund in favor of the Upazila Disaster Management Committee after the ownership of the cyclone shelters are transferred to the Government by the concerned constructing organization.

4) Upazila Disaster Management Committee shall prepare the Union-wise priority list and complete the repair works.

5) After the ownership is transferred in favor of the Ministry of Disaster Management and Relief, the Upazila Disaster Management Committee shall take necessary steps to repair, maintain, and use those cyclone shelters that were constructed earlier but are currently abandoned.

6) If there is any threat for any cyclone shelter to be affected by river bank erosion, coastal erosion or any natural cause or becomes unsuitable for repair or use due to passage of long time, then the Upazila Disaster Management Committee, on the recommendation of the Union Disaster Management Committee shall fix the Government price with the help of a committee comprising of Upazila Engineer, Upazila Project Implementation Officer and one other member nominated by the District Disaster Management Committee for its disposal by auction.

7) The District Disaster Management Committee shall thoroughly examine such proposals and forward the same to the Ministry of Disaster Management and Relief with recommendation for approval. The Ministry of Disaster Management and Relief, after careful consideration of the proposals, shall accord necessary approval for disposal on auction.

8) The Upazila Disasters Management Committee, after following the prescribed procedures, shall give wide publicity of the date and time in advance and arrange disposal of the shelters by public auction and deposit the sale proceeds to the Government specific account's code through Treasury Chalan.

**Use of Cyclone Shelter during Normal Time**

1) The cyclone shelters which are located within the boundary of school, college, madrasa, mosque, temple or any other organization, matters relating to overall management of such cyclone shelters will be determined by the relevant authorities of those establishments or organizations.

2) The cyclone shelters which are not being used on regular and fulltime basis, depending on local needs and circumstances, may be used by the Upazila Parishad for purposes of rendering various social services (such as school, madrasa, mass

education center, evening education center etc.) or the NGOs for their people's welfare Program (e.g. distribution of relief materials, temporary medical centers etc.).

3) The cyclone shelters which are not regularly used may be utilized by the Union Parishad for generating income by way of renting out as venue for weddings, meetings, cultural activities and office space.

4) Upazila Parishad and Union Parishad may raise funds locally for undertaking minor repair works of cyclone shelters. The fund thus collected shall have to be deposited in a savings bank account titled "Cyclone Shelter Repair and Maintenance", opened in favor of the concerned Upazila or Union Parishad.

5) The money deposited in the bank account shall be withdrawn under the joint signatures of the Chairman Upazila or Union Parishad and the Upazila Nirbahi Officer subject to prior authorization by the Upazila Disaster Management Committee or the Union Disaster Management Committee respectfully.

6) Rental for the cyclone shelter shall be collected against a proper 'money receipt' under the joint signature of the Chairman and one other designated member of the Cyclone Shelter Management Committee. All sums collected as rent shall be accounted for in the books of accounts. The Upazila Parishad shall provide the books of accounts as well as the "money receipt" books.

7) Fund collected shall not be used for any other purpose except for repair and maintenance of the cyclone shelters. The books of accounts and the counterfoil of the "money receipt" shall be preserved under the supervision of the Secretary of Union Parishad shall be maintained for purposes of audit.

8) Irrespective of the purpose of use of shelters in the normal time by individuals or institutions, the Upazila Disaster Management Committee shall decide how these shelters shall be used during emergency period and the decision of the Upazila Disaster Management Committee shall be treated as final. In such a situation, the Upazila Disaster Management Committee shall coordinate matters in accordance with the provision of the Standing Orders on Disaster (SOD) (Mallick, 2014).

## 3. Methodology

The methodology employed in this study is designed to assess the impact of climate change on cyclone shelter management in the Noakhali region. It combines both qualitative and quantitative approaches to gather, analyze, and interpret data. The study is carried out through the following key steps:

Study Area Selection—The study focuses on the Noakhali region, which includes three cyclone-prone districts: Noakhali, Feni, and Lakshmipur. These districts were selected because of their frequent exposure to cyclones and the vulnerability of their coastal communities. A regional map of these areas is used to identify the specific locations of the cyclone shelters to be evaluated.

Data Collection-Primary Data: Field surveys were conducted at various cyclone shelters in the study area to assess their current structural conditions, functionality, and management practices. Interviews with local shelter managers, community

members, and government officials were carried out to gather insights into the management processes, maintenance challenges, and preparedness efforts.

Secondary Data- Historical climate and cyclone data from the Bangladesh Meteorological Department (BMD) and other relevant agencies were collected to analyze trends in cyclone frequency and intensity over time. Existing literature on cyclone shelters and disaster risk reduction in Bangladesh was reviewed to provide context for the study's findings (Mohapatra et al., 2022).

## 4. Climate Risk Analysis

### 4.1. Temperature & It's Impact

Monthly average maximum and minimum temperature over Noakhali region are depicted in Figures 14 and Figures 15. Monthly maximum temperatures are higher in March to November and lower in other months. Due to changing climate, it has possibility to increase during warm period. This situation will help to raise sea level and intensity of cyclonic disturbances formed over the Bay of Bengal, life cycle of the Bay originated disturbances and intrusion of saline water. This situation will hamper the management of existing cyclone shelters (Mallick, 2014).

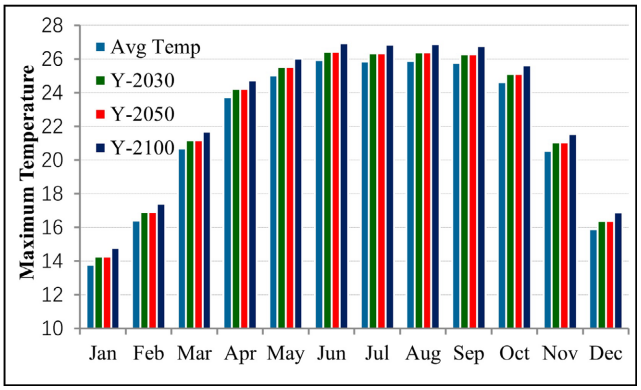


Figure 14. Monthly average minimum temperature (˚C) distribution with 2030-, 2050- and 2100-year projected value at Majidi Court as a representative station of Noakhali region.

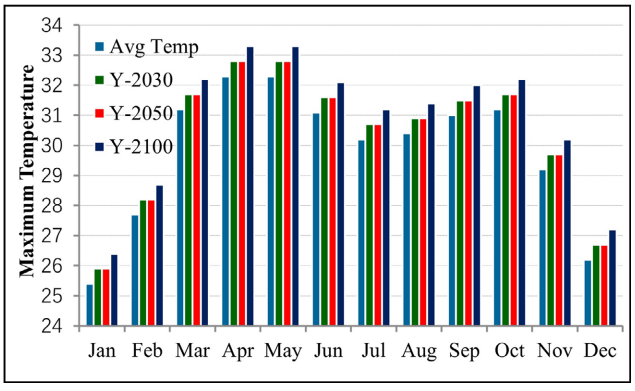


Figure 15. Monthly average maximum temperature (˚C) distribution with 2030-, 2050- and 2100-year projected value at Majidi Court as a representative station of Noakhali region (Islam et al., 2021).

Similarly, monthly minimum temperatures are higher in March to November and lower in other months. Due to changing climate, it has possibility to increase minimum temperature in warm period and decrease in other months. This situation will also help to increase the intensity of cold condition and may make the cyclone shelters uncomfortable to users. This situation will hamper indicates the improvement of cyclone shelter management. This includes Homestead reinforcement, Homestead ecosystem protection, Underground bunker construction for Cyclones and storm surges and Risk insurance mechanisms for sea level rise.

### 4.2. Rainfall & It's Impact

Rainfall of Noakhali region is high during the consecutive months of May to October. It is extremely high during monsoon months of June to September. During this period consecutive non-rainy days are very rare. If the rainfall amount increases or decrease it may increase or decrease by 30%. At this situation distribution would as in Figure 16. At this situation rainfall amount will be high in the rainy month and non-rainy days will less. This situation will have good impact on the society as well on the habitat. So, additional arrangements are required to maintain the cyclone shelters.

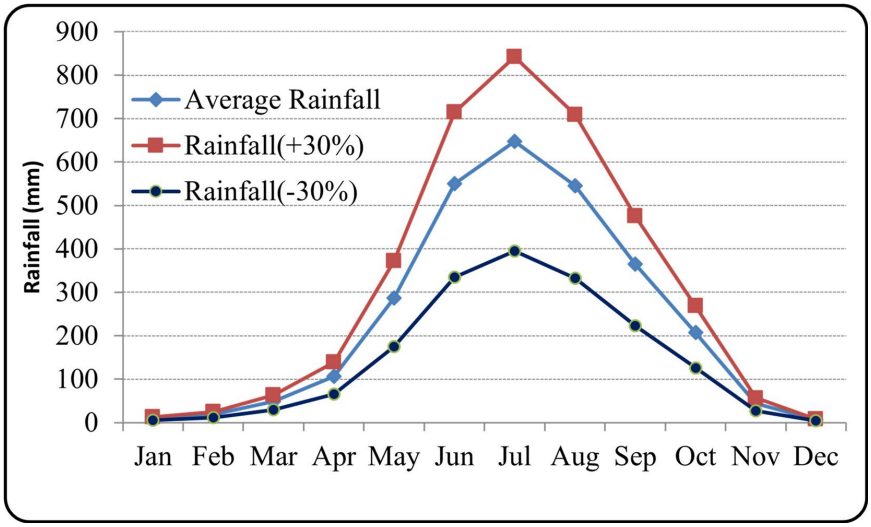


Figure 16. Monthly average rainfall (mm) distribution with ±30% change at Majidi Court. (as a representative station)

### 4.3. Cyclone & It's Impact

As per IPCC report, along the coasts of developing countries, weather and climate extremes impact on a wide range of economic activities supporting coastal communities and pose an additional risk to many of the fastest-growing low-lying urban areas, such as in Bangladesh. The Bangladesh Government initiated construction of cyclone shelters in the late 1980s, yet a cyclone in 1991 revealed that too few shelters were available. This prompted collaboration between the government of Bangladesh, the United Nations Development Program and the World Bank to

launch the Multipurpose Cyclone Shelter Program. That program characterized shelter needs along the coast and provided resources for their construction.

Bangladesh is identified as being at specific risk from climate change due to its exposure to sea-level rise and extreme events and concentrated multidimensional poverty. Bangladesh's population at risk of sea level rise is predicted to grow to 27 million by 2050. Vulnerability to cyclones is also expected to increase, but multiple opportunities can converge to facilitate adaptation. Bangladesh lost an estimated 5.9% of GDP to storms from 1998-2009. Bangladesh and India account for 86% of mortality from tropical cyclones, mainly due to having the rarest and most severe storm categories. World Bank estimates the adaptation deficit with respect to cyclones is USD 25 Billion.

It is expected that the intensity of cyclone will enhance in future and storm surge height is supposed to increase. Sustainability of existing cyclone shelters management will be in question. In this situation, cyclone shelters located over Noakhali region will require additional measures to keep their life time longer. In addition, some additional measure like paintings, flustering etc. are required to take (Dasgupta et al., 2013).

### 4.4. Projection for Temperature, Rainfall & Cyclone

IPCC Fifth Assessment Report (AR5) offers the following key messages for Bangladesh

1) Bangladesh's climate is changing and the impacts are already being felt;

2) Further climate change is inevitable in the coming decades;

3) Climate change poses challenges to growth and development in Bangladesh;

4) Adaptation will bring immediate benefits and reduce the impacts of climate change in Bangladesh;

5) Adaptation is fundamentally about risk management;

6) South Asia has many adaptation options;

7) Some low-carbon development options may be less costly in the long run and could offer new economic opportunities for Bangladesh and South Asia;

8) South Asia stands to benefit from integrated climate adaptation, mitigation and development approaches;

9) International cooperation is vital to averting dangerous climate change, and South Asian governments can promote ambitious global actions.

## 5. Climate Change Analysis

Climate change is one of the most pressing global challenges, and its effects are particularly acute in vulnerable regions like Bangladesh. The country's geographical location and low-lying topography make it highly susceptible to climate-related disasters, especially in its coastal regions. In the Noakhali region, which includes Noakhali, Feni, and Lakshmipur districts, the impacts of climate change are already evident, with increasing cyclone intensity, sea-level rise, and shifts in weather patterns. This analysis focuses on the key dimensions of climate

change affecting the region and their implications for cyclone shelter management.

Rising Temperatures Climate data over the past several decades has shown a steady increase in both maximum and minimum temperatures in the Noakhali region. This warming trend is expected to continue, with projections indicating that temperatures will rise further by 2030, 2050, and 2100. This increase in temperature is particularly significant in the pre-monsoon and monsoon periods (March to September), when cyclones typically form in the Bay of Bengal. The rise in sea surface temperatures, driven by global warming, is directly linked to the increased frequency and intensity of cyclones in the region.

As temperatures continue to rise, the region is expected to face more frequent extreme weather events, including stronger cyclones and heatwaves. These hotter conditions also have implications for the usability of cyclone shelters, as higher temperatures within poorly ventilated shelters can create uncomfortable or even dangerous conditions for occupants during emergencies. Shelter designs must be adapted to account for the growing heat risk, ensuring proper ventilation and cooling mechanisms.

Changes in Rainfall Patterns Rainfall patterns in the Noakhali region have become increasingly erratic due to climate change. Historical data shows that the region receives heavy rainfall during the monsoon season (June to September), but the intensity and frequency of rainfall events have been fluctuating. Climate projections suggest that this trend will continue, with heavier and more concentrated rainfall during the monsoon season coupled with extended dry spells in the post-monsoon season.

The increased rainfall intensity poses several risks to cyclone shelters. Many shelters, especially those in low-lying areas, are vulnerable to flooding due to poor drainage systems. Excessive rainfall during cyclonic events can lead to waterlogging around shelters, making them inaccessible. Additionally, the structural integrity of shelters may be compromised by prolonged exposure to heavy rainfall, especially for shelters that are not regularly maintained or are built with substandard materials.

Increasing Cyclone Frequency and Intensity Cyclones have always been a significant hazard in the Bay of Bengal region, but climate change is amplifying their frequency and intensity. Warmer sea surface temperatures provide the energy needed for cyclones to form, and the rising temperatures are leading to stronger storms with higher wind speeds and more devastating storm surges. Over the past two decades, cyclones have highlighted the increasing severity of these storms.

With more intense cyclones expected in the future, the cyclone shelters in the Noakhali region face a growing challenge. Many of these shelters were designed based on historical cyclone data and are not equipped to withstand the stronger cyclones predicted under current climate models. As wind speeds increase, the structural integrity of shelters will be further tested, necessitating urgent upgrades to ensure they can provide adequate protection.

Sea-Level Rise One of the most direct consequences of climate change for coastal regions like Noakhali is sea-level rise. According to estimates, global sea levels could rise by up to 1 meter by the end of the century, which would have catastrophic effects on Bangladesh's coastline. The Noakhali region, with its low elevation and proximity to the Bay of Bengal, is particularly vulnerable. Rising sea levels increase the risk of storm surges during cyclones, as higher base water levels mean that storm surges can penetrate further inland.

Many cyclone shelters in Noakhali are located in areas that are already prone to flooding. As sea levels rise, these shelters may become unusable or difficult to access during storm surges. Shelters that are not elevated sufficiently above the projected future flood levels will be at risk of inundation. This highlights the urgent need for a reassessment of shelter locations and designs, with a focus on elevating structures to protect them from rising waters.

Storm Surges and Coastal Erosion Alongside rising sea levels, storm surges present a significant risk to the Noakhali region. Storm surges occur when strong winds from cyclones push seawater onto land, causing rapid flooding. As cyclones grow stronger due to climate change, the height and reach of these storm surges will increase. Coastal erosion, another consequence of sea-level rise and increased storm activity, is already affecting the region. The erosion of coastal land weakens the foundations of buildings, including cyclone shelters, and makes these areas more vulnerable to future storms.

Shelters located near the coast face the dual threat of storm surges and erosion, both of which can compromise their structural stability. Without proper coastal management and protection measures, such as embankments or greenbelts, these shelters could be severely damaged or rendered unusable. Long-term adaptation strategies must include relocation of shelters at risk of erosion and the reinforcement of coastal defenses to mitigate the impacts of storm surges.

Vulnerability of Coastal Communities The communities in Noakhali, Feni, and Lakshmipur districts are heavily dependent on agriculture and fishing, both of which are highly vulnerable to climate change. Rising sea levels lead to saltwater intrusion, which damages crops and reduces agricultural productivity. Frequent cyclones and storms disrupt livelihoods and lead to loss of life and property. As these communities face growing risks from climate change, the importance of reliable, well-maintained cyclone shelters becomes even more critical. However, many of these shelters are already in poor condition due to inadequate maintenance, and the increasing frequency of disasters places additional strain on already limited resources.

Ensuring that cyclone shelters remain functional and accessible is essential for safeguarding the lives of vulnerable populations in the region. This requires not only improvements in the design and construction of shelters but also better coordination between government agencies and local communities to maintain and manage these structures effectively.

## 6. Changing Impact of Climate on Cyclone Shelters

The climate of Bangladesh can be characterized by High temperatures, Heavy rainfall, High humidity, and fairly marked three seasonal variations like Hot Summer, Shrinking Winter and Medium to Heavy Rains during the Rainy season. The adverse effects of Climate Change - especially High Temperature, Sea-level Rise, Cyclones and Storm Surges, Salinity Intrusion, Heavy Monsoon Downpours etc. has aggravated the overall Economic Development scenario of the country to a great extent (Sarker & Azam, 2013). Current and future climate will impact the infrastructure, environment, ecology, agriculture, water resources and livelihood of the people of coastal Bangladesh. The increase in temperature has the potential to cause material expansion resulting in damage concrete structures such as buildings, bridges, and culverts and bitumen seals to roads may be susceptible to softening unless higher temperature resistant bitumen's are used. Floods resulting from increased rainfall, cyclones and storm surges have the potential to damage infrastructure, road embankments, markets and housing. Some figures about changing impact of climate on cyclone shelters are given below:

Figure 17. Inside pictures of a cyclone shelter in Kabirhat Upazila of Noakhali District.

## 7. Management Procedure to be Taken to Cope Up with Changing Climate

Bangladesh is more vulnerable to cyclonic storms and flooding because of climate change and sea level rising. Geographically the country is situated in the danger zone of cyclone and consequently a large number of people living in the coastal area are in great risk of climate change and sea level rising. Coastal regions of Bangladesh are vulnerably affected by climate change. Rising of sea level is a

consequence of global climate change which affects the cyclone shelter situated in coastal regions as rise in sea level brings salt water into the surface. Cyclone shelter will be affected adversely by climate induced effects, especially cyclonic storm surges, high intensity floods, wave interactions and afal and to a lesser extent salinity ingress. Increased intensity of cyclonic storm surge will damage coastal infrastructure including people's dwellings, road networks, water supply and sanitation systems, administrative buildings and cyclone shelters. Similarly, high floods will tend to erode roads (Rahman et al., 2022).

It is well understood that the adverse impacts of climate change will increase with time. In future, Bangladesh will face exacerbated implications of climate change in terms of aggravated hazards and extreme weather events, people's lost livelihoods, potential non-availability of ecosystem services, loss of national economy and greater expenditure away from development to safeguard people's lives and livelihoods. Some mitigation measures that should be taken to cope up with the changing climate are as following:

1) To repair and rehabilitate existing cyclone shelter and ensure effective operation and maintenance systems;

2) To plan, design and construct urgently needed new infrastructure (various types of

3) Shelters, low-cost disaster resilient shelter, multipurpose shelter) to meet the changing conditions expected with climate Change;

4) To undertake strategic planning of future infrastructure i.e. cyclone shelter needs, taking into account the likely impact of climate change;

5) Ensuring a plinth level in excess of the year 2100 effective SLR level plus a freeboard of 500mm

6) Strict compliance with relevant Bangladesh building codes with respect to wind

7) Loading and floor bearing capacities.

8) Ensuring adequate water storage, sustainable power supply and appropriate toilet facilities

9) Ensuring the associated access road/s is upgraded to the equivalent of village

10) Road climate resilience.

11) To maintain the material specification with changing climate.

## 8. Implementation Procedure

The World Bank in 2011 noted that the housing sector experienced very extensive damage and loss during the Sidr cyclone in 2007. Analysis of housing damage by type indicated while "pucca" houses (brick and concrete) can withstand most of the wind damages from the average severe cyclone, they provide no remedy for inundation from storm surges; "semi-pucca" houses, "kacha" (thatched) houses and "jhupris" (bamboo/thatch shack) categories suffered catastrophic damage (Kabir et al., 2016).

Adaptation options in the infrastructure sector may generally be grouped into

engineering options and non-engineering options:

Engineering Options include:

1) Material specification

2) Protective engineering structures

3) Rehabilitation of current designs: The rehabilitation through "repair-maintenance" of current designs will reduce deterioration of the infrastructure but will not address key design and construction issues that are reducing the climate resilience and effectiveness of the current infrastructure

4) Roofing conditions

5) Foundation conditions

Non-Engineering options may include:

1) Maintenance, planning and early warning

2) Alignment, master-planning and land use planning

3) Environmental management

Housing

The principal proposed climate resilience measures associated with housing are:

1) The clustering of housing on raised plinths; these to be of compacted soil encased by a concrete perimeter wall. The level of these plinths to be to above existing maximum normal monsoon flood levels plus allowance for the effective year 2050 SLR.

2) Houses to be adequately wind-resistant in design.

Taking the following other measures can help to implement the risk management procedure:

1) Instead of developing large cyclone shelters, a dense network of small, sturdy and safe multipurpose buildings should be developed. Considering the population density, cyclone shelters should be established within a 2 km walking distance of households and villages.

2) Geographic Information Systems and remote sensing technology should be used to determine the best locations in terms of factors such as access, road networks and population density.

3) Schools, mosques, local government buildings or other locations where people congregate represent potential locations for these shelters. This should be given the highest priority in cyclone-preparedness programs.

4) Bangladesh is now fully covered by mobile telecommunication networks. Thus, distributing cyclone warning messages via mobile phones is a good option.

5) Colorful hot air balloons can be used to convey cyclone-warning messages in remote and coastal areas of Bangladesh.

6) The potential for the breakdown of water and sanitation systems during a cyclone should be considered carefully in the planning, design and implementation of future housing developments. This will help prevent waterborne disease outbreaks.

7) Initiatives to collect and store drinking water should also be considered.

Harvesting rain water during a cyclone can be an option.

8) Coastal embankment projects should be extended to all coastal areas. Existing embankments should be repaired and maintained. Careful planning with sufficient sluice gates, especially in the south-eastern area of Bangladesh, will protect against both flash floods and storm surges during a cyclone and will also help protect cropland, fisheries and livestock.

9) The development of a 500-meter coastal mangrove forest zone will further reduce the vulnerability to cyclones, which is especially important given the likelihood of a rise in sea level and an increase in tropical storm frequency and strength due to climate change.

10) Planners, policy-makers and development practitioners should endeavor to incorporate local knowledge into environmental and adaptation strategies. The building code in coastal zones should be changed to ensure that concrete houses are raised 3 meters off the ground. More broadly, a more compact development style may be recommended.

11) To increase people's awareness of the severity of cyclone hazards, the Bangladesh government and nongovernmental organizations should further strengthen the existing awareness Program and initiate educational campaigns in coastal districts to ensure prompt use of public shelters during cyclones. Awareness should focus on public health and hygiene issues. The awareness Program could target primary school children, following the Cuban model, which represents an excellent example for Bangladesh. Some operational research should be conducted in this regard.

12) People's misconceptions about the strength of their houses, a lack of interest in moving to a cyclone shelter and other potential risk factors should be identified through qualitative research. The design and delivery of community cyclone-preparedness education should be based on these research findings. Community-based volunteer intervention Programs should be introduced without further delay.

13) Cyclone-related loss in terms of economic and human capital is exacerbated by poverty and poor infrastructure in coastal areas of Bangladesh. Donor agencies, politicians and planners in Bangladesh should take this into account in future planning of coastal zones.

14) Industrialized countries and newly emerging industrialized countries should provide financial support to vulnerable countries to help them adapt to and mitigate cyclone-related risks. At the same time, all countries should reduce their emissions of carbon dioxide and other greenhouse gases.

## 9. Summary and Discussion

Bangladesh is one of the most natural disaster-prone countries. Over the last 40 years, many cyclones have affected the country accompanied with loss of lives and property. Global climate change will make the country even more vulnerable to cyclones and floods. For low-lying countries as Bangladesh, it is very important to adapt to climate change, to reduce impacts, which may lead to increased human

misery, social injustice, and damaged ecosystems. It is well understood that the adverse impacts of climate change will increase with time. In future, Bangladesh will face exacerbated implications of climate change in terms of aggravated hazards and extreme weather events, people's lost livelihoods, potential non-availability of ecosystem services, loss of national economy and greater expenditure away from development to safeguard people's lives and livelihoods.

Cyclone shelter will be affected adversely by climate induced effects, especially cyclonic storm surges, high intensity floods, wave interactions and afal and to a lesser extent salinity ingress. Increased intensity of cyclonic storm surge will damage coastal infrastructure including people's dwellings, road networks, water supply and sanitation systems, administrative buildings and cyclone shelters. Bangladesh is identified as being at specific risk from climate change due to its exposure to sea-level rise and extreme events. Bangladesh's population at risk of sea level rise is predicted to grow to 27 million by 2050. Vulnerability to cyclones is also expected to increase, but multiple opportunities can converge to facilitate adaptation. Adaptive measures such as the construction of (multi-purpose) shelters and measures at a household scale, are important to save lives, property and livelihood.

Initiatives at central and local governmental, nongovernmental and community levels seem to be key for success in minimizing cyclone-related mortality. Over the years, investments in cyclone preparedness and flood management helped save lives, reduce economic losses, and protect developmental gains. To maintain the service condition of the disaster shelters, it is mandatory to find out the effect of climate change on these structures as well as other conditions that may influence the service conditions.

It is expected that the intensity of cyclone will enhance in future and storm surge height is supposed to increase. Sustainability of existing cyclone shelters management will be in questions. At this situation, cyclone shelters located over Noakhali region will require additional measures to keep their life time longer. There is no doubt that the existing and new shelters are vital for mitigating or minimizing the casualties of vulnerable populations in the event of natural disasters.

## 10. Result

The findings from this study highlight several critical issues related to cyclone shelters in the Noakhali region, especially as climate change continues to intensify:

*Structural Weaknesses of Cyclone Shelters:* Many cyclone shelters, particularly the older ones, are simply not built to handle the increasing intensity of storms predicted due to climate change. Shelters constructed before 2007, when Cyclone Sidr struck, were designed with less severe storms in mind. Now, with stronger cyclones on the horizon, these shelters are showing their limitations. Cracked walls, weakened roofs, and worn-out structures leave them vulnerable, putting lives at risk during future storms.

*Maintenance is a Major Issue*: A significant portion of the shelters are in a state

of neglect. Basic maintenance, such as repairing leaks, cracks, and broken facilities, has been overlooked. Many of the shelters lack sufficient funding for proper upkeep, leading to rapid deterioration. Without consistent care, these buildings are becoming less reliable as safe havens during emergencies.

*Shelter Accessibility is a Challenge*: Reaching shelters during a cyclone can be a real challenge for many communities, especially those living farther away. Flooded roads, poor infrastructure, and lack of transport options make it difficult for people to reach safety in time. On top of that, many shelters lack essential facilities like separate areas for women, children, and people with disabilities, making them less practical for the entire community.

*Cyclones are Becoming More Frequent and Severe:* Data from the Bangladesh Meteorological Department and global climate projections show that cyclones are not only becoming more frequent but also more powerful. Rising sea temperatures are fueling these storms, and Noakhali is directly in their path. Many shelters are located in flood-prone areas and may not survive the higher storm surges and stronger winds expected in the future.

*Community Perceptions and Preparedness:* While people recognize the importance of cyclone shelters, many are reluctant to use them. Issues such as overcrowding, lack of safety, and concerns about the shelters' durability deter some from seeking refuge during storms. Additionally, there are gaps in disaster preparedness, with many residents unaware of the locations of nearby shelters or how to respond when a cyclone is approaching.

## 11. Conclusion

This study makes it clear: the cyclone shelters in Noakhali are underprepared for the growing threat posed by climate change. With cyclones becoming stronger and more frequent, the shelters' current state of disrepair, lack of maintenance, and poor accessibility put many lives at risk.

Several key issues need urgent attention:

1) Shelter Upgrades: The shelters need significant structural improvements to withstand the stronger storms that are expected. This includes reinforcing buildings, raising their elevation in flood-prone areas, and ensuring they are built with future climate risks in mind.

2) Consistent Maintenance: Regular upkeep is essential. Shelters should not be left to deteriorate between disasters. A clear plan for regular inspections and repairs must be established, along with allocated funding to make this happen.

3) Better Accessibility: Cyclone shelters need to be more accessible to all members of the community. Roads leading to them should be improved, and shelters must be equipped with proper facilities for women, children, the elderly, and people with disabilities.

4) Improved Community Preparedness: People need to be better informed and confident in using cyclone shelters. Raising awareness about early warning systems, shelter locations, and what to do during a cyclone is crucial. Addressing

fears around safety and overcrowding will also encourage more people to use shelters when necessary.

In conclusion, without immediate action to upgrade, maintain, and better manage these shelters, the ability to protect people from future cyclones will be seriously compromised. It is critical that we adapt to the changing climate now, to ensure that these shelters remain safe havens for vulnerable communities in the years to come.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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