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Author: Juliana Linhares Rubin

(signature author)

Course coordinator: Daniela Müller-Eie

Supervisor: Fabio Alberto Hernandez Palacio

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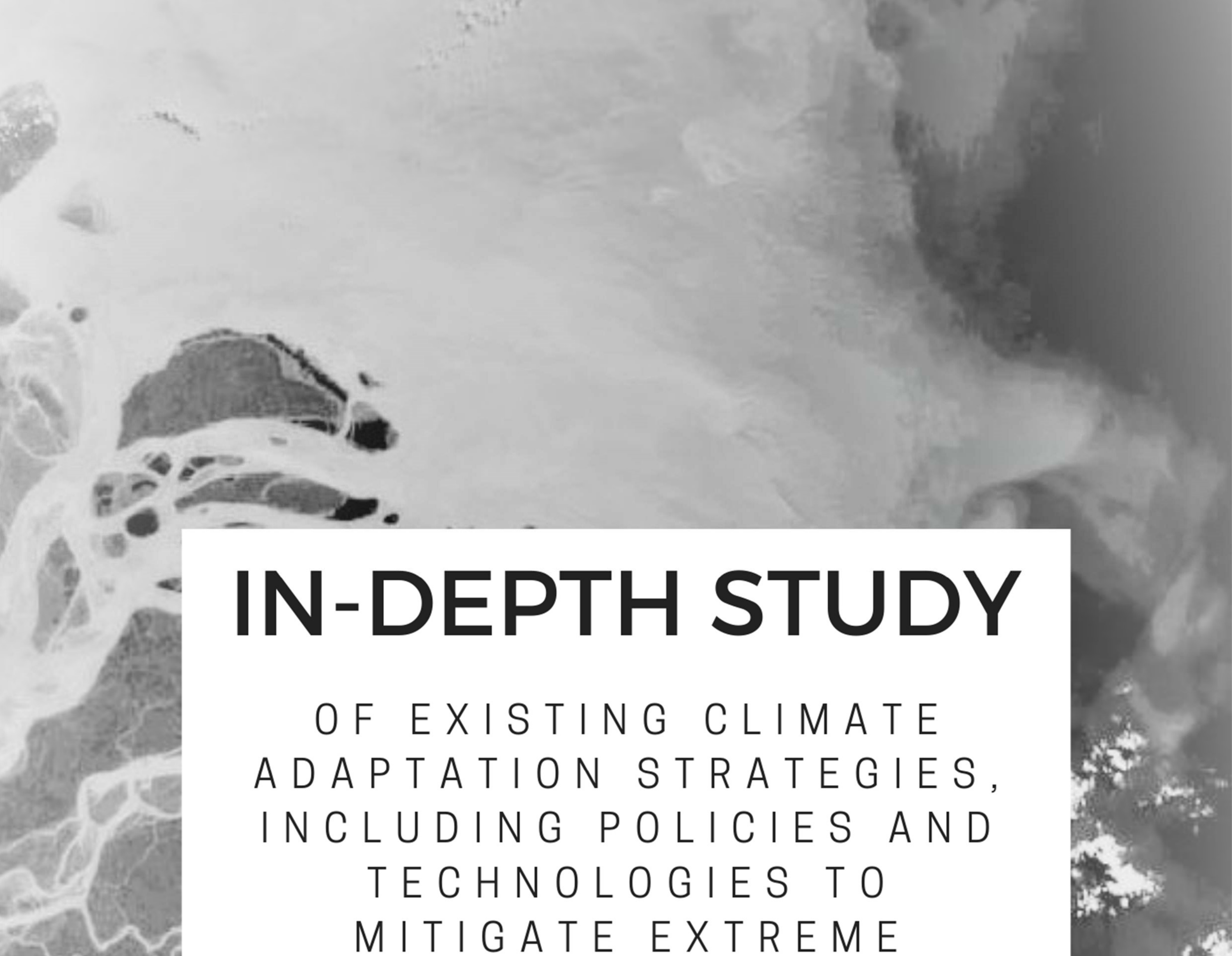

IN-DEPTH STUDY

OF EXISTING CLIMATE ADAPTATION STRATEGIES, INCLUDING POLICIES AND TECHNOLOGIES TO MITIGATE EXTREME WEATHER EVENTS

MASTER OF CITY AND REGIONAL PLANNING

JULIANA LINHARES RUBIN

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A person's decision to study abroad involves the cooperation and effort of all those who are part of their life. The support network, whether economic, emotional, functional or psychological, is dedicated and complex. To those who are always with me and are part of the network, my deepest gratitude.

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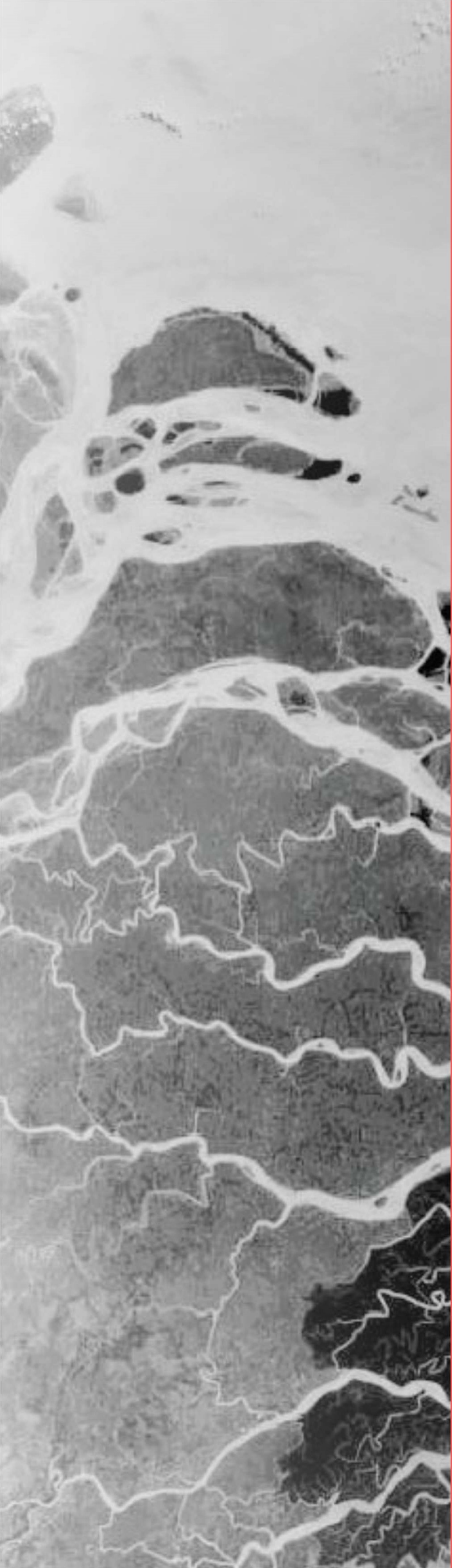
Abstract

The consequence of changes in the Earth's climate on a global scale is one of the greatest challenges of today's society. Its impacts affect all forms of life on the planet and the planet's deltaic regions are especially vulnerable to climate change due to their characteristics. They are rich in ecological systems and food production capacity, but are highly exposed to the consequences of climate change. The Ganges-Brahmaputra delta is home to millions of people who depend on its ecosystem for subsistence and among the various phenomena that climate change exerts on the region, the intrusion of salinity is one of the greatest challenges for local communities. It compromises access to fresh water, directly interferes in the health of residents, in daily activities, planting, fishing and land use and changes the ways in which communities carry out essential activities. When living with this problem, the need to build resilient communities through adaptations is a constant search to bear the problems arising from climate change on the delta. It is necessary to expand knowledge about the causes of salinity intrusion in the region, understand how it influences the ecological and socioeconomic systems and the ways communities, organizations and institutions find paths to deal with the interference of this phenomenon.

TABLE OF CONTENTS

TABLE OF CONTENTS



1

INTRODUCTION

1. Introduction

The consequences of changes in the Earth's climate on a global scale, whether arising from natural or anthropic causes, present themselves as one of the greatest challenges of today's society. Its significant impacts affect everything from natural ecosystems to the availability of drinking water, food production, distribution of goods and human health. On a regional scale, delta regions are especially vulnerable to climate change due to their characteristics. Home to more than half a billion people, they are rich in ecological systems, food production capacity, doing business and connections through transport networks, yet they are constantly exposed to sea level rise, tropical cyclones, floods, storms and consequences of these climatic phenomena. The Ganges-Brahmaputra Delta, the world's largest river delta, is among the most fertile regions on the planet and is home to millions of people who depend on its ecosystem for livelihoods. In this context, among the various phenomena that climate change exerts on the region, the intrusion of salinity into the soil and water presents itself as one of the greatest challenges for local communities, compromising access to fresh water, interfering in the daily activities, planting, fishing and land use. Excess salt has changed the way communities usually carry out essential activities and interfere with the health of the region's residents, proving to be a very serious and relevant consequence of climate change. It affects not only ecosystems with low or no population density, but also places that accommodate communities and individuals who use the natural means directly for their subsistence. When living with this problem, the necessity to build resilient individuals and communities through adaptations becomes imminent and presents itself as a constant search. The sixth IPCC report, released in February 2022, makes clear that the adverse impacts of climate change will worsen and that the urgent need to adapt to those already underway is urgent. Bangladesh does not treat this as a novelty, as it has seen and felt greater climate impacts especially in the last decade. Faced with the world situation, Bangladesh teaches the world, through the adaptability and effort of the whole society, how a real approach to dealing with climate change as it happens proves to be efficient. Even if its implementation may have consequences that lead to increased problems in the long term, immediate action solves urgent adaptation and livelihood problems. The use of innovation and partnership with organizations and companies in the private sector, in addition to the empowerment of women and poor people, is what makes Bangladesh different from other places, as the country implements actions in this regard. Tracking, alerting and training technology for natural disasters is also presented as a way of dealing with the threats of climate change, in the quest to avoid human losses (Daily News, 2021; IPCC, 2022; Scientific American, 2022; The World Bank, 2016).

This master thesis seeks to find answers about **what the causes of growing salinity intrusion are and how Bangladesh deals with the phenomenon.** In addition, and **considering that the salinity leads to food and water insecurity, in what way they can develop resilient communities and what city and regional planners can learn from this country's climate change strategy**. Thus, in addition to understanding the problems arising from climate change that the delta suffers, it is necessary to increase knowledge about the causes of salinity intrusion in the region, how the phenomenon influences ecological and socioeconomic systems and in what ways the communities, organizations and institutions deal with the interference that this phenomenon brings. Understanding the dynamics of communities in relation to climate change is important for understanding the extent to which humans can adapt to the consequences of climate change, through the implementation of policies and technologies, without having to resort migration, as a more dramatic measures.

1.1. Objective and relevance of the study

This master thesis aims to benefit the understanding of local residents' lives, as well as to provide a better understanding of ways to help affected communities. In addition, it seeks to understand in what way this information can be absorbed by organizations and institutions in searching for the development of resilient communities with more capacity to adapt to changes that interfere with local human life. This adaptation is necessary while movements towards the application of a truly effective global action in relation to the planetary damage caused by climate change are not enough. In addition, it aims to investigate how Bangladesh deals with the salinity intrusion in the Ganges-Brahmaputra delta in order to minimize the food and water insecurity problem that compromises the lives of human communities. These people are directly dependent on the delta ecosystems and it is essential to understand how they seek to develop resilience in relation to this consequence of climate change in order to reach a level of coexistence with the phenomenon that does not only result in dramatic measures such as internal and external migration.

Understanding the consequences of natural and mainly anthropogenic climate change on the planet's deltas represents an understanding of the ways in which these regions adapt related to the consequences of the phenomena considered implacable and devastating for their characteristic systems. It allows approximately 7% of the planet's population to have subsidies to deal with consequences that force them to change their way of subsistence to adapt to changes in the environment they live and on which they depend. In the Ganges-Brahmaputra Delta in Bangladesh, these climate changes directly affect the lives of approximately 78% of the population, who are directly subordinated to the functioning of their ecosystems because they depend on agriculture and animal husbandry in these places. The study about the reasons that aggravate the intrusion of salinity and the ways to minimize the damages or adapt to the changes that the phenomenon causes is of paramount importance for the population directly affected, for the organizations that work in this area and for the institutions directly responsible for implementing policies and technologies aimed at mitigating their consequences. In addition to the specific region, the information can be shared with other populations, organizations and institutions facing similar problems. Moreover, the adaptability and resilience of this population also emerges as an inspiration for various parts of the planet that face problems related to the consequences of climate change.

1.2. Methodology

This master thesis focuses on the construction of knowledge related to existing knowledge, seeking the interdisciplinary feature of the theme. It focuses on compiling data on ways to address climate change potentiated by the local characteristics of the Ganges-Brahmaputra Delta region in Bangladesh. The intrusion of salinity as consequence chosen to be analyzed in depth is relevant, as it leads to the scarcity of food and water, which directly interferes in the life of the population that resides and depends on the area. The literature review approach takes place through a narrative and semi-systematic research question (Hannah Snyder, 2019). The review seeks to identify and understand potentially relevant research that has implications for the topic studied and synthesize them using meta-narratives, providing an understanding of several complex areas. This approach maintains that the transparency of the research process and its strategy are important to allow the evaluation of arguments for the chosen theme, from a methodological point of view. Thematic or content analysis is the technique used to identify, analyze and report patterns in the form of themes within the text and is useful for detecting themes, theoretical perspectives or common issues within the specific research discipline to identify components of the theoretical concept.

The question that guides the research refers exclusively to obtaining data on how Bangladesh as a whole deals with the phenomenon. This is done through literature review as a research method, in a semi-systematic way of collecting and synthesizing previous research, creating a solid basis for advancing knowledge. It also seeks to help providing an overview of areas where research is disparate and interdisciplinary, synthesizing research findings to show evidence at a meta-level and to discover areas where more research is needed. The development is divided into four phases, which are the design, conduction, analysis and structure of the work (Hannah Snyder, 2019).

1.2.1. Project

The project focuses on broader ways of answering the research question as a methodological tool by exploring collective evidence in the research area and providing an overview of the subject in a narrative and semi-systematic way. It contributes to the understanding of the problem and the ways to solve the problems arising from it. The public potential of the review focuses on populations directly dependent on the delta ecosystem for their livelihood, which is directly affected by the increasing salinity of local water and soil.

The stated specific purpose of the review guides the study and seeks to understand the scale of the problem, both based on global and local causes. It seeks to list possible solutions to adapt or contain salinity at the site. In this way, research in gray and peer-reviewed literatures are used, starting from climate change in general to the specific case of Bangladesh, focusing on material related to the Ganges-Brahmaputra delta area, salinity intrusion and its implications for water and food scarcity. The research strategy uses academic databases and internet pages. It is based on keywords to identify the literature to be included to understand the deltas and cover the specific climatic phenomena of the region, go through them and culminate in the compiled modes to deal with the salinity phenomenon exclusively. These terms are based on words and concepts that are directly related to the research question, identifying the relevant ones according to the results sought, taking into account the research logic and valid reasons.

1.2.2. Conducting

The search for relevant literature takes place in bibliographic databases available on platforms with availability of titles, abstracts and citations of peer-reviewed literature and quality measurements. Reading summaries is useful for the selection of pieces compatible with the development of the review. Its collection and storage by theme in free software for managing and sharing references, aims to facilitate the preparation of the thesis, according to the structure of the thesis project.

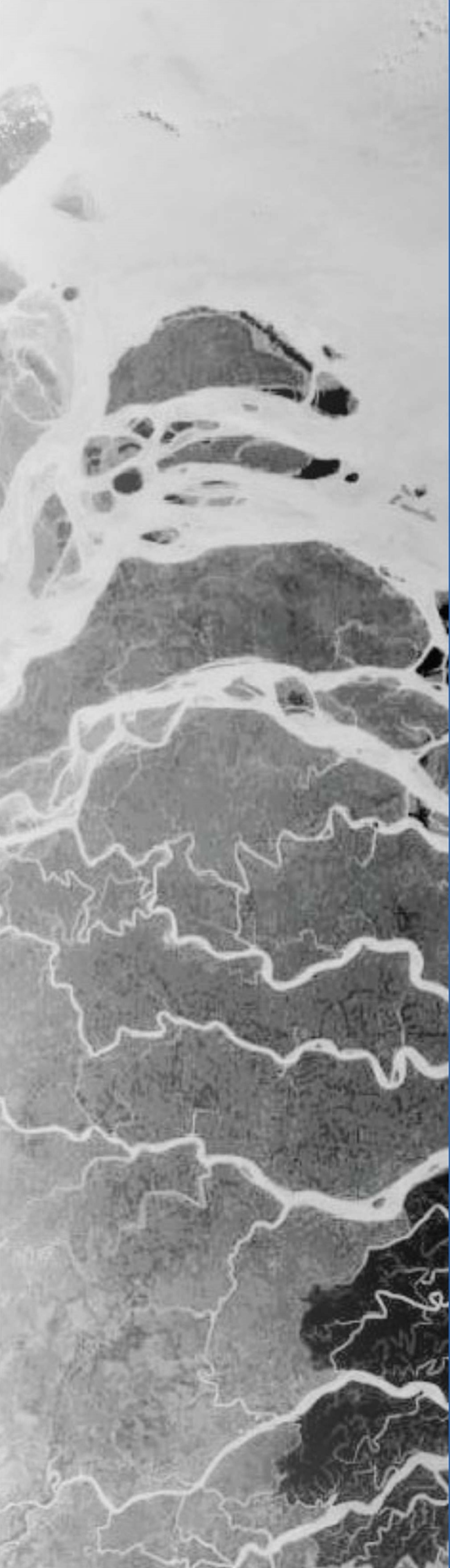
1.2.3. Analysis

After reviewing the literature and deciding on the pieces to be used according to the development of the thesis, data are abstracted in the form of descriptive information. They are based on the topics and type of study, and may also take the form of conceptualizations of an idea or perspective, according to the research purpose and question, ensuring that it is appropriate to answer the selected research question.

1.2.4. Structure

The motivation and need for the review is communicated through the structure of the thesis through different types of information and different levels of detail. The literature review results in an analysis of developments within the research field, opening space for further research within the evidence on the subject.

The main findings derived from the corpus of literature include a growing trend of concern about ways to address salinity problems and prevent human migration from the region. In this way, the initial result of the literary research on the phenomenon opened a path in the knowledge about the problems related to salinity and, consequently, the ways to solve it. The research aims at an academic contribution in order to seek the necessary understanding about the area, the problems it faces, the importance of changing attitudes towards current climatic conditions and the knowledge of ways and possibilities to minimize the problems caused by the phenomenon. Despite the availability of material on the subject, many of them are not current, which leads to the understanding that, despite the phenomenon being found there for some decades, it is still being mitigated, without, however, an effective search for a solution to remedy its consequences. The research paves the way to seek to understand the extent to which humans are able to adapt and adapt their activities in relation to the consequences of climate change, and, if not, what future consequences these phenomena may cause and what can be done and expected of them. The discussion is timely, given the speed of climate change and its increasingly visible effects around the world.



2

BACKGROUND

2. Background

2.1. Climate change – Concept

There is evidence that there are some natural factors responsible for climate change, such as variation in the Earth's orbital characteristics as the Earth's rotation, the tilt of the Earth's axis of rotation, the distance from the Earth to the Sun and changes in the shape of the Earth's orbit around the sun over geological time (Islam & van Amstel, 2018). Despite of this, nowadays, climate change, as a concept, is the term used to refer to changes in climates of the planet at different scales and the effects these changes cause. The term has been used more frequently to describe changes in the planet's climate driven primarily by human activity from 1850 onwards, i.e. since the pre-industrial period. It was from that date that the removal of forests and the burning of fossil fuels were introduced which resulted in a rapid increase in the concentration of carbon dioxide in the Earth's atmosphere. For this reason, the term global warming is used synonymously with climate change, as it is one of the most important parameters of global climate change. It refers to the increase in global average temperatures, linked to important impacts on ecosystems, wildlife and human life around the world, the term including increases in surface temperatures and their additional impacts (Andrew L. Dannenberg et al., 2019; Student Energy, 2021).

Climate change is therefore defined as the periodic changes in the terrestrial climate, because of changes in the atmosphere, interactions between the atmosphere and chemical, geological, geographic and biological factors. In addition to solar variability, volcanic and tectonic activities, and orbital variations, there are greenhouse gases, which have a profound effect on the energy balance of the Earth system. Its growth, largely due to human activities, affects the Earth's radiation balance and currently, makes the concept of climate change encompass both natural changes and those caused by human activities (Stephen T. Jackson, 2022).

2.2. Climate change in the context of human life

Climate change is confronting contemporary societies as a phenomenon with potential devastating effects on the planet. In 2007, the IPCC declared that the evidence of humans changing the climate is unambiguous and related to this, Nobel laureate Paul Crutzen argued for the existence of the Anthropocene. This is the period in which human activities exert an impact equivalent to the great forces of the Earth nature over almost all aspects of the Earth system, that is, where human actions are central to the warming of the planet (Urry, J., 2015). Climate change poses as a risk to sustainable urban and community development. During the last 30 years, the number of natural disasters around the world has nearly quadrupled, resulting in increasing economic and human losses. The susceptibility of societies tends to be amplified, even with uncertainties regarding their specific impacts, frequency and magnitude, that is, the climate changes that humanity face are happening at a speed and magnitude never seen before (Christine Wamsler et al., 2013) and have implications for urban infrastructure and human society (Vimal Mishra et al., 2015). This causes difficulty in inhabiting some places, with a major impact on populations that rely primarily on fishing, animal husbandry and subsistence agriculture, with health, sociocultural, and economic impacts (Andrew L. Dannenberg et al., 2019).

The severe impacts of climate variability and change and related hazards are felt around the world and more incisively on populations in delta regions. Coastal zones and river deltas are considered the most vulnerable, with considerable damage such as loss of human life, material damage, displacement, and interruption of daily activities. Low-income communities are particularly vulnerable, as they tend to settle in dangerous environments and at risk of diseases, ecological disturbances as storms and floods, most often even accompanied by great difficulty in adapting to cope with the climate changes (Gordon McBean & Idowu Ajibade, 2009).

2.3. Resilience, vulnerability and adaptability

According to Resilience Aliance (https://www.resalliance.org/) resilience is the "ability of a socioecological system to absorb or resist disturbances and other stressors in such a way that the system maintains its structure and functions. It describes the degree to which the system is capable of self-organization, learning and adapt" (Resilience Aliance, 2022). The term resilience has become usual around climate change adaptation in relation to all human activities (Michael D. Morecroft et al., 2012). Daniel Callo-Concha & Frank Ewert (2014) state that resilience "originally alluded to the biological capacity of ecosystems to absorb shocks and recover functions". It has recently been extended to the field of socioecological systems "by including concepts such as renewal and reorganization in a broad understanding of the systems". The same author states "the precise meaning of vulnerability lacks consensus and is still controversial, as it has been applied extensively in different contexts". The term is understood as "the susceptibility to change of a system exposed to a certain disturbance, which implies the assumption that a system is vulnerable to certain factors, but not to others" (Daniel Callo-Concha & Frank Ewert, 2014, p. 2).

Hans-Martin Füssel (2007) states that “vulnerability describes a central concept in climate change research, as well as in research communities dealing with natural hazards and disaster management, ecology, public health, poverty and development, secure livelihoods and hunger, sustainability science and land change” (Hans-Martin Füssel, 2007, p. 165). The IPCC (2022) states that vulnerability in the context of climate change is “the degree to which a system is susceptible and unable to cope with the adverse effects of climate change, including climate variability and extremes.” In its glossary, it states that vulnerability “encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of the ability to cope and adapt (IPCC, 2022).

The term adaptation deals with the behavioral characteristics of a species as a support for survival and reproduction, and in the social sciences, it is oriented to the ability of institutions, groups and individuals to adapt to changing situations (Daniel Callo-Concha & Frank Ewert, 2014, p. 2). Being able to adapt to climate change means adjusting and preparing for both its current effects and its predicted future impacts (European Comission, 2021).

2.4. Resilient communities

Climate change exacerbates the magnitude and frequency of natural disasters and has a multiplier effect on conflicts, which destroy people's ability to deal with the risks of natural disasters. The resilient community must be able to absorb disturbances and maintain its basic functions and structures, in an attempt to preserve some qualities and allow others to disappear, seeking to maintain its identity and valuing its place of residence. To build a community's resilience, efforts must involve and benefit all community members and take into account the challenges the community faces, based on the fact that human communities can adapt and persist in changing circumstances (Resilience, 2016). Moving a community towards sustainable development refers to increasing the community's resilience based on investments in research, innovation and forms of adaptability. Resilient communities are those that are able to absorb and/or adapt quickly to changes and crises. The necessary elements in the evolution of resilience in a community include the planning and development of strategies that minimize vulnerabilities, the development of ways to respond to crises, and partnerships between public, private and third sector agencies to support and develop strategies (Edith G. Callaghan & John Colton, 2008).

In the context of resilience communities, the search for social and human well-being seems to be relevant. Social or human well-being of delta ecosystems and the communities that depend on them refers to the non-material benefits and values that this ecosystems provide to communities and the negative impact the ecosystems experience. This situation necessitates adaptability on the part of managers and communities that live in them. A key attribute that contributes to building and maintaining healthy and resilient ecosystems, communities and economies is adaptability and the ability to recognize the full range of interactions within an ecosystem rather than considering isolated issues (Ellen Spooner et al., 2021).

The impact of climate change varies across space and time, which means that not all communities are equally vulnerable. Coastal, delta and riverine households are the most susceptible to the impact of climate hazards, which increases their vulnerability. Many governmental and non-governmental agencies around the world agree on the need for resilient practices and building resilience, particularly in the poorest small communities to deal with increasing climate risks. Increasing resilience often reduces vulnerability, and resilient communities are more likely to anticipate, cope, resist, and recover from impacts. Policymakers and practitioners need to understand how resilience can translate into practical implementation, as something to look for to facilitate long-term adaptation (Alam et al., 2018).

2.5. Bangladesh – Historical background and overview

Bangladesh is a country in South Asia, with an area of 147,570 km2, located in the delta of the rivers Ganges, Brahmaputra and Meghna, in the northeastern part of the Indian subcontinent. The "Land of the Bengals" as it is called, is one of the most densely populated countries in the world, currently counting approximately 167 and a half million inhabitants (World Population Review, 2022).

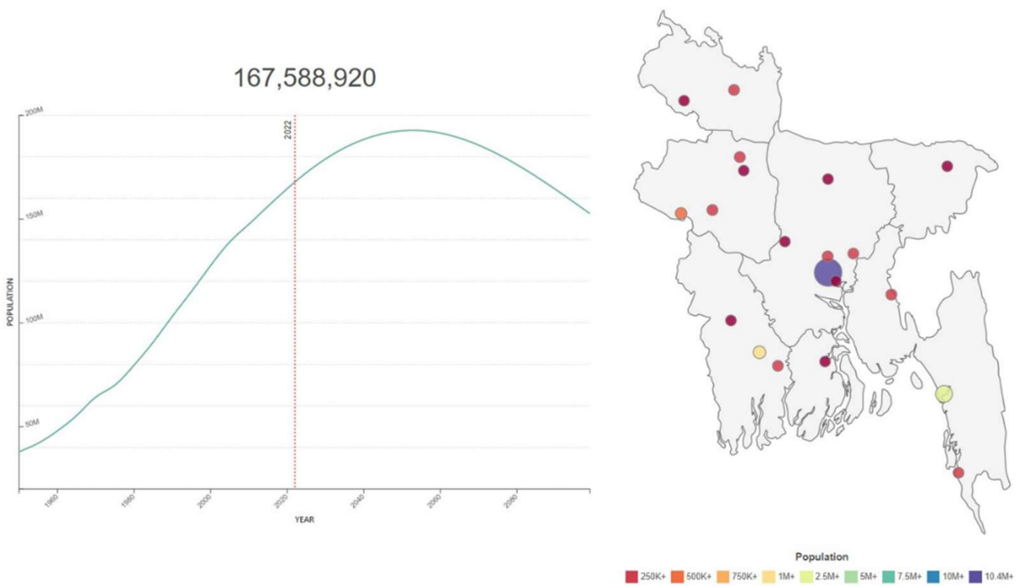


Figure 1 - (Left) Bangladesh current population and projection and (Right) Population by region

The annual GDP per capita is $2,326.63 (Statista, 2021) and the HDI is 0,632 points, ranking 133rd out of 189 United Nations member countries (United Nations Development Program, 2022). Its people are predominantly Muslim. It became an independent country in 1971, and its capital is Dhaka. Bangladesh borders on the west, north, northeast and east with India, on the southeast with Myanmar and on the south with the Bay of Bengal (World Population Review, 2022). It has been a member of the United Nations since September 17th, 1974 (United Nations, 2022).

Figure 2 - Asia on the Globe

Figure 3 - Location of Bangladesh

Bangladesh has a typical monsoon climate characterized by wide variations in precipitation, moderately warm temperatures and high humidity, with a dry and mild winter from November to February and hot summer from March to May and humid or from June to October. The average temperature in Bangladesh is 25.75°C, ranging from 18.85 to 28.75°C. Summer is the hottest season with average temperatures ranging from 23 to 31 °C, when there is some rain, including hail, often accompanied by tornadoes. April and May are the hottest months in Bangladesh with a maximum temperature of 45.1°C in 1972 in Rajshahi. January is the coldest month with a minimum temperature of 2.8°C recorded in 1968 in Srimangal. Precipitation in Bangladesh is seasonal, mostly occurring in the wet summer months. In winter, the rains are very scarce, with December being the driest month of the year. The country's climate is one of the wettest in the world, with average relative humidity in the country ranging from 70% to 78%, average rainfall of 2426 mm per year and rainfall ranging from 1400 to 4400 mm across the country (Islam & van Amstel, 2018). Bangladesh's humid tropical climate and its monsoon season in June and September cover over 80% of annual rainfall. The dry season is characterized by low relative humidity, low precipitation and higher average daily temperatures (Banglapedia, 2021).

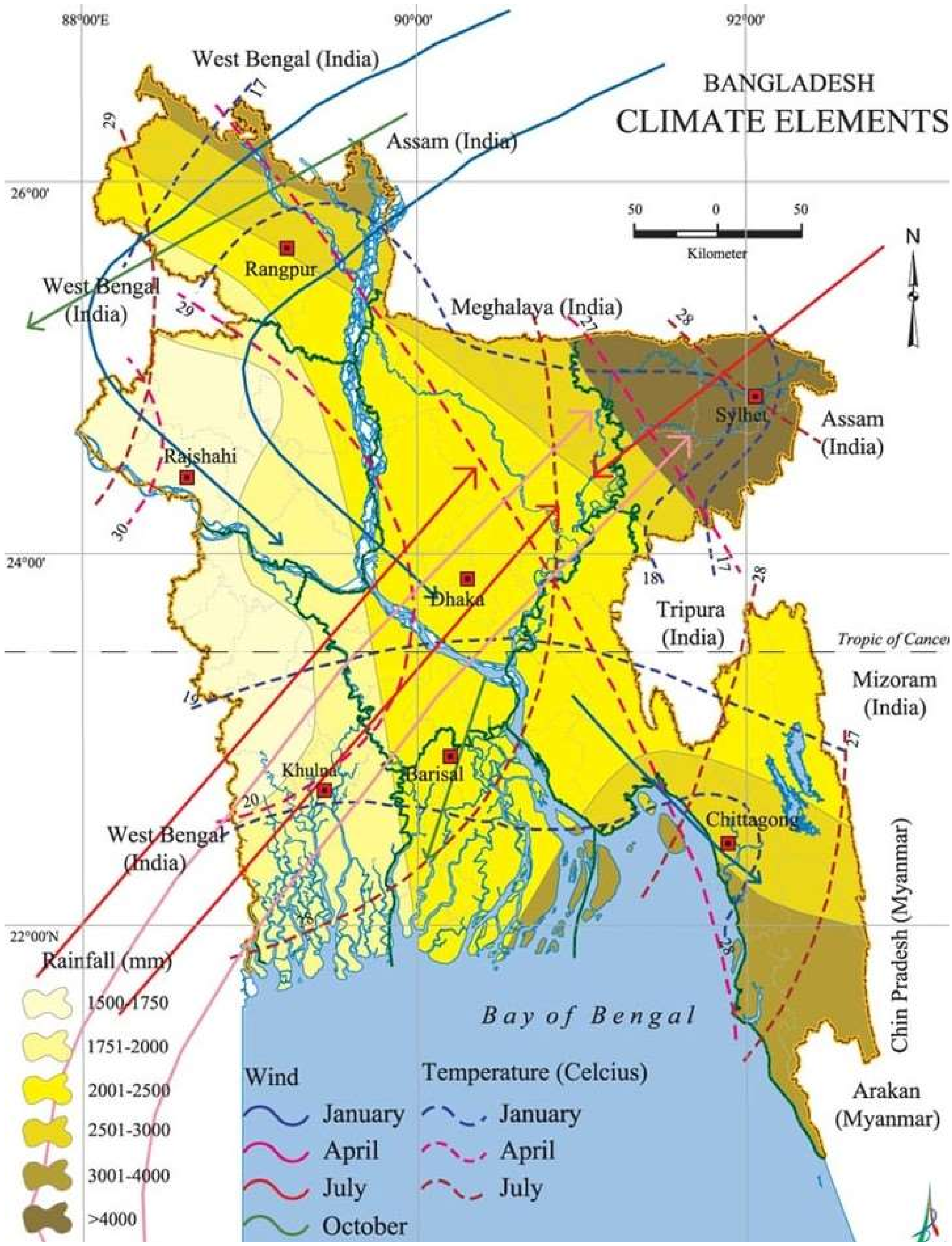


Figure 4 - Bangladesh climate elements

Bangladesh depends on agriculture, with rice as its predominant product, and almost half of the population is employed in this sector. It is one of the main suppliers of raw jute in the world and also stands out in the production of tea. Other agricultural products grown in the country are wheat, oilseeds, spices, sugar cane, tobacco, fruits, and it is one of the main producers of milk and goat meat.

Bangladesh's rivers are conducive to fish farming, and aquaculture accounts for more than two-fifths of the country's fish production, with opportunities for open water fishing on the rivers and coast, particularly in the estuaries of the Bay of Bengal.

The country has a deficit of mineral resources and natural gas is used to manufacture fertilizers and generate thermal energy. The most significant coal deposits are located at relatively inaccessible depths. There are several places with peat deposits, but their extraction is difficult to access because some beds remain submerged for half the year and there are still areas with limestone deposits. Thermal and hydroelectric processes produce Bangladeshi electricity.

The clothing industry is an important asset in the country and, since the beginning of the 21st century, the export value of clothing, socks and knitwear has far surpassed that of jute manufactures. Frozen fish and shrimp also increase exports.

Bamboo and various softwood trees provide raw materials for making paper. Bangladesh has fertilizer, sugar, aluminum, cement, textile and glass factories. There are shipyards and steel mills. The most important craft industry focuses on the production of coarse and medium quality yarns and textile fabrics. Another cottage industry produces cigarettes known as bidis. Ceramics, cane furniture and rugs help the economy as products from the craft industries.

The country's central bank is the Bank of Bangladesh. After independence, Bangladesh nationalized all domestic banks and the country has been a pioneer in microfinance to provide credit in the form of small loans to borrowers without financial resources.

Annual imports exceed exports. Imports come mainly from China and South Asia, while merchandise exports are destined for the United States, Canada and Europe, with an emphasis on agricultural products, seafood, apparel and knitwear, leather and jute.

The core of the country's transport system consists of networks of waterways, railways and roads, with waterways providing low-cost transport with access to areas that would make land transport more expensive. The main seaports are Chittagong and Mongla, and there are international airports in Dhaka and Chittagong, in addition to those offering domestic services. The forms of transport used on the roads include automobiles, buses and oxcarts. Field boats are used because of the annual flooding that jeopardizes much of rural roads.

The Bangladeshi system of government was determined by a military coup that led to a regime of martial law and from 1991 onwards, a parliamentary system was established, with a president as head of state and a prime minister as head of government. The parliament consists of a single legislative chamber composed of approximately 350 seats, mostly filled by direct election, held by the parliament itself, for a term of 5 years. The remaining seats are reserved for women. Parliament elects the president for a term of five years, for up to two terms. The president appoints the leader of the legislative majority party as prime minister.

Between the early 1980s and the 1990s, local government in Bangladesh underwent an administrative reorganization aimed at decentralizing power. The resulting structure consists of several main divisions, subdivided into several districts, called zila, divided into smaller units, called upzila and thana. Bangladesh consists of eight divisions, more than sixty districts and more than five hundred upzila and thana, with local governments under the responsibility of executives and councils headed by a commissioner, the system being assisted by professionals appointed by the national government.

Bangladesh has many government hospitals and rural health centers. The main diseases found in the country are tuberculosis, cholera and malaria, in addition to sporadic outbreaks of dengue (Britannica, 2022a; Country Economy, 2022; Statista, 2021; The World Bank, 2022; World Population Review, 2022; Worldometer, 2022).

Like other countries, Bangladesh has been significantly affected by the COVID-19 pandemic. It constrained economic activities and reversed some gains made in the last decade. However, real GDP growth accelerated as restrictions were eased, starting with a recovery in manufacturing and services sector activities. Exports and private consumption led growth. However, its growth faces new headwinds after rising global commodity prices amid uncertainty created by the Russia-Ukraine war (The World Bank, 2022).

The country demonstrates a strong record of accomplishment of poverty reduction and growth and has positioned itself, in the last decade, among the fastest growing economies in the world. From one of the poorest nations upon independence in 1971, it reached lower middle-income status in 2015. Poverty fell from 1991 to 2016 from 43.5% to 14.3%, with human development outcomes improving in many dimensions (The World Bank, 2022). In spite of this, climate change still devastates the country and deepens poverty in the affected areas, and needs to be deepened for its minimization and/or adaptation.

The Ganges-Brahmaputra Delta receives water from three major rivers. The Ganges rises in the Himalayas and passes through India. In Bangladesh, it receives water from the largest tributary of the Brahmaputra and then from the Meghna River, which is the second largest tributary of the Brahmaputra, flowing into the Bay of Bengal and being the third largest volume of water in the world (Britannica, 2022b).

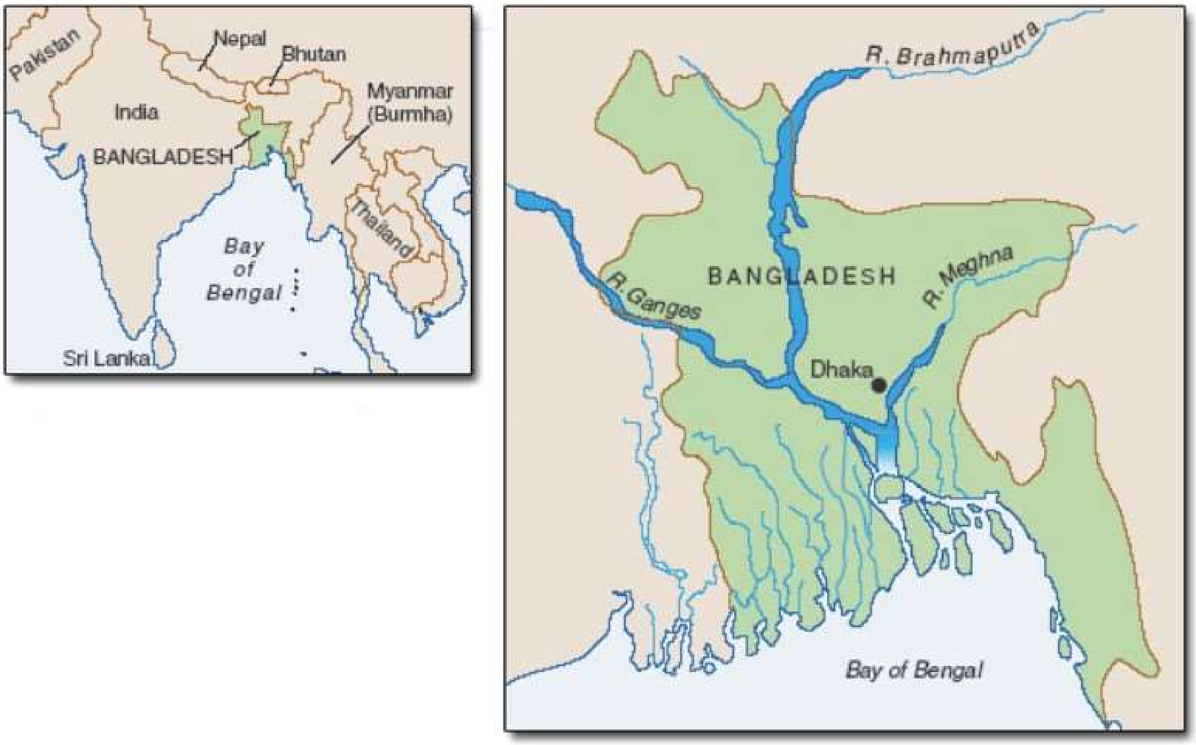
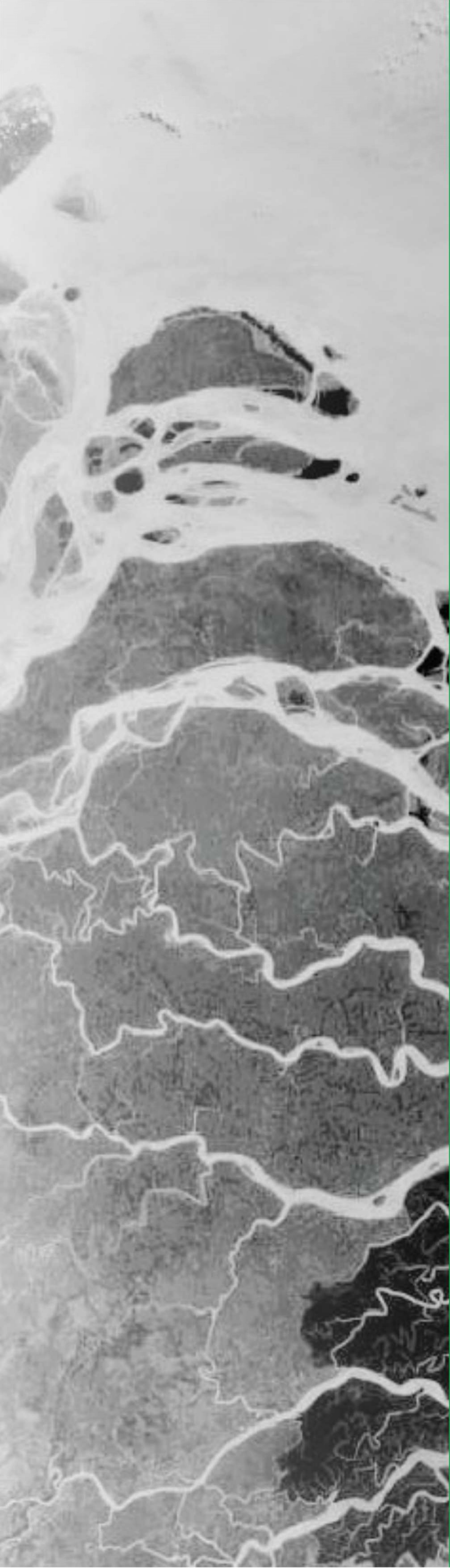


Figure 5 - Map of Bangladesh showing the extensive delta formed by the Ganges, Brahmaputra and Meghna rivers

The 1996 Ganges Water Treaty between India and Bangladesh exists, but there are also geopolitical obstacles to cooperation between countries for the development of river systems and opportunities for development. The cooperation between countries needs to meet a range of criteria that go beyond engineering or economic cost-benefit analyses. It also needs the inclusion of geopolitical criteria, ranging from global-scale environmental concerns to micro-scale issues of mutual regional benefit (Stephen Brichieri-Colombi & Robert W. Bradnock, 2003).



3

DELTA AREAS

3. Delta areas

Deltas form where large rivers deposit sediment as they flow into the ocean. When a river reaches the ocean, it loses its ability to continue carrying its sediment load, depositing much of the silt and sand, which after long periods results in the creation of new land.

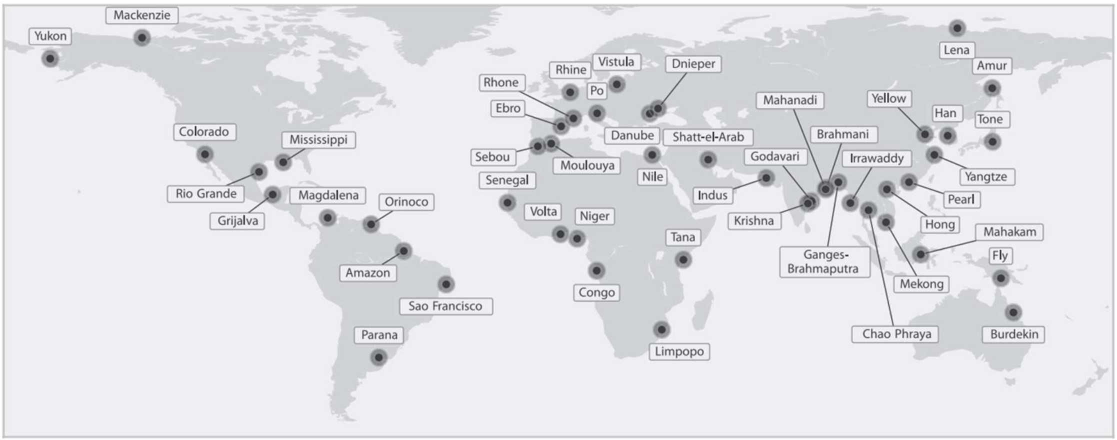


Figure 6 - Most important deltas in the world

Rich in nutrients and fertile soil for agriculture, famous river deltas are sites of development for many of known current and ancient societies. Currently, these areas are home to approximately half a billion people, often poor and more vulnerable (FAO - Food and Agriculture Organization of the United Nations, 2022), and are usually located very little above sea level. They are among the most productive agricultural and fishing regions and most threatened by climate change on the planet (Forbes, 2019). For a better understanding of the importance and danger that these areas are in, it is necessary to understand how a delta is formed, the importance of the flow of sediments in its formation, the effects of climate change and how human action interferes with development and maintenance of these areas.

Figure 7 - (Left) Mississipi Delta and (Right) Nile Delta

3.1. Delta formation

A delta is a landform made up of sediments, found at the mouth of a river. It forms when river channels carry sediment to another body of water. As the river channel flows over and makes contact with the ground, it carries with it sediments such as gravel, sand, silt and clay, losing speed when encountering another body of water and depositing these sediments on a flat area. The delta becomes the main channel that divides substantial land masses into multiple flows that look like a labyrinth of water channels (Sciencing, 2018).

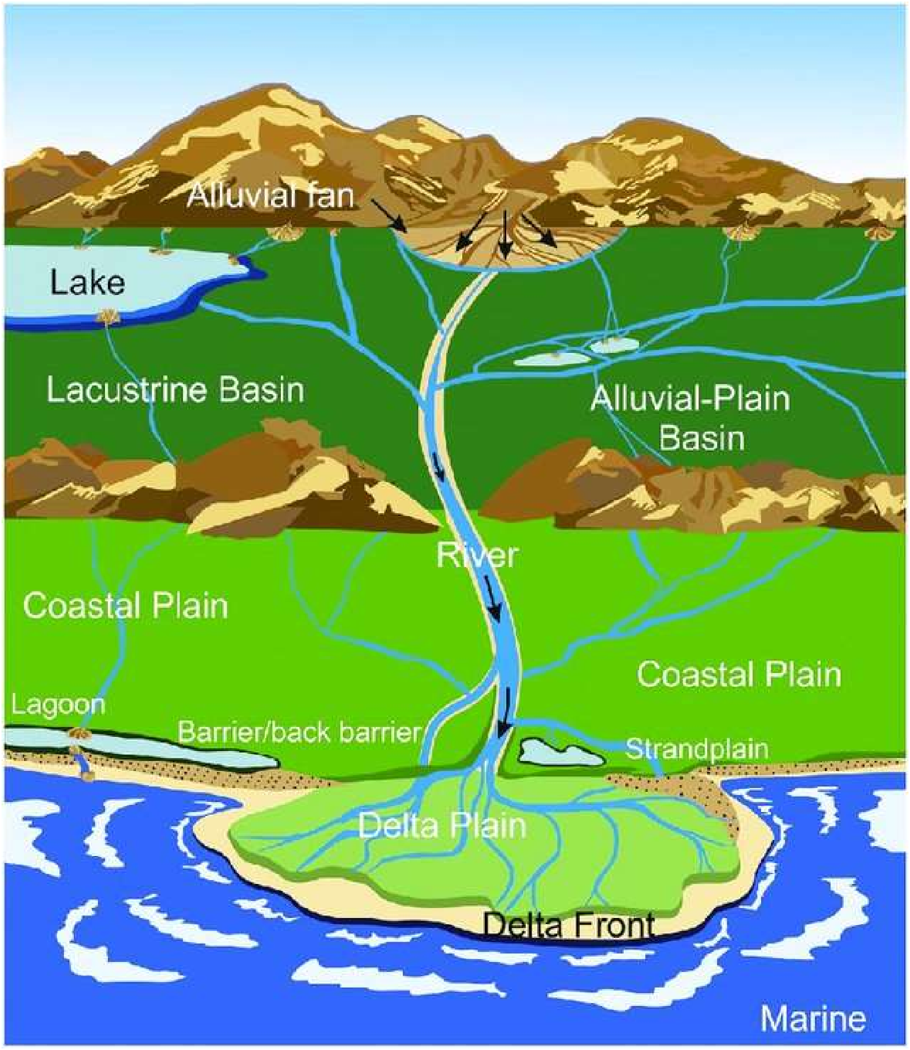


Figure 8 - Delta formation

Figure 8 shows a schematic diagram showing a representation of the elements of fluviodeltaic depositional systems.

3.2. Sediment flow

A river's depth, width and speed determine both the size and the amount of sediment it carries. When fast and turbulent, a river carries larger and more amount of sediments. Closer to the mouth, it becomes wider, with a slower current, with smaller sediment flow and size, producing beds with alternating layers of thin and thick sediments, through erosion actions upstream and deposition at the downstream. When the amount of sediment is excessive, the material obstructs the flow of water and eventually creates a buildup over time, which is called a delta. They act as filters, they are rich in land, water and ecological resources, and are not static landmasses. A delta constantly changes shape depending on a variety of factors such as sediment flow, changes in erosion, and the actions of water through river forces or how it interacts with the ocean forces. It depends on the tide, on the waves or on how the ocean and river waves move the silt and sediment. As sediment flow is always changing, as sediment accumulates, islands and sandbars form, which can be washed away over time, so the topography of a delta constantly changes with flooding and low tide (A. J. F. Hoitink et al., 2020; Forbes, 2019; Sciencing, 2018).

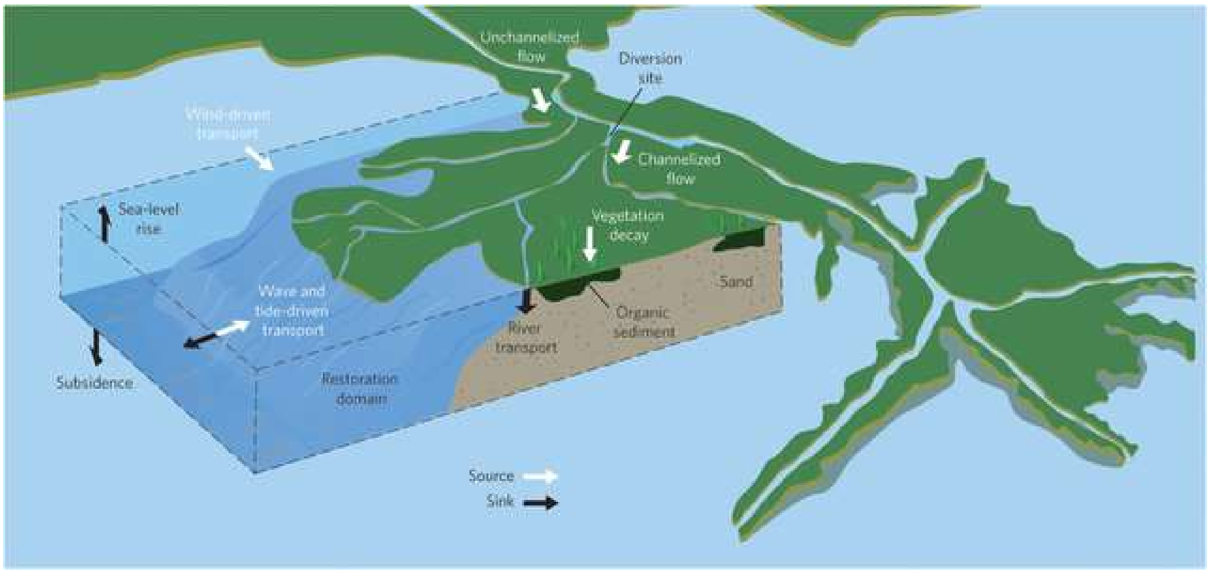


Figure 9 - Sediment flow

Figure 9 shows land-building sediment in a delta as a hypothetical illustration. The balance of sources and sinks, including contributions from organic and inorganic processes and the interactions between them, determines the growth rate of land.

Deltas are threatened by global warming. According to the IPCC report, deltas face risks due to global sea level rise and extreme storms, even in scenarios where there is a rapid reduction in greenhouse gas emissions and minimization of the rise in global temperatures and this risk is significant for the millions of people who live in them. However, the loss of sediment supply from watersheds, which is heavily dependent on human interference, in some cases presents a greater threat than sea level rise when associated with low altitude, coasts, cities and settlements (IPCC, 2021).

3.3. Effects of human interference

The IPCC report shows that the global average difference in sea level rise varies regionally and can reach more or less 30% in areas of rapid vertical land movements[1], including and mainly referring to local anthropogenic factors that culminate in subsidence[2]. This effect is the most important cause of the relative change in sea level rise (RSL) in delta regions. Anthropogenic subsidence demonstrates that local interferences must be strongly considered when projecting sea level impacts, as deltas provide economic and ecosystem services to those who live in them and neighboring regions (IPCC, 2021).

[1] Vertical land movement (VLM) is a generic term for all processes that impact uplift at a given location (tectonic movements, subsidence, and groundwater extraction), causing land to move up or down as a slow process with magnitudes commonly between -10 (sink) and +10 (increase) mm/year (CLIMsystems, 2022)

[2] Sinking of the ground because of underground material movement—is most often caused by the removal of water, oil, natural gas, or mineral resources out of the ground by pumping, fracking, or mining activities (NOAA - National Ocean Service, 2022).

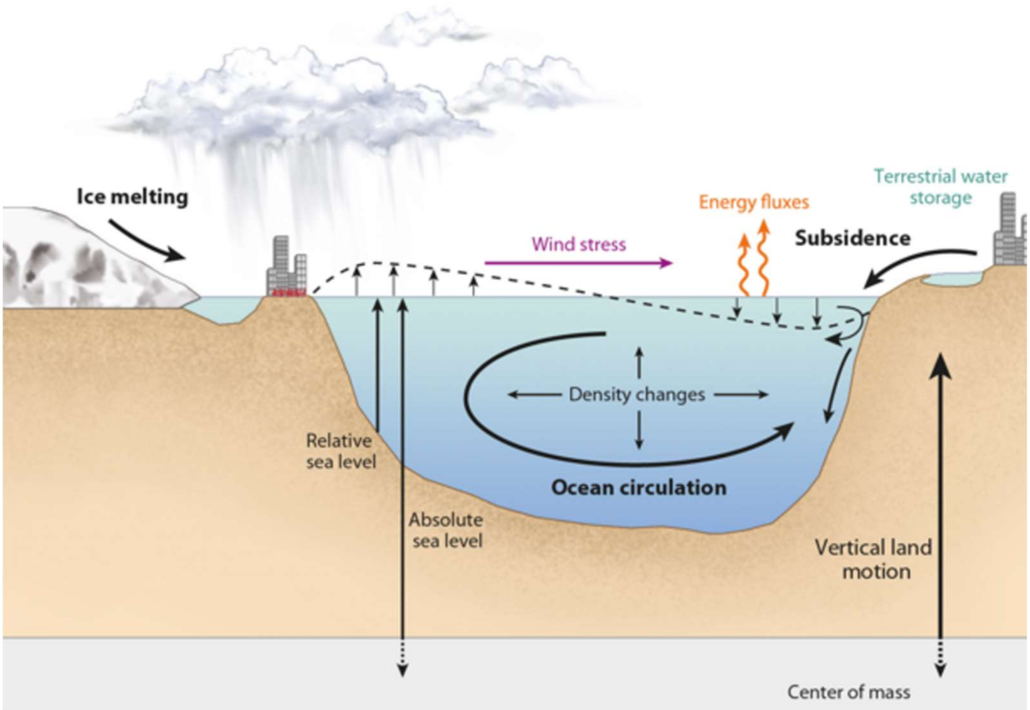
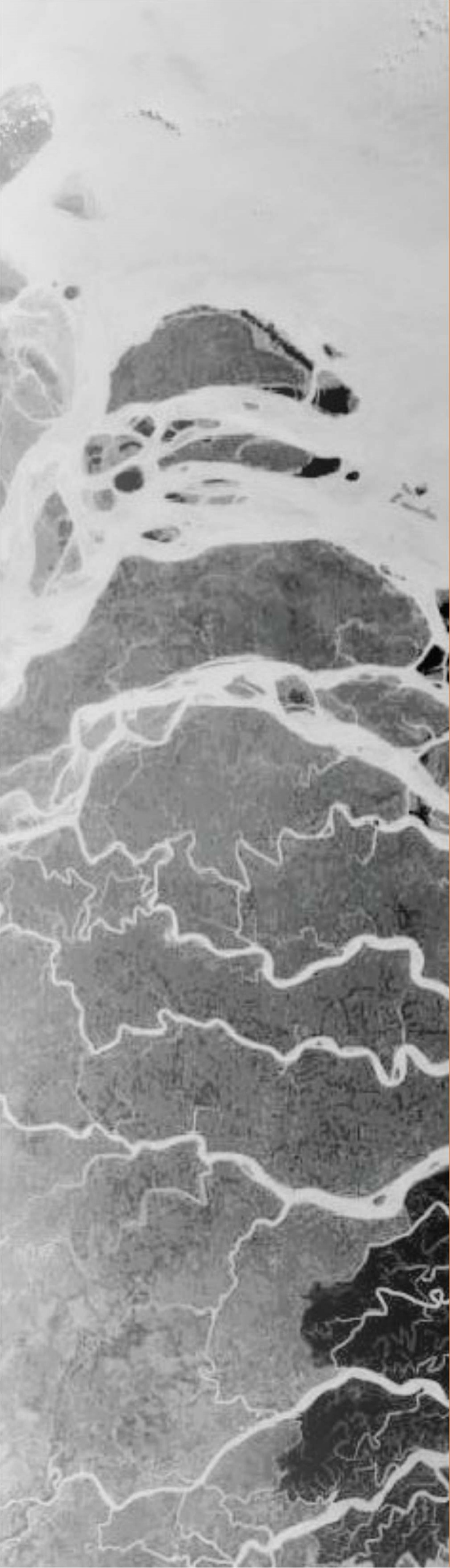


Figure 10 - Vertical land movements and subsidence

Figure 10 shows that the processes that influence regional sea level are associated with variations in ocean circulation, the static response to changes in atmospheric pressure, and mass variations in the Earth system. The adjustment of the earth's crust to past and present loads, changes in polar ice masses, changes in continental water storage, and local changes are also affected by vertical movement of the seafloor due to subsidence, earthquakes, or anthropogenic influences such as groundwater withdrawal.



4

SPECIFIC EVENTS THAT INTERFERE IN DELTAS

4. Specific events that interfere in deltas

Deltas have the ability to form different habitats and act as a source of diverse resources such as oil and gas or sand and gravel for concrete. They are a source of water for industrial and domestic purposes and natural protectors against storms. Because of their characteristics, they offer opportunities for tourism and recreation, agricultural production, fisheries development, industry and commerce, in addition to the creation of medicines from their flora. These characteristics attract socioeconomic development, encompass urbanization, agriculture and industrialization with the consequent formation of large urban centers and transport routes. They offer important resources and their economic proceeds accrue to a significant fraction of a country's annual GDP. They are among the most densely populated areas on the planet and their ecosystem services, because of their physical characteristics and variety of biodiversity, are estimated at a value in the trillions of dollars annually (Daniel P. Loucks, 2019). Despite this, many deltas suffer from erosion, subsidence and consequent flooding, culminating in the loss of their area and several other problems that are amplified by sea level rise and extreme weather events, in addition to decision-making regarding water and soil management. Many of the deltas face sustainability problems due to changes in their physical, ecological, environmental, economic and social status, climatic, technological, or human activity changes. Among the definitions of sustainability, which mostly contain the notions of timing and maintenance of benefits, Loucks states “a measure of the sustainability of a delta is the extent to which the benefits derived from the use and management of that delta can be maintained or increased over time” (Daniel P. Loucks, 2019, p. 3). These factors threaten the sustainability of deltas, as do increasing population density and the impacts of climate change, which increase the threat to deltas and the privileges these areas present. Many of these threats exist because delta morphologies are subject to rapid change as a result of the direct and indirect effects of human activity, which compromise their ecosystem services, including ease of navigation and protection from flood hazards and biodiversity (A. J. F. Hoitink et al., 2020).

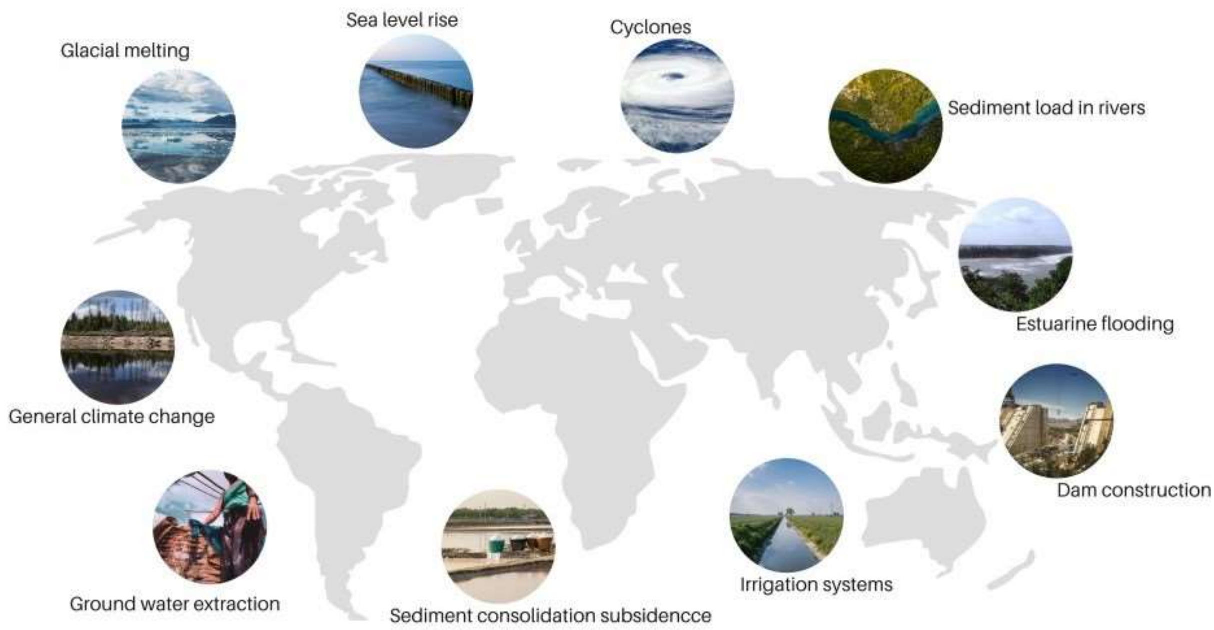


Figure 11 - Specific climate change events in delta region areas

4.1. Climate Change in the deltas

Climate change, as already covered in Chapter 2, refers to changes in the Earth's climates, at local, regional or global scales, and the term is widely used to describe human-caused events, and the effects these changes cause.

When it comes to the capacity of assessing the vulnerability of the socio-ecological systems of a delta, under the direct effects of climate change, the most common events are the occurrence of cyclones with greater frequency, sea level rise and consequent floods with salinity intrusion. The effects of these events put directly at risk the safety of people living in the deltas, as well as the health and resilience of their ecosystem as a whole (Institute for Environment and Human Security, 2015). It also puts at risk the population that doesn't live in the delta, but are affected by the lack of inputs from the delta ecosystems.

Figure 5 shows the specific characteristic events in deltas, which influence their functioning. They are characterized as naturally produced and manmade events. In this way, they are also characterized by occurring in the deltas or upstream at the rivers basin that feed the deltas. This categorization makes it easier to understand the events that interfere with the conditions of a delta, whether from natural causes, resulting from global or local climate changes or produced by anthropogenic action directly on the site or in the areas that interfere with the flow that feeds the deltas.

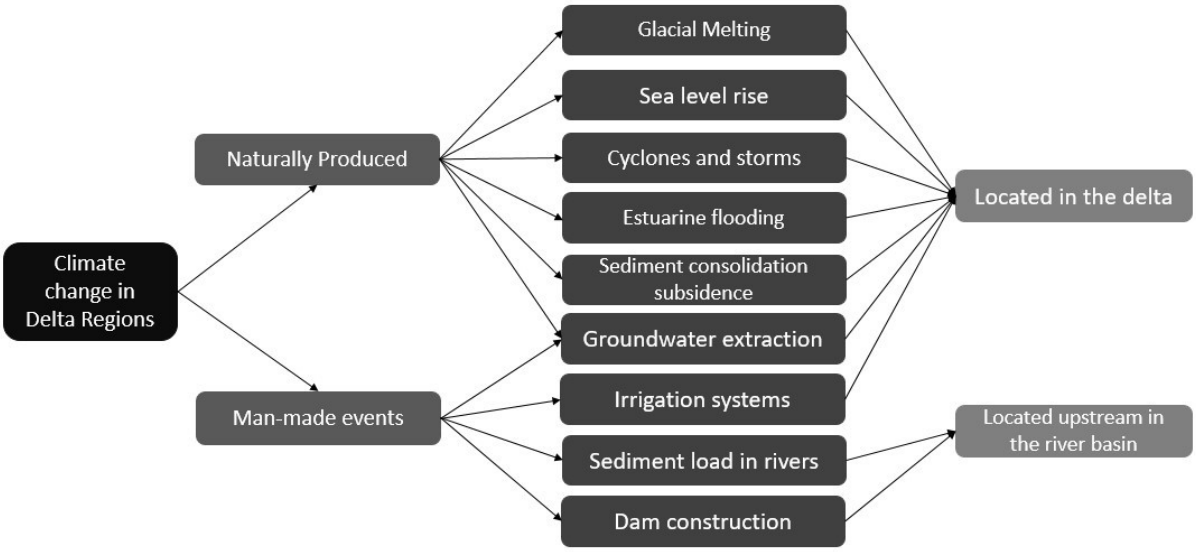


Figure 12 - Categorization of events in delta region areas

4.2. Glacial melting

Ice acts as a protective cover over land and oceans, which, by reflecting excess heat into the atmosphere, keeps the planet cooler. Currently, about 10% of Earth's land area is covered by glacial ice, of which 90% is in Antarctica and 10% is in the Greenland ice cap. Glaciers are stored on land, and when they melt, their flow influences the speed of ocean currents, interrupting the normal patterns of their circulation, increasing the amount of water in the seas and contributing to the consequent rise in sea level. In turn, rising sea levels increase coastal erosion and increase the frequency of storms. Warming air and ocean temperatures create more frequent and intense coastal storms. That is, as sea ice and glaciers melt and oceans warm, ocean currents disrupt weather patterns around the world, particularly in coastal communities, which face disasters as floods become more frequent and storms become more intense, affecting people and ecosystems (Daniel Glick - National Geographic, 2009; Global Climate Change, 2020; WWF, 2022).

Figure 13 - Glacial melting

Human activities have been at the root of the phenomenon of melting glaciers since the industrial revolution, when emissions of carbon dioxide and other GHG gases raised temperatures at the poles, melting them on their way to the sea and retreating ashore (Daniel Glick - National Geographic, 2009; US EPA, 2019; WWF, 2022).

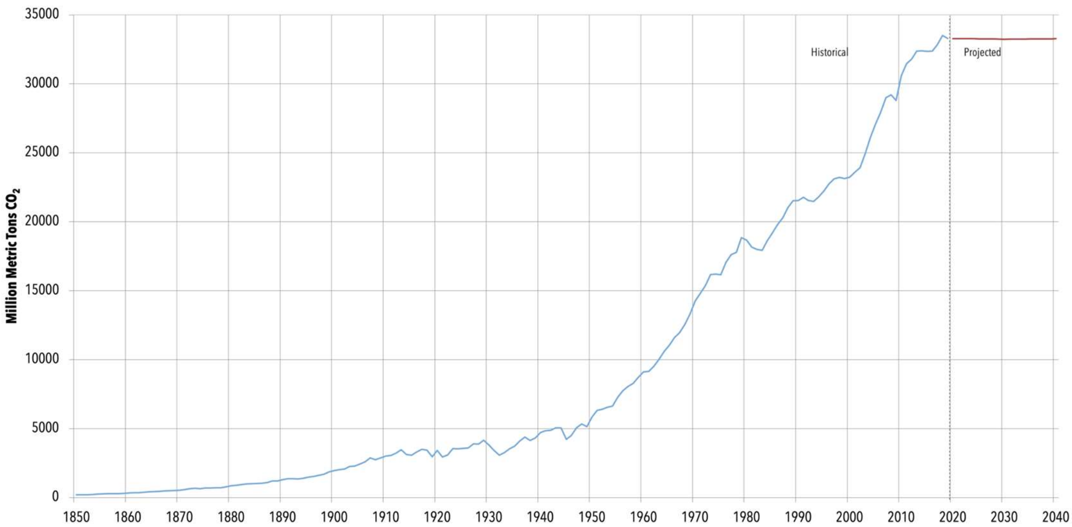


Figure 14 - Global carbon dioxide emissions, 1850-2040

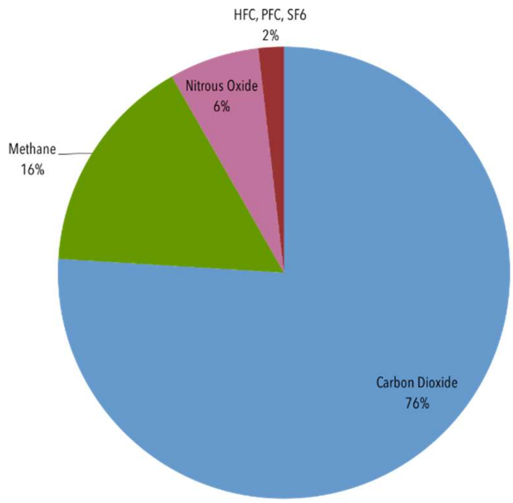


Figure 15 - Global man made greenhouse gas emissions by gas, 2015

4.3. Sea level rise

The global mean sea level is due to the combination of melting water from glaciers and ice sheets and the thermal expansion of seawater as it warms. This level has increased by about 21 to 24 centimeters since 1880, intensified by a third in the last twenty-five years, and in 2020, it was 91.3 millimeters above the 1993 average. By the end of this century, the global average level of sea could rise at least 30 cm above the levels recorded in the year 2000, even though it is possible that the emission of greenhouse gases will be relatively low in the coming years. However, the increase varies regionally according to regional characteristics. Regional differences exist because of natural variability in the strength of ocean winds and currents, which influence how much and where heat is stored in the deeper layers of the ocean. In some ocean basins, sea level rise may vary from the global average due to local factors such as flood control capacity, quality of soil settlement, ocean currents, erosion, among others (NOAA, 2020). Higher water levels represent storms with waves that are more destructive. They advance with devastating effects further and further inland and causing more frequent flooding, causing flooding in communities, plantation areas, and wetlands. They also cause more destructive erosion, contamination of aquifers and agricultural soils with salt, and loss of crops and habitat for various species of birds, fish and plants. (Cristina Nunez & National Geographic Staff, 2022).

Figure 16 - Sea level rise

Vulnerability, which is exacerbated by climate change and accelerates sea level rise, is much more intense in coastal areas, precisely because of the local geomorphological characteristics and the probability of more extreme climatic events. Urban environments along coasts around the world are threatened by rising sea levels, whether in the infrastructure needed for regional industries or local jobs, be it bridges, subways, roads, oil and gas wells, power plants of energy, water, sanitary landfills, sewage treatment plants and basic services such as internet (Mimura Nobuo, 2013). Specifically in these areas, the highest sea levels are coinciding with more threatening typhoons and hurricanes. They move more slowly and with greater amounts of precipitation, which can have more power of destroying everything they pass through, forcing the migration of people to higher terrain, and millions more are vulnerable to the risk of flooding and other effects of climate change (Cristina Nunez & National Geographic Staff, 2022).

As global temperatures continue to rise, the resulting sea level rise is inevitable, as the great ice sheets of Antarctica and Greenland will melt in a predictable and steady manner, or they may reach a point of disorientation and collapse depending on future GHG gas emission rates. Thus, once these events become real, many areas of land will disappear, and among them the delta areas as we know today (NOAA, 2020).

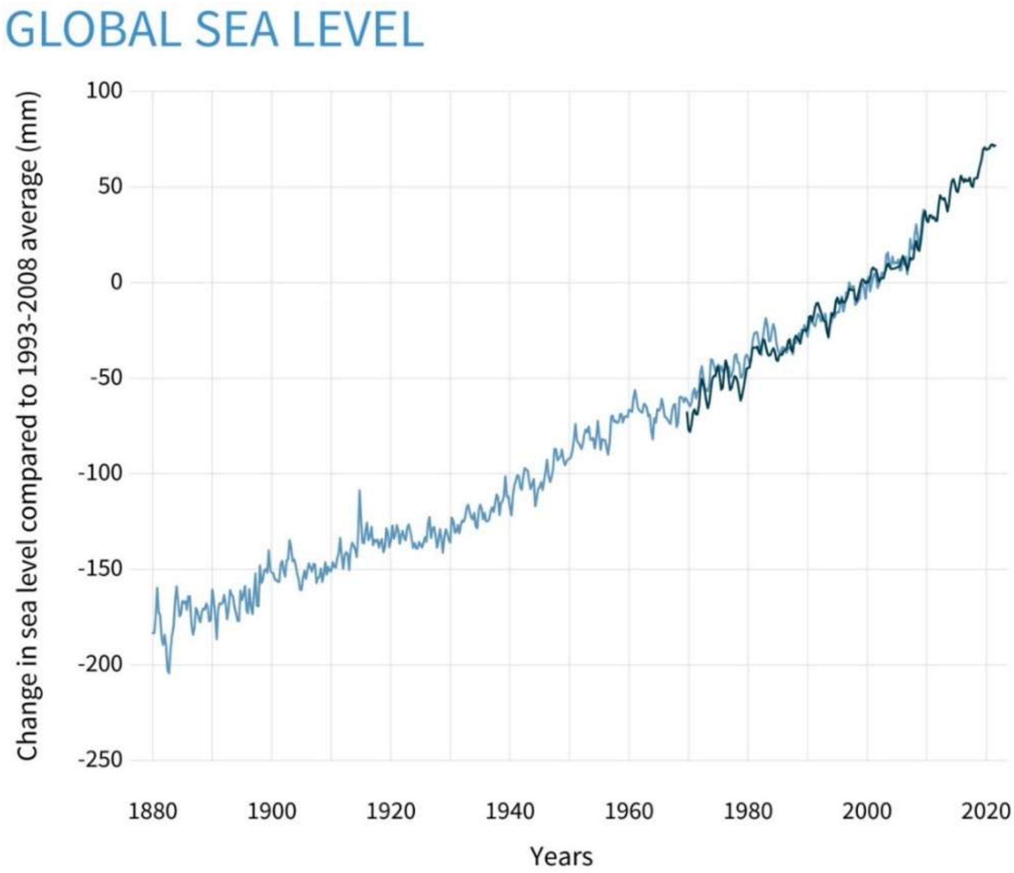


Figure 17 - Change in sea level during the years

4.4. Cyclones and storms

Due to the warming of the ocean surface, resulting from anthropogenic climate change reasons, tropical cyclones and storms that are more powerful have been fed, with greater destructive power. Its amplitude is exacerbated by the rise in sea level, which contributes substantially to the global scale of climate change from human causes, which, when associated with the increase in atmospheric humidity, contributes to the increase in its precipitation rates. In addition, rising sea levels exacerbate the risk of coastal flooding from tropical cyclones (Thomas R. Knutson et al., 2021).

The proportion of severe category 4 and 5 tropical cyclones has increased and is expected to continue increasing, bringing a greater proportion of storms with higher waves, more extreme rainfall rates and more damaging wind speeds. In fact, studies show that human activity is influencing tropical cyclones, including typhoons, tropical storms and hurricanes, and evidence of increasing climate change that fuels more intense events as a continuing trend as global temperatures increase. While the extent of human influence is difficult to be determined accurately, it is increasingly consistent that human activities are likely to be influencing some aspects of these climate events (High Meadows Environmental Institute & Laura Potts, 2021). Tropical cyclone precipitation rates are projected to increase in the future under a 2 degree Celsius global warming scenario, which would imply an even greater percentage increase in destructive potential per storm (Tom Knutson, 2021).

Delta regions are already extremely vulnerable to tropical cyclones, as the effects of climate change increase the vulnerability of the infrastructure of these locations, due to geographic, geophysical, financial and social contexts. Tropical cyclones are a major geophysical cause of loss of life and property. They turn into a disaster, especially when they occur in places with high vulnerability. They are greatly affected by climate change, interfering with their environment and society, which determines the importance of observing the impacts of climate change on vulnerability, whether socioeconomic, physical or environmental (Eva Bianchi & Liora Malki-Epshtein, 2021).

Figure 18 - Cyclones and Storms

4.5. Sediment load in rivers

Deltas, as wetlands that are formed by the emptying and sedimentation of rivers into another body of water, cause the sediment to moved more slowly near its mouth to fall to the bottom of the river, forming, under ideal conditions, a deltaic lobe. In it, the thickest and heaviest material settles first, while the thinner and smaller ones are carried downstream. All the finer material is deposited beyond the mouth of the river and helps plants and microbes to grow and as the sludge accumulates, new land is formed, i.e. a delta, which widens the mouth of a river to the body of water in which it ends (National Geographic Society, 2022). Deltas are therefore formed and elevated over time as sediment accumulates in the deltaic plain, rather than being dispersed by ocean currents. It is primarily anthropogenic influences such as population growth, land use, mineral exploration, infrastructure development and exploitation of water resources that result in significant changes in the sediment loads of rivers whose waters and surrounding areas are more extensively exploited (Chris Seijger et al., 2018). Therefore, it is of great importance that there is an understanding of river systems that have experienced various forcing mechanisms, such as tectonic forces, climate, sea level fluctuations and their linkages, in order to understand and avoid the lack of sediments necessary for delta areas to remain (Munendra Singh et al., 2007).

The union of sea level rise and delta sinking raises the relative sea level faster than in other parts of the planet, because as sediments compact under their own weight, sinking is natural. Where there is no disturbance, the supply of new sediment from the river compensates for subsidence and helps keep the delta surface above sea level. The problem centers on human activities, such as pumping groundwater, used to irrigate crops and supply water to rapidly growing cities. Regardless of the scenario of environmental change, the vast majority of deltas will receive less river sediment by the end of the century. Some of the most severe reductions will be concentrated in the Asian deltas, not as a coincidence, the largest and most densely populated deltas in the world. Sediment trapping by dams, along with the use of best soil conservation practices, flood embankments, and the removal of sand from rivers for building materials contribute to these reductions. Deforestation and damming change the shape of deltas across the planet, which needs local attention, even if events occur on a global level (Natalie Parletta, 2020; Stephen Darby & Frances Eleanor Dunn, 2019).

4.6. Estuarine flooding

By definition, an estuary is a coastal body of water opened to the sea, receiving discharges from one or more rivers, with lower salinity than that of seawater, and may become more saline in places where freshwater inflows are not significant and where water loss by evaporation is high (Ian Ceasar Potter et al., 2010). They are unique ecosystems and, as they are generally located between a river basin and the ocean, at the same time that they have some values that make them unique, they are more vulnerable to environmental phenomena. This fact causes particularly heavy losses for the population concentrated in the deltas, since rising sea levels and rising river flows together can produce severe flooding. The most disastrous floods are the result of a combination of coastal flooding, caused by storms and flooding from rivers and rain, which interacting are more severe than when they occur alone (Physics World, 2018; Water Technology, 2010).

Figure 19 - Estuarine flooding

The mean sea level (MSL) is a parameter used in civil engineering projects, mainly and obviously for coastal, estuarine and deltaic areas. Eighty percent of large cities with more than one million people are in the deltaic and estuarine regions of the planet and the elevations of most of these cities are not higher than the local high tide level. Adaptation and action strategies present themselves as an important agenda of governments and the scientific community around the world, in a demand for estuarine and deltaic cities that can adapt to rising sea levels (Cheng et al., 2018).

4.7. Dam construction

Figure 20 - Dam construction

One of the most significant specific events in delta regions is the damming of rivers upstream, which drastically reduces the flow of sediments downstream, causing loss of delta area, as the construction of dams often takes place without considering the consequences to the downstream areas (Natalie Parletta, 2020).

Since much of the land in river deltas is located just above or even below sea level, the risk of land subsidence and consequent flooding is, in addition to being high, often increased by human activity, either through entrapment of sediments in upstream reservoirs, whether through groundwater extraction, sand mining, control of river channels and accelerated sediment compaction. Sea level rise statistics show that the vulnerability of such areas to flooding will tend to increase in terms of duration and extent (Jeff Opperman, 2019).

While climate change calls for global attitudes, sediment loss needs local and shorter-term solutions. Hydroelectric dams capture large amounts of sediment along the way, decreasing a river's flow and amount of sediment, which robs a delta specifically the raw material it needs to protect itself against forces that tend to destroy it, such as waves, storms and rising sea levels. Without the natural protection of sediments, deltas shrink and sink (Jeff Opperman, 2019; N. Nageswara Rao et al., 2010; Xing Li et al., 2017).

The world's large deltas lose more than half of their sediments due to the construction of upstream dams, i.e. human activities have a direct and relevant impact on the global supply of sediment to deltas, as reservoirs retain approximately a quarter of the annual flow of silt and sand that would reach deltas and the ocean (Jeff Opperman, 2019).

4.8. Sediment consolidation subsidence

Soil subsidence due to sediment consolidation is largely the result of the consolidation of deltaic clay layers accumulated in the part of the delta that is located in calm seas. There, the sediments carried by the current are no longer predominant, in addition to the consolidation of sediments in the bays and marine clay layers contained in the delta (Changxing Shi et al., 2007).

Deltas experience varying degrees of land subsidence and much of the consolidation and compaction of their sediments considered natural (Yi Zhang et al., 2017). Despite the naturalness of the fact, subsidence is also linked to environmental degradation. It afflicts, in particular, areas located along coastal areas, swamps, deltas and lagoons, which are increasingly vulnerable to storms, floods and salinization. Among the natural sources of subsidence are the presence of tectonic movements, the compaction of sediments, volcanism, sinkhole formation, permafrost thaw, among others. Anthropogenic sources include drainage of organic soils, underground mining, compaction of the aquifer system associated with the depletion and storage of groundwater, natural gas or oil, and stress caused by new construction (Nicola Cenni et al., 2021; Truong & Nguyen, 2020). The 2012 Intergovernmental Panel on Climate Change (IPCC) report also states that climate change can bring with it, as an effect of sea level rise, a drastic increase in problems related to subsidence (IPCC, 2021).

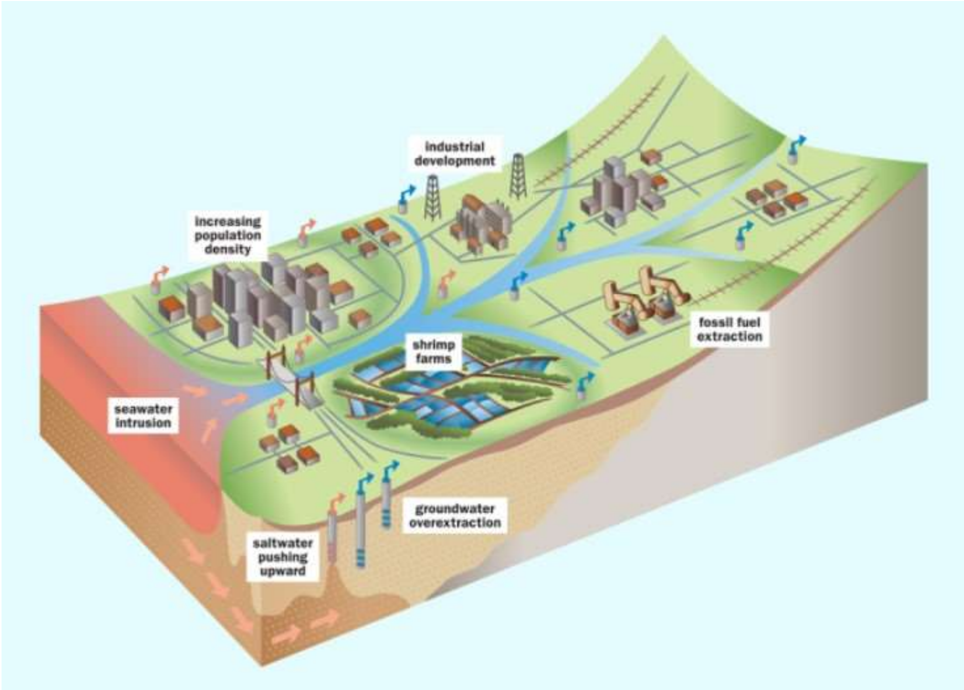


Figure 21 - Sediment consolidation subsidence causes

Figure 21 shows the causes of sediment consolidation subsidence and the various interconnected factors that contribute to their happening in delta regions, with growing populations having serious repercussions for the land. The construction of dams, dikes, and embankments blocks the natural deposition of sludge, making it impossible to replenish land and creating basins where water from floods accumulates without having a place to flow. The extraction of groundwater and extraction of fossil fuels that are often found near deltas allow layers of land to empty. The weight of the surface itself and the growing urban and industrial infrastructure further compresses the land and impermeable surfaces prevent groundwater replenishment. Saltwater intrusion is exacerbated as groundwater depletion reduces water pressure. Growing populations and intensive water use, such as shrimp farming, place a strong demand on groundwater resources. Wells must be drilled deeper and consequently the water that rises is saltier.

4.9. Groundwater extraction and irrigation systems

Groundwater presents itself as reliable source for human use and agriculture and its extraction puts pressure on these types of water resources, as it puts them at risk of quality deterioration and possible depletion (Eman Ragab Nofal et al., 2018; Qureshi, A.S. et al., 2015). It is an extremely essential part of public water supply and food production, as they can provide pathogen-free drinking water and groundwater irrigation can sustain dry seasons in many of the planet's deltas. However, this practice can cause crises such as contamination and decline of groundwater (Madhumita Chakraborty et al., 2021), in addition to being one of the main causes of land subsidence, representing a greater risk of flooding in coastal areas, already threatened by the increase in sea level rise (SLR). Excessive exploitation of groundwater, whether for human consumption or for irrigation systems, leads to a decrease in the water table, with consequent compaction of the sedimentary layers in these places, aggravating the subsidence process, which may increase the risk of additional flooding (Laura E Erban et al., 2014). More often than not, groundwater from aquifers in deltas serves as the primary source of drinking water and irrigation for the millions of people who reside there. The large-scale use of groundwater ends up disturbing the natural flow of the aquifer, reducing the hydraulic load, especially close to urban agglomerations (Madhumita Chakraborty et al., 2021).

One of the major problems of this practice is the focus of public policies on the development of resources instead of their management, which results in the problems mentioned above (Qureshi, A.S. et al., 2015).

Figure 22 - Ground water extraction and irrigation systems

5

SALINIZATION AND ITS EFFECTS ON DELTA REGIONS

5. Salinization and its effects on deltas

Salinity intrusion is a global phenomenon, a process by which seawater moves inland, reaching freshwater sources and surrounding terrain. The intrusion of salinity can be caused by natural causes, as it is the case of tidal flooding, or anthropogenic, as it is the case of excessive extraction of groundwater and can cause irreversible contamination of aquifers, rivers and soils, with implications to the water and food security of millions of people around the world (Yukyan Lam, 2017). Socio-ecological concern is most intense in the global river deltas, which are home to more than 500 million people with almost eight times the global average population density, fueled by global environmental changes and phenomena. As a critical consequence, it presents the reduction of access to fresh water, which is crucial for consumption, livelihood activities and hygiene (M.M. Rahman et al., 2018). The presence of water and rich sedimentary soil makes the delta regions potential attractions for high-intensity agriculture. These regions maintain their high population densities dependent on agriculture, but environmental changes reduce the quantity and quality of water available for this purpose. Added to this are anthropic influences, which result in the accumulation of salts in soils, reducing agricultural productivity (Yukyan Lam et al., 2018). In these areas, surface and groundwater sources, which are already significantly more saline than acceptable levels for consumption, still show a predisposition to increase, including a tendency to move further into the interior of the continents (Md. Mansur Rahman et al., 2022; Yukyan Lam et al., 2018). Several environmental and artificial factors play a role in driving salinity, including various climate impacts, in addition to heavy metal contamination of groundwater, which exacerbates food and freshwater insecurity (D. Clarke et al., 2015).

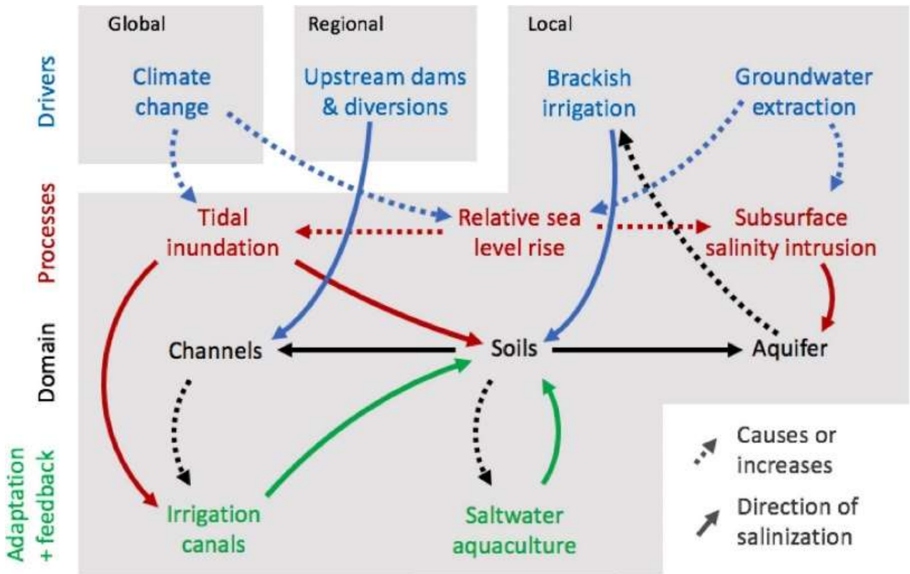


Figure 23 - Drivers of salinization

Salinity drivers are a combination of global, regional and local factors. These actions interfere in the processes at the three levels, reflecting between them, and interfere in the three domains, namely the delta channels, the soil and the aquifers. Under these conditions, they interfere with saltwater aquacultures and irrigation channels, amplifying the problems derived from salinity. When occurring in sparsely populated areas, salinization can alter ecosystems, including the death of local vegetation and its migration, with implications in terms of lost ecosystem services. When occurring in populated and cultivated delta areas, salinization can be overshadowed by its results on food, water, health and livelihoods security (M.M. Rahman et al., 2018). The sustainable development in the delta regions is therefore limited by the salinity of the water, which comes from different sources and, for this reason, must be studied taking into account agriculture, community water supply and groundwater, in order to that corrective actions be applied to all sectors (D. Clarke et al., 2015).

Salinization also causes direct impacts on human health through contamination of drinking water, and the impacts of it disproportionately affect the poor, including migration from rural areas to cities, mainly due to the fact that the most vulnerable populations are located in areas most affected by the effects of climate change and are less likely to fight these effects. Salinization is the result of multiple factors and its consequences are measured by harmonizing the available adaptation options with the socioeconomic situation of the affected population. The prevalence and impacts of salinization tend to be amplified by pressure from population growth, economics, transboundary water policies and ongoing climate change. The scale and main salinization factors are collective, but they act in different spaces (local, regional, transboundary or global) disturbing the socio-hydrological balance in places where there are human agglomerations. (Hossain, Peerzadi Rumana et al., 2018; M.M. Rahman et al., 2018).

Figure 24 - Soil and water salinization

5.1. Food and water insecurity and the effect on human life

When the natural salinity of river deltas is accentuated by environmental changes, it challenges those areas around the world and highlights one of the biggest consequences: access to fresh water, essential for basic livelihood activities (Yukyan Lam et al., 2018). As delta areas play an important role in the food security of the countries in which they are located, precisely because of their characteristics, the intrusion of seawater also causes difficulties for existing agricultural practices (Tran Thi Nhung et al., 2019). Thus, one of the biggest challenges for countries dependent on deltas is guaranteeing the security of water and food supply. The combination of environmental and socioeconomic factors intensifies the risks of food insecurity, especially in the most densely populated areas, with the fishing and agriculture sectors being greatly threatened by the increasing intrusion of salinity, leading to a significant effect on household food insecurity (Szabo, Sylvia et al., 2014).

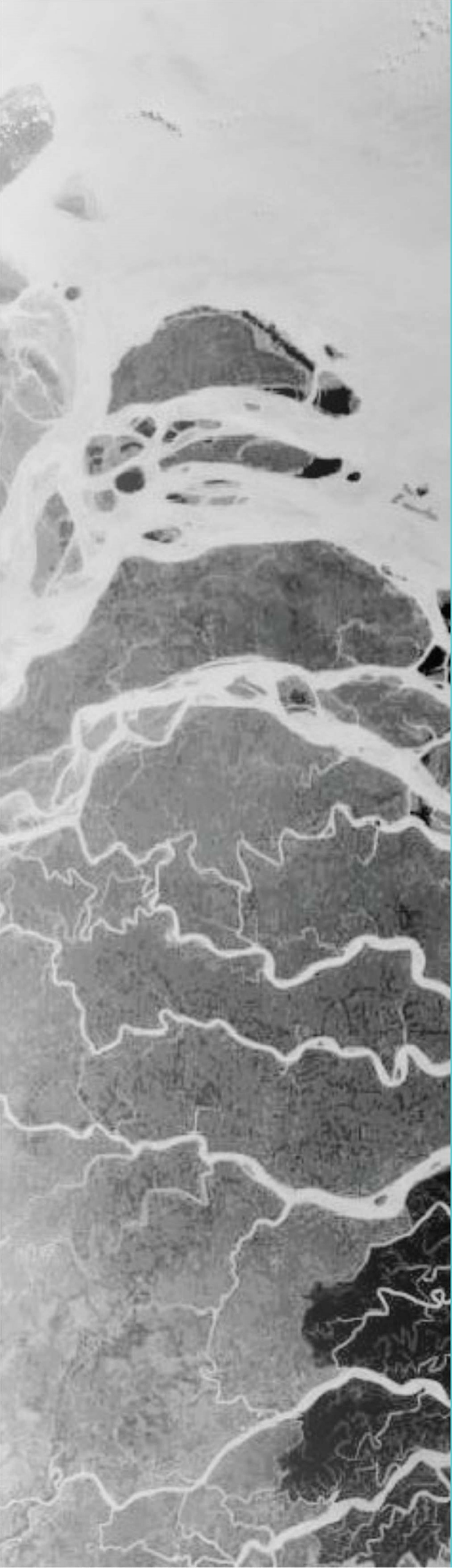
Figure 25 - Importance of water and agriculture in Bangladesh

It is in low-lying deltas that salinization of freshwater and soils negatively affects nearly half a billion people, where salinity influences water and food security, agricultural livelihoods and human health are most acute. Populations, especially the poor and rural, are forced to consume saline waters and end up with a higher occurrence of diseases (M.M. Rahman et al., 2018). The salt intrusion, together with seasonal droughts, causes a great impact on the capacity that agricultural practices have in many deltaic regions of the world, leading millions of hectares to be affected by salt intrusion, and affecting crop quality (Tran Thi Nhung et al., 2019).

Salinization also causes direct impacts on human health through contamination of drinking water, with secondary results in migration within and beyond borders (J. Chen & V. Mueller, 2018). When soil, surface and groundwater sources are reported to be more saline than acceptable levels for consumption and are contaminated by heavy metals (Yukyan Lam et al., 2018), the question arises as to how the affected population can adapt, diversifying economic activities to avoid migration. The relationship between human action and environmental change must result in effective adaptation, mitigation and implementation of continuous support policies, especially with the implementation of innovations that manage to maintain freshwater security, seeking to avoid loss of income and migration driven by the consequences of salinity in agricultural production and water sources (J. Chen & V. Mueller, 2018).

Adaptation options regarding water salinity focus on hot and dry seasons, when the tides have a much greater influence on the salinization of water and soil. The adaptations involve, among other options, rainwater harvesting as an option for drinking water, with the acquisition of tanks to collect and store rainwater. In addition, the use of water from ponds for drinking, cooking and other purposes, use of filters to provide water during the drier seasons, pay for water delivery via water trucks and construction of tube wells. The use of a managed aquifer recharge system, desalination of water through reverse osmosis and release of water from reservoirs (where available) to repel the intrusion of salt water from ocean tides are also considered (Ariel Rubissow Okamoto, 2014; Yukyan Lam et al., 2018).

Adaptation options related to agricultural practices range from encouraging land use practices, using salt tolerant crop varieties and engineering solutions to transitioning from coastal land use from agriculture to shrimp aquaculture and water use. groundwater as a source of easily accessible fresh water to replace increasingly brackish surface water (M.M. Rahman et al., 2018). The acceptance of salinity processes as normal natural phenomena is also used as a form of adaptation, causing residents to adjust their livelihoods, suffering from its consequences. Even when knowing that there is a tendency for soil and water salinity to come to reach levels where conflict is no longer a choice and different adaptation options are necessary to prevent migration it is a form of adaptation (D. Clarke et al., 2015; M.M. Rahman et al., 2018; Tran Thi Nhung et al., 2019; Yukyan Lam, 2017).



6

EFFECTS OF CLIMATE CHANGE IN GANGES-BRAHMAPUTRA DELTA IN BANGLADESH

6. Effects of climate change in Ganges-Brahmaputra delta in Bangladesh

The Ganges-Brahmaputra Delta encompasses nearly 87,300 square kilometers in Bangladesh and West Bengal, with two-thirds of the Ganges-Brahmaputra Delta located in Bangladesh. It covers most of the country's territory and is the largest and most populous delta in Asia, with approximately 111 million people who are at risk due to the sea level rise, linked to climate change and directly responsible for the increase in water and soil salinity. It is the cause of putting its population at risk of water and food insecurity (Szabo, Sylvia et al., 2014; Union of Concerned Scientists, 2011). The country's large population is squeezed into an area of less than 58,000 square miles, where nearly 50% of Bangladeshis live below the poverty line, and it exacerbates the risks the country faces (Saleemul Huq, 2016).

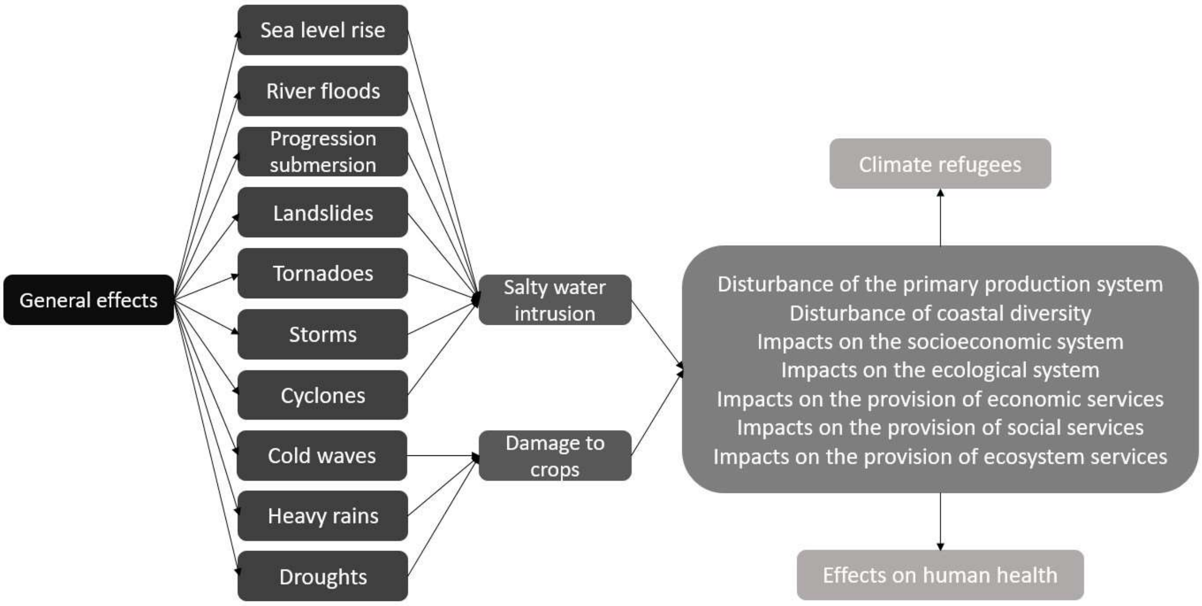


Figure 26 - The path that the effects of climate change take in Bangladesh

Bangladesh is keenly feeling the effects of climate change. As one of the most densely populated countries in the world (Worldometer, 2022) and situated over the delta where three of Asia's largest rivers meet, it deals with storms, cyclones and river floods. Even though these phenomena are a part of life in Bangladesh, they are now more frequent, less predictable and a lot more powerful. There has been an increase in erosion of rivers and an increase in sea level, which results in the invasion of salt water into the interior of the country, interfering with the lives of the population. Bangladesh's more than 165 million people seek to cope, adapt, and innovate in the face of the changes they witness (Yukyan Lam, 2017).

The increase in the frequency of natural disasters, sea level rise and salt-water intrusion are the main causes of the increase in salinity in deltaic regions around the world and, as expected, in the Ganges Delta is no different, especially in regions that are located at a low altitude in relation to sea level. These regions become especially vulnerable to the phenomenon, with consequent flooding and saltwater intrusion (Hossain, Peerzadi Rumana et al., 2018), which mainly affects land and water in coastal areas, but whose intrusion progressively grows into the interior of the country, disrupting the primary production system, coastal biodiversity and affecting human health (Reaz Haider, 2019). According to the Ministry of Agriculture of Bangladesh (2010), salt water entered up to 15 km north of the coast between 2000 and 2009, due to reduced upstream river flows in the dry season. The total amount of land affected by salinity intrusion in Bangladesh increased from 83.3 million hectares in 1973 to 102 million hectares in 2000 and 105.6 million hectares in 2009, also extending to non-coastal areas (Ministry of Agriculture - Soil Resource Development Institute, 2010). The phenomenon brought with it impacts on socioeconomic and ecological systems, on the provision of economic, social and ecosystem services, since the deltaic plains of the Ganges, Brahmaputra and Meghna rivers make up most of the land area of the country, and the vast majority of the coast of the country is at an altitude of less than 5 meters. It is currently experiencing rates of relative sea level rise of around 5 mm/year and this is expected to accelerate further throughout the 21st century, creating concerns that the delta will be progressively submerged, particularly the low-lying coastlines. and floodplain ecosystems (Md. Mansur Rahman et al., 2022).

The impacts of global warming seem to be more severe in Bangladesh due to the exposure and vulnerability of a large part of the population. This vulnerability is due to the geomorphological conditions and unique geographic location of the country, low altitude in relation to sea level, dominance of floodplains, high population density with high levels of poverty and great dependence on natural processes and resources, with a history of extreme weather event conditions. The country is also very poor, and the majority of its population lives below the subsistence level, making them vulnerable just for that fact. The country experiences frequent flooding and some of the worst disasters in terms of mortality have occurred in that region. Flash floods with severe consequences have intensified and occurred more frequently, mainly due to increased rainfall, with Bangladesh having been hit by three major floods in the last 25 years, when heavy rains in short periods culminated in massive cases of landslides. Cold waves break out, damage crops and claim lives, and droughts affect coastal regions, whose waters become dangerous for fishing boats. Losses from extreme events such as tornadoes, cyclones, floods or droughts are devastating for both the government and the population and research points to an increase of 25 million climate refugees in Bangladesh in the coming decades (Islam & van Amstel, 2018).

Nevertheless, not only sea level rise and deadly disasters are serious in Bangladesh, but also the consequences of human interventions, which accelerate subsidence and worsen the situation of excessive soil salinity, affecting the production of various crops and harming the local ecology (Hossain, Peerzadi Rumana et al., 2018; Islam & van Amstel, 2018).

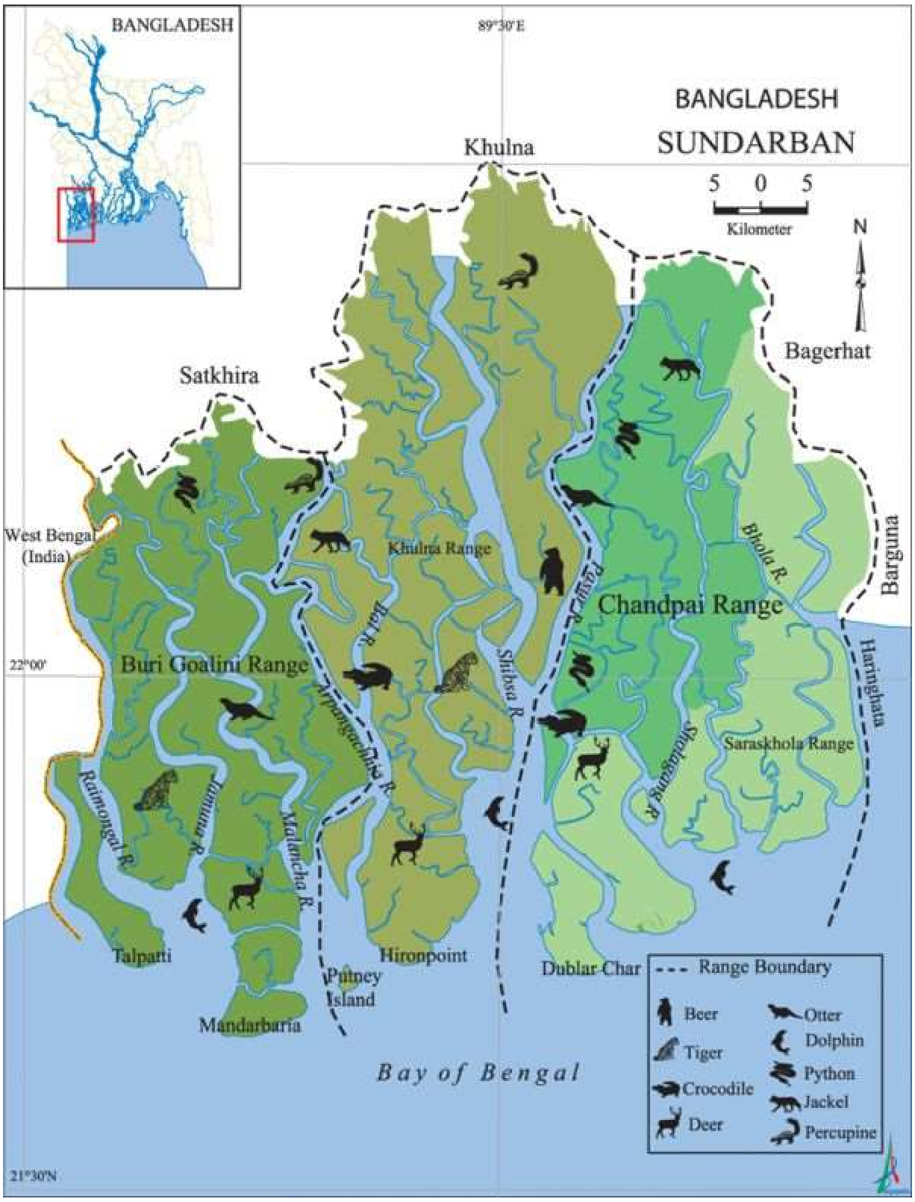
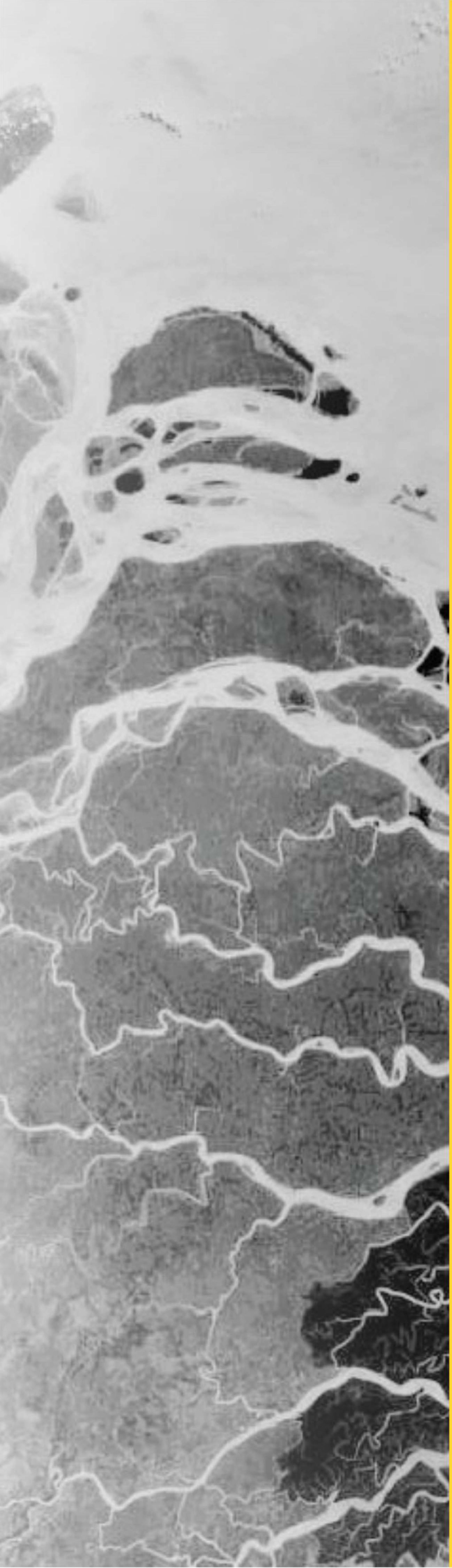


Figure 27 - Sundarbans location

The Sundarbans, the largest single stretch of mangrove in the world, as well as the agriculturally active hinterland and swamps, which together form a highly diverse ecosystem, are heavily affected by salinization, which also leads to extreme scarcity of fresh water for millions of people. They already undergo significant changes due to hydro climatic variables and problems induced by changes and reduced flow of upstream rivers (Md. Anwarul Abedin, 2014; Yukyan Lam, 2017).

Figure 28 - Sundarbans – Stream-Nipa Palm-Tidal forest

According to Islam & van Amstel (2018), based on data from the UNDP (United Nations Development Programme), Bangladeshi scientists agree that Bangladesh has already suffered difficult impacts, such as “flood and erosion, saline intrusion, deforestation, loss of biodiversity and agriculture and large-scale migration” (Islam & van Amstel, 2018, p. 21). Each year, drought affects about 2,32 million hectares during the summer and 1,2 million hectares of cultivated land during the winter, while soil salinity affects 3,05 million hectares, flooding affects 0,7 million hectares and acidification affects 0,6 million hectares of agricultural land (Islam & van Amstel, 2018; UNDP, 2021).



7

CAUSES OF SALINITY INTRUSION IN BANGLADESH

7. Causes of salinity intrusion in Bangladesh

The global causes of the increase of salinity and the frequency and severity of hydro climatic extremes are already known in deltaic regions. Nevertheless, a better understanding about the local socioeconomic and biophysical conditions appears to be incomplete when it is needed to identify the cross-causes of increased salinity and their impacts on different coastal systems. Although salt intrusion has clearly increased in recent times, future amounts are doubtful due to gaps in future climate change and local upstream and downstream structural developments (Hossain, Peerzadi Rumana et al., 2018).

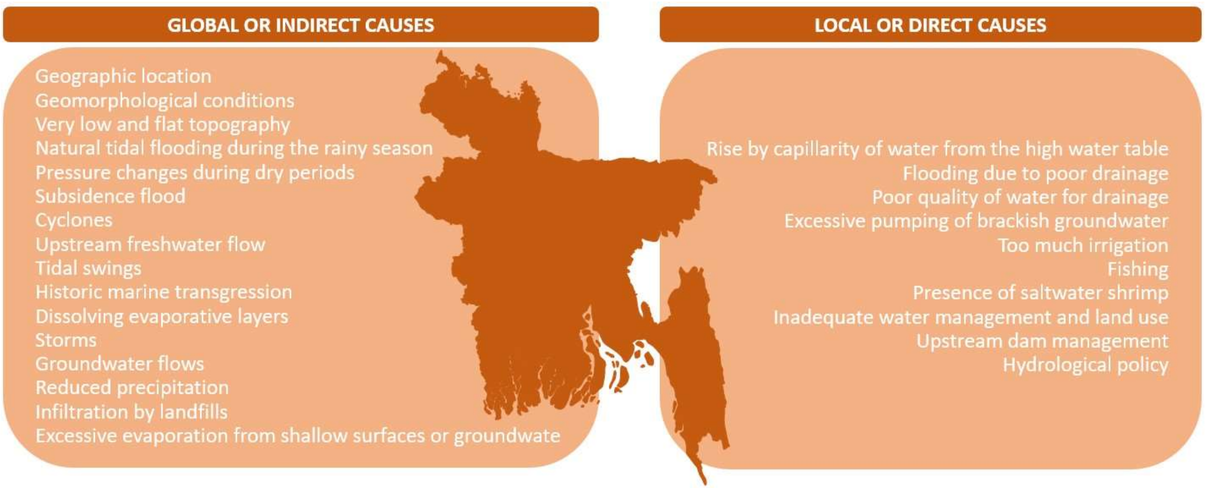


Figure 29 - Main causes of salinity intrusion in Bangladesh

The geographical location and geomorphological conditions of Bangladesh, in addition to its very low and flat topography, causes major monsoons and natural disasters, since about 10% of the country is 1 meter above mean sea level and one third of the territory is subject to excursions of tide. Numerous channels and streams with very low and flat topography cross the western part of the country, known as the Ganges tidal plain. The southwestern part of the region is home to the Sundarbans, the world's largest mangrove forest, which acts as a deterrent to tropical storms and cyclones. The central region is more active, where continuous processes of accretion and erosion take place, home to the estuary of the Meghna River. One of the largest river systems in the world, the combined flow of the Ganges, Brahmaputra and Meghna rivers discharges into the northeast of the Bay of Bengal, whose estuarine region is highly vulnerable and has seen the most disastrous effects of tropical cyclones and storms in the world. The eastern region is more stable as it is covered by mountainous areas, and has one of the longest beaches in the world (Islam & van Amstel, 2018).

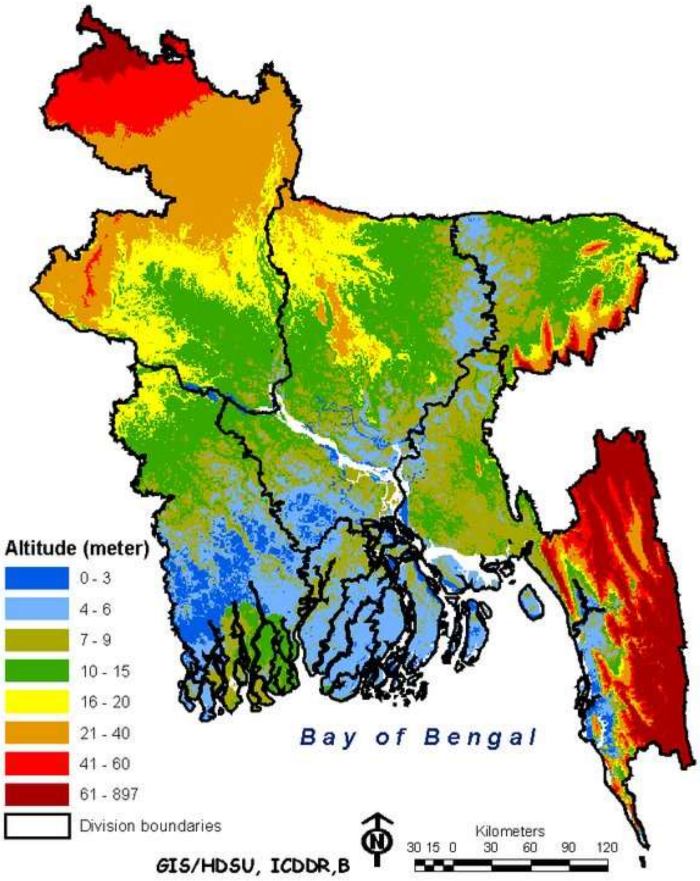


Figure 30 - Elevation map of Bangladesh

According to D. Clarke et al. (2015), the salinity present in the Ganges-Brahmaputra delta “comes from many sources”, whether they are “river salinity, groundwater salinity, waterlogging due to poor drainage, irrigation water quality and inundation” (D. Clarke et al., 2015, p. 3). From there, they take different paths, either through direct or indirect use of the source. As direct use, the irrigation through surface waters as canals and ponds, irrigation from rivers or groundwater and drinking from wells are cited. As an indirect use, the flooded areas and the capillary rise of water from the high water table, whose water evaporates leaving salt in the soil, excessive pumping of groundwater, which extracts brackish water from aquifers, excessive irrigation, fishing and the presence of farms shrimp (D. Clarke et al., 2015).

The attractiveness for high-intensity agriculture of the Ganges-Brahmaputra delta is mainly due to the availability of rich sedimentary soils and fresh water, and the high local population density depends on irrigated agriculture (D. Clarke et al., 2015). The Ganges-Brahmaputra delta is developed in terms of irrigation facility and hydrological infrastructure. However, sea level rise, tidal variation and river flow reduction, as well as human activities that demanded an increase in the use of low quality water from river inlets and underground water extraction, culminated in the accumulation of salts in the soils. These activities reduce the quantity and quality of water available for successful agriculture, decreasing crop productivity, and harming communities in this region, which often depend on the same water for cooking and drinking, as surface waters are so abundant contaminated by industrial, commercial and urban pollution. In this way, both pollution and salinity, which are largely the result of inadequate water management, pose a threat to water and food security (D. Clarke et al., 2015; Joyce J. Chen & V. Mueller, 2018; Pia Schneider & Folkard Asch, 2020).

In this region, people are highly dependent on activities such as marine and riverine fishing, as well as heavily dependent on traditional monsoon rice cultivation. They are highly exposed to the risks posed by climate change, with the average tidal range in Bangladesh varying by up to 4 meters and propagating up to 100 km inland. As the lower areas of the delta have an average elevation of no more than 2 meters above mean sea level, large areas of land are exposed to natural flooding. In addition to the subsidence of these areas, which yields from 2 to 3 millimeters per year, it contributes to the submersion of low-lying coastal areas and consequent intrusion of salinity (Md. Mansur Rahman et al., 2022).

According to Yukyan Lam (2017), the complex environmental phenomenon of salinity intrusion in the coastal region of Bangladesh contributes to "sea level rise, cyclone storms, diversion of the Ganges River by dams in India, tidal flooding during the wet season, changes in pressure during dry periods, and large-scale saltwater aquaculture, specifically shrimp farming" (Yukyan Lam, 2017, p. 25). Extensive shrimp farming off the coast of Bangladesh creates a direct conflict with agricultural activity and land use, as landowners often deliberately flood rice fields with brackish water and convert them into shrimp farming areas, harming not just agriculture, but also agroforestry, fisheries, livestock and physical infrastructure (Hossain, Peerzadi Rumana et al., 2018; Natalie Parletta, 2020). The transition from rice fields to brine shrimp farming, i.e. a local land use change, exacerbates the combined effect of reduced freshwater flow and rising sea levels, increasing brackish water infiltration and decreasing resilience to the tide, increasing land subsidence (M.M. Rahman et al., 2018). Started in the 1980s and 1990s, saltwater shrimp farming in ghers[3] was an adaptive response to natural salinity during the warm season. The proportion of agricultural area dedicated to ghers was increased, making the practice a year-round activity, which contributed to soil and water salinity (Yukyan Lam, 2017). In

[3] Gher is a modified rice field (generally situated in a floodplain) comprising a ditch around the rice field and dikes built to maintain a depth of about 1 meter in the ditch. (Md. Mostafa Kamal, 2010).

addition, in some areas, over pumping groundwater causes saline water in rivers closer to the tide to draw closer, even though the salinity of groundwater and saline river water is already amplified by factors such as cyclones, which raise the level of water and cause flooding (D. Clarke et al., 2015).

Bangladesh is naturally exposed to a number of salinity factors in response to environmental processes that include freshwater flow from the upstream watershed, tidal fluctuations, historic marine transgression, dissolution of evaporative layers, excessive evaporation from surface water or shallow groundwater and storms and groundwater flows. Despite of it, the Ganges-Brahmaputra delta deals with excess salinity intrusion into the delta's channel network, soils and aquifers. Rising mean sea levels and reduced water flow force salt encroachment further and further upstream into delta channels. Groundwater uptake together with lateral infiltration bring salt water into aquifers. Increased flooding due to land subsidence potentiated by climate change, infiltration that occurs through landfills, reduced precipitation and capillary rise salinize delta soils, making these forms of salinization linked, as salinization in one place in the delta can lead to salinization in another, either by natural or anthropogenic means (M.M. Rahman et al., 2018). That is, there are several factors at local, regional and global scales that interact and contribute to salinization, which are determined by the local social and environmental context.

Figure 31 - Breeding saltwater shrimp in ghers

Local decisions on land and water use are also considered causes of salinization. As groundwater is the main source of domestic drinking water, salinization is highest in shallow aquifers where water is allowed to be extracted for domestic use. Likewise, permission for brackish irrigation, which leads to the accumulation of salts in the soil as water evaporates, or groundwater, which receives salts leached from surface soils, in addition to saline aquaculture, which also increases salinization of water and soil. Despite receiving investments from the Central Bank and providing a significant profit to the Bangladeshi government, the destruction of rice fields in order to transform them into shrimp farms employs only a fraction of the people needed to harvest rice. In addition, it provides the replacement of a cheap food by a much more expensive one, which few inhabitants have the financial capacity to support (Islam & van Amstel, 2018). Regionally, salinization tends to be amplified when there is dependence on freshwater inflow into the upstream delta, with both sediment flow and water flow being managed by the Farakka dam upstream, built for navigability and access to drinking water in Kolkata, India. It retains sediment, alters natural deposition, gradually builds up material and naturally shifts delta lands. The hydrological policy also contributes to the salinization of the Ganges-Brahmaputra delta, since there are transboundary negotiations, with the conduction of water at the state level, compromising and affecting the local residents of the delta, who do not influence decision-making (M. M. Rahman et al., 2018).

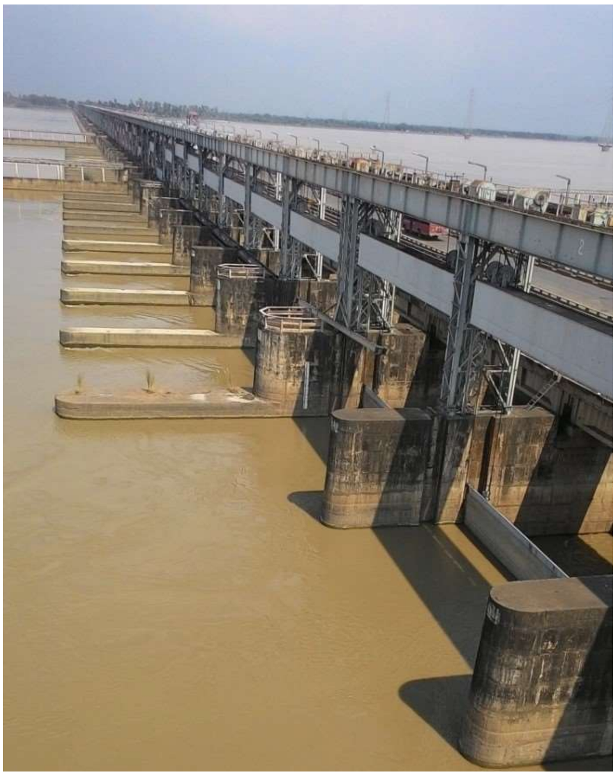
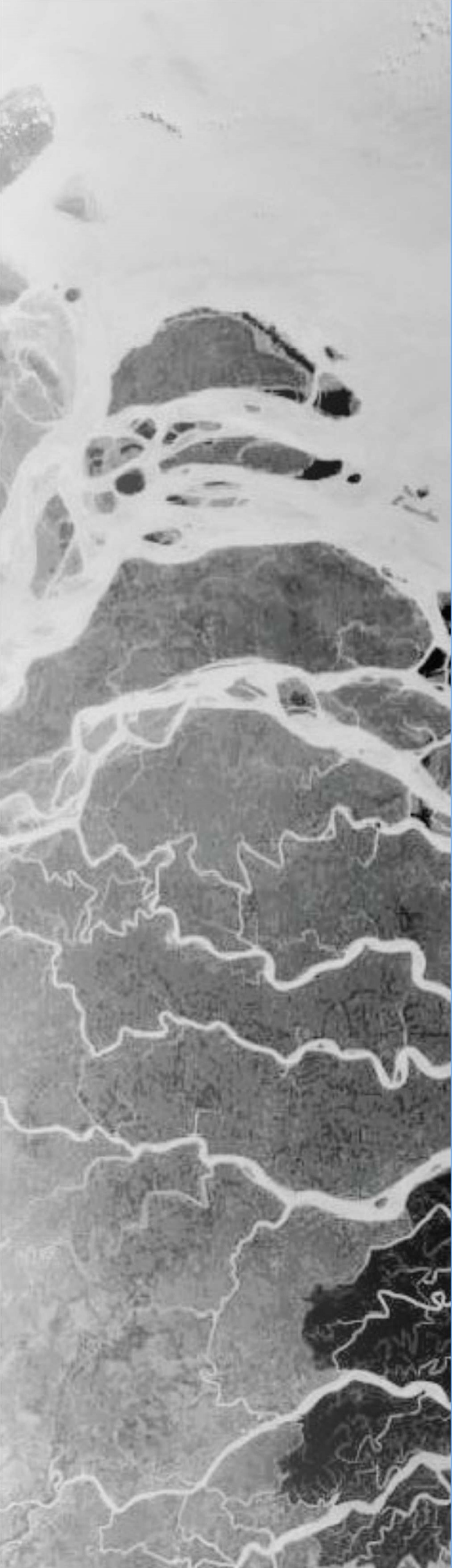


Figure 32 - Farakka Dam



8

IMPLICATIONS OF SALINITY INTRUSION IN BANGLADESH

8. Implications of salinity intrusion in Bangladesh

The salinity in the waters, whether surface or underground, as well as the salinity in the soil, have a great impact on the water and food security of the population. Its presence in soil and irrigation water compromises the cultivation of trees, pastures and crops, compromising soil quality and affecting plant development. Rice, the main staple crop for subsistence and local food security, is considered tolerant to medium salinity levels, although different varieties have different sensitivities. However, salinity affects the chances of subsistence and food production, as it interferes with the amount of pasture, feed and fresh water for livestock. The presence of higher salinity of water sources also affects the cultivation of freshwater fish, in addition to reducing the diversity of fish in rivers and streams. The fact that some tubular wells for capturing water do not have functionality or contain arsenic, in addition to the contamination of surface water and the salinity of groundwater, are pointed out as factors of the harmful lack of availability of drinking water in the region. In addition, a large majority of households often use more than one source for drinking water, varying with the time of year. Still, the high presence of sodium in drinking water causes visible public health problems for residents of the delta region. However, in addition to the damage to food and water consumption, salinity also interferes with the health of the population, including hypertension, skin diseases, miscarriage, acute respiratory infection and diarrheal disease (Susmita Dasgupta et al., 2015; Yukyan Lam, 2017).

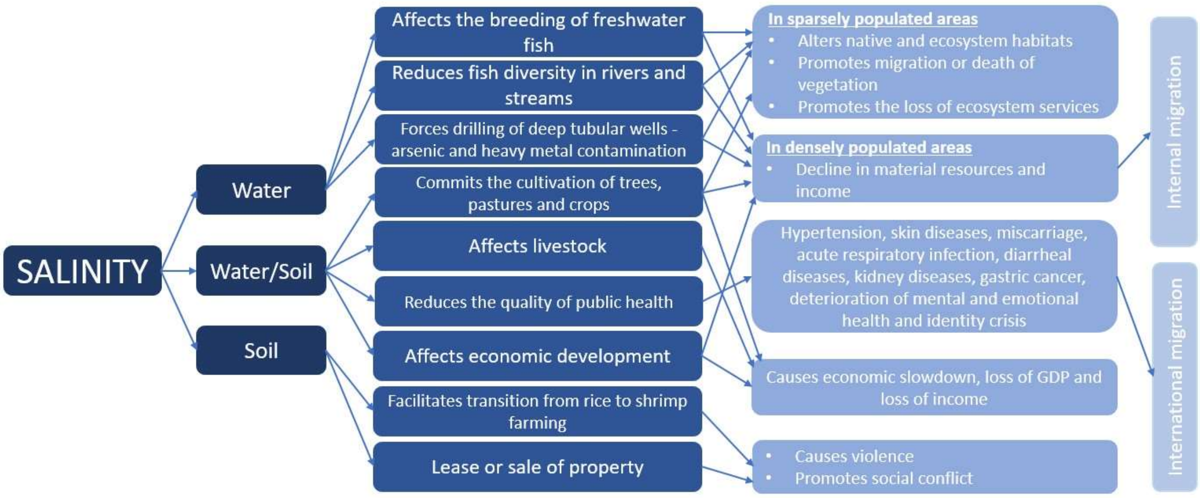


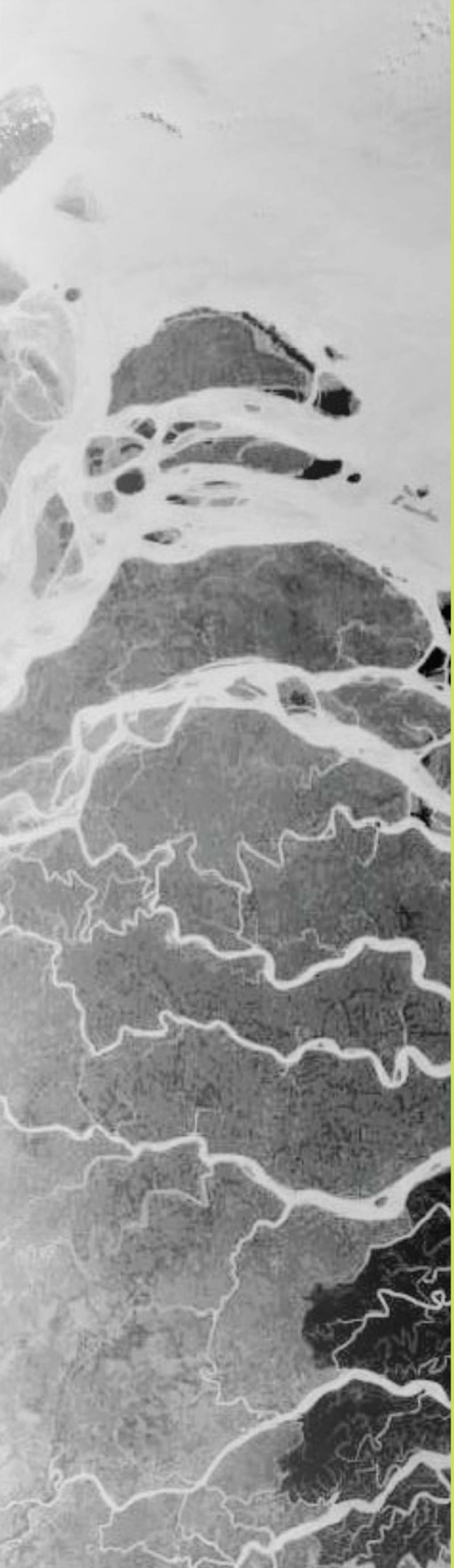
Figure 33 - Path of salinity implications

Salinization alters native habitats, ecosystem changes and migration or vegetation death, with social implications in terms of loss of ecosystem services when salinity intrusion occurs in sparsely populated areas. In the more densely populated and cultivated areas, its effects are masked by the serious influences of salinization on food security, health and livelihoods. Its effects include decline in material resources and income, as well as mental and emotional health problems and even an identity crisis due to the lack of a sense of place, resulting from the loss of viable means of subsistence and consequent migration. The decline in crop yields directly associated with salinization is particularly urgent in Bangladesh, as rice production has declined by 15-31% in salinity-affected coastal areas over a period of about 15 years, a trend that is expected to continue as the progress of salinization persists. Salinization forces small farmers to give up rice farming and transition to brackish shrimp farming or to lease or even sell their land to larger farmers, in some cases resulting in violence, local conflict and migration. Due to monsoon-related seasonal freshwater flows, traditional planting practices, especially winter crops, which rely on groundwater for irrigation, are the most affected (M.M. Rahman et al., 2018). The IPCC estimates that 8% of low-lying areas will be permanently flooded by 2050 (IPCC, 2022), causing huge food security problems.

Access to food plays an important role in food insecurity. Four ways to obtain food were identified, namely own cultivation, purchase, work and help, and only the last one does not suffer from the effects of salinization. Across the country, the problem of access to food is worse in rural areas with high salinization. Nearly 60 million people are small-scale subsistence farmers whose food security is directly threatened by salinization, especially among the least educated and poorest households, affecting various sectors of the rural economy on the Bangladeshi coast, coinciding with substantial migration to urban slums, particularly for Dhaka and Chittagong. Families that were dependent on their own cultivation now depend on precarious income to obtain food that varies with the fluctuation of global prices. The relationship between salinization and rural-urban migration in Bangladesh has a growing evidence base. Increasing salinity in drinking water is a water quality concern and has long-term health consequences. The World Health Organization's recommendation for salt consumption is less than 5g of salt per day, with high sodium consumption increasing blood pressure and the risk of hypertension, which are associated with heart attacks, cardiovascular disease and stroke, in addition to diarrheal diseases, acute respiratory and renal diseases, gastric cancer, and to the transmission of diseases transmitted by mosquitoes. Hypertension affects almost a third of women in Bangladesh, this amount being almost double that of men, as the intake of salt through drinking water arises for geographical and sociocultural reasons such as food conservation and even adaptation to taste. The result of this data is that in this region, the rates of preeclampsia and hypertension among hospitalized pregnant women are higher during the dry season, or more saline, than in the rainy season. Families in Bangladesh seek to avoid salinity in the shallow aquifer by seeking deeper water, this time contaminated by arsenic and bringing other health problems. Salinity also affects the microbial communities of aquatic environments, introducing microbes related to cholera disease and acute gastroenteritis associated with seafood consumption, as these communities thrive in brackish water and marine environments, leading to changes in the pattern of waterborne diseases (M.M. Rahman et al., 2018).

The saline environment has always been part of Bangladesh. But excessive salinity brings with it fears that in the event of further sea level rise, the entire coastal area will be hit hard, resulting in economic slowdown, losses in GDP, further ecological damage, and loss of livelihoods. Very small changes in temperature and precipitation variation can lead to serious consequences for Bangladesh. They already suffer environmentally, socially and economically, and temperature and precipitation projections for the country for the next few decades show significant temperature increases in both monsoon periods and winter, indicating more rain during the monsoon and less rain during dry periods (Islam & van Amstel, 2018).

Gradual increases in soil salinity represent an increasing demand for diversification in aquaculture and consequent internal migration of family members. Salinity also has direct effects on international migration, even after controlling for income losses, suggesting that migration is driven, in part, by the adverse consequences of salinity on agricultural production (Joyce J. Chen & V. Mueller, 2018). People along the coast of Bangladesh are trying to cope, innovate and adapt to changing salinity levels. Many migrated to the capital Dhaka and other cities further inland, which caused the population of these places to increase and living conditions to deteriorate while others went to work in India, Malaysia or the Persian Gulf countries. Nevertheless, even if life today is no longer like the life they used to know, they rebuild homes that were washed away by rivers and grow rice and vegetables in new ways. They try new small-scale farming methods despite the threat that salt water poses brings to their lands or when they also have no other option but to leave and seek a new life in the city (Jenny Gustafsson & Karim Mostafa, 2016).



9

HOW BANGLADESH COPES WITH THE PROBLEM - RESULTS AND FINDINGS

9. How Bangladesh copes with the problem – Results and findings

Civilizations around the world developed in water-scarce environments and have abilities that make it possible for them to live in these conditions. Dealing with or adapting to water scarcity means living in harmony with specific conditions that are dependent on available water resources and requires a process of recognizing changes in response. To achieve potable water scarcity reduction, key stakeholders can take a variety of approaches (Md. Anwarul Abedin, 2014). For the purposes of this study, the main ways of dealing with the salinity intrusion that affects the coastal region of Bangladesh are sub classified in order to cover the problems that the phenomenon causes. The most drastic way of dealing with the phenomenon is internal and external migration, followed by solutions in relation to water, subdivided into potable water and irrigation and drainage water, agriculture, land recovery, proactive planning and adaptations in general. The least drastic way is the building of resilient communities, with their ability to adapt to the phenomena.

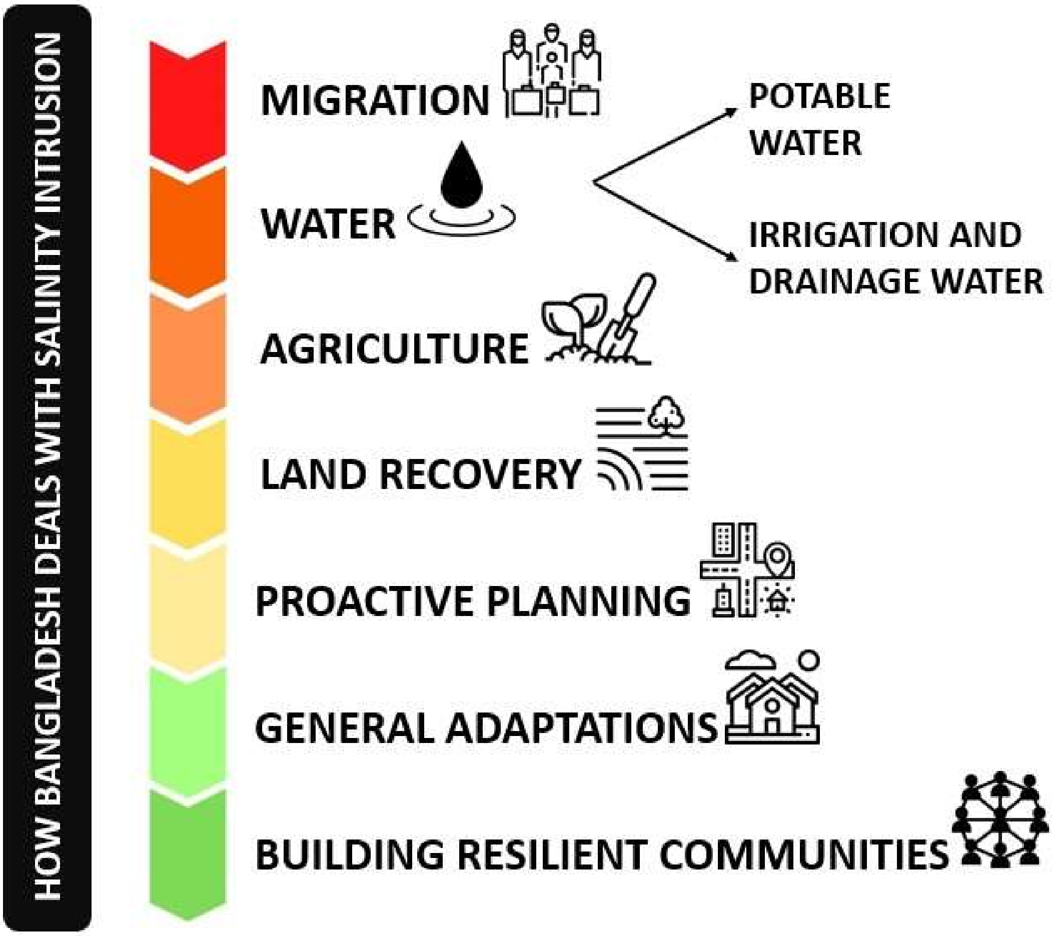


Figure 34 - Segments Bangladesh focuses on to deal with salinity intrusion

9.1. Internal and external migration

Climate change is not only altering weather patterns, but also forcing communities along the Bangladeshi coast to adapt, seeking to diversify their subsistence economic activities. The vulnerabilities associated with climatic events make the processes of migration within and outside borders a form of family adaptation, which is established to deal with environmental and economic changes. It can be successful, resulting in an increase in the resilience of the migrant family, or it can be characterized as unsuccessful, when it maintains the vulnerability of migrants, now in a new place that suffers from different and unknown impacts. The gradual increase in soil salinity represents an increasing diversification of their activities, in addition to solving the internal and international migration of family members, even after income losses are controlled, suggesting that, in part, migration is driven by adverse consequences of uncontrolled and big salinity intrusion on agricultural activities (J. Chen & V. Mueller, 2018).

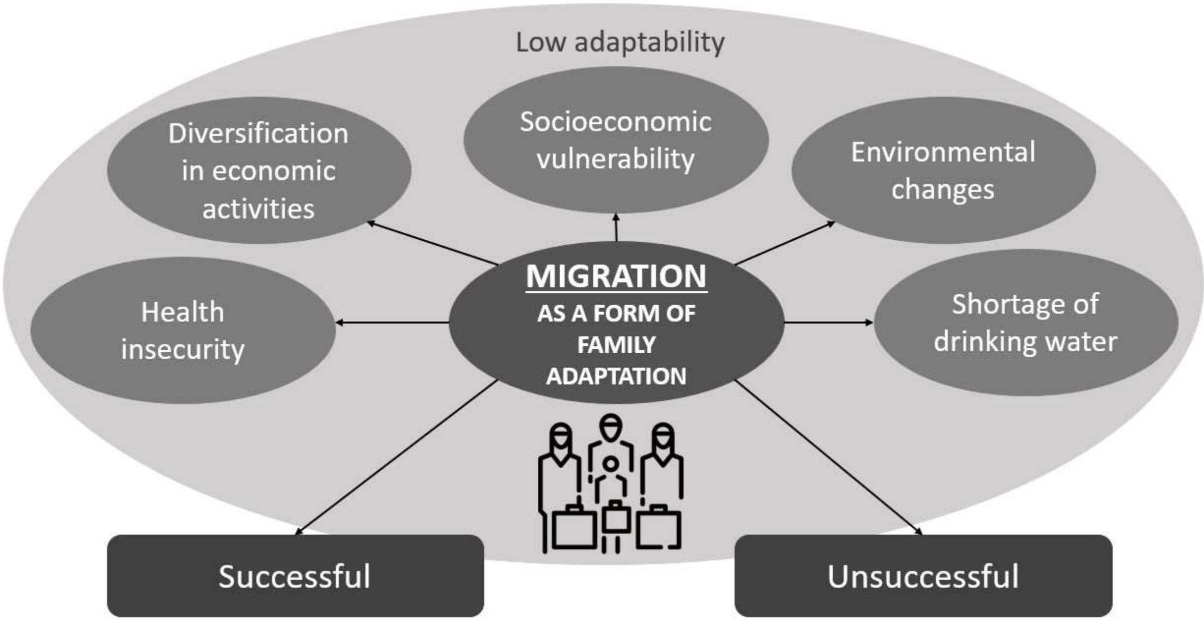


Figure 35 - Reasons and results of family migration

The risk of migration is linked to the scarcity of drinking water, socioeconomic vulnerability and health threats caused by increased salinity. Salinity brings socio-economic and water crises, poverty, spread of disease and rising treatment costs. Salinity risks have added migration as a new dimension related to health insecurities and financial instability of families residing in coastal communities. The risk of migration is high, especially when worsening situations in relation to the scarcity of drinking water, salinity risks and health risks that are related to low adaptive capacities in coastal areas.

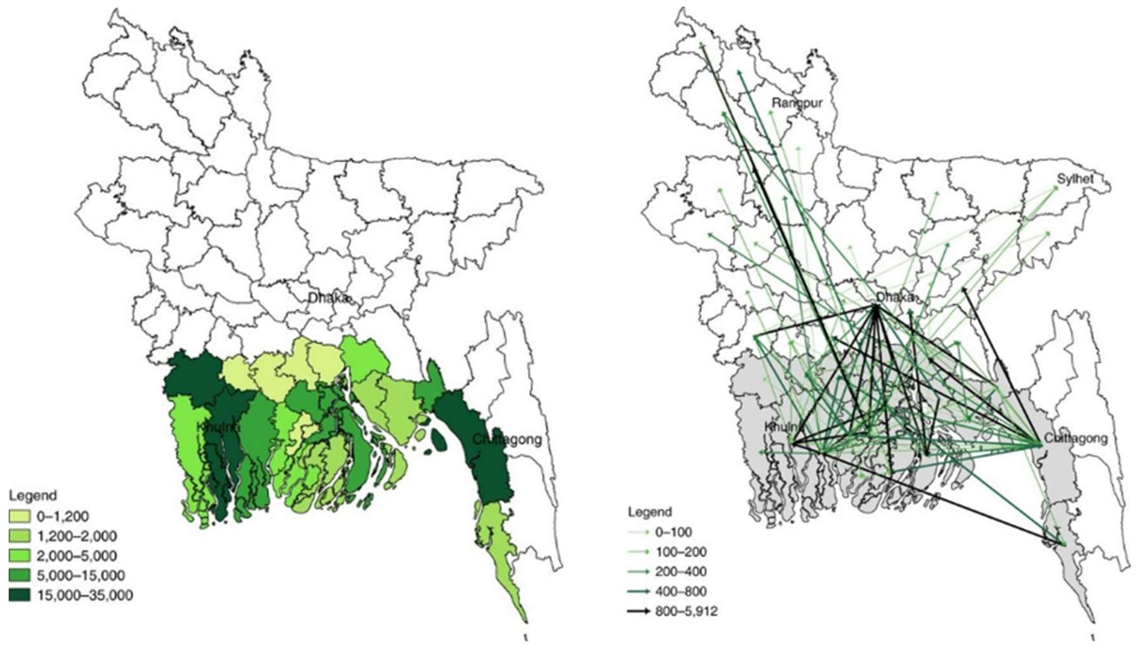


Figure 36 – Internal migration

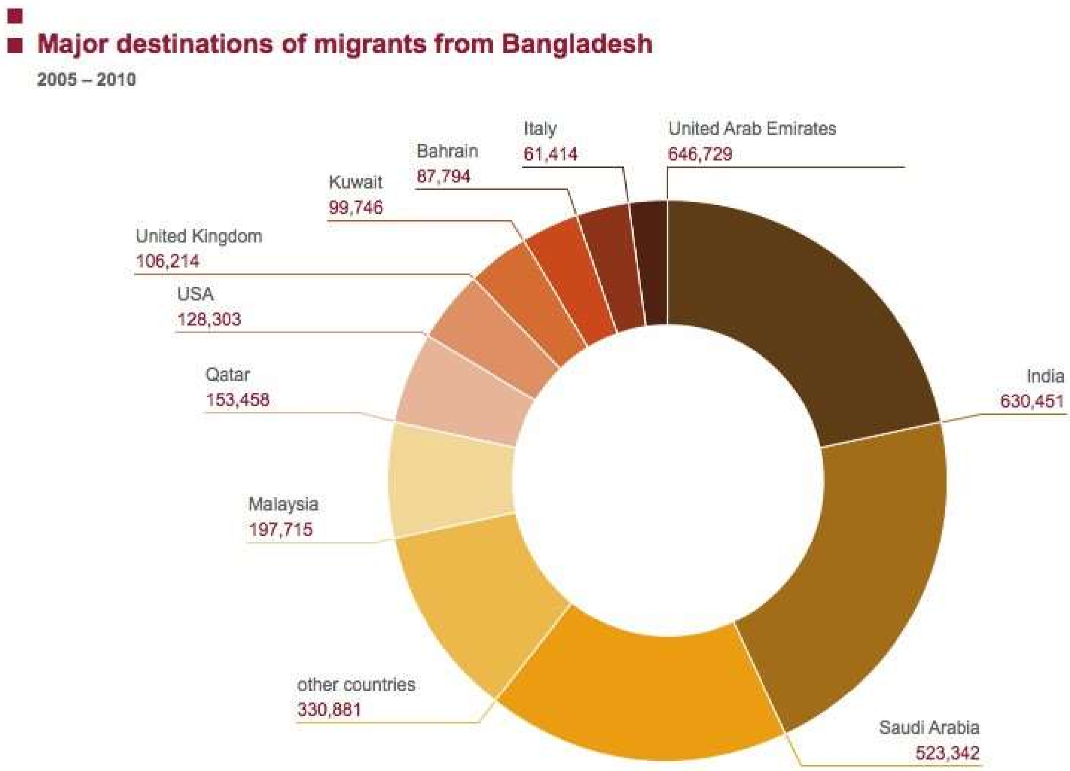


Figure 37 - Major destinations of migrants from Bangladesh

In the left, figure 36 show the projection of additional migrants in the coastal region of Bangladesh due to an increase in salinity. The image on the right shows the increase in the migrant population. Figure 37 shows the destinations most sought after by Bangladeshis when migrating to other countries.

Disasters associated with socioeconomic vulnerabilities have been considered common in Bangladesh's coastal belt for decades. Human diseases are a consequence of salt contamination in water and soil and the scarcity of potable water and health expenses put pressure on the household economy, causing additional cost, compounded by the lack of health support. According to M. A. Rakib et al. (2019), "health risks and additional health costs increase the migration risks of the coastal population that can lead to mass migration from the vulnerable coastal region to inland regions of the country or to neighboring countries" (M. A. Rakib et al., 2019, p. 240).

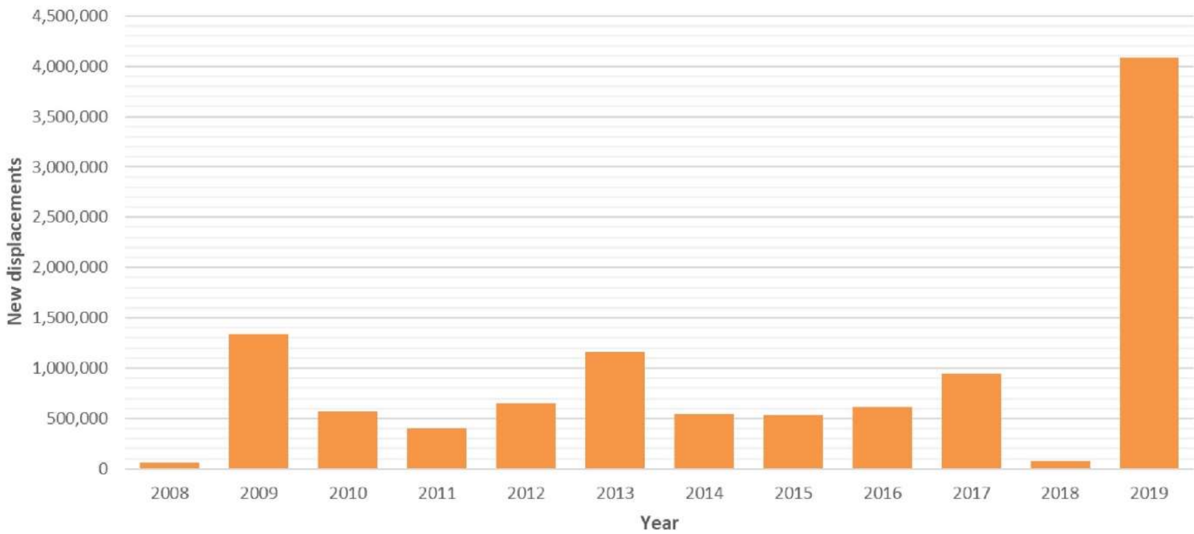


Figure 38 - Annual Disaster Displacements in Bangladesh (2008–2019)

The figure 38 shows that natural disasters caused millions of new climate migrants in 2019, particularly the events of the devastating cyclones Fani and Bulbul, with the projected average of new migrations reaching more than one million people in the near future. The years in which the country experienced the greatest number of displacements were 2009, 2013 and 2019 and that, due to the greater frequency of climatic events, the country has to face a large number of new displacements that will be induced by the consequences of climate disasters each year (Md Masud ParvesRana & Irina N.Ilina, 2021).

9.2. Water

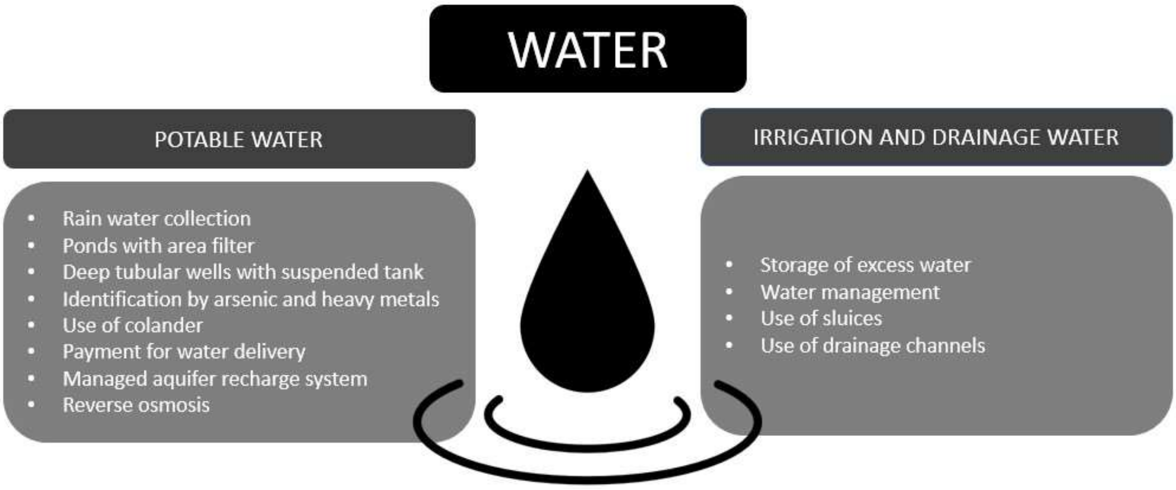


Figure 39 - Local solutions regarding water

9.2.1. Potable water

To reduce the scarcity of drinking water, specific adaptation and coping actions at the individual and community level are supported by organizations outside the local communities. On an individual level, small ponds with sand filters and rainwater harvesting systems are options. At the community level, large ponds and large rainwater harvesting systems are used. Sand filters for ponds are promoted by the government, international and local NGOs, which contribute to the supply of drinking water in the country, considering the salinity problem. NGOs contribute to the practice of capturing rainwater, filtering sand from the lagoon and using deep tube wells using suspended tanks. At the institutional or governmental level, identification of arsenic contamination from tube wells helps to mitigate arsenic contamination in Bangladesh. Most measures, however, are only reactive and not planned. The local population, suffering from lack of water and salinity, requires the installation of rainwater harvesting systems at the family level, in addition to the inclusion of NGO offices, private initiative, colleges and schools, in the formulation of policies at the national and local levels. Another demand is the installation of deeper, solar-powered tube wells that can provide piped water to homes and communities, as well as government-maintained community sand filters and re-digging ponds to provide reservoir benefits (Md. Anwarul Abedin, 2014).

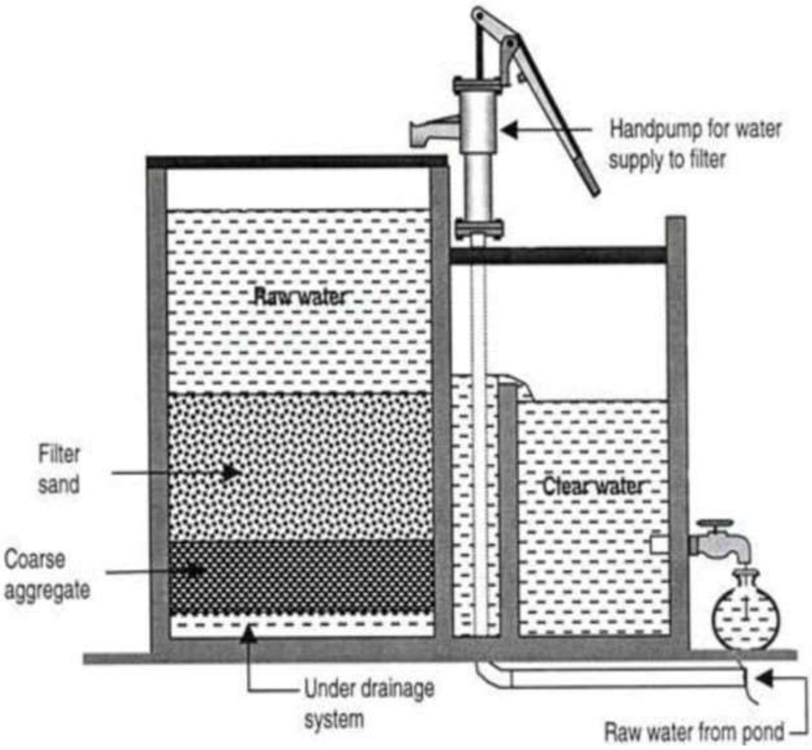


Figure 40 – Sand filters for ponds

Figure 41 - Rainwater harvesting systems

In terms of purity and appearance, rainwater harvesting presents itself as an option for obtaining drinking water. Rainwater is collected for a few days in plastic containers or clay pots, but there is a preference for large tanks of 1000 liters or more, which store the collected water mainly in homes with a tin roof. Plastic or concrete tanks are used, the latter tend to be larger and capable of supplying a set of residences. However, the tanks have technical flaws such as low durability of concrete and overheating of plastic, in addition to the high cost.

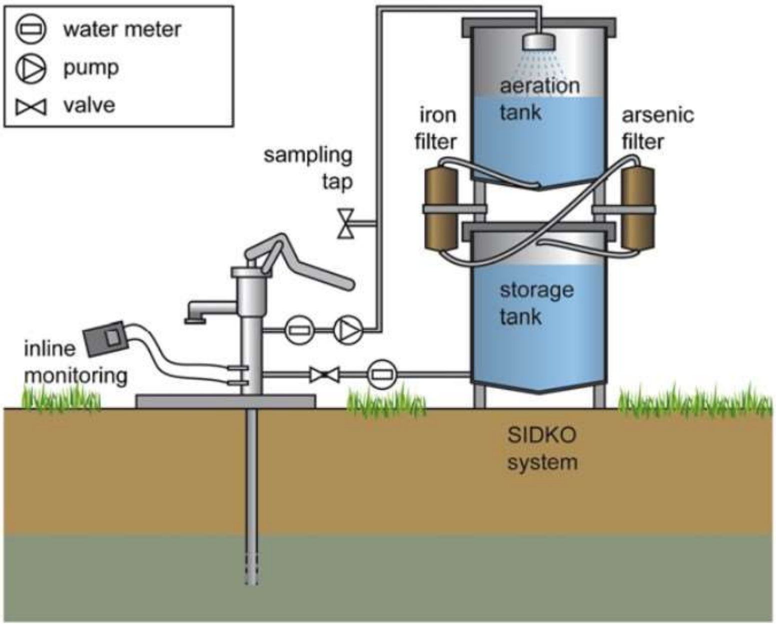


Figure 42 - Deep tube wells using suspended tanks

Figure 43 – Pond-sand filter system

Figure 43 is an example of a pond-sand filter system. This system, when constructed correctly, allows the only items to need replacement and repair are the moving parts, which makes it a viable and effective technology for removing bacteria from pond water where the turbidity level is not exaggerated. The system must be cleaned twice a month and the waste water must be disposed of properly (Department of Public Health Engineering, 2022).

Some inhabitants resort to using pond water for drinking, cooking and other purposes when fresh groundwater or enough rainwater is lacking to be stored for a year. Riparian forest ponds are partially affected by salinity, require displacement depending on the location, have bad odors and dirt, and low water levels in the dry season. For better quality water, in lakes farther from the coast, deep enough to have water during the dry season and containing filters installed, many residents need to travel outside their community or pay someone to deliver. The pond-sand filter system is used to improve pond infrastructure at the community level. The process consists of finding or excavating a large, less saline lake, reinforcing an embankment around it and installing a system to pump water from the lake through a sand filter into a storage tank with taps, a service carried out by NGOs or by the government. One problem with this technique is when the lake is on private property and therefore requires agreement with the common use of their land. Operating system maintenance is also a condition, as the system shows natural wear and tear over time and storms and floods are constant natural hazards. Responsibility for maintenance is compromised as power in Bangladesh is centralized and the government is unwilling to assume new responsibilities. Sometimes the quality of the water requires the use of a strainer, known locally as a fitkari, mainly to filter out dirt. The pond water is more contaminated in the hot season, causing a higher incidence of dysentery, diarrhea and other diseases. When very saline, the water from the ponds is used only for washing and cleaning.

Payment for the delivery of water used for drinking water supply is another option. The informal method is to pay a person to draw water from a source and, alternatively, provide piped water to households or to a distribution point in the community from an external source. Some families, however, refuse to pay a nominal fee for piped water, as they do not understand the benefits of an improved water source or feel that water should be free.

The tubular wells are manually pumped, their depths are approximately 60 meters and, due to their location close to the coast, they provide very saline water for consumption, with little variation between the hot and rainy seasons. The advantage is that water from tubular wells, even shallow and with brackish water, tends not to be in short supply. An option against excess salt is the location of the wells, that is, when located further from the coast, the salinity is lower. However, in this case, distance becomes a negative point, as communities have to travel long distances to fetch water, or pay to receive it at home.

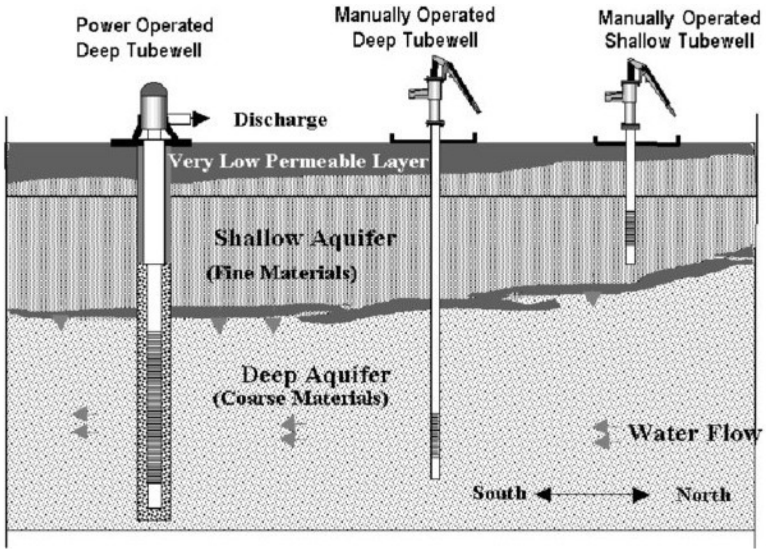


Figure 44 – Tubular wells

Figure 44 shows the different modes of tubular wells use for water supply in Bangladesh.

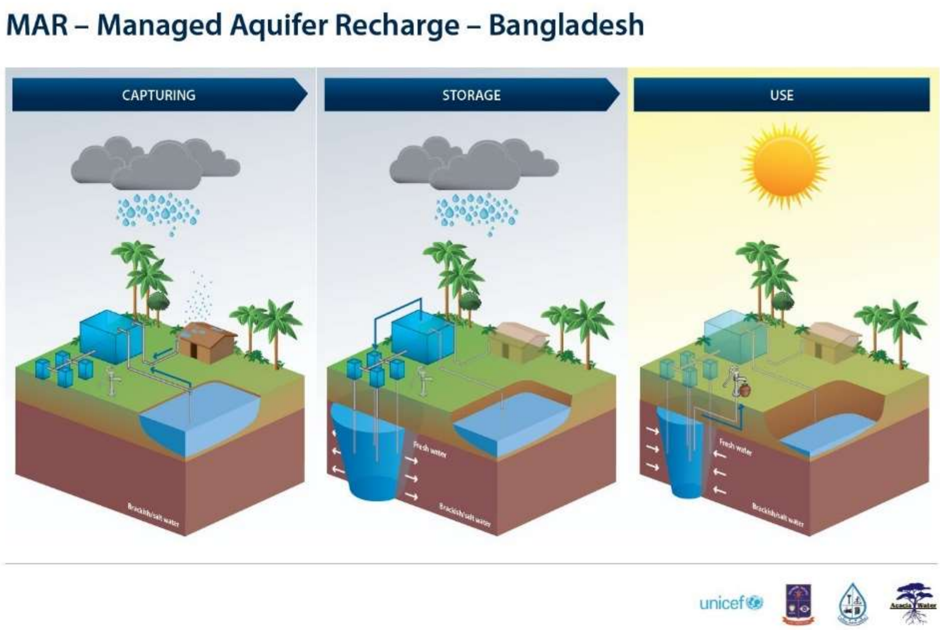


Figure 45 – Managed Aquifer Recharge

Two other community-level options based on more advanced technology to alleviate freshwater scarcity in salinity-affected areas are the managed aquifer recharge system, which consists of collecting rainwater during the rainy season and using it to artificially recharge a shallow aquifer, the water of which, stored underground, creates a freshwater buffer from the typically brackish groundwater of the aquifer. Fresh water could then be extracted at other times of the year. Another is reverse osmosis technology, a form of desalination, which consists of treating and pressurizing salt water, passing it through a water-permeable membrane to separate the salts. However, it requires a lot of energy, which makes it unfeasible in many poorer parts of Bangladesh (Yukyan Lam et al., 2018).

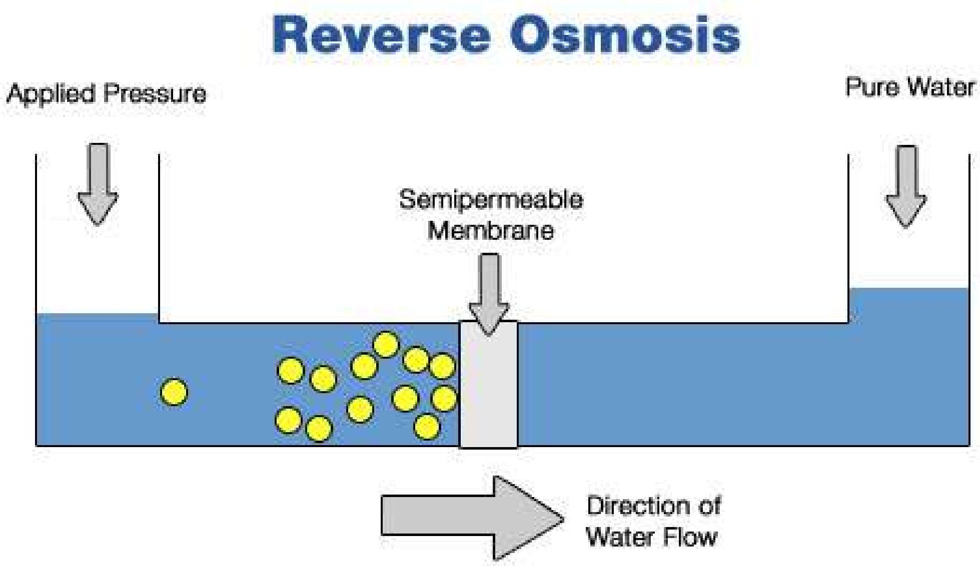


Figure 46 – Reverse Osmosis

The process of reverse osmosis (RO) is showed in figure 46. It occurs when pressure is used to drive water molecules through a membrane in a direction opposite to where they would naturally move due to osmotic pressure. RO has been most often used for brackish waters that are lower in salt concentration (Climate Technology Centre & Network, 2022).

9.2.2. Irrigation and drainage water

In the Ganges-Brahmaputra Delta region, water scarcity is also reflected in the need for irrigation of crops and this action takes place through the storage of excess rainwater after human needs are met. A part of this excess water is stored for later use as irrigation water during the dry season. Water management[4] through the availability of irrigation allows the introduction of different varieties of salt-tolerant crops (Ministry of Agriculture - Soil Resource Development Institute, 2010).

Figure 47 - Low cost water storage ponds for small producers

The dynamics of erosion and sedimentation of riverbeds, created by tidal forces, and the influence of fresh and salt water on the dynamic environment and hydrology determine water management in deltas. Functional water regulation systems, such as floodgates and drainage channels, protect the mainland from saltwater intrusion, with drainage channels that serve as storage of rainwater during the wet season for irrigation during the dry season. Although to some degree the people and the system have sufficient experience and knowledge to deal with the effects of variability in rainfall patterns, extreme temperatures, which result in crop damage, prevent farmers from having opportunities for more significant gains (Pia Schneider & Folkard Asch, 2020).

[4] Determining the timing, amount and how to apply water to the plantation, taking into account other aspects of the production system such as phytosanitary control, meteorological and economic conditions and crop management strategies (Amanda Balbino, 2016).

Figure 48 – Irrigation channels in Bangladesh

During the rainy season, the drainage of the basins must be done in such a way that the main and secondary drains allow excess rainwater to move from the areas towards the gate. As in the coastal regions of Bangladesh, the heaviest rains occur in the months of July and August, the floodgates must be opened more frequently and for longer periods to maintain the desired water levels for crop growth (Ministry of Agriculture - Soil Resource Development Institute, 2010).

Figure 49 - Drainage for harvesting a field before draining and after draining

9.3. Agriculture

Eighty percent of Bangladesh's soils are classified as alluvial soils highly suitable for year-round rice cultivation, with the most important time in terms of productivity being during the dry season from December to May. Rice is the country's most important staple food and Bangladesh ranks fourth in rice production in the world, with an annual harvested area of 11.3 million hectares and a production of around 49 million tons. About 70% of Bangladesh's population is employed in agriculture, which makes rice production essential for food security, employment and income. Due to the expansion of irrigated areas in the past, rice production has increased and currently, around 5 million hectares of rice paddies in the Ganges–Brahmaputra delta are equipped with irrigation infrastructure where approximately 75% of the water used is groundwater. Bangladesh's groundwater recharge potential is relatively high, with around 21 km^3 per year. Groundwater is an important source for irrigation, but also for municipal and industrial use (Pia Schneider & Folkard Asch, 2020).

Figure 50 - Polder with earth embankment and gate structure

Most salinity interventions focus on structural protection measures such as dams, embankments and polders[5]. However, it ignores the region's social, ecological and economic systems, without taking into account adaptation approaches that encompass biophysical and socioeconomic characteristics,

[5] Tract of lowland reclaimed from a body of water, often the sea, by the construction of dikes roughly parallel to the shoreline, followed by drainage of the area between the dikes and the natural coastline (Britannica, 2022c).

resulting in uncertainty about when, where and what different measures can be implemented by policymakers. The lack of fresh water in the dry season, excessive rain in the monsoon season, saltwater intrusion and sea level rise are challenges for livelihoods and food production, and attempts to adapt technologies to use water land and water savings are important. They require seasonal conditions of water availability, precipitation forecasting and early warning of flood and drought forecasts. With the speed of adaptation of rice production systems in managing seasonal differences in water availability, farmers improve their resilience to climate change. Collaboration of upstream and downstream water users, internationality of governance over coastal water rights and government plans to contain salt intrusion based on tidal management are important in the case of Bangladesh as water extraction freshwater and sediment occurs in rivers that originate in neighboring countries (Hossain, Peerzadi Rumana et al., 2018; Pia Schneider & Folkard Asch, 2020).

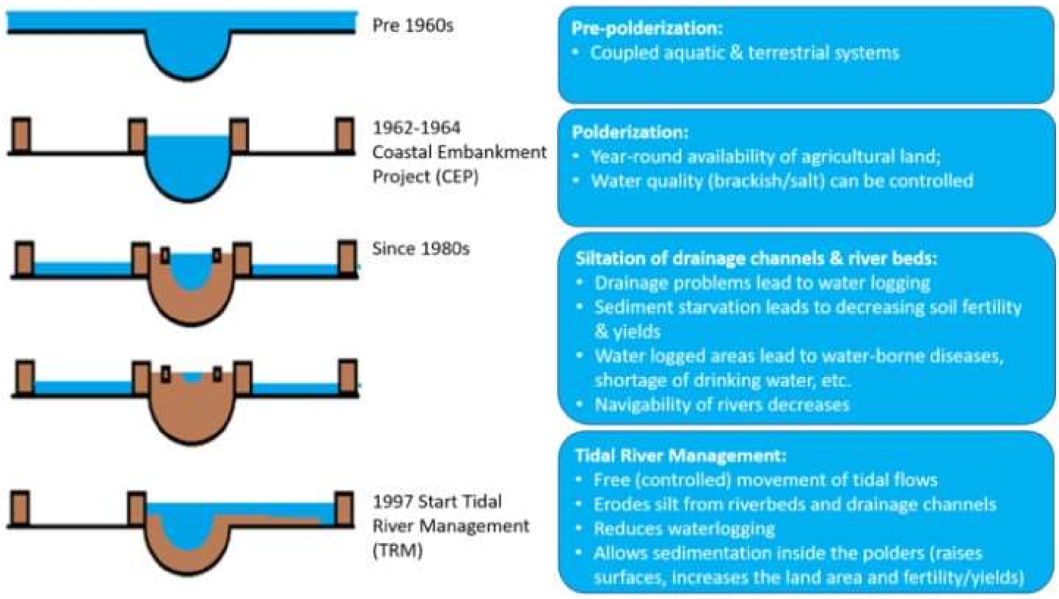


Figure 51 – Tidal River Management

Figure 50 shows a typical polder with earth embankment above and a gate structure of a polder in a coastal area in Bangladesh, used to protect low-lying coastal areas from tidal flooding and saline intrusion. Figure 51 shows how Tidal River Management controls sediment in rivers, as high tide brings a flow of muddy water with a dense concentration of sediment (Utrecht University, 2022).

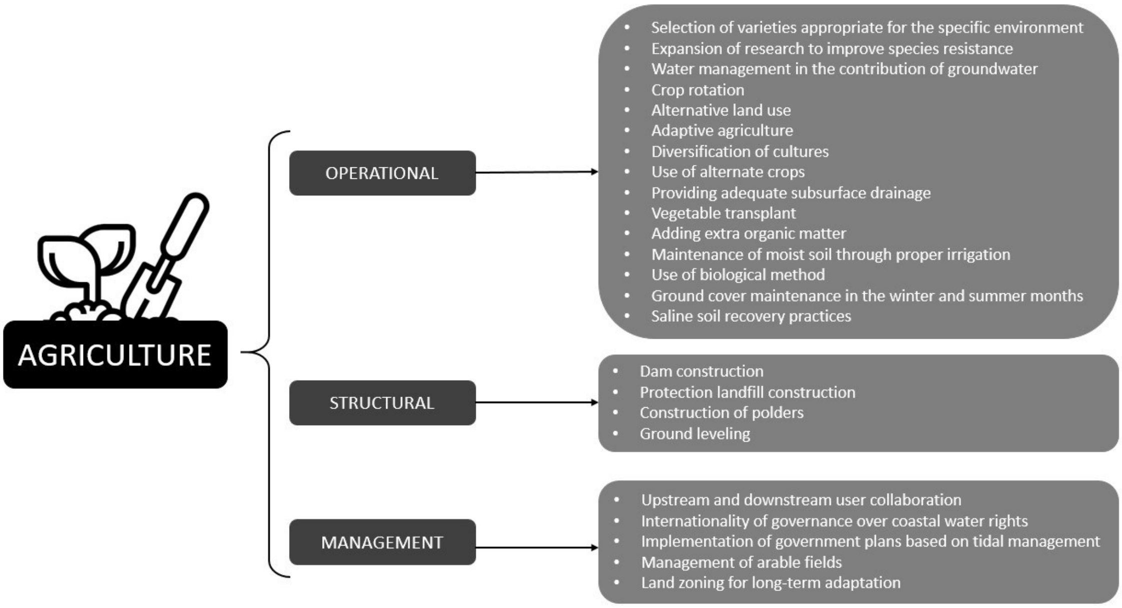


Figure 52 - Local solutions regarding agriculture

According to Pia Schneider & Folkard Asch (2020), there is no single solution for mitigation or adaptation in relation to salinity intrusion, but there are ways to treat the problem. A basic intervention option is the selection of varieties, appropriate for the specific environment, replacing more salt sensitive rice varieties with more tolerant varieties, including further research and improvement of salt and drought tolerant varieties. In rice fields, soil salinity is often caused by inadequate irrigation, particularly when saline water is used directly for irrigation, so another intervention option against salinity intrusion is water management in the groundwater contribution. This option aims to impact the reduction of water needs in the field and increase the availability of water in the system, changing from a permanently flooded system to a periodically flooded system. Crop rotations and alternative land use are other options to adapt to changes, in a rice-shrimp system or rice-fish system, where rice is grown during the monsoon season and shrimp or fish in the dry season under higher salinity levels (Pia Schneider & Folkard Asch, 2020). The measures include adaptive agriculture, crop diversification, management of arable fields and alternative crops, in addition to land zoning for long-term adaptation planning aimed at improving the socioeconomic conditions of farmers, promoting agriculture, and resolving conflicts between shrimp farming and farming (Hossain, Peerzadi Rumana et al., 2018).

Figure 53 - Rice-fish system

With different varieties of rice available in the country, the selection of kharif rice varieties, i.e. monsoon or autumn rice, may have a better yield. Adopting the introduction of different varieties of salt-tolerant crops can increase yields through proper soil and water management practices when sufficient and good quality irrigation water is available. The introduction of a second crop of radish or rice in winter maintains a water depth for rice cultivation that helps in the leaching of soluble salts, reducing the salinity of the soil, which is facilitated since the water table is relatively lower. In this case, the availability of good quality irrigation water limits the cultivation of winter rice. In areas where salinity is mild to moderate, the Lockpur[6] model is adopted.

Providing adequate subsurface drainage is one way to lower the salt-rich shallow water table and keep it below the critical depth to avoid salinization, which must be less than 1 meter below the surface of the ground. This measure is effective but expensive. Transplanting vegetables from weakly saline beds to more saline soils has good results, preventing early salt damage, as well as adding extra organic matter, improving soil properties and aiding plant growth and keeping the soil moist through irrigation. It is a suitable attitude for growing vegetables in saline soils, with sprinkler or drip irrigation. There is also the adoption of the biological method, which consists of using some plant species that absorb large amounts of salts. They can be grown and removed after full growth to minimize salt concentrations in the soil. (Ministry of Agriculture - Soil Resource Development Institute, 2010).

[6] Type of culture where both crops and fish are grown on the same land. In this model, a barrier is built along the boundaries of the land, through a ditch inside the barrier, where the ditch will be the water reservoir for small-scale fish farming and irrigation (Ministry of Agriculture - Soil Resource Development Institute, 2010).

Figure 54 - Biological method - perennial quinoa

Keeping the land covered in the winter and summer months, with a mulch crop, makes the saline groundwater present in shallow depths not evaporate and increases the leaching of salts present in it, increasing rice productivity in the subsequent harvest (Ministry of Agriculture - Soil Resource Development Institute, 2010).

It is important to maintain coastal saline soil recovery management practices, adopting methods that induce salt tolerance in different crops, including vegetables, various land and soil management practices, including agronomic techniques to reduce the adverse effect of salts. This can be done through a protection embankment, where the land is protected from salinity by raising slopes 1 meter high above the high tide level and with an adequate lateral slope, including a floodgate to facilitate the removal of excess rainwater and to prevent the ingress of saline water during high tide in the dry season. The land can also be leveled to avoid the accumulation of water in the low areas and to facilitate the uniform drainage of excess water and control the water through field dikes. It is done by making bunds about 25 cm high that demarcate the hydrographic basins and the field plots, allowing the flow of excess water from outside the area and from one plot to another to be regulated, helping to retain a few centimeters of standing water for needs during the subsequent dry period (Hossain, Peerzadi Rumana et al., 2018).

9.4. Land recovery

Figure 55 - Local solutions regarding land recovery

The loss of area in the delta region is due to subsidence and lack of sediment from rivers. Md. Mansur Rahman et al. (2022) states that "many infrastructure projects are planned to be implemented throughout this century, including ports, economic zones, power plants and tourist attractions, and as part of national development and adaptation to climate change, new land masses are a pre - requirement for these development projects" (Md. Mansur Rahman et al., 2022). To contribute to the recovery of land in the face of silting in the navigation channels and the intrusion of salinity due to the use of water on arable land, management is used to accelerate and promote de-silting. To speed up land reclamation and elevation, management of tidal rivers with cross dams[7] is implemented. For de-silting, dredging is used to complement the use of band structures[8] as a natural native solution. They are adopted to maintain navigation channels and landing ports and are mainly used for sand removal. They redistribute the form of sedimentation, creating an area of lack of sediment within the navigation channels and an area of excess sediment along the bank, with adequate opening and slope for the maintenance of navigation channels and bank stabilization. Typically, the techniques are applied in isolation to achieve specific project objectives. These options could affect existing hydrological conditions if implemented simultaneously in isolation with other sediment management practices, which could result in a long-term morph dynamic impact (Md. Mansur Rahman et al., 2022).

[7] Cross dams are closing structures employed to increase the residence time of marine sediments to increase sedimentation and are often used for land reclamation between the mainland and islands. (Md. Mansur Rahman et al., 2022).

[8] The band structure has a permeable opening at the bottom that allows flow to pass through the structure and an impermeable upper part blocked for flow near the surface upstream from the direction of the main channel (Hiroshi Teraguchi et al., 2012).

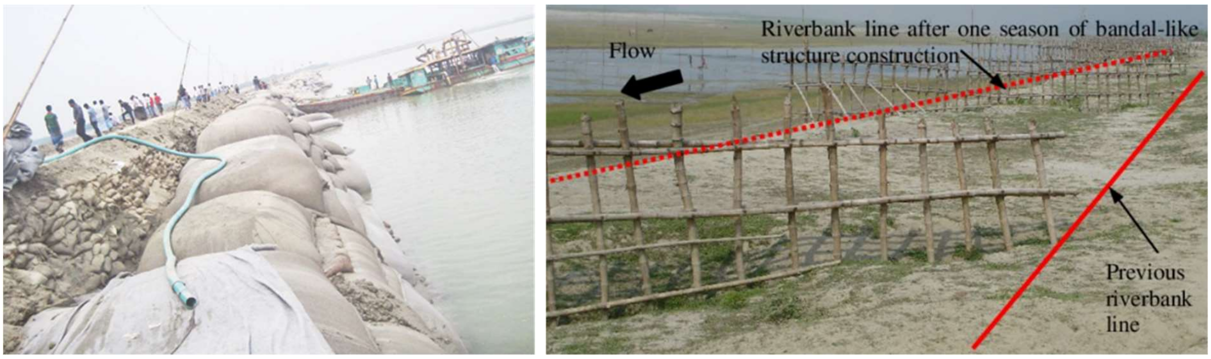


Figure 56 - (Left) Cross-dam (Right) Band-like structure

Figure 57 - Cross-dam plan

Figure 56 shows a Cross-dam construction and the functioning of a band-like structure. Figure 57 shows a plan for cross dam construction to restore land in the Bay of Bengal.

The slopes of the polders separate the floodplains from the peripheral rivers and prevent the flow of sediment to the polders, creating differences in elevation between the inside and outside of them, leading to their flooding. River tide management has been used for flood relief since the 1990s. This system involves periodic cutting and closing of strategically located polder slopes to increase the residence time of sediment-rich tides and accelerate accretion or recovery of land in the lower areas. The system also acts on the natural dredging of the river that is connected to the system (Hossain, Peerzadi Rumana et al., 2018).

9.5. Proactive planning

Deltas have always been attractive places to live, resulting in a concentration of people and business centers in the cities located in them, but they face complex challenges including population growth, ecosystem loss, land subsidence and salt intrusion, compounded by climate change. In this context, existing planning focuses on the short to medium term, but requires a multi-decade perspective to accommodate climate change and seek to adapt to changing circumstances. Uncertainty about future conditions, however, interferes with the structuring of interventions and paths to development, challenging planners. Proper planning also requires institutional organization, ongoing funding, and high stakeholder commitment (Jos van Alphen et al., 2021).

Bangladesh is often cited as one of the most climate-vulnerable countries in the world due to its location, exposure to extreme conditions and high population growth rate. This awareness and discourse on the implications of climate change for development is a critical part of political agendas and the international discourse on climate change. From 2002 onwards, proactive planning began, with the introduction of the country's first adaptation project using community-based approaches. From there, plans followed, such as the National Adaptation Action Program in 2005, the Bangladesh Climate Change Action Plan and Strategy in 2008, where two funds were created, one with government resources and the other with donor resources (Neha Rai et al., 2014). By intensifying efforts to combat climate change through strategy and plan development, the planning process has generated national and international debates, particularly on financing and including climate change in its development planning (Khurshid Alam et al., 2011). Bangladesh's planning covers six thematic areas classified as food security, social protection and health, comprehensive disaster management, infrastructure development, research and knowledge management, low carbon mitigation and development and capacity building and institutional development.

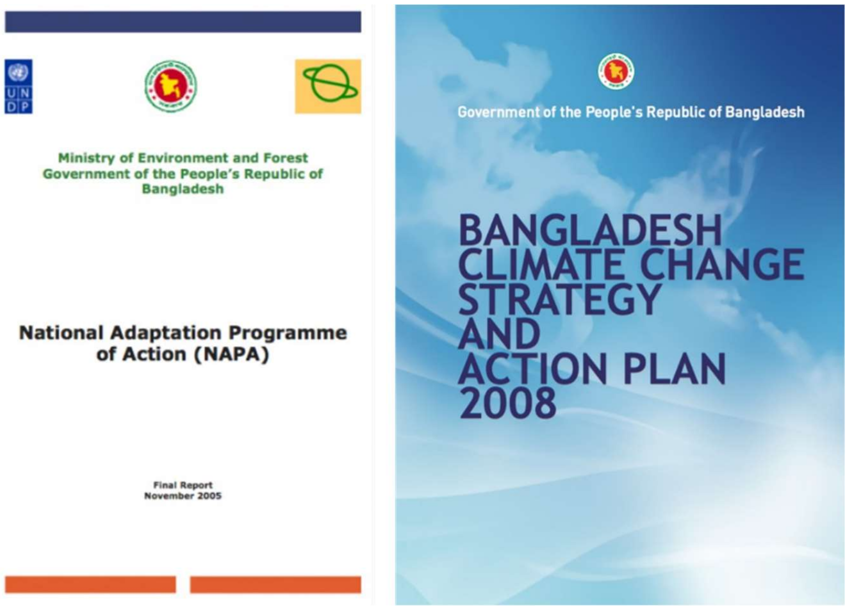


Figure 58 – National Adaptation Programme of Action and Bangladesh Climate Change Strategy and Action Plan

National planning aims to identify the adverse impacts of climate change as a critical challenge facing Bangladesh and focuses on mainstreaming adaptation across sectoral plans, policies and programs (Neha Rai et al., 2014).

Figure 59 - Local solutions regarding proactive planning

Currently, the country's GDP shows a growth trend and in the short term, it is expected to remain stable. The Bangladesh Vision 2021 and the Bangladesh Outlook Plan provide a path towards achieving accelerated growth, eradicating poverty and combating inequality, including human deprivation. However, economic growth and development potential are limited by the impact of global climate change, which interferes with processes. The implementation of the Sustainable Development Goals

(SDGs) can lead the country towards inclusive social development, but it involves the country having a strategy aimed at resilience to rapid climate change (Dwijen Mallick & Atiq Rahman, 2020).

Figure 60 - Sustainable Development Goals

9.6. General adaptations

Abundant salinization and the unfavorable impacts it causes are reflected in the adoption of small-scale adaptation measures, such as raising the level of housing, rainwater harvesting and afforestation (Hossain, Peerzadi Rumana et al., 2018).

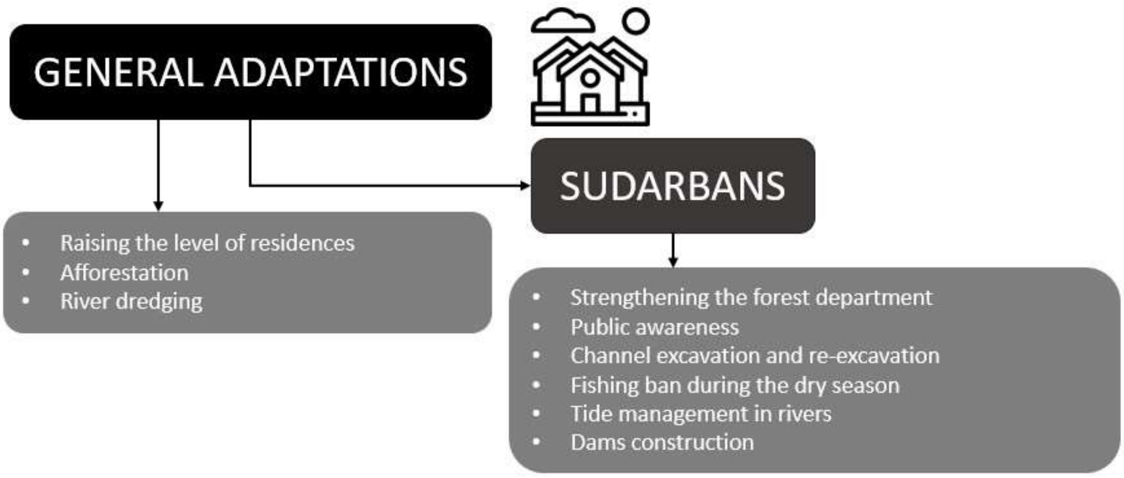


Figure 61 - Local solutions regarding general adaptation

River dredging is widely used in Bangladesh to maintain depth in rivers and ports for navigation. It reduces flooding and has been applied to prevent waterlogging in polders. Its impact is temporary and costly, putting its use in doubt as to long-term sustainability. Such measures tend to solve local problems, but can contribute to an uneven distribution of delta development by causing long-term morph dynamic changes, as well as not allowing the delta's natural state to be restored, once infrastructure becomes an active component to protect the land of the local population, helping to prevent flooding and salinity intrusion (Md. Anwarul Abedin, 2014).

Figure 62 – Afforestation, rising residences and river dredging

In the Sundarbans, strengthening the forest department along with public awareness, digging and re-digging channels, and banning fishing during the dry season are ways to deal with salinity levels. For higher salinity levels, tidal river management measures and dams are used, which assist in sediment management and ensure the ecological flow of rivers downstream during the scarcity period (Hossain, Peerzadi Rumana et al., 2018).

9.7. Building resilient communities

In order to achieve the ability to build resilient communities, in addition to governmental and management-level actions, it is necessary to implement actions at the local level, either on the community's own initiative, with the help of local and international NGOs, or on the initiative of the governmental community. The resilience of coastal communities is reflected in the ability to adapt to climate change through ways of dealing with them in day-to-day activities, maintaining their function and basic structure, in an attempt to preserve some qualities and allow others to disappear, maintaining their identity and valuing their place of residence (Resilience, 2016).

The increase in water and soil salinity in Bangladesh is reflected in an increasing diversification of activities, and brings various forms of family and community adaptation (J. Chen & V. Mueller, 2018). Resilience can be extremely radical, as is the case with migration within and outside borders, or it can happen in less incisive ways, through processes of adaptation of actions at the family or community level.

Organizations inside and outside the communities support and encourage adaptation to deal especially with the intrusion of salinity into the lives of the population of coastal regions. Aiming at the construction of resilient communities, there are several local and individual actions that can be incorporated in the process of adapting to the salinity of the soil and water. Among them, the excavation of small lakes with sand filters to filter the water, installation of small systems collection of rainwater, use of strainers to remove excess dirt from the water, in addition to the use of the biological method, the transplanting of vegetables to more saline soils, the addition of extra organic matter, raising the level of the residences, among others.

At the community level, several actions are carried out to adapt to salinity, such as the excavation of large lakes with a sand filter for water filtration and the installation of large rainwater collection systems, with the installation of larger tanks. The use of deep tubular wells with the use of suspended tanks is also common, as it is the identification of arsenic contamination in the wells. Solar-powered wells are also community solutions, as is the re-digging of ponds and installing water pumping systems for faucet tanks and storing water for irrigation. Land use, selection of varieties appropriate for the specific environment, including further research, improvement of salt and drought tolerant varieties, crop rotations, alternating land use, adaptive agriculture, crop diversification and alternative crops, among others, are common.

Local communities have used innovative methods to deal with endangered forests, riverbanks and farming communities in Bangladesh. The development of an adequate market chain aimed at reducing pressure on forests is a case of adaptation aimed at forest protection and recovery. The use of traditional knowledge to protect riverbanks from erosion in remote villages using local and natural materials to recover agricultural land and promote navigation is another example of adaptation. The use of indigenous knowledge and production of agricultural crops using floating beds in Bangladeshi wetlands is also an adaptation to climate change. These are some of the effective adaptation strategies to address the country's vulnerability to food insecurity. (Estiaque Bari et al., 2021).

The table below lists the activities that contribute to the resilience of communities. Activities are divided into subcategories, separated into policies, technologies or both and cover at what level they are applied and who is responsible for their application.

SUBCATEGORY	ACTION	CATEGORY		LEVEL		RESPONSIBILITY		
		POLICY	TECHNOLOGY	INDIVIDUAL	COMMUNITARY	INDIVIDUAL	ONGs	GOVERNMENT
MIGRATION	Internal and external migration							
WATER	Excavation of small lakes with sand filters							
WATER	Small rainwater collection systems							
WATER	Excavation of large lakes with sand filters							
WATER	Large rainwater harvesting systems							
WATER	Rainwater harvesting							
WATER	Use of deep tubular wells with use of suspended tanks							
WATER	Identification of arsenic contamination of tubular wells							
WATER	Installation of deeper tubular wells, powered by solar energy							
WATER	Re-excavation of ponds							
WATER	Water pumping system for tank with faucet							
WATER	Use of strainer							
WATER	Payment for water delivery							
WATER	Managed recharge of aquifers							
WATER	Reverse osmosis							
WATER	Water storage for irrigation							
WATER	Water management – water regulation							
WATER	Sluices and channel drainage systems							
WATER	Structural protection measures							
WATER	Technology adaptation of technologies							
WATER	Land use adaptation							
WATER	The collaboration of upstream and downstream water users							
WATER	Internationality of governance over coastal water rights							
WATER	Planning to contain salt intrusion based on tide management							
AGRICULTURE	Selection of appropriate varieties for the specific environment							
AGRICULTURE	Research on crop							
AGRICULTURE	Breeding of salt and drought tolerant varieties							
AGRICULTURE	Water management in the contribution of groundwater							
AGRICULTURE	Crop rotations							
AGRICULTURE	Alternative land use							
AGRICULTURE	Adaptive agriculture							
AGRICULTURE	Crop diversification							
AGRICULTURE	Management of arable fields							
AGRICULTURE	Alternative crops							
AGRICULTURE	Land zoning for long-term adaptation planning							
AGRICULTURE	Adequate subsurface drainage							
AGRICULTURE	Biological method							
AGRICULTURE	Vegetable transplant							
AGRICULTURE	Addition of extra organic matter							
AGRICULTURE	Maintenance of moist soil through proper irrigation							
AGRICULTURE	Maintenance of land cover in the winter and summer months							
AGRICULTURE	Saline soil recovery practices							
LAND RECOVERY	Leveling the land							
LAND RECOVERY	Land management							
LAND RECOVERY	Tidal River Management with cross dams							
LAND RECOVERY	Dredging							
LAND RECOVERY	Band structure							
PROACTIVE PLANNING	Proactive planning							
GENERAL ADAPTATIONS	Elevation in the level of residences							
GENERAL ADAPTATIONS	Afforestation							
GENERAL ADAPTATIONS	River dredging							
GENERAL ADAPTATIONS	Strengthening of the forestry department							
GENERAL ADAPTATIONS	Public awareness							
GENERAL ADAPTATIONS	Excavation and re-excavation of the channels							
GENERAL ADAPTATIONS	Fishing ban during the dry season							
GENERAL ADAPTATIONS	Management of tidal rivers and dams							
GENERAL ADAPTATIONS	Sediment management							

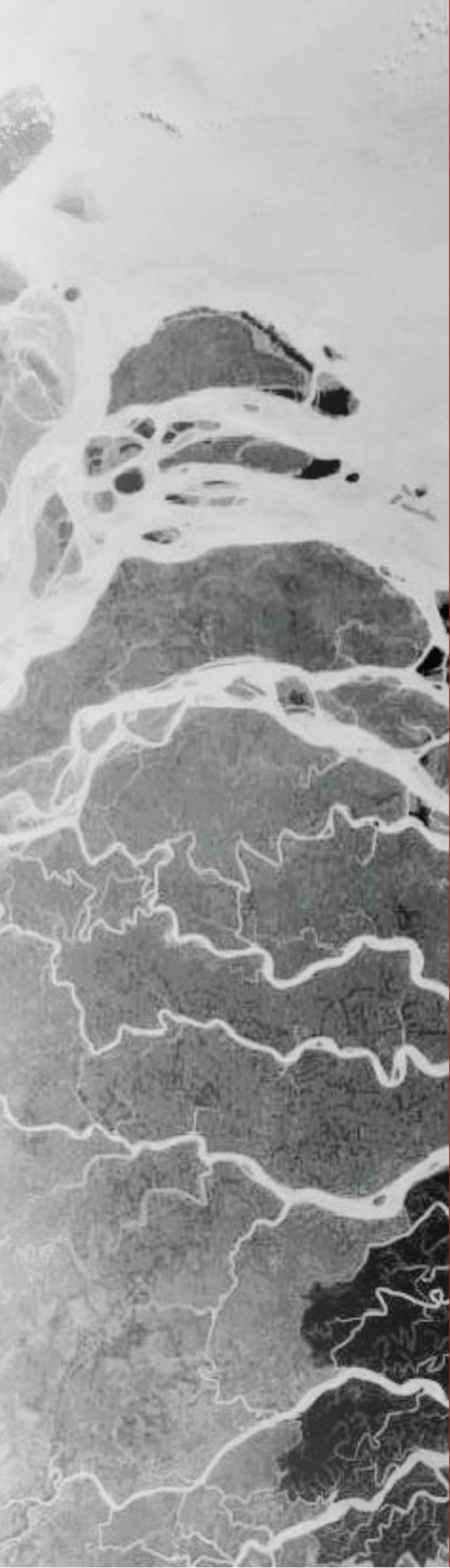
Figure 63 - Identified actions

Figure 64 - Actions distribution

All these actions were identified in relation to salinity intrusion, and contribute to the construction of resilient communities, understanding that for the most part, the actions do not allow the natural state of the delta to be restored, that is, they are only reactive actions and not are planned, mainly in the long term. However, they are important for communities to be able to absorb or adapt quickly to changes and crises, minimizing their economic losses (Hossain, Peerzadi Rumana et al., 2018; J. Chen & V. Mueller, 2018; Md. Anwarul Abedin, 2014; Md. Mansur Rahman et al., 2022; Ministry of Agriculture - Soil Resource Development Institute, 2010; Neha Rai et al., 2014; Pia Schneider & Folkard Asch, 2020; Resilience, 2016; Yukyan Lam et al., 2018).

If, on the one hand, the ability of communities to adapt in relation to the search for resilient communities proves to be effective, even if only in the short term, on the other hand, the increase in salinity that the search for resilience causes creates an expectation of future effects that, much will likely lead to migration if no further actions are taken. In turn, the consequence of the migration of 70% of a country's population, very dependent on agricultural activities in the delta area, tends to cause unimaginable problems, not only related to food supply, but also in the most vulnerable areas of large urban centers.

Figure 65 - Word cloud – Actions to cope with salinization



10

FINAL ANALYSIS

10. Final analysis

The consequence of salinity intrusion in the coastal region of Bangladesh not only interferes with ecological systems, but also with the way of life of communities that depend on this area for socioeconomic and subsistence activities. Seeking to avoid the internal and external migration of family members or entire families to urban centers with high density, usually in slums, depending on activities driven by global economic fluctuations, the inhabitants of the delta region seek to adapt in the most diverse ways. Even bearing in mind that the climate changes that affect the delta are a result of global climate changes that interfere with greater emphasis in these areas, even so, many of the consequences analyzed come from poor water, soil and land use management practices.

With 53 actions identified in the search for adaptation related to salinity, the development of this review made it possible to understand that, although communities are particularly creative when it comes to adapting to emerging salinization, in most cases the solutions found depend on aid of organizations and decisions taken by institutions. These adaptations, ranging from socio-economic policies such as encouraging diversified land use practices, to more dramatic structural measures such as dam construction, are also often to some extent responsible for the opposite feedback. Sometimes the level of salinity can end up being exacerbated by adaptations aimed at minimizing the consequences of salinity at the local level, that is, adaptations that contribute to inhibit the natural processes of sediment deposition, increase the tendency of communities to build in areas prone to flooding. Inducing transitions from land use to uses dependent on saltwater, intensifying the transition from surface water to groundwater use are actions that promote the mitigation of immediate economic losses, but they accelerate the salinization process and increase exposure and vulnerability of communities. Local decisions also intensify problems related to economic equity, land tenure and conflict over the right to use natural resources.

In general, it is understood that, excluding completely resilient actions, that is, those that do not involve some level of alteration, as is the case of greater displacements to find fresh water in ponds or capture and storage of rainwater, the most of them have an impact within a certain period of time, either for the individual, either at the community or longer term level, or at the delta level as a whole, contributing to the expansion of existing damages due to global climate change. .

On the other hand, actions focus more on adapting communities to the increasing level of salinity in water and soil than on seeking to minimize it. Building resilient communities is really important, but if there is no action to minimize the phenomenon, deltas remain at great risk, also putting at risk the existence of an important ecosystem, the Sundarbans arboreal mangrove, one of the largest forests of its kind in the world with extensive flora and fauna that include species unique to the region.

In this sense, there is an urgent need for a directed effort to increase research in these areas so that there are more long-term planning actions, including well-directed studies on the impact that each of the defined actions may have on the site and, as a result, throughout the delta ecosystem. While it is important to keep in mind that one form of adaptation is often the acceptance of salinity as a normal natural phenomenon, it soon tends to reach levels where coping with it is no longer a viable choice and adaptation options are no longer sufficient.

10.1. Lessons learned and recommendations for future approaches

The development of this master thesis provided a deeper understanding of the dynamics of deltas, how they form, how they work, what matters for their natural functioning to happen, what are the consequences of global climate change in these regions and how human activities interfere with the natural organization that deltas need to maintain themselves. Understanding how the riverside population behaves in the face of these changes and how it interferes in the delta proved to be an exciting subject, in addition to being highly relevant, both at a global level, but mainly at a community level in the chosen region.

The initial knowledge that deltas suffer from the effects of climate change at a global level was gradually complemented by the notion that local activities contribute greatly to the climatic effects being more felt, especially in these regions. The geomorphological characteristics that configure the deltas make them especially vulnerable to the rise in mean sea level. Although affecting all coastal regions of the planet, they are more incisive in these regions. The consequences of sea level rise especially and other phenomena such as heavy rains, tropical storms, cyclones and hurricanes are particularly dangerous in deltas and source of intrusion of soil and water salinity. However, in addition to these increasingly frequent events, the activities developed for the subsistence of coastal communities contribute to the maximization of salinity and, with it, the consequences of the presence of excess salt.

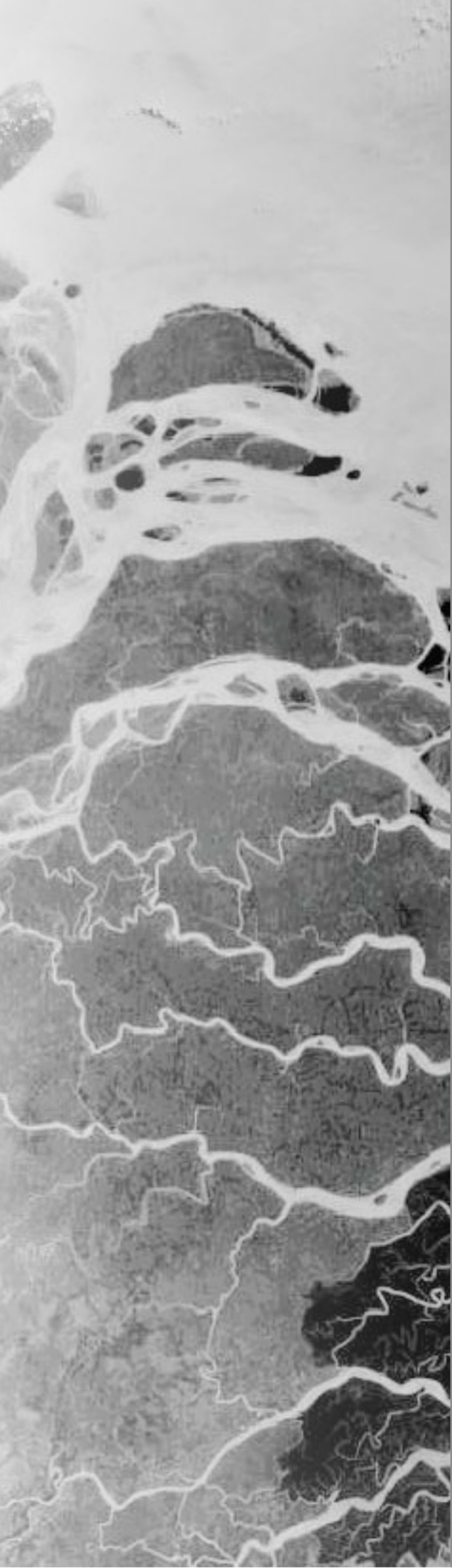
By identifying the indirect and direct causes of salinity intrusion into communities, it was possible to understand the dynamics that make these regions so vulnerable and so in need of attention. By understanding how human activity contributes to the increase in the phenomenon, it becomes clearer how it can be mitigated. However, the search for an answer to the research question led to an understanding that the actions applied to combat water and soil salinity are not exactly actions that are aimed at solving the problem. In addition to being more oriented towards adaptation than solution, they do not seem to be exactly coordinated so that, in the long term, they contribute to the mitigation of the phenomenon. That is, the intrusion of salinity seems to be a present problem with large trends to increase, mainly due to the fact that communities have tried to adapt their activities to live with the excess of salt. If, on the one hand, this fact demonstrates the human capacity to adapt to climate change, developing the resilience of communities and individuals towards living with the presence of salt, it also demonstrates that not much is being done in terms of research and planning to that the problem is lessened. In terms of human communities, ways of surviving and maintaining financial gains and livelihoods, the creativity that communities present, as well as the initiatives of organizations and the implementation of policies and technologies by institutions emerges as a proactive response to confront it even if it postpones for a certain time the need for migration of populations that live directly from the deltaic ecosystem. However, this same adaptability contributes to the acceleration of salinity and the intrusion more and more internally into the channels, consequently reaching larger areas and amplifying the problem in terms of the amount of area and population directly affected, that is, the migration process seems to be no longer an “if” problem, but a “when” question.

When it comes to resilience, it would have been quite enriching to research further and try to understand how actions towards the adaptation of communities actually interfere in local life and how this influence is not characterized by the application of immediate adaptations, aimed at ability to develop life locally.

When it comes to migration, further research can be opened for urban planners to identify the preferences of this population in relation to the places chosen to migrate, thus creating urban problems in big cities that already suffer from high population density.

Researching the effects of climate change in a specific region without, however, being able to actually be there is a challenge, as well as the need to search for reliable sources so that the result achieved can have relevance is a process of trust in the work of researchers.

As a recommendation for future approaches is the suggestion of deeper studies on adaptive and minimization actions, in which way they interfere in the daily life of communities and in the health of their residents and, mainly, in the functioning of the deltaic ecosystem, aiming at solutions that not only allow adaptation, but rather the minimization and escalation of the problem, in search of resilient communities that contribute to the recovery of the region.



11

CONCLUSION

11. Conclusion

From this master thesis, it was possible to understand the dynamics of the Ganges-Brahmaputra delta, its importance for Bangladesh and the risks that the region and its population face due to the effects of climate change. Salinity intrusion is an emerging local threat, not only affecting the livelihoods of thousands of people, but also inflicting direct impacts on human health, particularly the most vulnerable. Salinization occurs by the union of different factors, with consequences at different socio-ecological and economic levels. Bangladesh deals with the intrusion of salinity, mainly through actions aimed at adaptation, aiming to avoid the drama and consequences that are intrinsically linked to migration, even if this, in itself, is also considered a form of adaptation. The amount of policies and technologies aimed at adaptation is extremely more relevant than the amount aimed at mitigating salinity and seeking to reverse the current condition. In this way, the process of adaptation of communities to excess salinity presents itself as a postponement of migration, since successful short-term adaptation actions often worsen the phenomenon in the long term, causing the construction of resilient communities, although important for its survival in the delta, is not the best solution to the problem as a whole.

In order for the construction of resilient communities to be a way of approaching salinity intrusion that is consistent with the preservation of the delta area and maintenance of its population in place, it is necessary to implement studies aimed at human coexistence with the delta ecosystem, in an effort to understand the ways in which human activities can go hand in hand with preserving and maintaining the characteristics of the delta. Based on the information available in this review, a path is opened for the search for an understanding of how policies and technologies can be focused on how to make the populations dependent on the delta ecosystem to be able to carry out their activities without, however, compromising the delta itself. On the other hand, the speed of salinity intrusion as efforts for a short-term solution that amplifies its effects also opens, in a way, space, as a contribution and future preparation, for the deepening of cases of migration from the delta to poor regions in big cities and the consequences that this phenomenon has on urban life.

Future advances that seek to avoid migration and to maintain the characteristics of the delta will depend on innovations that maintain freshwater availability and security, as salinity intrusion is a rapidly developing phenomenon. Studies in this area should involve interdisciplinary research and analysis, given the level of complexity of the subject and the need that policymakers and stakeholders have for information that leads them to urgent and intelligent solutions.

12

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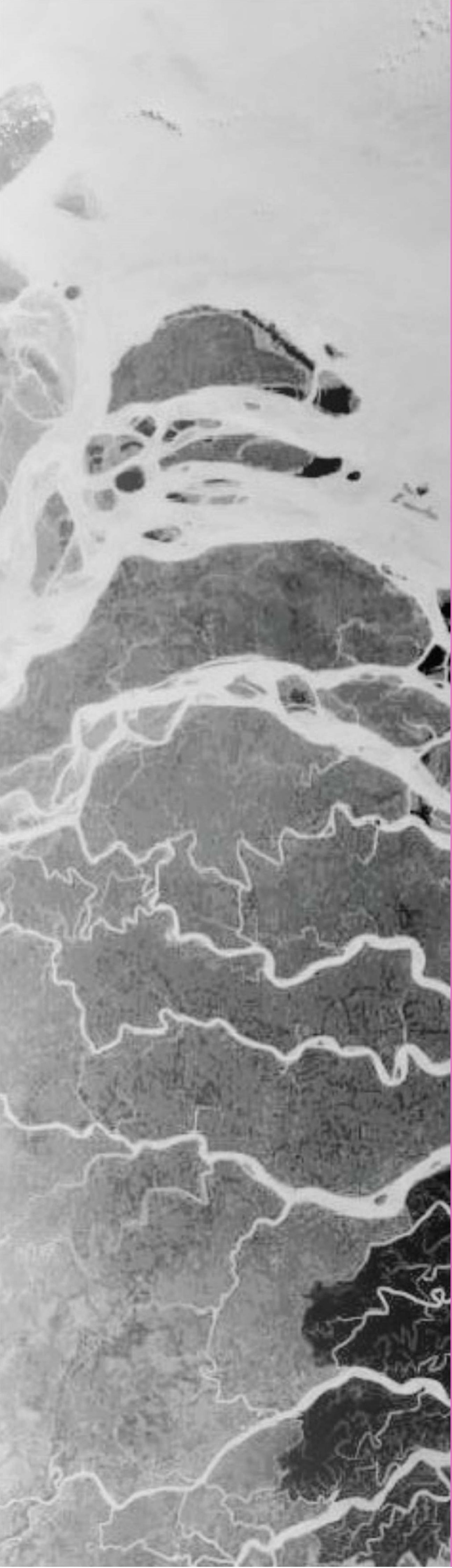

13

LIST OF FIGURES

13. List of figures