Research Article

Potential Climate-Induced Migration Determinants and Decision Support of Anticipatory Actions and Climate-Displacement Solutions in Coastal Districts of Bangladesh

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Abstract

Bangladesh is one of the most climate-vulnerable countries in the world. The country is experiencing climate-induced sudden and slow-onset extremes like sea level rise, salinity intrusion, floods and flash floods, drought, storm surges, tidal inundation, and waterlogging. Due to the slow onset and sudden disasters, including salinity intrusion, sea level rise, cyclones, and storm surges along the coastal belt of Bangladesh, climate-induced migration is a common scenario. Many of the coastal people are migrating as adaptation options to nearby urban centers or big cities. The study aims to explore the determinants of climate and environmental migrants, potential migration location identification, and migration trajectory determination of the climate-vulnerable districts. The study was conducted through Multi-Hazard Risk Assessment, Multi-factorial climate vulnerability assessment, Local climate scenario generation, application of Agent-based Modelling (ABM) to identify specific climate-induced displacement potential locations, and multi-variate probit regression analysis to determine the migration determinants. The study also applied participatory research methods, including Household Survey (HHS), Focus Group Discussion (FGD), and Key Informant Interview (KII) to identify the association between climatic extremes and migration from the respective study areas, and RS&GIS for detecting land use and land cover changes. The study reveals that shrinking livelihood opportunities and landlessness are the major causes of climate-induced migration.

Keywords

Climate Extremes, Migration, Determinants, Coastal Belt, Bangladesh.

1. Introduction

Bangladesh is a nation that is highly vulnerable to the effects of climate change (Rahaman et al., 2023). The country has faced various hydro-meteorological threats, including cyclones, floods, salinity intrusion, storm surges, erosion, and drought (ADB, 2021). Growing threats to biodiversity and nature include the effects of climate change, such as cyclones, storm surges, sea waves, tidal surges, tidal floods, sea level rise, and increased storminess. Bangladesh is located in a low-lying delta region created at the confluence of the Ganges and Brahmaputra River systems. Bangladesh is situated in South Asia. It is also regarded as the largest delta in the world, as a riverine nation that is particularly vulnerable to geophysical hazards because of its topography and location (Rahaman et al., 2023). Long-standing climatological (such as drought), hydro-Meteorological (such as cyclones, storm surges, and floods) and other geophysical (such as landslides

and erosion) hazards affect the nation. Due to its funnel-shaped southern coast and being a riparian nation, it is vulnerable to cyclones and storm surges, medium-to-high soil salinity, sea-level rise, monsoon, and flash floods (Reliefweb, 2021).

According to the Sixth Assessment Report of the IPCC, South Asia's climate is changing, and the impacts are already being felt (Pörtner et al., 2022). According to the Global Climate Risk Index (GCRI), Bangladesh ranked 9th on the list of 10 most affected countries and placed 7th on the long-term (1998-2017) risk index because of extreme climatic events (Eckstein et al., 2020). A long-term trend of disasters in Bangladesh based on 120 years (1900-2020) data from EM-DAT data suggests that cyclones and floods are the two most recurrent disasters that cause enormous economic loss and are associated with some of the significant catastrophic events in the history of Bangladesh, such as 1970 Bhola Cyclone where roughly 500,000 lives were lost (NIRAPAD, 2021). From 7 years' trend analysis starting from 2014 up to 2020, the 15 significant disasters (cyclone and storm surge, flood, salinity, and riverbank erosion) affected 42 million people, displaced 9.4 million people, damaged 4.6 million houses either fully or partially, caused 1,053 deaths, and resulted in an economic loss of $4.1 billion (NIRAPAD, 2021). Among the four major disasters, floods (including both Monsoon and Flash floods) affected 34.9 million people- it is the highest and 83% of the total affected 42 million; the next one to have a significant impact was cyclone and storm surges, which affected 7.05 million people and constitutes 16.78% of the affected population. These climate-induced extremes also restrict agricultural production in terms of land loss and production reduction. The Southern region of Bangladesh (Map 1), lying in the coastal zone, is exposed to salinity intrusion. In Bangladesh, the coastal region contains a deltaic plain that covers more than 30% of the arable land. 1.056 million hectares of coastal land, or about 1.689 million acres, are impacted to varying degrees by soil salinity (Miah et al., 2020).

People who live in coastal areas of Bangladesh cannot help but have to change their agricultural practices, livelihoods, and groundwater contributions due to saltwater intrusion. Barguna is one of the vulnerable climate districts of the southwest coastal belt, where salinity intrusion, tidal surges, storm surges, and cyclones are common phenomena. This district has a shortage of clean drinking water due to salinity intrusion and sea level rise (Nahin et al., 2020). Saline water intrusion into the agricultural land restricted agricultural production, reducing livelihood options. People's dependence on the extraction of mangrove resources is increasing daily. Coastal floods, tidal surges, riverbank erosion, saline intrusion in water and soil, tropical cyclones, etc., have significantly risen in Bangladesh's coastal region due to climate-induced sea level rise (Rahaman et al., 2020). Climate change is gradually increasing disasters like floods, riverbank erosion, cyclones, tornadoes, hailstorms, water logging, saline intrusion, etc., growing threats for the coastal residents (Rahman et al., 2017). In Patuakhali, extreme poverty in 2010 was 14.7% and increased to 27.4% in 2016 (BBS, 2016). In this district, the reported amount of violence against women was 59 in 2013 and increased to 132 in 2015. Salinity is responsible for reproductive health disturbance, which causes disabled childbirth (Rahaman et al, 2022). HIES 2016 also mentioned the chronically disabled in Patuakhali, 32% (BBS, 2016). Climate-induced migration is increasing in this district, and internal migration increased to 11.30% during 2000-2010, which was 4.80% during 1991-2000 (Brennan, 2020). Rahaman finds the migration 33.90% seasonal migration in Patuakhali. Rahaman also finds that during the winter and summer, seasonal migration increases (Rahaman et al., 2022).

The geographical location, climate, and topography of Cox's Bazar create a unique environment where local communities are exposed to multiple natural hazards and experience recurring extreme weather events. Vulnerable Bangladeshi communities in the district have long borne the brunt of cyclones, landslides, and flash floods. The Rohingya crisis has increased the size of the population at risk and is driving the creation of new risks due to deforestation, hill cutting, and infrastructure pressure. Since August 2017, more than 700,000 Rohingya refugees have temporarily settled in the Ukhiya Upazila, a region of critical environmental importance (Quader, 2019). The Rohingya refugee crisis has pressured the Bangladeshi community, affecting five ecosystem aspects, including natural forests, protected areas, critical habitats, vegetation, wildlife, and marine and freshwater ecosystems (Hossain & Mowla, 2021). This significant addition to the area's population resulted in more pressure on the resources, especially the forest resources. Population growth affects the local ecosystem and forest resources (Hassan et al., 2023). Most of Ukhiya's vegetation area has been converted to agricultural land and settlements to meet demand. Local forests are visibly affected by the influx of refugees into these areas, which has exacerbated conflicts between humans and wildlife. This results in a dispute between the host community and the refugee. Since August 2017, more than 744,400 stateless Rohingya refugees, an ethnic Muslim minority group from the Rakhine State, have entered Bangladesh to escape serious crimes against humanity conducted by the Myanmar Army. Extensive levels of deforestation, land leveling, and hill-cutting activities took place in Cox's Bazar District in Bangladesh to accommodate them (Kamal et al., 2022). As Cox's Bazar is a huge tourist attraction and tourism offers business opportunities, more and more hotels and resorts have been constructed by cutting down lots of trees and cutting down hills. This unplanned urbanization has become a core triggering point for landslides (Rasel et al., 2021). Besides, the Hill cut-

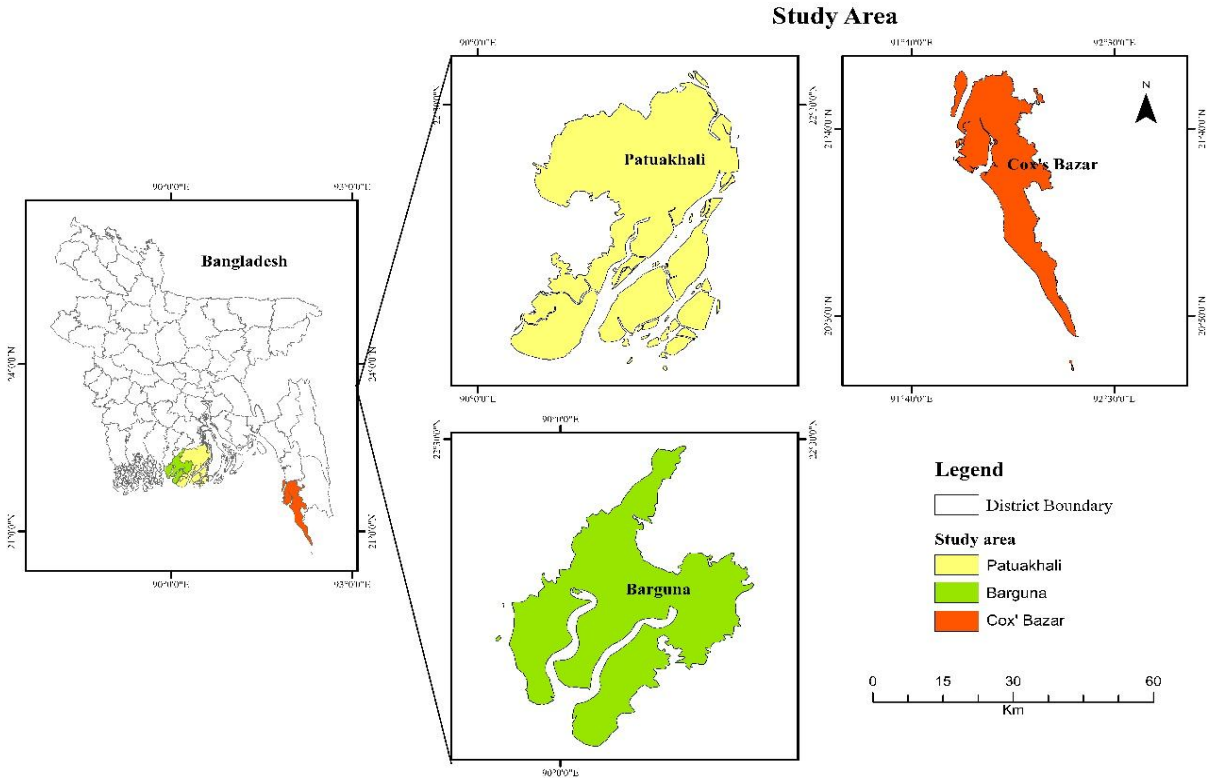
ting and the extensive loss of ground cover vegetation loosen the soil, bringing new risks, leading to soil erosion, sedimentation, siltation, and landslides. These effects are particularly noticeable during the rainy season. Bangladesh is most exposed to natural hazards and most vulnerable to climate change impacts.

2. Methodology

2.1. Data Collection

The study was conducted in three coastal districts (Cox's Bazar, Barguna, and Patuakhali) of Bangladesh (Map 1).

Map 1: Study Area



Long-term observational data on climate, water, and hazards were collected from the Bangladesh Meteorological Department (BMD), the Bangladesh Water Development Board (BWDB), the Department of Agricultural Extension (DAE), and the Disaster Management Bureau (DMB). The study also reviewed and analyzed Bangladesh Climate Change Strategy and Action Plan (BCCSAP), National Plan for Disaster Management (NPDM, 2021 to 2025), Standing Order on Disaster -2019, 8th Five-Year Plan of Bangladesh, Delta Plan, Integrated Coastal Zone Management Plan, Southern Agricultural Master Plan, Cyclone Shelter Management Plan, National Social Security Strategy 2015, National Energy Policy, National Plan on Water and Sanitation for hard to reach area, Coastal Embankment Improvement Plan, , Water Policy, Agriculture Policy, Forest Policy, and Gender Policy.

Primary information (qualitative and quantitative) was collected through Participatory research using a Household Survey (HHS), Focus Group Discussion (FGD), and Key Informant Interview (KII). For the household survey, Sex, Age, and Disability (SAAD) segregated 1335 respondents were surveyed in the study area. A total of 18 FGDs (6 in each district) were conducted with community people, including men, women, mixed group (male and female) youth, persons with disability, farmers, fisher folk, forest-dependent communities, and market actors to understand the existing climate vulnerability, capacity and resource to deal with shocks, capacity and resource needs, access to services, access to market and finance, etc. A total of 56 KIIs were conducted from the local level to the national level with key stakeholders including the Department of Disaster Management (DDM), Dept. of Climate Change, Department of Agriculture Extension (DAE), Department of Livestock (DLS), Department of Public Health Engineering (DPHE), Local Government Engineering Department (LGED), Department of Forest, Bangladesh Water Development Board (BWDB), Bangladesh Red Crescent Soci-

eties (BDRCS), Disaster Relief and Rehabilitation Officer (DRRO), Project Implementation Officer (PIO), Cyclone Preparedness Program (CPP), Department of Social Service (DSS), Department of Women and Children Affairs, Bangladesh Meteorological Department (BMD), NGO, MFI, financial institute, Ward Disaster Management Committee, UDMC, etc.

2.2. Data Analysis

Data analysis was performed with the statistical method. SPSS software was used to analyses frequency, percentile, and Regression Analysis in quantitative data. Qualitative data analysis was performed by NVivo software. This study developed a multi-hazard risk map for each district for the study area through (1) the collection of extreme event data through household surveys and the DDM reports over 42 years (1993-2023); (2) the identification of the most important effective factors (land use, land elevation, slope, water network, etc. through Remote Sensing and GIS; (3) Hazard modelling using a generalized linear model (GLM), a support vector machine (SVM) model, and a functional discriminant analysis (FDA) model and construction of multi-hazard risk maps (MHRM). The statistical downscaling methods were used to develop local climatic scenarios (temperature and precipitation) for the period from 2020 to 2100. The study adopted an Agent-based model (ABM) to capture potential climate displacement locations and potential communities from the study area.

We have applied Agent-based modeling (ABM) for climate-induced migration how an individual will make and is already making decisions about moving to another place. This model has simulated individuals with attributes like demographics, risk aversion, and migration goals, and then modeled their interactions with a simulated environment. In Agent-based Model (ABM), we have considered:

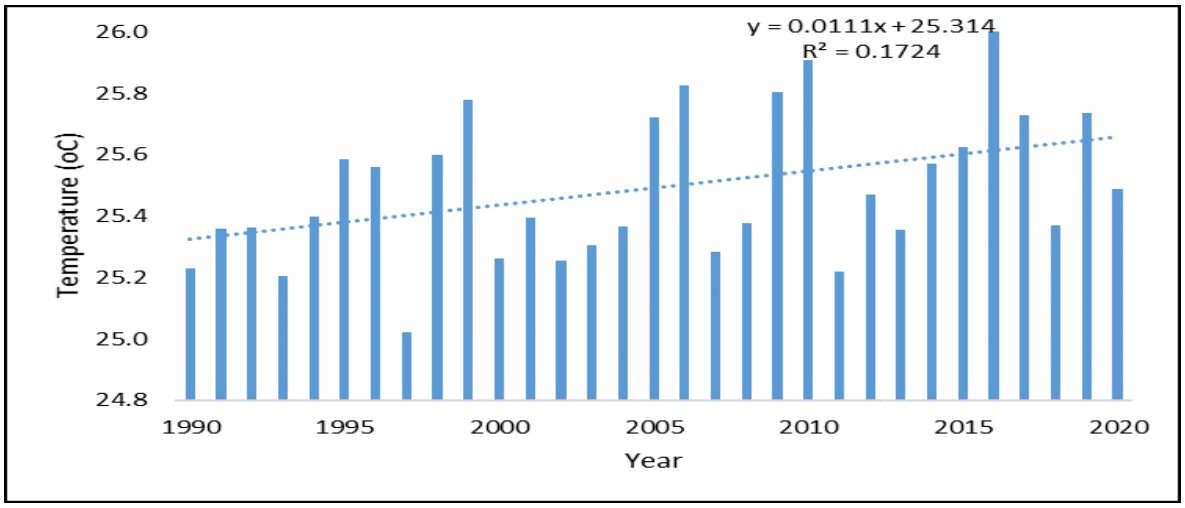
- **Agents:** Individuals or groups of people with attributes relevant to migration decisions (e.g., age, income, education, risk tolerance).
- **Environment:** Simulated the physical and social environment, including factors (climatic parameters, changing scenario of climate, resource availability, livelihood opportunity, land ownership, water availability, and infrastructure.
- **Parameters:** Variables like migration costs, climate change impacts, and other factors influencing migration decisions.

3. Results and Discussions

3.1. Climatic Scenario in the Study Area

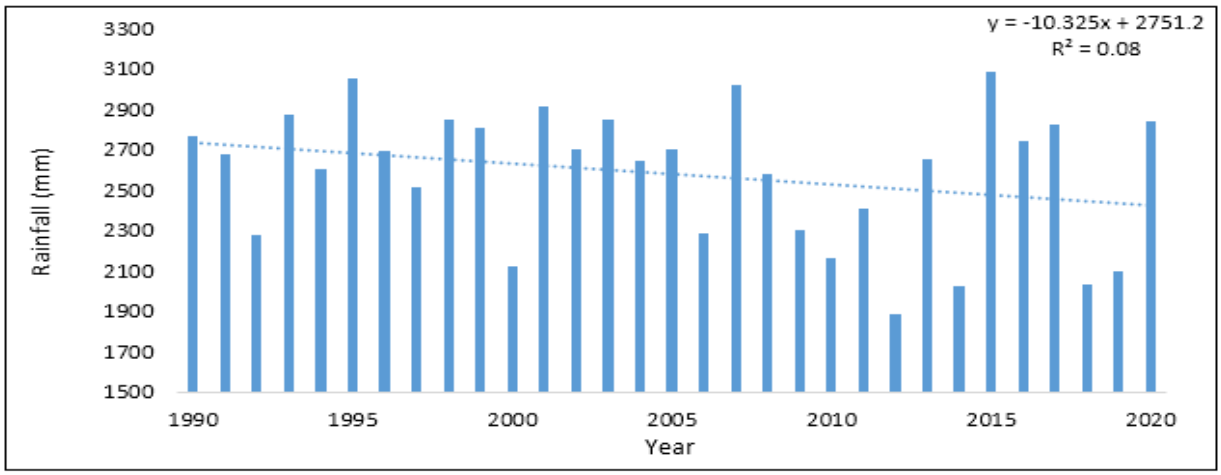
BMD observation data show that Cox's Bazar, Barguna, and Patuakhali stations' average temperatures are rising, while the average annual rainfall trend is falling in all those stations (Figures 1, 2, 3, and 4)**.** Based on an analysis of yearly average temperature patterns in the last 30 years in Patuakhali and Barguna, the temperature increased at a rate of 0.0111 degrees Celsius/year over the period 1990–2020 in Patuakhali. On the other hand, the trend of rainfall showed a decreasing pattern at a rate of 10.037 mm/year over the last 30 years in Patuakhali.

Figure 1: Average Annual Temperature of Patuakhali and Barguna (1990-2020)



Source: BMD, 2022

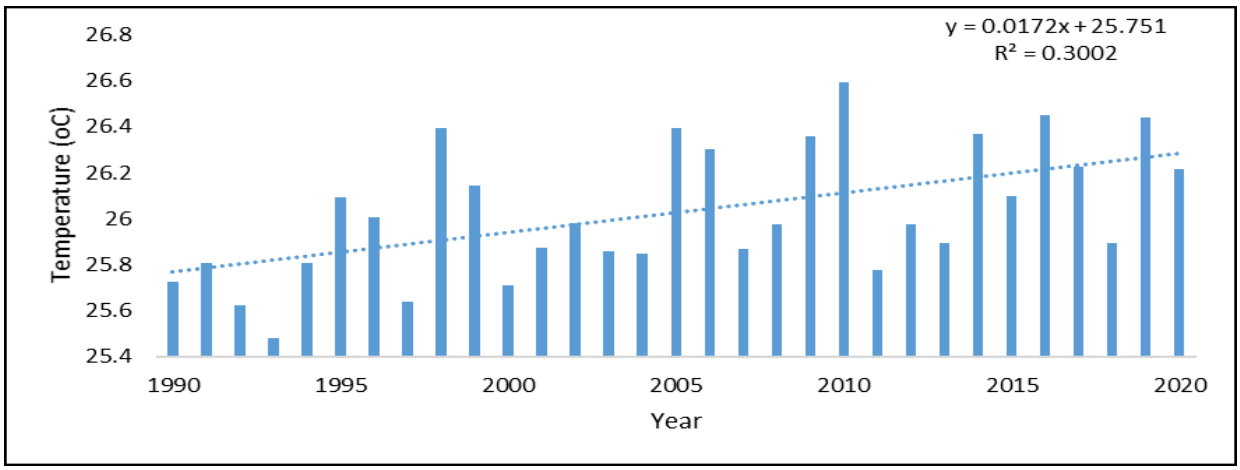
Figure 2: Average Annual Total Rainfall of Patuakhali and Barguna (1990-2020)



Source: BMD, 2022

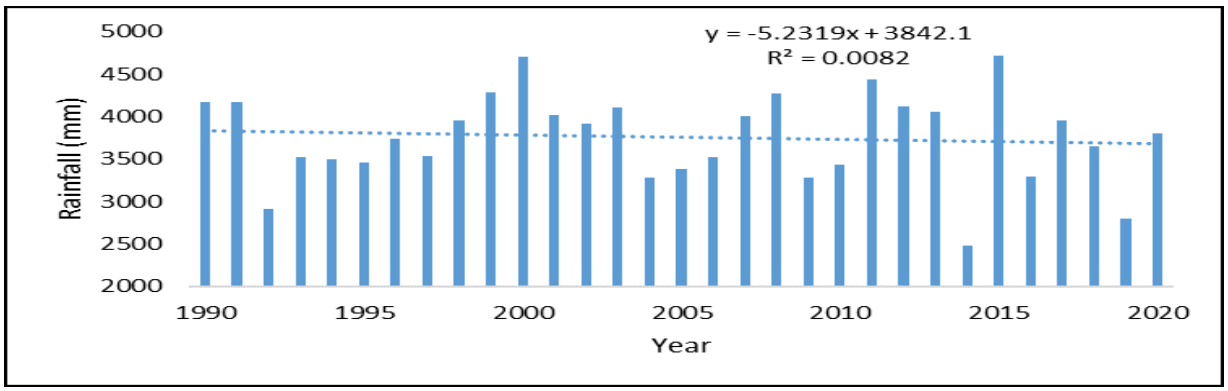
Among these study areas, Cox's Bazar station's average temperature showed a slightly higher increase rate than other stations. Temperatures have risen at a rate of 0.0172 degrees Celsius per year over the last 30 years, according to data. This station's rainfall pattern also showed a decreasing trend, with a rate of 5.2319 mm/year.

Figure 3: Average Annual Temperature of Cox's Bazar (1990-2020)



Source: BMD, 2022

Figure 4: Average Annual Total Rainfall of Cox's Bazar (1990-2020)



Source: BMD, 2022

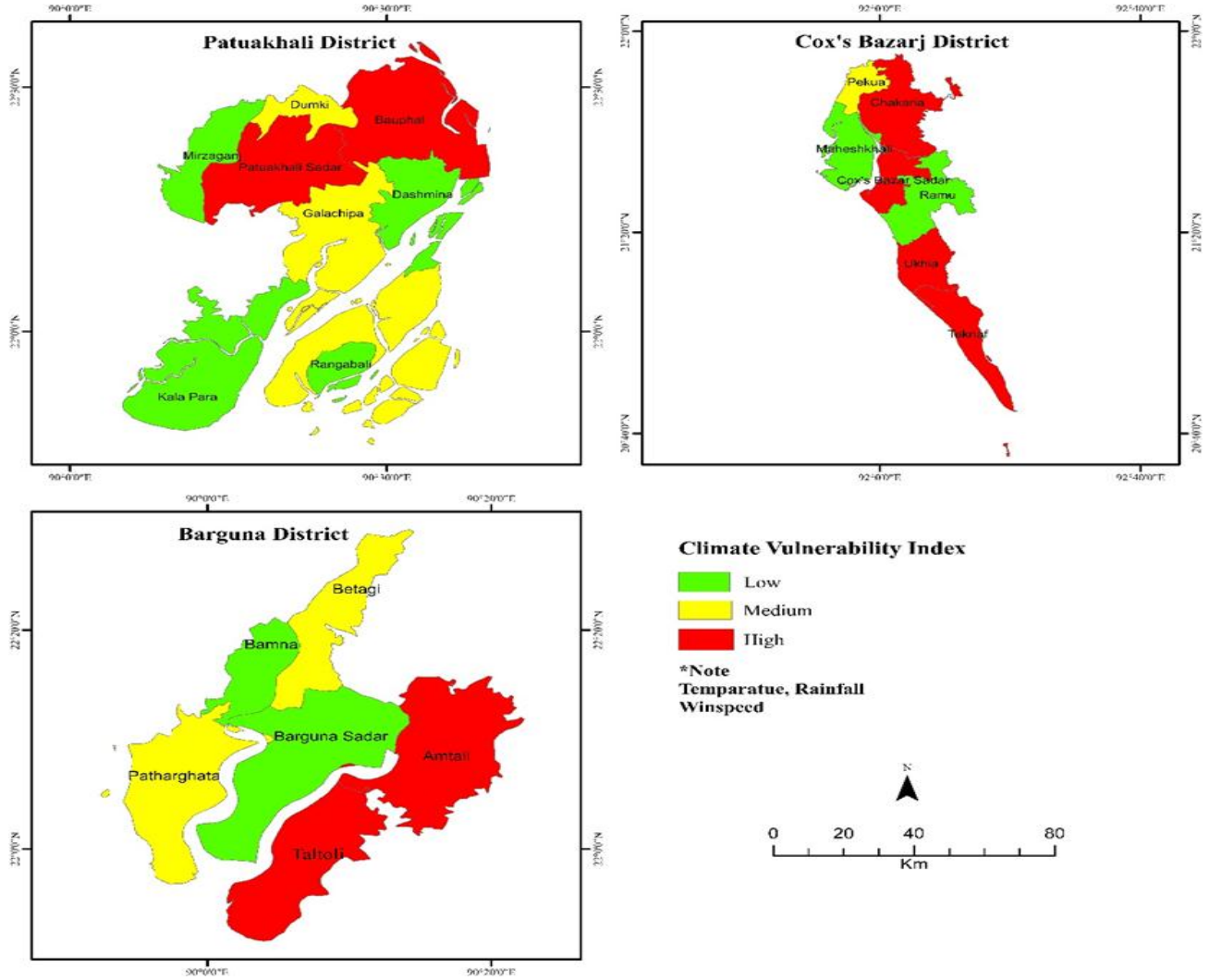
4.2. Climate and Disaster Vulnerability in the Study Area

4.2.1. Climate Vulnerability

Based on the respondent's perception, the study revealed that in all three districts, trends of temperature trends are increasing, but rainfall is decreasing. The Director of BMD, Cox's Bazar station, reported that though the rainfall is decreasing, heavy rainy days are increasing. This scenario was also found by the citation of FGD participants in Barguna and Patuakhali.

Based on the respondent's perception considering rainfall and temperature, the climate vulnerability matrix is developed using the perception normalizing index, and it is found that in the Patuakhali district, Bauphal, and Patuakhali Sadar are highly vulnerable to climate change, while Dumki and Galachipa are medium vulnerable, and Mirazganj, Dashmina, Kalapara, and Rangabali are low vulnerable. Similarly, Amtali is highly climate vulnerable, whereas Betagi and Patharghata are moderately vulnerable, and Bamna and Barguna Sadar are low vulnerable, considering the changing scenarios of climatic parameters. In Cox's Bazar district, Kutubdia is low climate vulnerable, but Pekua, Maheshkhali, and Ukhiya are medium vulnerable sub-districts. In this district, Chakaria, Cox's Bazar Sadar, Ramu, and Teknaf sub-districts are highly vulnerable to changing climatic parameters (Map 2).

Map 2: Climate Vulnerability in the Study Area



4.2.2. Disaster Vulnerability

The study areas are exposed to climate-induced disasters, including cyclones, storm surges, and salinity intrusion. Cyclone and salinity is the major climatic extreme of Patuakhali, Barguna, and Cox's Bazar. From 2015 to 2020, 112,163 Households were affected by the cyclone in Patuakhali, and 1503 households were affected by salinity in Cox's Bazar (Table 1).

Table 1: Disaster-Affected Households in the Study Area (2015-2020)

Number of the Affected Household			
Name of disaster	**Cox's Bazar**	**Patuakhali**	**Barguna**
Drought	115	693	-
Flood	49103	62136	-
Water Logging	6957	27117	16865
Cyclone	73976	103488	112163
Tornado	-	-	11366
Storm and tidal Surge	449	19674	95
Thunderstorm and Lightning	295	1231	1365
River and coastal Erosion	944	6250	268
Salinity	1503	-	-
Hailstorm	11141	868	740

Source: BDRS, 2020

The DRRO of Patuakhali reported that in recent years, lightning has become a hazard in Patuakhali. Along with lightning, hailstorms also pose the greatest risk to agriculture, which is mentioned by FGD participants in all three districts. The DRRO of Cox's Bazar reported that landslides are one of the major disasters in Cox's Bazar. In the last decade, a huge death toll occurred due to the landslides in Cox's Bazar as well as in the Chittagong division. It has been observed that in the year 2021, death casualties (72), the number of injured (10), and the number of shelters damaged (5000) due to landslides in Cox's Bazar were higher than in any other year from 2010-2022 (Table 2).

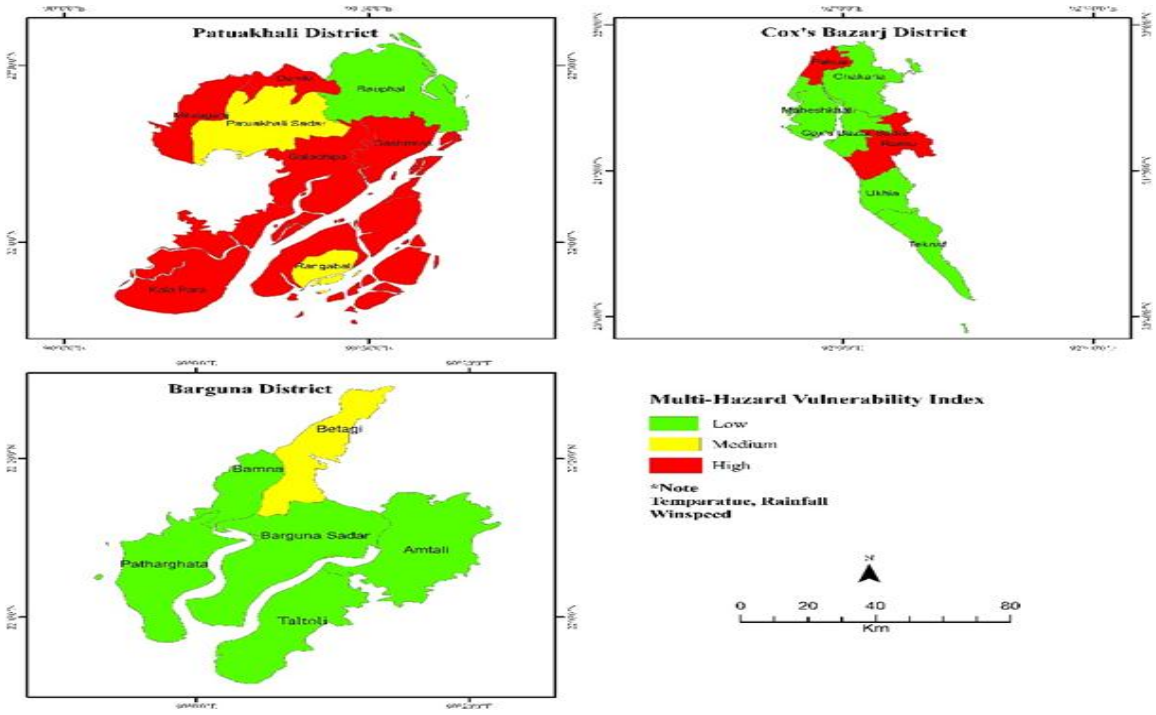
Table 2: Death Casualties and Injuries Due to the landslide in Cox's Bazar

Type of Casualty	Death	Injured
2010[1]	54	0
2011[2]	0	0
2012[3]	0	0
2013[4]	0	0
2014[5]	0	0
2015[6]	13	7
2016[7]	0	0
2017[8]	6	4
2018[9]	11	4
2019[10]	12	0
2020[11]	2	0
2021[12]	72	10
2022[13]	5	0
Total	**175**	**25**

[1] UNB, 2022
[2] NIRAPAD, 2015
[3] NIRAPAD, 2017
[4] The Daily Star, 2018b
[5] NIRAPAD, 2015
[6] NIRAPAD, 2015
[7] NIRAPAD, 2017
[8] NIRAPAD, 2017
[9] The Daily Star, 2018a
[10] Reliefweb, 2019
[11] Dailysun, 2020
[12] NIRAPAD, 2021
[13] Prothom Alo English, 2022; Kamal et al., 2022,Prothomalo, 2022

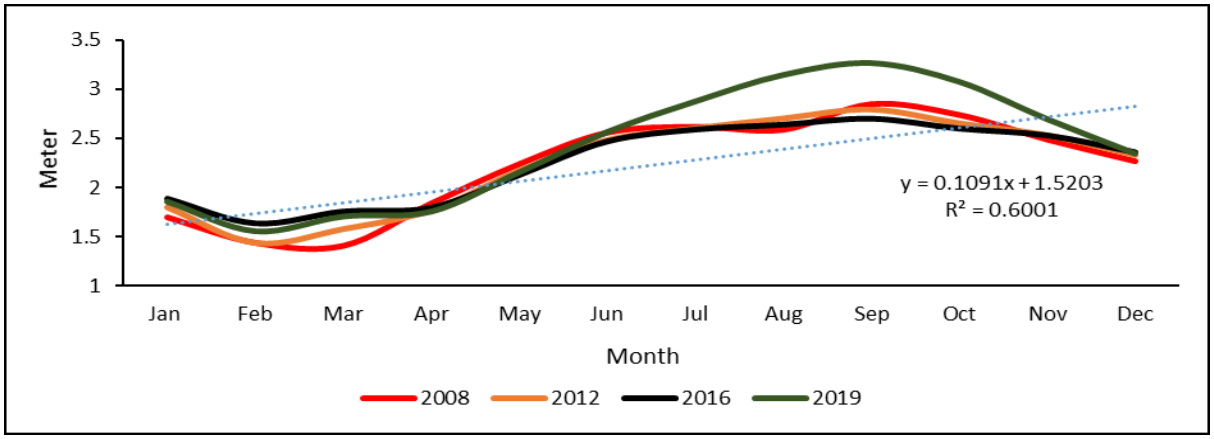
Based on the multi-hazard vulnerability index considering occurrences of floods, river bank erosion, water logging, agricultural drought, drought, heavy rainfall, hail storms, cyclones, thunderstorms, heatwaves, cold waves, salinity, etc., Dumki and Baupal of Patuakhali district are found as low vulnerable, while Mirazganj, Galachipa, Dashmina, and Kalapara of this district are highly vulnerable. Rangabali and Patukhali Sadar have shown medium-vulnerable sub-districts that consider multi-hazard risk. The majority of sub-districts of Barguna, including Betagi, Patharghata, Barguna Sadar, and Amtali, are found to be low vulnerable. Only Bamna was found as moderately vulnerable. In Cox's Bazar, the multi-hazard vulnerability mapping shows that Chakaria, Maheshkhali, Ukhiya, Cox's Bazar Sadar, and Teknaf are at low vulnerability, and Kutubdia, Pekua, and Ramu are categorized as highly vulnerable (Map 3).

Map 3: Multi-Hazard Vulnerability in the Study Area



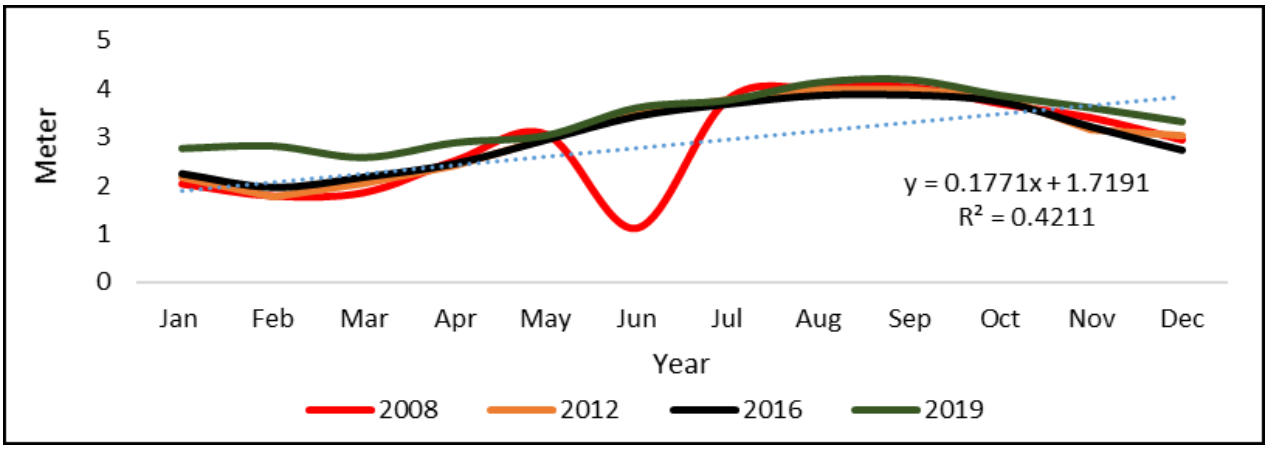
The Mean Sea Level (MSL) increasing trend was found along the Bangladesh coast by analyzing MSL data from 2008 to 2019 from Patuakhali Point, Khepupara Point, and Bakkhali Point. The Mean Sea Level (MSL) of the Patuakhali point was found as an increasing trend with a rate of 0.1091 meters/year. (Figure 5), In Khepupara point, the increasing trend was found to be 0.1771 meters/year, and at Bakkhali point (Figure 6), MSL is increasing at 0.134 meters/year (Figure 7).

Figure 5: Mean Sea Level (MSL) at Patuakhali Point



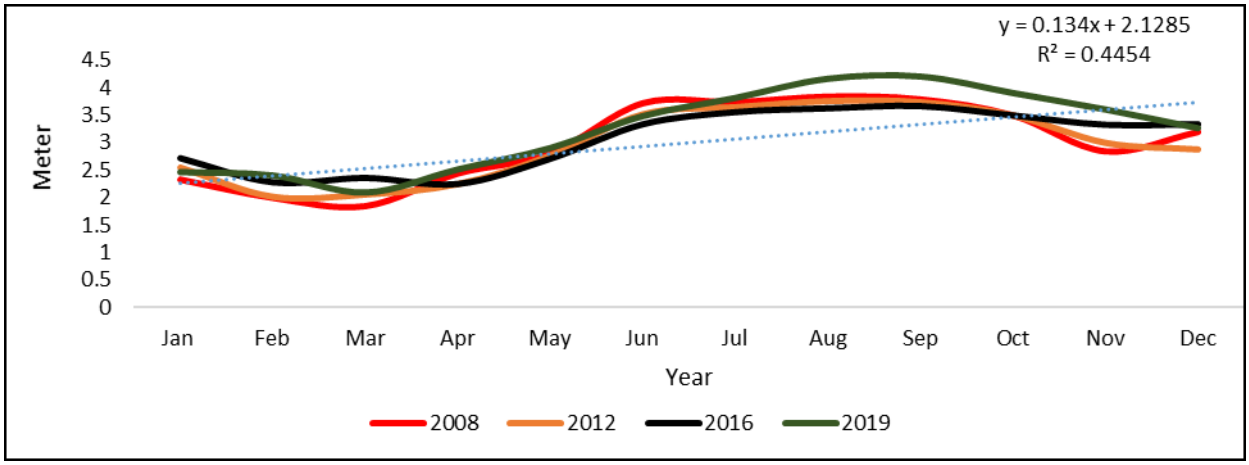
Source: BWTA, 2022

Figure 6: Mean Sea Level (MSL) at Khepupara Point



Source: BWTA, 2022

Figure 7: Mean Sea Level (MSL) in Bakkhali Point



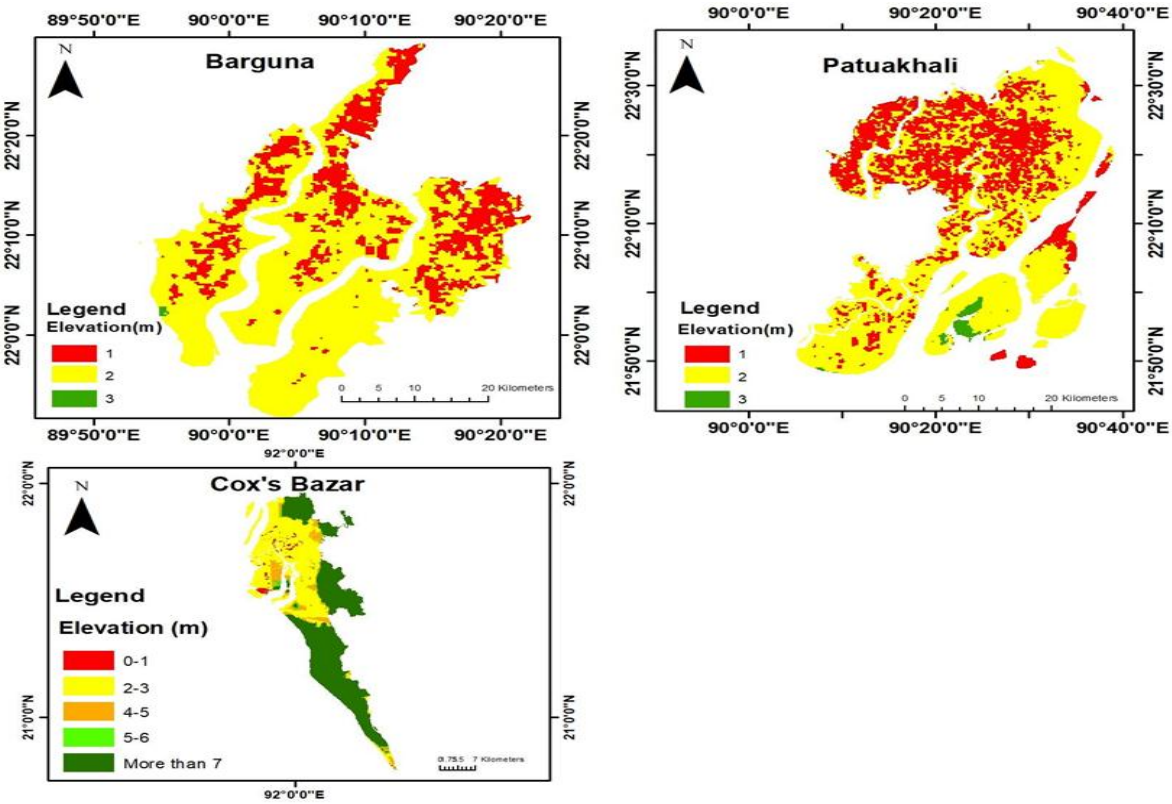
Source: BWTA, 2022

In the coastal districts, using the Digital Elevation Model (DEM), the highest elevation of Patuakhali was found with some portion of Rangabali Upazila to be 3 meters above Mean Sea Level (MSL)**.** The majority of the district has an elevation of 2 meters. The north eastern part of this district is found to be a low-elevation area.

This low elevation was found in Mirzaganj, Patuakhali Sadar, Dhumki, and some portions of Galachipa. The northern part of Dasmania Upazila also lies within the lowest elevation. The low elevation of this district made it more exposed to storm surges. The maximum elevation of Barguna is 3 meters, which is only seen in some small areas, in the south-western part of Patharghata Upazila.

The majority of the portion of the southern region of Patharghata, Barguna Sadar, and Amtali upazila is 2 m. Whereas, Betagi, Bamna, and the northern region of Amtali are the least elevated zones, being a 1-meter elevation. Cox's Bazar, being a hilly region, has the highest elevation compared to the other two coastal districts (Barguna and Patuakhali). Some portions Maheshkhali has a low elevation (0 to 1 meter). Chakaria, Pekua, and Kutubdia upazila of Cox's Bazar have a minimum elevation of 2 to 3 meters. The rest of the upazilas, Ramuu, Ukhia, Teknaf, and some northern parts of Chakaria, all have an elevation of more than three meters (Map 4)**.**

Map 4: Land Elevation in the Study Area



In the last decade (2013-2021), the lowest storm surge height was during Cyclone Jawad, which hit Cox's Bazar, and the highest surge was recorded during Cyclone Mohasen, which hit Cox's Bazar, Barguna, and Patuakhali (Table 3). Considering the storm surge height and elevation of the three coastal districts, some parts of Cox's Bazar (Maheshkhali, Ramu, Teknaf, and a small part of Ukhiya) are safe from inundation during storm surges. Considering storm surge height, increasing trend of MSL, and land elevation, Patuakhali and Barguna districts are more vulnerable than Cox's Bazar district.

Table 3: Impacted Storm Surge in the Study Area (2013-2022)

Cyclone	Storm surge (Meter)	Average storm surge (Meters)	Impacted Upazila
2013- Cyclone Mahasen	5 - 6	5.5	Cox's Bazar
			Barguna
			Patuakhali
2015- Cyclone Komen	0.3 - 1.5	0.9	Cox's Bazar
2016- Cyclone Roanu	1.7 - 2.7	2.2	Barguna
			Patuakhali
			Cox's Bazar
2017- Cyclone Mora	3 - 3.5	3.25	Cox's Bazar (Teknaf, Kutubdia, Ukhia, and Moheshkali)
2019- Cyclone Fani	1.2 – 1.5	1.35	Cox's Bazar
2019- Cyclone Matmo-Bulbul	3.5 – 4.5	4	Patuakhali
			Barguna
2020- Cyclone Amphan	3 – 5	4	Patuakhali
			Barguna
2021- Cyclone Jawad	0.5 - 1	0.75	Cox's Bazar
2021- Cyclone Yaas	1.8 - 2.2	2	Cox's Bazar (Sadar, Pekua, Maheshkhali, Chakaria and Teknaf)

			Patuakhali
			Barguna
2022- Cyclone Asani			Patuakhali
			Barguna
2022- Cyclone Sitrang	2 - 3	2.5	Cox's Bazar (Ukhiya, Teknaf)

4.2.3. Impact of Climate Change and Disaster in the Study Area

The effects of climate change and disasters have an impact on the people in the areas. Based on respondents' perceptions, a Composite Vulnerability Matrix was developed by normalizing the participants' responses; the study identified different vulnerable sectors and occupations. The study found that in Patuakhali and Barguna, agriculture is a highly vulnerable sector. Education in Cox's Bazar appears to be highly vulnerable. The livelihood sector, like agriculture, is similarly vulnerable in Patuakhali and Barguna. The livelihood sector is medium vulnerable due to climate change and disasters. Except for Cox's Bazar, the water sector is highly vulnerable in all other study areas (Table 4). The FGD participants from all these areas reported that during winter and summer, they suffer from a crisis of drinking water. The FGD participants from Patuakhali, Barguna also added that during winter and summer, salinity increases in the surface and groundwater, which restricts drinking water.

Table 4: Education, Water, Health, Agriculture, and Livelihood Vulnerability

	Barguna	Cox's Bazar	Patua-khali
Education			
Water			
Health			
Agriculture			
Livelihood			
Index			
Low		0-33%	
Medium		34-65%	
High		66-100%	

4.2.4. Impact of Climate Change on Livelihoods

Climate change and disasters also have an impact on socio-economic and livelihood activities in the areas. Based on respondents' perceptions, a Composite Vulnerability Matrix was developed by normalizing the participants' responses; the study identified different vulnerable occupational groups and found that farmers of all districts are highly vulnerable (Table 5). The disaster caused by climate change mostly affected the farmers. Farmers and fishermen in Barguna are highly vulnerable.

The FGD participants of all districts reported that farmers are the most susceptible group. The farmers of Cox's Bazar, Barguna, and Patuakhali reported that during the dry season, agriculture is hampered due to salinity intrusion and lack of irrigation, whereas during monsoon, due to tidal inundation, crops face tremendous loss. In Cox's Bazar, Patuakhali, and Barguna, many respondents are involved with fishing and mentioned that they could not access fishing during the rainy and dry seasons due to climatic extremes.

During the post-monsoon, though, they have the opportunity to fish, but due to fishing restrictions, they have restricted access to rivers for fishing. FGD participants of Shahporir Dwip reported that after the Rohingya influx, they are under restriction on fishing at the Naf River, which caused a food crisis all year round.

Table 5: Occupational Vulnerability

Occupation	Barguna	Cox's Bazar	Patua-khali
Fishermen			

Farmer			
Small Trader			
Boatman			
Day Labour			

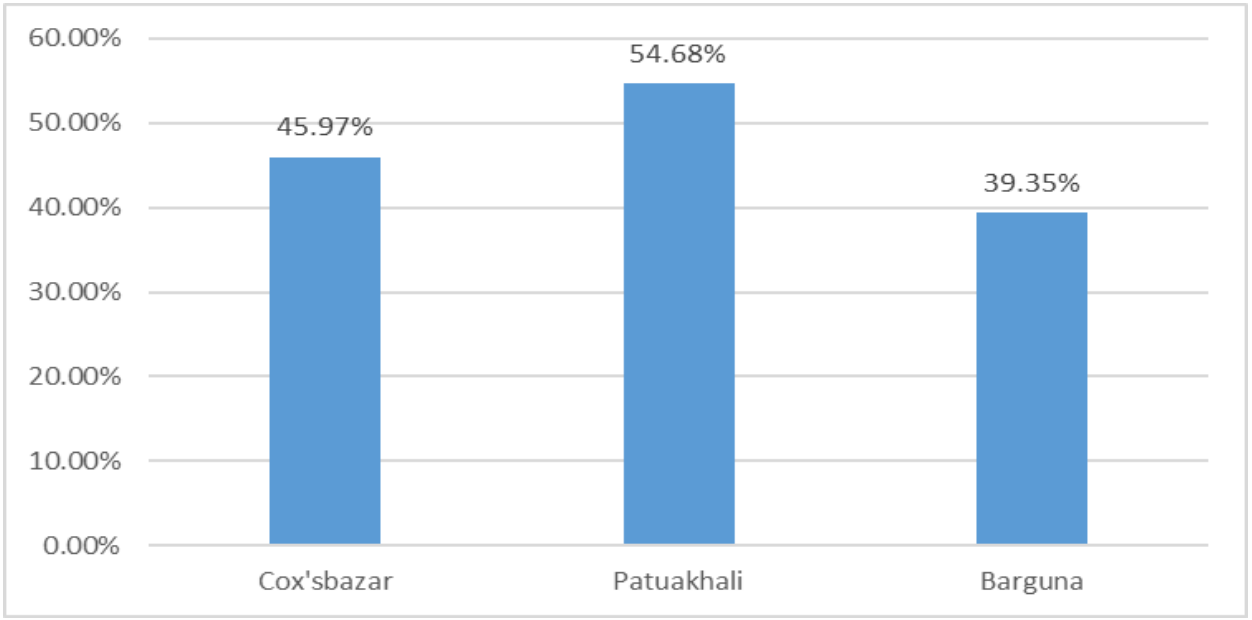
Index	
Low	0-33%
Medium	34-65%
High	66-100%

The increasing trend in the seasonal frequency of heatwave days is because maximum temperatures are reached during the summer season from mid-March to mid-June. However, these extreme temperatures are not only observed during summer, but also during the monsoon season (mid-June to mid-October) and, in some cases, during winter (mid-October to mid-March). During summer and winter, the DLS Officer cited that many livestock (cattle, goat) and poultry (hens, ducks) die from diseases because of consecutive heat and cold waves**.**

The FGD participants reported that during winter and summer, livestock and poultry death tolls increase. A woman from Sabrang reported that in the last year, during winter, 36 ducks died. The FGD participants also mentioned that there is no specialized veterinary support from the government or non-government sector. As a result, most livestock **rearers** depend on local unskilled veterinary medicine sellers, which causes a higher livestock death toll. The FGD participants also reported that consecutive crop and livestock production failures had decreased the employment rate amongst small-holders and agricultural labourers who experience limited access to food and suffer from seasonal hunger. Reduction of livelihood options and food insecurity causes poor nutrient intake for climate-vulnerable people, which leads to poor health and weakened immunity.

As a result, within the last ten years (2012-2022), many people have changed their livelihood activities. (Figure 8) represents the livelihood activity-changing scenario of three districts. In the Patuakhali district, there was a maximum (54.68 %) change in livelihood activity. In the Cox's Bazar district, the figure shows a significant number of respondents (45.97 %) whose livelihoods changed due to climate change.

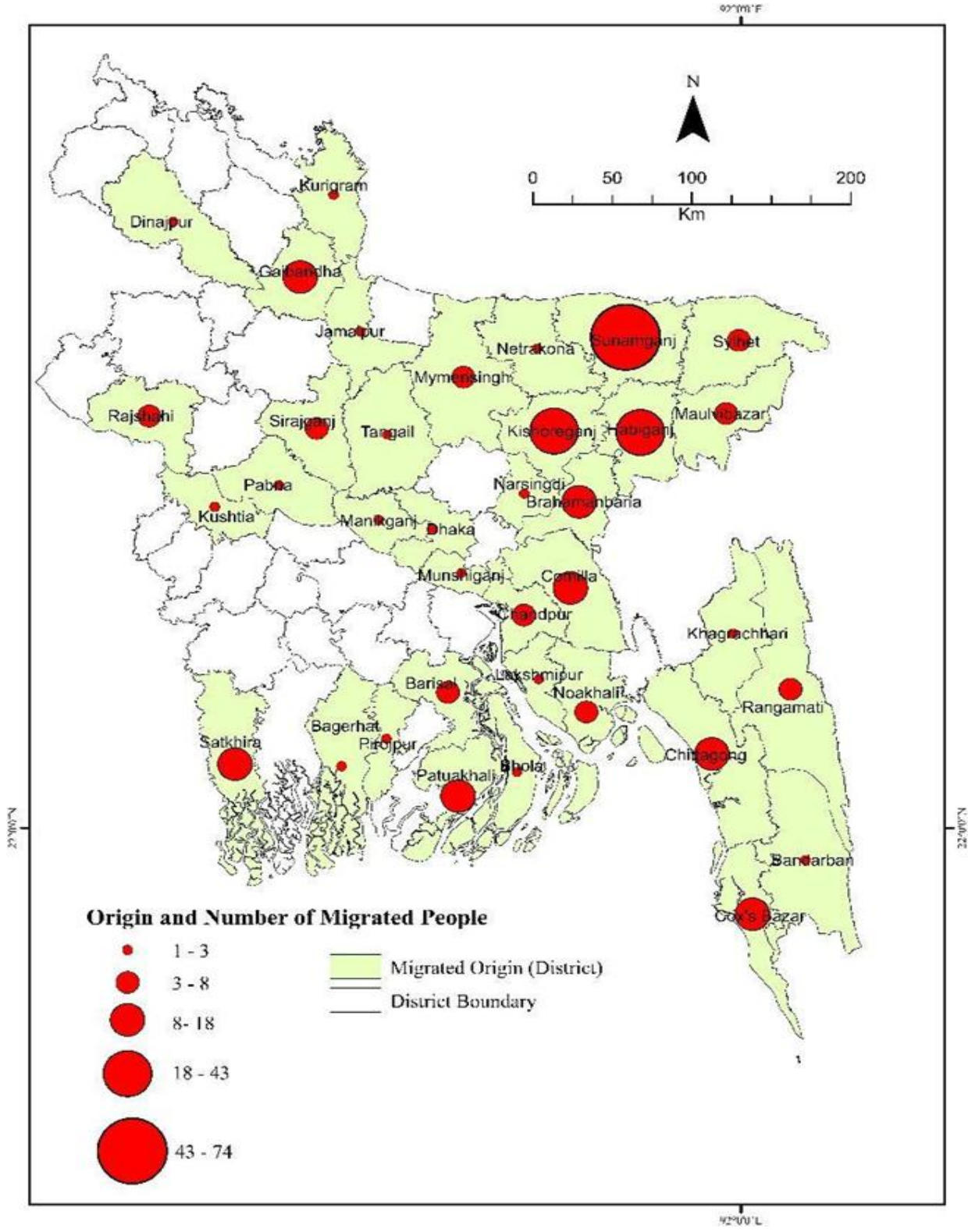
Figure 8: Livelihood Options Changing Scenario in the Study Area



4.2.5. Climate Change and Displacement

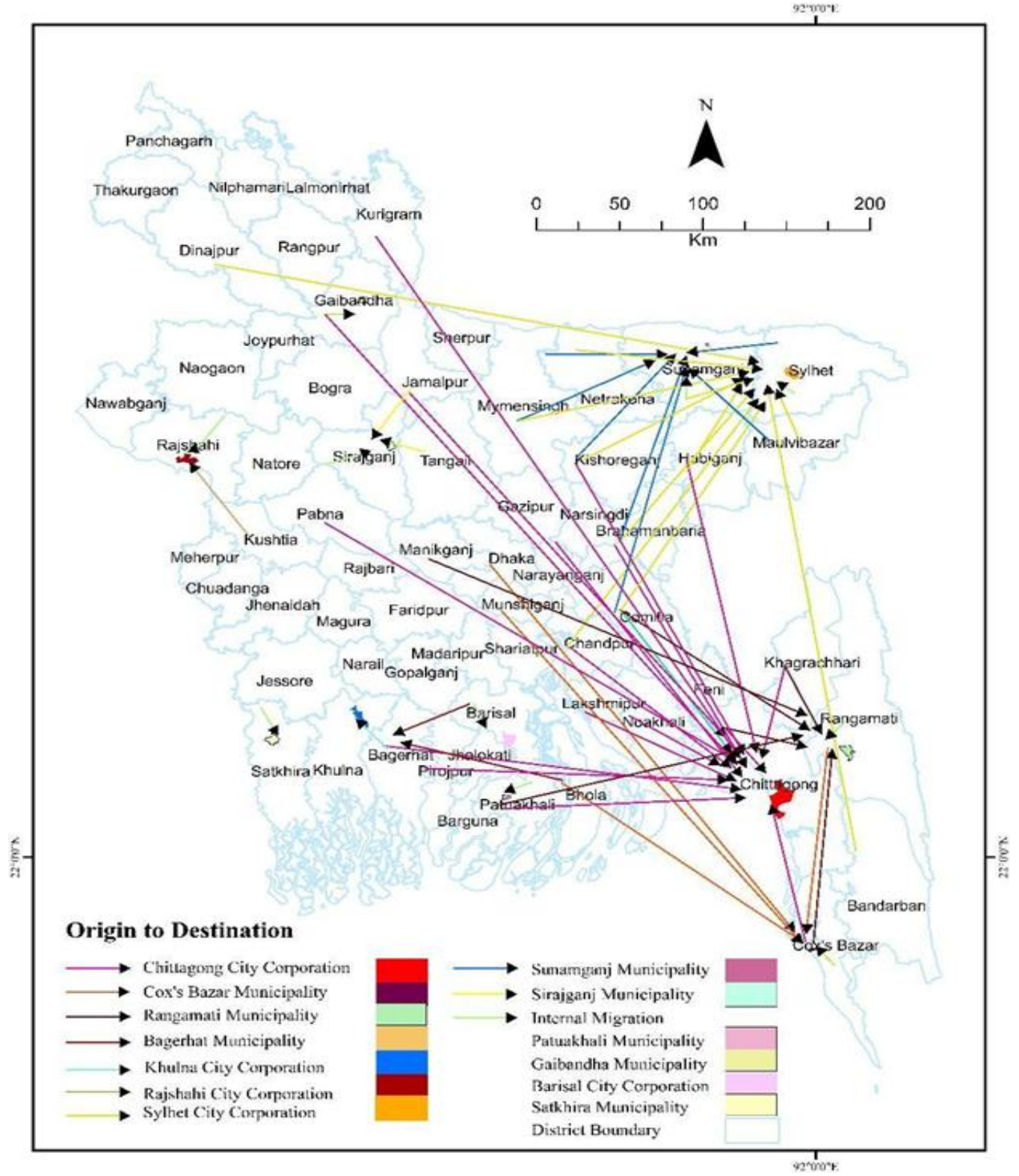
To varying degrees, most districts are witnessing migration primarily due to push factors such as disasters and climate change. This study reveals from (Map 5) that most of the migrated people were recognized in the Sunamganj district. Kishoreganj and Habiganj districts are also facing moderate migration. When talking about coastal areas, Satkhira, Patuakhali, Cox's Bazar, and Chattogram districts are also experiencing migration due to salinity, cyclones, poverty, tidal inundation, etc.

Map 5: Origin of Migrated Districts



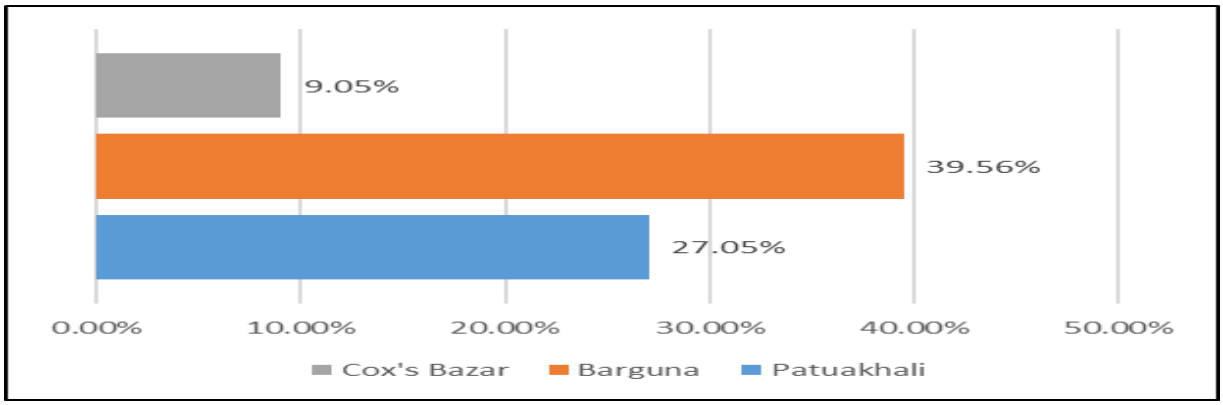
Internal migration within Bangladesh is also common, with people primarily moving from rural areas to urban areas. Centres. Among them, Chattogram, Rajshahi, and Sylhet city corporations, Cox's Bazar, Sunamganj, and Sirajganj municipalities are primarily hotspots for the migration of people's destinations for their pull factors (Map 6). Better employment opportunities, an improved standard of living, better education, security, and greater facilitation are the reasons behind the increase in rural-to-urban migration.

Map 6: Migration Trajectory



Displacement and migration are common scenarios found in the study area. Internal migration and external migration are both active in all upazilas with demographic change. The study revealed that Barguna has the highest migration threat, and 39.56% of the respondents in this district are interested in migrating immediately (Figure 9).

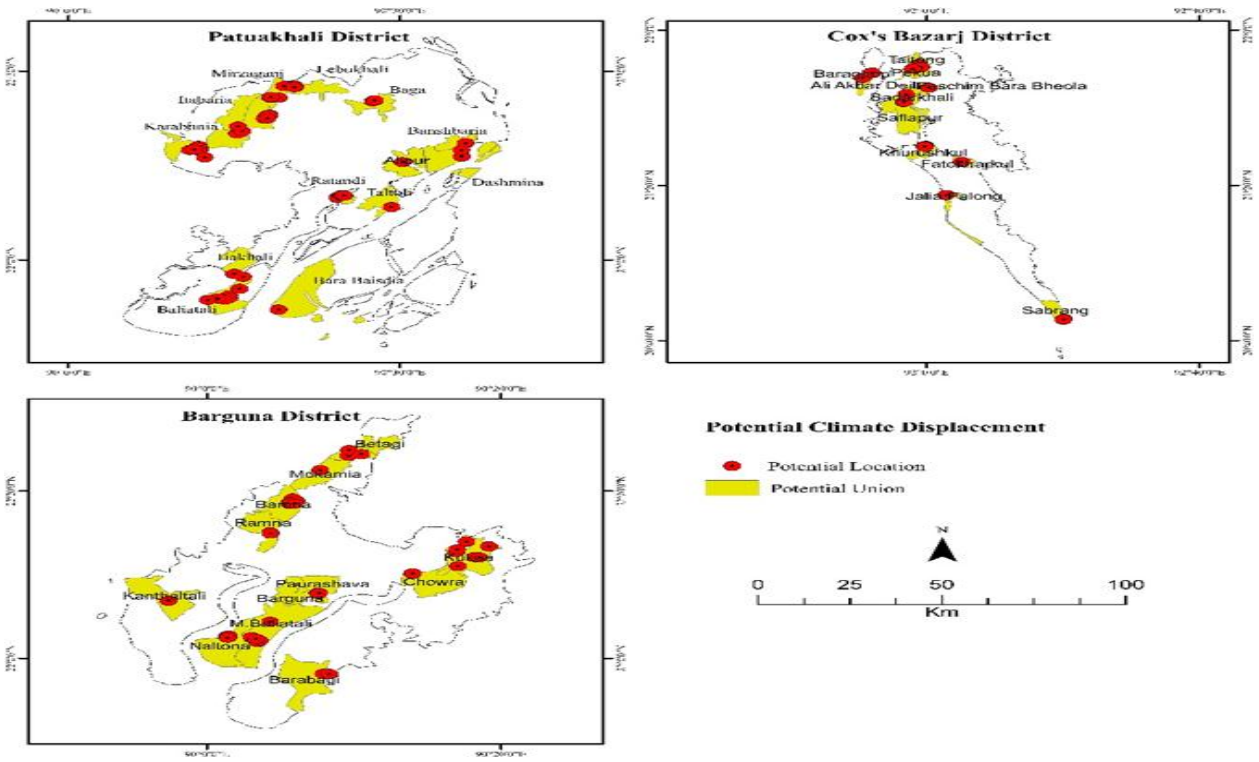
Figure 9: Migration Threat



The FGD participants mentioned that at the present location, they have no wage-earning opportunity due to climate change, like salinity and cyclones. They also reported that the freshwater crisis is rising daily, so they must migrate to other places for food and water safety. Respondents of Kutubdia and Char Montaz noted that most of them have lost their homesteads in riverbank erosion, so they need to migrate.

Due to losing homestead land, agricultural production, economic and livelihood crisis, and freshwater crisis, most of the people of some unions will migrate massively, which is detected by using ABM (Agent-based Model) (Map 7)**.** Most of the respondents of Boga, Dashmina, Bashbaria, Pangasia, Lebukhali, Itbaria, Motherbunia, Kakrabunia, Baliatli, Mithaganj Galachipa, Ratandi Taltoli, Bara Baishdia from Patuakhali district will migrate as an adaptation option to secure livelihoods. Similarly, the respondents of Betagi, Kazirabad, Mokamia, Bamna, Burir Char Naltona, M.Baliatali, Chowra, Kukua, Borobagi, and Chotobogi inhabitants of some unions are potential migrants of Barguna districts, and the inhabitants of Pekua, Ramu, Kutubdia, Maheshkhali, Ukhia, Teknaf, and Cox's Bazar Sadar upazila will migrate for adaptation.

Map 7: Potential Climate-Displacement Location in the Study Area



4.3. Determinants of Climate Migration

Linear regression is a statistical method used to model the relationship between a dependent variable and one or more independent variables. In this case, linear regression is applied to predict the migration intention (Yes/No) of respondents based on their livelihood change and agricultural land ownership. While the dependent variable is binary, Excel applies linear regression; therefore, the results approximate the relationship between the variables rather than estimating probabilities directly. The overall model was statistically significant ($F = 1089.08$, $p < 0.001$), explaining approximately 61% of the variation in migration intention ($R^2 = 0.613$).

Table 6: Model Fit Information

Regression Statistics					
Adjusted R Square	0.612				
Standard Error	0.095				
Observations	1375				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	19.755	9.877	1089.084	< 0.001
Residual	1373	12.452	0.009		
Total	1375	32.208			

Among the predictors, a change in livelihood was positively associated with migration intention. Respondents who reported a change in livelihood were significantly more likely to report migration ($B = 0.325$, $p < 0.001$). Agricultural land ownership was negatively associated with migration. Those who owned agricultural land were significantly less likely to migrate ($B = -0.438$, $p < 0.001$).

Table 7: Determinants of Climate Migration

Indicator	Coefficient (B)	t Stat	P-value	Lower 95%	Upper 95%
Change in livelihood	0.325	20.87	< 0.001	0.295	0.356
Agricultural land ownership	-0.438	-26.2	< 0.001	-0.471	-0.406

5. Conclusion

The study explored the causal relationship between climate-included migration and potential climate displacement locations in three climate-vulnerable coastal districts of Bangladesh. These districts are more exposed and sensitive to multiple climate hazards, including temperature, flood, agricultural drought and heat stress, erratic rainfall, cold waves, salinity, cyclones, and storm surges. Focusing on three defined districts, there is a need to promote resilient livelihood interventions and climate change adaptation activities, reintegration of climate migrants through alternate livelihood activities is highly essential for the potential displacement locations. Due to losing homestead land, agricultural production, economic and livelihood crisis, and freshwater crisis, most of the people in some locations will migrate massively. There needs to be land ownership, livelihood opportunities, and fresh water to prevent climate-induced migration in the study areas.

5.1. Theoretical Implications

This research has theoretical implications for understanding how changing climatic scenarios and their impact interact with other social and economic factors to drive human mobility. It challenges the traditional migration scenario by exploring the role of climate change as a "push" factor in migration decisions, and it emphasizes the interconnectedness of climate change and migration as a complex, multi-faceted issue.

5.2. Practical Implications

The research has practical implications for policy and action by prioritizing the need for proactive adaptation measures, especially to ensure adaptive livelihoods, water, and land ownership for potential climate migrants. The link between climate change and migration will allow for better preparedness for future displacements, including developing sustainable solutions and policies that will protect vulnerable populations in the identified locations.

5.3. Limitations

The study was conducted with a small population and captured limited parameters due to a lack of financial support. Identifying the specific locations that are vulnerable to climate displacement requires more time and funding. Agent-based Modelling requires a vast database to develop baseline scenarios such as climatic parameters, land use parameters, environmental conditions, and socio-economic parameters. There needs to be a longitudinal database to accurately measure the potential climate migrant demography.

5.4. Future Research

There needs to be a conducted study all over the country to identify potential locations of climate displacement with a large dataset. Along with the origin of potential location of climate migrants, there needs to identify the destination using Agent-based Modelling. Further research should be conducted to identify the destination of climate-displaced people to develop pathways of adaptation.

Declarations

Author Contributions

MAR: Study design, methodology, and study tools development, study supervision, data analysis, and article preparation. ZB: Climatic data and historical time series analysis. SA: Data analysis, article writing, and revision. MRJR: Statistical analysis, article writing, and revision. All authors have read and approved the final manuscript.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this study.

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