IMPACT OF WATER SALINITY ON LOCAL PLANT DIVERSITY OF THE BAKKHALI RIVER, COX'S BAZAR

BY

S. M. MAHMUDUR RAHMAN
ID # 152-30-129

This Thesis Report Presented in Partial Fulfilment of the Requirements for the Degree of Bachelor of Science (B. Sc) in Environmental Science and Disaster Management (ESDM)

Supervised by:

Dr. A. B. M. Kamal Pasha, PhD

Associate Professor and Head

Department of Environmental Science and Disaster Management

Daffodil International University

DAFFODIL INTERNATIONAL UNIVERSITY

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APPROVAL

This thesis report titled **"Impact of Water Salinity into the Local Plant Diversity of the Bakkhali River, Cox's Bazar",** submitted by S. M. Mahmudur Rahman to the Department of Environmental Science and Disaster Management (ESDM), Daffodil International University (DIU), has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Bachelor of Science (B.Sc.) in Environmental Science and Disaster Management (ESDM) and approved as to its style and contents. The presentation has been held on 12th May of 2019.

11/5/19

Dr. A. B. M. Kamal Pasha, PhD

Associate Professor and Head

Department of Environmental Science and Disaster Management (ESDM)

Daffodil International University (DIU)

DECLARATION

I hereby declare that this research project has been done by me under the supervision of **Dr. A. B. M. Kamal Pasha, Ph.D., Associate Professor and Head, Department of Environmental Science and Disaster Management (ESDM),** Daffodil International University (DIU). I also declare that neither this research project nor any part of this research project has been submitted elsewhere for the award of any degree.

S. M. Mahmudur Rahman
ID # 152-30-129; Batch - 15
Department of Environmental Science and Disaster Management (ESDM)
Daffodil International University (DIU)

DEDICATION

To,

my loving parents

S. J. Kaunine

S. M. Mashiur Rahman

my younger sister and brother

Ummay Jamila Khanam Siddika

S. M. Mahfuzur Rahman

my maternal grandmother and grandfather

Mrs. Marzan Begum

Late Md. Shamsul Huda Master

my respected teachers

Dr. A. B. M. Kamal Pasha, PhD

Md. Azharul Haque Chowdhury

Dr. Mahfuza Parveen

Mrs. Zannatul Ferdaus

Dr. Hasibur Rahman

and

to the loving memory of my beloved seniors, juniors, coordination officers and staffs from the ***Department of Environmental Science and Disaster Management (ESDM), Daffodil International University (DIU)*** *with whom I was spent a single second of my undergrad life in last four year (10th May 2015 to 12th May 2019).*

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ABSTRACT

Bangladesh is a deltaic land with hundreds of rivers. Many of them flow through and fall into the Bay of Bengal (BoB). Changing climate lead to the SLR and rising sea level causes the salinity in river water. The increasing salinity of river water directly affects the local ecosystem and plant diversity. In this study, we tried to assess the status of water salinity and existing plant diversity of the Bakkhali river of Cox's Bazar. We also tried to observe the impact of water salinity on local plant diversity of the Bakkhali river. In order to meet with the objectives, we directly measured the water salinity in the sampling locations, we collect plant diversity information from all sampling locations and estimated the status of plant diversity using both Simpson (D) and Shannon (H) Diversity Index Formula. Then statistically we observed the impact of salinity on the plant diversity on the riverside. We also collected water samples from the sampling location to measure the level of TDS and EC of the river water. A dam is situated in the middle of our study area. Due to that, we conducted our data collection process in two-phase, one is in the downstream zone (from the dam to Maheshkhali Channel) and another one is in the upstream zone (from the dam to Shikolghat, Rajarkul) of the river. In the downstream zone, highest salinity (250 ppt) was found in Maheshkhali Channel (transition point of Bakkhali river with the BoB). In the downstream zone, as salinity gradually increases (10 ppt to 250 ppt), the downward distance of sampling locations from the dam to Maheshkhali Channel also increase gradually. We observed almost zero salinity level in the river water of the upstream zone. Salinity level remains the same throughout the upstream zone. In the downstream zone, plant diversity value of both indexes decreases with the increase of downward distance from the dam to Maheshkhali Channel. The range of plant diversity value in downstream zone are, D = 1.808 to 3.311 and H = 0.635 to 1.552. In the upstream zone, any significant changes in plant diversity not observed at all. All values of plant diversity are almost the same and close to each other. Highest plant diversity also estimated in this zone (in Muktarkul, D = 5.848 and H = 1.767). The range of plant diversity value in the upstream zone is, D = 4.608 to 5.848 and H = 1.564 to 1.767. From the statistical analysis between all the findings above, we reach into a conclusion that in the downstream zone, as salinity increases, plant diversity tends to decrease towards the BoB from the dam. In the upstream zone, various anthropogenic factors lead to very slight changes in plant diversity rather than the salinity.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol or Unit	Name of the Symbol or Unit
'	Second
º	Minute
ºC	Degree Celsius
µS/cm	Micro Siemens Centimeter
mS/cm	Milli Siemens Centimeter
dS/cm	Deci Siemens Centimeter
ppt	Parts Per Thousand
ppm	Parts Per Million
m	Meter
m^2	Meter Square
km	Kilometer
sq.km	Square Kilometer

Abbreviation	Full Form of the Abbreviation
BoB	Bay of Bengal
CCC	Climate Change Cell
CCZ	Central Coastal Zone
CLD	Casual Loop Diagram
COP	Conference of the Parties
DAE	Department of Agricultural Extension
DIU	Daffodil International University
EC	Electrical Conductivity
ECA	Environmentally Critical Areas
ECZ	Eastern Coastal Zone
EPA	Environmentally Protected Areas
ESDM	Environmental Science and Disaster Management
GBM	Ganges-Brahmaputra-Meghna
GIS	Geographic Information System
GPS	Global Positioning System
KII	Key Informant Interview
MoEF	Ministry of Environment and Forest
NAPA	National Adaptation Programme of Action
SAARC	South Asian Association for Regional Cooperation
SL	Sampling Locations
SLR	Sea Level Rise
SMRC	SAARC Meterological Research Centre
SRDI	Soil Resourece Development Institute
TDS	Total Dissolved Solids
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WB	World Bank
WCZ	Western Coastal Zone

CHAPTER 1: INTRODUCTION

This introduction chapter describes the introductory information about the research project. Those include a brief discussion about the background, statement of the problem and objectives of the study. This part also demonstrates and briefly explain the structure of this research project report. This chapter divided into five (05) compartment. These are –

1.1. Background

Bangladesh, the world largest deltaic country, consist of a flat and low laying physical topography except for northeast and southeast region. That plane landscape, dynamic delta system and dynamic morphology of Bangladesh plays a vital role in the vulnerability of this country due to the climate change and rising sea level (CCC, 2016).

Bangladesh had a huge coastline at the edge of the Bay of Bengal. This huge coastline consists of 19 districts (Figure 1.1). Among them, twelve districts are known as exposed coast and seven are selected as interior coast. This huge coastline covers 32% of the land area of Bangladesh (Huq & Rabbani, 2014).

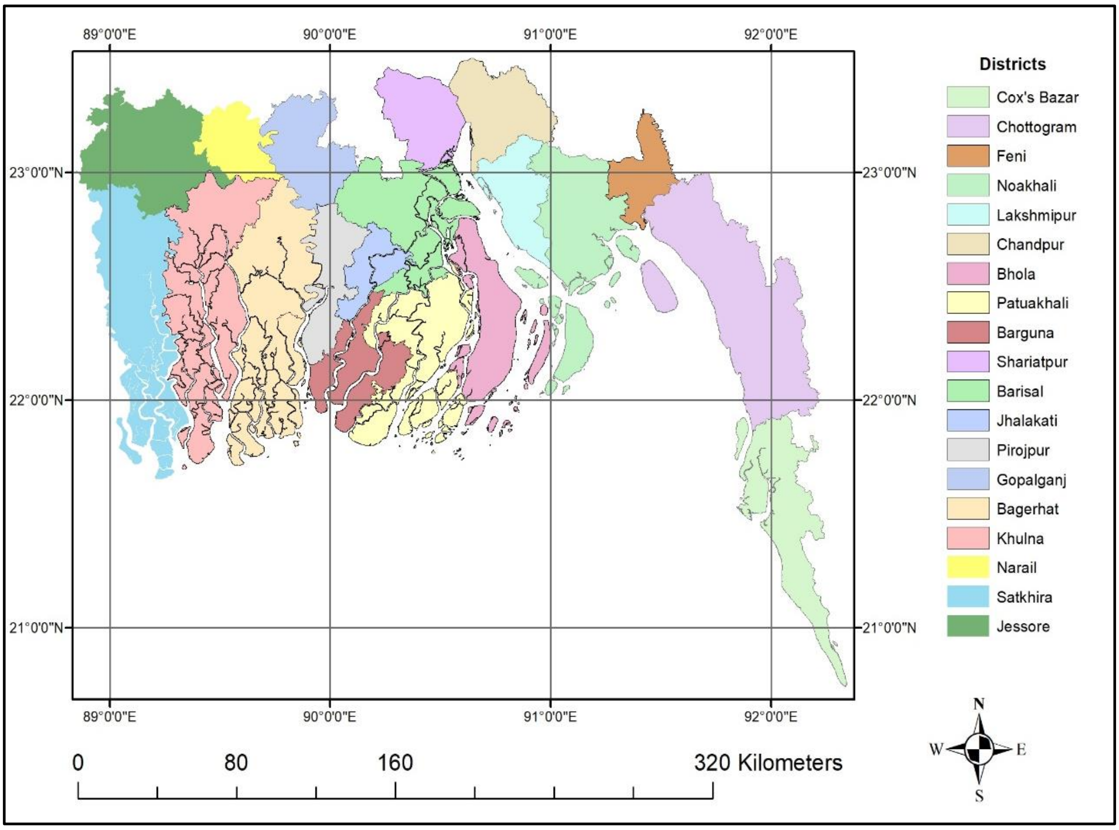


Figure 1.1: Coastal Districts Map of Bangladesh (own illustration).

Bangladesh is a land of river, that consists of hundreds (more than 700 rivers) of rivers. The Ganges, the Brahmaputra, and the Meghna are the three major rivers of our country. There are 57 trans-boundary rivers that are going through Bangladesh. Among them, the country shares 54 with India and 3 with Myanmar (Parven & Hasan, 2018).

1.2. Problem Statement

In the last couple of decades, the soil and water salinity have increased with an alarming rate. Sea Level Rise (SLR) due to climate change and widespread shrimp farming near the coast is the most influential factors for the increase of both soil and water salinity in the coastal region of Bangladesh. Sea Level Rise (SLR) automatically affect the natural ecosystem and biodiversity of the coastal areas. Saline water intrusion towards the inland is causing a severe impact on the local plant species and its diversity (Basar, 2012).

Due to the salinity, cultivable lands near the coast are not being used for agricultural production. The increased salinity is the main constraint for the growth of crops and plants. That limits the overall agricultural production and plant growth in the coastal area and makes the soil infertile for the crops and plants. So, increased salinity near the coast is a major problem that limits the food grain production in our coastal regions (Mahmuduzzaman et al., 2014).

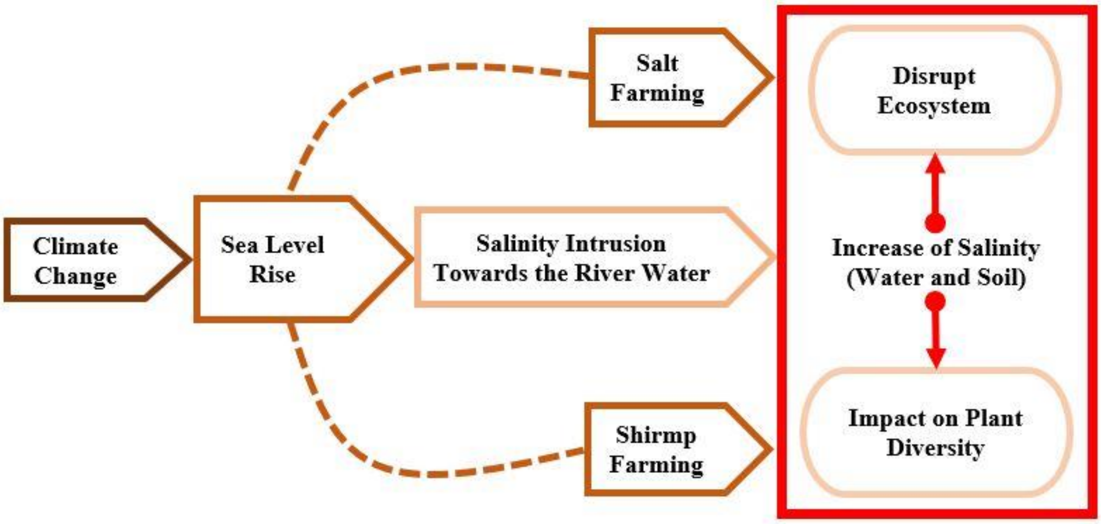


Figure 1.2: Flow Chart of Increase in River Water Salinity (own illustration).

Increased salinity due to the saline water intrusion towards the inland causes the changes in the crop and plant pattern in the coastal belt of Bangladesh (Soil Resource Development Institute, 2010).

There is a significant difference between the crop production of salinity affected coastal lands and non-saline inland areas. Due to the salinity, there is a restriction for normal crop production and normal plant growth. There is a big difference between salinity prone area and other non-salinity prone areas. In a salinity prone area, production of the crop, the intensity of cropping, level of production and quality of people's livelihood are much lower than the non-saline areas of our country (Ahsan & Bhuiyan, 2010).

Cox's Bazar, a southern coastal region of Bangladesh. The Bakkhali is a river which went through the Cox's Bazar and falls into the Bay of Bengal (BoB) through the Maheshkhali Channel. The regions near the Bay of Bengal (BoB) of that Bakkhali river is a highly salinity affected area. Due to the immense salinity, the local ecological system is directly threatened. Especially the plant species pattern and plant diversity of the Bakkhali river (CCC, 2016).

1.3. Justification of the Study

A lot of research work has had done at the western and central coastal region of Bangladesh about the salinity and its impact on various factors (such as mangrove forest, agriculture, biodiversity, etc.). There is a limitation of research study about the river water salinity and its impact on the coastal regions of Bangladesh. Especially there is no research work have had done on the rivers of the Chottogram division. Cox's Bazar is a district of Chottogram division.

Bakkhali river is an important river of Cox's Bazar district. No research work has been done on the Bakkhali river, its water salinity and water salinity impact on the surrounding. So, I have selected this topic as my research project in order to explore some new facts and phenomena about that region.

1.4. Objectives of the Study

This study is focusing on three specific objectives. Here we want to explore these three specific facts. We tried –

- To assess the status and variation of water salinity level between the downstream zone and the upstream zone of the Bakkhali river.
- To assess the status and variation of plant species diversity between the downstream zone and the upstream zone of the Bakkhali river.
- To assess the impact of water salinity on plant species diversity around the Bakkhali river.

1.5. Structure of the Study Report

This research project report is divided into five (05) separate chapters. The chapters are:

Chapter 01: Introduction

This introduction chapter describes the introductory information about the research project. Those include a brief discussion about the background, problem statement, and objectives of this research project. This chapter also demonstrates and briefly explain the structure of this research project report. This chapter divided into five (05) sections.

Chapter 02: Literature Review

This chapter provides a detail description in four sections. This chapter discusses the river water salinity, saltwater intrusion, the causes and factors that are responsible for the saltwater intrusion into the coastal rivers of Bangladesh and discuss the related study done in Bangladesh. This chapter divided into four (04) sections.

Chapter 03: Methodology

This chapter mainly provides a detailed description of the study area and discuss the various systematic techniques that are used to conduct this study. This chapter is divided into five major components.

Chapter 04: Result and Discussion

This chapter broadly discusses the findings and results of our study in a different form. At the beginning of this research project, we have assumed three different objectives and we worked on it. Here, in this chapter, we tried to get a well-organized understanding of the objectives by analyzing the collected data and findings in different ways. So, this chapter of result and discussion divided into five (05) different sections.

Chapter 05: Conclusion and Recommendation

In this final chapter of the study, I tried to assemble all study points from the literature review, data collection, data analysis, result, and discussions. Here, we also tried to justify the objectives of the study. Recommendations are also given for the researchers in order to better understanding of the future study. This chapter divided into two (02) part.

CHAPTER 2: LITERATURE REVIEW

This chapter provides a detail description in four sections. This chapter discusses the river water salinity, saltwater intrusion, the causes and factors that are responsible for the saltwater intrusion into the coastal rivers of Bangladesh and discuss the related study done in Bangladesh. This chapter divided into four (04) sections. That is –

2.1. Water Salinity

Salinity is the relative proportion of salt in soil or water. It is usually measured in ppt (parts per thousand). Water salinity is the relative proportion of the salts that are dissolved into the water. When the saline water from the ocean moves toward the land through the river, the river water gets salty and it's called as river water salinity. So, salinity happens or increase due to the landward movement of saline water from the sea, known as the saline water intrusion (Gain et al., 2014).

Due to the variation of density and pressure between saline water and freshwater, saline water moves towards the inland and it called the saline water intrusion. Saline water contains a high percentage of dissolved minerals and salts than fresh water. So, saline water has much more pressure than the freshwater in the circumstances of the same volume of water. Because of that, saline water always tends to move toward the inland beneath the freshwater (Duan, 2016)

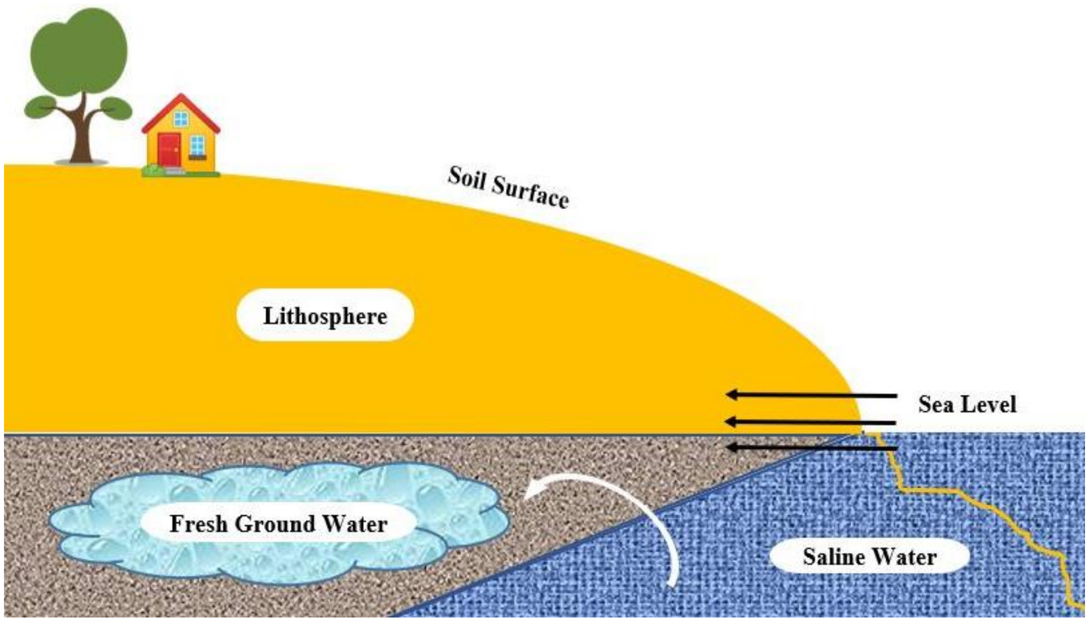


Figure 2.1: Conceptual Diagram of Salinity Intrusion Towards the Land, modified from (Duan, 2016).

River water salinity mainly depends on three important phenomena (Dasgupta et al., 2015):

- The volume of freshwater discharges from the upstream zone of a river
- The salinity of the ocean near the coast
- The circulation pattern of coastal water induced by the ocean currents and strong tidal currents

2.2. Causes of Salinity in the Rivers of Coastal Bangladesh

In Bangladesh, 80% of the country is floodplain, that has a very low elevation above the level of sea water. The average elevation of the southeast coastal areas are 4-5 m and the southwest coastal zones are 1-2 m (CCC, 2016).

Table 01: Land Area Under Various Elevation of the Coastal Area.

Elevation (m)	Area* (sq. km)	Area* (% of country)	Area* (% of coastal)
0 – 1	8, 459	6	21
1 – 2	11, 158	8	27
2 – 3	7, 019	5	7
3 – 4	9, 411	7	13
4 – 5	8, 789	7	8
Total	**44, 836**	**33**	**76**

*estimate only land surface without the area of the waterbody
Source: Climate Change Cell (CCC, 2016)

These are the main reasons for saline water intrusion in the coastal rivers of Bangladesh:

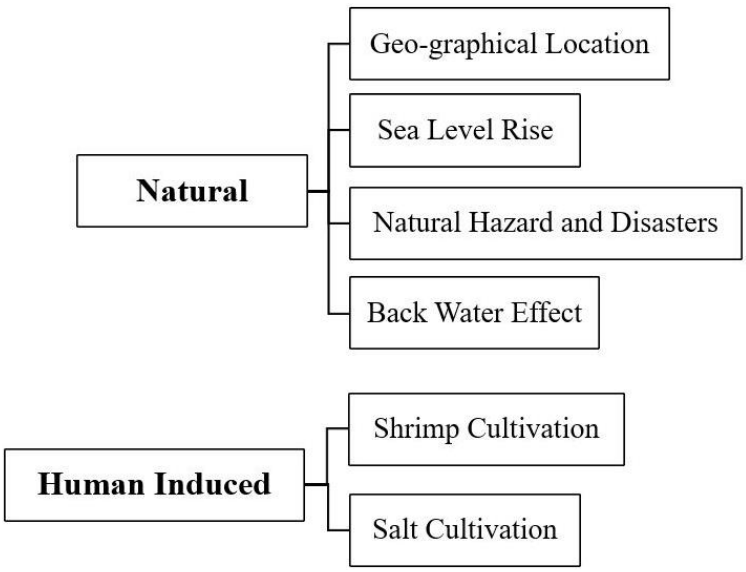


Figure 2.2: Causes of Salinity in the Rivers of Coastal Bangladesh.

2.2.1. Geographical Location

The southern region of Bangladesh is one of the most productive ecosystems of the world and this is a part of our coastal zone. A number of rivers are going through that region, including the Ganges-Brahmaputra-Meghna (GBM) river system. Except for this southern region of our country, all other regions of our country are plain land with an enormous river network system and char land (Sarwar, 2005).

According to (Islam, 2001), Coastal zone of Bangladesh has divided into three main regions:

- Eastern Coastal Zone (ECZ)
- Central Coastal Zone (CCZ)
- Western Coastal Zone (WCZ)

The Eastern Coastal Zone (ECZ) of Bangladesh is a very narrow region with a series of small hills that are run parallel to this part. This coastal zone starts from Bodormokam (the southern tip of the mainland to the estuarine area of the Feni river). The Karnafully, Matamuhury, Naf and Sangu river going through that region and falls into the BoB. Bangladesh and Myanmar are divided by the Naf river (Islam, 2001).

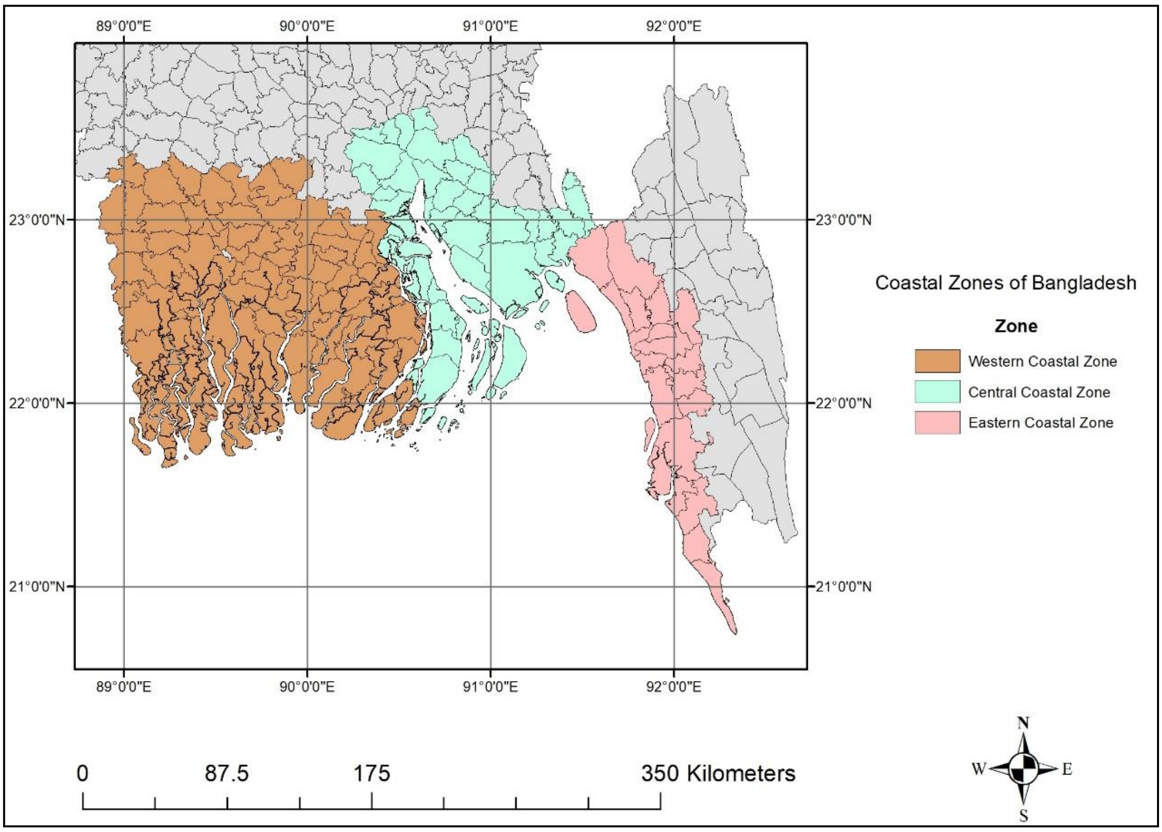


Figure 2.3: The Coastal Zone Map of Bangladesh (own illustration).

The submerged sand formed a 145 km long sandy sea beach from Cox's Bazar to Teknaf. Patenga and Cox's Bazar sea beach are the country's two most important sea beach from a tourism perspective. This coastal zone is widely important for its tourism activities. But, salt cultivation, fishing and fish farming is also the other major economic activities of this coastal zone (Sarwar, 2005).

2.2.2. Sea Level Rise (SLR)

Bangladesh is a densely populated country. The coastal regions of our country are also densely populated and that is very vulnerable to the sea level rise. According to United Nations Environment Programme (UNEP), Sea level will rise 1.5 m. in 2030 that will overwhelm around 16% of total land and effect around 15 million people of Bangladesh (Seal & Baten, 2012). Another study projected the sea level will rise 10 cm by 2020, 25 cm by 2050 and 1 m by 2100 that will overwhelm around 2%, 4% and 17.5% land of our country respectively (World Bank, 2000).

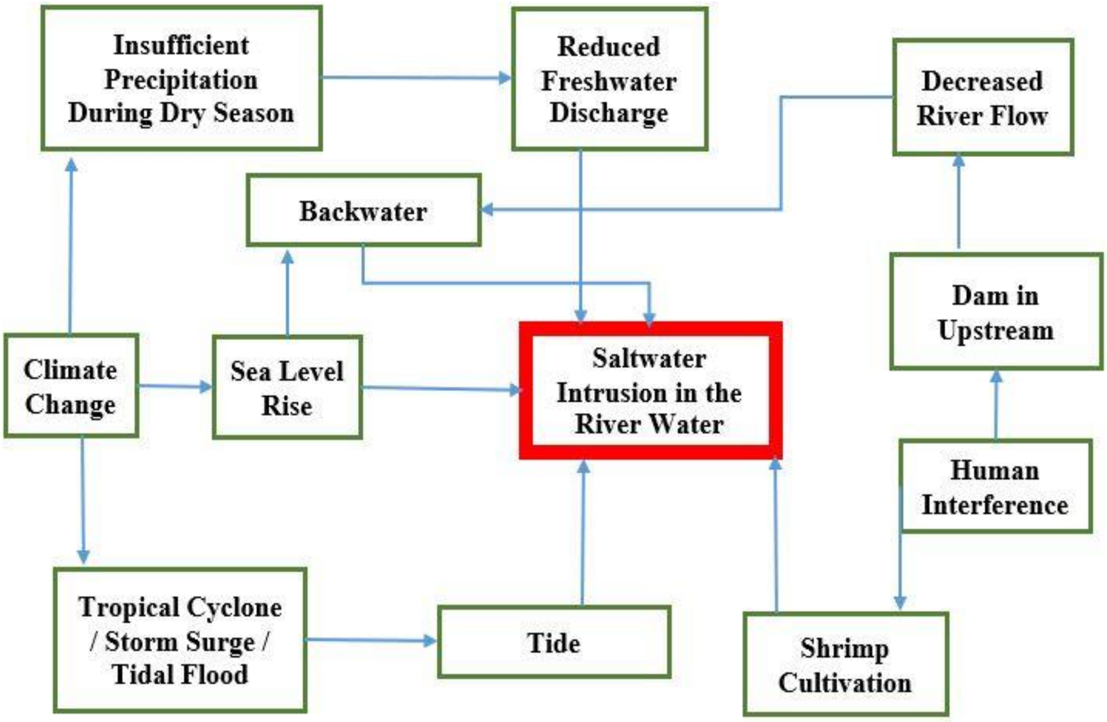


Figure 2.4: Flow Chart of Salinity Intrusion in the Rivers of Coastal Bangladesh, modified from (Seal & Baten, 2012).

In the response to the decision of UNFCCC's (United Nations Framework Convention on Climate Change) 7th Session of the Conference of the Parties (COP7), Ministry of Environment and Forest (MoEF), Bangladesh, has prepared National Adaptation Programme of Action (NAPA) (CCC, 2016).

In 2003, South Asian Association of Regional Cooperation (SAARC) Meteorological Research Centre (SMRC) observed the yearly tidal gauge from 1977-1998 and found that the tidal level in three-point of Bangladesh (Hiron Point, Char Changa, and Cox's Bazar) rose (Table 02). The tidal level of the Eastern Coastal Zone (ECZ) is much higher than the tidal level of the Western Coastal Zone (WCZ).

Table 02: Tidal Level in Three Points of Bangladesh.

Point	Region	Latitude	Longitude	Datum	Trend
Hiron Point	Western	21º 48' N	89º 28' E	3.784 m.	4.0 mm/yr.
Char Changa	Central	22º 08' N	91º 06' E	4.996 m.	6.0 mm/yr.
Cox's Bazar	Eastern	21º 26' N	91º 59' E	4.836 m.	7.8 mm/yr.

Source: SMRC, 2003

So, saline water enters the coastal regions of Bangladesh due to the rising of sea level (Seal & Baten, 2012). A study shows that 88 cm sea level rise influences the 5 ppt saline water intrusion towards 40 km inland of Tentulia freshwater river in Meghna estuary (Shamsuddoha & Chowdhury, 2007)

2.2.3. Natural Hazard and Disaster

Bangladesh is one of the most natural hazards and disaster-prone area in the world. Every year we must cope up with these phenomena. There are various types of natural hazard and disaster that are also responsible for the intrusion of the saline water towards the inland. Such as cyclone, storm surge, tidal flooding, etc.

In Bangladesh, we experienced some of the deadliest cyclones in various time. Bhola Cyclone (1970) and Bangladesh Cyclone (1991) is the major example of them (Ali 1996). During cyclone Sidr (2007) and cyclone Aila (2009), saline water intrudes in agricultural land, ponds, canals and rivers of the coastal zone that are still contaminated by the saline water. The peoples of the coastal zone are still suffering from that problem (Mahmuduzzaman et al., 2014).

The coastal zone of Bangladesh is a very flat and low-lying region with a height of fewer than 3 m above the mean sea level. Due to the prominent higher range astronomical tide and sea level rise, cyclone and storm surge is likely to be very common in the coastal Bangladesh (Seal & Baten, 2012).

Figure 2.5: Tidal Flood in Coastal Bangladesh. Source: (Mahmuduzzaman et al., 2014)

Frequency of tropical cyclone and storm surge would increase with the higher peak wind speeds and substantial precipitation due to the climate change in the coastal zone of Bangladesh (Khan et al., 2010).

With six hours of the consecutive time interval, Bangladesh faces two flood tide and two ebb tide in a day. Urban areas of coastal Bangladesh faces flooding due to the water logging during the monsoon because of the heavy rainfall and flood tide. So, due to the heavy rainfall and high tide during monsoon, saline water expands almost all over the coastal region (Mahmuduzzaman et al., 2014)

2.2.4. Back Water Effect

Backwater effect takes place at the mouth of the river (transition zone). Backwater effect is a special type of saline water movement towards the river from the sea. It takes place when freshwater is not adequate to counterpart moving tidewater (Seal & Baten, 2012)

There is various reason that is responsible for the backwater effect in the mouth of the river. The reasons are (Ali, 1999):

- Southwest monsoon wind
- Astronomical tides
- Storm surge

(Ali, 1999) also stated that the sea level rise is the non-dynamic and long-term reason for the backwater effect.

2.2.5. Shrimp Cultivation

Shrimp cultivation is also responsible for the saline water intrusion. Shrimp cultivation raises a serious alarming situation to the agricultural land in the coastal region of Bangladesh (Flaherty et al., 2000).

Figure 2.6: Saline Water Enters into Shrimp Gher and Causes Salinity. Source: (Mahmuduzzaman et al., 2014).

Shrimp cultivation needs saline water as an input in the gher (pond). So, saline water intrusion is also increasing day by day with the expansion of shrimp cultivation practice in the fresh agricultural land (Mahmuduzzaman et al., 2014)

Table 03: Land Use Changes in Shrimp Cultivation from 1975-76 to 2006-07.

District	**Shrimp Cultivation (ha.)**	
	1975-76	**2006-07**
Cox's Bazar	7, 500	48, 105
Khulna	500	52, 950
Bagerhat	20	61, 960
Satkhira	5, 000	60, 000
Noakhali	500	2, 670
Barisal	250	542
Patuakhali	101	4,360

Source: DAE and SRDI, 2007

Due to the vast shrimp farming, the salinity of soil is increasing, and the availability of agricultural land is reduced. *Penaeus monodon* is a brackish water shrimp that has a massive demand in the international market. Due to the huge demand in the international market, this shrimp farming has taken place the almost the whole coastal region of our country (Mahmuduzzaman et al., 2014).

2.3. Impact of Salinity in the Rivers of Coastal Bangladesh

Generally, saline water intrusion is a common threat to freshwater sources like aquifers. Also, the excessive content of salt and minerals of saline water can have a negative impact on the animal species and to the many kinds of plant species also (Thompson 2014).

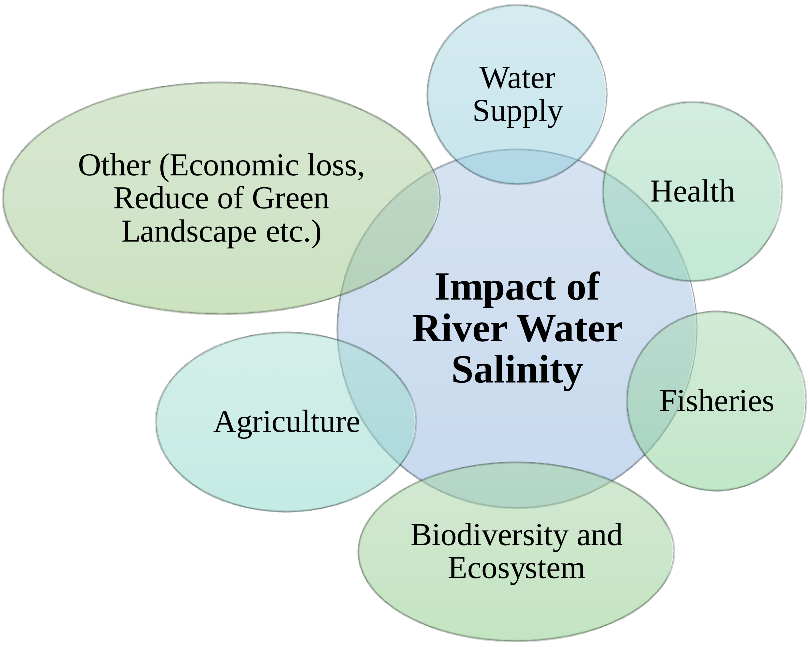


Figure 2.7: Possible Impacts of Salinity in the Rivers of Coastal Bangladesh, modified from (Seal & Baten, 2012) and (Gain et al., 2014).

2.3.1. Water Supply and Health

Water is a symbol in Chinese culture. They believe that water can bring vitality and wealth to them. The densely populated coastal regions of our planet proved that believe of the Chinese culture. People always try to move or migrate towards the coast for mankind in order to obtain the great productivity of the coastal regions. Integrated human activities with some hydrological issues (such as contamination of groundwater through saline water intrusion) extent the problem of drinking water scarcity day by day in the coastal regions (Duan, 2016)

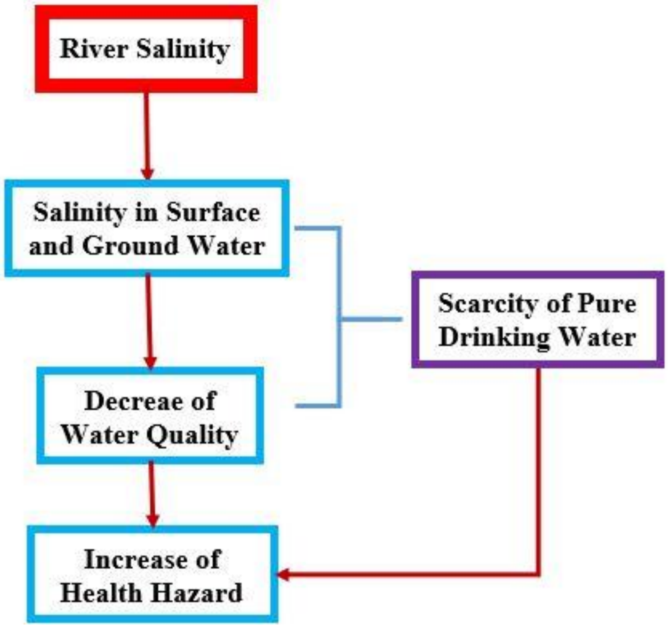


Figure 2.8: Impact of Salinity on Water Supply and Health, modified from (Seal & Baten, 2012).

The increased immense pressure of saline water on the freshwater zone decreases the availability of the fresh water in the coastal zone. People drink contaminated water and got sick on water-borne diseases (such as cholera, diarrhea, etc.) due to the unavailability of fresh water, malnutrition problem also increased due to the decrease of food production (Sarwar, 2005).

2.3.2. Agricultural

In terms of various factor such as reducing of crop production, hampering of industrial production, increasing of health hazard and reducing the productivity of forest goods and forest species, saline water intrusion in river water may cause immense economic loss. Saline water reduces the plants to grow through salt fixation in the plant's root and causes nutrient imbalance. Due to that, agricultural production is reduced by the time span. When industries used the saltwater from the river to cool the condenser and keep the turbine running, then the industrial production is reduced automatically. Saltwater not only limits the usability of the river water but also causes leakages in the equipments. So, production loss is taking place and cost production is increased. In 1993, Pakshi Paper Mill closed for the saltwater intrusion in north Khulna (Mirza, 1998).

The increase of water salinity in the rivers restricts the growth of the forest species at the river channels. The decrease of freshwater and intrusion of saline water deplete the quality of soil that limits the plant growth and decrease the productivity of the plants. So, the whole thing places an adverse impact on the surrounding wildlife and biodiversity (Seal & Baten, 2012).

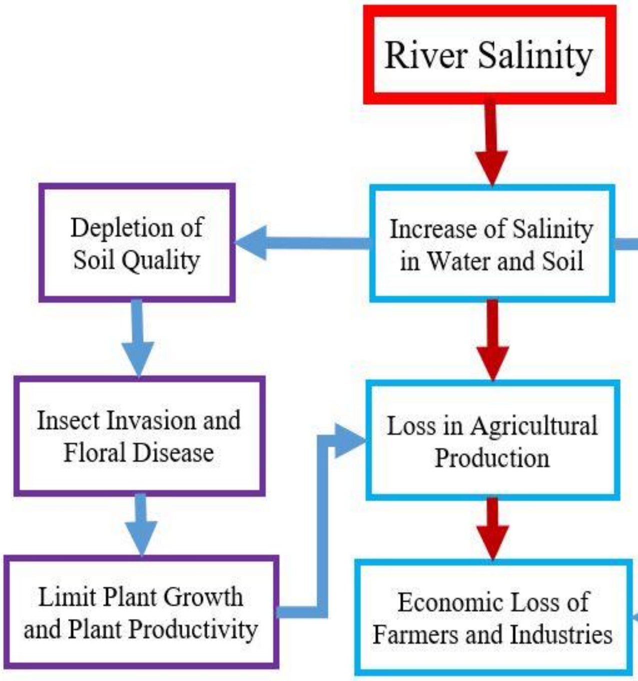


Figure 2.9: Impact of Salinity on Agriculture, modified from (Seal & Baten, 2012).

Simply, saline water intrusion led to a change in the soil or water condition that increases the floral disease and insect invasion in the soil. These factors slow down the plant's growth and decrease plant species diversity (Gain et al., 2014).

2.3.3. Fisheries

According to CLD (Haraldsson, 2004) - Casual Loop Diagram between sea level rise and coastal fisheries of Bangladesh (a cause impact relationship model between two phenomena), coastal fisheries resources are mainly affected by the rise of sea level in three different ways (Sarwar, 2005). These ways are:

- Saltwater intrusion
- Coastal flooding, and,
- Increase the intensity of the cyclone

In our coastal Bangladesh, these three phenomena respectively responsible for the decrease of coastal fisheries resources that are the main protein source of coastal people. People of Bangladesh intake around 60-80% of their animal protein demand from the consumption of fish (Alam & Thomson, 2001).

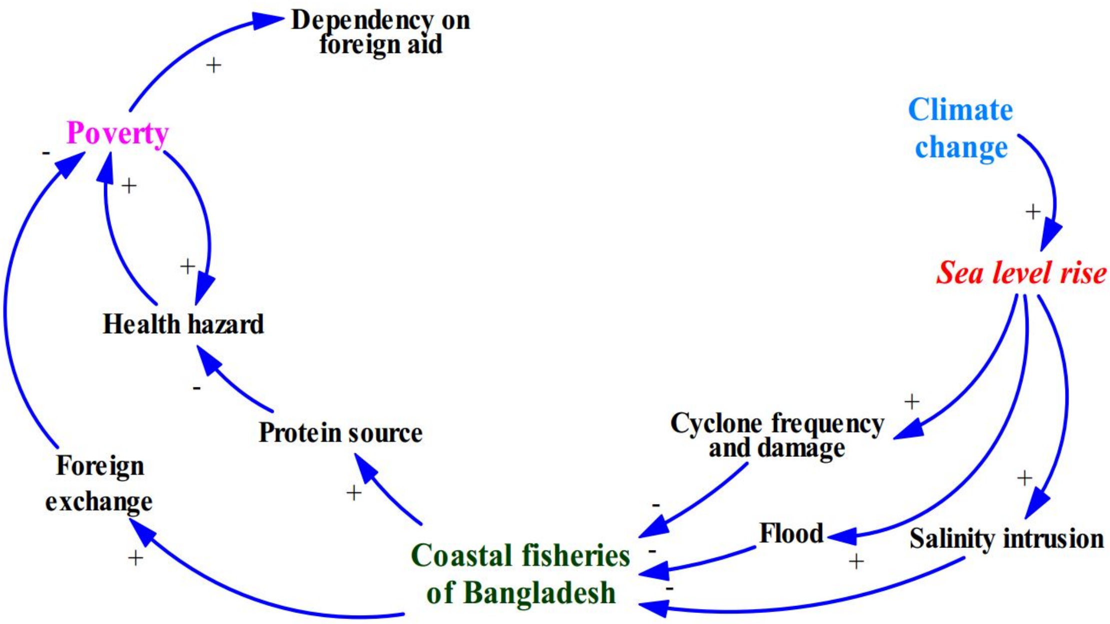


Figure 2.10: Impact of Salinity due to SLR on the Fisheries Resources of Coastal Bangladesh. A CLD, adopted from (Sarwar, 2005).

Due to the immense increase of salinity and increasing the intensity of other phenomena decreased the coastal fisheries and cause scarcity of protein into the mass people of the country. This scarcity of protein eventually increases the possibility of public health hazard. The poor status of public health will increase poverty among the coastal areas. On the other hand, the increase in poverty will gear up the health hazard (Sarwar, 2005).

In Bangladesh, the frozen food industry is one of the largest foreign exchange earning sector that is extremely dependent on the production of fisheries resources from the coastal regions. So, the decrease in coastal fisheries will reduce the earning of foreign exchange. Due to that, poverty will increase that will cause us to seek out foreign aids (Sarwar, 2005).

2.3.4. Biodiversity and Ecosystem

Ecosystems are widely known for its several important environmental or ecological functions. Such as nutrient cycling, a habitation for the floral and faunal species and so on (Fretwell et al., 1996).

An insignificant change in the soil salinity due to the saline water intrusion can cause water stress of the plants and can cause deadly consequences to them. So, when the habitats of an ecosystem will become eroded than the biodiversity of that surrounding will decline automatically (Duan, 2016).

Considering the higher biodiversity value of our coastal Bangladesh, a few areas are declared as an Environmentally Protected Area (EPA) in order to save the natural habitat for the species and save them from the extinction (Islam 2004).

Table 04: Environmentally Protected Areas (EPA's) of Coastal Bangladesh.

EPA Type	Name	Area (ha.)	Location
Reserve Forest	-	885, 043	Bagerhat, Barguna, Bhola, Chottogram, Cox's Bazar, Feni, Khulna, Lakshmipur, Noakhali, Patuakhali, Satkhira
National Park	Himchari	1, 729	Cox's Bazar
	Nijhum Dweep	4, 232	Noakhali
Eco-park	Sitakunda	808	Chottogram
Wildlife Sanctuaries	Sundarban East	31, 227	Bagerhat
	Sundarbans South	36, 970	Khulna
	Sundarban West	71, 502	Satkhira
	Char Kukri Mukri	2, 017	Bhola
	Chunati	7, 761	Chottogram
Game Reserve	Teknaf	11, 615	Cox's Bazar
Ramsar Site	The Sundarban	601, 700	Bagerhat, Khulna, Satkhira
Environmentally Critical Areas (ECA)	Sonadia	4, 916	Cox's Bazar
	Teknaf beach	10, 465	Cox's Bazar
	St. Martin Island	590	Cox's Bazar
World Heritage Site	Sundarban Wildlife Sanctuaries	-	Bagerhat, Khulna, Satkhira
	Shaat Gombuz Mosque	0.16	Bagerhat
Marine Reserve	-	69, 800	Bay of Bengal
Fish Sanctuaries	-	15, 614	Barisal, Bagerhat, Bhola, Narail, Jessore, Khulna, Lakshmipur, Patuakhali, Feni

Source: Islam 2004

Many threatened animal species of our country living a safe and sound life in these Environmentally Protected Areas (EPA).

Table 05: Protected Species in Environmentally Protected Areas (EPA).

Species Class	Species Number
Fish species	7 species
Amphibian species	2 species
Reptile species	7 species
Bird species	8 species
Mammal species	8 species

Source: Islam 2004

So, increasing salinity in the coastal zones of our country will hamper the ecosystems and their biodiversity.

2.4. Related Study (Bangladesh)

Limited work has been done on this kind of "River Salinity Impact on Plant Diversity" study in our country.

2.4.1. Study 01

Salinity Intrusion in Interior Coast of Bangladesh: Challenges to Agriculture in South-Central Coastal Zone (Baten et al., 2015).

2.4.1.1. Study Objective

This study was willing to find these three (03) following facts (Baten et al., 2015):

- To identify the river salinity in the southern Meghna estuaries through measuring Electrical Conductivity (EC).
- To identify the affected zone by saltwater intrusion in the study area.
- To identify the effects of river salinity on yields, farms, livestock as well as depending human.

2.4.1.2. Study Result

These are the results of the study (Baten et al., 2015):

- The Electrical Conductivity (EC) of irrigation water in the study area was found as 1305 µS/cm or 0.72 ppt at 25ºC.
- The measured soil salinity of the study area was <4 dS/cm.
- River water with a high level of salinity, when used for drinking purpose, may have numerous impacts on human health and livestock.
- Increasing salinity in the river not only affect the surrounding yield as well as other potential yields.

- The agricultural diversity is being reduced in an accelerated manner because of sea level rise and saline water intrusion.

2.4.2. Study 02

Effect of River Salinity on Crop Diversity: A Case Study of the South West Coastal Region of Bangladesh (Gain et al., 2014).

2.4.2.1. Study Objective

This study was willing to find these two (02) following facts (Gain et al., 2014):

- Measure the salinity of the Shibsha river of Bagerhat district and Pashur river of Khulna district.
- Assess the effect of river salinity on crop diversity of those regions.

2.4.2.2. Study Result

These are the key findings or results of the study (Gain et al., 2014):

- The salinity of the Shibsha river of Paikgacha, Bagerhat rages from 20, 000-45, 000 micro-mhos.
- The salinity of the Pashur river of Rampal, Khulna ranges from 10, 000-30, 000 micro-mhos.
- Due to the increased salinity, the summer vegetable species in Paikgacha and Rampal have been reduced from 16 to 2 species and 15 to 9 species respectively from 1975-2005.
- For winter vegetable species, this figure was reduced from 13 to 9 species in Paikgacha but in Rampal, this number remained unchanged.
- Standing plant species in Paikgacha and Rampal have been reduced from 31 to 14 species and 35 to 21 species respectively during this period.

CHAPTER 3: METHODOLOGY

This chapter mainly provides a detailed description of the research project area (study area) and discuss the various systematic techniques that are used to conduct this research project. This chapter is divided into five (05) major components.

3.1. Study Area

Cox's Bazar, one of the most visited tourist destinations in Bangladesh under Chottogram division. Cox's Bazar is a coastal district at the edge of the Bay of Bengal (BoB) with 120 km world largest sea beach. The geographical position of Cox's Bazar is in between 20º43' and 21º56' north latitude and in between 91º50' and 92º23' east longitude. It is bounded by Chottogram district on the north, by Bandarban district and Myanmar on the east, by the Bay of Bengal on the south and west (BBS, 2011).

Bangladesh is a land of the river. In Cox's Bazar district there are four main rivers (The Matamuhuri, Bakkhali, Reju Khal and Naf) that went through the Cox's Bazar and fall into the Bay of Bengal. The Masheshkhali and Kutubdia channel is the main two channels of Cox' Bazar district that are linked with the Bay of Bengal (BoB). Cox's Bazar district is divided into 8 Upazilas. The Upazilas are Cox's Bazar Sadar, Chakoria, Maheshkhali, Teknaf, Ramu, Kutubdia, Ukhia, and Pekua. Cox's Bazar district is consisting of a total area of 2, 491.85 sq.km (BBS, 2014).

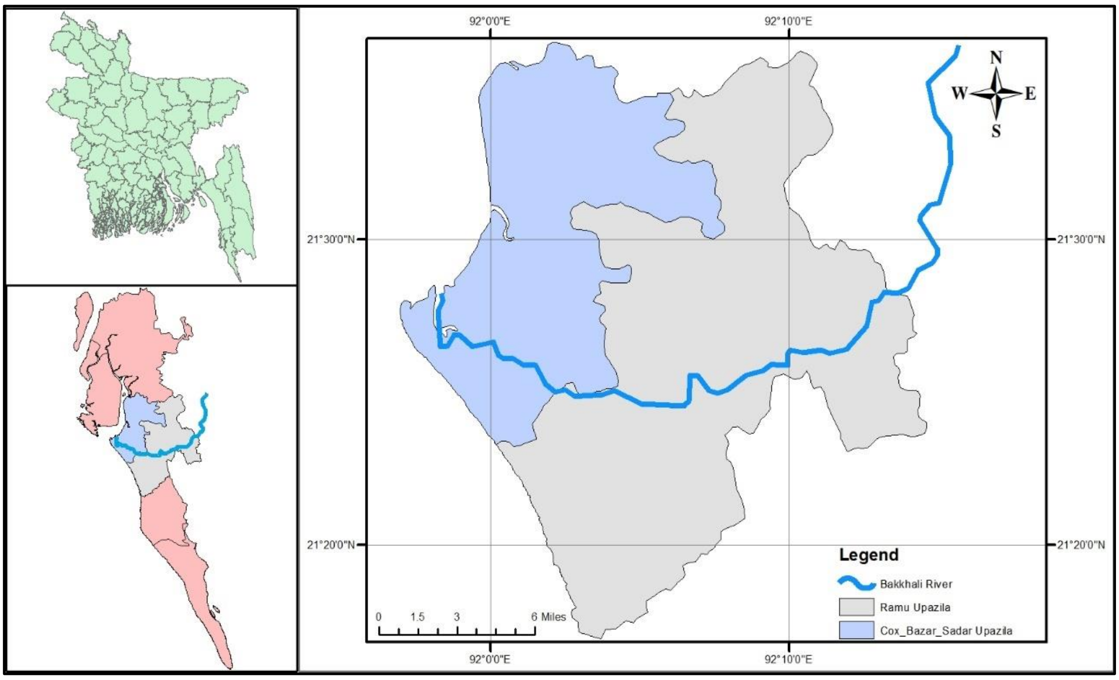


Figure 3.1: Map of the Bakkhali River. (own illustration)

The Bakkhali is one of the main rivers of Cox's Bazar District. The source of the river is the hills of the south-west hilly region of the Mizoram, India. A few water flows came down and entered the Bandarban of Bangladesh from that south-west hilly region of the Mizoram, India. Then the water flows meet at the Naikhongchhari of Bandarban and form the Bakkhali river. From that Naikhongchhari point, the river went through the Ramu and Cox's Bazar Sadar Upazila, then fall at the Maheshkhali channel that linked with the Bay of Bengal (BoB).

The Bakkhali river is 69 km in length and went through like a snake. It is around 47 km long from the border of Ramu Upazila-Bandarban to the Maheshkhali Channel. Cox's Bazar Sadar Upazila consist of around 20 km from this total length of the Bakkhali river. So, the study mainly conducted based on the 20 km long Bakkhali river from Maheshkhali Channel to Ramu Upazila-Cox's Bazar Sadar Upazila border.

But we covered almost 26.40 km of the Bakkhali river (from the Maheshkhali Channel to the Ramu-Mariccha road connecting bridge of Shikolghat over the Bakkhali river) after went to the field data collection. That means we also covered some portion (around 7 km) of the Bakkhali river from the Ramu Upazila.

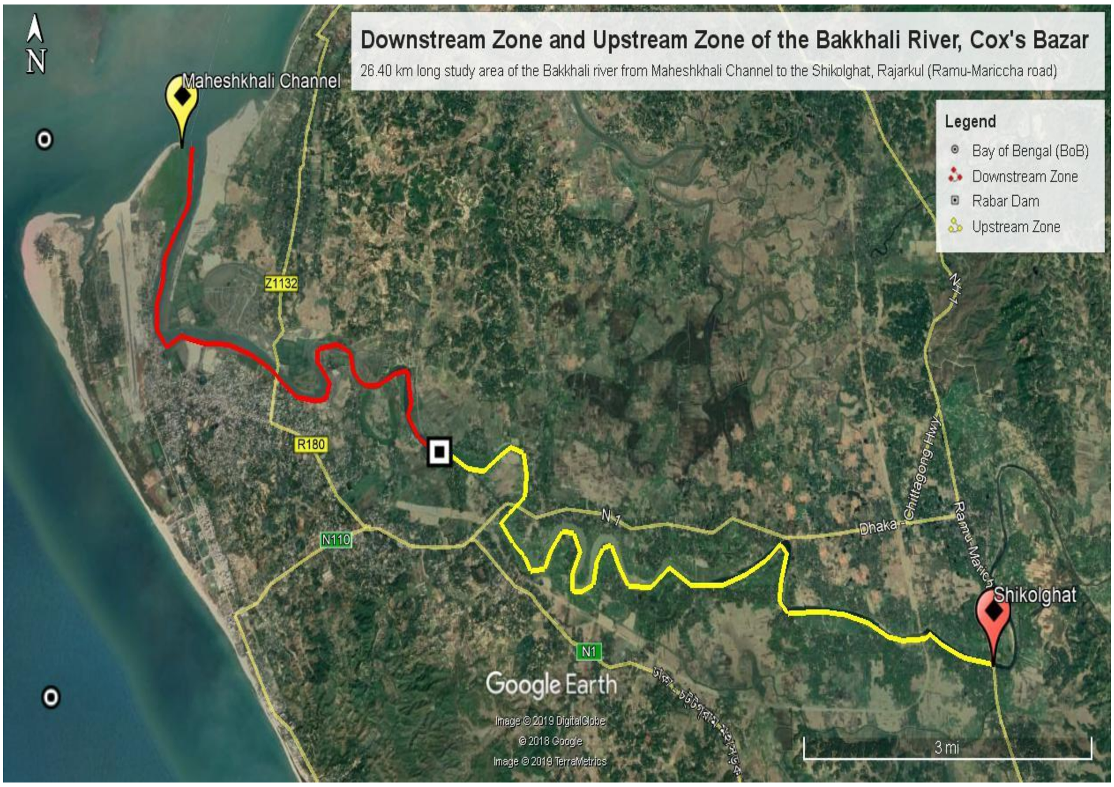


Figure 3.2: The 26.40 km long Study Area of the Bakkhali River. (own illustration by using google earth pro)

An embankment or a dam is located almost at the middle of that 26.40 km distance. The embankment or dam is situated at the distance of almost 11.10 km from the Maheshkhali Channel of Bay of Bengal (BoB) to the upward. Generally, the down part of the river from the dam to the Maheshkhali Channel of Bay of Bengal (BoB) is considered as the downstream zone of the Bakkhali river. The upper part of the river from the dam to the Ramu-Mariccha road connecting bridge is considered as the upstream zone of the Bakkhali river.

3.1.1. Sampling Locations

From 26.40 km long study area of the Bakkhali river, the downstream zone is almost 11 km and the upstream zone is almost 15 km in length. Randomly selected 16 locations (7 locations from the downstream zone and 9 locations from the upstream zone) were used to collect data. So, we selected a total of 16 locations throughout the study area.

Table 06: Sampling Locations and their Distance from the Dam.

No.	Sampling Location	Distance from the Dam to the Locations (km)
	Downstream Zone (from Dam to Maheshkhali Channel, BoB)	
01	Pata Sadar Para	0.85
02.	S. M. Para	2.28
03.	Gudar Para	4.59
04.	Khurushkul Bridge	5.69
05.	Kastura Ghat	7.08
06.	Nuniar Chara	9.04
07.	Maheshkhali Channel	11.05
	Upstream Zone (from Dam to Shikolghat, Rajarkul)	
08.	Chandu Para	0.2
09.	North Muhuripara	2.2
10.	Muktarkul	3.85
11.	West Muktarkul	4.98
12.	Darga Para (Kharulia)	6.94
13.	South Mithachari (Umkhali)	9.04
14.	Muijerdwip (Chakmarkul)	11.98
15.	Shikdar Para (Rajarkul)	13.87
16.	Shikolghat (Rajarkul)	15.39

As we said, the Rabar dam is situated in the middle of our whole study area of the Bakkhali river. It is divided the study area into two (02) separate zone. One is downstream zone and another one is the upstream zone. So, we conducted our data collection process in two (02) specific phase.

Figure 3.3: Sampling Locations of Downstream Zone, Bakkhali River. (own illustration by using google earth pro)

We conducted our first phase of the data collection process in the downstream zone. We started this data collection process phase from the Rabar dam and ended it at the Maheshkhali Channel of the Bay of Bengal (BoB). So, in the downstream zone, we conducted downward data collection from the Rabar dam to the Maheshkhali Channel. This zone consists of nine (07) sampling locations.

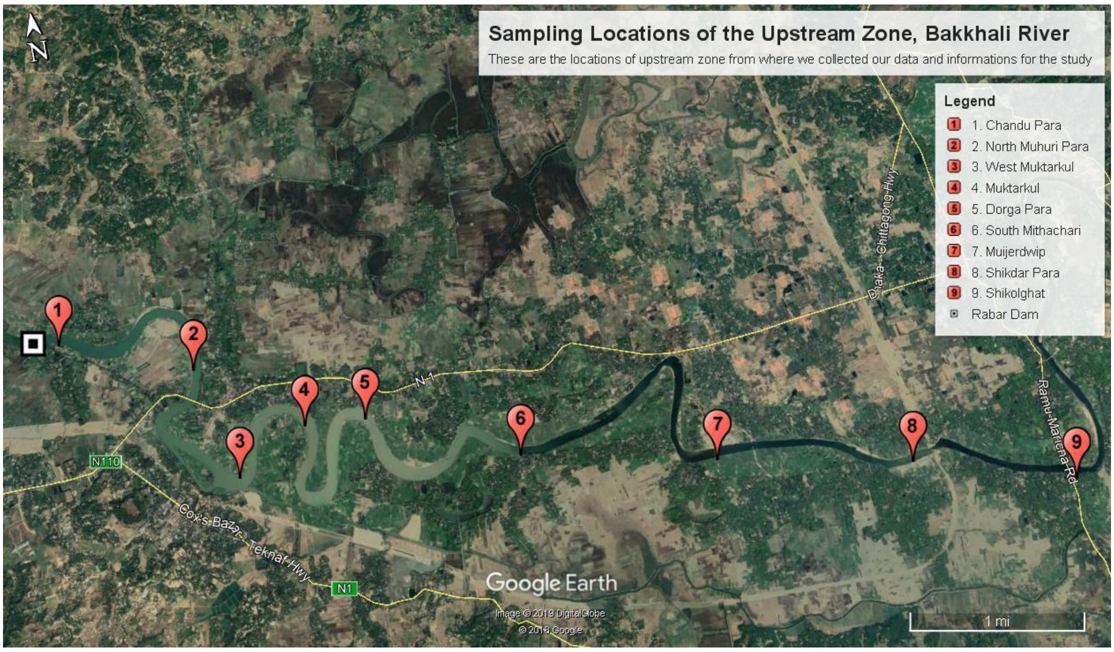


Figure 3.4: Sampling Locations of Upstream Zone, Bakkhali River. (own illustration by using google earth pro)

We conducted our second phase of the data collection process in the upstream zone. We started the data collection process phase from the Rabar dam (Chandu Para) and ended it at the Ramu-Mariccha road connecting bridge over the Bakkhali river (the last sampling location of our study area and the place is known as Shikolghat). So, in the upstream zone, we conducted the upward data collection from the Rabar dam (Chandu Para) to the Shikolghat. This zone consists of seven (09) sampling locations.

Due to some inconvenience, we couldn't maintain the exact distance between the sampling locations in both downstream and upstream zone. Although, we tried to keep a distance between the sampling locations that are not too far or not too close.

3.2. Data Collection Techniques of the Study

To collect and analyze the data here we implemented both qualitative and quantitative tactics on this study. Although, the study widely focuses on primary data collection through various data collection techniques in the sixteen (16) sampling location. The secondary data mainly has been assembled by evaluating various research papers or scientific research papers. So, the data collection techniques of this study have been structured according to the following framework:

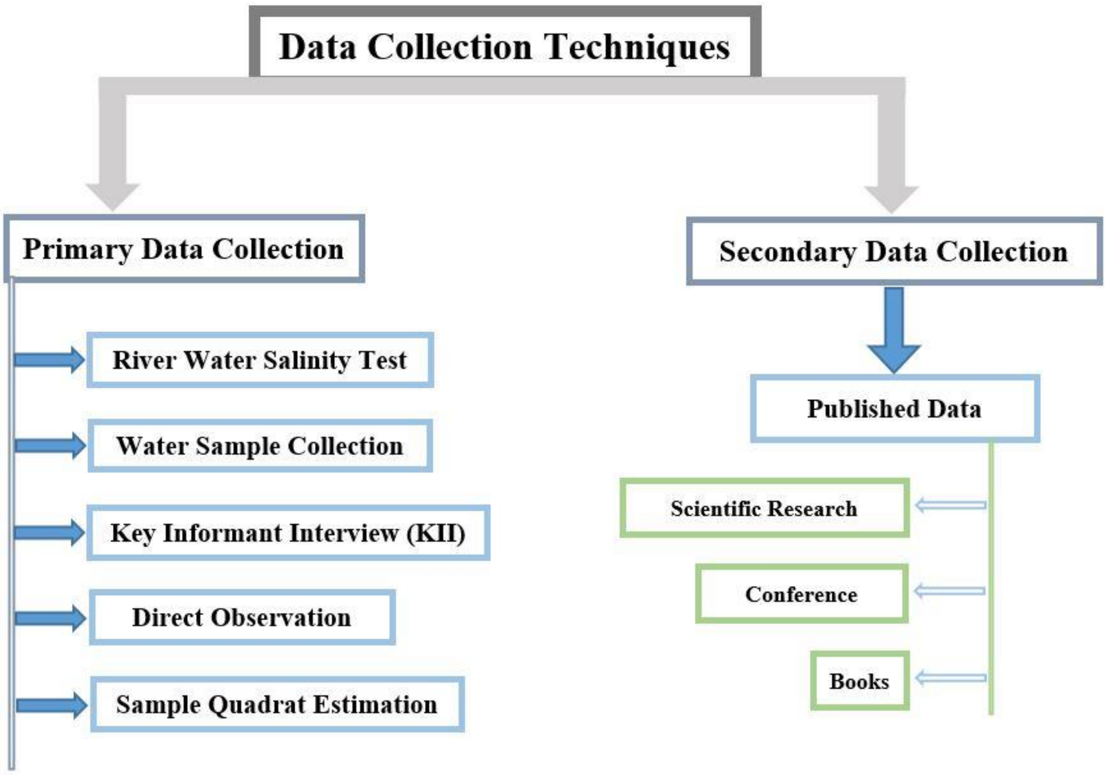


Figure 3.5: Data Collection Techniques of the Study. (own illustration)

The literature review of the secondary data sources helps us to understand the present salinity status of the coastal rivers of Bangladesh. It also helps us to identify the causes and impacts of river salinity on coastal Bangladesh.

3.2.1. River Water Salinity Test

In a specific sampling location, we collect water from four different spots of the river. Then we mixed these collected waters and measured the salinity of that water directly in that location using the portable salinity refractometer. We repeated the procedure in every 16 sampling locations to measure the water salinity of the Bakkhali river.

3.2.2. Water Sample Collection

In a specific sampling location, we separately collected 50 ml of water from four different spots of the river. Then we mixed these collected waters in a 250 ml water collection bottle. We repeated the procedure in every 16 sampling locations of the Bakkhali river.

We labeled the 16 sample water bottles and safely kept them for further analysis in the laboratory. Finally, we brought the water samples to the Environmental Science and Disaster Management (ESDM) Laboratory of Daffodil International University (DIU).

3.2.3. Key Informant Interviews (KII)

KII is a qualitative approach of data collection with the experts or peoples who exactly know about an issue (Taylor & Renner, 2003). Here, we used this technique to collect some rigorous information about salinity and its impact on local plant diversity throughout the study area. We selected two key informants from those local government organizations that are related to our study. We also selected two local people who consist of rigorous information about the local surrounding of the study area. The age of the two local people is above 45 years.

Table 07: List of Selected Individuals for the Key Informant Interviews (KII).

Category	Organization / Village	Individuals
Local Government	Department of Environment, Cox's Bazar	**Saiful Asrab** Assistant Director
	Forest Department, South, Cox's Bazar	**Md. Humayun Kabir** Divisional Forest Officer
Local People	Chandu Para, Rabar Dam Pump House	**Md. Selim** Controller, Age – 45
	Gudar Para	**Mrs. Marzan Begum** Age – 70

The interview was taken face to face as a discussion based on a semi-structured questionnaire. The informative comments of them also taken into consideration.

3.2.4. Direct Observation

With the test of water salinity of the Bakkhali river, we also tried to observe the environmental condition of every place around the sampling locations. We walked almost the whole study area throughout the Bakkhali river. We tried to observe the surrounding environment of the study area to identify any consequences or issues that are important for our study and tried to find out some issues that could be an issue for further work particularly.

We also tried to capture the existing environmental surroundings, the identified consequences or issues and other important phenomena that are important in terms of our study. In every sampling location, we also talked with the local people to understand their approach to the water salinity and its impact on local plant diversity throughout the study area of the Bakkhali river.

3.2.5. Sample Quadrat Estimation

In a sampling location, we selected a $4m^2$ plot in the riverside, within the range of 50 m from the river water salinity test spots. The plot is known as a quadrat (Odum, 1969). Now, we identified the existing plant species in the plot. Then we estimated the number of individuals for one plant species in the plot. We separately repeated the technique for all 16 sampling locations. We implemented the technique using the following table:

Table 08: Sample Tabulation Sheet for Sample Quadrat Estimation.

Sampling Quadrat ($4m^2$) Location 01: **Pata Sadar Para**	
Plant Species	**n (Number of Individuals)**
Acacia auriculiformis	~~IIII~~ I (6)
Gossypium arboreum	III (3)
Syzygium cumini	I (1)
Erythrina fusca	III (3)
Areca catechu	III (3)

3.3. Data Analysis

We measured the river water salinity, estimated the sampling quadrat, collected water samples and conducted four key informant interviews. So, the collected data have been analyzed according to the following framework:

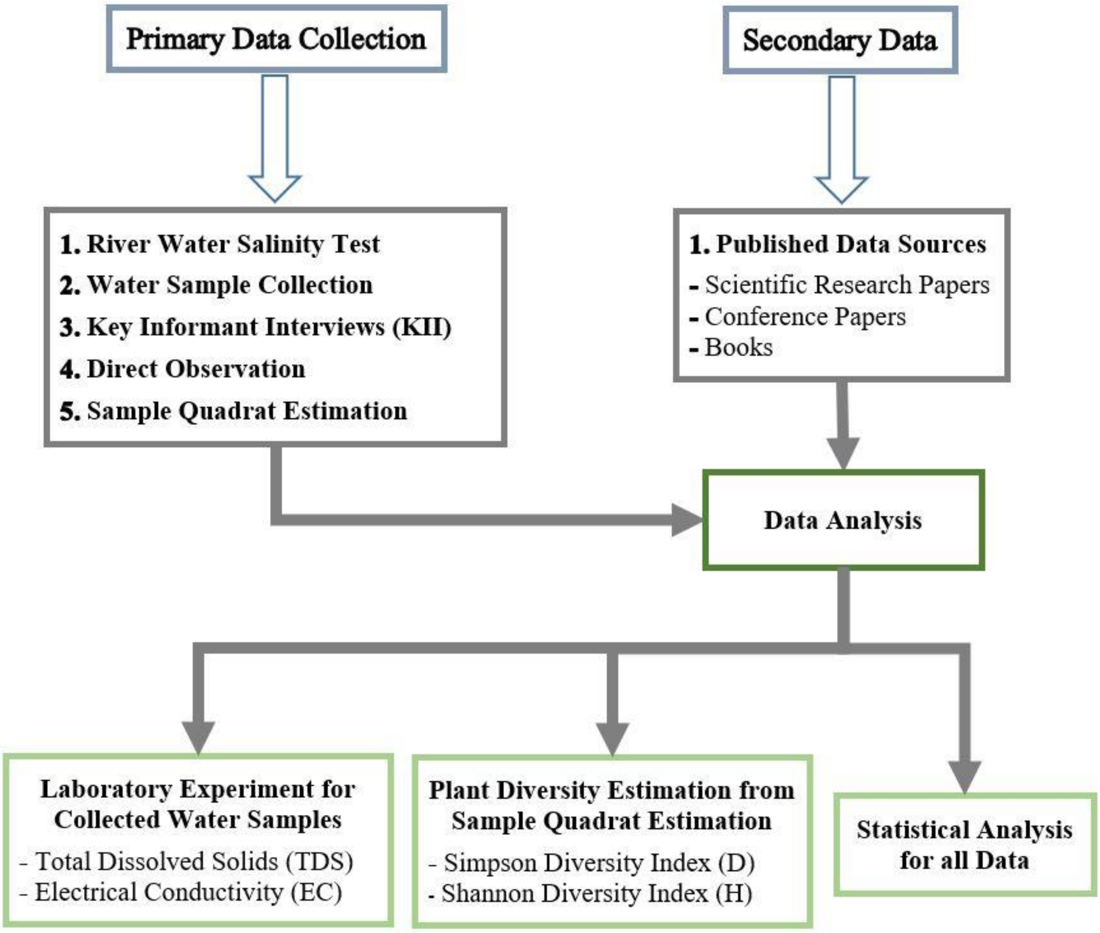


Figure 3.6: Structured Framework for Data Analysis. (own illustration)

Analysis and interpretation of qualitative data have been done through the following steps constructed by (Taylor & Renner, 2003), that are:

i. Explore the knowledge of the data
ii. Give focus on the analysis of the data
iii. Compile and categorization of the information

3.3.1. Laboratory Experiment

This study conducted to explore the status and variation of water salinity level between the downstream zone and the upstream zone of the Bakkhali. Collected water samples from all the 16 locations where we conducted the test to measure the water salinity of the Bakkhali river.

Both Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were analyzed separately from the water samples collected from the 16 sampling locations. This experiment was taking place in the Environmental Science and Disaster Management (ESDM) Laboratory of Daffodil International University (DIU), Ashulia, Savar.

HANNA Ph/EC/TDS/Temperature Meter (HI9814) used to measure the TDS value of the 16- water sample separately. *HANNA* EC Tester (HI98304) used to measure the EC value of the 16- water sample separately. The water samples that were consisting of above 60 ppt salinity, they were diluted 8 times before the lab test to get the value within the existing range of the equipment.

3.3.2. Plant Diversity Estimation

Diversity indexing is a mathematical measurement that estimates the species diversity of a given area or a community. The more species an area or a community have, the more diverse the area or the community. Normally, there are two types of diversity indexing (Odum, 1969). These are –

3.3.2.1. Simpson Diversity Index (D)

Simpson diversity index is a kind of dominance index as it gives more and more weight to common and dominance species. The main feature of this index system is that a few rare species with a few individuals will not affect the overall diversity of an area (Simpson, 1949). So, the equation is –

$$\boldsymbol{D = 1 \Big/ \sum_{i=1}^{s} P_i^2}$$

Where, D = Simpson Diversity; P_i = Proportion of (n/N); n = Individuals of one species; N = Total number of all species individuals; Σ = Sum of the calculations.

3.3.2.2. Shannon Diversity Index (H)

Shannon diversity index is a widely used information statistic index by which all species are represented in a sample and samples are collected randomly (Shannon & Weaver, 1963). So, the equation is –

$$\boldsymbol{H = \sum_{i=1}^{s} -(P_i \times \ln P_i)}$$

Where, H = Shannon Diversity; P_i = Proportion of (n/N); n = Individuals of one species; N = Total number of all species individuals; ln = Natural log; Σ = Sum of the calculations.

3.3.2.3. Estimation Procedure

In every place, we selected a plot in the riverside within the range of 50 m of river water salinity test spots. The selected plots were a quadrat of $4m^2$ area. So, each of the 16 plots was a quadrat of $4m^2$ area. Then we identified the existing plant species and find out the number of individuals for one plant species in every single plot of a quadrat. Later we calculated the diversity for a specific quadrat plot using the equation or formula of both Simpson Diversity Index (D) and Shannon Diversity Index (H) by the following estimation procedure –

Table 09: Diversity Estimation Procedure by Using both Simpson (D) and Shannon (H) Diversity Index.

Sampling Location (01): **Pata Sadar Para**					
Plant Species	**n**	**$n/N = P_i$**	**P_i^2**	**$\ln P_i$**	**$P_i \times \ln P_i$**
Acacia auriculiformis	6	0.375	0.140	-0.980	-0.367
Gossypium arboreum	3	0.230	0.053	-1.469	-0.338
Syzygium cumini	1	0.062	0.003	-2.772	-0.171
Erythrina fusca	3	0.230	0.053	-1.469	-0.338
Areca catechu	3	0.230	0.053	-1.469	-0.338
N = 16		**$\Sigma P_i^2 = 0.302$**		**$\Sigma P_i \times \ln P_i = -1.552$**	
$\boldsymbol{D = 1 \Big/ \sum_{i=1}^{s} P_i^2}$		$\boldsymbol{D = 1/0.302}$		**D = 3.311**	
$\boldsymbol{H = \sum_{i=1}^{s} -(P_i \times \ln P_i)}$		$\boldsymbol{H = -(-1.552)}$		**H = 1.552**	

We repeated this procedure for other 16 sampling locations separately. By following this procedure, we were able to estimate the plant diversity of every sampling locations throughout the study area of the Bakkhali river.

3.3.3. Statistical Analysis

First, we compile and organize the data in Microsoft Excel. Then we checked it out to avoid any kind of data missing or errors in the excel sheet that we input. Now, using Microsoft Excel, data has been investigated to find out the correlation coefficient and regression between the variables. T-test also is done also to prove the hypothesis of the study that was assumed.

3.4. Instrumental Techniques

To the successful completion of this study, we used various materials. We used three separate instruments to measure the river water salinity, total dissolved solids, and electrical conductivity. We used one google product for mapping. We used a tool to identify the geographical position of the places. We used one modeling software that helps us to make the various maps. We used statistical software to analyze the collected data.

Table 10: Used Instruments, Tool, and Software's to Conduct the Study.

Category	Parameters	Name or Model
Instruments	Water Salinity	Portable Salinity Refractometer
	TDS	*HANNA* Ph/EC/TDS/Temperature Meter (HI9814)
	EC	*HANNA* EC Tester (HI98304)
Tool	Navigation	Garmin eTrex® 10 (GPS Navigation Device)
Software's	Mapping	ArcGIS 10.2.1
		Google Earth Pro
	Statistics	Microsoft Excel 2016

So, these are the materials that we used during our study to collect, measure and analysis of the collected data.

Table 11: Major Characteristics of the Instruments.

Instruments	Characteristics Category	
	Range	Resolution
HANNA pH/EC/TDS/Temperature Meter (HI9814)	0 to 3999 ppm	10 ppm
HANNA EC Tester (HI98304)	0.00 to 20.00 mS/cm	0.01 mS/cm
Portable Salinity Refractometer	0 to 100 %	20 %

CHAPTER 4: RESULT AND DISCUSSION

This chapter broadly discusses the findings and results of our study in a different form. At the beginning of this research project, we have assumed three different objectives and we worked on it. Here, in this chapter, we tried to get a well-organized understanding of the objectives by analyzing the collected data and findings in different ways. So, this chapter of result and discussion divided into five (05) different sections. The sections are –

4.1. Study Findings

In this section, we tried to show all our findings and results that we observed from the beginning to the end of this research study. Here we tried to demonstrate the status of salinity, measured TDS and EC from the water samples that were collected from the sampling locations of the study area. Status of plant diversity also shown here throughout the study area, in both the upstream zone and downstream zone of the Bakkhali river, Cox's Bazar.

In the downstream zone, we've shown the measured river water salinity, TDS, EC, and estimated plant diversity according to the downward distance from the Rabar dam to the Maheshkhali Channel of the Bay of Bengal. In the upstream zone, we've shown the measured river water salinity, TDS, EC, and estimated plant diversity according to the upward distance from Rabar dam (Chandu Para) to the inland hilly areas or Ramu-Mariccha road connecting bridge over the Bakkhali river (Shikolghat, Rajarkul). We directly measured river water salinity in places. We measured the TDS and EC of water samples by laboratory experiment and we estimated the plant diversity using both Simpson (D) and Shannon (H) diversity index.

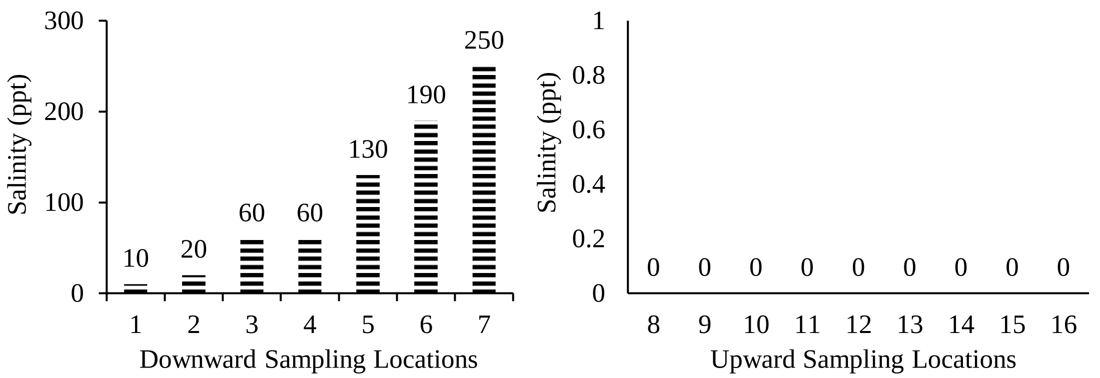
4.1.1. Salinity

In the downstream zone, river water salinity increases with the increase of downward distance from Rabar dam to the Maheshkhali Channel of the Bay of Bengal (Gain et al., 2014; Petersen & Shireen, 2001). In the upstream zone, measured river water salinity was zero (0) in every sampling locations of that zone. Though we measured the river water salinity in nine (09) sampling locations of the upstream zone, we were not finding any salinity in the water of that upstream zone of the Bakkhali river. So, river water salinity is much higher in the downstream zone and zero (0) in the upstream zone.

Table 12: Measured Salinity at the Sampling Locations (SL) of the Study Area.

Downstream Zone				
#	*Sl.*	*Downward Distance of SL from Dam to the BoB (km)*	*Location Name*	*Salinity (ppt)*
Sampling Locations	*01*	0.85	Pata Sadar Para	10
	02	2.28	S. M. Para	20
	03	4.59	Gudar Para	60
	04	5.69	Khurushkul Bridge	60
	05	7.08	Kastura Ghat	130
	06	9.04	Nuniarchara	190
	07	11.05	Maheshkhali Channel	250
Upstream Zone				
#	*Sl.*	*Upward Distance of SL from Dam to the Inland Hills (km)*	*Location Name*	*Salinity (ppt)*
Sampling Locations	*08*	0.2	Chandu Para	0
	09	2.2	North Muhuri Para	0
	10	3.85	West Muktarkul	0
	11	4.98	Muktarkul	0
	12	6.94	Dorga Para (Kharulia)	0
	13	9.04	South Mithachari(Umkhali)	0
	14	11.98	Muijerdwip (Chakmarkul)	0
	15	13.87	Shikdar Para (Rajarkul)	0
	16	15.39	Shikolghat (Rajarkul)	0

10 ppt salinity measured at the 0.85 km downward distance from the dam to the Bay of Bengal. The name of the location is Pata Sadar Para. 20 ppt, 60 ppt, 60 ppt, 130 ppt and 190 ppt salinity measured at the 2.28 km, 4.59 km, 5.69 km, 7.08 km and 9.04 km downward distance from the dam to the BoB respectively. Highest 250 ppt salinity measured at the Maheshkhali Channel of the Bay of Bengal. Maheshkhali Channel is the transition point between the BoB and the Bakkhali river.



(a) **(b)**

Figure 4.1: Status of Salinity in the Water of the Bakkhali River, (a) Downstream Zone, (b) Upstream Zone.

So, the status of water salinity in the Bakkhali river is –

a) In the downstream zone, 250 ppt is the highest and 10 ppt is the lowest value of water salinity. Salinity increases from 10 ppt to 250 ppt with the increase of the downward distance of sampling locations from the dam to the BoB.
b) In the upstream zone of the Bakkhali river, salinity is not existing at all. Measured salinity is zero (0) in all sampling points or locations.

4.1.2. Total Dissolved Solids (TDS)

During the laboratory experiment we diluted (08 times) some samples to get the TDS value within the range (0 to 3999 ppm) of the used TDS Meter (*HANNA* Ph/EC/TDS/Temperature Meter - HI9814) (Corwin & Yemoto, 2017). We diluted the water samples of those sampling locations that contain salinity up to 50 ppt. The sampling locations are Gudar Para, Khurushkul Bridge, Kastura Ghat, Nuniar Chara and the Maheshkhali Channel of the Bay of Bengal.

Table 13: Measured TDS at the Sampling Locations (SL) of the Study Area.

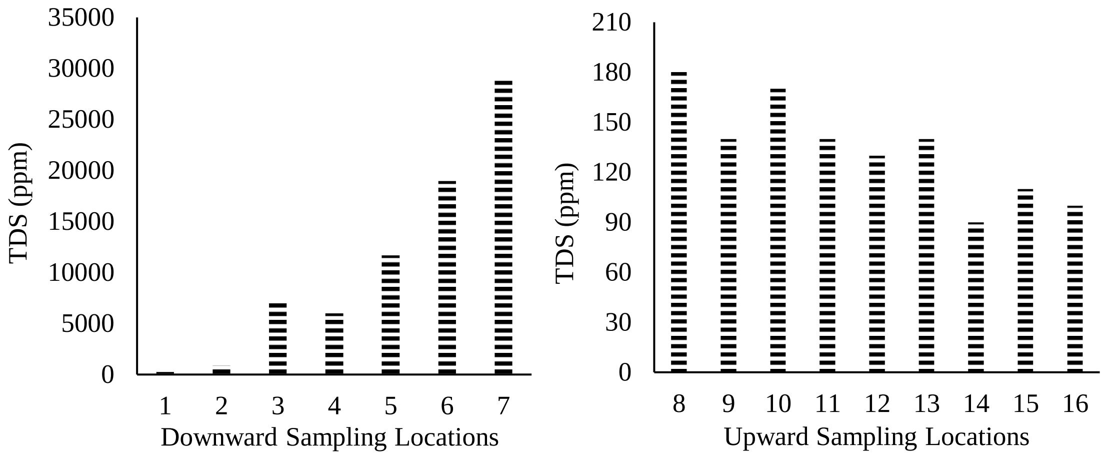
Downstream Zone

#	*Sl.*	*Downward Distance of SL from Dam to the BoB (km)*	*Location Name*	*TDS (ppm)*
Sampling Locations	*01*	0.85	Pata Sadar Para	240
	02	2.28	S. M. Para	870
	03	4.59	Gudar Para	7200
	04	5.69	Khurushkul Bridge	6000
	05	7.08	Kastura Ghat	11680
	06	9.04	Nuniarchara	18960
	07	11.05	Maheshkhali Channel	28800

Upstream Zone

#	*Sl.*	*Upward Distance of SL from Dam to the Inland Hills (km)*	*Location Name*	*TDS (ppm)*
Sampling Locations	*08*	0.2	Chandu Para	180
	09	2.2	North Muhuri Para	140
	10	3.85	West Muktarkul	170
	11	4.98	Muktarkul	140
	12	6.94	Darga Para (Kharulia)	130
	13	9.04	South Mithachari(Umkhali)	140
	14	11.98	Muijerdwip (Chakmarkul)	90
	15	13.87	Shikdar Para (Rajarkul)	110
	16	15.39	Shikolghat (Rajarkul)	100

In the downstream zone, the TDS increases with the increase of the downward distance from the dam to the BoB or increase of water salinity towards the Bay of Bengal from the dam. Here, the highest TDS value is 28,800 ppm at the Maheshkhali Channel of the Bay of Bengal. The lowest TDS value is 240 in Pata Sadar Para, the downward edge of the dam. So, like salinity, the value of TDS also higher in the downstream zone of the study area.



(a) **(b)**

Figure 4.2: Status of TDS in the Bakkhali River, (a) Downstream Zone, (b) Upstream Zone.

In the upstream zone, measured river water salinity was zero (0) in every sampling location. Though, we measured the TDS of the collected water samples from the sampling locations of the upstream zone. So, in the measured TDS values, all the values are almost the same or close to one another. But the fact is, TDS decreases with the increase of upward distance from the Rabar dam (Chandu Para) to the inland hilly areas (Ramu-Mariccha road connecting bridge over Bakkhali river, Shikolghat, Rajarkul). Here, the highest TDS value is 180 at Chandu Para, the upward edge of the dam. The lowest TDS value is 90 at Muijerdwip (Chakmarkul). In the upstream zone, all TDS values are close to each other and all the values are within 90 ppm-180 ppm. On the other hand, in the downstream zone, 240 ppm is the lowest TDS value.

We did not dilute the water samples of the upstream zone to measure the TDS value within the range of the instruments. Due to the zero (0) salinity of the river water of the upstream zone, the TDS value of the sampling locations remains lower and relatively close to each other. So, in the upstream zone, TDS values tend to be lower due to the zero (0) salinity in all sampling locations.

4.1.3. Electrical Conductivity (EC)

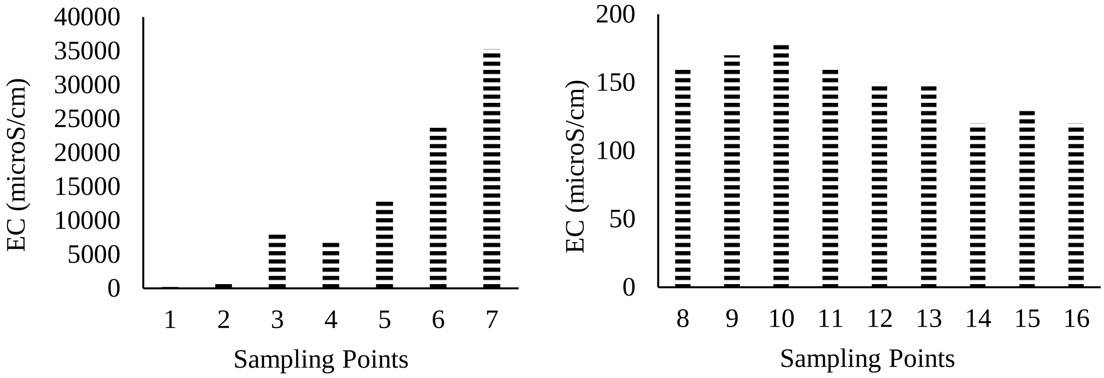
During the laboratory experiment, we diluted (08 times) five samples to get the value of EC within the range (0.00 to 20.00 mS/cm) of the used EC Tester (*HANNA* EC Tester – HI98304) (Corwin & Yemoto, 2017). We diluted the water samples of those sampling locations that contain salinity up to 50 ppt. The sampling locations are Gudar Para, Khurushkul Bridge, Kastura Ghat, Nuniarchara and the Maheshkhali Channel of the Bay of Bengal.

Table 14: Measured EC at the Sampling Locations (SL) of the Study Area.

Downstream Zone				
#	*Sl*	*Downward Distance of SL from Dam to the BoB (km)*	*Location Name*	*EC (µS/cm)*
Sampling Locations	*01*	0.85	Pata Sadar Para	220
	02	2.28	S. M. Para	720
	03	4.59	Gudar Para	8160
	04	5.69	Khurushkul Bridge	6800
	05	7.08	Kastura Ghat	13200
	06	9.04	Nuniarchara	23680
	07	11.05	Maheshkhali Channel	35280
Upstream Zone				
#	*Sl*	*Upward Distance of SL from Dam to the Inland Hills (km)*	*Location Name*	*EC (µS/cm)*
Sampling Locations	*08*	0.2	Chandu Para	160
	09	2.2	North Muhuri Para	170
	10	3.85	West Muktarkul	180
	11	4.98	Muktarkul	160
	12	6.94	Darga Para (Kharulia)	150
	13	9.04	South Mithachari(Umkhali)	150
	14	11.98	Muijerdwip (Chakmarkul)	120
	15	13.87	Shikdar Para (Rajarkul)	130
	16	15.39	Shikolghat (Rajarkul)	120

In the downstream zone, the EC increases with the increase of the downward distance from the dam to the BoB or increase of water salinity towards the Bay of Bengal from the dam. Here, the highest EC value is 35,280 µS/cm at the Maheshkhali Channel of the Bay of Bengal. The lowest EC value is 220 µS/cm in Pata Sadar Para, the downward edge of the dam. So, like salinity and TDS, the value of EC also higher in the downstream zone of the study area.

In the upstream zone, measured river water salinity was zero (0) in every sampling point or location. Though, we measured the EC of the collected water samples from the sampling points of the upstream zone. So, in the measured EC values, all the values are almost the same or close to one another. But the fact is, EC decreases with the increase of upward distance from the Rabar dam (Chandu Para) to the inland hilly areas (Ramu-Mariccha road connecting bridge over Bakkhali river, Shikolghat, Rajarkul). Here, the highest EC value is 180 µS/cm at West Muktarkul, sampling location number ten (10). The lowest EC value is 120 µS/cm at Muijerdwip (Chakmarkul) and Shikolghat (Rajarkul). In the upstream zone, all EC values are close to each other and all the values are within 180 µS/cm – 120 µS/cm. On the other hand, in the downstream zone, 220 µS/cm is the lowest EC value.



(a) **(b)**

Figure 4.3: Status of EC in the Bakkhali River, (a) Downstream Zone, (b) Upstream Zone.

Like TDS, we did not dilute the water samples of the upstream zone to measure the EC value within the range of the instruments. Due to the zero (0) salinity of the river water of the upstream zone, the EC value of the sampling locations remains lower and relatively close to each other. So, in the upstream zone, EC values tend to be lower due to the zero (0) salinity in all sampling locations.

4.1.4. Plant Diversity

We also estimated the plant diversity and show the estimated plant diversity according to the all sampling locations of the study area. In the downstream zone, we estimated the plant diversity according to the downward distance of sampling locations from Rabar dam to the Maheshkhali Channel of the Bay of Bengal. In the upstream zone, we estimated the plant diversity according to the upward distance of sampling locations from Rabar dam (Chandu Para) to the Ramu-Mariccha road connecting bridge over Bakkhali river (Shikolghat, Rajarkul). We calculate the plant diversity for every sampling location using both the Simpson Diversity Index (D) and Shannon Diversity Index (H) formula or equation respectively.

4.1.4.1. Simpson Diversity Index (D)

In the downstream zone, we estimated plant diversity according to the downward distance of the sampling locations from the dam to the Maheshkhali Channel of the Bay of Bengal. The diversity decreases with the increase of the downward distance of sampling locations from the dam to the Maheshkhali Channel (Gain et al., 2014). In the downstream zone, the highest plant diversity exists in S. M. Para, second or number two sampling location of our study area. This plant diversity consequently decreases with the increase of downward distance from the dam to the Maheshkhali Channel of the Bay of Bengal.

Table 15: Estimated Plant Diversity using the Simpson Diversity Index (D) at the Sampling Locations (SL) of the Study Area.

Downstream Zone

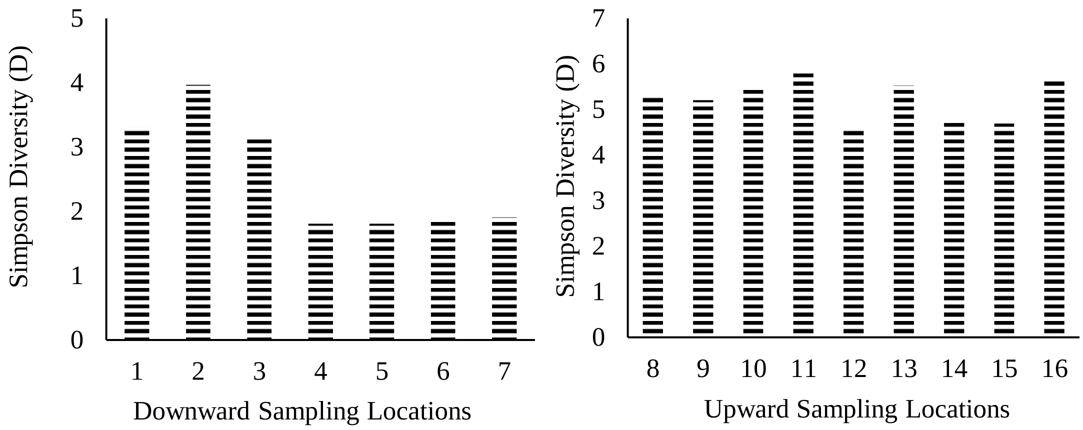
#	Sl.	*Downward Distance of SL from Dam to the BoB (km)*	*Location Name*	*Diversity (D)*
Sampling Locations	*01*	0.85	Pata Sadar Para	**3.311**
	02	2.28	S. M. Para	**3.968**
	03	4.59	Gudar Para	**3.125**
	04	5.69	Khurushkul Bridge	**1.808**
	05	7.08	Kastura Ghat	**1.808**
	06	9.04	Nuniarchara	**1.856**
	07	11.05	Maheshkhali Channel	**1.905**

Upstream Zone

#	Sl.	*Upward Distance of SL from Dam to the Inland Hills (km)*	*Location Name*	*Diversity (D)*
Sampling Locations	*08*	0.2	Chandu Para	**5.291**
	09	2.2	North Muhuri Para	**5.208**
	10	3.85	West Muktarkul	**5.494**
	11	4.98	Muktarkul	**5.848**
	12	6.94	Dorga Para (Kharulia)	**4.608**
	13	9.04	South Mithachari (Umkhali)	**5.525**
	14	11.98	Muijerdwip (Chakmarkul)	**4.762**
	15	13.87	Shikdar Para (Rajarkul)	**4.694**
	16	15.39	Shikolghat (Rajarkul)	**5.634**

In the downstream zone, 3.311 diversity estimated at the 0.85 km downward distance from the dam to the Bay of Bengal. The name of the location is Pata Sadar Para, the number one sampling location of the study area. 3.968 (highest in the downstream zone), 3.125, 1.808, 1.808, 1.856, 1.905 diversity estimated at the 2.28 km, 4.59 km, 5.69 km, 7.08 km, 9.04 km, and 11.05 km downward distance from the dam to the Bay of Bengal respectively. Higher salinity is a major cause of low diversity in the downstream zone. Due to that, diversity decreases gradually with the increase in river water salinity in the downstream zone.

In the upstream zone, 5.848 (highest) plant diversity estimated at Muktarkul, the upward distance of Muktarkul is 4.98 km from the dam to the inland. 4.608 (lowest in the upstream zone) plant diversity estimated at Dorgapara (Kharulia), which is the next sampling location of Muktarkul. In the upstream zone, all the value of Simpson diversity (D) is close to each other and all values are almost similar. Here, all estimated diversity values are placed within the range of 4.608 – 5.848. On the other hand, 3.968 is the highest estimated plant diversity in the downstream zone of the Bakkhali river.



(a) (b)

Figure 4.4: Status of Plant Diversity using Simpson Diversity Index (D) in the Bakkhali River, (a) Downstream Zone, (b) Upstream Zone.

According to the Simpson diversity index (D), the status of plant diversity around the Bakkhali river is –

a) In the downstream zone of the Bakkhali river, 3.968 is the highest and 1.808 is the lowest value of plant diversity. Plant diversity decreases gradually with the increase of the downward distance of sampling locations from the dam to the Bay of Bengal (BoB).

b) In the upstream zone of the Bakkhali river, 5.848 is the highest and 4.608 is the lowest value of plant diversity. All the values of plant diversity in the upstream zone are close to each other and almost similar.

4.1.4.1. Shannon Diversity Index (H)

In the downstream zone, we estimated plant diversity according to the downward distance of the sampling locations from the dam to the Maheshkhali Channel of the Bay of Bengal (BoB). The diversity decreases with the increase of the downward distance of sampling locations from the dam to the Maheshkhali Channel (Gain et al., 2014). In the downstream zone, the highest plant diversity exists in S. M. Para, second or number two sampling location of our study area. This plant diversity consequently decreases with the increase of the downward distance of sampling locations from the dam to the Maheshkhali Channel of the Bay of Bengal (BoB).

Table 16: Estimated Plant Diversity using the Shannon Diversity Index (H) at the Sampling Locations (SL) of the Study Area.

Downstream Zone

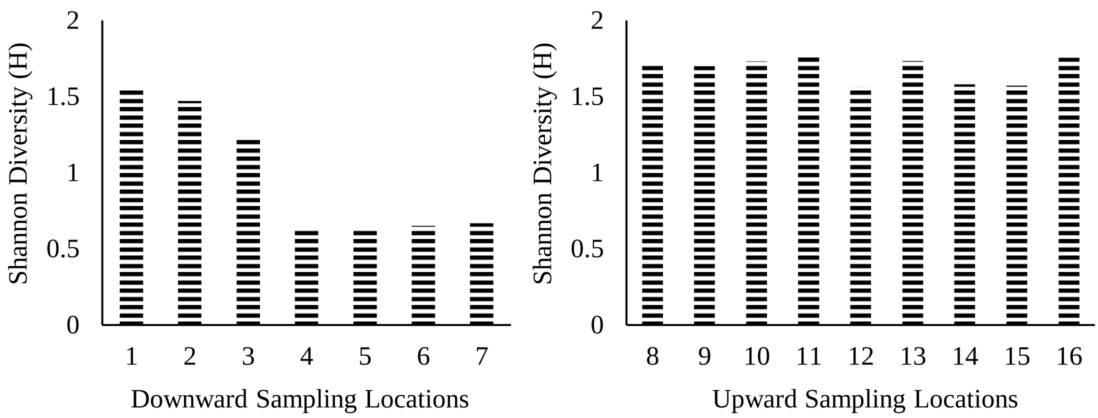
#	*Sl.*	*Downward Distance of SL from Dam to the BoB (km)*	*Location Name*	*Diversity (H)*
Sampling Locations	*01*	0.85	Pata Sadar Para	**1.552**
	02	2.28	S. M. Para	**1.472**
	03	4.59	Gudar Para	**1.237**
	04	5.69	Khurushkul Bridge	**0.635**
	05	7.08	Kastura Ghat	**0.635**
	06	9.04	Nuniarchara	**0.651**
	07	11.05	Maheshkhali Channel	**0.668**

Upstream Zone

#	*Sl.*	*Upward Distance of SL from Dam to the Inland Hills (km)*	*Location Name*	*Diversity (H)*
Sampling Locations	*08*	0.2	Chandu Para	**1.707**
	09	2.2	North Muhuri Para	**1.701**
	10	3.85	West Muktarkul	**1.731**
	11	4.98	Muktarkul	**1.767**
	12	6.94	Dorga Para (Kharulia)	**1.564**
	13	9.04	South Mithachari (Umkhali)	**1.735**
	14	11.98	Muijerdwip (Chakmarkul)	**1.58**
	15	13.87	Shikdar Para (Rajarkul)	**1.573**
	16	15.39	Shikolghat (Rajarkul)	**1.754**

In the downstream zone, the highest 1.552 diversity estimated at the 0.85 km downward distance from the dam. The name of the location is Pata Sadar Para. 1.472, 1.237, 0.635, 0.635, 0.651, 0.668 diversity estimated at the 2.28 km, 4.59 km, 5.69 km, 7.08 km, 9.04 km and 11.05 km downward distance from dam respectively. Higher salinity is a major cause of low diversity in the downstream zone. Due to that, diversity decreases gradually with the increase in river water salinity in the downstream zone.

In the upstream zone, 1.767 (highest) plant diversity estimated at Muktarkul, the upward distance of Muktarkul is 4.98 km from the dam to the inland. 1.564 (lowest in the upstream zone) plant diversity estimated at Dorgapara (Kharulia), which is the next sampling location of Muktarkul. In the upstream zone, all the value of Shannon diversity (H) is close to each other and all values are almost similar. Here, all estimated diversity values are placed within the range of 1.564 – 1.767. On the other hand, 1.552 is the highest estimated diversity in the downstream zone of the Bakkhali river.



(a) **(b)**

Figure 4.5: Status of Diversity using the Shannon Diversity Index (H) in the Bakkhali River, (a) Downstream Zone, (b) Upstream Zone.

According to the Shannon diversity index (H), the status of plant diversity around the Bakkhali river is –

a) In the downstream zone, 1.552 is the highest and 0.635 is the lowest value of plant diversity. Plant diversity decreases gradually with the increase of the downward distance of sampling locations from the dam to the Bay of Bengal.
b) In the upstream zone, 1.767 is the highest and 1.564 is the lowest value of plant diversity. All the values of plant diversity in the upstream zone are close to each other and almost similar.

So, according to the both Simpson (D) and Shannon (H) diversity index, the plant diversity status of the downstream zone and upstream zone of the Bakkhali river is –

a) In the downstream zone of the Bakkhali river, plant diversity is relatively lower than the upstream zone. Also, plant diversity decreases with the increase of the downward distance of sampling locations from the dam to the Bay of Bengal.
b) In the upstream zone of the Bakkhali river, plant diversity much higher than the downstream zone. Also, plant diversity values of sampling locations are close to each other and relatively similar.

4.2. Salinity (Downstream Zone Vs. Upstream Zone)

In the downstream zone, salinity gradually increases with the increase of the downward distance of sampling locations from the dam to the Maheshkhali Channel of the BoB.

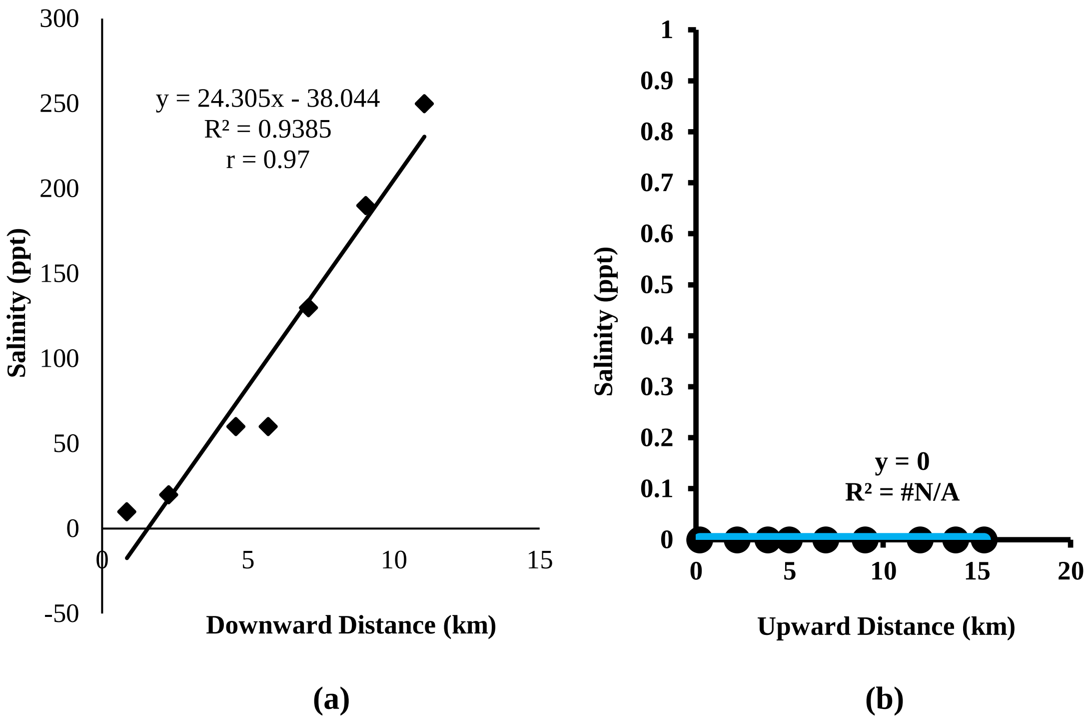


Figure 4.6: Relation between Salinity and Distance, (a) Salinity Vs. Downward Distance, (b) Salinity Vs. Upward Distance.

Figure 4.6 (a) shows the relationship between the salinity and downward distance of sampling locations from the dam to the BoB. In the figure, the linear trendline represented the correlation coefficient between the salinity and downward distance. Here, the value of correlation coefficient (r) is 0.97. That means, it represented almost a perfect positive or a strong positive relationship between the salinity and downward distance. As the downward distance increases from the dam to the BoB, the salinity tends to increase. Regarding the strength of the relationship, the figure shows that it's a very strong relationship where the data points strongly hug the linear trendline. It's an amorphous blob with a very high correlation.

Figure 4.6 (b) shows the relationship between the salinity and the upward distance of sampling locations from the dam to the inland hilly areas. In the figure, the linear trendline represented the correlation coefficient between the salinity and the upward distance. Here, the value of the correlation coefficient (r) is zero. That means it's representing no relationship between the salinity and the upward distance. As one value increases, there is no tendency for the other values to change in a specific direction.

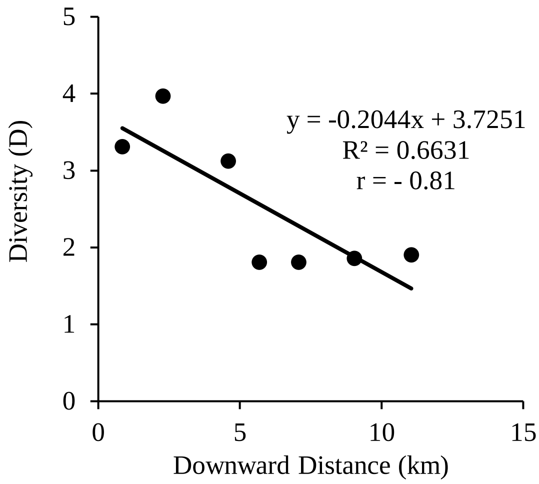
So, there is a huge variation exists for salinity between the downstream zone and the upstream zone of the Bakkhali river. In the downstream zone, salinity gradually increases with the increase of downward distance from the dam to the Bay of Bengal. Also, the downstream zone of the Bakkhali river is consisting of a high amount of salinity in the river water. On the other hand, there is no sign of salinity in the upstream zone of the Bakkhali river.

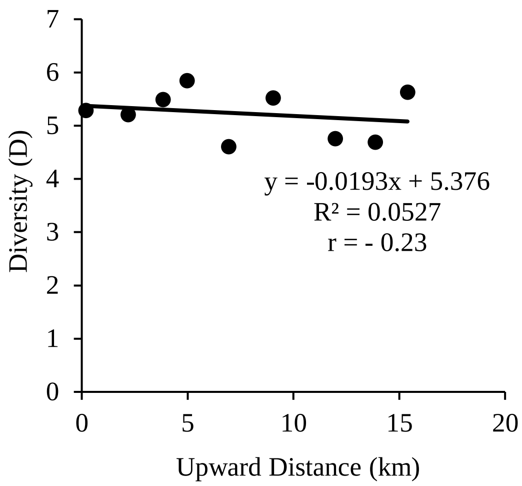
4.3. Plant Diversity (Downstream Zone Vs. Upstream Zone)

Here we have shown the variation of plant diversity in the downstream zone and the upstream zone of the Bakkhali river. We estimated the plant diversity in both the Simpson Diversity Index (D) and Shannon Diversity Index (H) for every single sampling location or each 16-sample quadrat.

4.3.1. Simpson Diversity Index (D)

Figure 4.7 (a) shows the relationship between the diversity (D) and downward distance of sampling locations from the dam to the Bay of Bengal. In the figure, the linear trendline represented the correlation coefficient between the salinity and downward distance. Here, the value of correlation coefficient (r) is - 0.81. That means it is represented as a strong negative relationship between diversity (D) and downward distance. As downward distance increases, the diversity (D) tends to decrease. Regarding the strength of the relationship, the figure shows that it's a negative strong relationship where the data points almost strongly hug the linear trendline. It's an amorphous blob with a very fair correlation.





(a) **(b)**

Figure 4.7: Relation between Diversity (D) and Distance (a) Downward Distance of Sampling Locations from Dam to BoB, (b) Upward Distance of Sampling Locations from Dam to the Inland Hilly Areas.

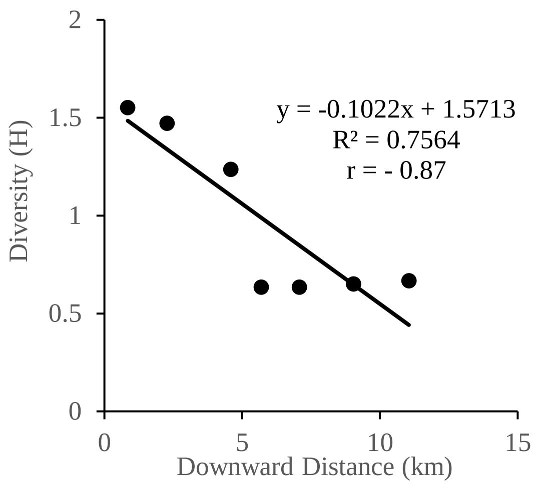
Figure 4.7 (b) shows the relationship between the Diversity (D), and the upward distance of sampling locations from the dam to the inland hilly areas. In the figure, the linear trendline represented the correlation coefficient between the salinity and the upward distance. Here, the value of correlation coefficient (r) is - 0.23 That means, it's represented the weak negative relationship between the diversity (D) and the upward distance.

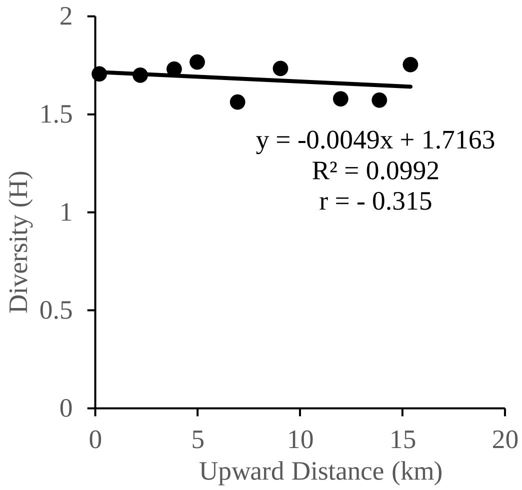
So, there is a huge variation exists for diversity (D) between the downstream zone and the upstream zone of the Bakkhali river. In the downstream zone, diversity (D) gradually decreases with the increase of downward distance from the dam to the Bay of Bengal. Also, the downstream zone of the Bakkhali river is consisting of a low value of diversity (D). On the other hand, the upstream zone of the Bakkhali river is consisting of a weak negative correlation.

In the downstream zone, the highest and lowest diversity (D) value is 3.968 and 1.808 respectively. In the upstream zone, 5.848 and 4.608 is the highest and lowest diversity (D) value.

4.3.2. Shannon Diversity Index (H)

Figure 4.8 (a) shows the relationship between the diversity (H) and downward distance from the dam to the Bay of Bengal. In the figure, the linear trendline represented the correlation coefficient between the salinity and downward distance. Here, the value of correlation coefficient (r) is - 0.87. That means, it represented a strong negative relationship between the diversity (H) and downward distance. As downward distance increases, the diversity (H) tends to decrease. Regarding the strength of the relationship, the figure shows that it's a negative strong relationship where the data points almost strongly hug the linear trendline. It's an amorphous blob with a very fair correlation.





(a) **(b)**

Figure 4.8: Relation between Diversity (H) and Distance (a) Downward Distance of Sampling Locations from Dam to BoB, (b) Upward Distance of Sampling Locations from Dam to the Inland Hilly Areas.

Figure 4.8 (b) shows the relationship between the Diversity (H), and the upward distance from the dam to the inland hilly areas. In the figure, the linear trendline represented the correlation coefficient between the salinity and the upward distance. Here, the value of correlation coefficient (r) is - 0.315 That means, it's represented the weak negative relationship between the diversity (H) and the upward distance.

So, there is a huge variation exists for diversity (H) between the downstream zone and the upstream zone of the Bakkhali river. In the downstream zone, diversity (H) gradually decreases with the increase of downward distance from the dam to the Bay of Bengal. Also, the downstream zone of the Bakkhali river is consisting of a low value of diversity (H). On the other hand, the upstream zone of the Bakkhali river is consisting of a weak negative correlation. In the downstream zone, the highest and lowest diversity (H) value is 1.552 and 0.635 respectively. In the upstream zone, 1.767 and 1.564 is the highest and lowest diversity (H) value.

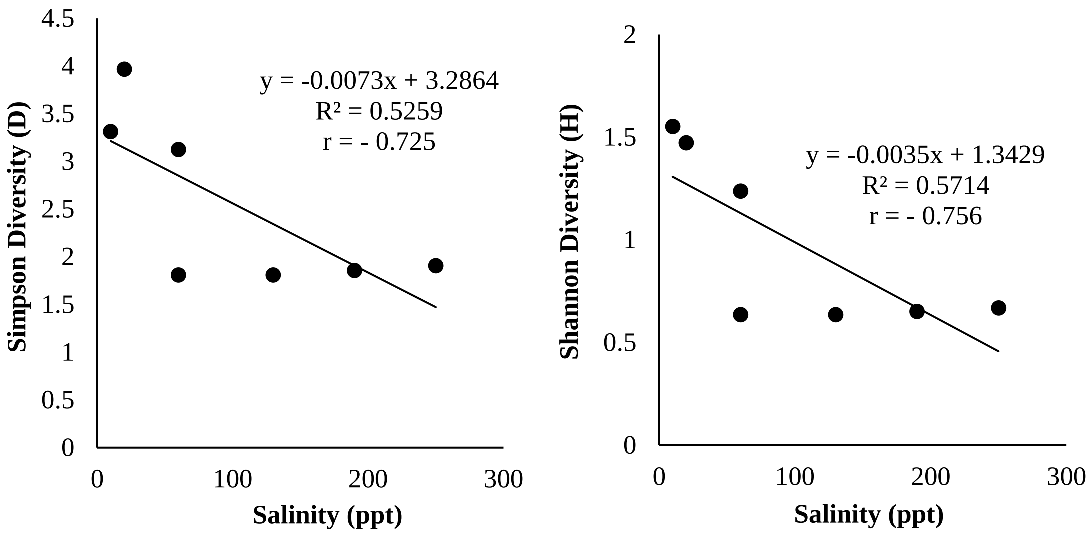
So, in the downstream zone of the Bakkhali river, both Simpson (D) and Shannon (H) diversity value are lower for the plants. But, in the upstream zone of the Bakkhali river, both Simpson (D) and Shannon (H) diversity value are much higher for the plants than the downstream zone. That means the downstream zone of the Bakkhali river is a weak and upstream zone of the Bakkhali river is rich in plant diversity.

4.4. Impact of Water Salinity on Plant Diversity

Here we tried to investigate the impact of water salinity on plant diversity in both the downstream and the upstream zone of the Bakkhali river. We used both the Simpson (D) and Shannon diversity index (H). We investigated the impact using correlation regression formula in Microsoft Excel (Gain et al., 2014; Briggs & Taws, 2003).

4.4.1. Downstream Zone

If we observe the figure 4.9 (a) and (b) we can easily understand the relationship between salinity and plant diversity in both Simpson (D) and Shannon (H) diversity index. Plant diversity decreases as the salinity increases in the downstream zone.



(a) **(b)**

Figure 4.9: Impact of Salinity in Plant Diversity of the Bakkhali River (Downstream Zone), (a) Simpson Diversity Index (D), (b) Shannon Diversity Index (H).

Both figures show the negative relation between salinity and plant diversity in the downstream zone. Both linear trendlines are similar and represented a negative correlation between salinity and plant diversity. So, the value of correlation coefficient (r) is – 0.725 for Simpson (D) and – 0.756 for Shannon (H) diversity index.

That means, in the downstream zone, both trendlines show the negative (fairly) relationship where diversity decreases as the salinity increases towards the Bay of Bengal (BoB) from the Dam.

4.4.2. Upstream Zone

In the upstream zone of the Bakkhali river, the pattern of plant diversity is almost the same or close to each other in both Simpson (D) and Shannon (H) diversity index. We didn't observe any significant changes in the pattern of plant diversity throughout the upstream zone.

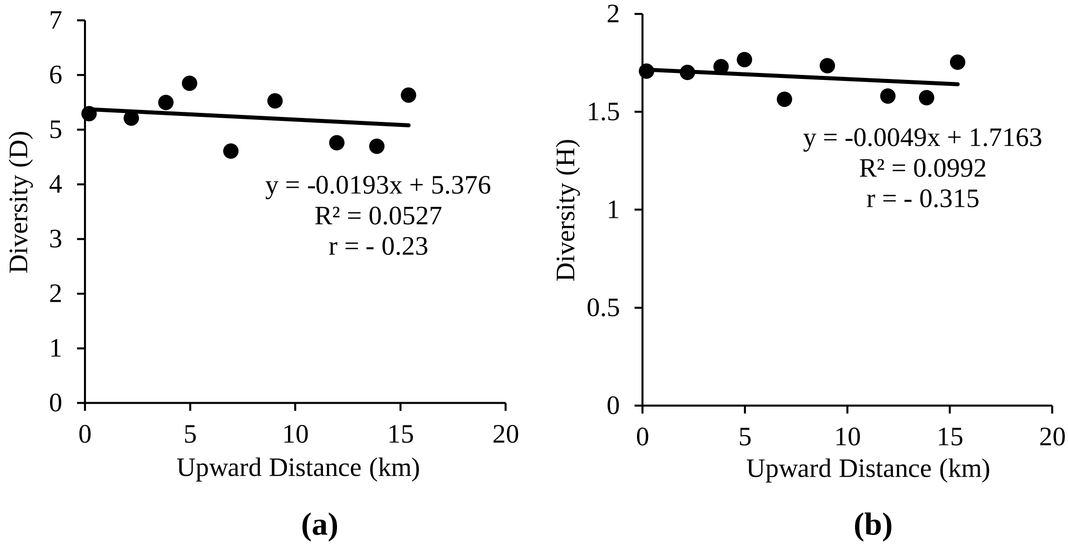


Figure 4.10: Plant Diversity in Upstream Zone of the Bakkhali River, (a) Simpson (D) Diversity Index, (b) Shannon (H) Diversity Index.

In Figure 4.10 (a) and (b), both linear trendline is almost flat and represented no relation between the diversity and salinity or any other phenomena. That means, in the upstream zone, there is no factor exist at all for the changes in plant diversity pattern.

Although, we identified the reasons behind the very slight changes in plant diversity pattern in the upstream zone. So, the reasons are –

a. Immense riverbank erosion
b. Restrained population settlement
c. Excessive agricultural activity near the riverbank
d. Excessive cropping of tobacco in the riverside of the Ramu Upazila
e. A huge amount of agricultural field (acres to acres) in both sides of the river

These are the major reasons for the very slight changes in the plant diversity pattern in the upstream zone of the Bakkhali river.

4.5. T-test Analysis of Water Salinity Impact

In both Simpson (D) and Shannon (H) diversity index, the p-value (t-test value) between water salinity and plant diversity of the downstream zone is in below $p < 0.5$. That means, in the downstream zone, a significant difference exists between water salinity and plant diversity.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

In this final chapter of the study, I tried to assemble all study points from the literature review, data collection, data analysis, result, and discussions. Here, we also tried to justify the objectives of the study. Recommendations are also given for the researchers in order to better understanding of the future study. This chapter divided into two part.

5.1. Recommendations

Here, I tried to give certain recommendations that are informative and valuable based on a few facts or criteria. Such as –

a. Study limitations
   - The local language of Cox's Bazar is very tough to understand in any way. You always must be patient on this issue.
   - You will not get adequate water transport facilities wherever you need. So, you must have to be aware of that.
   - Sometimes, a significant difference can be existing between the water of the riversides. So, you must have to conscious and aware of the proper parameter measurement or collection of the water from both sides of a river.

b. Study outcomes or understandings
   - The Maheshkhali Channel and the transition point between the Bakkhali river and Bay of Bengal (BoB) could be the most valuable estuarine zone of our country. For that, the government should have to think about that.
   - The government easily can extend the range of mangrove forest in our country by the cropping of salt-tolerant mangrove plants in the very downstream zone of the Bakkhali river.
   - Due to the immense increase of salinity in the downstream zone of the Bakkhali river, local faunal species are migrating or dying. Simply, they become extinct day by day.

c. Future study on this coastal region of Bangladesh
   - Always try to give priority to the very local people's knowledge and understanding of the surrounding environment.

- Further research work could be done on the control of salinity in the downstream zone of the Bakkhali river and Impact on fisheries resources of the Bakkhali river.

So, these are the major points of recommendations of this study from the beginning to till the end of the study.

5.2. Conclusion

In the Bakkhali river, the downstream zone is a highly saline zone and the upstream zone is a zone with almost zero (0) salinity. In the downstream zone, salinity gradually increases with the increase of the downward distance of the sampling locations from the Rabar Dam to the Maheshkhali Channel of the Bay of Bengal (BoB). So, here we can see a huge difference in water salinity between downstream zone and the upstream zone of the Bakkhali river.

In the downstream zone of the Bakkhali river, plant diversity gradually decreases with the increase in water salinity. Because of that, the pattern of plant diversity is not well distributed throughout the downstream zone. On the other hand, in the upstream zone of the Bakkhali river, plant diversity pattern is almost similar and very close to each other in all sampling locations of the upstream zone. Because of that, the plant diversity pattern of the upstream zone is well distributed throughout the upstream zone. So, well-distributed plant diversity pattern is existing in the upstream zone of the Bakkhali river. The pattern of plant diversity is not well distributed at the downstream zone of the Bakkhali river being the high saline zone.

In the downstream zone of the Bakkhali river, plant diversity decreases with the increase of salinity towards the Maheshkhali Channel of the Bay of Bengal (BoB) from the Rabar Dam. In the upstream zone, there is no impact of salinity observed on the local plant diversity.

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Appendix – I

Diversity Estimation Tables for Simpson (D) & Shannon (H) Diversity Index

⇒ **Downstream Zone**

Sampling Location (01): **Pata Sadar Para**					
Plant Species	**n**	**$n/N = P_i$**	**P_i^2**	**$\ln P_i$**	**$P_i \times \ln P_i$**
Acacia auriculiformis	6	0.375	0.140	-0.980	-0.367
Gossypium arboreum	3	0.230	0.053	-1.469	-0.338
Syzygium cumini	1	0.062	0.003	-2.772	-0.171
Erythrina fusca	3	0.230	0.053	-1.469	-0.338
Areca catechu	3	0.230	0.053	-1.469	-0.338
N = 16		**$\Sigma P_i^2 = 0.302$**		**$\Sigma P_i \times \ln P_i = -1.552$**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.302$		**D = 3.311**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.552)$		**H = 1.552**	

Sampling Location (02): **S. M. Para**					
Plant Species	**n**	**$n/N = P_i$**	**P_i^2**	**$\ln P_i$**	**$P_i \times \ln P_i$**
Cocos nucifera	5	0.384	0.147	-0.957	-0.367
Gossypium arboreum	2	0.153	0.023	-1.877	-0.287
Erythrina fusca	2	0.153	0.023	-1.877	-0.287
Acacia auriculiformis	3	0.230	0.053	-1.466	-0.337
Artocarpus heterophyllus	1	0.076	0.006	-2.564	-0.194
N = 13		**$\Sigma P_i^2 = 0.252$**		**$\Sigma P_i \times \ln P_i = -1.472$**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.252$		**D = 3.968**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.472)$		**H = 1.472**	

Sampling Location (03): **Gudar Para**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**P_i × ln P_i**
Ficus benghalensis	2	0.181	0.032	-1.709	-0.309
Areca catechu	5	0.454	0.206	-0.789	-0.358
Erythrina fusca	1	0.090	0.008	-2.407	-0.216
Artocarpus heterophyllus	3	0.272	0.074	-1.301	-0.354
N = 11		**Σ P_i^2 = 0.32**		**Σ P_i × ln P_i = -1.237**	
$D = 1/\sum_{i=1}^{s} P_i^2$		$D = 1/0.32$		**D = 3.125**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.237)$		**H = 1.237**	

Sampling Location (04): **Khurushkul Bridge**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**P_i × ln P_i**
Acacia auriculiformis	10	0.666	0.443	-0.406	-0.270
Samanea saman	5	0.333	0.110	-1.098	-0.365
N = 15		**Σ P_i^2 = 0.553**		**Σ P_i × ln P_i = -0.635**	
$D = 1/\sum_{i=1}^{s} P_i^2$		$D = 1/0.553$		**D = 1.808**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-0.635)$		**H = 0.635**	

Sampling Location (05): **Kastura Ghat**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**P_i × ln P_i**
Sonneratia apetala	8	0.666	0.443	-0.406	-0.270
Avicennia species	4	0.333	0.110	-1.098	-0.365
N = 12		**Σ P_i^2 = 0.553**		**Σ P_i × ln P_i = -0.635**	
$D = 1/\sum_{i=1}^{s} P_i^2$		$D = 1/0.553$		**D = 1.808**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-0.635)$		**H = 0.635**	

Sampling Location (06): **Nuniarchara**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Acacia auriculiformis	2	0.222	0.049	-1.504	-0.334
Samanea saman	5	0.555	0.308	-0.587	-0.326
Cocos nucifera	2	0.222	0.049	-1.504	-0.334
N = 9		**$\Sigma P_i^2 = 0.406$**		**$\Sigma P_i \times \ln P_i = -0.994$**	
$D = 1/\sum_{i=1}^{s} P_i^2$		$D = 1/0.406$		**D = 2.463**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-0.994)$		**H = 0.994**	

Sampling Location (07): **Maheshkhali Channel**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Sonneratia apetala	11	0.611	0.373	-0.492	-0.300
Avicennia species	7	0.388	0.151	-0.944	-0.367
N = 18		**$\Sigma P_i^2 = 0.524$**		**$\Sigma P_i \times \ln P_i = -0.668$**	
$D = 1/\sum_{i=1}^{s} P_i^2$		$D = 1/0.524$		**D = 1.905**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-0.668)$		**H = 0.668**	

⇒ **Upstream Zone**

Sampling Location (08): **Chandu Para**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Erythrina fusca	2	0.181	0.033	-1.704	-0.308
Acacia auriculiformis	3	0.272	0.074	-1.299	0.353
Samanea saman	2	0.181	0.033	-1.704	-0.308
Syzygium cumini	1	0.09	0.008	-2.397	-0.215
Anthocephalus indicus	1	0.09	0.008	-2.397	-0.215
Ladum Gula Tree	2	0.181	0.033	-1.704	-0.308
N = 11		**$\Sigma P_i^2 = 0.189$**		**$\Sigma P_i \times \ln P_i = -1.707$**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.189$		**D = 5.291**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.707)$		**H = 1.707**	

Sampling Location (09): **North Muhuri Para**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Samanea saman	1	0.071	0.005	-2.639	-0.187
Acacia auriculiformis	2	0.142	0.02	-1.945	-0.276
Erythrina fusca	2	0.142	0.02	-1.945	-0.276
Areca catechu	4	0.285	0.081	-1.252	-0.357
Cocos nucifera	3	0.214	0.046	-1.54	-0.329
Anthocephalus indicus	2	0.142	0.02	-1.945	-0.276
N = 14		**$\Sigma P_i^2 = 0.192$**		**$\Sigma P_i \times \ln P_i = -1.701$**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.192$		**D = 5.208**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.701)$		**H = 1.701**	

Sampling Location (10): **West Muktarkul**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Bam Tree	2	0.111	0.012	-2.197	-0.243
Acacia auriculiformis	5	0.277	0.077	-1.28	-0.354
Samanea saman	3	0.166	0.027	-1.791	-0.297
Syzygium cumini	3	0.166	0.027	-1.791	-0.297
Cocos nucifera	2	0.111	0.012	-2.197	-0.243
Tectona grandis	3	0.166	0.027	-1.791	-0.297
N = 18		**Σ P_i^2 = 0.182**		**Σ $P_i \times \ln P_i$ = -1.731**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.182$		**D = 5.494**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.731)$		**H = 1.731**	

Sampling Location (11): **Muktarkul**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Erythrina fusca	3	0.2	0.04	-1.609	-0.321
Rhizophora apiculata	3	0.2	0.04	-1.609	-0.321
Gossypium arboreum	2	0.133	0.017	-2.014	-0.268
Swietenia mahagoni	3	0.2	0.04	-1.609	-0.321
Bam Tree	2	0.133	0.017	-2.014	-0.268
Samanea saman	2	0.133	0.017	-2.014	-0.268
N = 15		**Σ P_i^2 = 0.171**		**Σ $P_i \times \ln P_i$ = -1.767**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.171$		**D = 5.848**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.767)$		**H = 1.767**	

Sampling Location (12): **Darga Para (Kharulia)**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Cocos nucifera	3	0.1875	0.035	-1.674	-0.314
Mangifera indica	3	0.1875	0.035	-1.674	-0.314
Gossypium arboreum	2	0.125	0.015	-2.079	-0.259
Areca catechu	5	0.3125	0.097	-1.163	-0.363
Samanea saman	3	0.1875	0.035	-1.674	-0.314
N = 16		**$\Sigma P_i^2 = 0.217$**		**$\Sigma P_i \times \ln P_i = -1.564$**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.217$		**D = 4.608**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.564)$		**H = 1.564**	

Sampling Location (13): **South Mithachari**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Rhizophora apiculata	2	0.154	0.023	-1.871	-0.288
Samanea saman	2	0.154	0.023	-1.871	-0.288
Bam Tree	2	0.154	0.023	-1.871	-0.288
Swietenia mahagoni	3	0.23	0.053	-1.466	-0.337
Gossypium arboreum	1	0.077	0.006	-2.565	-0.197
Erythrina fusca	3	0.23	0.053	-1.466	-0.337
N = 13		**$\Sigma P_i^2 = 0.181$**		**$\Sigma P_i \times \ln P_i = -1.735$**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.181$		**D = 5.525**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.735)$		**H = 1.735**	

Sampling Location (14): **Muijerdwip**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Erythrina fusca	4	0.25	0.0625	-1.386	-0.346
Acacia auriculiformis	4	0.25	0.0625	-1.386	-0.346
Swietenia mahagoni	3	0.1875	0.035	-1.674	-0.314
Ficus (Fig Trees)	2	0.125	0.015	-2.08	-0.26
Bam Tree	3	0.1875	0.035	-1.674	-0.314
N = 16		**$\Sigma P_i^2 = 0.21$**		**$\Sigma P_i \times \ln P_i = -1.58$**	
$D = 1/\sum_{i=1}^{s} P_i^2$		$D = 1/0.21$		**D = 4.762**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.58)$		**H = 1.58**	

Sampling Location (15): **Shikdar Para**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Bam Tree	3	0.214	0.046	-1.54	-0.33
Gossypium arboreum	2	0.143	0.02	-1.946	-0.278
Acacia auriculiformis	4	0.285	0.081	-1.252	-0.357
Areca catechu	3	0.214	0.046	-1.54	-0.33
Barringtonia acutangula	2	0.143	0.02	-1.946	-0.278
N = 14		**$\Sigma P_i^2 = 0.213$**		**$\Sigma P_i \times \ln P_i = -1.573$**	
$D = 1/\sum_{i=1}^{s} P_i^2$		$D = 1/0.213$		**D = 4.694**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.573)$		**H = 1.573**	

Sampling Location (16): **Shikolghat**					
Plant Species	**n**	**n/N = P_i**	**P_i^2**	**ln P_i**	**$P_i \times \ln P_i$**
Samanea saman	2	0.125	0.015	-2.08	-0.26
Areca catechu	4	0.25	0.0625	-1.386	-0.346
Acacia auriculiformis	3	0.1875	0.035	-1.674	-0.314
Swietenia mahagoni	2	0.125	0.015	-2.08	-0.26
Ziziphus mauritiana	2	0.125	0.015	-2.08	-0.26
Ficus (Fig Trees)	3	0.1875	0.035	-1.674	-0.314
N = 16		**ΣP_i^2 = 0.1775**		**$\Sigma P_i \times \ln P_i$ = -1.754**	
$D = 1 \Big/ \sum_{i=1}^{s} P_i^2$		$D = 1/0.1775$		**D = 5.634**	
$H = \sum_{i=1}^{s} -(P_i \times \ln P_i)$		$H = -(-1.754)$		**H = 1.754**	

Appendix – II

Photographs

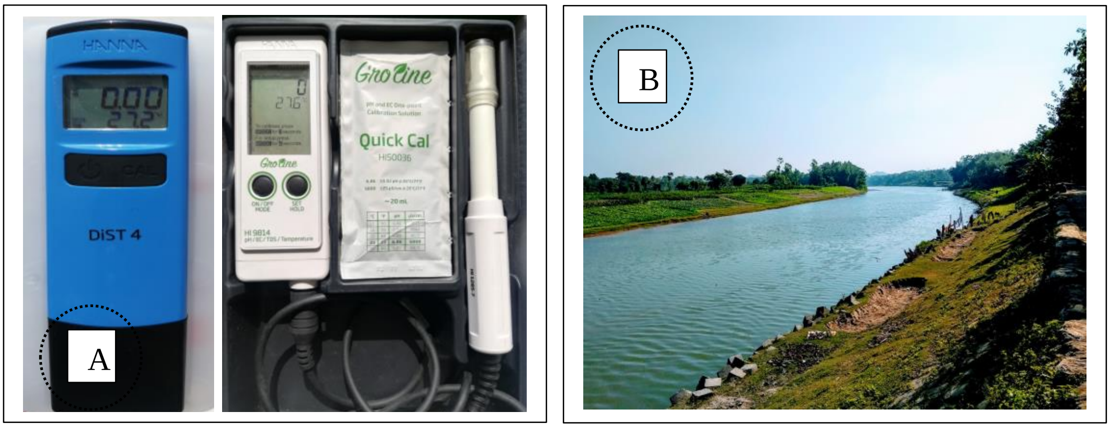
Photographs: (A) Transition point between Bakkhali river and Bay of Bengal, (B) Measuring the water salinity of the Maheshkhali Channel

Photographs: (A) Calibrating the portable salinity refractometer, (B) Identifying the water salinity in refractometer (Chandu Para).

Photographs: (A) Collecting the water samples in Kastura Ghat, (B) Collecting the water samples in Gudar Para.

Photographs: (A) Collected 16 water samples, (B) Collected water samples and the tools and equipment's of the study. (in Environmental Science and Disaster Management Laboratory of Daffodil International University)

Photographs: (A) Collected water samples and the tools and equipment's of the study in Environmental Science and Disaster Management Laboratory of Daffodil International University, (B) Portable Salinity Refractometer and its range of measurement.



Photographs: (A) The EC Meter (blue) and The TDS Meter (white), (B) The Bakkhali river at South Mithachari.