Modeling on the Effects of Coastal Hazard Threats to the Seasonal Migration Patterns of Coastal Communities in Saint Martin Island

This report is submitted to the Department of Geography and Environment under the Faculty of Social Sciences, Jahangirnagar University partial fulfillment of the requirements for the Degree of Bachelor of Science (BSc.) in Geography and Environment.

Submitted By:

Eyanur Hossain

Exam Roll-190801

Registration No.- 20190948818

Session -2018-2019

Department of Geography and Environment, Jahangirnagar University

Dhaka- 1342

DEDICATION

In the tapestry of my existence, two radiant spirits have colored it with the most vibrant hues. I now dedicate my first study effort to my cherished parents, Farid Ahmed Khan and Shamima Akter. Despite my father's departure in 2014, his affection and mentorship continue to be deeply felt. Ever since then, my mother has readily embraced every obstacle, providing me with steadfast care and fortitude. You both have encountered the challenges of life in order to enable me to fly and explore the world with the freedom of a curious bee.

CERTIFICATE OF APPROVAL

This is to certify that the report entitled ***"Modeling on the Effects of Coastal Hazard Threats to the Seasonal Migration Patterns of Coastal Communities in Saint Martin Island"*** has been conducted by **Eyanur Hossain** (Exam Roll: 558; Session: 2018-2019).

The study, conducted under my supervision, has demonstrated academic rigor and is at this moment accepted as satisfactory in partial fulfilment of the requirements for the **Bachelor of Science** degree at the **Department of Geography and Environment**, Jahangirnagar University, Savar, Dhaka.

Supervisor

Dr. Md. Nazrul Islam
Professor,
Department of Geography and Environment
Jahangirnagar University
Savar, Dhaka-1342
0.8.09.2024

CANDIDATE'S DECLARATION

This report, titled "***"Modeling on the Effects of Coastal Hazard Threats to the Seasonal Migration Patterns of Coastal Communities in Saint Martin Island"*** " or any portion thereof, has not been submitted elsewhere for the award of a degree, diploma, or any other academic qualification.

In addition, I agree to indemnify the university responsible from any loss or damage resulting from breaking any of the aforementioned obligations.

Eyanur Hossain
Exam Roll: 190801,
Registration Number: 20190948831;
Session: 2018- 2019
Department of Geography and Environment,
Jahangirnagar University, Savar, Dhaka.
Date: 08.09.2023

ACKNOWLEDGMENT

First and foremost, I am deeply grateful to Allah for granting me the strength, patience, and wisdom to complete this research. Without His countless blessings, none of this would have been possible.

I would like to extend my sincere thanks to my supervisor, Professor Dr. Md. Nazrul Islam, of the Department of Geography and Environment, Jahangirnagar University, for his invaluable guidance and unwavering support throughout this study. His expertise, patience, and encouragement have been essential to the successful completion of this work.

I am also immensely grateful to my seniors, Shahriar Islam and Khaled Mahmud Khan, for their guidance and assistance throughout the course of this research. Their insights and experience have played a significant role in shaping my work. Special thanks go to Al Rabby Siemens, whose support and encouragement have been a constant source of motivation during this journey. I would also like to express my heartfelt appreciation to my dear friends, Zobaer Rahman and Istiyak Ahmed, for their continuous support, motivation, and friendship.

Lastly, I am eternally thankful to my family members, Nadia Islam Anima, Fardina Jahid Tahia, and Sharika Islam Fiha, for their endless love, encouragement, and unwavering belief in me. Their support has been my foundation throughout this journey.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION

- **BBS**: Bangladesh Bureau of Statistics
- **DEM**: Digital Elevation Model
- **DG**: Sustainable Development Goals
- **DPSIR**: Driving forces, Pressures, State, Impact, Responses
- **DSAS**: Digital Shoreline Analysis System
- **ECA**: Ecologically Critical Area
- **EEA**: European Environment Agency
- **GIS**: Geographic Information System
- **ICZM**: Integrated Coastal Zone Management
- **IUCN**: International Union for Conservation of Nature
- **LULC**: Land Use and Land Cover
- **MPA**: Marine Protected Area
- **NASA**: National Aeronautics and Space Administration
- **NOAA**: National Oceanic and Atmospheric Administration
- **SIDS**: Small Island Developing States
- **SLR**: Sea Level Rise
- **UNDP**: United Nations Development Programmed
- **UNEP**: United Nations Environment Programmed
- **UNFCCC**: United Nations Framework Convention on Climate Change
- **USA**: United States of America
- **WLR**: Weighted Linear Regression

ABSTRACT

This study investigates the effects of coastal hazards and the vulnerabilities driving seasonal migration patterns in Saint Martin Island, Bangladesh. Utilizing the Digital Shoreline Analysis System (DSAS) and Weighted Linear Regression (WLR), the research analyzes shoreline changes from 1992 to 2024. The results reveal a significant imbalance between land erosion (averaging -1.5797 meters per year) and accretion (0.6815 meters per year), indicating ongoing land loss. This loss accelerates the island's vulnerability, particularly for communities reliant on the land for agriculture and livelihoods. Cyclone and storm surge data, examined within a 200-nautical-mile radius, show frequent extreme weather events, including Category 1 to Category 5 cyclones. These hazards, combined with projected sea-level rises, threaten both the island's physical integrity and socio-economic stability. A projected 2.5-meter sea-level rise would inundate 11.27% of the island, reducing habitable land and disrupting essential infrastructure. Saltwater intrusion into freshwater sources and agricultural land further heightens community vulnerabilities, reducing access to drinking water and impacting crop productivity. Socio-economic vulnerability data reveal that 48.4% of the population relies on fishing, 20.8% on business, and 6.5% on farming. These livelihoods are highly sensitive to coastal hazards, leaving the population vulnerable to economic shocks, displacement, and health challenges due to limited access to basic services. Gender disparities in education and employment further increase women's vulnerability. Migration patterns show that of residents migrate seasonally to Teknaf, with significant numbers relocating to Cox's Bazar and Chattogram. To address these vulnerabilities, the study proposes a comprehensive DPSIR-based mitigation model focusing on structural, policy, economic, and ecosystem strategies to build resilience and reduce migration pressures.

Chapter 01:

Introduction

1.1 Background of the study

Saint Martin's Island is one of the Biodiverse hotspots in Bangladesh, full of a wide spectrum of marine and terrestrial species. This tropical Island of about eight km-2 has leaned towards a stage for beachcombers, both local and international (Siddique et al., 2022). With coral reefs, fish species and sea turtles just a few of the examples within this region it has judge number diversity when looking at marine life as well.

Near the issuing and receiving places Just north of the Myanmar border, 8 km west of Teknaf & South East from both relevant points in the southernmost tip of Cox's Bazar-Teknaf peninsula (9 km away by land). It's much closer to Saint Martin Island, which is only about further southeast (tour, 2018) (to, 2006). The proximity of peninsular and insular ecosystems to these areas is a concentrated example of such an island, which will act as a stepping stone needed on this marine life international center itself, but we must, therefore, ensure breeding grounds are preserved, thus increasing biodiversity. Just both their holiday destination boasting glorious beaches, crystal clear oceans, and relaxed settings of thousands year after year caught the spirit of spirit. However, as more tourists come to this island paradise, problems of mass tourism are looming (Kamruzzaman & Uchinlayen, 2018).

Hence, in order to save the stories of only habitats and cultural destinations, a sustainable tourism approach is considered to be inevitable. Rising sea levels and storm surges, along with more frequent eroding events and flooding, have made Saint Martin another climate-hot coastal hazard hotspot. These unique challenges will require active management if the Island's exceptional biodiversity – and livelihoods, food security, and cultural identity in local communities — are to be conserved (Golam et al., 2005). The most threatening peril is sea level rise, the unstoppable but relentless advance of the water over the portions of the island shoreline that money can never but back. Long before the hurricane hit, sea levels were rising and putting storm surges that have done tens of billions worth of damage in the steroids because they built up a higher base thanks to the sea levels rising, eating away borderless and coral beaches. Powerful episodes of extreme weather mostly fuel the surge. As soon as the cyclone hits later, the sea overhands vast portions of it, causing mass destruction of infrastructure, and residents will fill up. Another major obstacle is flooding, which is mostly caused by storm surges in the river valley, which increases flooding and exposes contaminated water. Flooding creates immediate physical damage; the loss of homes knish, schools, and vital infrastructure infuses vulnerable water (Karim & Mimura, 2008).

One such sociocultural and economic life-related domain of future life is the losses due to these coastal hazards, that is, future life associated with insecurity in terms of livelihoods largely based on tradition for traditional-oriented local communities. The homogenization of the pool, the wiping away of this rainbow kaleidoscope of coral reefs, causes biologists to worry about the diminishing yield of fisheries. The dip in agricultural output is attributed to land degradation and soil salinization (Afjal Hossain et al., 2011).

Tourism is one of Lebanon's most significant sources of revenue. These climactic shifts are causing the fraying of traditional communities and cultural infrastructure. Many of these traditional communities and cultural sites fall into the South China Sea each year, washed away by erosion or inundated during floods, which is our heritage. There has been a significant erosion of cultural links and community spirit as well (Siddique et al., n.d.).One such location is off the coast of Bangladesh, named Saint Martin's Island (Al Nahian et al., 2022). It is a well-known holiday spot in Saint Martin; it can be quite an attractive tourist destination spot due to its coral reefs and sandy beaches. The Island is a significant source of revenue for tourism, as its fine sandy beaches and colorful coral reefs are crucial to draw. Every year, thousands of tourists visit this region. However, the rooms are stacked and reserved during seasonal tourism events, with the off-season mating cycle causing a periodic economy—the hospitality industry. Hotels and, restaurants and service sectors perform huge employment during peak tourist season times (Rivera et al., 2020).

The locals have seasonal income to them. Storm surges and other risks to the east coast, such as cyclones, are less problematic later in the season. Both actions waned, and the economy crashed even more rapidly, with more severe flooding. All of this takes place around the central Island, Saint Martin's Island (Hossain, 2001). It is one of the most enchanting and most wretched islands. One of the greatest land use and land cover adjustments has taken place. Frontal progression does present one way in which it can operate between a degree of seasonal mobility and create a smooth dramatic economy. Tourism accomplishments are seasonal, but (and on other occasions) exposure is minimal despite all-natural hazards. The front of the Island only changes for the feeding tourism infrastructure like hotels, resorts or another recreational facility. Lands and virgin habitats are becoming markets for more people.

The tourism season innovates on how its populations operate. In the dark months, residents tend to move out. As a result, the waterfront community experiences pretty much higher hazards than it would in flood season (Paszkowski et al., 2024). Also, these people are likely to move in search of jobs that offer them a new future in less adversely hazardous environments. The departure as well as the arrival of populations on this bustling Island, which also depend on certain seasonal demands, leads us to evidence how thin the line may be between being able to seemingly be able to economically support a tourist abuse environmentally, whilst such ventures becoming overly controlling for naturally occurring environmental hazards (Kiper, 2013).

Saint Martin's Island is lethal yet so alluring to prospective tourists. Saint Martins is an example of rapid land use and cover change. The hotels and resorts that constitute the industry's infrastructure, or basic tourism equipment, have altered the very landscape to cope with the dramatic increase in visitor numbers; areas that had once been natural ecosystems or had been set aside for agricultural purposes have now been transformed by mass commercialization. This rapid change in the arena following disasters has also led to even more coastal exposure and vulnerability to hazards (Marengo et al., 2023). The volume of large-scale structures on the beach points to shedding plenty of reasons as to why the area is tendered as being vulnerable and

being changed from its natural process by humans with no re-enforcement development of the Island which leads to the vulnerability of the Island being worsened, which highlights the potential reliefs all round up-surge in events that are endured there even if no incidents rendered the area instantaneously or wholly vulnerable (Uddin, 2006).

The land use and land cover scenario has changed massively over the decade in Saint Martin's Island, Bangladesh. The changes due to both natural change and human activity were different for very interrelated ecosystems like native coral reefs in Belize and a broad range of changes over the landscape (Siddique et al., 2022).

Reef damage. The damage across some of the Island's coral reefs is quite severe. These reefs are important, not only in a marine ecological sense but also as commercial resources, not to mention serving as a natural defense; as a buffer from storm surges and erosion. Such enhanced human activity is resulting in more pollutants, over-fishing and physical reef loss. Reef loss severely weakened their ability to support marine life where the continent meets an island due to damages caused by artificial additions and ill-carrying industry buildings on coasts. One of these pollutants that are being released into the ocean is garbage; the dumping of industrial and residential waste into the sea causes a disturbance over the nature-performed maintenance processes that tend towards keeping coral reefs healthy at a state. Moreover, garbage in the ocean can disrupt wildlife, intoxicate marine life, and cause the ingestion of waste, to name a few (*Marine Pollution in the Caribbean: Not a Minute to Waste*, n.d.).

LULC change. Natural conditions had also considerably influenced the LULC of Saint Martin's Island. This, of course, is due to climate change; sea levels are rising, and bigger and more deadly storms are increasingly common (Md Ashikur Rahman et al., 2024). This is having a significant effect on the pattern of weather, driving the erosion in these island coastlines. The Island's landform has been changing rapidly as a result of natural erosion and human-induced manipulations. Not all areas of the ecoregion have lost large extensions of land, while other sites could become new deposits for sediments. These changes have affected the composition of vegetation and abiotic conditions on islands, affecting native ecosystems and species that rely upon these repositories. There has been a remarkable change in LULC over Saint Martin's with human-caused and natural activities, which directly or indirectly triggers the overall landform of the coral reefs surrounding this Island to be changed, which is a threat to the vicinity and living state of native folks. However, to restore them, the economic growth and preservation of Saint Lucia's special ecosystems must be considered very carefully. The Saint Martin's Island is unique with its rich marine ecosystem. The warm water surrounding it and some 234 species of wildlife fish recorded in the warm water of Saint Martin's Islands are combined with excellent potential biodiversity (Ara et al., 2021).

A country that is in dire need of one so much is due to the impact on people and is one of the most affected by climate change. In particular, the situation in which the majority of Pacific Islanders reside – coastal communities which have their lives practically relying on natural

resources (Rojas, 2021). Given the relatively simple changes resulting from an increase in climate risk, typhoons may become more frequent and severe, and other natural conditions may likewise become more extreme, such as sea-level rise or coastal erosion. At the same time, these provide a greater impact, both disrupting traditional lifestyles and also by impacting vital ecosystems, such as mangrove belts or coral reefs. This, in turn, only worsens other threats to these very rich ecosystems that also provide storm protection; food supplies and livelihood materials make use of their subitizing chance. Coastal resilience is at risk when the natural resources are scarce or much harder to extract.

Many men have had to resort to adjusting their chosen economic activities or leaving the area for better and safer places. Yet the undeniable impacts of climate change on these most endangered sites simply reiterate the full relevance and necessity for sustainable management as well as adaptive policy if their future is to be guaranteed.
Among the most important threats to seasonal migration in that area are sea level rise, storm surges and flooding, as well as coastal (*S H O Re L I N E S*, 2017). This is visualized at a theatre near you in National Geographic, which provides relief and climate influences on tracks for migratory animals to behaviors associated with more perennial migratory routes, taking the natural seasonal changes for granted. For one, of the push-pull factors above, many of them related to climate change influences in the paragraph above could provide the impetus for dangerous and less adaptable plants (fish, as well as hard corals such as tides or storms) to move around in currents or waves, uplands or ridges. Resources are provided for feeding or sheltering individuals as well as helping them move to new habitats(Geldard, 2023).

However, as worsening coastal hazards lead to habitat disturbance. Nevertheless, it illustrates the importance of ecologically engineered social and socio-economic systems and infrastructure that can alleviate coastal hazards along seasonal migratory routeways and eventually improve the resilience and well-being of the communities (Mō Te Taiao, 2024).

1.2 Scope of the Study

Geographical approaches

Hazard Identification and Assessment

Here, the researcher will look at the different hazards that are constantly present and specific to the SM Island. These will be permanent hazards, such as storm impacts, flooding, sea-level rise, and coastal erosion. This research will then look at the history and future hazards in terms of their frequency of occurrence, severity, and geographic ranges across the island (Karim & Mimura, 2008)

Climate Hazards Mapping

Application of the World Climatologist data: It will be necessary to determine the research, the change of climate related to the cases, whether the temperatures have increased for the SM Island, and what changes in temperature and precipitation levels have been occurring (*North Carolina Climate Science Report :: North Carolina Institute for Climate Studies*, n.d.).

Migration Patterns Mapping

The spatial patterns of population coastal migration are to be analyzed on Saint Martin Island. The research will show how the environmental changes and recreational and cultural activities have resulted in the coastal hazards and the seasonal patterns of the hazardous migratory routes; some of the questions asked will be when do populations move closer to the coast, and where do they settle (Ahmed et al., n.d.).

Impact Modelling

Once the model has been built to show how these coastal hazards impact the migratory patterns, the habitats, houses, and infrastructure are lost, changes in the availability of resource (Murshed et al., 2022).

Cultural Approach

Community Selection and Profiling

The coastal communities and the populations will be identified and assessed at Saint Martin Island. These will be the touristic communities; the populations are known for their seasonal recreational and entertainment purposes. This analysis should also include these populations and communities and their behaviors, socioeconomic and cultural practices, and dependence on the coats of the island. The analysis of the cultural patterns of these populations and communities is part of the migratory season, the cultural migratory habits, and the hobbies (Md Ashikur Rahman et al., 2024).

Cultural influences

The research will show how these promotional activities lead to the season trips during their migratory season and relate to some of the festivals, cultural activities, other cultural activities, and practices of the international and commercial presence of the communities along the coast.

Evaluate the new migratory behaviors that are caused by these hazards (*Tourism & Management Studies*, n.d.).

Impact on Livelihoods and Social Structures

The coastal hazards affect these cultural activities and their traditional migratory patterns. The research will also look at the population and communities' economic and social effects, and the different communities can change because of migration (Roy et al., 2022).

Adaptive Techniques and Resilience

How can these communities and the populations resettle in light of the changes in the adaptive technique and their culture to the hazards? The research should also analyze the traditional practices that are used and can also be used on a larger scale. It will be communicated in the risk reduction measures the -increase of the lower-hazards measures from initiation through implementation

Geographical and cultural approaches provide an analysis of how these two approaches obtain a clearer picture of the research and, therefore, can yield a better understanding of how coastal hazards affect seasonal migration on Saint Martin Island, as well as insightful physical and cultural heatmap understanding outcomes (Ahmed et al., 2018)

1.3 Aim and Objectives of the Study

Aim:

This research aims to implement modelling techniques to analyze the impacts of coastal hazard threats on the communities of Saint Martin and understand the resulting Seasonal migration patterns within the local communities.

Objectives:

1. To investigate the types of coastal hazard threats and their impact on seasonal migration patterns on Saint Martin Island.
2. To assess the vulnerability of the local communities due to coastal hazard threats.
3. To propose a mitigation strategies model in response to seasonal migration due to coastal hazard threats.

Research Questions

1. To investigate the types of coastal hazard threats and their impact on seasonal migration patterns on Saint Martin Island.

- *What are the major types of coastal hazard threats that Saint Martin Island coastal communities face?*
- *How have these coastal hazard threats changed over the past decade?*

2. To assess the vulnerability of the local communities due to coastal hazard threats.
- *How is this vulnerability affecting the lives of local communities?*
- *What are the impacts of coastal hazard threats on the socio-economic dynamics of the local communities?*
3. To propose a mitigation strategies model in response to seasonal migration due to coastal hazard threats.
- *What are the factors that influence individuals' decisions to migrate in response to coastal hazard threats?*
- *How can mitigation strategies help respond to seasonal migration?*

1.4 Rationale for the Study

Saint Martin Island, a small, environmentally rich island in Bangladesh. It is increasingly being plagued by severe coastal hazards such as cyclones, floods, sea-level rise and erosion. These environmental factors not only endanger the island's one-of-a-kind ecosystems, but they also dramatically impact the seasonal migration behaviors of many coastal residents (Rahman, 2023).

Islanders living on the coast are particularly vulnerable because they depend heavily on marine resources and experience repeated cyclones. Seasonal migration patterns of these communities long associated with a history tied to fishing operations, agricultural labor during planting and harvesting periods or transhumance in response to environmental conditions is essential for their economies and survival. Consequently, they are equally vulnerable to cyclones and flooding, which can cause significant destruction of fishing infrastructure and agricultural and habitation areas. It breaks these migratory paths and demands large economic sacrifice. In an attempt to quantify the financial costs associated with coastal hazards, this study uses modelling of migratory responses to changes. This gives a better sense of how these disruptions affect local life as well as the broader economy (Uzzaman, 2014).

Coastal populations are especially at risk, given their high dependence on marine resources and the exposure of these areas to frequent weather events. The seasonal movement patterns of these communities, usually related to fishing activities and access to seasonal agricultural labor as well as migration associated with weather-related factors, are crucial for economic livelihoods and survival. Therefore, cyclones and heavy rain spells can cause huge damage to fish infrastructure, paddy fields, and human habitats. This disrupts these migrations and creates economic misery. This research modelled the effect of coastal hazards on migratory patterns in an attempt to quantify the financial costs of these threats. This provides more insight into the life and economic impacts of these disturbances on a local scale (Roy et al., 2022).

Informs action for social, cultural, and natural issues that is the need of planners as well as policymakers, but they require thorough knowledge on how far sociocultural or environmental crisis emerged just to take an appropriate place-based response, which should further add

relevant data. So, there will be some thoughtful insights about how coastal risks — like sea level rise, urban and habitat loss or pollution consequences— influence migratory patterns from this study that can help inform planning and policy initiatives. This eventually will help in the development of more rational policies and plans for adaptation options at the community level, disaster response as well as infrastructure strengthening. It made the communities on the island stronger and more resilient (Martin et al., n.d.).

As a result, the study will analyze migratory trends also considering climate change implications. While this provides a preliminary sense of how future climate change and coastal risks may influence seasonal migration, our proactive approach will empower communities and governments to develop adaptation plans that are adaptive to changing local environmental conditions. Risking less you ensure continuity in the long term and can become even more resistant to destructive vectors (*MIGRATION as a CLIMATE ADAPTATION STRATEGY Challenges & Opportunities for USAID Programming*, n.d.)

.

The investigation also opens a big void in the stock of knowledge on Saint Martin Island by integrating environmental, economic and cultural perspectives. At the same time, research on coastal hazards and impacts on the ecosystem has been well-studied. It also contributes more generally to understanding how these hazards impact migration patterns and cultural activities in different settings, less well-studied aspects of coastal risk landscapes that are nonetheless important from a human perspective.

This research addresses practical problems of sustainability and resilience in coastal settlements on Saint Martin Island. By examining the multifaceted influence of coastal hazards on seasonal migratory patterns, this research seeks to support the development of holistic adaptation strategies that improve societal resilience. It ensures the conservation of cultural assets, and it is more successful in cases where their efforts toward seasonal migration (Rahman, 2017).

1.5 Limitations of the Study

- The first major limitation is in the geographic constraints since this is a small island. Further, the aspects of the study may not have provided the most accurate or most logical results due to the restricted size of the location and how it reflected the seasonal changes. This limited study area is associated with coastline hazards and their related hazards.

- Significant restriction resulted from the low availability of high-resolution images for mapping the risky areas. However, the materials that were collected did provide an alternative means of preparing the maps. One of the limitations of the study is what researchers decide about the use of satellite images or restricted on-the-ground data. In the case of Saint Martin Island, restricted images from space could not present real

determinants of findings, as far as it was necessary to identify the interrelations between enough social and natural data associated with coastline hazards and seasonal migration

- Longitudinal analysis, and it is once again associated with the fact of having limited satellite images. Those data are to be used to make some general conclusions about the hazards of the coastline. Thus, one of the tasks in the study was to evaluate possible hazards at certain time intervals. The problem is that this data could not be properly collected on the island and with the needed frequency. This is why there are no longitudinal results for this region. As a result, there is no relevant information allowing us to make the necessary suggestions to study and refine this study in future and make some comments on the impact of the hazards on the populations that currently exist on the island.

- In this research, satellite photos cannot always be correlated with ground-based data because of the discrepancy in the size of the areaIt goes without saying that in this article, there is very little potential for theoretical generalization, and the first reason is the small size of Saint Martin Island. The second problem is that a potential number of other geographical areas may have a different size, different conditions, or climate, and the results of this study may not apply to the geographical regions mentioned.

- As such, generalizability is dependent on the size and features of the site considered. However, in general, it is a small disadvantage of the study if we consider the two most important ones, which are geographic restrictions and the disadvantages of satellite images. As such, we need to be more careful with the interpretation, given the limitations and the use of remote sensing approaches to deepen the understanding of the relationship in the geographical area mentioned (Achard & Hansen, 2016). A broader ground-based study is needed to correct it.

1.6 Organization of the Study

This study is based on the seasonal migration patterns of coastal villagers in Saint Martin Island, Bangladesh. It helps in managing the survey by sectioning the project with each chapter addressing a part of the study. Through the study of the review, the literature ensures that the work is effectively presented to let the readers keep track of the development of the study. Therefore, it presents the major conclusions and implications of the study to the readers. This study is made up of six chapters, as given below.

Chapter One: Introduction

This chapter provides the background of the study, which is the increased burden of coastal hazards in the case of close migration of coastal patrons. It presents the statement of the problem and the purpose of the study. It presents the scope and limit of the research project; in other

words, it conceptualizes and justifies the research project. Therefore, the significance figure of the study is laid out while the structures of these theses, for instance, the word limit, the manner of writing, and the organization of the whole work, are given in a clear presentation.

Chapter Two: Literature Review

The basis for reference has already been laid out in the first chapter, and the understanding of the phenomenon of topics like coastal hazards, migration behaviors, and social-economic fundamentals to support the susceptive theses. The literature review provides a clear theoretical basis for the study to fully help understand how the coast hazards determine the migration behaviors of the objects of the study, which are the migratory instincts of the villagers in the Saint Martin Island case of Bangladesh (Al Nahian et al., 2022). More so, the literature review will show the different paths or rather different interests in which every cited writer tries to tackle the research question.

Chapter Three: Study Setting Information

The research gives a vivid view of Saint Martin so as to offer features of the unique site of study, the economic, environmental, and physical characteristics of the site, the study location, and the islands. It brings out the details of the special study setting in regard to the islands. It also borrows more literature from another given section of the survey. The site of the study is unique because the economic condition places it at a high risk of coastal hazards, as revealed by the survey. This chapter provides detailed information on the location and site of the study, which is central to the study.

Chapter Four: Sources of Data Collection and Methodology

This chapter presents a vivid description used to indicate the sources and strategies used to collect data, including the information collected, the methodologies used and relied on the manipulative base of the study. It also presents us with a track of primary and secondary data sources, with the primary sources being composed of the country's physical presence locations and relying on fieldwork, surveys, and archival sources that are directly relevant to the topic. The secondary source is foot geography; Arabic accounts and European Geography were composed to become sources of secondary data. This information will act to give a directive of interpretation of the methodology and hence ensure their conclusion.

Chapter Five: Results and Discussions

With the illustrations from the maps and some other types of research, it is very easy to draw a reliable conclusion after going through the literature studied in this chapter. The discussion provides information on the findings, which relates to the available information and literature, with the sections revealing the source of the data information.

Chapter 2:

Literature Review

2.1 Introduction:

Saint Martin Island is one of the areas exposed to the great impacts of climate change and other coast-related hazards. This small and lowland island in the Bay of Bengal is more likely to face environmental problems such as seawater, cyclone increment, soil erosion, and salt intrusion (Golam et al., 2005). More than that, they cannot only influence the current state of the environment but also make the social and economic life of the people living in the region vulnerable. The present literature review aims to analyze such perspectives as the existing information exposure of current coastal hazards and the way they influence the migration process, particularly the seasonal migration of the local populations. The people who live on the island have to be focused on their dependence on the natural resources of the region utilized to survive, and hence, a great number of people are considered to migrate to the best environment place, fishing place, tourism, and other land-related economic activities (Kuhnt, 2009).

The present review aims to analyze, assess, and summarize the existing information concerning coastal hazards and migration. Such goals can be achieved by developing the objectives and aims of collecting a set of assumptions, theoretical background, and empirical information to identify

the reasons why people are eager to migrate to hazardous places. Moreover, it is required to determine the general and realistic outcomes connected with the impact of the coast on the island's seasonal migration. The data collected to support these objectives and the assumptions made will be used to define the theoretical perspective for further analysis of the available data to identify the information gap according to the new research directions that can be developed (De Haas, 2021).

2.2 Understanding the Concept of Climate Change

Climate change is a global issue that has devastating impacts on every part of the earth's system (Dawson & Spannagle, 2008). Generally, the term climate change refers to singular and long-lasting changes in the temperature of the Earth, as well as the pattern of precipitation or frequency of severe weather events (Hickey, 2023). Climate change is occurring at a speed faster than anything in modern history. People cause this problem due to activities such as the burning of fossil fuels, deforestation, and industrial processes. The burning of coal, oil, and gas increases the concentration of so-called greenhouse gases (Dawson & Spannagle, 2008) in the atmosphere, namely carbon dioxide, methane, nitrous oxide, and others, trapping more heat and making the planet even warmer. Climate change, from a global perspective, is a multi-dimensional, multi-faceted social problem that affects multiple levels across all social, economic, and political life. The phenomenon is coming in different ways:

1. In the Polar Regions, the ice caps and glaciers are melting, and all coastal settlements are threatened by the quickly rising levels of the sea.
2. In tropical and subtropical regions of the Earth, the rise in temperature and stable patterns of precipitation are changing. The increase in temperatures and erratic rainfall patterns are leading to a drop in agricultural output and water and food insecurity.
3. The number of severe weather events is growing, such as hurricanes, droughts, and fires. (Sachs & Santarius, 7 C.E.)

These destroy buildings, habitats, and farmlands and displace millions of people.

Climate change is truly a global issue in every meaning of the term. First, the chain of consequences is closely interrelated, interconnected across multiple places, often transcending borders. The loss of biodiversity in some regions leads to an environmental response impacting the ecosystems' capacity to provide serious services to people globally. For instance, the decline in the bee population due to higher temperatures, less diverse habitats, and increasing pollution in the region impacts fruit and vegetable pollination in the entire area. This affects the availability of food, the local and international economy, and the health of people worldwide (*Scientific Outcome IPBES-IPCC CO-SPONSORED WORKSHOP BIODIVERSITY and CLIMATE CHANGE*, 2021). Second, these environmental consequences are not shared equally across the global population: those most in need are impacted the most and are the poorer countries and small island states. They receive the harshest consequences of climate change

despite contributing minimal amounts of greenhouse gases that are causing the issue (*The Climate-Changed Child a CHILDREN'S CLIMATE RISK INDEX SUPPLEMENT*, 2023). Third, any given issue that causes serious consequences on the global level is considered a global issue. Climate change caused a global response on a global level. This global response can take many shapes forms and forms, such as the establishment of international agreements, like the latest Paris Agreement obligating countries not to let the rise of the global temperature exceed 2˚C, to various strains of focus and discourse on adaptation and resilience. Thus, there is more than enough evidence to conclude that climate change is a global issue in every meaning of the term, as not only is the problem global in scale, but it also poses global security, development, and human rights threats (*Causes of Climate Change*, 2023).

As for the lives of each of these concepts, we may refer to numerous ones connected to the ideas of global climate as well as justice. Climate justice refers to the normative dimension of the idea of climate change. It means that no group of people can lawfully be regarded as inferior by another human group or should be disavowed by environmental differences under any form or lost reward. Therefore, what climate justice demands is some equitable solution in order for the people to be strengthened, for the promotion of human and basic social systems, for vulnerable populations to be empowered, and for the aversion of impacts. Consequently, the notion of climate change for the world implies developing and understanding the high variability and sensitivity of global processes, various types, and degrees of vulnerability of specific zones, as well as the need for international cooperation and agreement. Thus, the problem can be seen as partially scientific, technical, and truly humanitarian (World Bank, 2023). However, it is directly connected with human values, which are the ability to privilege equity, environmental conscience and sustainable development over capitalism accumulation. Finally, seeing that the international community cannot accept the disastrous climate change across the globe, humanity must be aware of the danger of not acknowledging this statement as true and reacting to it properly to ensure peoples' safety and the fact that the world will remain suitable for living planet (OHCHR, 2015).

2.3 Understanding the Concept of Coastal Hazard Threats

Various risks are generated by coastal hazard threats to both natural environments and human populations within the coastal zones, and they are among the fastest-growing concerns globally. Among the common coastal hazards are a range of natural and anthropogenic events: sea level rise, coastal erosion, storm surges, tsunamis, and saltwater intrusion, all of which are the products of the effects of climate change (Manou et al., 2017). Awareness of the worldwide menace of these threats is essential because the coastlines are one of the largest concentrations of the population and the most economically important areas of the globe. They provide homes to a significant part of the world's population and are crucial for the global economy, feeding people

through fisheries, providing opportunities for tourism, and ensuring prosperous economies through shipping.

Not abating for a minute, the most troubling threat from a global viewpoint today is the equivalent rate of sea level rise. Much of this threat is due to the melting of the polar ice caps and stratospheric ice (*ECCC Data Catalogue / Catalogue de Données D'ECCC*, 2024) and to the expansion of seawater as it becomes increasingly heated (M, 2021). Low-lying coastal zones are in serious danger of being permanently flooded and of losing valuable beaches and land, or valuable urban or agricultural areas, as well as invaluable habitats, in the form of wetlands and mangroves. Some of the countries with the largest coastlines are also those with the greatest number of major cities. For many of the events listed above, Miami, New York, Jakarta, and Dhaka are certainly the most vulnerable insofar as they are the ones in which the phenomenon of rising seas is multiplied by the subsidence experienced, rendering exceedingly devastating the risks of flooding and potential displacement of millions (Hossain et al., 2013).

At the same time, the coast of facilities of the coastal zone and activity are systematically destroyed by huge material costs, and in some cases, the lives of both people and animals are lost. However, over time, they lead to the gradual destruction of coasts. Unfortunately, the latter problem is so acute. In addition, in developed areas, it is caused by the use of land close to the water for people to engage in various activities such as recreation and tourism, and people have a significant impact on this territory and nature, namely the action of waves, currents, and storms. The most important lever that accelerates the course of the process of coastal destruction at present and cannot be unseen or unfelt around the world is the human use of the transport capacity of the sea over a changing area. The worst side is that it can destroy the coast as well as the infrastructure laid on all of it, and it can be used for beaches and recreation for thousands of tourists and others in the future or are using it now. Therefore, in the case of small island developing states by the abbreviation SIDS and the deltaic regions, it can be an even more serious risk since it is truly a land with very limited and very invented resources (Manou et al., 2017).

Throughout the storm, storm surges raise the water levels of rivers and seas worldwide, as they occur in storms beginning in tropical cyclones or rather hurricanes. Meanwhile, rising sea levels and excessive pumping of the groundwater are the cause of the spread of saltwater intrusion, a growing coastal hazard, meaning the movement of saline water into freshwater aquifers, the type of coastal hazard which is most common in areas where groundwater is the principal water source for agricultural or human consumption. A rising globally important risk. This is a type of hazard in which the spread of contamination of the group is soon followed by food security, neither public health nor economic growth, and increased damage to all. These issues are all related to each other, thus requiring a global perspective to be integrated (Society, 2011).

2.4 Socio-Economic Vulnerability of Coastal Communities

The environment is affected by their condition of life. Thus, coastal communities can be characterized as rather vulnerable to external threats. Regardless of a range of causes of socio-economic vulnerability, including increased dependence on natural resources, poverty, lack of access to education and care, insufficient regional infrastructure, and others, the given population is rather susceptible to climatic change, sea landscape degeneration, and some other environmental challenges typical of the current epoch. All the above-mentioned factors contribute greatly to the given state of affairs, and the community in question should be regarded as a high-risk population. To be sure, the vulnerability of the regions in question constitutes a tremendous threat, and the communities are rather vulnerable to a considerable range of threats

One of the defining characteristics of an affecting coastal community is the fact that the people in question used a vast selection of natural resources, including fish, agricultural and touristic. While there is no need to stress the fact that the process of climate change is recognized as one of the defining factors taking place in regard to the condition of the natural resources and the environment as well, the populations define themselves as a part of the given area become vulnerable and see their incomes reduced greatly. As an example, due to the fact that there can be different reasons defining the increased level of pollution, overfishing, and coral bleaching, the marine ecosystem may be subject to irreparable suffering. As a result, the number of fish to be found in the area in question will be reduced with each day, and such a tendency can be considered a direct cause of the lowered amount of food resources and the source of income for the people belonging to the area. Furthermore, due to the levels of the sea are expected to rise in the future, the levels of saltwater are to increase as well, getting into the freshwater sources and the levels of water will no longer be available for the needs of the farming-related population (Daw et al., 2009). The question of educational and health support also has to be addressed as a common issue that adds to the vulnerability of the population.

On the one hand, one of the defining reasons defining the fact that no steps can be taken by the communities in question to move to different sources of livelihood or technologies ought to secure and produce more sustainable charges for the people with very low levels of education the populations have. On the other hand, an equal lack of health services creates a situation where environmental change is an added risk to influencing the two types of disaster conditions around. As a result of the lack of the required help, the communities found in question will be confronted with several diseases and epidemics and will die due to the fact that those people will turn out to be untreatable on location as no Health Care services will be available there

However, the built environment can also be viewed as a source of vulnerability. First of all, the constructions which people erect in order to be able to dwell in a particular location are frequently of very low quality and need help to adapt to all sorts of changes taking place in the environment at large. Indeed, a large number of houses, roads, and public buildings in the overwhelming majority of coastal communities can be classified as low-quality constructions. In addition to that, the built environment can be washed away as a result of all of the three types of

coastal hazards: i.e., flooding, storm, and erosion. To put it in other words, the constructed facilities do not exhibit a sense of inherent fairness, adequate to provide the needed support. Yet another source of vulnerability, whose appearance can also be justified by the necessity of proper fairness, has to do with the choice of drainage, water management, and transportation networks that are far from being sufficient in providing all of the people from faraway domains (especially when it comes to Saint Martin Island) with the access to leave them readily (*C40 Knowledge Community*, 2024).

Speaking of the socio-economic vulnerability of the island communities, the fact that these communities rely heavily on fishing and tourism is exceptionally risky when the coastal hazards become even more hazardous. In other words, the communities located on small islands are very vulnerable in economic terms; However, there are long-lasting problems such as decreasing stocks of fish, addled anglers and their family's lives as they often become poor, the decrease in fishers' numbers also results in the decreasing number of tourists, the growth of environmental damage, the storms drowning the infrastructure of the islands and the erosion washing it out becomes faster than it is rebuilt on, and the growing rates of unemployment as the employment opportunities drop increase the hazardousness of the situation. The vulnerability and the emergency of the population can also be explained by the fact that healthcare options and access to education on the islands are far from perfect (Laila, n.d.).

2.5 Absence of Basic Needs Due to Coastal Hazard Threats in Coastal Communities

The crucial problem that is increasing in coastal communities in every part of the world is the impact of coastal hazard threats that not only constantly destroy their daily life routine but increase the absence of vitally important. Sea-level rise Marine flooding with storm surges, coastal erosion, and saltwater intrusion are connected with the hazard threat of the lack of important resources. In other words, the problem is that saltwater intrudes into freshwater resources, leaving them untapped. Thus, food, shelter, and health services remain unavailable. The absence of vitally important resources subjects the coastal population to the threat effects. It increases their vulnerability, which is a crucial issue for the region's already unmanageable poverty and pernicious infrastructure (*Socioeconomic Impacts of Coastal Tourism on Local Communities in Kuakata, Bangladesh*, 2024).

The appearance of the most impacted source of freshwater resources is vulnerable to the impacts of coastal hazards. Coastally-based communities are likely to rely on the superficial source of water or shallow groundwater clearwater lens. Both sources are prone to the hazard's impact, as the intensifying storm surges not only bring the threat of flooding along with the problem but also intensify the salt intrusion in the area due to the increased sea level. As a result, fresh, superficial sources of water become unpotable, and drinking water scarcity appears in numerous low-lying coastal areas and Small Island states (Manou et al., 2017).

The areas might be extremely vulnerable in terms of water scarcity, and the communities are obliged to use alternatives such as water importation, desalination, or purifying their drinking water to satisfy their basic need for drinking water. The absence of drinking water drastically impairs public health and diminishes the agricultural productivity of the area, affecting food security. Another factor that largely leads to the concern of insecurity is the consecutive and persistent impacts of the hazards on the same affected areas. As a result, low-lying coastal communities are likely to lose their freshwater supply system, turning them into water-stressed regions. High drinking water scarcity throughout numerous coastal states brings the constant danger of contracting waterborne diseases. The mentioned water sources are not effective for their drinking, yet they do not have better alternatives to maintain a basic level of public health. The risk of contracting waterborne diseases significantly undermines public health due to the absence of drinking water (Wood, 2024).

In most of the coastal communities, people are left vulnerable to further recovery because of the lack of ability to provide their citizens with secure shelter. Homes or their intracule infrastructures in no such areas can withstand the impacts of natural hazards as they are not designed to do so. As such, many people many of these people familiarize themselves with their homes, which get destroyed either by storm surges or long-term erosion of the sea and gay many families, leaving many families homeless and inclined to contact them. In addition, the displacement of people and their communities has to shift from one place to death in the other. Hence, people familiarized with such areas not only lose their social order in that their community is functioning by something totally different, but additional pressure, that is, favorite resources, occurs in the areas where these people will be moved. Although the argument needs to pick the future recovery people are left in soak vulnerable to not it being usually, living in the places where these shelters are constructed, people have not even the most primitive access to healthcare: this has the potential to raise mortality and complicate the recovering reparations at a constantly slow pace. In any case, the major factor that influences this is the absence of secure shelter. Hence, in most coastal communities, people are left vulnerable to further recovery (*Shelter from the Storm: Protecting Bangladesh's Coastal Communities from Natural Disasters*, 2022).

Thus, the absence of even limited access to basic needs due to the constant threat of coastal hazards creates a vicious circle of vulnerability for these regions. As the availability of the limited resources decreases and the need for these resources grows, the more difficult it is for the population of these communities. Unable to cope or adapt to the changing environmental conditions, the communities face an increase in hazard frequency and even more difficult situations, leading to increasing vulnerability and decreasing resiliency (Ehsan et al., 2022).

The limited freshwater resources of the island are in a constant state of danger of saltwater intrusion, as are the agricultural fields and fish population due to frequent erosion or loss of habitat. These regions' houses and infrastructure are threatened by flooding or storm surges, and

the often-limited access to healthcare cannot offer much help during and after extreme weather conditions (Afjal Hossain et al., 2011).

In conclusion, the presented information demonstrates that the lack of basic needs related to the threat of coastal hazards is a significant and increasing issue for coastal community representatives worldwide. The problem can be addressed by improving the existing infrastructure, developing new approaches to resource management, and creating comprehensive disaster response plans. As a result, while the world faces growing insecurity, meeting basic needs provides an additional layer of resiliency for people living in the most dangerous conditions.

2.6 Seasonal Migration Patterns of Coastal Communities:

Migration of people from one territory to another is traditionally inherent to humanity; so-called seasonal migration has a great history and is a part of the life of many maritime communities. People move under the influence of environmental change; it may occur that many people do not treat seasonal movement as a response to changes in the economy. Such movement frequently starts from either coastal or fishing stations; therefore, it is closely associated with the transition from one fish or seafood to another, from a hot to a cold current, from a rainy season to a year of drought. However, seasonal migration is closely connected not only with environmental changes but also aimed at the optimization of people's lives, and therefore, it is always related to positive changes. Being associated with the sustainable development of people in a certain maritime community, it should be studied from an all-round point of view. Migration concerning a better life for people leaves much to be desired and, therefore, helps to create the adaptive capacity of people to change (International Organization for Migration, 2016).

The most common causes of movement are usually related to the availability of resources in a certain area, certain climatic features, the growth of crops, and the provision of employment. However, it needs to be noted that, more often than not, moving individuals from the coastal and fishing areas, as in this case, are always at the complete mercy of nature. Moreover, it is the specifics of the people's occupation that make a new flock of fish the best to follow. In particular, the people of South Asia – the inhabitants of Bangladesh, India, and Sri Lanka, always and everywhere knew all the secrets of the seasonal pilgrimage. The fact is that the livelihood of these regions primarily involves food, which the locals get by fishing. Thus, local fishermen moved from place to place depending on the presence of fish, often following the monsoons and often on hot or cold currents (*Climate-Smart Agriculture (CSA) Considerations*, n.d.). Similarly, in the WC of Africa, this entirety is enforced for the people in Senegal, Ghana, and Nigeria. Here, it is a matter of moving from one island, sandbar, and one place of fishing to another, moving from one island to another in order to evade rainfall. This moving is prescribed for the people of the region since the people are, by and large, entirely at the mercy of nature for food (Rigaud et al., n.d.).

Seasonal movement of residents is a characteristic of other countries' coastal areas primarily due to economic determinants based on the presence of working places. This type of migration is observed in different coastal regions of the world, such as Southeast Asia, the Mediterranean, and the Caribbean, where the tourism industry has undoubtedly developed. People leave their native cities or countries and travel to work seasonally in coastal towns or resort hotels. In the autumn, at the end of the tourist season, people leave. They come back at the beginning of spring when tourists no longer visit this place. This process is extremely important for both these coastal regions and the cities whose residents go on seasonal migration. From an economic point of view, the money the latter is paid for this job is a significant percentage of the local economy. Also, the money that tourists bring to these places consists of a certain part of the money spent on people in their hometowns to take care of their families (*State of the Environment and Development in the Mediterranean State of the Environment and Development in the Mediterranean State of the Environment and Development in the Mediterranean State of the Environment and Development in the Mediterranean*, n.d.).

One should note that seasonal migrations are a vital part of coastal community life. Traditional patterns of seasonal migrant movement are best considered as responses to natural variability. Furthermore, there is a discernible and well-established pattern that characterizes the phenomenon, as the worse of the two seasons requires migration to conditions that are typically at the upper ramp of the property ladder. Although such an approach had been successful in the past, seasonal migrations have become both a response to geographic adversity and a financial boon. Nevertheless, as the Earth presents people and their assets with new challenges in the form of weather variability and sustainability, the pressure on those communities to be able to both weather and migrate can be observed. Moreover, the link to the enormous shifts in the market can be felt as well, which is why it is impossible to consider seasonal migrations in isolation (*Human Vulnerability to Climate Change and Migration in Bangladesh–Sundarbans – INTERNATIONAL CENTER for CLIMATE CHANGE and DEVELOPMENT (ICCCAD)*, 2021).

It is easier to correlate this concept with other ideas, including internal migration, with which seasonal migration is often integrated into existing studies. Second, it has become apparent that the phenomenon is influenced by a large number of conditions, including socio-economic position, emotional states, publicity of bearing, the nature of the place, and other factors. On the whole, the phenomenon is also perceived in a more general manner, and there is a sufficient amount of information about it. Third, the research also suggests that grouping a number of people leads to greater mobility and a more significant scale of seasonal migration. However, it is crucial in the future to explain in more detail the link of seasonal migration with globalization, urbanization, development, and other socio-economic forces (Kuhnt, 2009).

2.7 Modelling the Effects of Coastal Hazard Threats

Modelling the impact of coastal hazard threats is one of the most powerful tools used in research and managing the risk of destruction for various types of coastal communities. Such threats as sea-level rise, storm surges, coastal erosion, and flooding may pose a severe danger to the assets, infrastructure, and environment of coastlines (*Save the Basin*, 2024). By using different modelling techniques, researchers and decision-makers may be able to predict the danger of these threats, develop adaptive measures, and increase the resilience of the population currently living in these or those areas. One of the most significant purposes of modelling and understanding the processes of coastal hazards, in the long run, is the possibility to predict the spread of this phenomenon geographically and to understand the physical processes causing these natural catastrophes, particularly wave dynamics, sediment transport, and changes of shorelines. In such a way, it is possible to predict these changes and their influence using different numerical models. Such numerical models help predict how the phenomenon may vary across geologically similar coasts under varying scenarios of climate change and sea-level rise, assuming different shoreline boundary conditions (Jung Hee Hyun et al., 2021). For example, different hydrodynamical models designed to model the movements of water along the coast may predict different storm surges and floods that may occur with different storm conditions. This method of data analysis is particularly essential in determining which areas are most likely to withstand these dangers and in managing these areas with protective engineering structures such as seawalls and storm-surge barriers (Seenath et al., 2016).

The population density, key forms of land use, industrial activity, and availability of natural resources are the main information focused on throughout the creation of the model. Therefore, researchers can identify the approximate level of potential losses in terms of property losses, decline in income, and number of people displaced. Different sources of information on the given hazard could be combined to develop an impression of the vulnerability of the local coast and search for long-term implications for the local population.
The first simulation approach to the given phenomenon is scenario modelling, which involves forecasting by running scenarios, such as storm surges, based on information about the previous process of the same kind (FAO, 2015).

This approach makes it possible to identify the major implications of the given event and suggest appropriate prevention measures. Proxy modelling is the following simplified approach which, when assessing the coast's vulnerability, is focused on the existing proxy, such as high tide for storm surge. Therefore, the process simulation might be generalized, and appropriate prevention measures might be implemented. In particular, this would be useful for understanding people's behavior under the danger and decision-making. Here, an agent is a household or a business, each of which lives in the social and built environment. Tinos et al. give an example of such a model used to simulate the response behavior of an agent to an earthquake hazard and the effectiveness of adaptation strategies. For instance, the simulation could show whether an agent would evacuate in case of a storm or a riot or where it would go to live if the flood destroyed the house. Migration patterns and changes in land use and community adaptation may be examined

and evaluated by means of this type of model. There are also global climate change models that should be used to understand the long-term effects of hazards. They can be employed to simulate rising sea levels, increased temperatures, and extreme weather events. (Coherent Market Insights, 2024).

Combining the last ones with the coastal hazards allows us to understand how the future climate will affect the existing dangers and create certain new ones there. For example, even a small rise in sea level still makes the existing coastal inundation two to ten times more frequent. Modelling the impacts of coastal hazard threats is one of the most important areas of coastal risk management. Apart from being highly important, this area is specifically necessary to the case of the Saint Martin Island situation. The island is among the most vulnerable to coastal hazards as it is small, highly populated, and comprises many ecosystems that are vital for the local population. Together, these characteristics make the island extremely vulnerable to the specific impacts of sea-level rise, erosion, and storm surges. (Sea-level rise and climate change, 2016).

Therefore, advanced modelling technologies must be used to learn about the evolution of these hazards and the resistance of the island's communities and ecosystems to these hazards to inform the policies that should be implemented to protect the island's communities and ecosystems. For instance, the models may demonstrate that certain areas on the island are at the highest risk of flooding, land loss, or both and inform the implementation of shore-hardening coastal protection measures in the areas or rejuvenation of the mangrove forests that would stabilize coastlines and eventually prove a more effective flood barrier. In addition, models can be used to model the early warning systems and disaster situations to design effective evacuation routes, emergency shelters, and communication systems so that the vulnerable people on the island are properly prepared for and able to survive the coastal disasters. Similarly, the models must be used to assess the effectiveness of these adaptation strategies and recommend the prompt use of public resources depending on the type of disaster response or adaptation strategy (Zaman & Raihan, 2023).

In conclusion, the modelling of the coastal hazard threat impact is a central part of coastal risk management. Through the application of different modelling techniques, the various physical processes involved in coastal hazards, the influence of those hazards on sensitive communities, and the adaptation strategies that need to be developed to confront those impacts can be explored by researchers and policymakers. In light of climate change, the vast majority of the types of coastal hazards are said to increase, both in their frequency and in their severity. Therefore, the use of modelling can at least partially reduce the risks that the sensitive communities, including the communities on Saint Martin Island, face.

2.8 Conclusion

The literature suggested below demonstrates the fact that the threats of coastal hazards, seasonal migration patterns, socio-economic vulnerability, and lack of basic needs in coastal communities are interrelated and concern a set of challenges for the population of vulnerable areas. In particular, a small Saint Martin Island in Bangladesh, the population of which is about 8000 people, has already proved the fact that small islands are the first line of climate change. Saint Martinicans, as well as people in the rest of the countries on the coast, are directly exposed to the dangerous threats of sea-level rise, storm surges, coastal erosion, and a range of other coastal hazards. Moreover, these phenomena affect the present-day physical landscape as well as the socio-economic context of the area exposed, enlarge human vulnerability and decrease human resilience. However, even such adaptive strategies used by the people from the coast as seasonal migration become riskier, as environmental conditions tend to be less predictable. Moreover, these people may still lack their basic needs because of the threats of coastal hazards. Clean water, food, shelter, and health care are a range of preconditions that are missing to be safe and unexposed in these communities. It should be stressed that modelling is one of the essential tools developed to affect the impact of coastal hazards. These models can simulate the processes and human behaviors in this regard and supply strong backgrounds for adaptive strategy, which can make people more resilient concerning these vulnerabilities.

Climate models, hydrodynamic models, agent-based models, integrated assessment models, etc., are examples of types of modelling the reports on which have been provided in the literature. Saint Martin Island population needs this modelling effort. The fact that the island has high exposure to coastal hazards and that a range of socio-economic vulnerabilities intensifies exposure has already mostly pushed people and the area they live with into risk avoidance. The employment of advanced modelling techniques can also help to find the most vulnerable and exposed locations. The developed adaptation strategies can also be used to provide disaster preparedness plans that have to give a range of alternatives for the island and its population.

Thus, threats of coastal hazards, problems related to socio-economic vulnerability and lack of basic needs, and the interconnectedness of these phenomena have been essential. Further research and the employment of modeling and adaptive measures can decrease vulnerability in each of the mentioned areas and build resilient communities in all the regions on the planet's coasts. Dangers demand actions while this help is still available to be implemented.

Chapter 3:

Study Area

3.1 Introduction

The project of documenting and analyzing the impact of coastal hazards on Saint Martin Island, Bangladesh, and the seasonal migration of local communities is crucial to providing a full assessment of environmental risks and the corresponding socioeconomic consequences. For such a small and peculiar island located in the southeastern part of Bangladesh, its specific physical and environmental conditions, as well as particular cultural and economic features, make the topic of coastal hazards and seasonal migration important. Being situated in the Bay of Bengal, the island is extremely prone to numerous coastal hazards, such as cyclones, sea-level rise, flooding and coastal erosion. However, all these threats are important not only for the island's environment but also pose the same dangers to the natural resources of the island. Without understanding the actual affectations of these factors would result in the incomprehensive and superficial consideration of the problem and a vague interpretation of the impact of coastal hazards on migration (Ahmed et al., 2021).

For this reason, a careful study of the environment and the ability to migrate within a particular territory is necessary. Although the island's area is not large and does not imply the same means of satellite imagery and the methods of examination as larger areas, the resolution of the data used for the analysis of its seasonal migration will still be required to ensure an adequate degree of reliability. At the same time, based on the millennium goal towards the reduction of coastal hazards, meaning the decrease of the number of people living in the most hazardous zones in quite openly located houses not inside lands far enough, it will be crucial at the beginning of the course to define the features characterizing the area being studied, from the physical and environmental to the social and economic ones (*Migration and Global Environmental Change Future Challenges and Opportunities*, n.d.). Along with the geomorphologic and hydrologic characteristics of the island, including the climate and land use, a description of the demographic situation and financial activities of the people living on the island and the specifics of the local culture associated with the migration should be provided, as people tend to develop a seasonal migration pattern for a reason – their local knowledge allows to keep the operation of the ecosystems. This description of the area will provide a basis for the formulation of the way of understanding how coastal hazards affect the seasonal migration of the people, create the foundation for providing the people of the coastal communities of Saint Martin Island with adaptation measures and programs tailored for their conditions, and help them to adjust better to environmental changes (Arsenault et al., 2015).

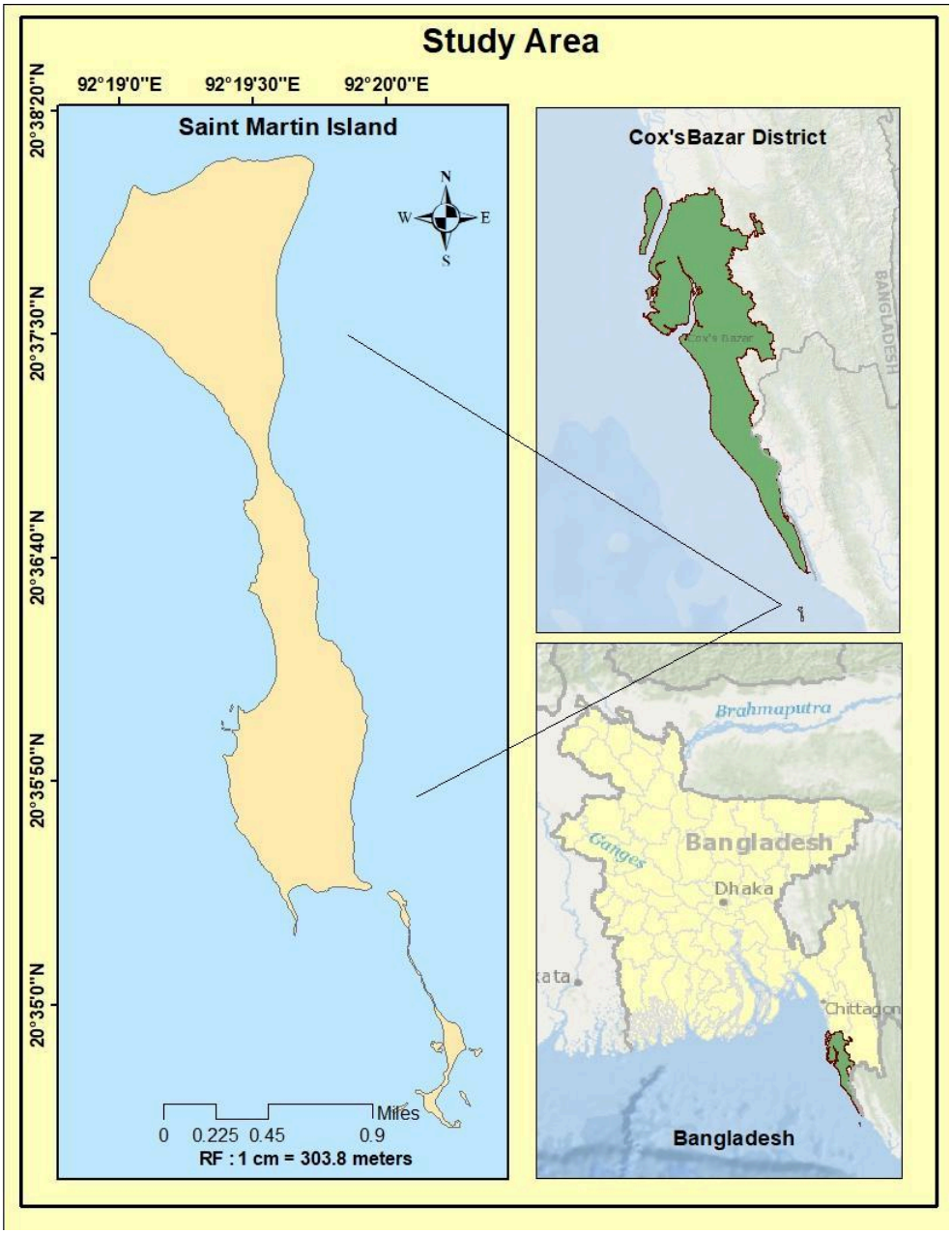


Figure 1: Map of the Study Area: Saint Martin Island

3.2 Delineation of Study Area

The study area is defined to be the entire geographic extent of Saint Martin Island, located in the southeastern extreme of Bangladesh in the Bay of Bengal. The island has an approximate area of 3 square kilometers (Hossain, 2001). The survey of the island's natural and socioeconomic features defines the context for understanding the effects of coastal hazards on the seasonal

migration pattern and, thus, life of the island's community. The geographical features of the delineation and the relevance of each to the study are as follows.

a. The northern boundary of the island is the high-water mark, as it is the strip of contiguous land that separates Saint Martin Island from the open land or water to the north. This boundary is relevant because this is the neighboring area to which the impact of the sea-level rise and storm surges should extend (Dawson & Spannagle, 2008).

b. The southern boundary extends to the edge of the coral reefs enclosing the island. The boundary is relevant because it marks the role of coral reefs and tidal flats in the deposition and erosion of coastal sediment (Tebbett et al., 2023).

c. To the east and west, the boundary of the study area runs 'along' the sandy shore and the mangrove fringe, which is eroded by the tidal action and storms of the Bay of Bengal, forming mudflats to the north and west of the island. The factors affecting this boundary, and therefore relevant to the study, are coastal erosion and its effect on the natural and socioeconomic features of the island. Also relevant is the physical extension of the sandy dunes, the coral reefs, and the tidal flats hosting marine and plant life (Hossain et al., 2023).

Table 1: Delineation of Saint Martin Island

Study Area Aspect	Description	Source
Geographic Coordinates	Located at approximately 20.63°N latitude and 92.32°E longitude.	(Hossain & Lin, 2001)
Island Size	Total area is about 3 square kilometers, with a maximum length of approximately 7.3 km and width of 1.6 km.	(Islam & Shamsuddoha, 2018)
Topography	The island is relatively flat, with elevation not exceeding 3 meters above sea level.	(Brammer, 2014)
Coastal Features	Features sandy beaches, coral reefs, and tidal flats, with a significant presence of rocky outcrops.	(Chowdhury & Rasul, 2011)
Habitats	Includes coral reefs, mangroves, and seagrass beds, which are crucial for marine biodiversity.	(IUCN, 2015)
Population	The island has a permanent population of around 8,000 people, with seasonal increases due to tourism.	(Bangladesh Bureau of Statistics [BBS], n.d.)
Tourism Impact Zones	Northern and eastern parts of the island experience more tourism activities due to beach access.	(Rahman et al., 2019)
Protected Areas	Parts of the island are designated as Ecologically Critical Areas (ECA) by the Government of Bangladesh.	(Islam & Shamsuddoha, 2018)

The delineation includes admitted hydrological features, such as rivers and water bodies located in the northern part of the island during the monsoon season, wet seasons and drainage systems. Rivers and water bodies, together with the wetlands, influence the flows and changes of water and the frequency of flooding. This also includes all climatic features of the island, together with the temperatures, precipitation conditions and the variance of the two. The western part of the finish line also includes the farthest that cyclones are able to reach from the globe. The socioeconomic features of the delineation include areas of residents, such as where wholesome people live, the fishing grounds, the agricultural lands and the beach areas, including the instance facilities belonging to visitors. The delineation also includes areas where the natural and the artificial drainage systems are and those of tourism value on the island, such as the sites of the traditional artificial salt. The environmental, socioeconomic, socio-cultural and climatic features are included in the delineation response. The delineation consists of the features because they affect the interaction between the threats of coastal hazard and the stakeholders, and the manner in which the phenomena affect seasonal migration on Saint Martin Island. The features are also included in the delineation because they are vital in the identification and analysis of factors and selection of mitigation measures for the coastal hazards (Hossain, 2024).

The methods to be employed in data collection and analysis in Saint Martin Island using these defined lines will include the representation of the island with signs and written descriptions. High-resolution images will be acquired for the on-site visual recognition of the features. The data collection will combine satellite images of the island with information on the features that occupied each section of the island. The delineation will guide the collection of high-resolution satellite images, using these signs and descriptions combined with what will be seen on the ground. Given the small size of the island and the need for the data to be detailed on a temporal and spatial scale, field observation will help in the analysis of the various studies. With field observation, the delineation will be used to define and analyze how the coastal hazards affecting Saint Martin Island influence seasonal migration (Hossen & Sultana, 2023).

I have used the delineation of the study area in this way because I want to study factors to be in their most detailed form in relation to the coastal hazards and migration factors interaction. It will make it relatively easy to find appropriate solutions to the factors affecting the island's communities.

3.3 Location of Study Area

One of the sites prone to the seasonal effects of coastal hazards is Saint Martin Island. It is to the southeast of Bangladesh in the Bay of Bengal (Al Nahian et al., 2022). It is approximately 9 kilometres from Tekna Peninsula, which is the southernmost part of Bangladesh. The Saint Martin Island is at a latitude of about 20°38′N to 20°41′N and a longitude of 92°20′E to 92°24′E. It is the only coral island in Bangladesh (Avi, 2023).

Moreover, it is renowned for its unique marine fauna and flora and the relatively less disturbed natural environment. However, there is a downside to this as its proximity to the Bay of Bengal exposes it to the whole spectrum of hazards associated with its location on the mainland, hence the action of the peninsula-like climatic hazards (Hossain & Islam, 2006). These are cyclones, sea-level rise and storm surges, and coastal hazards. In addition, the southeast and southern parts of mainland Bangladesh, where the island is located, are the most vulnerable to sea-level increase and low land coast elevation, therefore a key contributor to flooding (Ahmad & Jhara, 2009).

It is appropriate to focus attention there since it is part of the Bay of Bengal, and hence, it is likely to fall into the path of tropical cyclones and the effects of the sea-level rise. The tropical storms and prevalent flooding have detrimental effects on land encroachments by the sea level, and the residential spaces of the island are prone to be submerged. It, therefore, makes the site suitable to investigate as a seasonal migration effect site due to coastal hazards as a result of higher flood percentages and the displacement of human settlements (Rahman & Rahman, 2015).

Figure 2: Location of Saint Martin Island

3.4 Demographic Aspect

The demographic characteristics of Saint Martin Island are essential for the assessment and understanding of the impact of coastal hazard threats on migration patterns, which represent the

system of monsoon migration patterns. Apparently, it is to be pointed out that the size, structure, and peculiarities of population distribution should be taken together. As for Saint Martin Island, the rapid growth of the island's settlements, which was associated with a number of natural and social-economic factors, such as the availability of resources and influence of the other economic aspects, has resulted in the establishment of approximately 8,000 people community (Hossain, 2024).

It is mostly composed of indigenous people – the Moth and Rakhine – and other settlers from Bengal. The small size and differentiated origin of the population also signified that this cultural feature of the population of Saint Martin Island is associated with the adaptation of the local population to the local environmental conditions. The significant cultural population feature of Saint Martin Island is, thus, connected with the population distribution. The island's whole population is settled in dense settlements in small areas, where the main one – Saint Martin Village, is the main center of almost all residential, commercial, and administrative activities, which take place there. That is one of the reasons why the importance of the village saves on the exceptionally strong population concentration, which is associated with the high building density as well (Hossain, 2020).

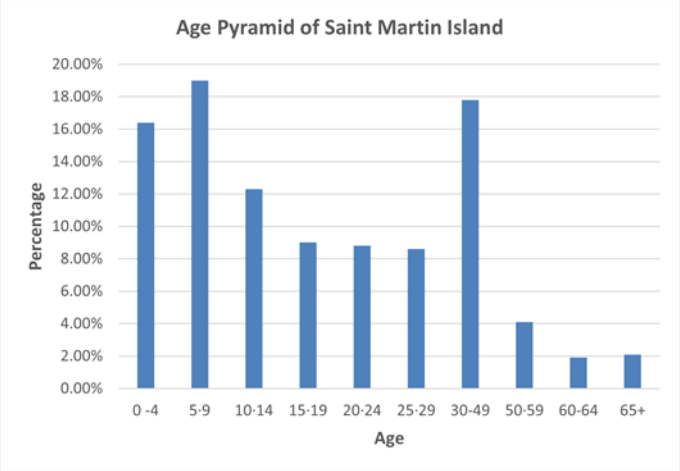


Figure 3: Age group of Saint Martin Island

Source: (Bangladesh Bureau of Statistics (BBS), 2022)

The age pyramid represents how a population is distributed based on the size of various age groups. Therefore, the age pyramid provided is an interpretation of what it shows and what it can imply.

Young population

The age pyramid shows that the population is mainly young. Three age groups, 0-4, 6-9, and 10-14, make up the most prominent part of the whole.

- The prime period is the 5-9 range, which contains around 20% of the whole population.

- There are also many people belonging to the 0-4 range, which can imply that the birth rate is high or the population overall is young.

Youth and young adults

The percentages of people of these ages decreased a little from 15-19 to 20-24 and 25-29.

It can also imply that with the fertility rate declining in the past, fewer children were born in the period closest to the recent one or that the emigration of young adults is being reflected here.

Prime working age

This period increases for every age group in general but more strongly for the 30-34 and 40-49 age groups, which implies a productive prime-age population.

- This is the period people usually work and is thus crucial for the health of society.

Middle and older adults

The size of the group of those aged 50-59 and 60-64 dropped significantly.

It can either imply that the population does not live long enough for there to be many old people or that everyone above a certain age leaves the island.

Elderly population

Those aged 65 and up are the fewest overall, which implies that few people can be considered elderly.

- Thus, people from around a certain age are known to leave the island.

Overall, this means that the island of Saint Martin has a young population, many of the children and young adults. Many people are also of working age, which can be good for the health of the island's economy. Nevertheless, the fact that there is a very steep decline in the old age groups can be a problem. The people in the old populations may not be taken care of, so they stay on time or emigrate. The distribution can affect many different aspects of life, such as education, the share of the age group in the labour force, and the necessitated provision of services for people of certain ages.

3.5 Socioeconomic Perceptions

Understanding the socioeconomic perceptions of the residents of St. Martin Island is important since it helps to interpret the effect of coastal hazard threats on their seasonal migration. The

economy of the island is primarily marine-based, and most of the residents work as fishermen. However, both agriculture and tourism also play a significant role. The islander's postulate that coastal hazards, such as cyclones, storm surges, and floods, are a major threat to their livelihoods as they interrupt economic activity and create new vulnerabilities. Fishing is highly sensitive to the effect of coastal hazards, as it serves as a direct source of income for a substantial share of the population (*INTEGRATED COASTAL ZONE MANAGEMENT PLAN PROJECT Proceedings of for Sustainable Management of St. Martin's Island Government of the People's Republic of Bangladesh Ministry of Water Resources Water Resources Planning Organization (WARPO)*, 2005).

Table 2: Socio-Economic Aspect of Saint Martin Island

Socio-Economic Aspect	Details
Population	~8,000 (Seasonal population increase due to tourism)
Primary Economic Activities	Fishing, tourism, agriculture (limited), seaweed collection
Tourism Dependency	High; contributes significantly to the local economy
Fishing Industry	Subsistence and small-scale commercial fishing, local consumption
Agriculture	Limited due to soil salinity; mainly subsistence farming
Per Capita Income	Lower than national average; most residents live below poverty line
Education Level	Low; limited access to higher education; primary schools available
Health Facilities	Limited; reliant on basic health centers and periodic mobile clinics
Water Supply	Dependence on rainwater and groundwater; facing salinity intrusion
Infrastructure	Poor infrastructure, limited electricity, and inadequate roads
Sanitation	Limited access to proper sanitation; high risk of waterborne diseases
Migration Patterns	Seasonal migration for fishing and tourism-related jobs
Vulnerability to Climate Change	High; rising sea levels, erosion, and storms impact livelihood
Housing	Predominantly small, informal housing vulnerable to climate events
Gender Roles	Women involved in household work; some participate in seaweed collection and small trade

Source: (Islam & Shamsuddoha, 2018), (Bangladesh Bureau of Statistics, n.d.), (IUCN, 2015)

Cyclones and storm surges can obliterate the fish stocks and equipment and inundate the boats, causing high losses. The same effect is observed with pertains to agriculture, as when the fields are covered in water, the crops drown. The yield is significantly diminished, and food security is compromised. The third important source of income is tourism, which uses the beauty of the island and the coral reefs. The dirty water and ruined infrastructure create a repulsive effect, and the tourists stay away, leading to a plummet of local businesses. In order to deal with the hazards, the residents practice temporary migration to the mainland and come up with temporary alternative money-making opportunities when the effect of the economic hazards is high (Ortiz et al., 2023).

Permanent migration stabilizes their income and shields them from the monetary impact of environmental threats. The islanders also try to protect their belongings and buttress their houses, alongside investments in storage facilities. From the current observation, the islanders face significant constraints in their capacity to cope with and adapt to the effects of coastal hazards. The interview respondents voiced that they knew about the issues and that they mostly agreed that the island needs better infrastructure, early warning systems, and disaster response planning. The islanders predominantly cite the lack of revenue to enact these arrangements as a major problem. The islanders perceive that they can be more capable of dealing with hazards if the planning and adaptation planning are more participatory. The effect of the hazards is also constrained not only to the economic effect but also to the color of social dynamics and the decision to migrate. If the level of environmental stress and economic situation difficulty is prevalent for too long, older people are more likely to migrate (*Action Plan on Climate Change Adaptation and Resilience*, n.d.)

.

In comparison, in times like these, most younger people migrate as they see no alternatives. The demographic and social structure of the island can be altered permanently. Thus, the socioeconomic perceptions of St Martin Island residents are paramount since they help link their seasonal migration and coastal hazard threats.

3.6 Geomorphology

Saint Martin Island is a small coral island located in the Bay of Bengal (Siddique et al., 2022). It is interesting to describe how the geomorphology of the place affects the multiple ways different types of environmental stresses affect the unique island, its population, and its migration patterns. The geomorphology affects the areas and the land in general. The geomorphologic

features and the characteristics of the land infer the multiple ways and types of threats to the island. St. Martin Island's landform is "a relatively low elevated landform".

The island and the area are mostly consisting of sandy beaches and coral reefs. The beaches are mostly sand-covered areas, which are subject to frequent movement and change. The waves and tides move the sediments, and the tides deposit or erode the sand. The landform is mostly on the island's beaches (Short, 2012).

Table 3: Geographical Feature of Saint Martin Island, Bangladesh

All the other cases of coastlines of a landform, including the affected cases for the erosion and the displacement of the sand area covered, exist, and they are highly varied with the probable existence of abnormal geomorphology, which includes an abnormal landform. The coastal areas are always and certainly disastrous for the island's community. The geomorphology is a threat to the island as the increased sea temperature and the pollution are probably a hazard

Geomorphological Feature	Description	Source
Coral Reefs	The island hosts coral reef ecosystems, a unique feature in Bangladesh.	(Islam & Shamsuddoha, 2018)
Beach Ridges	Prominent beach ridges formed by sediment deposition over time.	(IUCN, 2015)
Sand Dunes	Sand dunes are present primarily on the southern part, formed due to wind deposition of beach sand.	(Bangladesh Bureau of Statistics [BBS], n.d.)
Tidal Flats	Extensive tidal flats are exposed during low tide, especially on the western side of the island.	(Islam & Shamsuddoha, 2018)
Rocky Outcrops	Rocky outcrops visible during low tides, particularly on the northern side of the island.	(IUCN, 2015)
Lagoon	A small lagoon influenced by tidal changes contributes to the island's hydrology.	(Islam & Shamsuddoha, 2018)
Barrier Islands	The island is classified as a barrier island, formed from coral and marine sediments.	(BBS, n.d.)
Mangrove Areas	Small mangrove patches are found on the southern part of the island.	(IUCN, 2015)
Coastal Erosion Zones	Areas of significant erosion, particularly on the eastern side due to wave action.	(BBS, n.d.)

and would potentially cause the bleaching of the coral. This would lead to the area's loss of defenses and will become highly active for the weather as all of the coral dying areas will leave

the surge and the big waves overtaking the island. Saint Martin Islands' geomorphology and the characteristics of the land, especially low land, are threatened by floods. The rising of waters, especially during cyclones and storms, will have an all-time high effect on the low land with the raising of waters, and the increased threat of water eroding and depositing the sediments would create a serious impact. The low land geomorphology threatens the coastal area's current developed and existing defenses and creates a new type of threat to the human.

Land; for the island, geomorphology depends on the morphological consequences. The geomorphologic areas of the sandy, coral, and tidal flats should be taken into consideration for land depletion. The morphological areas play a large part in the seasonal migration patterns and the geomorphology of the island (Choi, 2014).

3.7 Soil

The geological and soil characteristics of Saint Martin Island are important to consider since they help identify the influence of coastal hazards and threats on the island's environmental stability and, as a result, the seasonal migration of people to the island. The soil type of Saint Martin Island is associated with its geomorphology, including sandy beaches, coral reefs, and tidal flats. The prevalent soil type is sandy soil, because it stretches across the whole area, from beaches to areas alongside the coast. The sandy soil has a low water-retention capacity, high infiltration rate, and water drainage. It is characterized as a coarse type that is less fertile compared to other types of soil. During storms and heavy rain, the island may experience mass losses of the topsoil, accompanied by the erosion of soil and land desalination, which is, therefore, unfavorable for agriculture (Hossain, 2020).

Table 4: Types of Soil in Saint Martin Island, Bangladesh

Soil Type	Description	Source
Sandy Soil	Predominantly found along the coastal areas; it is porous and lacks nutrients.	(Hossain & Lin, 2001)
Loamy Soil	A mix of sand, silt, and clay, found in limited areas, supports some agriculture.	(Brammer, 2014)
Saline Soil	Affected by saltwater intrusion, primarily in low-lying areas.	(Rahman et al., 2019)
Coral-derived Soil	Derived from the island's coral reefs, coarse and well-draining.	(Chowdhury & Rasul, 2011)
Alluvial Soil	Found in tidal flats, rich in minerals but prone to salinity.	(Hossain & Lin, 2001)
Peaty Soil	Rich in organic matter, found near mangrove patches, but limited in extent.	(Rahman et al., 2019)

Apart from sandy soil, saline soil is present on the island, particularly in areas affected by tidal waves and the influence of seawater interaction. The southeast area is least fertile because of the high concentration of salt, which negatively affects plant normal development. High soil salinity is important to consider due to its influence on agriculture, decreased productivity, and land availability for agricultural crops.

Because of soil conditions and coastal hazards, the resources necessary for people's livelihoods become imbalanced; people try to adapt to the changes with the help of various coping strategies. The sample people of the island are likely to resort to coping strategies by adjusting their agricultural strategies to the new types of soil or developing new ways to make a living. Since not all of the above strategies are available, the choice of these strategies is likely to necessitate further help from the side of national or international organization (Hossain, 2020).

3.8 Hydrology

The freshwater resources of Saint Martin Island are rather rare and are primarily represented by rainwater, as well as a few small natural springs. Its low elevation and soils are prone to drainage, which makes it easy for water to flow, and the island cannot accumulate water in large amounts. This feature diminishes the availability of freshwater for residents to drink or use in agriculture. The issue becomes even more pronounced due to the post-cyclonic and rainy season when most water from the channel flushes through the island directly into the sea. With the shortage of freshwater and the presence of extreme tidal dynamics, the island is more prone to experiencing natural hazards, which provides stress. The stress factor may condition the quarters of the emerging migrant flow of seasonal workers – families of island residents follow their relatives due to worsened opportunities to access water. Therefore, with the indicated knowledge, one can claim that the island's freshwater and tidal dynamics seem inconvenient for those who experience migration and those of the isle who perceive this change (Musfirat N I Tahiti, 2018).

Hydrological Feature	Description	Source
Groundwater	Freshwater lens is limited, and groundwater is vulnerable to salinity intrusion.	(Hossain & Lin, 2001)
Tidal Influence	The island is heavily influenced by tides, with tidal flats exposed during low tides.	(Chowdhury & Rasul, 2011)
Rainwater Harvesting	Due to limited freshwater resources, rainwater harvesting is practiced for drinking water supply.	(Rahman et al., 2019)
Surface Water Bodies	Very few permanent surface water bodies due to the small size of the island; mostly seasonal ponds.	(Islam & Shamsuddoha, 2018)
Salinity Levels	Groundwater and coastal areas have high salinity levels, especially during the dry season.	(Rahman et al., 2019)
Coastal Erosion	Erosion affects the hydrological balance, especially with rising sea levels, altering water pathways.	(Brammer, 2014)
Mangrove Hydrology	Small mangrove patches rely on tidal inundation for maintaining their ecosystem.	(Chowdhury & Rasul, 2011)

Table 5: Hydrology of Saint Marti Island, Bangladesh

The tidal dynamics of the island, therefore, can be considered in connection with the interaction of tidal movements with the inlets and other bathymetric conditions. The feature influences the hydrology of the island and the motion of the sediments, as well as the two contrary processes of erosion and accretion, together with the flooding of the low areas. On occasions of high tide and the rise of storm surges, the sea starts flooding the island's coast, covering the low regions and flushing saline waters on the freshwater sources and fields (Hossen & Sultana, 2023).

3.9 Climate

The climate of Saint Martin Island's coastal hazard threats impacts the environment of Saint Martin Island, and the seasonable migration of the island's communities, so the environment of the location should be considered an essential category. Almost the entire island is related to the 'Am' tropical maritime climate in Zone division of climates, and it is known to embrace both wet and dry monsoons and be defined by high temperatures and high humidity. The general characteristics of the tropical maritime climate create the background for the factors of the island's vulnerability to coastal hazards, which are determined by daily life and migration specifics of the community that lives on the island.

The geographical location of Saint Martin Island in the Bay of Bengal defines the external factors that have an impact on the island's climate (Al Nahian et al., 2022). In particular, the high humidity and exposure of the island to the monsoon winds result from the fact that it is placed on the route of the main masses of southwestern and northeastern monsoons. The exposure of the monsoon winds that blow the island from the end of the spring to the middle of the autumn

defines the limitation of the temperature variational peculiarities in the island's climate regime to relatively high values. In the existing systems of climatic classification, the influence of the monsoon winds on the climate of the location is used as a substantial factor that creates severe climatic conditions in the particular region and as the subsequent responsible factor for the exposure of the island to high temperatures almost all year round with monthly maximum and mean temperatures staying on the level of 32°C and 25°C. The temperature regime defines the high humidity level of the island and the impact it makes on the quality of life of the island's residents (Bolan, 2024).

There are other reasons, such as immunity in December-May and June-November, as the difference can be considerable in the rainfall outcomes in terms of the two seasons and their potential damage. Monsoon season is a phenomenon rather characteristic of June to October, with its heavy rainfall resulting in an average annual precipitation of 2,000-3,000 mm still combined with relatively uncommon rainy days within this period (SACRISTÁN & MIGUEL AYANZ, 2016). On the one hand, expectations from the monsoon rains are related to the provision of fresh drinking water and the necessary outcomes for the island's agricultural process. On the other hand, there are considerable disadvantages to monsoon rains, such as the related degree of high flooding and waterlogging. The latter phenomena can result in soil and sand erosion, salinization of the soil, and damage to the infrastructure of the island in general. In addition, cyclone activity remains one of the most important distinctive climate factors that pose a threat to Saint Martin Island. The degree of proximity of the island to the equator, along with the general weather conditions on the island, exposes it to a high degree of risk, particularly tropical cyclones and their high wind speed, storm surge, and rainfall outcomes. The outcomes of cyclone activity are flooding, beach erosion, and damage to buildings and infrastructure. The degree of frequency and amplitude of cyclone outcomes depend on a variety of factors, such as whether the quality of the sea surface and the general atmospheric conditions play a considerable role. Finally, this seasonal difference and the limited immunity capacity of the island relate to the seasonable migration activity characteristic of Saint Martin Island. The dry season, the overall less precipitation, and the related high temperature make the island experience some water shortage and soil salinity. Therefore, while the periodical nature of the island is considerably reduced in the rainy season, there are habits for the community to migrate when the natural conditions disappear. Overall, the differences in Saint Martin Island and their seasonality relate to both the availability and condition of the resources found on the island. As such, these resources are causing the community a variety of problems that can be addressed with adaptation and seasonable migration activity (Abdullah et al., n.d.).

Table 6: Climate of Saint Marti Island, Bangladesh

Climate Factor	Details	Source
Average Temperature	Ranges from 20°C (68°F) in winter to 32°C (89.6°F) in summer.	(Hossain & Lin, 2001)

Monsoon Season	The monsoon lasts from June to September, bringing heavy rainfall and strong winds.	(Brammer, 2014)
Annual Rainfall	Approximately 2,500 mm, with most rain occurring during the monsoon season.	(Rahman et al., 2019)
Humidity	High year-round, ranging between 70-90%.	(Rahman et al., 2019)
Cyclones and Storms	The island is frequently affected by tropical cyclones during the pre- and post-monsoon periods.	(Chowdhury & Rasul, 2011)
Dry Season	Lasts from November to March, with low rainfall and mild temperatures.	(Islam & Shamsuddoha, 2018)
Wind Speed	Average wind speed ranges from 15-20 km/h, with stronger gusts during the monsoon and cyclone events.	(Rahman et al., 2019)

3.10 Agriculture

The agriculture of Saint Martin Island is one of the most important parts of the local economy and the direct cause of local people's lives. In fact, the agricultural conditions are due to natural conditions such as the climate of the particular region and the soil, as well as vulnerabilities to the most noticeable of the coastline hazards. First of all, Saint Martine is a subcontinental climatic island; in other words, it has two types of geographical locations on the rise of coastlines. As such, the prevailing type of island soil appearance is sandy soil, which is associated with the tendency to land drainage and a limited capacity to hold water and moisture. Therefore, the direct impact of the seasonal climate and the extreme climatic events and conditions prove to have an important and specific effects on Saint Martin Island (*Nationwide Climate Vulnerability Assessment in Bangladesh*, 2018).

The prime importance of agriculture in the life of the local people of Saint Martin Island directly impacts their demand to use this way of growing foods for fertility purposes. The most important types of farming for the island include the cultivation of rice and mixed cultivation of vegetables and fruit. The particular season that is the most influential on the cultivation of rice is the monsoon season because it provides the soil with the necessary water. The seasonal growth of vegetables and fruit is also dependent on the season and the climatic events. Overall, the island soil is unsafe from waterlogging at the same degree throughout the year, and therefore, it might erode, crops might be damaged, and productivity might be low. During the monsoon season, the saltwater collection is vulnerable on the land of the island, which leads to soil corrosion in crop fields. As a matter of fact, due to the high vulnerability of the soil to coastline hazards, the arable land on Saint Martin Island is being reduced. The raised level of soil salinity proves to be more difficult to farm. The direct influence of coastline hazards might lead to a tremendous reduction in the production and income of the local people due to cyclone events (Afjal Hossain et al., 2011).

Overall, the agriculture of Saint Martin Island might be defined as highly dependent and insecure to the coastline hazards. The reduced area of the arable soil and poor growth of the seasonal crops are the direct indicators of climate change and the high levels of salinity of the arable soils of the local people. I consider that the most appropriate in those circumstances in terms of the creation of the conditions of living and work and improvement farming is to use the abundant rainwater and implement the corresponding concepts and guidelines and secure water conservation and rainwater harvesting scheme constructions (Yeasmin et al., 2020).

Table 7: Agriculture Activity of Saint Marti Island, Bangladesh

Agricultural Activity	Description	Source
Coconut Farming	Coconut trees are widely cultivated, and coconuts are one of the primary crops of the island.	(Hossain & Lin, 2001)
Betel Leaf Farming	Betel leaf is a significant cash crop, typically grown in small plots by local farmers.	(Chowdhury & Rasul, 2011)
Limited Rice Cultivation	Rice is grown on a small scale due to saline soil conditions, with low yields compared to mainland areas.	(Rahman et al., 2019)
Vegetable Farming	Seasonal vegetables like eggplant, chili, and gourds are grown, but production is limited due to soil salinity.	(Hossain & Lin, 2001)
Seaweed Farming	Recently, seaweed cultivation has been introduced, offering an alternative livelihood for locals.	(Chowdhury & Rasul, 2011)
Date Palm Cultivation	Date palm trees are grown in some areas, primarily for local consumption.	(Rahman et al., 2019)

3.11 Fisheries

Fisheries are the leading part of the economy and population growth of Saint Martin Island The number of marine resources available in the Bay of Bengal, therefore, the island's fishing based on these resources, is systematically related to the principal economic trend of the islanders (Al Nahian et al., 2022). As such, it can benefit households by providing them with livable and profitable advantages. Meanwhile, there are numerous coastal hazard threats, which significantly reduce the productivity and sustainability of the island's fisheries sector. The hazards of the island fisheries, including its subspecies of fish, crustaceans, and mollusks, and major types, such as cyclones, storm surges, and flooding, and their effects will be discussed in the present concern.

There are a variety of resources that differ by the type of fish, crustaceans, and mollusks, which contribute to the island's economy and well-being. The available data prove that the island's fisheries consist of family fishing that is both small and large-scale. However, locates use rich

marine biodiversity, which is discovered across the habitat, available around the island and the local coastal desert. At the same time, other species are found in the crest from offshore to the coral reef and fishery ecosystems **(Shamsuddoha & Islam, n.d.)**. A profound insight into a mix of commercial, at the same time traditional and family fisheries, demonstrates the variety of types of hazards that have the potential to affect the island's population. In the present essay, attention will be given to the significant kinds of hazards, including cyclones, storm surges, and flooding, and their effects, including boat and equipment losses, environmental degradation, and damage.

The physical effects of cyclones and intense surges can be characterized by the loss of both boats and gear and damage to the fishing boats, sampan, and other types of craft and facilities. The loss of both types of equipment leads to fishers' income reduction and, simultaneously, harm exposure to both jobs and economic and poverty recovery due to the job closures and delayed replacements and repairs (Lakshman & Ojha, 2023). Flooding has the following factors: sedimentation, fish degradation of fish catches, cod degradation, and coral reef degradation. As such, the physical effects include pollution, which harms fish and human health, and surges and heavy rains, and lead to the algal bloom, existing coral degradation and the proliferation of new corals. Additionally, the fish species cannot live in Estuaries because of saltwater, instead of freshwater, reach. As far as the effects of climate change are concerned, I have decided to pay attention to seasonal monsoons and year-round fluctuations (Manou et al., 2017).

Table 8: List of fishes which is mainly found of Saint Martin Island, Bangladesh

Fish Family	Common Species	Scientific Name	Type (Pelagic/Demersal/Reef -associated)
Scombridae (Mackerel)	Indian Mackerel	*Rastrelliger kanagurta*	Pelagic
	King Mackerel	*Scomberomorus cavalla*	Pelagic
Carangidae (Trevally)	Giant Trevally	*Caranx ignobilis*	Pelagic
	Bigeye Trevally	*Caranx sexfasciatus*	Pelagic
Sphyraenidae (Barracuda)	Great Barracuda	*Sphyraena barracuda*	Pelagic
Exocoetidae (Flying Fish)	Fourwing Flying Fish	*Hirundichthys affinis*	Pelagic
Serranidae (Groupers)	Malabar Grouper	*Epinephelus malabaricus*	Demersal
	Brown-marbled Grouper	*Epinephelus fuscoguttatus*	Demersal
Lutjanidae (Snappers)	Red Snapper	*Lutjanus campechanus*	Demersal
	Mangrove Snapper	*Lutjanus argentimaculatus*	Demersal

Mullidae (Goatfish)	Indian Goatfish	*Parupeneus indicus*	Demersal
Haemulidae (Grunts)	Blue-striped Grunt	*Haemulon sciurus*	Demersal
Dasyatidae (Rays)	Blue-spotted Stingray	*Neotrygon kuhlii*	Demersal
Carcharhinidae (Sharks)	Blacktip Reef Shark	*Carcharhinus melanopterus*	Demersal
	Whitetip Reef Shark	*Triaenodon obesus*	Demersal
Scaridae (Parrotfish)	Bicolor Parrotfish	*Cetoscarus bicolor*	Reef-associated
Chaetodontidae (Butterflyfish)	Redfin Butterflyfish	*Chaetodon trifasciatus*	Reef-associated
Pomacanthidae (Angelfish)	Regal Angelfish	*Pygoplites diacanthus*	Reef-associated
Acanthuridae (Surgeonfish)	Convict Surgeonfish	*Acanthurus triostegus*	Reef-associated
Tetraodontidae (Pufferfish)	Black-spotted Puffer	*Arothron nigropunctatus*	Reef-associated
Scorpaenidae (Lionfish)	Red Lionfish	*Pterois volitans*	Reef-associated
Syngnathidae (Seahorses)	Common Seahorse	*Hippocampus kuda*	Reef-associated

Source: (Islam & Shamsuddoha, 2018; IUCN, 2015)

3.12 Tourism

Tourism is one of the primary economic sectors for Saint Martin Island, and it generates significant of the territory's income for residents. The island's outstanding natural beauty in the form of untouched beaches, coral reefs, and the variety of marine life they contain serves as its key attractions for both the locals and overseas (Sheikh & Alam, 2018). However, the revealed high vulnerability of these invaluable assets to diverse coastal hazards may constantly reduce the overall interest in island-based travel. Therefore, it would not be an exaggeration to note that the dominative role of the island's premier nature-related advantages in its tourism sector seems rather evident. First of all, the coral reefs historically serve as the number one destination for both certified diving enthusiasts and newcomers, as there is no other site in the world that would offer the same extent of marine flora and fauna and remain the most exquisite underwater location (National Oceanic and Atmospheric Administration, 2019). Secondly, the local climate and the profusion of sandy beaches and crystal-clear waters considerably facilitate the opportunities for peaceful relaxation and other seaside-based activities. Finally, some may consider ecotourism to be slightly too advanced in case of minimal consequences, as various alternating measures appear to be taken to aid the reduction of the sector's environmental footprint (Afroz & Mahmud, 2017).

Table 9: Tourism Activities on Saint Martin Island

Tourism Activity	Description	Source
Beach Tourism	Saint Martin Island's beaches attract both local and international tourists, with pristine sandy shores.	(Islam & Shamsuddoha, 2018)
Coral Reef Snorkeling	The coral reefs around the island are a major attraction for snorkeling enthusiasts.	(IUCN, 2015)
Boat Tours and Island Hopping	Tourists enjoy boat trips and island-hopping experiences around the island and nearby smaller islands.	(Bangladesh Bureau of Statistics [BBS], n.d.)
Fishing Tours	Recreational fishing trips are arranged for tourists, often combined with traditional fishing experiences.	(IUCN, 2015)
Seafood Restaurants	Local seafood, including fresh fish, crabs, and lobsters, is a major draw for culinary tourists.	(Islam & Shamsuddoha, 2018)
Camping	Beach camping is a popular activity for eco-tourists who want a more natural experience.	(Bangladesh Bureau of Statistics [BBS], n.d.)
Eco-Tourism	Efforts to promote sustainable tourism focus on educating tourists about conserving the island's fragile ecosystem.	(IUCN, 2015)
Scuba Diving	Although less common, there are opportunities for scuba diving in the clear waters surrounding the island.	(IUCN, 2015)

Table 3.9: Tourism Activities on Saint Martin Island

The first type of hazard is cyclones. Firstly, they can spoil the existing hotels and resort complexes, and the tourism sector will have to spend its money on their restoration. However, if the whole infrastructure is demolished, the island will be unable to keep its reputation as an effective tourist place, and the power of restore soar reopening the hotels is under a big threat. Secondly, the hazardous storm surges can threaten the existence of the coral reefs, as the waves of high energy will bring the extra masses of sand to the island, and the reefs will be bleached. Moreover, like the coral reefs, sandy beaches are taken away by the ocean pads, and the requirement to deliver constant coast stability is the second factor to be recognized by the tourism sector of Saint Martin Island (Coral Reef Alliance, 2021). Thirdly, floods caused by rains are also able to ruin the profit of the tourism sector on the island, as they trigger a diverse leak of the pipes, and, thus, spoil the living conditions in the hotels, causing the danger of lethal hazard for the tourists' health. The overall impression of the disaster storm forms this island's impression to be totally outstandingly unpopular (Araújo Vila et al., 2019).

The tourism sector in Saint Martin Island has several adaptation measures:

1. It introduces the new standards for building. If the hotel is destroyed, it has to be built anew, but with better parameters that will provide improved resistance to the same hazard threats.
2. An automatic warning system is also maintained, which makes it possible to evacuate people from the territory. It has to be admitted that the evacuation of the population is relatively efficient, which is critical to the sector.
3. The industry adheres to sustainable tourism, recommending the careful selection of the venue and looking very closely at its environmental record before deciding to visit it.
4. The sector uses policies and technologies for the management of disaster risk. Nevertheless, the ecological effects have a scale which makes protecting the island impossible, and the latter could only be left to the immediate response.
5. To make this adaptation process more efficient in general, it is vital to invest in disaster-resistant infrastructure and the stabilization of the coast to make sure that the economy is provided with stable conditions (Yeasmin et al., 2020).

To sum up, the tourism sector is threatened by coastal hazards in Saint Martin Island. The sector is vitally important to the country's economy because it specializes in the territory's unique assets and its association's attractiveness to travel. That is why understanding coastal hazards and proficient adaptation are critical to the sector's economic viability.

3.12 Conclusion

In this work, the environmental hazard threats and impacts on seasonal migration patterns of coastal hazard threats will be analyzed, referring to Saint Martin Island, Bangladesh. In particular, the environmental hazards combined with human behavior aspects determine the necessity of a combination of adaptation strategies that are able either to prevent the negative effects of the dangers on Saint Martin Island or to make the island more integrated, resilient, and sustainable. It is possible to realize that the unique geographic and climate conditions of Saint Martin Island create premises for coastal hazard threats of all types, which include cyclones and other frequent hazardous events like storm surges or flooding (Adams & Kay, 2019).

However, it is possible also to state that these coastal hazard threats actually influence the island and the communities living in its area. Thus, the geomorphology of the island, the sandy soils, low elevation, and frequent hazardous events of different capacity functioning are contributing factors to the island's exposure to coastal hazards. Such influences and impacts varieties do not only determine the living conditions of the residents of Saint Martin Island but also their migration and adaptation patterns. In particular, the effects of the hazardous events are quite diverse. Thus, agriculture occupants are frequently affected by soil erosion and salinization (Cambers, 2001).

Note that the development of fisheries is associated with both the destruction of marine habitats and human-made infrastructure. Migration pathways of islands' inhabitants tend to regard the ways representatives of the island's population travel to other areas. Generally, such migration flows occur due to challenging environmental conditions and seasonal unrest. The hydrology and climate of the islands also cause problems. Seasonal increase in rainfall contradicts the insufficiency of water supplies throughout the rest of the seasons. Human migration with lower and upper-temperature extremes is expressed through cyclones and droughts, which occur throughout the summer and winter, respectively. In addition, the tourism industry assisted the seasonal migration of people and caused problems for island development. Saint Martin Island is extremely poor, and tourism is increasing income for the Indonesian region. However, the negative consequences of tourism are the increased levels of export of corals and exploitation of the island's beach and sand, which constitute a serious concern as tourism becomes the cause of several coastal hazard threats, such as cyclones or storm surges (The daily star, 2023).

To develop a strategy, it is necessary to reveal interactions between a problem, sub-problems, causes of a problem, and effects of coastal hazard threats. The problem's cause is the frequency and force of tropical cyclones, which originate in the Gulf of Bengal. The geomorphology of the island further impacts the situation as it has sandy soils and the character of soils, such as its olamines and low elevation. Thus, the causes of the issue are tropical cyclones and the geomorphology of the island, and the cause of the sub-dilemma is the degradation of agriculture and fisheries. The sub-dilemmas promote the causes of migration patterns of people that can be characterized by seasonally occurring unrest on the island. They also affect the island's tourism, which has seasonally varying incomes depending on the peculiarities of the seasonality of migration. Thus, the two causes define the migration patterns and the seasonality of unrest and tourism seasonality. Adaptation strategies developed in the context of the cause enumeration can help people and the island avoid the negative effects of the coastal hazard threats. The causes help to find out that adaptation of the agriculture and fisheries activities is urgent, especially in the eradication of undeveloped sustainability of these sectors. The local government and NGOs will undertake the activities that will eventually ensure that people are ready for adaptation and can cope with the consequences of those coastal threat hazards (*National Plan for Disaster Management Government of the People's Republic of Bangladesh National Plan for Disaster Management 2010-2015 Disaster Management Bureau Disaster Management & Relief Division*, 2010).

Chapter 4:

Sources of Data Collection and Methodology

Introduction:

The study which I consider under the title "Modeling on the Effects of Coastal Hazard Threats on the Seasonal Migration Patterns of Coastal Communities on Saint Martin Island," is quite complex and needs a solid methodology covering a list of variables concerning the ways the environmental stressors are interacting with human reactions (Islam et al., 2012; Karim & Mimura, 2008). To my mind, the coastal area of Saint Martin Island in Bangladesh is a peculiar case, ecologically and socio-economically affected by a number of coastal hazards (Ahmed et al., 2021; Brammer, 2014).

On the one hand, these hazards are destroying the natural resources of the island, and on the other, they have forced reconsider the coastal communities' way of living and their migration practices. Thus, the methodology is based on a mix of quantitative and qualitative data. As for the data source, the methodology contains primary data collected on the island itself during a number of field surveys and interviews with the locals, the use of remote sensing to get a more

distant look at the ways of the island, and the analysis of available secondary sources on the topic exemplified with the literature and the experts of the island reports and such.

The data collection and the sources differ for the sake of balancing the actual picture of what is happening with the scale of coastal hazards; this combined approach is also applied to balance the socioeconomic drivers of the migration patterns (Murshed et al., 2022). Still, the methodology of the study uses a mix of several research techniques, including the use of a Geographic Information System for the spatial needs of the study, the Central Place Theory for the model of population distribution on the island and the statistical modelling approach to differ the relative trends and correlation; the methodology also includes a qualitative discourse analysis to deliver the evidence basing on the experience of the locals. Thus, the study uses a mix of several tools, which is usually used for a mixed method (Islam et al., 2012). At the same time, it aims to examine the pattern of seasonal migration and the perception of islanders for the sake of adopting effective adaptation and mitigation strategies.

Simple size calculation

We may calculate the sample size for the population of Saint Martin Island using the formula generally used for finite populations:
Estimation of Sample Size
Proceed to calculate for a population that is unlimited.
Determine the sample size for an infinite population by applying the following formula:
Let n_0 be defined as \fracZ^2^times p^times (1 - p). Square of the vector E

Location:

• Z denotes the Z-value with a confidence level of 95%, assigned a value of 1.96.
The population percentage, denoted as P, is often established at 0.5 in order to attain the highest

level of variability.
E represents the error margin, measured at 0.05 on a 5% scale.

Computational estimation of values:

Let n_0 be defined as the equation \frac {(1.96) ^2 \times 0.5 \times (1 - 0.5)} (0.05) ^2
When the square root of 3.8416 is multiplied by 0.25A, the resulting value is 384.16.
N_0 is around 384.
Consider the constraints of finite population size
In order to accommodate the limited population size (N) of 8,000, we utilize the adjusted formula:
The equation for n is given by \frac{n_0} {1 + \left (\frac {n_0 - 1} {N}\right)}.
By substituting the numerical values:
may be calculated using the formula \frac {384} {1 + \left (\frac {384 - 1} {8000} \right)}.
The quotient of the equation n = \frac {384} {1 + \left (\frac {383} {8000} \right)} has a value of around 366.65.
Therefore, the observed sample size n is around 367.

The study's sample size is 367 observations. Given a 5% margin of error and a 95% confidence level, the sample size of **370** individuals is considered a sufficient representation of the population of Saint Martin Island.

4.1 To investigate the types of coastal hazard threats and its impact of seasonal migration pattern on Saint Martin Island.

4.1.1 Changes of shoreline over the time:

Shoreline residence time is fundamental to assessing the impact of coastal hazards and the effectiveness of coastal protection. This chapter will focus on describing the data and methodology used to analyze shoreline changes over time using the Digital Shoreline Analysis System and available Landsat images.

4.1.1.1 Data Collection

1. Remote sensing data

Landsat images:

Table 10: Specification of Landsat images used with DSAS

Details of Landsat Images Used in DSAS				
Landsat				ection
Lands...	30 meters	1/31/1992	Winter	3/3/2024
Landsat 7	15 meters (panchromatic) / 30 meters (multispectral)	1/21/2003	Winter	3/5/2024

Above shows the specific Landsat imagery that was used with DSAS for the analysis of shoreline changes. Specifically, the table shows the year that the images were taken, the resolution and the type of instruments used to take the images. Temporal coverage of the available data: For taking the images that were taken in the individual year, the analysis of changes to Salem's shoreline implies taking a long time. Therefore, the use of images taken over various years informs the analysis of this work on long-term tendencies and seasonal variations in shoreline migration.

2. GIS data

Topographic and coastal zone data:

Topographic maps and shore zone data: Together with Landsat imagery, these data increased the accuracy and analysis of the cliffs and coastline.

3. Field validation of remote sensing data

Land surveys were used to take points of the detected position of the ear line. Using the article to define the position of the eye will help obtain accurate data. The accuracy of the data on the location of the eyes can be trusted.

4.1.1.2 Methodology

Shore extraction

Shoreline change is critical to determining the impact of the coast hazard and possible reduction strategies. In this chapter, we will discuss the data and methods used in this study.

DSAS extraction tool

The position of the shoreline is transmitted using the tool since it can implement coast frontage vectorizing, which is helpful in pumping out the position of the shoreline. Besides, the transect fixed towards the Land-water junction and across to the dune, which is used to measure the rate of change, will be labelled as DSD in order to measure the position of the shore. Image is available, thereby a good number of positions could be improved. In any case, the color was brightened, and the designed image of edge Development was thus applied to detecting the position of the shoreline.

In the context of shoreline change analysis using the Digital Shoreline Analysis System (DSAS), the terms "offshore," "onshore," and "uncertainty" are crucial for understanding how shorelines are measured, analyzed, and interpreted. Here's a breakdown of these concepts:

- **Offshore and Onshore:**

Offshore:

- **Definition:** In DSAS, "offshore" refers to the seaward side of the shoreline, typically extending into the ocean or sea. It includes areas beyond the waterline where the land meets the ocean.
- **Shoreline Movement:** When a shoreline retreats due to erosion, the change is described as a movement toward the "offshore" direction. Essentially, this indicates that land is being lost to the sea.
- **Significance in DSAS:** Tracking offshore movement is critical for understanding erosion patterns. This movement can be influenced by natural factors like sea-level rise, storm surges, and human activities such as dredging or construction of coastal infrastructure.

Onshore:

- **Definition:** "Onshore" refers to the landward side of the shoreline, including areas that are on the land side of the waterline.
- **Shoreline Movement:** When a shoreline advances or builds up, the change is described as a movement toward the "onshore" direction. This generally means land is being gained, either naturally through sediment deposition or artificially through activities like beach nourishment.
- **Significance in DSAS:** Onshore movement is indicative of accretion, where sand or other materials are added to the coastline, expanding the land area. This can result from processes like longshore drift, where sediments are transported along the coast by wave action.

Uncertainty:

Table 11: Calculation of Uncertainty

Scene ID	Time (GMT+6:30)	Acquired Date/Time	Satellite	Sensor	Error	Spatial Resolution	Pixel Error	Mean tide Level (m) (Tid)	Tide Condition	Rectification Error (Er)	Digitization Error	Uncertainty
		01/12/1992 01/12/1992	Landsat 5		0	30	0	7.045	Slack Rising/NA	0	15	30.82067833
		01/12/2003 01/12/2003	Landsat 7		0	30	0	7.077	Slack Rising/NA	0	15	30.82340149
		01/12/2014 01/12/2014	Landsat 8		0	30	0	7.252	Slack Rising/NA	0	15	30.83605113
		01/31/2024 01/31/2024	Landsat 9		0	30	0	7.39	Slack Rising/NA	0	15	30.84675717

Positional Error (m)	1992	2003	2014	2024	Remarks
Seasonal error (Es)	NA	NA	NA	NA	season
Tidal fluctuation (Et)	7.045	7.077	7.252	7.39	As per Tidal Data
Shoreline survey offset (Es)	NA	NA	NA	NA	
Measurement errors (m)	0	0	0	0	
Geo-referecing/Rectification error (Er)	0	0	0	0	All data are orthorectified
Digitizing error (Ec)	15	15	15	15	As per spatial Resolution
Topo Sheet survey offset (Et)	NA	NA	NA	NA	Na
Pixel Error (Ep)	0	0	0	0	spatial resolution
Total Shoreline position error (Eqn) m	22.07	22.08	22.00	22	

Year	1992-2003	2003-2014	2014-2024	1992-2024
Uncertainity	0.60	0.60	0.66	0.293387409

Definition:

Uncertainty in DSAS refers to the potential error or inaccuracy in the measurement of the shoreline position. This can arise from various factors, including the resolution of the satellite imagery, the method of shoreline delineation, and environmental conditions at the time of image capture.

Components of Uncertainty:

- **Image Resolution:** The spatial resolution of the satellite images affects how precisely the shoreline can be identified. Lower resolution may lead to greater uncertainty as the shoreline becomes more difficult to define accurately.
- **Temporal Variation:** Shoreline position can vary depending on the tide, weather conditions, and seasonal factors. If images are taken during different conditions, this could introduce variability or uncertainty in shoreline positions.
- **Delineation Method:** The method used to define the shoreline, such as the high-water line, low water line, or a vegetation line, can also contribute to uncertainty. Different methods might yield slightly different shoreline positions.

Quantifying Uncertainty:

- **Buffer Analysis:** One way to quantify uncertainty in DSAS is by creating a buffer zone around the identified shoreline position. This buffer represents the potential range within which the true shoreline might lie, considering the sources of error.
- **Confidence Intervals:** Uncertainty can also be expressed using confidence intervals, which provide a statistical range where the actual shoreline is expected to be located with a certain probability (e.g., 95% confidence interval).

o **Predictive Modeling**:

What has been noticed about the beach changes will be used to generate some scenarios that can be used for direct evaluation and determination of the future behaviors and positions of the shoreline. Retrospective variables will be included, i.e., is there any eustatic change or upriver build-up of sand, and was it ever solved by storm, human action, or offshore limit.

4.1.2 Identifying Cyclones and Storm Surges Using NOAA Data

4.1.2.1 Data Collection

NOAA data is taken to identify the cyclones and storm surges. The NOAA provides real-time and past historical data on tropical cyclones and storm surge occurrences all over the world. For cyclones, the following parameters are taken from NHC and JTWC;
Storm Tracks – the latitudes and longitudes of the location where the storm surge is passing.
Wind speeds – the maximum speed of the wind at around the eye of the Storm at any time.
Pressure – the central pressure of the Storm, which gives the intensity of the Storm.
Category—From the above, the type of the cyclone is identified as TS, 1, 2, 3, 4, or 5.
Time and date since.

For Storm surge, the following parameters are taken from CO-OPS and Storm Surge Database;
We recorded water levels in decimeters at each coast where the Storm was passing.
The heights of the surge from the lowest astronomical tide level.
The duration of the cyclone is equivalent to the duration of the storm surge.
The affected places or the range of the places will be the coastal places.

Table 12: Extraction of Cyclone and Strom Surge

Location: 20.628479, 92.32280
Categories: H5, H4, H3, H2, H1
Months: ALL
Years: (1991-2022)
Niño Southern Oscillation (ENSO): ALL
Minimum Pressure (mb) below: 1030
Buffer Distance: 200 Nautical Miles

4.1.2.2 Methodology

The process of the data collection and the analysis of the cyclones and the storm surges is given below,

- **Data Extraction:**

The historical data, which are related to cyclones and storm surges, are taken from NOAA. The filtered data, which are related to the area of study and the study institution-related data, are taken to identify the cyclones and storm surges.

Identifying cyclones from historical data

The extracted storm track data consists of the latitudes and longitudes of the storm's position. Storms are plotted on the map. From the plot, the areas of the storm's Storm' verse Storm versed, the pathways of the storm surge, the pattern of all the storms in Storm world, the area of devastation by the cyclones, and the area of the cyclones' landfall can be identified.

- **Intensity Analysis**

Wind speed and pressure data are used to categorize cyclones by their intensity, which helps us understand each cyclone's accompanying potential.

- **Storm Surge Identification**

Water Level Comparison Storm surges' temporal assessment is done to find the difference between the observed water levels and the tide's prediction. The time when there is an abnormal

explosion of water level causes storm Storm spatial analysis Storm surges' spatial assessment is presented in the form of maps. In other words, the affected coastlines are picturized based on which area is most affected by storm surges; height-wise, that is how the height of the storm surges. Temporal analysis The time period of cyclones occurring and regressing and the equivalent storm surges are identified. Storm surges might possess the same period as cyclones.

- **Validation**

The identified events are validated with different reports from the surroundings, other sources from meteorological departments, and various archive sources.

- **Visualization**

This is done with GIS and various plots, graphs, and maps. Storm track maps, storm surge height plots, and location-affected maps are visualized. Cyclones of every season are visualized, and storm surge heights and locations are plotted in a graph. In this way, data can be validated and visualized to produce effective results.

This study can be said to be quite effective and efficient. It uses the NOAA datasets and complete analytical methodology to identify cyclones and storm surges. This is important since it ensures the preservation of the lives and property of those who live in these areas or regions.

4.1.3 Identifying Probable Sea Level Rise Using DEM Data from Google Earth Pro and ArcGIS

4.1.3.1 Data Collection:

Digital Elevation Model (DEM) Data:

- Source: The DEM data was collected using Google Earth Pro, which offers reliable elevation data for geographic analysis.
- Extraction Process: The DEM data was extracted specifically for the coastal regions of the study area, ensuring that the focus was on zones most vulnerable to sea-level rise.
- Resolution: The data provided by Google Earth Pro was verified for sufficient resolution to accurately model elevation differences in the study area.

4.1.3.2 Methodology:

The steps to model probable sea-level rise and its potential impacts involved the following key processes using ArcGIS:

DEM Data Processing:

- Data Import: The DEM data obtained from Google Earth Pro was imported into ArcGIS for spatial analysis and visualization.
- Elevation Classification: In ArcGIS, the DEM data was categorized into elevation bands representing 0.5 meters, 1.5 meters, and 2.5 meters above mean sea level. These categories were chosen to represent varying degrees of probable sea-level rise scenarios.

Modeling Sea Level Rise Scenarios:

- Inundation Simulation: For each sea-level rise scenario (0.5m, 1.5m, and 2.5m), ArcGIS tools were used to simulate the extent of land area that could potentially be inundated. This simulation allowed for the identification of low-lying areas at risk of flooding under these conditions.
- Map Creation: ArcGIS was utilized to generate maps that depict the areas that would be affected under each of the probable sea-level rise scenarios. These maps visually represent the potential future shoreline and the regions at risk.

Analysis and Interpretation:

- Impact Assessment: The maps produced were analyzed to assess the potential impact on infrastructure, communities, and natural resources in the identified at-risk areas.
- Decision Support: The results of this analysis were compiled into a format suitable for use by policymakers, urban planners, and emergency management officials, providing a clear understanding of the potential risks associated with sea-level rise.

4.1.4 The intrusion of saline water

4.1.4.1 Data Collection

Google Earth Pro:

- Satellite Images: Use the satellite images which are available in the Google Earth Pro to determine the areas where the island is being intruded by the saline water.
- Yellow Arrow Area: Focus on the area where the yellow arrow in the image has pointed. This is the area where the saline water is intruding to the island.

- Historical Imagery: Use the timeline available in the Google Earth Pro to determine the satellite images of the years before. This will also help you to determine how the intrusion of the saline water to the island has changed over the years.

4.6.2 Methodology

- **Visual Inspection**

Identify Saline Water: Look at the water and the lands surrounding the yellow arrow. If you observe that the water is getting darker, or spends more time to be wet surrounding the yellow arrow, or no trees around the arrow; you can assume that this area is being intruded by the saline water.

- **Mark the place**

Use the "Placemark" in the Pro to mark the place.

- **Data Extraction**

Elevation and Distance: Use the "Ruler" in the Google Earth Pro to determine the distance between the shore and the tipped area at which the saline water is intruding. Try to measure the elevation if possible.

Flooding Extent: Use the polygon tool to mark the area of the saline water intrusion. Try to measure it by drawing a polygon of the are

- **Determination**

Seasonal Variations: The main issue with the imagery would be to compare the images of the different years whether any changes have been made depending on the season.

- **Trend**

Use the old images to determine whether the intrusion of the saline water is becoming more with the years.

This simple method is a very rudimentary one, but can provide a practical way in which the saline water intrusion to the Saint Martin's Island can be attended to and observed with the help of only Google Earth Pro.

4.2 To assess the vulnerability of the local communities due to coastal hazard threats.

4.2.1 Understanding Extreme weather phenomena on Saint Martin Island

4.2.1.1 Data Collection

NASA POWER Data:

- Source: The data for this analysis was sourced from the NASA Prediction Of Worldwide Energy Resources POWER project, which provides reliable long-term meteorological data.
- Locations: I have collected data from four key locations near Saint Martin Island: Chattogram, Saint Martin Island itself, Teknaf, and Cox's Bazar. These locations provide the best information for my studies to determine which other parts may be affected by the weather and need availability.
- Parameters:
  - Humidity: This will be to find the moisture that can be affected either by sensory comfort or by crop growth.
  - Precipitation: This will be used to estimate the simple amount of rain that might impact the drinking source and irrigation. It also impacts soil erosion.
  - Wind speed: This will be used to analyze the need for wind speeds or the nearness of the seaside. Wind speed may drive storms and can erode soil.
  - Temperature: To do my part in the evaluation, I will use the temperature data I will find from the three areas to find the heat or cold stress.

4.2.1.2 Methodology

The methodology of data analysis involves the process I used during my analysis of the collected data to determine how the absence of the basic may have been influenced by the environmental conditions on Saint Martin Island.

- Data Import and Cleaning: I imported the data from my reliable source into analysis software like GIS platform or Excel or GIS platform like QGIS. To estimate the consistency of the data, I dropped some values and anomalous points from it.

- Temporal and Spatial Analysis: I have analyzed my data over time and space from the four locations. The analysis estimated the changes and trends of humidity, wind, or temperature. Temporal analysis estimated the attributes, for example, the dry or wet seasons.

4.2.2 Data Analysis on Absences of Basic Needs of Saint Martin Island

4.2.2.1 Data Collection:

- BBS—Demographic data: The primary source for the data analysis and information was obtained from the Bangladesh Bureau of Statistics. The BBS provides comprehensive data and information on the demographics of the population and the distribution of the population based on age census on a male-female basis.

- BBS—Education data: The BBS data was also required to understand the age distribution and status of schooling on Saint Martin Island on a male-female basis.
- Methodology: The methodology was mainly concentrated on analyzing the demographic structure and availability of education facilities on Saint Martin Island to assess the extent of basic needs, particularly in education.

4.2.2.2 Methodology:

- Data Import and Cleaning: The BBS data for demographics and education was imported into analytical software such as Excel or statistical software such as SPSS. Data cleaning was performed to get the required data.

- Data construction of age pyramid: Using the BBS data on the population of Saint Martin Island, the population was divided into age groups such as 0-4, 5-9, and so on. The distribution of the total number of males and females in the age groups produces the age pyramid of the total population of Saint Martin Island.

- **Age-wise schooling rates:** The schooling rate was calculated for each age category group. The schooling rate calculation involved identifying the percentage number of individuals who attend schools in the given age group. In addition, the percentage total number of males and females who attend school in the given age group was undertaken.

4.2.3 Understanding the Socioeconomic Vulnerability of Saint Martin

4.2.3.1 Data Collection

Questionnaire Survey
Purpose: The survey intended to collect detailed information on the socioeconomic status, agricultural practices, hazards, income sources, and occupational patterns of the people residing in Saint Martin.

Design: A structured questionnaire was developed to obtain basic information required for analyzing the residents' livelihoods. The survey covered issues related to household demography, crop production, sources of income, situation of occupation, hazard risks, and exposure patterns.

4.2.3.2 Methodology

The methodology was designed to analyze the given population in various aspects, focusing on agricultural practices, risks of hazards, income levels, and ways of occupation.
Data Processing
Survey Data Entry and Cleaning: The data was entered into the Excel sheet or statistics software like SPSS. The data was then cleaned by removing the inconsistencies and errors while entering the data. The missing values were also imputed with some approaches based on the frequency consideration.

- **Crop Calendar Analysis:**

Data collection: The survey respondents stated the types of crops and varieties they cultivated. They also reported the beginning and ending seasons of each crop's cultivation. They further stated when a particular operation was required to be done in a year.
The information provided by the respondents was transformed into a crop calendar. The calendar displayed the months in which various crops were present in the field or were in the operations on a large scale. The calendar, in fact, gave information on how agriculture-dependent this population was. This also showed when the income was likely to be spent on the different operations or the time when hazards were going to be faced by the crops.

- **Hazard Calendar Analysis:**

Data Collection: The survey entailed inquiring about the various natural hazards, including cyclones, floods, and droughts, and their timing. The respondents were required to recall the specific hazard events that took place.
Analysis: The timing and frequency of the natural hazards were integrated into a hazard calendar of Saint Martin Island. This was instrumental in understanding when the population was frequently exposed to the hazards and their impact on the people's livelihoods. The hazard calendar helped determine the period during which the population was more susceptible.

- **Income Calendar and Occupational Analysis:**

The survey also obtained information about households' sources of income, income realization periods, and occupation types practiced by the population.

Income Calendar Construction: Similarly, the input obtained on income was incorporated into the income calendar. The income calendar displays the flow of income throughout the year, demonstrating when the income is scarce or plenty. This was instrumental in guiding the determination of the eco-cycles and the influence of various activities. Occupational Analysis: The data on the type of occupations that the respondents were involved in were adjusted. This was instrumental in determining the extent of diversity of the people's livelihoods on Jayapura Island. The occupations were further grouped, and the extent to which the respondents in each group relied on the particular occupation.

- **Vulnerability Assessment:**

Integration of Calendars: In making an overall reassessment of the population's vulnerability, the crop calendar, hazard calendar, and income calendar were incorporated. The relation of time or the unplanned alignment of the timing of the crop calendar, hazard events, and the income calendar was curtailed to obtain when the population is most vulnerable. Socioeconomic Indicators: The overall vulnerability of the Saint Martin Island population was assessed based on various socioeconomic indicators. The assessment entailed determining the island's population, whose livelihoods are more susceptible.

4.2.4 Understanding the Decay of Land Area on Saint Martin Island

4.2.4.1 Data Collection

Landsat Imagery:

- Source: The satellite imagery data has been taken from the Landsat program. The Landsat program has provided high-resolution images of the earth's surface since the 1970s. It has been critical to the analysis of change in the land area for several decades.
- Time Frames: The data consists of multiple Landsat images of Saint Martin Island from different years. They help in observing and quantifying the change in the island's land area. The time frames consist of images from several decades ago and adjacent photos to get a precise view of the land decay.
- Data Acquisition: The Landsat data has been acquired from reputable sources. Rest, Earth Explorer or similar satellite data sites.

4.10.2 Methodology:

The methodology aims to analyze and assess the decay of the land area of Saint Martin Island. Since the change has happened over time, the methods involved analyzing the change over time and predicting the future change through satellite data and prediction methods.

- Purpose:

DSA, or Digital shoreline analysis, is a prominent tool in determining a change in the shoreline through a baseline and transects. Statistical analysis of the shoreline change is performed and effectively represented. The visualization of the change determines the pattern of the erosion and deposition of the shoreline.

- Shoreline Extraction:

The first phase involved extracting the shoreline from the Landsat images, which were the basis for calculating the rates and representing the change in the coastlines. It involved storing the images in the tool and effectively extracting the shorelines between the periods. The shorelines were also fed to the DSAS tool to represent and calculate the rate of change.

- Shoreline Change Analysis:

The DSAS was provided to calculate the rate of change of the Isle of Saint Martin. It involved the addition of the baselines and the transects parallel to the coast. The points on the coast with each period are considered against one, and it is the rate of their movement. The movement of the points is the rate at which the transect forms on the baseline. The projected data from the previous paragraph could be considered the exact rate at which Saint Martin Island's coast has been manipulated over the years. Thus, the points are either moving inland or receding into the sea due to the buildup of construction debris.

- Projection to 2034 and 2044:

The amount of coastland manipulated has been modelled over the years to determine the rate and projected onto the years 2034 and 2044. The rate of change is prolonged many times for developing scenarios and assuming future shorelines through normal linear regression models or other statistical approaches. The scenarios assume abrupt changes, including sudden erosion of the coast leading to additional changes, and reclamation is one of the major geotechnical works. The scenario analysis and linear regression models themselves have projected at least two outcomes, a maximum of at least up to which the values could grow. The addition of the change around the island has significantly manipulated for reaching the outcomes.

- Map Production: The availability of predictive maps in the GIS tools provides a solid image of the prediction of land loss. The coastlines for 2034 and 2044 are clearly demarked in the published map. Maps are critical in determining and publishing the loss of lands predicted in the Isle of Saint Martin.

4.3 To proposes a mitigation strategies model in response to seasonal migration due to coastal hazard threats.

4.3.1 Modeling on the Effects of Coastal Hazard Threats to the Seasonal Migration Patterns of Coastal Communities in Saint Martin Island Using the DPSIR Framework

4.3.1.1 Dynamic Interaction among DPSIR Framework Components

Table 13: DPSIR Framework Modified from (EEA, 1995, 2020)

Components	Linkage	Components	Overview
Driving Forces	Generate	Pressure	The underlying driving forces, such as human activities or socioeconomic factors, lead to the emergence of pressures on the environment.
Pressure	Causes	State	The pressures exerted on the environment result in changes in the state of the ecosystem or environmental conditions.
State	Affects	Impact	The changes in the state of the environment have direct impacts on various aspects of society, economy, and ecosystem services.
Impact	Interacts	Response	The impacts of environmental changes require responses or actions to mitigate or adapt to the effects.
Response	Feedback	Impact	The response measures implemented can have feedback effects on the impacts.
Response	Improves	State	The response measures aim to improve the state of the environment by addressing the underlying pressures and promoting sustainable practices.
Response	Release	Pressure	The response measures also aim to alleviate the pressures on the environment by implementing measures to reduce pollution, regulate resource use, or promote sustainable development practices.
Response	Coordinates	Driving Forces	The response measures are designed to coordinate and influence the underlying driving forces.
Source: The idea has been modified from (Allen, 2022b; Kosamu et al., 2022; Puma et al.,2011)			

The **DPSIR framework** assembles all of its parts to get an understanding of the environmental, social, and economic perspectives that quantify the factors associated to the research topic and study region (EEA, 2020; Zandebasiri et al., 2021). The framework is intended to show how various aspects of the environment and human activities are interconnected, and how changing one aspect can have an impact on other aspects, covering many important indicators for implementing efficient management policies (Islam et al., 2012; Pakzad and Osmond, 2015).

4.3.1.2 Data collection

Questionnaire survey:

- Objectives: To collect complete data on the effect of the coastal hazard threats on the seasonal migration pattern of the coastal community in Saint Martin Island. The questionnaire survey was enforced using relevant sub questions in the DPSIR framework such as drivers, pressures, state, impact and response. The other main objective was to validate the conceptual model using available data collected from questionnaire.
- Design: The questionnaire was properly arranged with respect to each of the DPSIR sub categories, they are drivers, such as Climate change in the targeted area because climate change is the driver in this context, pressures, such as the coastal erosion, sea level rise, storm surges, Salinity intrusion, state, that is Land Area Change, Extreme Weather Phenomena, Decay of Embankment, Socioeconomic Vulnerability, absence of Basic Needs, impact, namely migration type, pressures on migration, main source of income, possess for danger, attitude for leaving and residence already left and response, such as adapting the new environment, preparation and strategies towards improve of coastal hazard, decision making to leave and policy follow up by the government. This will also validate the data collected through conceptual model.
- Sample size and selection: The household sample is selected from the representative sample of the Saint Martin Island. The sample size is high_____ households. Stratified random programming was selected to take into consideration different volumes and different populations.

4.3.1.3 Methodology

The methodology for the work was in the form of developing a conceptual model with regard to the DPSIR framework, validating the model with the present survey data and calculating the overall weightage to each of the components in relation to the DPSIR framework.

Conceptual model development

DPSIR framework components are arranged to organize the conceptual model. Mode structure In the DPSIR model we include the rows of the rows of the DPSIR components i.e., drivers, pressures state, impacts, and responses. Assumptions are provided in respect to each of the DPSIR components in the case of selecting the important variables and discussing the problems in the two referees one driving and another is response aspect. Model character A compartment model is developed based on the compartment rows in the DPSIR model with respect to drivers, pressures, state, pressure to extenuation between the compartments are taken in to consideration.

Identification of Variables

- Based on the survey responses, the important variables were identified for each DPSIR category.
- These variables were then dissected with the model to show the relationships, connections between drivers, pressure, state, impact and responses
- Validation of the Conceptual Model
- Data Survey Analysis.
- The data from the questionnaire survey was quantitatively analysed and validated the conceptual model.
- The frequency, degree of severity from the respondent on different issues that they assumed considered when they were thinking and their support that either is relevant o non-relevant.
- The strength and the relevance of the data that was collected was used to consider the model of DPSIR.

Weightage Assignment

- The contribution of each variable identified in the DPSIR conceptual model was assessed. Moreover, the overall total contribution in different order 1st, 2nd, and 3rd were calculated in each group.
- 10. There was a need to assign a weightage for each variable based on the involvement of the contribution to the overall order
- 11. The weightage of each variable was based on theoretical and survey response.
- 12. The weight for each variable was than assigned based on theoretical and report.
- 13. Each and every respondent response is considered using the Likert scale was the requirements or the variable and how much it is important for the cause.

Calculation of Total Contribution

- DPSIR total contribution was than calculated following Eq. (a) as proposed above
- Total Contribution=∑(Wi×Ri) Total Contribution = \sum (W_i × R_i)
- Where:

- Wi= weightage assigned for the variable
- Ri= response or the score for the variable in the survey
- the total number of Ri variable was than considered
- the process in the calculation was that all responses were multiplied by the allotted weightage were taken and then other in total addition
- The identical process was then repeated for each order of DPSIR

Model Refinement

Once the total contribution was calculated, the DPSIR model was refined based on the contribution of each variable. Variables with high contributions were highly considered to the order while the variables with low contribution are reviewed. The whole process was repeated in the iteration of the respondent feedback making the model very close to the ground situation on Saint Martin Island was implemented.

Final Validation

The accurate conceptual model to the local context was reviewed by community stakeholders and experts

The above data collection and the methodology explained above provide a systematic way of developing and validating a conceptual model using the DPSIR model. With survey data being one data source, we were able to build the model based on the perceptions and experiences of members of the coastal communities of Saint Martin Island. Also, a weightage-based calculation of the total contribution gives a great opportunity to have a specific estimate of how including the relevant factors that contribute to the seasonal migration. In general, the methodology adopted in this paper will help to make some targeted efforts to minimize the effect of the coastal impact.

4.3.2 Analyzing the seasonal migration of the Saint Martin Island

4.3.2.1 Data Collection

Questionnaire Survey

- **Purpose:** The purpose of the questionnaire survey was first to obtain comprehensive data on the migration behaviors of the coastal community of Saint Martin Island due to the effects of the coast hazards. Accurately speaking, the survey collects data on whether the individual migrates or not, why they migrate, and to which district they migrate. It is this

information that will then be used to draw the influence of the DPSIR model on migration on the map. The queue

- **Samples:** In the sample selection for the questionnaire survey, I decided to take a stratified random sample of the coast community households of Saint Martin Island at different locations. This is to ensure a variety of responses from people of different socioeconomic statuses and locations of habitation.

4.3.2.2 Methodology

- **Migration Status**: This is the first part of the survey that includes questions on whether the respondents or their households have migrated since there was or is an existing deadly coast hazard, such as SLR, storm surges, and coast erosion.

- **Destination district:** For the individuals who have migrated or are about to migrate, the survey extracts this data. The respondent is asked to state whether he or she has migrated to which district he is migrating or she is migrating to. Drivers and pressures for migration: This is the third part of the survey, which further delves into the major drivers and pressing forces of migration. State, Impact, and Response: the rest of the questions in the survey include the current state of the suitability of the physical and livelihood environments of the people, if the hazards do directly impact the process of change of their motivation to migrate, and if there has been any response option or alternative including any adaptation of the hazards or initiatives from the coast community.

Visualization of DPSIR Impact

The method involves drawing the migration behavior on a map and drawing the influence of the DPSIR model using the model on the map. This will happen after I have analyzed the survey and after I have used ArcGIS in the map design.

- **Layering:** Multiple layers were created.
- **Drivers and Pressures Layer:** The pressure and the driver data were entered into the software. This layer shows the invisible forces that cause migration.
- **State Layer:** The situation surrounding Saint Martina Island with respect to the current time was shown. The most affected zones were also yellow.
- **Impact Layer:** The migration data entered was used to sort the impact of coastal hazards. The arrows showing the flow of people from Saint Martina Island to the district were demarcated by the DPSIR component that influences.

- **Response Layer:** The adaptation actions that the community and the localities have adopted were shown. The actions that were taken to solve the issues raised were also expressed.

Migration Mapping

The migration data was analyzed, and the flow of people from Saint Martin Island to other districts was determined. The frequency and direction of the migrants were also tracked to identify the most visited place.
Creation of Map Using ArcGIS

The flowchart graphic presented in the present assignment showed some clear illustrations of the migration of people to the different districts of the area depending on the status of their environment. For a better demonstration of the DPSIR components, colours were used with the following codes: red for drivers, orange for pressures, yellow for status, green for impacts, and blue for the responses. Thus, the graphic showed that the high status of the environment in the districts is associated with the high migration of the population to this district.

Map Validation

The final version of the map was validated by direct comparison to the survey's raw data. The local experts and stakeholders were also asked to evaluate the data conducted for the present analysis with representatives of the simulated data.

It is important to stress that the present study and the data collection approach used in the case of Saint Martin Island allowed the development of a coherent and detailed model showing the effects of the coastal hazards related to the environment on the migration of the population in the given region. The DPSIR model implemented in the current research was then added to ArcGIS, which led to the creation of the migration pattern map with the introduction of causes and response reasons. As a result, it is possible to analyze clearly and visualize the main reasons for issues in the environmental, socioeconomic, and policy-related components.

4.3.3 Develop mitigation strategies of seasonal migration on Saint Martin Island

4.3.3.1 Data Collection

Literature Review:

Do comprehensive reading of works available concerning climate change impacts, socio economical vulnerabilities and migration trend on Saint Martin Island such as various studies,

reports, and article. Gather secondary data concerning the environmental change including extreme weather events, modification in the land area, and the situation of the coastal embankments.

Field Surveys, Interviews:

Conduct field surveys to collect the primary data by interviewing the local people concerning their experience with the extreme weather events and also the socio-economic status along with their basic needs/access issues.

Record the Interviews with the local authority and community leaders to know about the condition of the Island, the extent of the local vulnerabilities, and also the prevalent or effectiveness of the existing mitigation measures

Geospatial Data Analysis:

Use the satellite imageries along with the GIS tools to analyze the land area change, coastal erosion, and the status of the embankments concerning the time

Map the most affected areas of the climate change and overlay with the socio-economical data to know the high-risk areas

Socio-Economic Data:

The available data concerning the demography and economy have been collected from government department and international organizations to know the high imbalances. Evaluate the data concerning the incomes, occupation, and the extent of the dependence over the natural resources to know about the areas of vulnerabilities

Meteorological and Climate Data:

Gather the data concerning the extreme weather from meteorological departments along with the research organizations concerning the hurricanes and the tropical storms

Study the previous trends and projected work for its better understanding for their influence on migration and climate change

4.3.3.2 Methodology

Based on the data, variables have been identified such as the effect of climate change, socio-economic vulnerabilities, and the extent of the instability at the Saint Martin Island and on the places migrated to which is the focus of the mitigation measures. Developing the conceptual

chart with the above identified key variables having the relationship between the climate change and the socio-economical factor with the migration

Mentioned various strategies that mitigate the effect of these identified key variables and can have a longer stay at both places that would reduce the influence of instability. Categorize this mitigation strategy into Structural, Policy and regulatory, Economical Management, and Ecosystem based with the measures/actions corresponding to these.

A simple diagram has been designed with different shapes and colors for representing the stability, the climate change, the migration, the instability, and various mitigation strategies. The arrows used to indicate the flow and the steps that influence combinations of the strategies passed on the designated places. Sharing of the models with the stakeholders and modify accordingly Based on the above data collection process and method used, the chart tells the need in a self-explanatory manner, with the various impacts and the path of the strategies that can make the stay longer on the Saint Martin Island.

Chapter 5:

Result and Discussion

5.1 To investigate the types of coastal hazard threats and their impact on seasonal migration patterns on Saint Martin Island.

5.1.1 Shoreline Changes Over Time:

Digital Shoreline Analysis System (DSAS) and Weighted Linear Regression (WLR) methodologies were employed to analyze the changes in shoreline from 1992 to 2024. The study specifically investigated the rates of erosion and accretion along the coastline of Saint Martin Island.

The statistics are displayed in meters of yearly variation, accurately representing both erosion (negative changes) and accretion (positive changes) along several transects.

5.1.1.1 Results

Geometric patterns of erosion and accumulation:

The coastal analysis map illustrates the distribution of erosion and accretion rates across different regions. The map is color-coded to indicate regions affected by significant erosion (dark red areas) and accretion (dark blue areas).

The research findings reveal that there is a grand total of 282 transects, most of which are erosional (196 transects) and a smaller proportion representing accretion (49 transects). A smaller subgroup of transects (37 in number) demonstrate stability.

Table 14: Erosional and Accretional of Saint Martin Island

Total Transect	2922

Erosional Transections(%)	82.9911
Accretional Transections(%)	12.90212

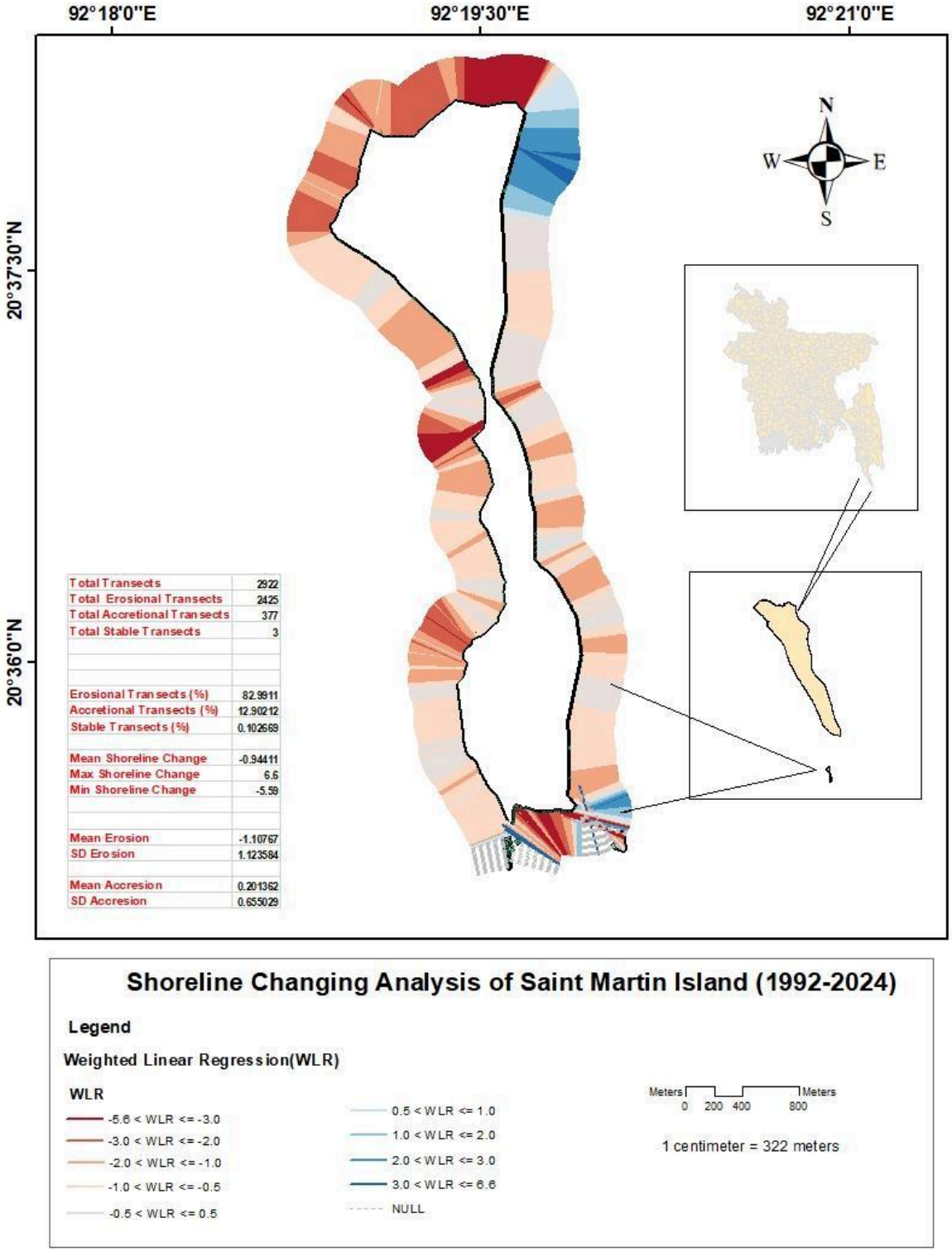


Figure 4: Shoreline Changing Analysis of Saint Martin Island(1992-2024)

The computed mean coastline change indicates an average annual erosion rate of -1.5797 meters and an annual accretion rate of 0.6815 meters. The observed results indicate that this land is undergoing a greater rate of land loss caused by erosion in comparison to the rate of land acquisition through accretion.

5.1.1.2 Discussion

The outcomes of the shoreline analysis performed for Saint Martin Island, based on the use of the Digital Shoreline Analysis System and Weighted Linear Regression methodologies, provide significant insights into the island's dynamic coastal processes. One of the primary results of the research is that the island demonstrates large variations in spatial proportions when considering both erosion and accretion in terms of the maximum and minimum lengths identified in the datasets. The difference between the values was seen to be pronounced, with the primary trend being the erosion of the island over time. Thus, the most significant implication that can be drawn from the outcomes is that the island's loss of land occurs at an incomparably larger rate than its accretion. The data has described the average annual erosion as -1.5797m, meaning that the shoreline of Saint Martin Island is heavily prone to the impacts of various types of coastal hazards. In particular, the dangers of storm surges, the rise of sea levels, and wave actions associated with climate change are identified as primary contributing predators that make the existing erosion problems worse. The results show that the practically entire shoreline under analysis is actively eroding. Thus, the primary conclusion of the research is that the swift implementation of defense and preservation strategies is long overdue.

As such, it is possible to assess that the presence of a significant negative trend puts the island's land in great danger in terms of the level of changes it is expected to experience. The strength of this position is shown by the data of the current study, which shows that only 49 transects demonstrate positive changes that suggest the nature of accretion. However, the discovered annual value of 0.6815 is at a far lower level and is heavily confined, and acts of self-deposition are seen as taking place on a minuscule proportion of the land. Finally, 37 transects stay consistently stable and remain important whether they will change or stay the same. It is vital to mention that the provided portion cannot be considered significant as it is not large enough to create a positive barrier against the gradual degradation of the land. Similarly, the nature of erosion is incomparably more substantial than the presence of accretion.

5.1.2 The phenomena of cyclone and Strom surge:

The following is a presentation of the results and analysis from the study entitled "Modeling the Effects of Coastal Hazard Threats to the Seasonal Migration Patterns of Coastal Communities in Saint Martin Island." This study focuses on investigating the consequences of cyclones and storm surges.

5.1.2.1 Result

Cyclone and storm surge frequencies:

The provided graphic and dataset illustrate the frequency and paths of cyclones and storm surges observed within a 200 nautical mile radius around Saint Martin Island. In particular, this region experiences a significant occurrence of tropical cyclones and the subsequent storm surges, especially during the monsoon season.

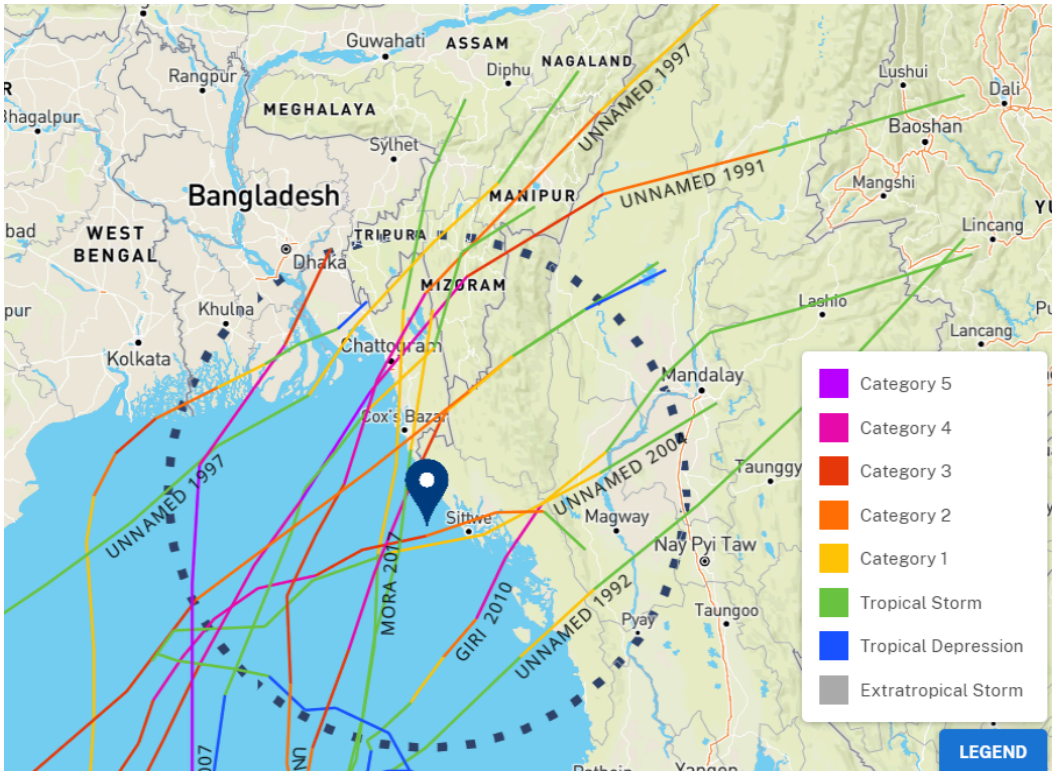


Figure 5: Route of Cyclone and Strom Surge in 1990 to 2022

Table 15: Information About the Frequency of Cyclone and Storm Surge in nautical miles

Information About the Frequency of Cyclone and Storm Surge in 200 Nautical Miles				
STORM NAME	DATE RANGE	MAX WIND SPEED (mph)	MIN PRESSURE (mb)	MAX CATEGORY
BULBUL-MATMO 2019	Oct 28, 2019 to Nov 11, 2019	100	959	H3
MORA 20				
GIRI 201				
SIDR 20(				
AKASH 2007	May 12, 2007 to May 15, 2007	65	976	H1
UNNAMED 2004	May 14, 2004 to May 19, 2004	65	976	H1
UNNAMED 1998	May 13, 1998 to May 20, 1998	70	No data	H1

Cyclones are categorized from Category 1 to Category 5 based on their intensity, with higher classifications indicating cyclones of more severe magnitude. The graphic illustrates many cyclone trajectories, varying in severity from tropical storms to Category 5 cyclones.

Cyclone Intensity and Movement Pathways:

The diagram illustrates the geographical path of cyclones that have impacted Saint Martin Island, encompassing tropical depressions as well as powerful Category 5 hurricanes.

Historical empirical data suggests that certain routes are more prone to storms of higher intensity, therefore increasing the susceptibility of the communities living in these areas.

5.1.2.2 **Discussion**

The study highlights the frequency and impact of cyclones and storm surges on Saint Martin Island, a region frequently affected by extreme weather events. Cyclones, ranging from tropical storms to Category 5 hurricanes, occur regularly, particularly during the monsoon season, within a 200 nautical mile radius. The analysis reveals that cyclone pathways frequently intersect with the island, making coastal communities highly vulnerable to these hazards.

The pathways of these cyclones, illustrated in the data, suggest that certain areas of the island are more prone to severe storms. Historical patterns show that higher-intensity cyclones, especially those classified as Category 3 and above, tend to follow specific routes, increasing the risk of destruction in these areas. Accompanying storm surges further exacerbate the threats by causing coastal flooding and erosion, worsening land loss and damaging infrastructure.

The study underscores the need for comprehensive disaster preparedness and resilience-building strategies for Saint Martin Island's coastal communities. As cyclones pose regular and increasing threats, both short-term emergency responses and long-term adaptation plans are essential. Targeted interventions in cyclone-prone regions are crucial, as these communities face the greatest risk of displacement and loss of livelihoods due to repeated storm impacts.

In conclusion, the study emphasizes that Saint Martin Island's geographic vulnerability to cyclones necessitates immediate action to protect its residents. Enhancing early warning systems, strengthening infrastructure, and incorporating cyclone risks into migration patterns are vital for the island's long-term sustainability.

5.1.3 Analysis of scenarios for sea level rise and inundation

5.1.3.1 Result

The elevation map of Saint Martin Island illustrates the varied geomorphology found spanning the entire island. A considerable proportion of the island has a low elevation, with numerous areas located at an altitude below 5 meters above sea level. The highest elevations are found in the central and northern parts of the island.

The inundation maps reflecting sea level rise illustrate the potential outcomes of two different levels of sea level rise: 0.5 meters, 1.5 meters, and 2.5 meters. These maps indicate that a significant portion of the island will be affected by even a moderate rise in sea level.

- Extent of inundation:

Assuming a 0.5 meter increase in sea level, roughly 3.20% of the island would be inundated, while 96.80% would remain unaffected.
A 1.5 meter increase results in the inundated area expanding to 7.48% of the island, while 92.52% of the island remains inundated.
According to the above scenario, a 2.5 meter increase is expected to cause 11.27% of the island to be inundated, while 88.73% will remain unscathed.

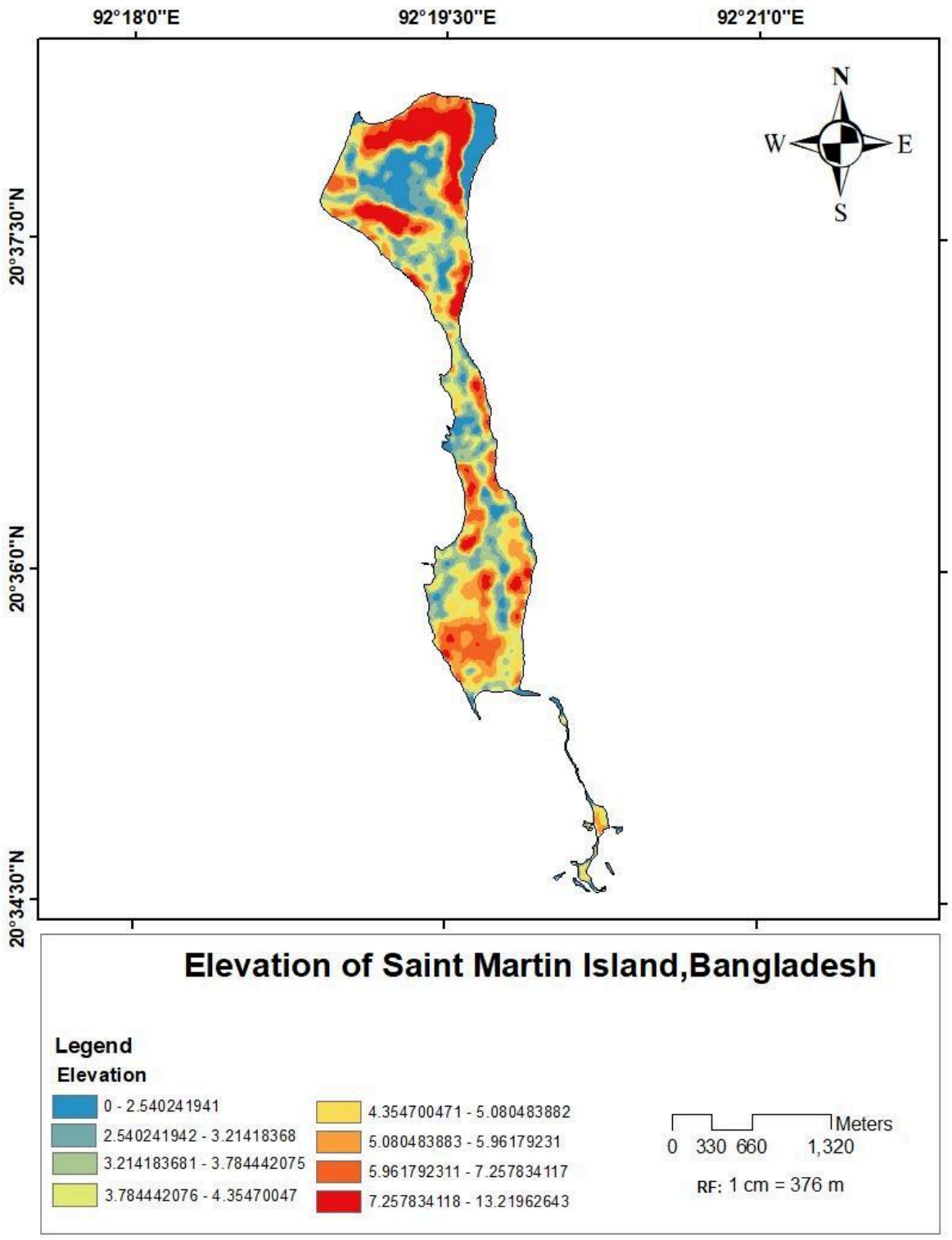


Figure 6: Elevation of Saint Martin Island

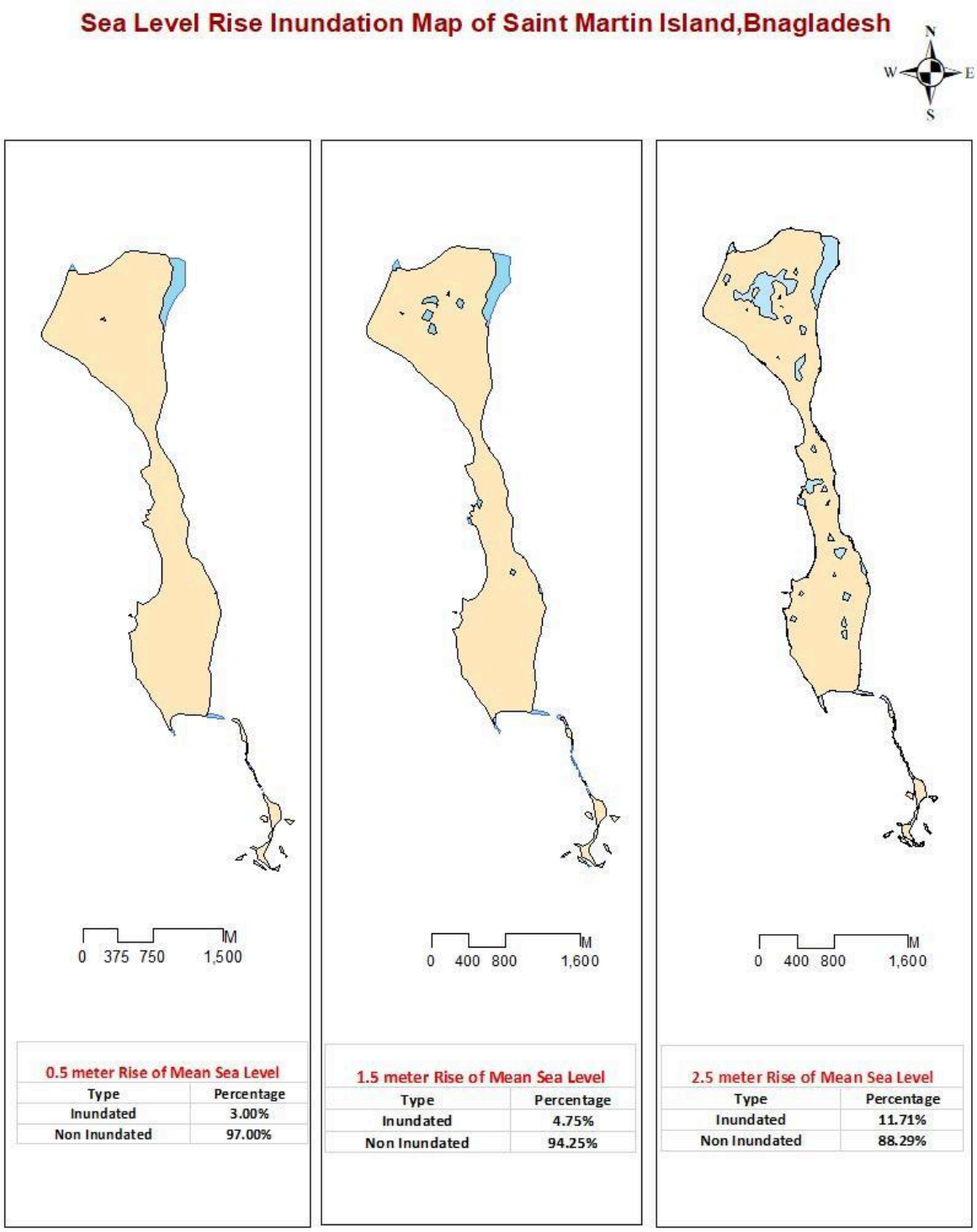


Figure 7: Probable Sea Level Rise of Saint Martin Island

- Key areas of greatest susceptibility:

The area's most susceptible to floods are those distinguished by the lowest altitude, primarily in the southern and certain center portions of the island. Within the elevation map, the colors blue and light yellow are used to indicate areas that are situated at an altitude below 3 meters above sea level.

5.1.3.2 Discussion

An evaluation of the coastal hazard posed by sea level rise:
The available data indicates that Saint Martin Island is highly vulnerable to the effects of increasing sea levels due to its low elevation and specific features of its shoreline. The probable consequences of a modest increase in sea level (0.5 meters) include land loss and adverse effects on the livelihoods of coastal populations, hence increasing their vulnerability to flooding and storm surges.

The progressive inundation caused by the increasing sea levels (1.5 meters and 2.5 meters) suggests that significant portions of the island may become uninhabitable or require substantial adaptation measures to maintain their suitability for human habitation.

5.1.4 Examination of the infiltration of saltwater into Saint Martin Island

The satellite image highlights a particular area of Saint Martin Island where widespread saline intrusion is a significant issue. This phenomenon is exemplified by the near proximity of the coastal communities on the island to the ocean, which enables the ingress of seawater into highly important freshwater resources.

5.1.4.1 Result

The yellow arrow on the map denotes a specific location where the infiltration of salt is anticipated to exert an impact on the adjacent environment, potentially causing harm to both the aquatic surface and subsurface water supplies.

Impacts on Freshwater Water Resources:

Infiltration of saltwater results in the contamination of freshwater resources, including wells and surface water bodies that are used by nearby people for drinking, cooking, and irrigation

operations. Blending seawater with freshwater sources results in an increase in salinity levels, rendering the water unsuitable for both human consumption and agricultural use.

Soil salinization caused by the intrusion of saltwater can adversely affect soil quality, leading to reduced agricultural productivity and hindering the growth of salt-sensitive crops.

Figure 8: Intrusion of Salinity in Saint Martin Island

5.1.4.2 Discussion

- **Infiltration of Soil Salinity:**

The intrusion of saline water presents a significant coastal hazard to Saint Martin Island, especially for communities that heavily rely on freshwater resources. The probability of seawater exceeding natural barriers and contaminating freshwater supplies concurrently increases with the rise in sea levels and the escalating frequency of storm surges.
The ingress of saline water into freshwater aquifers can lead to extended degradation of water quality, therefore posing substantial health risks to adjacent communities and reducing the availability of potable groundwater.

- **Variables influencing coastal communities and migration:**

As the salinity of freshwater supplies increases, communities face mounting pressure to move, either temporarily or permanently, to areas with more reliable freshwater availability. This is particularly true during the dry season or periods of drought when the availability of freshwater is already limited.

Salt intrusion-induced migration can disrupt traditional methods of subsistence, especially for those involved in agriculture and fishing. Aggregate degradation of soil and water quality results in a decline in agricultural productivity, prompting farmers to seek alternative sources of income or move to metropolitan areas.

- **Analysis of the impact on livelihoods and health:**

The incorporation of saltwater into freshwater resources can lead to notable health implications, including increased occurrence of hypertension, dehydration, and other health issues associated with excessive salt intake. Moreover, this exacerbates the vulnerability of coastal communities, namely the elderly populations, children, and persons with pre-existing health conditions.

Moreover, the economic ramifications of saline intrusion are significant. Rural agriculture, a major sector of the local economy, is negatively impacted by soil deterioration, reduced crop yield, and the increasing costs related to irrigation and soil management. Fluctuations in salinity can also potentially effect aquatic communities by influencing fish populations and breeding areas.

5.2 To Assess the Vulnerability of the Local Communities to These Coastal Hazard Threats.

5.2.1 Extreme Weather Pattern

5.2.1.1 Result

- **Analysis of Specific Humidity time series from 1990 to 2022**:

The graph depicting the variation in specific humidity between 1990 and 2022 shows a persistent upward trend in specific humidity levels across Saint Martin Island, Teknaf, Cox's Bazar, and Chattogram.
A significant increase in specific humidity is observed after the year 2000, peaking between 2010 and 2015, suggesting a progressive rise in atmospheric moisture levels.

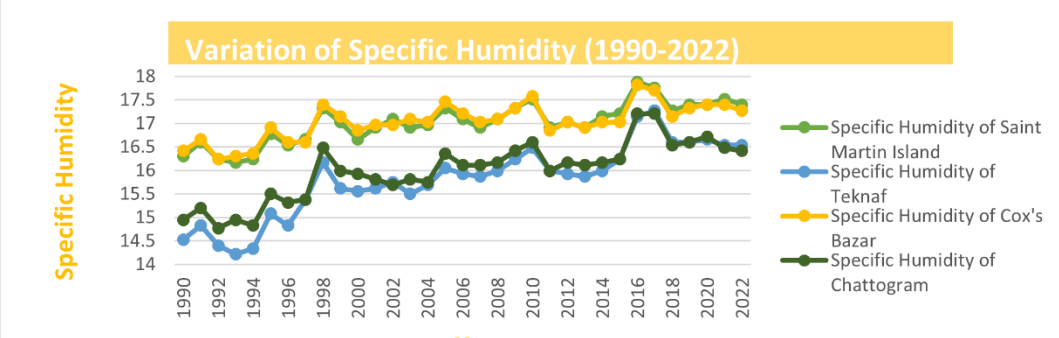


Figure 9: Variation of Specific Humidity (1992-2022)

- **Time series data on temperature variations from 1990 to 2022**:

The temperature graph illustrates the fluctuations in temperature for Saint Martin Island and its adjacent islands (Cox's Bazar, Chattogram, Teknaf) from 1990 to 2022.

Despite slight variations, there has been a tiny rise in temperatures, indicating a warming trend over the past three decades. Saint Martin Island exhibits a relatively stable temperature, with minimal fluctuations, when compared to other locations.

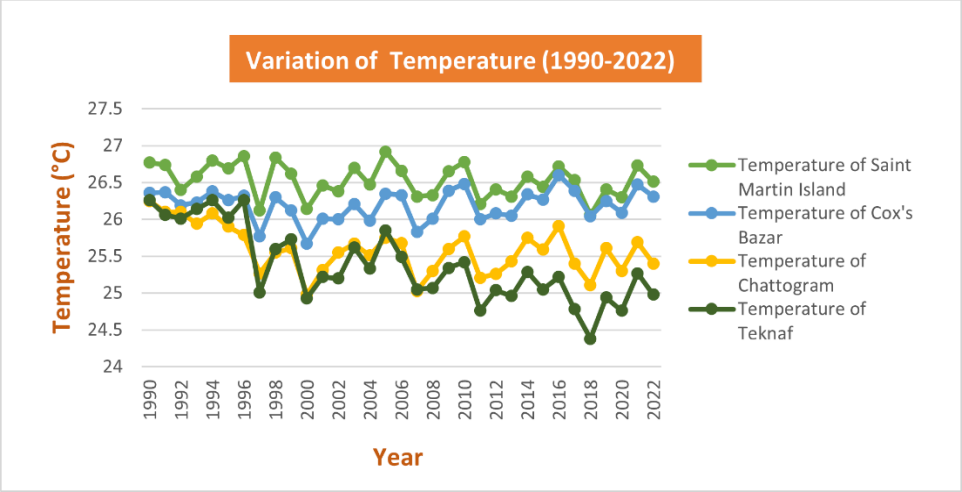


Figure 10: Variation of Temperature (1992-2022)

- **Analysis of Historical Precipitation Variation from 1990 to 2022:**

The observed precipitation data displays significant variation in rainfall patterns across the several geographical areas. A sudden and significant increase in precipitation took place from 2005 to 2015, peaking at about 10,000 mm, particularly in Cox's Bazar and Teknaf, and then declining.

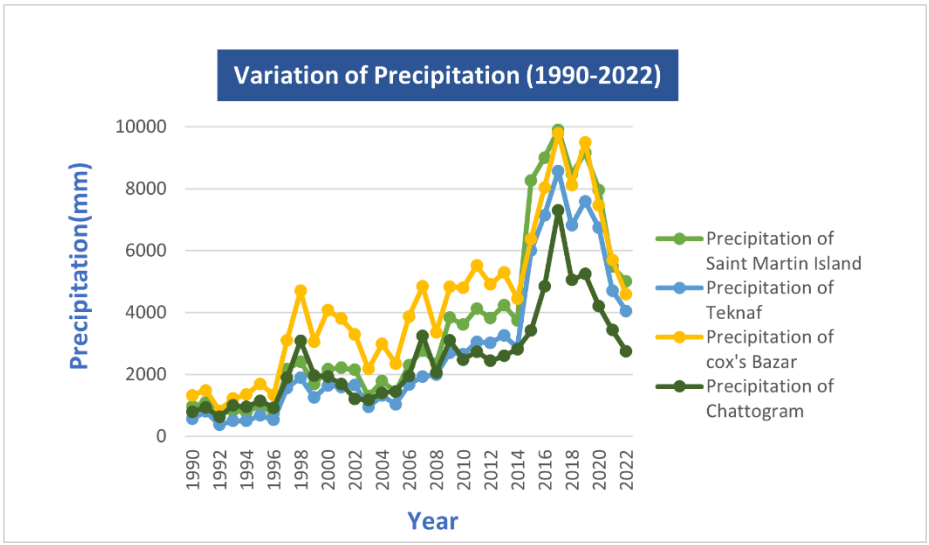


Figure 11: Variation of Precipitation (1992-2022)

Saint Martin Island has exhibited a very consistent rainfall pattern, characterized by notable peaks that align with those of nearby geographical regions, indicating vulnerability to intense meteorological events such as monsoons and cyclones.

- **Time series data on variations in wind speed at a distance of 10 meters from 1990 to 2022:**

The wind speed graph shows a rather stable degree of variation over the years, with Saint Martin Island showing relatively greater wind speeds by comparison to the other locations. The data suggests uniform but sporadic oscillations in wind velocity, most likely linked to storm events or seasonal changes.

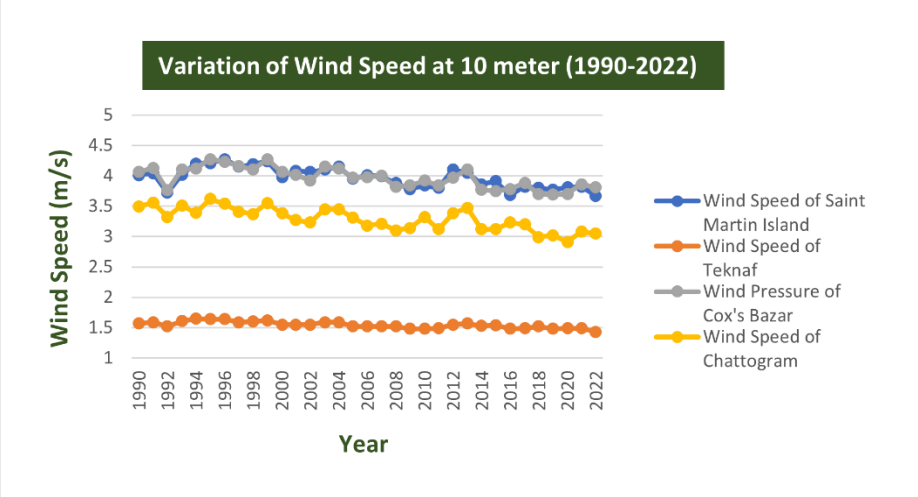


Figure 12: Variation of Wind Speed at 10 meter (1992-2022)

5.2.1.2 Discussion

An evaluation of the vulnerability of local communities to severe weather events:

Increasing levels of both specific humidity and temperature contribute to a growing vulnerability of local populations to heat stress and the associated health risks. The phenomenon of increased humidity levels can exacerbate the effects of increased temperatures, leading to heat-related illnesses and reduced labor productivity, particularly in outdoor activities such as fishing and agriculture.

Highly variable precipitation episodes marked by oscillations and abrupt surges in rainfall indicate an increased vulnerability to floods, particularly during periods of intense monsoon or cyclone-induced rainfall. Adverse weather events of this magnitude can lead to significant damage to infrastructure, homes, and livelihoods, forcing communities to move to safer areas either temporarily or permanently.

An examination of variations in wind speed highlights the potential for strong winds, particularly during cyclone events. Vigorous wind speeds can lead to structural damage, tree displacement, and disruption of communication and transportation networks, therefore worsening the isolation of communities and impeding rescue operations.

5.2.2 Absences of Basic Needs of Saint Martin Island

5.2.2.1 Result

Gender-based comparative analysis of school attendance statistics

- **In-depth Statistical Examination of Gender Disparities:**

The attendance rates for males and females had mean values of 26.35% and 20.08% correspondingly. These statistical results indicate that males exhibit a higher average attendance rate than females across all age groups.

The standard deviation for male attendance is 28.59%, slightly higher than the coefficient of variation for females, which is 26.46%. These findings suggest that the attendance rates for males show more considerable variation among different age groups.

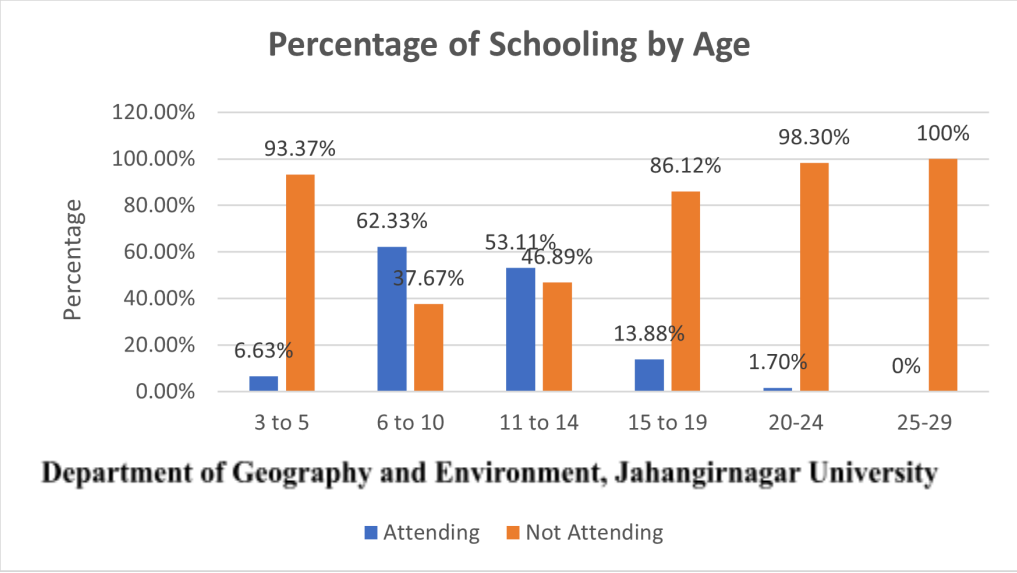
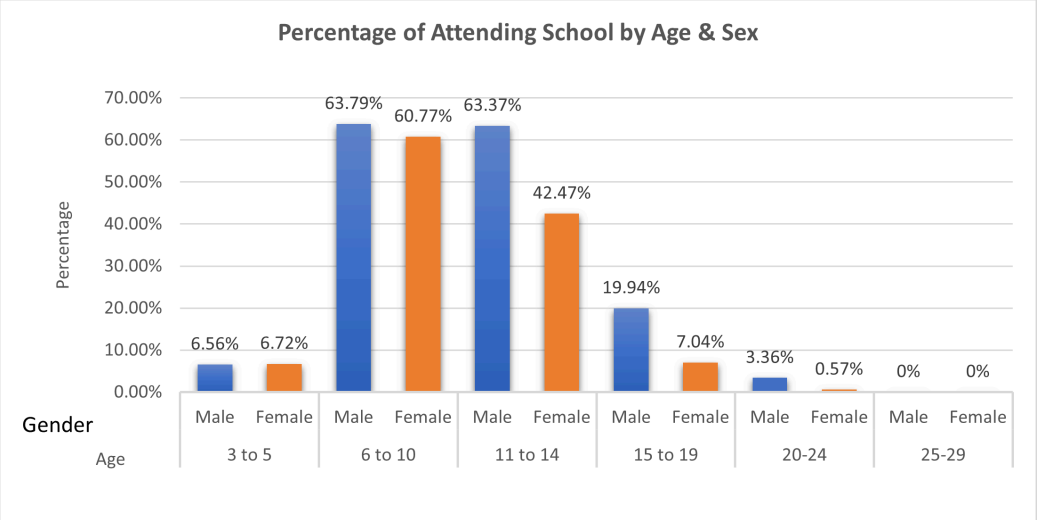


Figure 13: Percentage of Attending School

An examination of the rates of school attendance between males and girls using a t-test indicates that the t-statistic is 0.39 and the p-value is 0.70. Based on the 95% confidence level, the obtained high p-value indicates that there is no statistically significant difference in school



attendance rates between genders. However, the consistently lower rates of attendance among females suggest inherent socio-cultural barriers that may contribute to their increased vulnerability.

Figure 14: Percentage of attending School by Sex

Consequences of Gender Disparities:

Inadequate educational attainment among women may increase their vulnerability to coastal hazards due to limited economic opportunities, less access to resources, and reduced participation in decision-making processes. Indeed, this could lead to a heightened reliance on migration as a means of adapting to environmental risks.

In order to address gender disparities in education and enhance community resilience, it is crucial to prioritize the implementation of gender-sensitive initiatives. Possible treatments include scholarships intended only for females, community awareness campaigns targeting gender equality, and the provision of reliable transportation options to guarantee female school attendance.

- **Analysis of mortality rates using an age pyramid chart:**

Examination of the age pyramid data uncovers a significant discrepancy in mortality rates among various age cohorts. To provide an example, the death rate for males aged 65 and older is 10%, whereas for females it is 9.5%. This situation serves as a prime example of a widespread trend in which older populations are more vulnerable to health problems and environmental hazards.

Influence of Population Distribution: The age pyramid reveals a demographic makeup marked by a predominantly young population, with a higher percentage of individuals belonging to the younger age groups (e.g., 0-4 and 5-9 years). Although the mortality rates are lower in these specific demographic groups, the overall vulnerability of the local population remains substantial due to the dependence on the working-age population and the need for adequate healthcare and resources for both young people and the elderly.

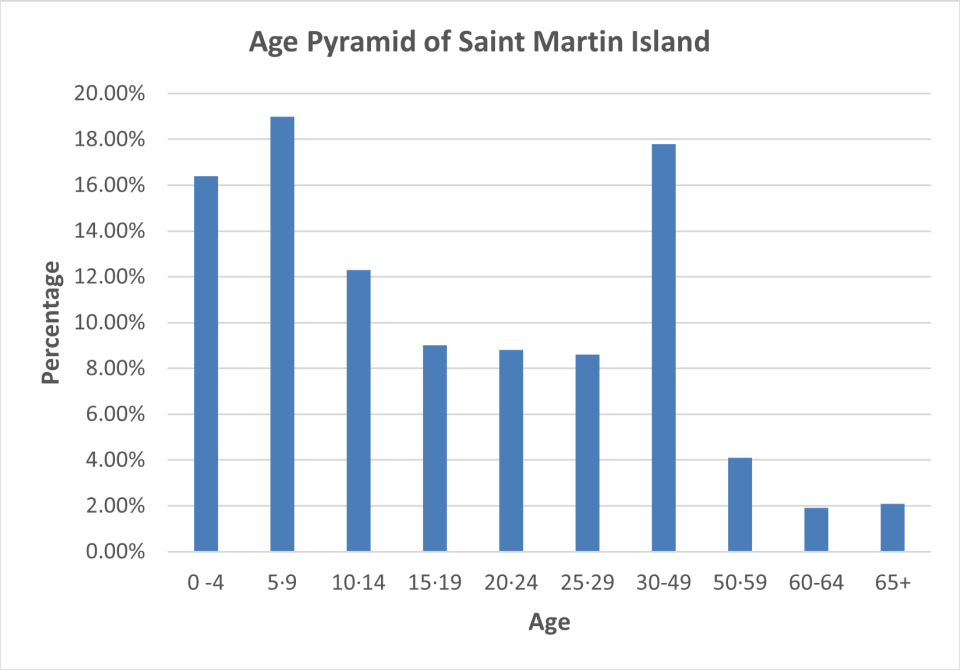


Figure 15: Age Group of the People of Saint Martin Island

Ramifications of increased death rates encompass:

The higher death rates among older age groups highlight the need of improving healthcare accessibility and disaster preparedness tailored to meet the specific needs of the elderly population. The objective is to improve the healthcare infrastructure, provide targeted health services, and ensure that elderly persons have access to vital resources during emergencies.

Community-Wide Vulnerability: While the mortality rates for males and females are similar, the high levels of death in older age groups emphasize the need of implementing a comprehensive

approach to community resilience that includes health, social services, and disaster risk reduction operations.

An analysis of gender disparities in education and higher mortality rates, particularly among various age groups, uncovers significant vulnerabilities within the local populations of Saint Martin Island. The resolution of these weaknesses requires the implementation of a thorough approach that promotes gender equality in education, enhances the availability of healthcare services, and reinforces preparedness for disasters across all age groups. By adopting these strategies, the region can reduce its vulnerability to coastal disasters and strengthen its capacity to prevent and recover from environmental threats.

5.2.3 The Socioeconomic Vulnerability of Saint Martin

5.2.3.1 Results

- **Analysis of the occupation distribution**

Data from Saint Martin Island indicates a diverse economic basis. The primary employment sectors include fishing (42%), agriculture (20%), services (15%), unpaid work (10%), entrepreneurial endeavors (8%), community assistance (3%), and students (2%).
A significant portion of the population relies on fishing and agriculture, making them particularly vulnerable to coastal hazards such as hurricanes, storm surges, saline intrusion, and coastal erosion.

Table 16: Occupation of people of Saint Martin Island People

Occupation of the people of Saint martin	
Occupation	**Percent**
Business	**20.8**
Community Support	**2.2**
Day Labor	**4.1**
Farmer	**6.5**
Fisherman	**48.4**
Services	**14.1**
Student	**4.1**
Total	**100**

- **Hazard Calendar Analysis:**

The hazard calendar offers a detailed summary of the precise timing and frequency of various coastal hazards that arise throughout the year. Specifically, cyclones and storm surges

predominantly occur from April to August, but coastal erosion and saline intrusion present more enduring hazards throughout the year.

An analysis of the calendar shows a notable concentration of hazards throughout the monsoon season (June to August), which aligns with the times of peak fishing and land agricultural activity. This intersection exacerbates the vulnerability of persons who depend on these occupational fields for their livelihood.

Hazard Calendar

Hazard	Month											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cyclone & Strom Surge												
Coastal Erosion												
Salinity Intrusion												
Sea Level Rise												
Rainfall												

Figure 16: Crop Calendar of Saint Martin Island

- **Examination of the Income Calendar:**

The revenue calendar depicts the temporal trend of earnings for different categories of occupations. Peak revenue periods for fishermen and farmers are observed between April and September, coinciding with the pre-monsoon and monsoon seasons marked by abundant fish and agricultural production.

Day laborers and persons in community support vocations enjoy a consistent income throughout the year, but their opportunities are restricted during periods of significant risks (June to August), highlighting the disruptive impact of coastal hazards on these livelihoods.

Income Calendar

Activity	Month											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Business												
Community Support												
Day Labor												
Farmer												
Fisherman												
Services												
Student												

Figure 17: Income Calendar of Saint Martin Island

- **Crop Calendar Analysis:**

The crop calendar reveals that the primary agricultural operations, such as cultivating paddy and watermelon, typically occur from June to November. Vegetable and pepper farming takes place year-round, with the peak crop yield being from March to September.

This calendar highlights the vulnerability of agricultural output to seasonal hazards, especially during the monsoon season when floods, increasing sea levels, and saline intrusion pose the greatest threats.

Crop Calendar

Hazard	Month											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Paddy												
Water Melon												
Vegetables												
pepper												

Figure 18: Crop Calendar of Saint Martin Island

5.2.3.2 Discussion

Their reliance on climate-sensitive industries such as fishing and farming highlights the socio-economic susceptibility of the inhabitants of Saint Martin Island to coastal risks. Due to the heavy dependence of these activities on predictable weather patterns and stable environmental conditions, any disruption caused by hazards directly endangers the quality of life for a considerable portion of the population.

The concentration of economic activities during months susceptible to hazards increases susceptibility and magnitude of risk. For example, fishing communities are highly susceptible to the impacts of cyclones, leading to loss of life, destruction of fishing vessels, and extensive damage to infrastructure. Consequently, this has a profound impact on their income and food security. An analysis of the impact of seasonal hazards on livelihoods.

The correlation between the highest hazard season and the peak seasons for income-generating activities suggests that many households face amplified risks. Their susceptibility encompasses not just immediate physical dangers posed by hazards, but also economic shocks that arise from the loss of potential income.

Agricultural activities, in particular, are highly sensitive to variations in salinity, floods, and erosion dynamics. High levels of salt penetration can degrade soil quality, reduce agricultural output, and render land unsuitable for extended periods, leading to long-lasting economic difficulties and even displacement of farming communities.

5.2.4 Land Area Change

5.2.4.1 Results

- Land area change analysis using time series:

The analysis utilizing Landsat imagery and the DSAS methodology uncovers significant temporal fluctuations in the coastline of Saint Martin Island. The charted coastlines for the years 1992, 2003, 2014, and 2024 indicate a consistent pattern of progressive erosion and reduction in land area, primarily focused on the eastern and southern edges of the island.

Between 1992 and 2024, the data shows a significant retreat of the shoreline. The primary factor contributing to this land loss is coastal erosion, largely resulting from natural occurrences including wave action, storm surges, rising sea levels, and human activities that are prone to exacerbate erosion.

- Projected Land Area Changes for the years 2034 and 2044 indicate:

Furthermore, the DSAS model predicts that there will be further erosion by 2034 and 2044, in addition to the current land loss. Prognosticated coastal positions for 2034 and 2044 suggest that if the present trends continue, considerable portions of the island's existing land area, particularly in vulnerable regions, will be greatly reduced.

The projected modifications provide a substantial hazard to the island's infrastructure, basic resources, and capacity to sustain human settlement. Projected land losses are expected to be especially significant in areas now experiencing high erosion rates. vulnerable to damage resulting from storms and flooding, so increasing the risk of displacement and economic harm.

Table 17: Year Wise Land Area Change of Saint Martin 1992 to 2044

Year Wise Land Area Change of Saint Martin	
DATE	**Area(Km)**
1/31/1992	3.885218
1/27/2014	3.833284
1/21/2003	3.347699
1/31/2024	3.280948
Predicted 2034	3.23508
Predicted 2044	3.205555

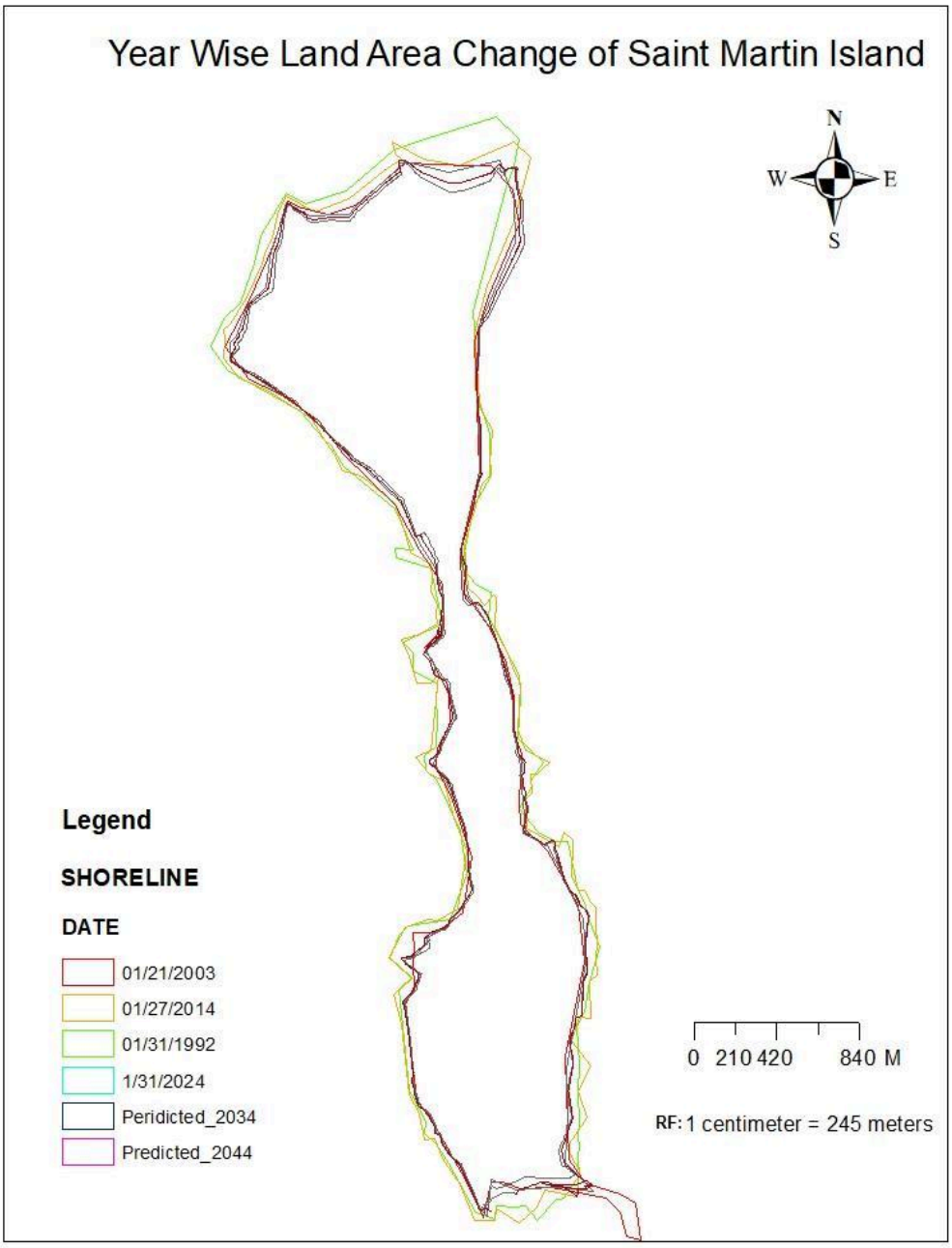


Figure 19: Land Area Change of Saint Martin Island 1992 to 2044

5.2.4.2 Discussion

- Impact on Local Communities: Empirical Evidence

The communities residing on Saint Martin Island rely heavily on terrestrial economies, including agriculture and tourism. The persistent and expected exhaustion of land presents a direct threat to these economic activities. For instance, the depletion of agricultural land reduces the land area available for growing crops, which is essential for guaranteeing food security and producing income.

Coastal erosion and land loss pose a substantial risk to major infrastructure, including residential buildings, educational institutions, and commercial enterprises, particularly those located along the shoreline. Through the decrease in land area, these properties become more

- Vulnerability to Coastal Hazards:

The continuous decline in land area highlights the growing vulnerability of the human populations located on Saint Martin Island to coastal hazards. Erosive processes not only diminish the available land for residential and agricultural use, but also increase the susceptibility of the remaining land and infrastructure to the impacts of storm surges, sea-level rise, and other hazards linked to coastal phenomena.

The estimated future coastline configurations for 2034 and 2044 highlight the urgent need for proactive measures to mitigate the effects of coastal erosion. These communities face increased susceptibility to displacement, economic instability, and loss of cultural heritage associated with the island's territory in the absence of aid.

- Socioeconomic Ramifications:

Moreover, the reduction in overall land area has significant socio-economic implications. The exhaustion of agricultural land directly affects food production, while the limited supply of land limits the ability to build new residences or expand tourism facilities, which are crucial streams of revenue for many residents.

Furthermore, due to the continuous degradation of land, there is an increased intensity of competition for the scarce resources, which can lead to social disputes and exacerbate vulnerable situations, particularly for the most marginalized communities who may lack the capacity to adapt or relocate.

Implementing coastal protection measures such as building sea walls, restoring mangroves, and establishing breakwaters can successfully reduce erosion and protect vulnerable areas from uncontrolled land loss.

An essential element of sustainable land use planning is the formulation and execution of strategies that consider the many risks associated with coastal erosion and sea-level rise. Coastal hazard mitigation refers to the methodical relocation of critical infrastructure and residents from high-risk areas and the encouragement of land uses that are less susceptible to marine disasters.

The involvement of communities in coastal management activities and the enhancement of their understanding regarding erosion risks and potential adaptation strategies might enhance the resilience of local populations. By implementing community-led initiatives to grow vegetation or build simple barriers, further protection against erosion could be achieved.

By providing support for alternative livelihoods that are less dependent on land and less vulnerable to coastal hazards, it is possible to significantly reduce economic reliance on high-risk occupations. Prospective endeavors may include the advancement of aquaculture, eco-tourism, and skill enhancement programs aimed at non-agricultural professions.

Analysis of Landsat images and DSAS reveals that the observed changes in land area on Saint Martin Island suggest a notable vulnerability to coastal erosion and associated hazards. In light of the projected future land loss in 2034 and 2044, it is crucial to promptly implement steps to protect the remaining land and reduce the vulnerability of local communities. Through the implementation of targeted strategies in coastal protection, sustainable planning, community engagement, and livelihood diversification, the island's capacity to manage coastal hazards can be significantly enhanced, hence reducing the need for population displacement and ensuring the socio-economic stability of the community.

5.3 To proposes a mitigation strategies model in response to seasonal migration due to coastal hazard threats.

5.3.1 Conceptual Framework (DPSIR)

- The Driving force (D) is the underlying and essential reason, which in this case is Climate Change.
- Pressure (P) precisely refers to the direct effects of the propulsive force. The pressures observed in this particular setting include Coastal Erosion, Cyclone and Storm Surge, Salinity Intrusion, and Sea Level Rise.
- State (S): Indicates the current condition of the environment resulting from the exerted pressures. Land Area Change, Extreme Weather Phenomena, Rural Land Decay, Socioeconomic Vulnerability, and Lack of Basic Needs are the state factors.

- Impact (I): Refers to the consequences of the activities carried out by the state on both human and natural systems. The consequences include both permanent and seasonal migration, as well as the choice to remain in Saint Martin, which involves issues such increased death rates, escalating living costs, dependence on assistance, restricted availability of medical services, and economic hardships.
- Response (R): Comprises the actions taken to prevent, counterbalance, or adapt to the consequences. The responses are categorized into three groups: Public Awareness, Techniques for Adaptation, and Strategies for Policy.

5.3.1.1 A comprehensive analysis of the DPSIR Framework in the context of seasonal migration:

To assess the impact of coastal risks on seasonal migration patterns, we can examine the framework as follows:

Climate change is the primary causal factor (D) responsible for environmental stresses (P) such as coastal erosion and sea level rise. The aforementioned forces alter the state (S) of the environment, leading to the deterioration of land quality, increased frequency of extreme weather phenomena, and the emergence of socioeconomic stresses.

The effects of these environmental and socioeconomic changes on the population lead to the emergence of new migration patterns. Although migration may be a lifelong choice for certain individuals, it is more often a seasonal phenomenon, motivated by temporary conditions or the anticipation of recurring threats.

In order to mitigate these impacts, many Responses (R) are employed:

The primary goal of public awareness campaigns is to equip communities with comprehensive information regarding possible hazards and vulnerabilities. Adaptation Techniques provide practical mechanisms for ensuring safety and preparedness.

Policy Strategies enact legislation and formulate strategies to enhance long-term ability to adapt and sustain sustainability.

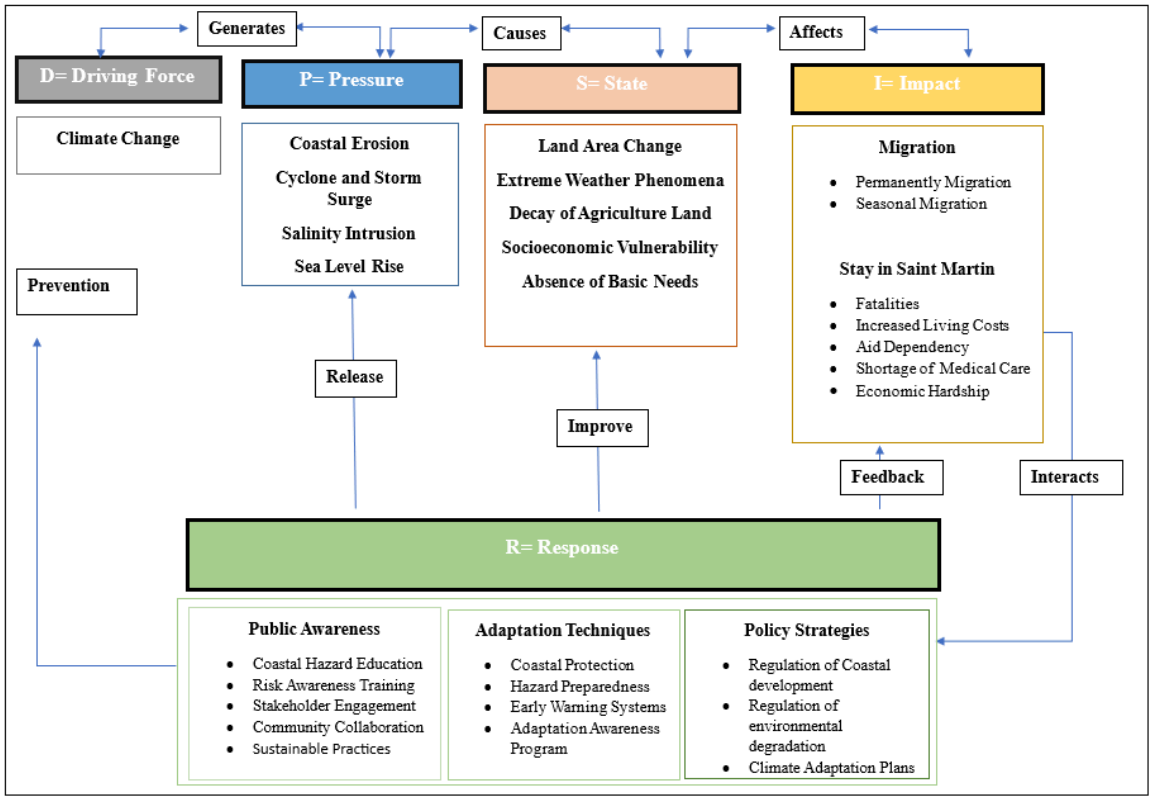


Figure 20: DPSIR Framework of Modelling of Coastal Hazard and Migration Patterns of Saint Martin Island

5.3.1.2 Calculation and assessment of weights

The results acquired from the questionnaire survey would have provided necessary understanding of the different levels of seriousness and perception linked to each element in the DPSIR model. Conducting the calculations necessitates:

1. Establish Weightages: Assign weightages to each facet (D, P, S, I, R) according to the perceived importance or seriousness as provided by the survey responses. Analysis of the frequency and severity of replies allows for the determination of weightages, which indicate the degree of intensity with which each component is perceived or observed by the respondents.
2. Compute the cumulative score for each category by multiplying the total number of replies by the assigned weight for each response choice. Conduct an analysis of these scores to ascertain the most essential components.
3. The study entails evaluating the combined scores to identify the most important pressures, their environmental impact, the severity of negative outcomes, and the perceived efficacy of existing solutions.

5.3.1.3 Computational Methodology for Conducting the Calculations

1. Data Preparation: Examine the questionnaire data to identify relevant questions that accurately represent each component of the DPSIR.
2. Weightage Assignment: Generate a score template (e.g., a scale ranging from 1 to 5) for each question based on the claimed level of importance or severity by survey respondents.
3. To calculate scores, multiply the frequency of each response by its corresponding weightage and then combine these numerical values to derive the total scores for D, P, S, I, and R.
4. Analyze Results: Employ score comparisons to ascertain the principal determinants, pressures, conditions, effects, and responses.
5. Provide Mitigation solutions: Suggest specific mitigation measures that specifically target the most pertinent areas identified in the research.

5.3.1.4 Pressure Component Estimation

The initial image displays statistical data on the independent contributions of different sub-parameters to the pressure component. Procedure for calculating the weightage for each is as follows:

1. Establish numerical values:
The total number of sub-parameters is 4, and each sub-parameter is allocated an equal weight.
Number Value: Each sub-parameter is allocated a specific numerical value.
A weightage value quantifies the normalized impact of each sub-parameter.

2. The contribution of each sub-parameter to the pressure component can be determined using the following formula:
Determine the contribution to the pressure component by multiplying the value of the sub-parameter by the specified weightage. Next, compute the total count of sub-parameters. The contribution to the pressure component is equivalent to the multiplication of the value of the sub-parameter and the weightage value.

Sub-Parameter Name	Number of Total Sub Parameters	Sub Parameter Value	Sub Parameter Value	Weightage Value	Contribution to Pressure Component
Cyclone and Storm Surge	4	0.25	95.87	0.239675	0.3831
Coastal Erosion	4	0.25	55.81	0.139525	0.223
Salinity Intrusion	4	0.25	48.24	0.1206	0.1927
Sea Level Rise	4	0.25	50	0.125	0.2001

Table 18: Contribution of Pressure Component

5.3.1.5 Determination of State Components

Displays data over the state component that exhibits similar patterns.

1. Establish numerical values:
Total Sub-Parameters: This parameter is clearly defined (sometimes used interchangeably with pressure, but we will treat them as comparable for now unless stated otherwise).
Every sub-parameter is specified with a corresponding value.
Weightage Value: Standardized relative impact of each sub-parameter.

2. Moreover, the expression for calculating the contribution of each sub-parameter to the state component is as follows:

The calculation of the Contribution to State Component involves multiplying the Sub-Parameter Value by the Weightage Value of the Total Sub-Parameters. The value is obtained by multiplying the corresponding Sub-Parameter Value with the Weightage Value of the Total Sub-Parameters.

Table 19: Contribution of State Component

Sub-Parameter Name	**Number of Total Sub Parameters**	**Sub Parameter Value**	**Sub Parameter Value**	**Weightage Value**	**Contribution to State Component**
Socio Economic Vulnerability	**5**	**0.2**	**95.4**	**0.1908**	**0.3189**
Absence of Basic Needs	**5**	**0.2**	**74**	**0.148**	**0.2474**
Decay of Embankment	**5**	**0.2**	**54**	**0.108**	**0.1805**
Extreme Weather Phenomena	**5**	**0.2**	**46**	**0.092**	**0.1538**
Land Area Change	**5**	**0.2**	**29.729**	**0.059458**	**0.0994**

5.3.1.6 Methods of computation

Pressure component

Assigning the values obtained from the picture analysis:

Cyclonical and meteorological storm surge phenomena:

The sub-parameter value is 95.87.

The assigned weight is 0.279673.

The calculation of the contribution is as follows: 95.87×0.2796734=0.3361\frac{95.87 \times 0.279673}{4} = 0.3361495.87×0.279673=0.3361, as previously specified.

Coastal erosion:

The sub-parameter value is 55.81.

The assigned weight is 0.193925.

The contribution is supplied as 55.81×0.1939254=0.2323\frac{55.81 \times 0.193925}{4} = 0.2323455.81×0.193925=0.2323.

Salinity intrusion:

Indicative Sub-Parameter Value: 45.24

Weightage Estimate: 0.1702

The contribution is computed as 45.24×0.17024=0.1927\frac{45.24 \times 0.1702}{4} = 0.1927445.24×0.1702=0.1927, which is currently known.

Sea level rise:

The current value of the sub-parameter is 50.

Numerical Weight: 0.01705

As previously stated, the contribution is equivalent to 50×0.017054=0.0001\frac{50 \times 0.01705}{4} = 0.0001450×0.01705=2001.

The calculations confirm the contributions to the pressure component as graphically shown.

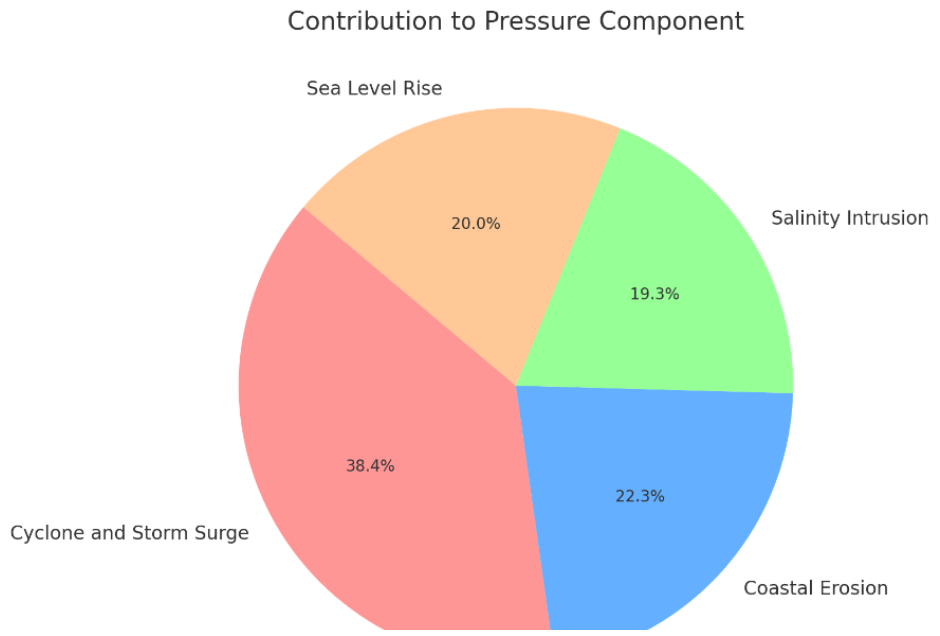


Figure 21: Contribution of State Component

State component

To compute the contributions of the state components, we need appropriate data, namely the Sub-Parameter Value and Weightage Value, as depicted in the image.
Assuming similar methodologies:
Compute the product of the Sub-Parameter Value and the Weightage Value for every sub-parameter that has been allocated.
Partition the data by the number of sub-parameters, if not equal to 5, and make necessary modifications.
With reference to the two provided images, let us analyze the patterns of migration of individuals from Saint Martin Island to other areas in Bangladesh.

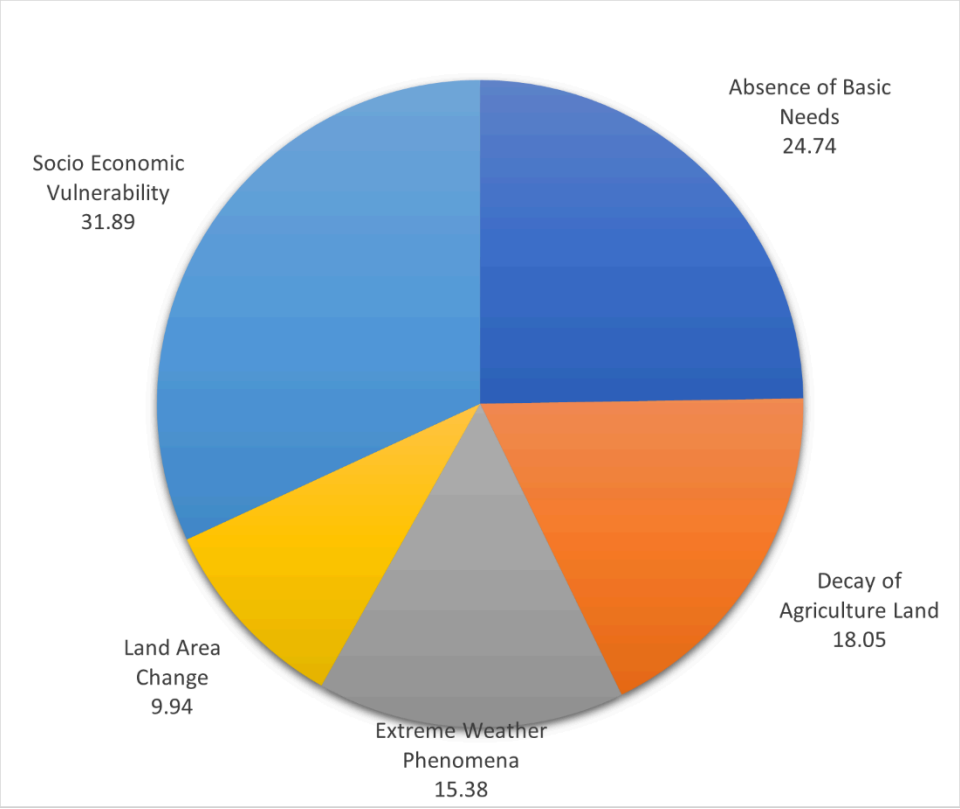


Figure 22: Contribution of State Component

5.3.2 Seasonal migration of Saint Martin Island

5.3.2.1 Impact:

The above figure visually represents the migration patterns from Saint Martin Island to different areas within Bangladesh. It exhibits the following:

5.3.2.1.1 Seasonal Migration

- **Migratory pathways:**

The map utilizes arrows to indicate the direction of migratory movements from Saint Martin Island to various locations.

The thickness of the arrows and the size of the circles are directly related to the percentage of migration to each district, thereby visually indicating the degree of migration intensity experienced.

- **Emphasized districts and their respective percentages:**

A significant proportion of migrants from Saint Martin Island, specifically 26.4%, opt to relocate to Teknaf, the district that is geographically nearest to them. Its accessible accessibility and possible commonalities in socioeconomic or environmental aspects are the basis for this strategic decision.

Table 20: Information about if they migrate or not

Information of Migration	Percent
No	78.4
Yes	**21.6**
Total	100

Table 21: District wise Migration of Saint Martin Island

District	Percent
Chandpur	3.3
Chattogram	18.7
Comilla	6.6
Cox's Bazar	19.8
Dhaka	12.1
Feni	5.5
Naokhali	7.7
Teknaf	26.4

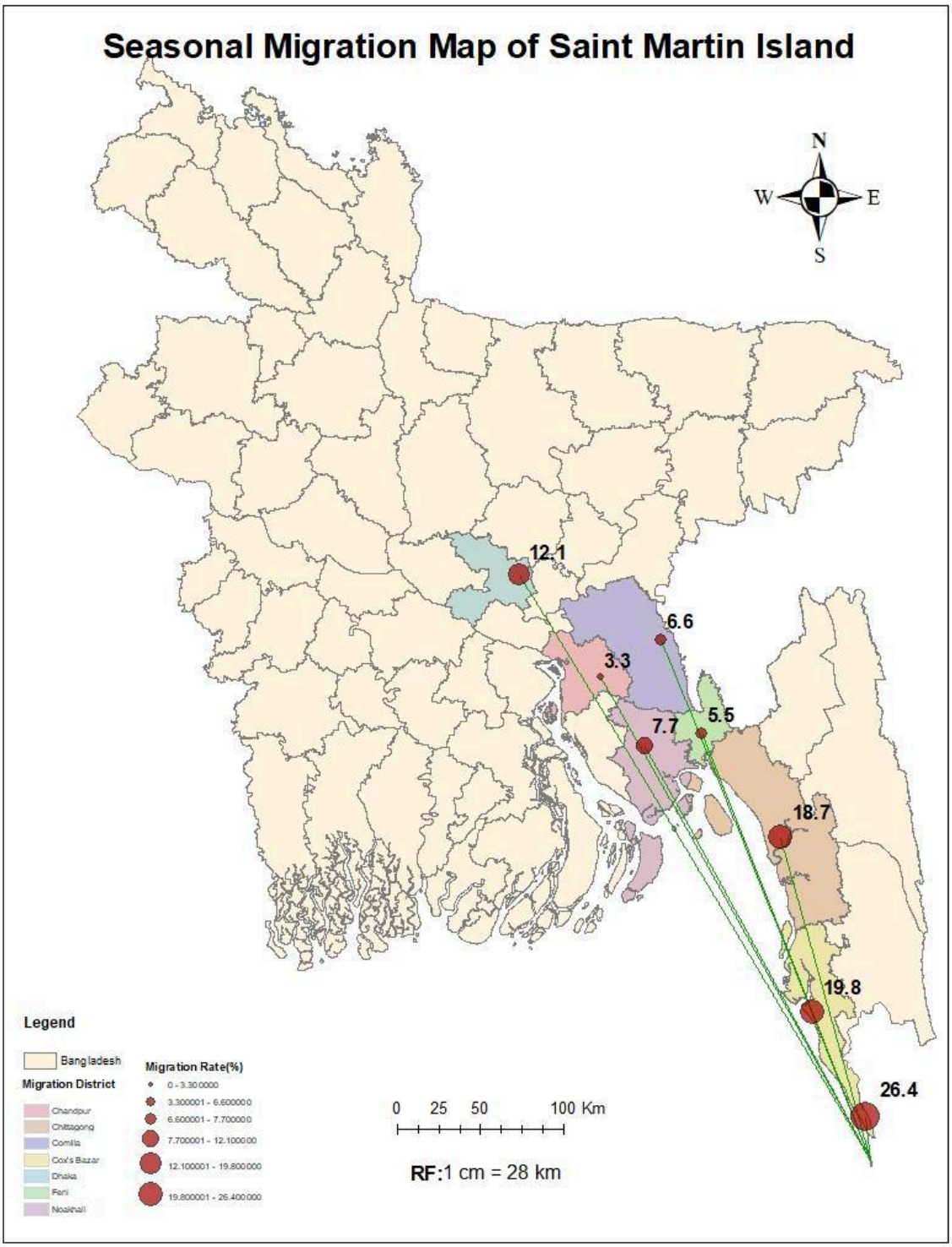


Figure 23: Seasonal Migration Map of Saint Martin Island

The migratory destinations of Cox's Bazar (19.8%) and Chattogram (18.7%) are significant due to their close proximity and the presence of advantageous economic opportunities.

Although Dhaka is situated at a greater distance from Saint Martin Island, it nevertheless receives a substantial number of migrants, accounting for 12.1% of the population. The observed phenomenon can be ascribed to the existence of a broader spectrum of economic opportunities or the presence of extended familial ties.

Low shares of migrants in the districts of Noakhali (7.7%), Comilla (6.6%), Feni (5.5%), and Chandpur (3.3%) indicate either less frequent movement or smaller migration volumes relative to the total population.

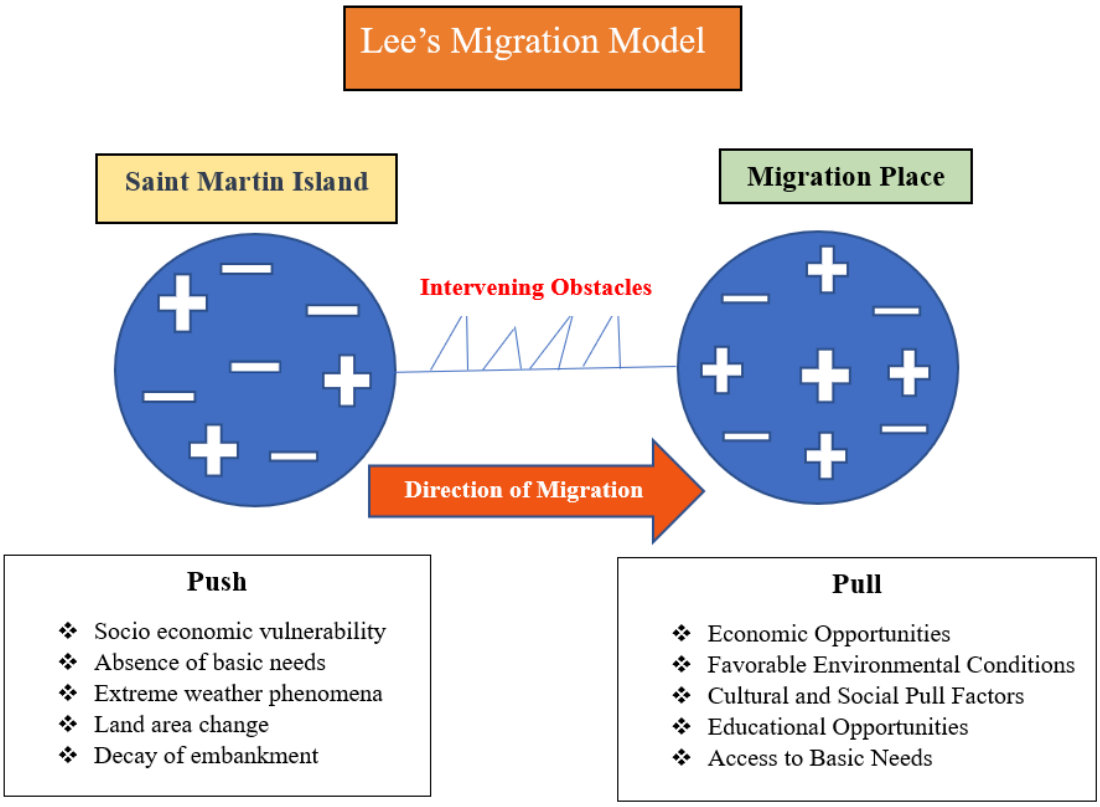


Figure 24: Lee's Migration Model

- **Cartographic Legend:**

The legend illustrates the color hierarchy that assigns to the migration rate of each district, with darker shades indicating higher movement percentages.

Examination and analysis of the observed migration trends

Proximity and Access: The main regions characterized by migration are the neighboring districts of Teknaf, Cox's Bazar, and Chattogram. Hence, the proximity and easy reach of a destination are crucial factors in influencing migration decisions, as shorter distances can reduce travel costs and risks, and migrants may have more prior knowledge of these regions.

Despite its physical distance, Dhaka attracts a significant number of migrants because of its thriving economic and social growth opportunities. This may be attributed to its status as the capital city, which offers a diverse array of job opportunities, better infrastructure, and more comprehensive social services compared to other jurisdictions.

The seasonal migration from Saint Martin Island is likely influenced by environmental stressors such as coastal erosion, sea level rise, and severe weather occurrences. These pressures hinder the island's ability to support human habitation and ensure its economic sustainability during certain times of the year. Migrants seek temporary refuge in other geographic regions, where they may perhaps obtain temporary employment or receive necessary assistance.

5.3.2.1.2 No Migration

The scope of migration destinations indicates that while some persons opt to stay near familiar environments (e.g., Teknaf), others are willing to travel to more urbanized regions in pursuit of better opportunities. The aforementioned differentiation highlights the many strategies that people or families use to address environmental and economic constraints.
The data obtained from both images illustrates that the seasonal migration from Saint Martin Island is influenced by a combination of elements such as proximity in geography, economic opportunities, and environmental conditions. Adopting a thorough understanding of this notion is crucial for developing effective policies and support systems to meet the needs of migrants, strengthen local resilience, and perhaps reduce the necessity for migration resulting from environmental risks.

The bar graph titled "Impact of Off-Season Stay in Saint Martin Island" illustrates the specific challenges faced by those who opt to visit Saint Martin Island during the off-peak season, perhaps due to environmental constraints or financial concerns. Presented below is a comprehensive study of the consequences as depicted in the chart:
Classification of Impact Categories and their respective percentages

- **Economic adversity (40.4%):**

The predominant issue voiced by the inhabitants of the island is the considerable weight of economic hardship, affecting 40.4% of the population.

These data suggest that a significant percentage of the residents have financial difficulties, most likely due to limited employment opportunities, reduced tourism (a principal source of income), and maybe the excessively high pricing of necessary goods and services during times of low demand.

- **Limited accessibility of healthcare services (28.2%):**

Lack of adequate availability of medical care is the second most prevalent issue, affecting 28.2% of the population.
This indicates a deficiency in adequate healthcare infrastructure or services on the island, which may be exacerbated during the non-peak season due to limited accessibility or supply chain issues, so leaving the population vulnerable to health crises.

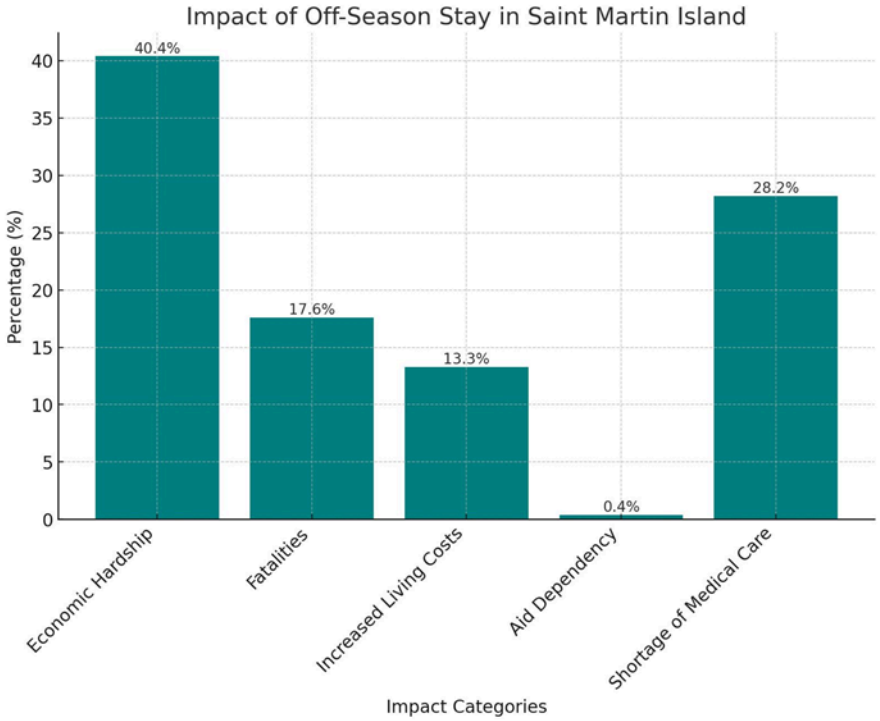


Figure 25: Impact of Off-Season Stay in Saint Martin Island

- **Mortality rate: 17.6%**

The mortality rate of 17.6% highlights the substantial hazards faced by the inhabitants, which may be ascribed to extreme weather events, inadequate emergency services, or other highly dangerous conditions prevalent on the island.

- **Increase in living expenses (13.3%):**

The rising cost of living presents a difficulty for 13.3% of the population.

This phenomenon can be ascribed to the increase in prices for goods and services during the not-peak season, when supply networks face strain or when fewer commodities are brought to the island due to reduced demand.

- **Aid Dependency (0.4%):**

Aid dependency is reported by 0.4% of the population, suggesting that while some persons indeed rely on external help, it is not as widespread as other issues. However, it may indicate a reliance on government or NGO support in particular urgent circumstances.

Analysis and interpretation of the collected data
The considerable percentage of persons experiencing economic hardship and acute constraints of medical care suggests that those who stay on the island are very vulnerable to both economic and health disasters. This phenomenon can be ascribed to the factors of isolation, limited economic diversification, and insufficient provision of public services.

The significant prevalence of economic hardship and deficiencies in medical care underscores the pressing need for improvements in infrastructure and comprehensive economic support. Enhancements in healthcare infrastructure and improved economic opportunities have the potential to mitigate some of these challenges.
The presented graphic highlights the need of improving the management of seasonal hazards. The elevated mortality rate underscores the risks associated with staying on the island during off-peak seasons, maybe resulting from natural disasters or inadequate safety measures.

Residents opting to remain on Saint Martin Island during the off-peak season face significant challenges, particularly in terms of financial hardship and access to healthcare services. This data underscores the need of adopting targeted strategies to improve living conditions, enhance healthcare services, and develop sustainable economic strategies to support the local population during times of environmental stress and economic downturn.
Proposed measures to alleviate the seasonal migration pattern observed on Saint Martin Island

5.3.3 Develop mitigation strategies of seasonal migration on Saint Martin Island

This study presents a Mitigation Strategies Model designed to precisely address the issue of Seasonal Migration caused by Climate Change and Coastal Hazards on Saint Martin Island. In order to understand the interrelationships among different stages and the goals of the mitigation efforts in stabilizing both Saint Martin Island and the migrated areas, let us examine the components of the flowchart.

5.3.3.1 Mitigation strategies Model in response to Seasonal Migration in Saint Martin Island

Stability in Saint Martin Island is represented by the first block in the flowchart. This reflects the ideal state of the island, marked by a balanced state of harmony between environmental conditions and socio-economic factors, therefore allowing the culture to thrive without the need for seasonal migration. The phenomenon of Climate Change presents a significant obstacle to maintaining stability, as it serves as the main driver for a series of impacts and changes in the existing conditions.

Global warming is the primary catalyst for a cascade of interconnected environmental and socio-economic issues. The aforementioned encompass:
Extreme weather phenomena are characterized by an increased frequency and intensity of cyclones, hurricanes, and other high-impact weather events that directly endanger the life and livelihood of the island's residents.

Socio-economic vulnerability: The community's heavy dependence on climate-sensitive occupations, such as fishing and agriculture, makes them very vulnerable to the impacts of environmental changes.

Absence of Basic Needs: Limited access to essential resources such as safe drinking water, fuel, and medical treatment significantly increases vulnerability.

Land Area Change: Coastal erosion and sea-level rise lead to the reduced availability of cultivable and inhabited land, requiring the relocation of individuals.

The deterioration of defensive infrastructure, such embankments, results in increased susceptibility to flooding and storm surges.
The aforementioned consequences result in a state of instability, prompting residents to consider migration as a strategy for adapting.

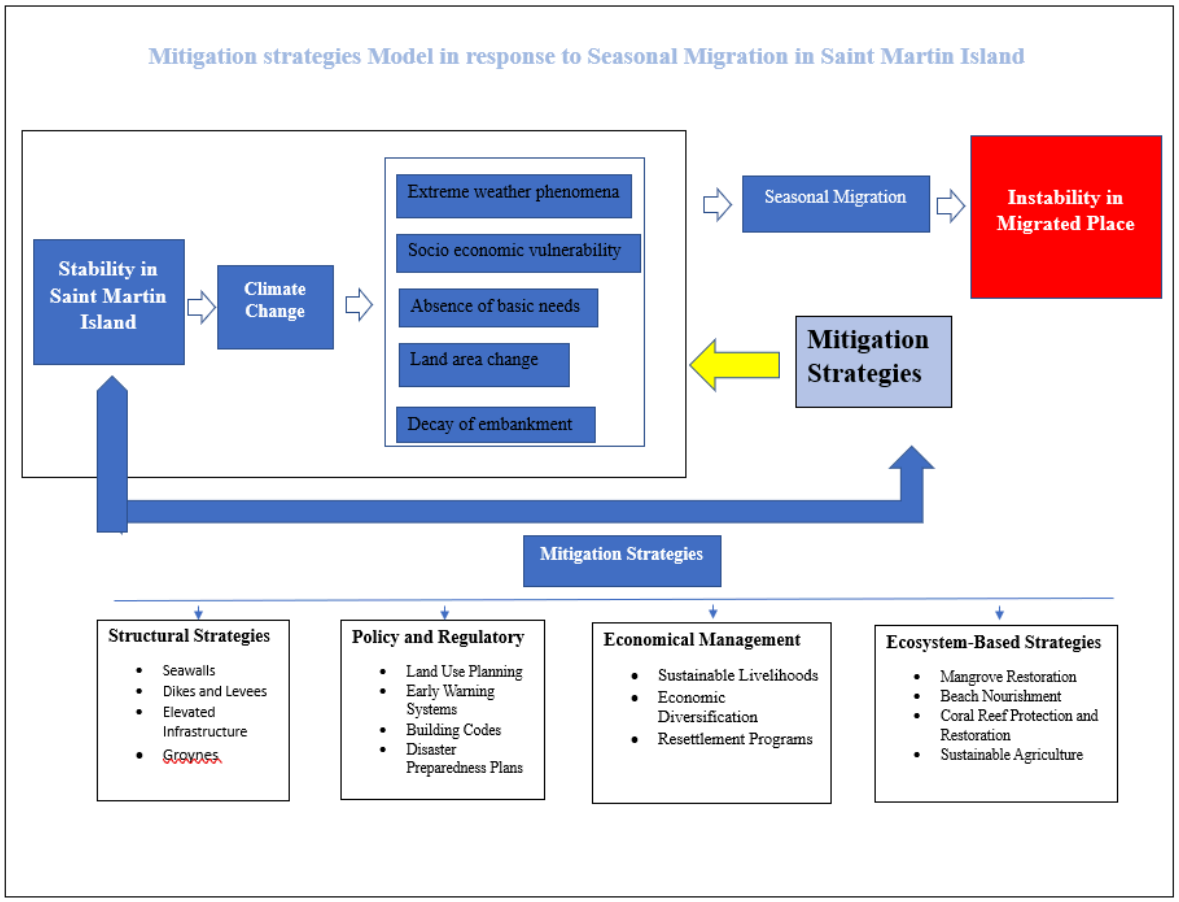


Figure 26: Mitigation strategies Model in response to Seasonal Migration in Saint Martin Island

- **Seasonal migration**

Due to the consequential effects and modifications in the environment caused by climate change, residents are compelled to participate in Seasonal Migration. Migration of this kind sometimes arises as a temporary response to environmental constraints, when individuals or families move to different regions during specific seasons to find work, acquire resources, or escape from unfavorable conditions.

Hence, although seasonal migration may offer momentary relief, it is not a feasible long-term alternative. Such circumstances might lead to a multitude of challenges for both the migrants and the places they journey to.

- **Dynamic instability at a relocated site**

An analysis of the flowchart reveals that seasonal migration is a significant element in the creation of instability in migratory communities. The instability arises due to several causative elements:

The phenomenon of overcrowding occurs when migrants are drawn to areas characterized by a high population density, therefore exerting an unsustainable burden on local resources.

Heightened competition for employment and resources: Migrants may face substantial competition for employment, housing, and vital services, potentially leading to socio-economic tensions.

Inadequate Infrastructure: Migrated regions may suffer from a dearth of essential infrastructure or services to accommodate the substantial influx of migrants, resulting in problems such as substandard housing, restricted access to sanitation, and inadequate healthcare.

Migrants may encounter significant obstacles in their pursuit of stable employment or income, leading to economic hardship and increased need on aid.
An adverse outcome of the arrival of migrants is the disturbance of indigenous social and cultural dynamics, perhaps leading to conflicts or the division of society.

5.3.3.2 **Mitigation Strategies**

This model proposes a range of Mitigation Strategies to address both the causes of migration and the resulting instability in the relocated regions. The strategies may be categorized into four main major classifications:

Structural strategies:

The use of structural strategies, such as seawalls, dikes, and elevated infrastructure, serves to protect Saint Martin Island from coastal hazards, therefore reducing the need for migration.

- The implementation of seawalls along vulnerable coastlines functions to alleviate land erosion and protect settlements from storm surges and strong waves. Seawalls serve as

defensive structures that reduce the destructive power of approaching waves, therefore limiting their ability to erode coastal land and damage infrastructure.

- Dikes and levees are purpose-built structures designed to effectively control and reduce the flooding resulting from storm surges and high tides. The implementation of dikes and levees can effectively mitigate the inundation of low-lying areas by seawater, therefore ensuring the protection of agricultural areas and residential communities.

- The development of elevated infrastructure, such as residential buildings, educational institutions, and medical facilities, ensures the uninterrupted operation of critical operations. Buildings featuring raised structures exhibit greater resistance to water damage and provide safer havens during extreme weather conditions.

- Groynes are elongated and slender man-made structures intentionally built from the shoreline to the ocean in order to reduce coastal erosion. Groynes trap sand, carried by longshore drift, functions to maintain the width of the beach and provide a defensive barrier against wave activity.

Policy and regulatory strategies :

land use planning, construction rules, early warning systems, and disaster preparedness plans are essential for effectively managing the risks posed by climate change and coastal diseases.

- Optimal land use planning ensures that development occurs in secure sites, distant from regions with a high susceptibility to flooding, erosion, or storm surges. Zoning restrictions are regulations that establish limitations on the kind of buildings permitted to be built in areas deemed endangered.

- Systematic early warning systems are essential for facilitating safe evacuation and proactive execution of protective measures in communities impacted by cyclones, storm surges, and other extreme weather events. Continuous monitoring and reliable communication channels are essential for the efficient functioning of these devices.

- The effective mitigation of damage during severe weather phenomena can be achieved through the implementation and enforcement of stringent building codes that require structures to possess the ability to withstand strong winds and flooding. These regulations may include requirements for elevated foundations, reinforced materials, and storm-resistant shutters.

- The implementation of thorough disaster preparedness plans, including established evacuation routes, emergency shelters, and community response strategies, has the capacity to prevent loss of life and reduce economic damages. The implementation of systematic exercises and the active engagement of the community are essential to ensure preparedness.

Economic Management Strategies:

By promoting sustainable livelihoods, economic diversification, and resettlement programs, the community's dependence on labor that is vulnerable to climate change is greatly reduced, so decreasing economic vulnerability and the incentive to migrate.

- Fostering sustainable livelihoods, such as crafts, eco-tourism, or aquaculture, could reduce dependence on fishing and farming, which are more susceptible to coastal hazards and consequently less susceptible to environmental fluctuations. These livelihoods can be advanced through the implementation of training courses and microfinance initiatives.

- Economic diversification refers to the deliberate effort to encourage manufacturing diversification, therefore reducing the community's reliance on a single industry. By developing multifaceted economic sectors such as tourism, agriculture, and service industries, the local economy strengthens its capacity to endure and rebound from environmental hazards.

- Resettlement programs are systematic efforts that enable the transfer of communities facing severe risk from highly vulnerable areas to more secure locations. The careful design of these programs is crucial to ensure that relocated populations have access to essential services and sustainable livelihood opportunities.

By adopting ecosystem-based approaches such as the restoration of mangroves, nourishment of beaches, protection of coral reefs, and practice of sustainable agriculture, the island's intrinsic capacity to endure environmental changes can be enhanced. Consequently, this process fosters stability within the community and mitigates the elements that contribute to migration.

Ecosystem Management

- The rehabilitation of mangroves functions as an inherent mechanism to alleviate the impacts of waves and storm surges, impede erosion, and facilitate the accumulation of silt. The rehabilitation and enlargement of mangrove forests along the coast possess the

capacity to protect coastlines, provide a habitat for marine fauna, and support sectors such as fishing and tourism.

- Beach Nourishment: The incorporation of sand into decaying beaches can efficiently maintain the width of the beach, establish a defensive barrier against wave action, and save surrounding coastal infrastructure. Executing beach nourishment necessitates scrupulous care to avoid any detrimental impact on marine habitats.

- Reef protection and restoration: Coral reefs act as natural barriers, reducing wave energy before it reaches the shoreline. Conserving the ecological balance of existing reefs and restoring damaged reefs can enhance coastal protection and stimulate marine biodiversity and tourism.

- Employing sustainable agricultural practices such as cultivating salt-tolerant crops, practicing organic farming, and implementing efficient water management systems can help alleviate the negative impacts of saltwater intrusion and soil degradation on agricultural crop productivity.

- The successful application of these techniques helps to preserve stability in Saint Martin Island by reducing vulnerability and strengthening ability to withstand climate change and coastal disasters.

Feedback loop

Moreover, the flowchart incorporates a Feedback Loop process.

• Prevention and Improvement: The effective implementation of this mitigation strategy not only addresses current deficiencies but also prevents further degradation of the environment and socio-economic conditions. For example, the adoption of efficient coastal protection strategies and sustainable livelihood initiatives can lead to improved resilience and reduced limitations on migration.

• Interactions and Feedback: This component illustrates the dynamic correlation between the mitigation strategies and the ongoing state of Saint Martin Island and the areas where human migration has taken place. By implementing mitigation mechanisms, the conditions on the island are improved, resulting in a reduction of the factors that cause migration. This, in turn, has the potential to alleviate the instability in the places where migrants have established themselves.

The flowchart offered illustrates a comprehensive conceptual framework designed to understand and efficiently address the challenges related to seasonal migration resulting from coastal hazards on Saint Martin Island. By identifying the origins of driving forces, pressures, state changes, and repercussions, the model proposes a comprehensive approach to stabilize the island and reduce the socio-economic and environmental causes that stimulate migration. The methodologies give priority to interventions based on structure, policy, economy, and ecology, with the simultaneous objective of bolstering resilience, promoting sustainable development, and improving the quality of life for the residents of the island. Consequently, this phenomenon contributes to a reduction in the need for migration and mitigates instability in the regions where migrants have established themselves.

Chapter 6:

Recommendation and conclusion

6.1 Recommendations

- **Infrastructure and Coast:** There needs to be a strategic plan for setting up infrastructure, especially in coastal zones where sea level rise is at its peak and storm surges weaken the coast due to erosion. This will include building sea defences, raising homes, and sustainable floodwater storage.

- **Early Warning Systems and Disaster Preparedness Plan:**
  State-of-the-art technology has been used in the installation of early warning systems for cyclones, storm surges, etc., which can give advanced information to prepare well ahead, including managing evacuations at community levels and other disaster preparedness measures. A disaster preparedness plan is tailored to each community, taking into account the risks in that area.
- **Ensuring Livelihoods Sustainable:** Create opportunities for diversification in local sources beyond climate-sensitive resources, such as fishing and agriculture, to reduce dependence on a shrinking baseline. The necessity of a fisheries management system is even more critical to help communities know how the regime operates since training programs and assistance for a transition toward alternative income-generating activities — such as sustainable tourism or small-scale aquaculture – can create reliable alternatives that allow theistic alternatives.
- **Ecosystem-based Adaptation Strategies:**
  Utilize natural defense systems like mangroves, coral reefs, and beach dunes to lessen the islands' ability to protect against coastal hazards, such as storm surge buffers, and decrease the intensity of extreme weather events that harbor plant life biodiversity.
- **Community engagement:**
  Involvement at the community level in planning and decision-making will be crucial for delivering practicable adaptation options. Local capacity building should focus on developing and applying local knowledge, supporting hazard preparedness, resource management, and sustainability.
- **Policy and Regulatory Frameworks:**
  A suite of improved policies for land use, coastal development, and any environmental conservation in general is a must. This would require the regulations to ensure while preventing enhancement in physical exposure of these coastal populations due to developmental activities, they lead development pathways that are sustainable and not on social and environmental costs over a longer-term period.
- **Better Access to Resources and Services:**
  It is very important for the stakeholders in civil defense planning that all those actions demand access to clean water, health facilities, dispensaries near me, high education institutions, and emergency services. Addressing the direct and indirect effects of seasonal migration and burdens is only possible by providing social infrastructure.
- **Research and Monitoring:**
  Coastal hazard research and monitoring programs for adaptive management strategies; information being collected on changes in migration volume (associated with socio-economic change) may feed into the development of more targeted interventions. Climate-Resilient Agriculture: Introduce a climate-resilient agriculture system and salt-tolerant crops under water-stressed field conditions. This could mean producing

salt-tolerant varieties of rice and organic agronomic practices that aid in soil health without the use of chemicals.

- **Water Resource Management:**
  Implement integrated water management strategies to address fresh and saline water scarcity due to salt incursion caused by level rise, an approach to drinking water and service, and agricultural quality agriculture. Among the most immediate actions to end "The Day" are rainwater harvesting, small-scale desalination plants, and efforts to keep freshwater aquifers from being depleted.
- **Create social safety nets:**
  Create effective support systems for those most likely to be impacted by these shocks (pre, during, and post). Some of the options that might be in place include initiatives like direct cash transfers, distribution of food rations for free, temporary employment programs, or insurance schemes, which can provide safety net coverage to lessen economic losses from coast-related hazards.
- **Promotes Sustainable Tourism:**
  Developing Sustainable Property into high value and creating dividends promotes sustainable tourism and leverages the natural environment without degrading the ecology. Generate economic benefits via eco-tourism initiatives, where such activities promote conservation values by reducing environmental footprints due to tourism pressures in coastal habitats.
- **Integrated Coastal Zone Management:**
  (Integrated Coastal Zone Management) that must consider all relevant issues of coastal development, from the health ecosystems to economics. (Integrated Coastal Zone Management) is a process that increases integration -it coordinates, and between government, local civic leaders, even the non-profit sector, such as confederation includes more countries- which also involves the private in relation to managing the coast sustainably.
- **Build Community through Education:**
  To prepare for the future, create a community around conversation, books, discussion clubs, online news stations, and wikis. This means free training on how to create sustainable and equitable success. Educating children and adults to identify potential threats and what they should possibly run out of their homes on a cold winter's night in no shoes just prepares them for being able to survive alone during an emergency.
- **Rebuild Transportation and Communication Networks:**
  Re-establish transportation communications systems to rescue affected people and quickly shift them to safer places, also restoring a steady supply of ration material. Reducing response time and subsequent loss faced from coastal hazards requires efficient road networks, bridges, and communication systems.
- **Enhancing Local Governance and Institutional Capacity Strengthen:**

Local governance structures and institutions to plan, implement, coordinate, and monitor adaptation measures for disaster risk reduction efforts. Some ideas include training local officials in climate resilience and technical expertise and getting financiers to adjust their budgets.

- **Regional and global collaboration on coastal management planning:** participation in lab engagement (1x) on climatic resiliency. Sharing knowledge, resources, and best practices with neighboring countries and international bodies will enhance Fiji's capacity to adapt to hazards.
- National governments and states with high-risk areas that are not actually sustainable for settlement must establish planned relocation strategies that employ participatory methods. It requires identifying safe havens and ensuring that people are guaranteed their basic needs, whether or not at the whims of a storm; it also demands the celebration of something more than just racial identity.
- **Gender-responsive approaches:** Recognize and mitigate disparate impacts to ensure that when men are differently affected from women, responses plan and respond accordingly. Create a community resilience strategy that is more inclusive and intervention-effective through the equitable distribution of resource provision to women who undergo training programmed as they participate in decision-making.
- **Design Of Monitoring & Evaluation System:** Design good dual-monitoring and interviews or evaluations to measure the effectiveness of those unsuccessfully put in place mitigation [mitigation] measures. The system should give feedback on what works, what does not and why — that, in turn, leads to an iterative process of improvement and changing strategies given circumstances.Saint Martin Island could also insure itself sustainability and resilience — but only if its members address the root sources of increased risk without emigrating, again in a more holistic way with these additional suggestions.

6.2 Conclusion

Since the Island is located in Bay Bengal, it will face a number of coastal hazards, such as sea-level rise, storm surges, and flooding, as well as increased wind speed. These threats persist

and severely impact the social drivers of susceptibility to local communities, which now adapt to variations in seasonal migration patterns. The findings highlight the need for comprehensive, cross-cutting approaches to mitigating these hazards and building community resilience.

This complex mix of problems calls for a solution that involves physical, biological, economic, and social strategies. Key interventions that can reduce vulnerability are investments in infrastructure, early warning systems, alternative livelihoods, and the restoration of natural ecosystems. Complementarily, an effective policy framework is needed to guarantee a stable long-term adaptation approach, and adaptability strategies need community engagement and capacity-building efforts.

Implementing these suggestions will transform Saint Martin Island into a resilient community, less vulnerable to coastal calamities. This will alleviate the pressure of seasonal migration and preserve its unique cultural and natural attributes. Noting the recent great attention given by planners to calls such as those above, this integrated approach will not only safeguard the island-dwellers but also propel us towards our larger objectives in sustainable growth.

Reference

1. Abdullah, M., Miraj, C., Chowdhury, A., Hossain, A., Abdul, D., Rana, K., & Cox's Bazar. (n.d.). *Cleaning up of Saint Martin Coral Island Team Members Under the project Mainstreaming CSR to Address Poverty Implemented by Management and Resources*

Development Initiative. https://mrdibd.org/wp-content/uploads/2021/08/Cleaning-up-of-Saint-Martin-Coral-Island.pdf

2. Achard, F., & Hansen, M. C. (2016). *Global Forest Monitoring from Earth Observation*. CRC Press. https://doi.org/10.1201/b13040
3. *Action Plan on Climate Change Adaptation and Resilience*. (n.d.). https://documents1.worldbank.org/curated/en/519821547481031999/The-World-Bank-Groups-Action-Plan-on-Climate-Change-Adaptation-and-Resilience-Managing-Risks-for-a-More-Resilient-Future.pdf
4. Adams, H., & Kay, S. (2019). Migration as a human affair: Integrating individual stress thresholds into quantitative models of climate migration. *Environmental Science & Policy*, *93*, 129–138. https://doi.org/10.1016/j.envsci.2018.10.015
5. Afjal Hossain, Md., Imran Reza, Md., Rahman, S., & Kayes, I. (2011). Climate Change and its Impacts on the Livelihoods of the Vulnerable People in the Southwestern Coastal Zone in Bangladesh. *Climate Change and the Sustainable Use of Water Resources*, 237–259. https://doi.org/10.1007/978-3-642-22266-5_15
6. Afroz, N., & Mahmud, M. S. (2017). Analyzing the problem and prospects of ecotourism: A review on bangladesh. *IOSR Journal of Business and Management*, *19*, 59–65. https://doi.org/10.9790/487X-1905035965
7. Ahmad, H., & Jhara, S. (2009). *Present status of Impacts of climate change and adaptations in Bangladesh coastal areas*. https://ypsa.org/ypsa/wp-content/uploads/2021/08/Present-status-of-Impacts-of-climate-change-and.pdf
8. Ahmed, A., Nawaz, R., Drake, F., & Woulds, C. (2018). Modelling land susceptibility to erosion in the coastal area of Bangladesh: A geospatial approach. *Geomorphology*, *320*, 82–97. https://doi.org/10.1016/j.geomorph.2018.08.004
9. Ahmed, M. K., Yeasmin, F., Islam, M., Barman, A., & Hossain, Z. (2021). *Climate change-induced livelihood vulnerability and adaptation of st. Martin's island's community, bangladesh* (pp. 267–282). https://doi.org/10.1007/978-3-030-71950-0_9
10. Ahmed, Md. K., Yeasmin, F., Islam, M., Barman, A., & Hossain, Z. (n.d.). *limate Change-Induced Livelihood Vulnerability and Adaptation of St. Martin's Island's Community, Bangladesh*.
11. Al Nahian, S., Rakib, Md. R. J., Haider, S. M. B., Kumar, R., Mohsen, M., Sharma, P., & Khandaker, M. U. (2022). Occurrence, spatial distribution, and risk assessment of microplastics in surface water and sediments of Saint Martin Island in the Bay of Bengal. *Marine Pollution Bulletin*, *179*, 113720. https://doi.org/10.1016/j.marpolbul.2022.113720
12. Ara, S., Uj, A., Alif, M. A., & Islam, K. M. (2021, July 6). *Impact of Tourism on LULC and LST in a Coastal Island of Bangladesh: A Geospatial Approach on St. Martin's Island of Bay of Bengal*.

13. Araújo Vila, N., R. Toubes, D., & Fraiz Brea, J. A. (2019). Tourism Industry's Vulnerability upon Risk of Flooding: The Aquis Querquennis Complex. *Environments*, *6*(12), 122. https://doi.org/10.3390/environments6120122
14. Arsenault, M.-P., Azam, M., & Ahmad, S. (2015). *Riverbank erosion and migration in bangladesh's char lands* (pp. 41–62).
15. Avi, A. R. (2023). Issues Affecting Tourists' Satisfaction at Saint Martin Island, Bangladesh: Empirical Evidence and Suggestions. *Tourism in Marine Environments*, *18*(1-2), 1–17. https://doi.org/10.3727/154427323X16835293069953
16. Bangladesh Bureau of Statistics (BBS).
17. *Bangladesh Statistics bureau* (2022). Bbs.gov.bd. https://bbs.gov.bd/site/page/47856ad0-7e1c-4aab-bd78-892733bc06eb/-
18. Bolan, S. (2024). Impacts of climate change on the fate of contaminants through extreme weather events. *Science of the Total Environment*, *909*, 168388. https://doi.org/10.1016/j.scitotenv.2023.168388
19. Brammer, H. (2014). Climate change, sea level rise and development in Bangladesh. The University Press Limited.
20. Brammer, H. (2014). *Climate change, sea level rise and development in Bangladesh*. The University Press Limited.
21. *C40 Knowledge Community*. (2024). C40knowledgehub.org. https://www.c40knowledgehub.org/s/article/Climate-change-resilience-in-the-built-environment-Principles-for-adapting-to-a-changing-climate?language=en_US
22. Cambers, G. (2001). *PROFESSIONAL DEVELOPMENT PROGRAMME: COASTAL INFRASTRUCTURE DESIGN, CONSTRUCTION AND MAINTENANCE A COURSE IN COASTAL ZONE/ISLAND SYSTEMS MANAGEMENT CHAPTER 4 COASTAL HAZARDS AND VULNERABLITY*. https://www.oas.org/cdcm_train/courses/course1/Chapter%204-Coastal%20Hazards%20and%20Vulnerability.pdf
23. *Causes of Climate Change*. (2023). European Commission. https://climate.ec.europa.eu/climate-change/causes-climate-change_en
24. Choi, K. (2014). Morphology, sedimentology and stratigraphy of Korean tidal flats – Implications for future coastal managements. *Ocean & Coastal Management*, *102*. https://doi.org/10.1016/j.ocecoaman.2014.07.009
25. Chowdhury, A. J., & Rasul, G. (2011). Coral conservation and restoration program in Saint Martin's Island, Bangladesh. Journal of Marine Science Research and Development, 1(2), 1-4.
26. Chowdhury, A. J., & Rasul, G. (2011). Coral conservation and restoration program in Saint Martin's Island, Bangladesh. *Journal of Marine Science Research and Development*, *1*(2), 1-4.

27. *Climate-smart agriculture (CSA) considerations*. (n.d.). https://climateknowledgeportal.worldbank.org/sites/default/files/2019-06/CSA-in-Bangladesh.pdf
28. Coherent Market Insights. (2024). *Climate And Carbon Finance MarketChallenges and Opportunities*. Coherentmarketinsights.com. https://www.coherentmarketinsights.com/market-insight/climate-and-carbon-finance-market-5743/market-challenges-and-opportunities
29. Coral Reef Alliance. (2021). *Global Threats to Coral Reefs*. Coral Reef Alliance. https://coral.org/en/coral-reefs-101/global-threats/
30. Daw, T., Adger, W., Brown, K., & Badjeck, M.-C. (2009). *Climate change and capture fisheries: potential impacts, adaptation and mitigation*. https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/1339/WF_2545.pdf?sequence=1
31. Dawson, B., & Spannagle, M. (2008). The Complete Guide to Climate Change. In *Routledge eBooks*. Informa. https://doi.org/10.4324/9780203888469
32. De Haas, H. (2021). A theory of migration: the aspirations-capabilities framework. *Comparative Migration Studies*, *9*(1). https://doi.org/10.1186/s40878-020-00210-4
33. *ECCC Data Catalogue / Catalogue de données d'ECCC*. (2024). Ec.gc.ca. https://data-donnees.az.ec.gc.ca/data/climate/plansreports/climate-action-map/MapDataDonneesdeCart.csv
34. Ehsan, S., Ara Begum, R., & Nizam Abdul Maulud, K. (2022). Household external vulnerability due to climate change in Selangor coast of Malaysia. *Climate Risk Management*, *35*, 100408. https://doi.org/10.1016/j.crm.2022.100408
35. FAO. (2015). *Climate change and food security: risks and responses*. https://openknowledge.fao.org/server/api/core/bitstreams/a4fd8ac5-4582-4a66-91b0-55abf642a400/content
36. Geldard, R. (2023, October 5). *Here's how extreme weather is affecting animal migration*. World Economic Forum. https://www.weforum.org/agenda/2023/10/climate-crisis-impacting-animal-migration/
37. Golam, M., Sarwar, M., Supervisor, & Wallman, P. (2005). *Impacts of Sea Level Rise on the Coastal Zone of Bangladesh*. https://www.lumes.lu.se/sites/lumes.lu.se/files/golam_sarwar.pdf
38. Hickey, N. (2023, December 14). *Forthcoming review: UK aid's international climate finance commitments - ICAI*. ICAI. https://icai.independent.gov.uk/forthcoming-review-uk-aids-international-climate-finance-commitments/
39. Hossain, E. (2024). *Saint martin island 2024 report*.
40. Hossain, M. (2020a). *Ecological and geomorphological study of saint martin island, bangladesh*. https://doi.org/10.13140/RG.2.2.35203.04649

41. Hossain, M. (2020b). *Ecological and geomorphological study of saint martin island, bangladesh*. https://doi.org/10.13140/RG.2.2.35203.04649
42. Hossain, M. S., & Lin, C. K. (2001). Land use zoning for integrated coastal zone management: Remote sensing, GIS and RRA techniques in the Saint Martin's Island, Bangladesh. Ocean & Coastal Management, 44(3), 601-614.
43. Hossain, M. S., & Lin, C. K. (2001). Land use zoning for integrated coastal zone management: Remote sensing, GIS and RRA techniques in Saint Martin's Island, Bangladesh. *Ocean & Coastal Management*, *44*(3), 601-614.
44. Hossain, M. S., Yasir, M., Shahriar, S., Jahan, M., Liu, S., & Niang, A. (2023). *Morphological change assessment of a coastal island in SE Bangladesh reveal high accumulation rates* (p. 102969).
45. Hossain, M., & Islam, M. (2006). STATUS OF THE BIODIVERSITY OF ST. MARTIN'S ISLAND, BAY OF BENGAL, BANGLADESH. *Pakistan Journal OfMarine Sciences*, *15*(2), 201–210. https://aquadocs.org/bitstream/handle/1834/34330/PJMS15.2_201.pdf?sequence=1&isAllowed=y
46. Hossain, M., Minar, M., Belal, M., & Shamsuddin, M. (2013). Climate Change and Coastal Zone of Bangladesh: Vulnerability, Resilience and Adaptability. *Middle-East Journal of Scientific Research*, *13*(1), 114–120. https://doi.org/10.5829/idosi.mejsr.2013.13.1.64121
47. Hossain, Md. Shahadat. (2001). Biological aspects of the coastal and marine environment of Bangladesh. *Ocean & Coastal Management*, *44*(3-4), 261–282. https://doi.org/10.1016/s0964-5691(01)00049-7
48. Hossen, Md. F., & Sultana, N. (2023). Shoreline change detection using DSAS technique: Case of Saint Martin Island, Bangladesh. *Remote Sensing Applications: Society and Environment*, 100943. https://doi.org/10.1016/j.rsase.2023.100943
49. *Human Vulnerability to Climate Change and Migration in Bangladesh–Sundarbans – INTERNATIONAL CENTER FOR CLIMATE CHANGE AND DEVELOPMENT (ICCCAD)*. (2021). Icccad.net. https://icccad.net/blog/human-vulnerability-to-climate-change-and-migration-in-bangladesh-sundarbans/
50. *INTEGRATED COASTAL ZONE MANAGEMENT PLAN PROJECT Proceedings of for Sustainable Management of St. Martin's Island Government of the People's Republic of Bangladesh Ministry of Water Resources Water Resources Planning Organization (WARPO)*. (2005). https://warpo.portal.gov.bd/sites/default/files/files/warpo.portal.gov.bd/page/aa04373f_0ca3_49a5_b77e_5108186638dc/wp038.pdf
51. International Organization for Migration. (2016, March 16). *Key Migration Terms*. International Organization for Migration; IOM. https://www.iom.int/key-migration-terms

52. Islam, M. M., & Shamsuddoha, M. (2018). "Coastal and Marine Conservation Strategy for Saint Martin's Island, Bangladesh."
53. Islam, M. M., & Shamsuddoha, M. (2018). *Coastal and marine conservation strategy for Saint Martin's Island, Bangladesh.* Bangladesh Bureau of Statistics (BBS).
54. Islam, M. M., & Shamsuddoha, M. (2018). *Coastal and marine conservation strategy for Saint Martin's Island, Bangladesh*. Bangladesh Bureau of Statistics (BBS).
55. IUCN (2015). "Environmental and Socio-economic Baseline Study of Saint Martin's Island."
56. IUCN. (2015). *Environmental and socio-economic baseline study of Saint Martin's Island.*
57. Jung Hee Hyun, Ji Yeon Kim, Chae Yeon Park, & Dong Kun Lee. (2021). Modeling decision-maker preferences for long-term climate adaptation planning using a pathways approach. *Science of the Total Environment*, *772*, 145335–145335. https://doi.org/10.1016/j.scitotenv.2021.145335
58. Kamruzzaman, M., & Uchinlayen. (2018). Assessment of Destination-specific factors of Bangladesh: A review of Saint Martin Island as an emerging Tourist Destination. *Journal of Business Studies*, *XXXIX*(1). https://www.fbs-du.com/news_event/511561027502(Page%20113-125).pdf
59. Karim, F., & Mimura, N. (2008, August 4). *Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh | Request PDF*. ResearchGate. https://www.researchgate.net/publication/223945495_Impacts_of_climate_change_and_sea-level_rise_on_cyclonic_storm_surge_floods_in_Bangladesh
60. Kiper, T. (2013). Role of Ecotourism in Sustainable Development. In *www.intechopen.com*. IntechOpen. https://www.intechopen.com/chapters/45414
61. Kuhnt, J. (2009). *Literature Review: Drivers of Migration Why Do People Leave Their Homes? Is There an Easy Answer? A Structured Overview of Migratory Determinants*. https://www.idos-research.de/uploads/media/DP_9.2019.pdf
62. Laila, F. (n.d.). *Examensarbete i Hållbar Utveckling 154 Assessment on Social Vulnerabilities to Climate Change -a Study on South-Western Coastal Region of Bangladesh Assessment on Social Vulnerabilities to Climate Change -a Study on South-Western Coastal Region of Bangladesh*. Retrieved September 3, 2024, from http://www.diva-portal.org/smash/get/diva2:648362/FULLTEXT01.pdf
63. Lakshman, M., & Ojha, C. (2023). Cyclones and its Impact on the Fishermen of Coastal region of Midnapore district in nineteenth century. © *2023 IJNRD* |, *8*(1), 2456–4184. https://www.ijnrd.org/papers/IJNRD2301336.pdf
64. M, P. K. (2021, April 26). *Review: 7 of the 8 most vulnerable states to "Climate Risks" are the Eastern States*. FACTLY; FACTLY. https://factly.in/review-7-of-the-8-most-vulnerable-states-to-climate-risks-are-the-eastern-states/

65. Manou, D., Baldwin, A., Cubie, D., Mihr, A. M., & Thorp, T. (2017). Climate Change, Migration and Human Rights. In *Durham Research Online (Durham University)*. Durham University. https://doi.org/10.4324/9781315622217
66. Marengo, J. A., Alcantara, E., Cunha, A. P., Seluchi, M., Nobre, C. A., Dolif, G., Goncalves, D., Assis Dias, M., Cuartas, L. A., Bender, F., Ramos, A. M., Mantovani, J. R., Alvalá, R. C., & Moraes, O. L. (2023). Flash floods and landslides in the city of Recife, Northeast Brazil after heavy rain on May 25–28, 2022: Causes, impacts, and disaster preparedness. *Weather and Climate Extremes*, *39*, 100545. https://doi.org/10.1016/j.wace.2022.100545
67. *Marine Pollution in the Caribbean: Not a Minute to Waste*. (n.d.). Retrieved September 3, 2024, from https://documents.worldbank.org/curated/en/482391554225185720/pdf/Marine-Pollution-in-the-Caribbean-Not-a-Minute-to-Waste.pdf
68. Martin, M., Kang, Y., Billah, M., Siddiqui, T., Black, R., & Kniveton, D. (n.d.). *Policy analysis: Climate change and migration Bangladesh support from Climate & Development Knowledge Network (CDKN)*. http://www.migratingoutofpoverty.org/files/file.php?name=wp4-ccrm-b-policy.pdf&site=354
69. Md Ashikur Rahman, Tulon, H., Rana, M., & Abdullah Al-Maruf. (2024). A Tale of Coral Colony: Examining the Socio-Ecohydrological Status of St. Martin's Island in Bangladesh. *Environmental Advances*, *15*, 100506–100506. https://doi.org/10.1016/j.envadv.2024.100506
70. *Migration and Global Environmental Change Future Challenges and Opportunities*. (n.d.). https://assets.publishing.service.gov.uk/media/5a74b18840f0b61df4777b6c/11-1116-migration-and-global-environmental-change.pdf
71. *MIGRATION AS A CLIMATE ADAPTATION STRATEGY Challenges & Opportunities for USAID Programming*. (n.d.). https://www.climatelinks.org/sites/default/files/asset/document/2023-01/FTF1537_USAID_Climate%20Migration%20Strategy_012723.pdf
72. Mō Te Taiao, M. (2024). *Coastal hazards and climate change guidance*. https://environment.govt.nz/assets/publications/Coastal-hazards-and-climate-change-guidance-2024-ME-1805.pdf
73. Murshed, S., Griffin, A. L., Islam, M. A., Wang, X. H., & Paull, D. (2022). Assessing multi-climate-hazard threat in the coastal region of Bangladesh by combining influential environmental and anthropogenic factors. *Progress in Disaster Science*, *16*, 100261. https://doi.org/10.1016/j.pdisas.2022.100261
74. Musfirat N I Tahiti. (2018, June 13). *Field Report on Saint Martin's Island*. Academia.edu. https://www.academia.edu/36836479/Field_Report_on_Saint_Martins_Island

75. National Oceanic and Atmospheric Administration. (2019, February 1). *Coral Reef Ecosystems*. Www.noaa.gov; National Oceanic and Atmospheric Administration. https://www.noaa.gov/education/resource-collections/marine-life/coral-reef-ecosystems
76. *National Plan for Disaster Management Government of the People's Republic of Bangladesh National Plan for Disaster Management 2010-2015 Disaster Management Bureau Disaster Management & Relief Division*. (2010). https://ddm.portal.gov.bd/sites/default/files/files/ddm.portal.gov.bd/page/332124ba_20b1_42cc_816b_d97d7eb4f478/npdm_final.pdf
77. *Nationwide Climate Vulnerability Assessment in Bangladesh*. (2018). https://moef.portal.gov.bd/sites/default/files/files/moef.portal.gov.bd/notices/d31d60fd_df55_4d75_bc22_1b0142fd9d3f/Draft%20NCVA.pdf
78. *North Carolina Climate Science Report :: North Carolina Institute for Climate Studies*. (n.d.). Retrieved April 15, 2022, from https://ncics.org/nccsr
79. OHCHR. (2015). *Understanding Human Rights and Climate Change*. https://www.ohchr.org/sites/default/files/Documents/Issues/ClimateChange/COP21.pdf
80. Ortiz, A. M., Chua, P., Salvador Jr, D., Dyngeland, C., Albao Jr, J. D., & Abesamis, R. (2023). Impact of tropical cyclones on food security, health and biodiversity. *Bulletin of the World Health Organization*, *101*(02), 152–154. https://doi.org/10.2471/blt.22.288838
81. Paszkowski, A., Finn Laurien, Mechler, R., & Hall, J. W. (2024). Quantifying community resilience to riverine hazards in Bangladesh. *Global Environmental Change*, *84*, 102778–102778. https://doi.org/10.1016/j.gloenvcha.2023.102778
82. Rahman, M. M. (2023). Impact of Climate Change on Saint Martin's Island of Bangladesh. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4397578
83. Rahman, M. M., Hasan, M. M., & Islam, M. N. (2019). Assessment of soil salinity and its impact on agriculture in the coastal areas of Bangladesh: A case study of Saint Martin's Island. Environmental Monitoring and Assessment, 191(3), 1-13.
84. Rahman, M. M., Hasan, M. M., & Islam, M. N. (2019). Assessment of soil salinity and its impact on agriculture in the coastal areas of Bangladesh: A case study of Saint Martin's Island. *Environmental Monitoring and Assessment*, *191*(3), 1-13.
85. Rahman, S. (2017). *Integrated coastal resources management of Saint Martin's Island, Bangladesh*. Journal of Coastal Conservation; Springer Nature. https://www.academia.edu/84093841/Integrated_coastal_resources_management_of_Saint_Martin_s_Island_Bangladesh
86. Rahman, S., & Rahman, M. A. (2015). Climate extremes and challenges to infrastructure development in coastal cities in Bangladesh. *Weather and Climate Extremes*, *7*, 96–108. https://doi.org/10.1016/j.wace.2014.07.004
87. Rigaud, K., De Sherbinin, A., Jones, B., Abu-Ata, N., & Adamo, S. (n.d.). *DEEP DIVE INTO INTERNAL CLIMATE MIGRATION IN SENEGAL*. https://documents1.worldbank.org/curated/en/776881634532602504/pdf/Groundswell-Africa-Deep-Dive-into-Internal-Climate-Migration-in-Senegal.pdf

88. Rivera, H. E., Chan, A. N., & Luu, V. (2020, August 5). *Coral reefs are critical for our food supply, tourism, and ocean health. We can protect them from climate change*. MIT Science Policy Review. https://sciencepolicyreview.org/2020/08/coral-reefs-are-critical-for-our-food-supply-tourism-and-ocean-health-we-can-protect-them-from-climate-change/
89. Rojas, D. (2021, December 9). *How the Climate Crisis Is Impacting Bangladesh*. The Climate Reality Project. https://www.climaterealityproject.org/blog/how-climate-crisis-impacting-bangladesh
90. Roy, B., Penha-Lopes, G. P., Uddin, M. S., Kabir, M. H., Lourenço, T. C., & Torrejano, A. (2022). Sea level rise induced impacts on coastal areas of Bangladesh and local-led community-based adaptation. *International Journal of Disaster Risk Reduction*, *73*, 102905. https://doi.org/10.1016/j.ijdrr.2022.102905
91. *S h o re L i n e s*. (2017). APCC. https://apcc.org/wp-content/uploads/2020/04/87039-APCC-summer-2017-News_proof.pdf
92. Sachs, W., & Santarius, T. (7 C.E.). *World Trade and the Regeneration of Agriculture by Wolfgang Sachs and Tilman Santarius with contributions from Sophia Murphy and Daniel De La Torre Ugarte in cooperation with moderated by*. http://www.santarius.de/wp-content/uploads/2007/01/EcoFair-Trade-Paper-No.9-Sachs+Santarius.pdf
93. SACRISTÁN, M. M., & MIGUEL AYANZ, A. S. (2016, August 23). *JESUS FERNANDEZ MOYA*. Studylib.es. https://studylib.es/doc/1165659/jesus-fernandez-moya
94. *Save the Basin*. (2024). Savethebasin.org.nz. https://savethebasin.org.nz/
95. *Scientific outcome IPBES-IPCC CO-SPONSORED WORKSHOP BIODIVERSITY AND CLIMATE CHANGE*. (2021). https://files.ipbes.net/ipbes-web-prod-public-files/2021-06/2021_IPCC-IPBES_scientific_outcome_20210612.pdf
96. Sea-level rise and climate change. (2016). *Understanding sea-level rise and climate change, and associated impacts on the coastal zone | CoastAdapt*. Coastadapt.com.au. https://coastadapt.com.au/information-manuals/understanding-sea-level-rise-and-climate-change-and-associated-impacts-coastal
97. Seenath, A., Wilson, M., & Miller, K. (2016). Hydrodynamic versus GIS modelling for coastal flood vulnerability assessment: Which is better for guiding coastal management? *Ocean & Coastal Management*, *120*, 99–109. https://doi.org/10.1016/j.ocecoaman.2015.11.019
98. Shamsuddoha, M., & Islam, M. (n.d.). *BANGLADESH NATIONAL CONSERVATION STARTEGY COASTAL AND MARINE RESOURCES*. https://bforest.portal.gov.bd/sites/default/files/files/bforest.portal.gov.bd/notices/c3379d22_ee62_4dec_9e29_75171074d885/24%20Coastal%20and%20Marine%20Resources_NCS.pdf

99. Sheikh, M., & Alam. (2018). ST. MARTIN'S ISLAND -A TOURIST PARADISE HAS LANDED IN THE MIDDLE OF THE OCEAN ALONG THE BAY OF BENGAL. *International Journal of Economics, Business and Management Research*, *2*(02). https://www.ijebmr.com/uploads/pdf/archivepdf/2020/IJEBMR_02_152.pdf
100. *Shelter from the Storm: Protecting Bangladesh's Coastal Communities from Natural Disasters*. (2022, August 29). World Bank. https://www.worldbank.org/en/results/2022/08/29/shelter-from-the-storm-protecting-bangladesh-s-coastal-communities-from-natural-disasters
101. Short, A. (2012). *Coastal Processes and Beaches | Learn Science at Scitable*. Nature.com. https://www.nature.com/scitable/knowledge/library/coastal-processes-and-beaches-26276621/
102. Siddique, H., Fatima, K., Azim, F., & Sadik. (n.d.). Challenges of Marine Tourism in Bangladesh. *BMJ*, *6*(6 Issue 1 ISSN 2519-5972). https://bsmrmu.edu.bd/public/files/econtents/621c736e82b8b10-Challenges%20of%20Marine%20Tourism%20in%20Bangladesh_compressed.pdf
103. Siddique, M. A. M., Hossain, Md. S., Islam, Md. M., Rahman, M., & Kibria, G. (2022). Heavy metals and metalloids in edible seaweeds of Saint Martin's Island, Bay of Bengal, and their potential health risks. *Marine Pollution Bulletin*, *181*, 113866. https://doi.org/10.1016/j.marpolbul.2022.113866
104. Society, N. G. (2011, January 21). *storm surge*. National Geographic Society. https://www.nationalgeographic.org/encyclopedia/storm-surge/
105. *Socioeconomic Impacts of Coastal Tourism on Local Communities in Kuakata, Bangladesh*. (2024, February 9). Asian Development Bank. https://www.adb.org/publications/socioeconomic-impacts-of-coastal-tourism-on-local-communities-in-kuakata-bangladesh
106. *State of the Environment and Development in the Mediterranean State of the Environment and Development in the Mediterranean State of the Environment and Development in the Mediterranean State of the Environment and Development in the Mediterranean*. (n.d.). https://planbleu.org/wp-content/uploads/2020/11/SoED-Full-Report.pdf
107. Tebbett, S. B., Schlaefer, J. A., Bowden, C. L., Collins, W. P., Hemingson, C. R., Ling, S. D., Morais, J., Morais, R. A., Siqueira, A. C., Streit, R. P., Swan, S., & Bellwood, D. R. (2023). Bio-physical determinants of sediment accumulation on an offshore coral reef: A snapshot study. *Science of the Total Environment*, *895*, 165188–165188. https://doi.org/10.1016/j.scitotenv.2023.165188
108. *The climate-changed child A CHILDREN'S CLIMATE RISK INDEX SUPPLEMENT*. (2023). https://www.unicef.org/media/147931/file/Theclimage-changedchild-ReportinEnglish.pdf

109. The daily star. (2023, April 6). *Tourism is harming St. Martin Island's natural environment*. The Daily Star. https://www.thedailystar.net/shout/news/tourism-harming-st-martin-islands-natural-environment-3289706
110. THE DEPARTMENT FOR INTERNATIONAL DEVELOPMENT. (n.d.). *Sustainable livelihoods guidance sheets Sustainable livelihoods guidance sheets*. https://www.livelihoodscentre.org/documents/114097690/114438878/Sustainable+livelihoods+guidance+sheets.pdf
111. to, C. (2006, December 3). *Saint Martin's island is a coral in Bangladesh*. Wikivoyage.org; Wikimedia Foundation, Inc. https://en.wikivoyage.org/wiki/Saint_Martins_Island
112. tour, taabu. (2018, May). *Cox's Bazar And Saint Martin Trip – TaabuTour*. Taabutour.com. https://taabutour.com/coxs-bazar-saintmartin-trip/
113. *Tourism & Management Studies*. (n.d.). https://www.redalyc.org/pdf/3887/388743883015.pdf
114. Uddin, A. (2006). *Bangladesh Climate Change Impacts and Vulnerability A Synthesis Comprehensive Disaster Management Programme Government of the People's Republic of Bangladesh*. https://www.preventionweb.net/files/574_10370.pdf
115. *UNDERSTANDING THE IMPACT OF CLIMATE CHANGE ON POOR AND VULNERABLE CHAR PEOPLE JANUARY 2021 STUDY CONDUCTED BY SUBMITTED TO PROJECT FUNDED BY PROJECT SUPPORTED BY*. (2009). https://admin.concern.net/sites/default/files/documents/2022-01/Understanding%20the%20impact%20of%20climate%20change%20on%20poor%20and%20vulnerable%20Char%20people%202021.pdf
116. Uzzaman, M. (2014). Impact of Sea Level Rise in the Coastal Areas of Bangladesh: A Macroeconomic Analysis. *Online)*, *5*(18). https://core.ac.uk/download/pdf/234646573.pdf
117. Wood, J. (2024, April 15). *Desalination: How can it help tackle water scarcity?* World Economic Forum. https://www.weforum.org/agenda/2024/04/desalination-drinking-water-water-scarcity/
118. World Bank. (2023). *Social Dimensions of Climate Change*. World Bank. https://www.worldbank.org/en/topic/social-dimensions-of-climate-change
119. Yeasmin, F., Ahmed, M. K., Barman, A., & Islam, M. (2020). *Climate change, vulnerability and adaptation of saint martin's island's community, bangladesh*. https://doi.org/10.13140/RG.2.2.18136.32002
120. Zaman, M. O., & Raihan, M. M. H. (2023). Community resilience to natural disasters: A systemic review of contemporary methods and theories. *Natural Hazards Research*, *3*(3). https://doi.org/10.1016/j.nhres.2023.05.003

Annex

Questionnaire Survey

1. **Name (Optional):**
2. **Age:**
3. **What is your primary occupation?**
4. **Do you have an alternative income source during the off-season (if applicable)**
   a) Yes

b) No

5. **How frequent you face the coastal hazard thread?**
    - Frequent
    - Occasionally
    - Never
    - **o** Rarely
6. **Difficulty for you to find work due to coastal hazards?**
7. **Coastal hazards affected your household income?**
8. **Question about hazard calendar?**
9. **Question about crop calendar?**
10. **Question about income calendar?**

11. **What is the most significant coastal hazard affecting your livelihood?**

o (Please rate each hazard on a scale of 1 to 4, where 1 = Least significant, and 4 = Most significant)

- Cyclones1 2 3 4
- Storm surges1 2 3 4
- Salinity intrusion1 2 3 4
- Coastal erosion 1 2 3 4

12. **What is the major vulnerability your household faces due to coastal hazards?**

o (Please rate each vulnerability on a scale of 1 to 5, where 1 = Least significant, and 5 = Most significant)

- Land Area Change1 2 3 4 5
- Extreme Weather Phenomena1 2 3 4 5
- Decay of Embankment1 2 3 4 5
- Socioeconomic Vulnerability1 2 3 4 5
- Absence of Basic Needs (e.g., food, water, shelter)1 2 3 4 5

13. **Has your household ever been forced to migrate due to coastal hazards?**

a) Yes

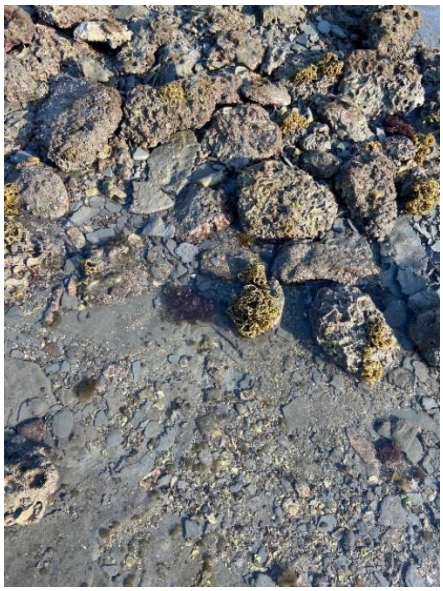
b) No

14. **If yes, where do you migrate?**
15. **Types of Vulnerability if they stay at Saint Martin During Hazard?**

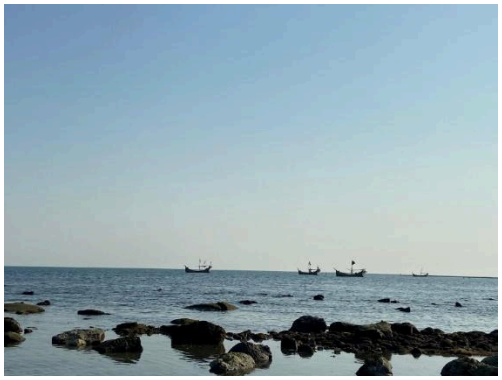
- Economic adversity
- Limited accessibility of healthcare services

- Mortality rate:
- Increase in living expenses
- Aid Dependency

Photos of the Study

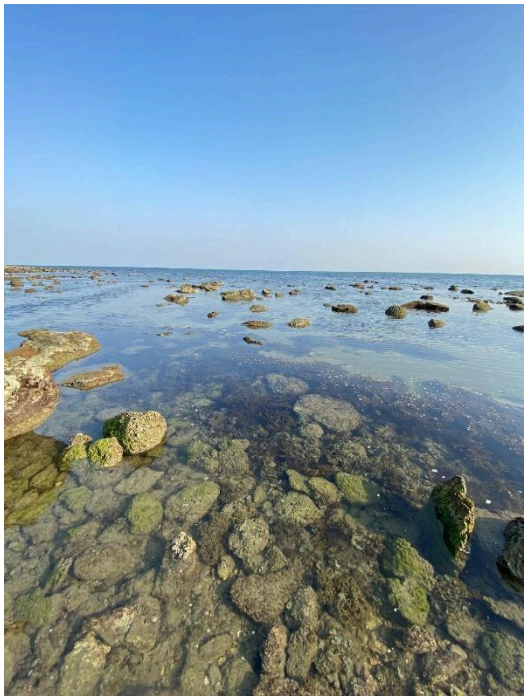


Beach soil Characteristics

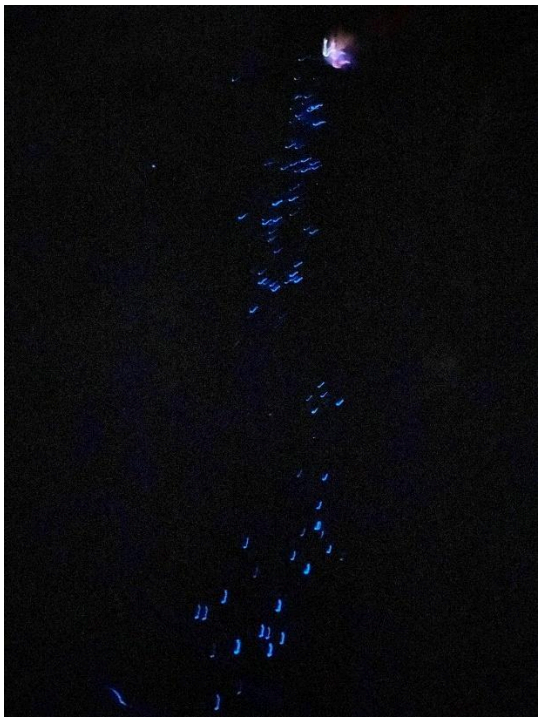


Picture: Coral Reef and Sea

Department of Geography and Environment, Jahangirnagar University



Decay of Coral Reef



Plankton in the night of Saint Martin

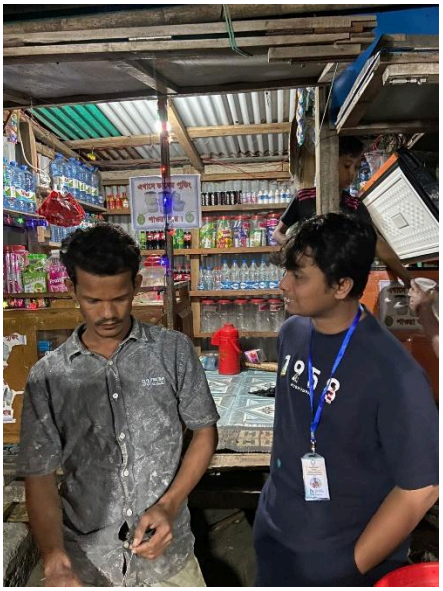
Pond of Mosque

seaweed

FGD with NGO worker and other

FGD, they were playing

Most Southern BGB Check post



Questionnaire survey with a shop keeper, he was also a resort owner