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Impacts of Climate Change on Water Quality in Selected Coastal Areas of Bangladesh

Serder, Md. Ferog

University of Rajshahi

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IMPACTS OF CLIMATE CHANGE ON WATER QUALITY IN SELECTED COASTAL AREAS OF BANGLADESH



A Thesis Submitted to the Institute of Environmental Science, University of Rajshahi as Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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FEBRUARY 2020

Dedicated to
Md. Abdul Barek Serder
&
Feroja Begum
My beloved Parents, the Best Wisher

DECLARATION

I declare that the thesis entitled “**IMPACTS OF CLIMATE CHANGE ON WATER QUALITY IN SELECTED COASTAL AREAS OF BANGLADESH**” is an original research work. It is submitted to the Institute of Environmental Science (IES), University of Rajshahi, Bangladesh for achieving the degree of Doctor of Philosophy in the field of Environmental Science.

I further declare that the manuscript of the thesis is quite unique and has not been submitted in parts or full previously for the award of any other degree or diploma in any institution. It is my belief that the research contains no material previously published or written by another person, except where due reference has made in the text of the thesis.

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CERTIFICATE



This is to certify the thesis entitled “**IMPACTS OF CLIMATE CHANGE ON WATER QUALITY IN SELECTED COASTAL AREAS OF BANGLADESH**” is an original research work carried out by Md. Ferog Serder, Reg. No.1613086510 session: 2015-16, Institute of Environmental Science, RU under our direct supervision and submitted to the Institute of Environmental Science, University of Rajshahi for partial fulfilment of the requirements of the degree of Doctor of Philosophy.

We are forwarding the thesis to examine for the degree of Doctor of Philosophy in the Institute of Environmental Science (IES), University of Rajshahi, Bangladesh. The primary data presented in the thesis are generated through the research work at the Laboratory of IES and Central Science Lab of the University of Rajshahi, and BCSIR Lab, Rajshahi. The secondary data used in the thesis have been collected from the Bangladesh Meteorological Department, Bangladesh Water Development Board, Soil Research Development Institute, Dhaka which have been acknowledged accordingly. The Fellow has fulfilled all the requirements for the Doctor of Philosophy imposed by the University of Rajshahi.

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MD. FEROG SERDER

ABSTRACT

A hydro-meteorological study was conducted at Kalapara Upazila in Patuakhali District to assess the impacts of climate change on water quality in coastal areas of Bangladesh. Some secondary meteorological data of Khepupara (now Kalapara) station from 1975 to 2017 from BMD and mean sea level and salinity data of few decades from BWDB, SRDI, and PSMSL have been collected for the present study. The water samples from the selected estuaries, rivers, canals, ponds, and tube-wells have also been collected during the pre-monsoon, monsoon, and post-monsoon seasons of 2016 and 2017. Some major water quality parameters, including water temperature, DO, pH, EC, TDS, TSS, Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Fe, Cu, Pb, Mn, As, Zn, Cl⁻, SO_4^{2-} , NO_3^- , HCO_3^- and PO_4^{3-} were analyzed and the interpretation was made to determine the present water quality of the area using various diagrams, indices, formulas, and graphs.

The meteorological data showed significant positive increasing trends of annual average temperature, relative humidity, and rainfall. The annual average temperature increased to 0.7°C, and the projected trend line is likely to raise 1.2°C by the year 2050. The study estimated that the projected relative humidity and rainfall would be increased by 6.6 % and 234.7 cm, respectively, by the same period. The available secondary tide gauge data of four stations named the Cox's Bazar, Khepupara, Hiron point, and Diamond Harbor were assessed and found a positive increasing trend. The higher increasing trend was observed at Khepupara station of the study area. The results showed that the water level of the Khepupara station would raise to 1.35 m by the year 2050. The EC level of the Andhermanik river increased 2.54 ds/m from 2000 to 2015 and will be increased by 8.09 ds/cm by the year 2050.

The water samples of the estuaries, rivers, and canals showed a higher salinity during the pre- and post-monsoon seasons. The results showed higher EC, TDS, and TSS values during the dry seasons. The major ions, including Na^+ , K^+ , Cl⁻, SO_4^{2-} , and HCO_3^- exceeded the permissible limit of the DoE, WHO, and FAO standards during the pre- and post-monsoon periods. The study observed the dominant water type during the pre- and post-monsoon periods was Na-Cl, whereas a mixed water type, Na-Cl-HCO₃, was found in the monsoon period.

The study evaluated the water quality for specific uses such as irrigation, domestic, and drinking purposes. The water quality of the estuaries, rivers, and canals was found to be poor to unfit for all purposes during the pre-monsoon season, furthermore, the water quality turned into good quality in the monsoon and post-monsoon seasons. The selected pond waters showed good quality for irrigation uses especially in the monsoon season, nevertheless, a few pond water showed poor quality during the pre and post-monsoon seasons. The tube-well waters showed good quality except for the few water samples of the estuarine areas during the pre-monsoon season. However, all of the groundwater samples were found good quality during both the monsoon and post-monsoon seasons.

The study results illustrated that the humidity, rainfall, mean sea level, and EC of the coastal areas showed a positive correlation with temperature. It showed that the increased temperature remarkably influenced the seawater level and salinity in the coastal watershed. The study exhibited a good correlation with existing EC and WQI values, indicating that EC values have great influences on the water quality of the coastal areas. As the EC level of the coastal watersheds was increased from 2000 to 2015. Hence, it is expected that it would severely affect the water quality in the areas by the three to four decades. The study recommends the appropriate adaptation and mitigation options to reduce further degradation of the coastal water quality as well as the entire coastal environment.

CONTENTS

	Page No.
Acknowledgements	i
Abstract	iii
Content	v
List of Tables	ix
List of Figures	x
List of Abbreviations	xii
CHAPTER-1: INTRODUCTION	1-5
1.1 General Background	1
1.2 Statement of Problems	3
1.3 Research Gap	4
1.4 Research Questions	4
1.5 Objective of Research	5
1.6 Outline of Research	5
CHAPTER-2: LITERATURE REVIEW	6-14
2.1 Climate Change	7
2.2 Meteorological and Hydrological Changes	7
2.3 Impacts of Meteorological and Hydrological Changes on Waters	8
2.4 Climate Change and Sea-Level Rise	11
2.5 Impacts of Climate Change on Water Quality	11
2.6 Climate Change Impacts on Coastal Water Quality	12
2.7 Climate Change Impacts on Coastal Bangladesh	13
CHAPTER -3: MATERIALS AND METHODS	15-39
3.1 Study area	15
3.2 Sampling Location and Sample Type	17
3.3 Water Sampling	19
3.4 Water Sample Preparation	19
3.5 Water Sample Analysis	19
3.5.1 Temperature, pH, DO, and EC	19
3.5.2 Total Dissolved Solids (TDS)	19
3.5.3 Total Suspended Solids (TSS)	20
3.5.4 Determination of Cations	21
3.5.4.1 Sodium Ion	21
3.5.4.2 Magnesium Ion	22
3.5.4.3 Potassium Ion	23
3.5.4.4 Calcium Ion	24
3.5.4.5 Manganese	25
3.5.4.6 Iron	26
3.5.4.7 Copper	26
3.5.4.8 Zinc	27
3.5.4.9 Arsenic	28
3.5.4.10 Lead (Pb)	29
3.5.5 Determination of Anions	30
3.5.5.1 Chloride Ion	30

		Page No.
3.5.5.2	Nitrate Ion	31
3.5.5.3	Sulfate Ion	32
3.5.5.4	Phosphate Ion	34
3.5.5.5	Total Alkalinity	35
3.6	Water Quality Assessment Tools	36
3.7	Secondary Data Collection	39
3.8	Data Analysis	39
3.9	Research Lab	39
	CHAPTER-4: RESULTS AND DISCUSSION	40-120
4.1	Meteorological Data Analysis	40
4.1.1	Annual Maximum Temperature	40
4.1.2	Annual Minimum Temperature	42
4.1.3	Annual Average Temperature	43
4.1.4	Annual Average Relative Humidity	45
4.1.5	Annual Average Rainfall	46
4.2	Secondary Hydrological Data Analysis	47
4.2.1	The Mean Sea water Level Assessment	47
4.2.1.1	Annual Mean Sea Level at Khepupara Station	48
4.2.1.2	Annual Mean Sea Level at Cox's Bazar Station	49
4.2.1.3	Annual Mean Sea Level at Hiron Point Station	50
4.2.1.4	Annual Mean Sea Level at Diamond Harbor Station	51
4.2.2	River Salinity Assessment	53
4.3	Water Sample Analysis	55
4.3.1	Surface Water (Estuaries, Rivers and Canals) Samples Analysis	55
4.3.1.1	Physical Parameters	55
4.3.1.1.1	Water Temperature	55
4.3.1.1.2	Dissolved Oxygen (DO)	56
4.3.1.1.3	Total Acidity/Alkalinity (pH)	57
4.3.1.1.4	Electro-Conductivity (EC)	58
4.3.1.1.5	Total Dissolved Solids (TDS)	59
4.3.1.1.6	Total Suspended Solids (TSS)	60
4.3.1.2	Chemical Parameters	61
4.3.1.2.1	Sodium Ion (Na ⁺)	61
4.3.1.2.2	Potassium Ion (K ⁺)	62
4.3.1.2.3	Calcium Ion (Ca ²⁺)	63
4.3.1.2.4	Magnesium ion (Mg ²⁺)	64
4.3.1.2.5	Chloride ion (Cl ⁻)	65
4.3.1.2.6	Sulfate ion (SO ₄ ²⁻)	66
4.3.1.2.7	Bi-carbonate Ion (HCO ₃ ⁻)	66
4.3.1.2.8	Nitrate (NO ₃ ⁻) and Phosphate (PO ₄ ³⁻) Ions	66
4.3.1.3	Trace Elements	67
4.3.1.4	Estuaries, Rivers and Canals Water Type Assessment	68
4.3.2	Surface (Ponds) Water Sample Analysis	73
4.3.2.1	Physical Parameters	73
4.3.2.1.1	Water Temperature	73
4.3.2.1.2	Dissolved Oxygen (DO)	74
4.3.2.1.3	Total Acidity/Alkalinity (pH)	75

	Page No.
4.3.2.1.4	Electro-Conductivity (EC) 75
4.3.2.1.5	Total Dissolved Solids (TDS) 76
4.3.2.1.6	Total Suspended Solids (TSS) 76
4.3.2.2	Chemical Parameters 77
4.3.2.2.1	Sodium Ion (Na ⁺) 77
4.3.2.2.2	Potassium Ion (K ⁺) 77
4.3.2.2.3	Calcium Ion (Ca ²⁺) 78
4.3.2.2.4	Magnesium Ion (Mg ²⁺) 78
4.3.2.2.5	Chloride Ion (Cl ⁻) 79
4.3.2.2.6	Sulfate Ion (SO ₄ ²⁻) 79
4.3.2.2.7	Bi-carbonate Ion (HCO ₃ ⁻) 79
4.3.2.2.8	Nitrate (NO ₃ ⁻) and Phosphate (PO ₄ ³⁻) Ions 80
4.3.2.3	Trace Elements 80
4.3.2.4	Ponds Water Type Assessment 81
4.3.3	Groundwater Sample Analysis 86
4.3.3.1	Physical Parameters 86
4.3.3.1.1	Water Temperature 86
4.3.3.1.2	Dissolved Oxygen (DO) 87
4.3.3.1.3	Total Acidity/Alkalinity (pH) 88
4.3.3.1.4	Electro-Conductivity (EC) 88
4.3.3.1.5	Total Dissolved Solids (TDS) 88
4.3.3.1.6	Total Suspended Solids (TSS) 89
4.3.3.2	Chemical Parameters 89
4.3.3.2.1	Sodium Ion (Na ⁺) 89
4.3.3.2.2	Potassium Ion (K ⁺) 90
4.3.3.2.3	Calcium Ion (Ca ²⁺) 91
4.3.3.2.4	Magnesium Ion (Mg ²⁺) 91
4.3.3.2.5	Chloride Ion (Cl ⁻) 91
4.3.3.2.6	Sulfate Ion (SO ₄ ²⁻) 92
4.3.3.2.7	Bi-carbonate Ion (HCO ₃ ⁻) 92
4.3.3.2.8	Nitrate (NO ₃ ⁻) and Phosphate (PO ₄ ³⁻) Ions 92
4.3.3.3	Trace Elements 93
4.3.3.4	Tube-wells Water Type Assessment 93
4.4	Water Quality Assessment 98
4.4.1	Irrigation Water Quality Assessment 98
4.4.1.1	Irrigation Water Quality Assessment in Pre-monsoon Season 98
4.4.1.2	Irrigation Water Quality Assessment in Monsoon Season 100
4.4.1.3	Irrigation Water Quality Assessment in Post-monsoon Season 101
4.4.2	Domestic Water Quality Assessment 102
4.4.2.1	Domestic Water Quality Assessment in Pre-monsoon Season 102
4.4.2.2	Domestic Water Quality Assessment in Monsoon Season 103
4.4.2.3	Domestic Water Quality Assessment in Post-monsoon Season 104
4.4.3	Drinking Water Quality Assessment 106
4.4.3.1	Drinking Water Quality Assessment in Pre-monsoon Season 106

		Page No.
4.4.3.2	Drinking Water Quality Assessment in the Monsoon Season	107
4.4.3.3	Drinking Water Quality Assessment in Post-monsoon Season	107
4.5	Climate Change Impacts on Water Quality	109
4.5.1	Assessment of Meteorological Changes	109
4.5.2	Assessment of Hydrological Change	111
4.5.3	Correlations Studies	113
4.5.3.1	Temperature and Relative Humidity	113
4.5.3.2	Temperature and Rainfall	114
4.5.3.3	Relative Humidity and Rainfall	115
4.5.3.4	Temperature and Mean Sea Level	115
4.5.3.5	EC and Temperature	116
4.5.3.6	EC and Water Quality	118
4.5.3.6.1	EC and WQI (Pre-monsoon)	119
4.5.3.5.2	EC and WQI (Post-monsoon)	119
	CHAPTER-5: CONCLUSION	121-124
	REFERENCES	125-131

LIST OF TABLES

		Page No.
3.1	Detailed sampling locations and sample type	18
3.2	Water Quality Rating as per AWQI method	37
3.3	Parameter limiting values for quality measurement (q_i) calculation	37
3.4	Weights for the IWQI parameters	38
3.5	Restrictions to water use classes	39
4.1.1	Mathematical study of annual maximum temperature at Khepupara station	41
4.1.2	Mathematical study of annual minimum temperature at Khepupara station	43
4.1.3	Mathematical study of average annual temperature at Khepupara station	44
4.1.4	Mathematical study of annual average humidity at Khepupara station	45
4.1.5	Mathematical study of annual average rainfall at Khepupara station	47
4.2.1	Mathematical study of MSL at Khepupara station	48
4.2.2	Mathematical study of MSL at Cox's Bazar station	50
4.2.3	Mathematical study of MSL at Hiron Point station	51
4.2.4	Mathematical study of MSL at Diamond Harbor station	52
4.2.5	Mathematical study of EC value in Andhermanik River	54
4.3.1	Bi-yearly descriptive statistics of physical parameters of estuaries, rivers and canals water	57
4.3.2	Bi-yearly descriptive statistics of chemical parameters of estuaries, rivers and canals water	63
4.3.3	Bi-yearly descriptive statistics of trace elements of estuaries, rivers and canals water	67
4.3.4	Bi-yearly descriptive statistics of physical parameters of ponds water	75
4.3.5	Bi-yearly descriptive statistics of chemical parameters of ponds water	78
4.3.6	Bi-yearly descriptive statistics of trace elements of ponds water	81
4.3.7	Bi-yearly descriptive statistics of physical parameters of tube-wells water	87
4.3.8	Bi-yearly descriptive statistics of chemical parameters of tube-wells water	90
4.3.9	Bi-yearly descriptive statistics of trace elements of tube-wells water	93
4.5.1	The meteorological changes of Kalapara station from 1975-2050	110
4.5.2	Mean sea level study	111
4.5.3	EC values of the Andhermanik and Lohalia Rivers	112

LIST OF FIGURES

	Page No.	
3.1	Study area and sampling spots	16
4.1.1	Annual maximum temperature at Khepupara station	41
4.1.2	Annual minimum temperature at Khepupara station	42
4.1.3	Annual average temperature at Khepupara station	44
4.1.4	Annual relative humidity at Khepupara station	45
4.1.5	The annual average rainfall at Khepupara station	46
4.2.1	Tide gauge data at Khepupara station	48
4.2.2	Tide gauge data at Cox's Bazar station	49
4.2.3	Tide gauge data at Hiron Point station	50
4.2.4	Tide gauge data at Diamond Harbor station	51
4.2.5	EC of Andhermanik River water at Kalapara	53
4.3.1	Water type of the estuaries, rivers and canals during pre-monsoon season	69
4.3.2	The proportion of major cations and anions in the estuaries, rivers and canals water during pre-monsoon season	69
4.3.3	Water type of the estuaries, rivers and canals during monsoon season	70
4.3.4	The proportion of major cations and anions in estuaries, rivers and canals water during monsoon season	71
4.3.5	Water type of the estuaries, rivers and canals water during post-monsoon season	72
4.3.6	The proportion of the estuaries, rivers and canals water during post-monsoon season	72
4.3.7	Water type of ponds water during pre-monsoon season	82
4.3.8	The proportion of major cations and anions in ponds water during pre-monsoon season.	82
4.3.9	Water type of ponds water during the monsoon season	83
4.3.10	The proportion of major cations and anions in ponds water during monsoon season.	84
4.3.11	Water type of ponds water during post-monsoon season	84
4.3.12	The proportion of Major cations and anions in ponds water during post-monsoon season.	85
4.3.13	Water type of tube-wells water sample during pre-monsoon season	94
4.3.14	The proportion of major cations and anions in tube-wells water during pre-monsoon season.	94
4.3.15	Water type of tube-wells water during monsoon season	95
4.3.16	The proportion of major cations and anions in tube-wells water during monsoon season.	96
4.3.17	Water type of tube-wells water during post-monsoon season	96

4.3.18	The proportion of major cations and anions in tube-wells water during post-monsoon season.	97
4.4.1	Irrigation water quality index values during pre-monsoon season	99
4.4.2	Irrigation water quality index value during monsoon season	100
4.4.3	Irrigation water quality index value during post-monsoon season	101
4.4.4	Domestic water quality index value during pre-monsoon season	103
4.4.5	Domestic water quality index value during monsoon season	104
4.4.6	Domestic water quality index value during post-monsoon season	105
4.4.7	Drinking water quality index value during pre- monsoon season	106
4.4.8	Drinking water quality index value during monsoon season	107
4.4.9	Drinking water quality index value during post-monsoon season	108
4.5.1	Temperature and humidity at Kalapara station	113
4.5.2	Temperature and Rainfall of Kalapara station	114
4.5.3	Humidity and Rainfall of Kalapara station	115
4.5.4	Temperature and MSL at Kalpara station	116
4.5.5	EC and Temperature at Kalapara station	117
4.5.6	EC and WQI values during pre-monsoon season	119
4.5.7	EC and WQI values during the post-monsoon season	120

LIST OF ABBREVIATIONS

BWDB	-	Bangladesh Water Development Board
BMD	-	Bangladesh Meteorological Department
PSMSL	-	Permanent Service of Mean Sea Level
SRDI	-	Soil Resource Development Institute
PW	-	Pond Water
RW	-	River Water
TW	-	Tube-well Water
SW	-	Sea Water
EW	-	Estuary Water
WQI	-	Water Quality Index
AWQI	-	Arithmetic Water Quality Index
IWQI	-	Irrigation Water Quality Index
BCSIR	-	Bangladesh Council of Scientific and Industrial Research
NR	-	No Restriction
MR	-	Moderate Restriction
HR	-	High Restriction
SR	-	Severe Restriction
LR	-	Low Restriction

CHAPTER - 1

INTRODUCTION

1.1 General Background

Climate change is one of the unavoidable but challenging issues of the world, which is gradually increasing threats to the ecosystem, water resources as well as the entire environment. The meteorological and hydrological changes factors are including, the rise in global earth's temperature, rainfall patterns, mean sea level, catastrophic storms, and flooding that support the continuous climate change. The rising of global temperatures will bring changes in weather patterns though Bangladesh plays very little role in greenhouse gas emissions, leading to climate change and sea-level rise. Sea level rise contributing to saline intrusion or inundation of coastal freshwater resources is probably the most direct impact of climate change, particularly for shallow aquifers along with low-lying coastal areas. However, there are some ambiguities about the magnitude of future climate change at local, regional, and global levels. Nevertheless, using some climate models, some schools of thought provided the available information about future climate change and its impacts on water resources as well as water quality.

Bangladesh is a low-lying deltaic land, flat topography, and gradually slopped down to the Bay of Bengal, enriched with huge coastal areas. The coastal areas of the country cover an area of 47,201 km², which is about 32% of the total area that encompasses the landmass of 19 districts (Ahmad, 2019). The coastal zone and offshore island in Bangladesh are very flat with the highest less than 3 m above the Mean Sea Level (Baten *et al.* 2015), unique physical characteristics, gifted with vast floodplain lands, overlapped with numerous estuaries, tidal rivers, creeks, and their tributaries. The river systems of coastal areas have tidally influenced from the Bay of Bengal as well as freshwater flow from the upstream. Throughout the rainy season, local rainfall upsurges with freshwater flow preserve good water quality, but the pressure of that flows decreases during the dry season, due to insufficient rainfall and human-induced settlements. As a result, the consequential backwater effect forms, and thus the surface water quality deteriorates. Water quality refers

to the suitability of water for particular purpose use. Sweet water is a small portion of the total volume of water (0.72%), must have to maintain a minimum quality for drinking, domestic, industrial, and agricultural purposes. Water quality mainly depends on several factors, including general geology, degree of chemical weathering of various rock types, recharge water, and upstream water flows (Albarède 2003; Mostafa et al. 2017).

The southern part of Bangladesh under the coastal zone that receives the discharge of numerous rivers, including the Ganges-Brahmaputra-Meghna (GBM) river system, creating one of the largest deltaic floodplain ecosystems of the world. Coastal ecosystems have key inbuilt features or functions. The coastal ecosystems provide habitat to genetically, ecologically, and economically valuable biological organisms.

Several climatologists have agreed that the gradual meteorological and hydrological changes can have far-reaching consequences on water quality as well as water resources. Again, global warming changes the precipitation patterns in response to climate change that significantly alters the surface water quality. Temperature-induced meteorological and hydrological changes would severely affect the coastal water ecosystem as the areas are located in low-lying areas. Due to the sea level rise, saline water would intrude into the inland surface as well as groundwater that depreciates the water quality. Again, insufficient and irregular rainfall, as well as heavy runoff from the upstream deposited to the lower coastal reservoir could seriously affect the water quality. Saline water intrusion is considered to be a major hazard for the coastal water system. The seawater intrudes or encroaches on inland water bodies through penetration or seepage due to tidal bores or unusual high tide. Thus, the saltwater gradually mixes with the freshwater and deteriorates the water quality. Again, the reduction of freshwater flow from the upstream could decrease the hydrostatic pressure and thus freshwater head flow at the seawater interface. Anyway, increasing the volume of seawater (i.e. the rising of sea level) and lowering the flow of sweet water pressure, seawater gradually intruded to the inland through the surface and ground and devalues water quality.

1.2 Statement of problems

Recent studies state that the coastal areas of Bangladesh are facing enormous challenges in meeting freshwater demand as the surface and groundwater sources are contaminated with water quality problems (Rahman *et al.*, 2013; Chowdhury *et al.*, 2014; Minar *et al.* 2013). The problem becomes intensified due to some climate change associated hazards like the sea level rise, river-bank erosion, land accretion, diversion of river route, insufficient and irregular rainfall, cyclone, tidal surge, etc. Dasgupta *et al.* (2014) illustrated that over-extraction of groundwater, upstream diversion of surface water, and shrimp farming, the coastal Ganges-Brahmaputra delta has been experiencing a relatively rapid measure in groundwater, river, and soil salinity. The study assumes that climate change is predominantly liable for hydrological changes in the coastal areas of Bangladesh.

In the coastal area of Bangladesh, drinking water is mainly derived from deep wells. The irrigation water supply is restricted to surface water bodies. Freshwater is also available at shallow depth sourced from seasonal precipitation but turns to brackish conditions during the dry period.

Climate change and sea-level rise are already affecting the coastal environments in many locations of Bangladesh. Especially, it has been affected the mid-central coastal region where a lot of hydro-morphological changes such as seashore and riverbank erosion, unusual siltation, and human migration are observed. Some researchers found that the sea shoreline is tremendously eroding and now it is more attacking phenomena than in the past few decades. Already about 1.5-2 kilometers of sea line have been eroded and the seawater invaded the coastal inland areas. Elevated rates of sea-level rise (up to 1 cm/per year) affect coastal infrastructure, freshwater resources, and the marine ecosystem of the coastal region of Bangladesh. Alteration of rainfall and storm patterns, freshwaters are contaminated by saltwater flooding and permanent inundation by rising sea level. Many of the deep tube-well contain turbid and saline water that creates problems for drinking, domestic and irrigation purposes uses. However, Seashore and riverbank erosion is an important factor in this area which seriously compelled the local people to migrate from the invaded areas. Eventually, the migrated people go to the urban areas for shelters which create severe local socio-economic problems.

1.3 Research Gap

The study reviewed several related research works accomplished mainly focusing on global and local climate change, their impacts on hydrology, as well as the impacts of salinity on agriculture, fisheries, land uses, crop production, etc. Climate change and water resources are widespread issues among scientists and the governments of all countries. The possible impacts of climate change on water resources have been widely reported. Due to the complex nature of climatic conditions, the assessment of the impacts of climate change on water quality is not easily understandable. The Fourth Assessment Report (AR4) of the IPCC summarized that the trends of climate change in the 20th century would have adverse effects on the water quality, but the report did not provide details (Rosenzweig et al. 2007). Besides, the implications of climate change for saltwater intrusion in the coastal region have not been investigated in great detail. There is no any conclusive report on climate change impacts on water quality in the coastal areas of Bangladesh so far. Therefore, a detailed investigation is imperative to understand whether there would be any climate change impacts on water quality in the coastal areas of Bangladesh.

1.4 Research Questions

The research questions are the initial steps of research. Before initiating the research work, it has raised the following questions, which helped to realize the objectives of the study.

- How many meteorological and hydrological changes observed in the study area?
- What is the present status of the water quality in the area?
- How climate change affects the water quality in the coastal areas of Bangladesh?

1.5 Objectives of Research

The main objective of the study was to assess the impacts of climate change on water quality in coastal areas of Bangladesh. The study conducted a comprehensive investigation of the hydro-meteorological changes, existing water quality. Finally, it assessed the climatic impacts on water quality in the coastal areas of Bangladesh. The study also considered some specific objectives, and those are as follows:

1. To assess the trend in meteorological factors, including temperature, humidity, and rainfall in the study area.
2. To assess the trend in hydrological factors, including sea-level rise and salinity intrusion in the area.
3. To characterize the surface and groundwater samples in the area.
4. To evaluate the existing water quality in the area.

1.6 Outline of Research

The thesis encompasses five chapters. A brief description of these chapters are given below:

Chapter-1: It describes the general background of the thesis. The statement of the problems, the research gap, the research questions, hypothesis, outcome of the research, and objectives of the research are written in the chapter.

Chapter-2: It illustrates the reviewing works which help to identify the research gaps, develop a solid background for the investigation, and justify the arguments in research findings.

Chapter-3: This chapter states the methodology used in the design of the experiments. It also presents the approach is taken and the mathematical tools used in the analysis.

Chapter-4: The detailed results of both the laboratory and secondary data analysis are interpreted and described in this chapter using several graphs, tables, charts, and figures. The chapter also describes the existing water quality which was measured with suitable water quality indices. Finally, it assesses the impacts of climate change on the water quality of the areas.

Chapter-5: The chapter summarizes the main results and findings of the thesis and presents some recommendations

CHAPTER - 2

LITERATURE REVIEW

The study has made an effort to present a brief literature review concerning the climate change impacts on coastal water quality of mid-southern part of Bangladesh. The literature review helps to identify research gaps, develop a solid background for the investigation, and justify the arguments in research findings. It has explored the applicable information about the climatic (i.e., meteorological and hydrological) changes that have direct or indirect impacts on water quality in the coastal areas. Climate change has diverse impacts on the hydrosphere, lithosphere and atmosphere as well as the biosphere. The individual impact has specific characteristics and dimensions.

The impacts of climate change is a substantial discussed issue around the world. In recent times, several studies about climate change project that it is likely to affect the physical environment and lead to the change of the hydrology, hydro-morphology, and water resource as well as water quality. Climate-induced vulnerabilities such as the sea-level rises, floods, cyclones, storm surges, droughts, etc. are expected to become more frequent and severe. Climate change is not the only factor that affects water quality. According to the global and local changing concept, land use evolution, deforestation, urban spreading, and embanking water bodies also exaggerate the water quality degradation. However, only highlighting the impacts of climate change on the water quality, a part of the hydrosphere, the study frequently reviewed several related research works included the published and grey articles, papers, proceedings, reports, essays, case studies, and public opinions, etc. In this chapter, a detailed description of such reviewing works is stated with appropriate sources.

2.1 Climate Change

Climate change, also defined as global warming, refers to the rise in average surface temperatures on Earth. An overwhelming consensus amongst scientists maintains that climate change is due primarily to the human use of fossil fuels, which releases carbon dioxide and other greenhouse gases into the air. The most recent reports of the Intergovernmental Panel on Climate Change (IPCC) confirmed the arrangement amongst the concerned scientists and policymakers that human-induced climate change is now arising. The latest 6th IPCC report declared that in the previous century, the global average air and ocean temperatures increased and there was widespread melting of snow and ice, and the global average sea-level rise occurred. During the last century, the global surface temperature was increased by 0.74°C in the period between 1906 and 2005 with a faster warming trend over the past 50 years (Verweij *et al.*, 2010). According to Leeuwen and Darriet (2016) depending on the scenario of greenhouse gas emissions, temperatures are predicted to increase by from 1 °C to 3.7 °C until the end of the century, compared to the reference period 1985–2005 (IPCC, 2014). Observed change in the climate over recent decades has been linked with changes in the global hydrological cycle, including increased atmospheric water content and changing precipitation patterns (Watts *et al.* 2015). The studies of Arnell (2004); Alcamo *et al.* (2007) suggested that billions of people living in the water-stressed areas will be adversely affected by climate change. The projections of the climate model by Alcamo *et al.* (2007) showed that water stress of the total global river basin area increases over 62-75.8 % between 2007 and 2050, and that will significantly decline the surface and ground water quality.

2.2 Meteorological and Hydrological Changes

Recently, most of the climatologists argue that climate change is occurred due to the increase of carbon dioxide concentration in air, defined as global warming. The excess amount of carbon dioxide increases the surface temperature, which directly affects the rainfall, evaporation, storms, floods, droughts, sea-level, and other extreme events. The most popular concept stated that climate change is mainly attributed to anthropogenic factors. The highest amount of carbon dioxide and other greenhouse gases in the

atmosphere is reported in recent years that proved the opinion of scientists. According to Irby et al. (2018) global climate change is projected to alter the world's marine environments with coastal and estuarine systems bearing exacerbated impacts. A study showed that anthropogenic activities caused global warming by increasing the concentrations of carbon dioxide and other greenhouse gases (Houghton *et al.*, 2001).

A study of Rojas-Downing et al. (2017) stated that global climate change is primarily caused by greenhouse gas (GHG) emissions that result in warming of the atmosphere (IPCC, 2013). Many scientists concurred that the indiscriminate emission of greenhouse gases is predominantly liable for changing global temperature. A study showed that the atmospheric concentration of carbon dioxide increased from 280 to 369 mg/L (ppm), and the global temperature of the earth increased by about 0.6°C (Mall *et al.* 2006). It also showed that the average global surface temperature projected to increase by 1.4-3°C from 1990 to 2100 for low-emission scenarios, and 2.5-3°C for higher emission scenarios of greenhouse gases. Over the same period, the associated rise in global mean sea-level projected between 9 and 88 cm. The Intergovernmental Panel on Climate Change (IPCC) declared that a climate model projected the global temperatures would increase by 1.5-4°C by 2100 (Jenkins *et al.* 2009). According to Alamdari *et al.*(2017) nearly 30% of the urban areas exhibited a significant increase in extreme precipitation which seriously affect the hydrological regimes.

2.3 Impacts of Meteorological and Hydrological Changes on Water bodies

Most important meteorological and hydrological factors such as temperature, evaporation, and precipitation are directly or indirectly linked with the river flow changes and groundwater recharge (Chew, 2007). Climate change is expected to have far-reaching consequences for river regimes, flow velocity, hydraulic characteristics, and connectivity across habitats (Brown *et al.*, 2007). Global climate change is likely to have significant effects on the hydrological cycle (IPCC, 1999; Huntington, 2006). The hydrological cycle will be intensified, with more evaporation and precipitation, but the extra precipitation will be unequally distributed around the globe (Jun *et al.*, 2010). About one-sixth of the world

people live in the river basin supplied by melting water from mountain ranges (Kundzewicz *et al.*, 2008). Rosenzweig *et al.* (2007) stated that some climate change impacts on hydrological processes have been observed already, and further changes are projected.

The study of Kundzewicz *et al.* (2008) stated that many of the present water-stressed semi-arid and arid areas are likely to suffer from decreasing water resource availability due to climate change, as both the river flows and groundwater recharge decline. Murdoch *et al.* (2000) described that global warming will change the precipitation patterns, and the changes significantly alter the quality of surface waters. IPCC report, 2007 affirmed that the Freshwater availability in the Central, South, East, and Southeast Asia, particularly in large river basins, projected to decrease due to climate change, could adversely affect more than a billion people by the 2050s. Climate change can have far-reaching consequences for water resources (Arnell, 2003) as well as water quality (Hejlar *et al.*, 2003; Webb *et al.*, 2003; Whitehead *et al.*, 2009). The results of some studies indicated that water quality can be directly affected through several climate-related mechanisms in both the short and long term (Park *et al.*, 2009). A study was conducted on three lakes of Western Victoria, Australia over 15 years and found a strong relationship between climate change and water quality (Jun *et al.*, 2010)

The temperature must be viewed as the predominant factor affecting almost all the physicochemical equilibriums and biological reactions (Delpla *et al.*, 2009; Della *et al.*, 2007). Surface water bodies are directly affected by the air temperature, and thus the water quality is influenced by increased heat of the atmosphere. River water temperatures are found in close equilibrium with air temperature and, as the air temperature rises, so will rise river temperatures. Hassan *et al.* (1998) and Hammond and Pryce (2007) stated that the most immediate effect on climate change is expected to be in river and lake water temperatures. Another study describes that there has already been a 1-3°C temperature that was raised over the last 100 years in large European rivers such as River Rhine and the River Danube (EEA report, 2007a). An increase in water temperature alters the rate of operation of some key chemical processes in water. Increases in the water temperature

decrease the oxygen-holding capacity of surface water can decrease the productivity of water living species (Jacoby, 1990).

Changes in flood and drought frequency are visible around the world. According to the report of the Intergovernmental Panel on Climate Change, the proportion of total rainfall from heavy precipitation events is very likely to increase over most of the tropical and high latitude areas (IPCC, 2007a). Kundzewicz *et al.* (2008) described that the flood frequency and its magnitude was projected to increase in the regions of increasing precipitation intensity. The study of Brunette *et al.* (2001) and Bates *et al.*, (2008) claimed that in the temperate regions, climate change will decrease the number of rainy days but increase the average volume of each rainfall event. Bates *et al.* (2008) mentioned that an increase in precipitation at high latitudes and a decrease in precipitation at low latitudes are expected. Delpla *et al.* (2009) described that floods and droughts are the main impacts of climate change on water availability as well as water quality. These factors can be able to modify water quality by direct effects of dilution or concentration of dissolved substances. A study conducted by Jun *et al.* (2010) stated that the extreme events such as floods and droughts, the frequency of which is predicted to increase, also modify water quality through direct impacts of dilution or concentration of dissolved substances. Again, the more intense rainfall and flood would increase loads of suspended solids (Lane *et al.*, 2007). Arnell *et al.*, (2014) described that the extreme precipitation in many regions increased since 1950, which suggests an increase in rainfall intensity that would enhance soil erosion and stream sediment loads. Dissolved Oxygen (DO) can be affected by both the temperature and rainfall events. Several studies stated that the concentration of dissolved substances increased with decreasing of dissolved oxygen (DO) (Prathumratana *et al.*, 2008 and Van Vliet and Zwolsman, 2008).

2.4 Climate Change and Sea-Level Rise

In recent times, scientists have given the highest attention about the global sea-level rise and its impacts on the hydrology, water resources as well as water quality. The experts described that the rising temperature melts the mass volume of ice of the Polar Regions. The augmented temperature also expands of the ocean water, and increases the seawater level. Wigley and Raper (1987) reported that the global mean sea-level raised about 2-5 cm during 1880-1985 due to the greenhouse-gas-induced thermal expansion. Mall *et al.* (2006) showed that the global mean sea-level raised about 10 to 20 cm and there has been a 40% decline in Arctic Sea ice thickness in late summer to early autumn during the past 45 to 50 years. According to the IPCC report 2007, the global average sea-level raised by 1.8 mm per year from 1961 to 2003 and the Arctic sea ice extent decreased by 2.7% per decade from 1978. The IPCC predicted that the sea-level is projected to rise between 1980 – 1999 and 2090 - 2099 by 35 cm in the A1B scenario (Mondal *et al.*, 2013). The rise of sea-level will extremely affect the low-lying coastal regions. Nicholls *et al.* (1999) estimated that the sea-level rise could lose up to 22% of the world's coastal wetlands by the 2080s. Bangladesh is a predominantly coastal country, highly vulnerable to the sea-level rise. A report showed that about 10 cm, 25cm, and 1 m rise of sea-level by 2020, 2050 and 2100 would affect about 2%, 4% and 17.5% of the total landmass of Bangladesh, respectively (Report of World Bank 2000).

2.5 Impacts of Climate Change on Water Quality

Climate change generally influences to some primary and secondary hydrological factors as well as water quality such as chemical reactions, acidification, salinization, nutrient contaminations, stratification, and oxygen concentration. Such changes can speed up the weakening of both surface and ground water quality. It is important to note that direct and indirect processes related to climate change affect the physicochemical water quality (Verweij *et al.*,2010). It is expected that the increased precipitation increases nutrients runoff from the agricultural lands to surface waters and load nutrients to waters and make eutrophication (Mooij *et al.*,2009). Several climatologists have agreed that the gradual meteorological and hydrological changes can have far-reaching consequences in water

quality (Hejzlar *et al.*, 2003; Webb *et al.*, 2003) as well as water resources (Arnell, 2003). Again, Global warming changes the precipitation patterns in response to climate change that significantly alters the surface water quality (Murdoch *et al.*, 2000; Kundzewicz *et al.*, 2008). Whitehead *et al.* (2009) described that some climate model scenarios provided the best available information for assessing future impacts of climate change on the water quality and ecology of surface water bodies. Battarbee *et al.* (2008) stated that a mega project was taken in Europe to investigate the impacts of climate change on rivers, lakes and wetlands across Europe.

2.6 Climate Change Impacts on Coastal Water Quality

About one-quarter of the global population lives in coastal regions that have less than 10% of the global renewable water supply and are undergoing rapid growth. Salinity intrusion is due to the excessive water withdrawal is expected to reduce the freshwater availability (Kundzewicz *et al.*, 2007). Minar *et al.*, 2013 described that man-made global climate change and associated sea-level rise can have a major adverse penalty for the coastal ecosystem. Salinity has been viewed as one of the most important variables in the coastal water system. Saltwater intrusion poses a hazard to drinking water, crop irrigation, and freshwater aquatic life. The salinization or increasing the chloride ion concentration in freshwater bodies can occur with the intrusion of the seawater through the surface or ground. Salinity is considered as the most hydrological hazard in the coastal areas. Sea-level rise mainly contributes to the salinization of rivers connected to the sea and groundwater in the low lying area. According to Van Dijk *et al.* (2009), saltwater intrusion greatly influences the groundwater close to the coastal, particularly in polder areas. The study also specified that the coastal freshwater aquifers are the most vulnerable to salinization by the advance of seawater intrusion (Verweij *et al.*, 2010). The working group II contribution to the 4th assessment report (*IPCC report, 2007*) illustrated that heavily-populated mega-delta regions in the coastal areas in the South, East, and Southeast Asia will be at risk due to the increase of flooding from the sea and rivers.

2.7 Climate Change Impacts on Coastal Bangladesh

The southern part of Bangladesh under the coastal zone that receives the discharge of numerous rivers, including the Ganges-Brahmaputra-Meghna (GBM) river system, creating one of the most productive ecosystems of the world. The coastal zone and offshore island in Bangladesh are very flat with a height of fewer than 3 m above the Mean Sea-Level (MSL). The country has sub-tropical monsoon, one of the most vulnerable countries to climate change in the world and will become more susceptible in the future (Islam *et al.*, 2011). According to the report of MOP, 2011 Climate change has already affected the life and livelihood of people in the coastal areas and in the arid and semi-arid region of Bangladesh (Rahman *et al.*, 2015).

The humid and subtropical countries like Bangladesh would be more exposed to the impending impacts of global warming. Mondal *et al.* (2013) stated in a study that cyclone, storm surge induced flooding, coastal flooding, water-logging, salinity intrusion, and coastal erosion are considered as the predominant climatic and hydrologic event of coastal Bangladesh. The study also stated that about a 1-meter rise of sea-level would submerge about 18% of the total land area of Bangladesh. Cruz *et al.* (2007) illustrated that most of the Global Circulation Models (GCM) considered in the IPCC 2007 report. The study predicted that a slight increase (<10%) of rainfall would increase by 2040 over most of the Ganges-Brahmaputra-Meghna catchment area of Bangladesh. Hu *et al.* (2010) described a <5% increase in monsoon rainfall by 2050 in that region. The scientist predicted that due to climate change, crop production would be seriously troubled in the sub-tropical region. Brammer (2014) described that the combined effects of changes in temperature, rainfall, flood, cyclone frequency, and sea-level rise rice production could reduce about 1.5-3.5 and 5.5% during the monsoon and dry season, respectively in Bangladesh. Bangladesh is exposed to several climate change-induced primary and secondary hazards including temperature and rainfall variations, droughts, cyclone and storm surges, floods, saline intrusion and rises of the sea-level. Bangladesh has been marked as the third most vulnerable country in the world in terms of the number of people affected by sea-level rise. Pender *et al.* (2008) described that about 33 million people of Bangladesh would be

affected adversely by 2050 due to sea-level rise. Gore and Houghton (2009) also described that Bangladesh would be overwhelmed line by line as the sea-level rises with global warming, and millions of people would be displaced as the sea encroached.

The review signified that climate change has a static impact on water resources and water quality, especially in coastal areas. It showed that Bangladesh is considered vulnerable to climate change and the huge population in coastal areas is at risk of displacement due to sea-level rise. The study reviewed several related research works performed mainly directing on global and local climate change, their impacts on hydrology, as well as the impacts of salinity on agriculture, fisheries, land uses, crop production, etc. However, there is a research gap in finding climate change impacts on coastal water resources and water quality in particularly in Bangladesh. Therefore, the study considered to conduct a detailed investigation to understand climate change impacts on water quality in the coastal areas of Bangladesh.

CHAPTER - 3

MATERIALS AND METHODS

The study aimed to assess the impacts of climate change on water quality in the selected coastal areas of Bangladesh. The study collected some secondary meteorological (e.g. temperature, humidity, and rainfall) and hydrological (e.g. mean sea level, salinity, etc.) data of Kalapara station of previous few decades. At the same time, it collected some water samples from the selected estuaries, rivers, canals, ponds, and tube-wells were analyzed within the research period. The analyses were performed using several scientific methods such as gravimetric, micro and semi-micro analytical procedures. Modern scientific instruments including, Atomic Absorption Spectrophotometer (AAS), UV spectrophotometer, a sensitive pH, EC, DO meters, etc. were used for analytical tests. The standard methods were applied in the analyses to maintain maximum accuracy. Finally, the study tried to evaluate the existing water quality of the study area using two suitable water quality indices, i.e., irrigation water quality index (IWQI) and arithmetic water quality index (AWQI). In this chapter, the methods and systematic procedures of water samples preparation, preservation, analyses, and quality indexing are thoroughly discussed.

3.1 Study Area

The study selected Kalapara Upazila under Patuakhali district situated in the mid-south central coastal areas of Bangladesh. The area located in between 21°48' and 22°05' north latitudes and 90°05' and 90°20' east longitudes (Banglapedia, 2019). The north and western parts of the area are bounded by another coastal district, Borguna. The eastern side is bounded by the largest channel named, Rabnabad channel of Golacipa Upazila in Patuakhali district of Bangladesh. The southern part of this area is joined with the Bay of Bengal. (Fig. 3.1)

Kuakata is the second largest tourist center of the country, located on the southern extremity of Kalapara Upazila. Both the sunrise and sunset can be viewed from the 18 Km long Kuakata sea beach. The average breadth of the beach is about 3 to 3.5 km. The shutki (dried fish) Palli is also an important place of Kalapara, which is about 7 km away from the west of Kuakata (Banglapedia, 2019). Dry fish is from the Palli and transported to different parts of the country. Kalapara is becoming an economically important place for the proposed Payra seaport and coal-based power plant. The Payra seaport is considered the third-largest seaport in Bangladesh. Paddy, pulse, potato, vegetables and are the main crops of Kalapara Upazila, and main fruits such as Banana, papaya, coconut, guava, plum, nut, watermelon, etc. are grown here. Moreover, the inhabitants keep several shrimps, dairies, poultries farm, and hatcheries.

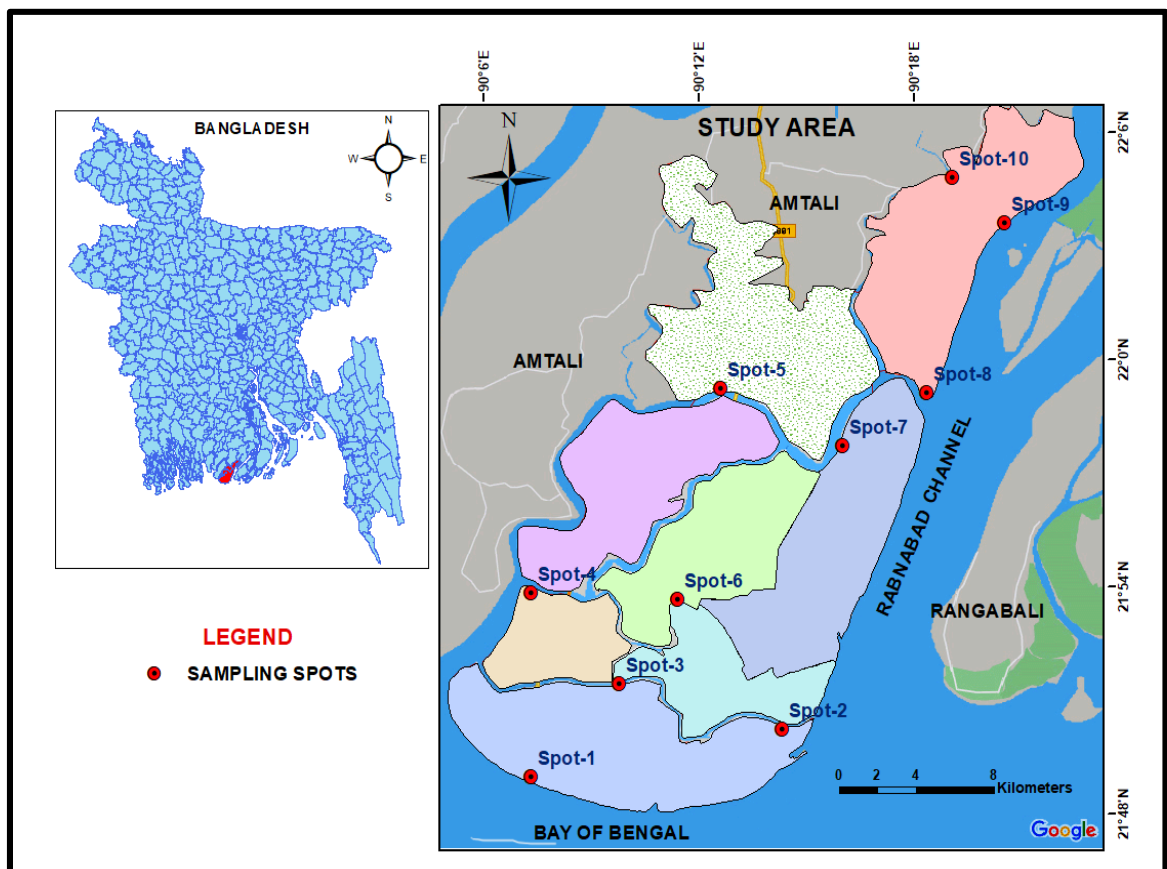


Fig 3.1 Study area and sampling spots

The study area is defined as inland coastal areas that far away about 30-40 kilometers from the sea shore line. The area is crossed with a number of the rivers, channels, their tributaries and numerous canals. The main rivers are named as the Andhermanik, Nilgong, Sonatola, Shibbaria, Khapravanga, etc. The land area of Kalapara is about 492.102 square kilometers, where approximately 2,37831 people live (Website, 2017). The entire area is surrounded by high man-made polders and embankments along with the side of the rivers and the sea shore. The total agricultural land area of Kalapara is about 49210.2 hectares where Rice, Water lemon, pulses, chilies, sweet potatoes, etc are grown. Farming and fishing are the major occupations of the inhabitants of the area. The climate of this area is classified as the tropical where the annual average temperature and rainfall are found to be 25-26⁰C and 265-270 cm, respectively (Website, 2017). Generally, May is the hottest, and January is the coldest month. The geology of the study area is fully diversified. It is a low-lying area and sloped down to the south where the average elevation is about 10-15 feet from the mean sea-level. The hydrology of this area is being greatly influenced by the tide of the sea and sweet water pressure from the upstream region has a unique brackish water ecosystem (Mondal *et al.*, 2013). The intact area is affected by various class A hazards such as the salinity, sea-level rise, cyclone, and storm surge, etc. (Rahman *et al.*, 2015).

3.2 Sampling Location and Sample Type

The water samples were collected from ten sampling spots of Kalapara Upazila. The spots were marked through the coordination of the GPS. The samples were collected three times a year, i.e., the pre-monsoon (March-April), monsoon (Aug-September), and post-monsoon (December-January) covering two years, 2016 and 2017. The detailed sampling locations and sample types are shown in Table 3.1

Table 3.1 Detailed Sampling Locations and Sample Type

Spot	Lat	Long	Location information	Sample type
Spot-1	21.816	90.122	Kuakata sea spot, Union Latachapli	Estuary, Pond & Ground water
Spot-2	21.837	90.239	^a Vill.- Tettrish kani Union : Latachapli	Estuary, Pond & Ground water
Spot-3	21.857	90.163	Vill- Laksmi bazar Union : Latachapli	River, Pond & Ground water
Spot-4	21.897	90.122	Vill- Hazipur Union : Nilgang	River, Pond & Ground water
Spot-5	21.987	90.21	Vill- Nashnapar Union : Tiakhali	River, Pond & Ground water
Spot-6	21.894	90.19	Vill- East Madhukhali Union: Mithagang	River, Pond & Ground water
Spot-7	21.962	90.267	Vill- Charipara Union: Lalua	River, Pond & Ground water
Spot-8	21.985	90.306	Vill- Tiakhali Union : Tiakhali	River, Pond & Ground water
Spot-9	22.06	90.342	Vill- Dhankhali Union : Dhankhali	River, Pond & Ground water
Spot-10	22.08	90.318	Vill- Rajapara Union : Taikhali	River, Pond & Ground water

^aVill.: Village; Union: an administrative area consists of some villages.

3.3 Water Sampling

Surface water samples were collected from the sampling sites of the estuaries, rivers, and ponds and marked as EW, RW, and PW, in the order. The water samples from the open sea, estuaries, and rivers were collected during the high tide period. The groundwater samples were collected from tube-wells and marked as GW. The water samples were collected carefully and maintained the standard collection procedures. The samples were collected in plastic bottles (500 mL) closed with an airtight cap and marked with a permanent marker. The bottles were previously washed and rinsed thoroughly with the water samples. In the spot, 2 ml 5% HNO₃ was mixed with the water samples that would be used for the cations analysis. Then the acidic water sample and freshwater sample bottles were kept in the cold vessel of a cool sheet and transported to the laboratory for the analyses.

3.4 Water Sample Preparation (Digestion Method)

100 mL of water sample was taken in a beaker and added 2 mL concentrated HNO₃ and 3 mL concentrated HCl. The beaker was heated up to 90-95°C on a hot plate until the water volume was reduced to 10-15 mL. It was allowed to cool and filtered through a 0.15µm pore membrane filter. Finally, the volume was made up to 100 mL with distilled water. The prepared sample was used to determine the cations, including Na, Mg, K, Ca, Mn, Fe, Cu, Zn, As, Cd, Pb, etc.

3.5 Water Sample Analysis (Procedure and Methods)

3.5.1 Temperature, pH, DO, and EC

The water temperature, pH, DO, and EC of the samples was taken on the spot using an alcohol thermometer, pH meter, DO meter, and EC meter (EC-210, HANA, Italy), respectively.

3.5.2 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) was determined by the evaporation method. A Pyrex beaker (150 mL) was dried in the oven at 105°C for about 24 hours and allowed to cool. Then, 100 mL sample water was filtered to the beaker through filter paper (Whatman-42) and

evaporated to dry in the oven at 105°C for 24 hours. The heated beaker was allowed to cool and weighted.

$$\text{Total Dissolved Solids (TDS), mg/L} = \frac{(A-B) \times 100000}{V}$$

Here, A = Final weight of beaker (g)

B = Initial weight of beaker (g)

V = Volume of Water sample (100 mL)

3.5.3 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) of the water samples was determined by the evaporation method. A filter paper (Whatman-42) was dried in the oven at 105°C for about 24 hours and then allowed to cool. A 100 mL sample water was filtered through the dried filter paper and evaporated to dry in an oven at 105°C for 24 hours, and finally, it was allowed to cool and weighted.

$$\text{Total Suspended Solids (TSS), mg/L} = \frac{(A-B) \times 100000}{V}$$

Here, A = Final weight of filter paper (g)

B = Initial weight of filter paper (g)

V = Volume of Water sample (100 mL)

3.5.4 Determination of Cations

The cations including, Na^+ , Mg^{2+} , K^+ , Ca^{2+} , Mn (total), Fe (total), Cu (total), Zn(total), As(total), Cd(total), As (total), and Pb (total), etc. were determined by using atomic absorption spectrophotometric method.

3.5.4.1 Sodium Ion (Na^+)

(a) Standard Solution Preparation

To prepare the standard solution, exactly 2.54 g of analytical pure 99% NaCl was taken in a 100 volumetric flask and made up to the mark with distilled water.

(b) Suppressing Agent

About 5.24 g KCl was taken in a 1000 mL volumetric flask and made up to the mark with distilled water gradually. Then, 100 mL of 1% potassium ion solution was taken in a 1000 mL volumetric flask and diluted with distilled water.

(c) Procedure

(i) Standard Curve

The proportion of 2, 5, 8, and 10 mL standard solution was taken in different 100 mL volumetric flask and made up to the mark with distilled water with continuous shaking. The absorbance of standard samples was determined by AAS at a wavelength of 330.2 nm with 0.7 nm slit to make the standard curve.

(ii) Absorbance of Sample

The absorbance of the collected samples water was determined by maintaining the same procedures.

(iii) Calculation

The absorbance of the samples and standard solution were determined in the wavelength of 330.2 nm with 0.7 nm slit. By using absorbance, the concentration of samples was determined directly from the standard curve.

3.5.4.2 Magnesium Ion (Mg^{2+})

(a) Standard Solution Preparation

To prepare the standard solution, A exactly 1.650g of analytical pure 99% MgO was taken in a 100 mL Volumetric flask and made up to the mark with distilled water with continuous shaking.

(b) Suppressing Agent

Suppressing agent of 1% solution was made by taking 1 g of $LaCl_3$ and 1.50 mL 1M HCl in a 100 mL volumetric flask and made up to the mark with distilled water. Then, 10 mL of the 1% Lanthanum solution was taken in a 100 mL volumetric flask and diluted with distilled water. About 1-2 drops of 0.1% lanthanum solution were used for standard and sample solutions.

(c) Procedure

(i) Standard Curve

The proportion of 50,100,150, and 200 mL standard solutions were taken in different 100 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard samples was determined by AAS in the wavelength of 285.20 nm with 0.7 nm slit to make the standard curve.

(ii) Absorbance of Samples

Following the same procedure, the absorbance of collected samples was determined.

(iii) Calculation

The absorbance of the samples and standard solution were determined in the wavelength of 285.20 nm with 0.7 nm slit. By using the absorbance, the concentration of samples was determined directly from the standard curve.

3.5.4.3 Potassium Ion (K⁺)

(a) Standard Solution Preparation

The standard solution of potassium was prepared by taking exactly 1.910g of analytical pure 99% KCl in a 1000 mL Volumetric flask and made up to the mark with distilled water.

(b) Suppressing Agent

About 1 g Potassium Chloride was taken in a 100 volumetric flask and made up to the mark with distilled water. Then, 1-2 drops of 0.1% potassium solution were added to each standard and samples to reduce % relative standard deviation (RSD).

(c) Procedure

(i) Standard Curve

The proportion of 2, 4, 8, and 16 mL standard solutions were taken in different 1000 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard samples was determined by AAS in the wavelength of 766.49 nm with 0.7 nm slit and a standard curve was formulated in the excel sheet.

(ii) Absorbance of Sample

The absorbance of collected water samples was taken by maintaining the same procedure described earlier.

(iii) Calculation

The absorbance of samples and standard solution were taken the wavelength of 766.49 nm with 0.7 nm slit. By using the absorbance, the concentration of samples was calculated directly from the standard curve.

3.5.4.4 Calcium Ion (Ca^{2+})

(a) Standard Solution Preparation

Exact 0.250g of analytical pure 99% CaCO_3 was taken in a 1000 mL Volumetric flask and made up to the mark with distilled water.

(b) Suppressing Agent

About 2 g of LaCl_2 and 3 mL 1M HCl was taken in a 100 volumetric flask and made up to the mark with distilled water. Then, 100 mL distilled water was added with 10 mL of 2% lanthanum solution. About 1-2 drops of 0.2% solution were added to each standard and sample.

(c) Procedure

(i) Standard Curve

The proportion of 0.5, 1, 2 and 4 mL standard solutions were taken in different 1000 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard samples was determined by AAS in the wavelength of 422.7 nm with 0.7 nm slit to make a standard curve.

(ii) Absorbance of Sample

Following the same procedure, the absorbance of collected samples was taken.

(iii) Calculation

The absorbance of samples and standard solution were taken the wavelength of 422.7 nm with 0.7 nm slit. By using the absorbance, the concentration of samples was calculated directly from the standard curve.

3. 5.4.5 Manganese (Mn)

(a) Standard Solution Preparation

Exact 3.070 g of analytical pure 99% $\text{MnSO}_4 \cdot 10\text{H}_2\text{O}$ was taken in a 1000 mL Volumetric flask and made up to the mark with distilled water.

(b) Suppressing Agent

About 2 g CaCO_3 and 3 mL 1M HCl was taken in a 100 mL volumetric flask and made up to the mark with distilled water. To prepare a 0.2% solution, 10 mL of 2% CaCO_3 solution was taken and diluted with 100 mL distilled water. Then, 1-2 drops of 0.2% solution were used in standard and samples.

c) Procedure

(i) Standard Curve

The proportion of 1, 3. and 5 mL standard solutions were taken in different 1000 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard samples was determined by AAS in the wavelength of 279.48 nm with 0.7 nm slit to make a standard curve.

(ii) Absorbance of Sample

Following the same procedure, the absorbance of collected water samples was taken.

(iii) Calculation

The absorbance of samples and standard solution were taken at the wavelength of 279.48 nm with 0.7 nm slit. By using the absorbance, the concentration of samples was calculated from the standard curve.

3. 5.4.6 Iron (Fe)

(a) Standard Solution Preparation

Exact 4.980 g analytical pure 99% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ was taken in a 1000 mL volumetric flask and made up to the mark with distilled water.

(b) Procedure

(i) Standard Curve

The proportion of 0.50, 1, and 2 mL standard solution was taken in different 1000 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard samples was determined by AAS in the wavelength of 248.3 nm with 0.7 nm slit to make a standard curve.

(ii) Absorbance of Sample

Following the same procedure, the absorbance of collected samples was taken.

(iii) Calculation

The absorbance of samples and standard solution was taken at the wavelength of 248.3 nm with 0.7 nm slit. By using the absorbance, sample concentrations were calculated directly from the standard curve.

3. 5.4.7 Copper (Cu)

(a) Standard Solution Preparation

Exact 3.930 g of analytical pure 99% $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ was taken in a 1000 mL volumetric flask and made up to the mark with distilled water.

(b) Procedure

(i) Standard Curve

The proportion of 0.50, 1, and 2 mL standard solution was taken in different 1000 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard

samples was determined by AAS in the wavelength of 324.75 nm with 0.7 nm slit to make a standard curve.

(ii) Absorbance of Sample

Following the same procedure, the absorbance of collected water samples was taken.

(iii) Calculation

The absorbance of samples and standard solution was taken at the wavelength of 324.75 nm with 0.7 nm slit. By using the absorbance, sample concentrations were calculated directly from the standard curve.

3. 5.4.8 Zinc (Zn)

(a) Standard Solution Preparation

Exact 4.98 g analytical pure 99% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ was taken in a 1000 mL volumetric flask and made up to the mark with distilled water.

(b) Procedure

(i) Standard Curve

The proportion of 1, 3, and 5 mL standard solution was taken in different 1000 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard samples was determined by AAS in the wavelength of 213.86 nm with 0.7 nm slit to make a standard curve.

(ii) Absorbance of Sample

Following the same procedure the absorbance of collected water samples was taken.

(iii) Calculation

The absorbance of samples and standard solution were taken at the wavelength of 213.86 nm with 0.7 nm slit. By using the absorbance, sample concentrations were calculated directly from the standard curve.

3. 5.4.9 Arsenic (As)

(a) Standard Solution Preparation

Exactly 1.3203 g of analytical pure 99% As_2O_3 was taken in a 1000 volumetric flask and made up to the mark with distilled water.

(b) Procedure

(i) Standard Curve

The proportion of 4, 12, and 20 mL standard solution were taken in different 1000 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard samples was determined by AAS in the wavelength of 193.70 nm with 0.7 nm slit to make a standard curve.

(ii) Absorbance of Sample

Following the same procedure the absorbance of collected water samples was taken.

(iii) Calculation

The absorbance of samples and standard solution were taken at the wavelength of 193.70 nm with 0.7 nm slit. By using the absorbance, sample concentrations were calculated directly from the standard curve.

3. 5.4.10 Lead (Pb)

(a) Standard Solution Preparation

Exact 1.6 g analytical pure 99% $\text{Pb}(\text{NO}_3)_2$ was taken in a 1000 volumetric flask and made up to the mark with distilled water.

(b) Procedure

(i) Standard Curve

The proportion of 2.50, 5, and 10 mL standard solution were taken in different 1000 mL volumetric flask and made up to the mark with distilled water. The absorbance of standard samples was determined by AAS at a wavelength of 283.31 nm with 0.7 nm slit to make a standard curve.

(ii) Absorbance of Sample

Following the same procedure, the absorbance of collected samples was taken.

(iii) Calculation

The absorbance of the samples and standard solution was taken at a wavelength of 283.31 nm with 0.7 nm slit. By using the absorbance, the concentration of samples was calculated.

3. 5.5 Determination of Anions

3. 5.5.1 Chloride (Cl⁻) Ion

The Chloride ion in sample water was determined by titration method.

i. Reagents

(a) 0.141 AgNO₃

Exact 2.397 g AgNO₃ was taken in a 1000 mL volumetric flask and made up to the mark with distilled water. The solution was standardized with NaCl solution.

(b) 5% K₂CrO₄ Indicator

About 2.5g K₂CrO₄ was taken in a 50 mL volumetric flask and 25 mL distilled water was added. The prepared 0.141 N AgNO₃ solution was added into the flask until the permanent red precipitation was produced. The solution was filtered and diluted up to the mark with distilled water.

ii. Procedure

Exact 10 mL sample water was taken in a 250 mL conical flask. About 2-3 drops of K₂CrO₄ indicator were added in the flask and shaken slowly. The sample was titrated with 0.014 N AgNO₃ until the brick red color detected.

iii. Calculation

$$\text{Chloride Cl}^- \text{ (mg/L)} = \frac{A \times N \times 1000 \times 50}{V}$$

Here, A = Volume of AgNO₃ (mL)

N = Normality of AgNO₃

V = Volume of water sample (mL)

3.5.5.2 Nitrate (NO_3^-) Ion

The nitrate ion (NO_3^-) in water sample was determined using ultraviolet (UV) Spectrophotometric method.

(a) Stock Nitrate Solution

Analytical grade Potassium nitrate (KNO_3) was dried in the oven at 105°C for 24 hours. Exactly 0.7218 g KNO_3 was weighted transferred to 100 volumetric flask and made up to the mark with distilled water. (Here, 1 mL solution = 1000 ppm $\text{NO}_3^- \text{ N}$). The solution was preserved with a 2 mL CHCl_3 solution.

(b) Intermediate Nitrate Solution

10 mL stock solution was taken in a 100 mL volumetric flask and made up to the mark with distilled water. (Here, 1 mL solution = 100 ppm $\text{NO}_3^- \text{ N}$). The solution was preserved with a 2 mL CHCl_3 solution.

(c) 1 N Hydrochloric Acid (HCl) Solution

83 mL of concentrated HCl was measured and transferred to a 1000 mL volumetric flask and made up to the mark with distilled water.

(d) Procedure

(i) Sample Treatment

1 mL of 1 N HCl solution was mixed thoroughly in 50 mL sample and then filtered.

(ii) Standard Curve

The proportion of 0.50, 1, and 2 ml intermediate nitrate solutions were taken in 3 different 100 ml volumetric flasks, and made up to the mark with distilled water. The absorbance of the water sample was determined in AAS. A Standard curve was formulated by plotting the absorbance against the concentration.

(iii) Spectrophotometric Measurement

The absorbance was read against distilled water set at zero absorbance. A wavelength of 220 nm was used to obtain NO_3^- ion absorbance and a wavelength of 275 nm used to determine interference due to dissolved organic matter.

(iv) Calculation

The absorbance of the samples and standard solution was taken at two wavelengths and the absorbance reading at 275 nm was subtracted from the reading at 220 nm for each sample and standard. By using the absorbance, the concentration of samples was calculated from the standard curve.

3.5.5.3 Sulfate Ion (SO_4^{2-})

The sulfate ion (SO_4^{2-}) in water sample was determined using Ultraviolet (UV) Spectrophotometric method.

(a) Buffer Solution

Exactly 30 mg of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 5 g sodium acetate ($\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$), 0.111 g sodium sulfate (Na_2SO_4) and 20 mL acetic acid (CH_3COOH) were taken in a 1000 mL volumetric flask. They were dissolved with distilled water through continuous shaking and made up to the mark with distilled water.

(b) Barium Chloride

About 20-30 mesh BaCl_2 crystal was used to make uniform turbidity.

(c) Standard Sulfate Solution

Exact 0.1479 g anhydrous Na_2SO_4 was taken to a 1000 mL volumetric flask. It was dissolved with distilled water through continuous shaking and made up to the mark with distilled water. (Here, 1 mL solution = 100 $\mu\text{g SO}_4^{2-}$ S)

(d) Procedure

(i) Sample Turbidity Formation

A 10 mL water sample was taken in a 250 mL Erlenmeyer flask and 4 mL buffer solution was added. At the time of shaking a spoonful of BaCl_2 crystal was added and the solution was shaken for 2-3 minutes.

(ii) Standard Curve

The proportion of 5, 10, 20, and 40 ml intermediate sulfate solutions were taken in 5 different 100 ml volumetric flasks and made up to the mark with distilled water. The absorbance of the samples was determined by AAS. A Standard curve was made by plotting the absorbance against the concentration.

(iii) Spectrophotometric Measurement

The absorbance was read against distilled water set at zero absorbance. A wavelength of 420 nm was used to obtain SO_4^{2-} ion absorbance against concentration.

(iv) Absorbance of Sample

Following the same procedure, the absorbance of collected samples was taken.

(v) Calculation

The absorbance of samples and standard solution were taken at the wavelength of 420 nm. By using the absorbance, the concentrations of samples was obtained directly from the standard curve.

3.5.5.4 Phosphate (PO_4^{3-}) Ion

The Phosphate ion (PO_4^{3-}) in sample water was determined using Ultraviolet (UV) Spectrophotometric method.

(a) Ammonium Metavanadate (NH_4VO_3) Solution

A 2.5 g NH_4VO_3 was taken in 500 mL hot water and 20 mL concentrated HNO_3 was added. After filtration it was diluted in a 1 L graduated flask with distilled water.

(b) Ammonium Heptamolibdate Solution

A 5 g of $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}$ was taken in a 100 mL beaker and diluted with the warm water. Finally the solution was filtered.

(c) Sulphuric Acid

A 1:6 H_2SO_4 was prepared and kept in a glass bottle.

(d) Standard Phosphate Solution

Exactly 0.4391 g KH_2PO_4 was taken in a 100 mL volumetric flask. It was dissolved with distilled water through continuous shaking and made up to the mark with distilled water. (Here, 1 mL solution = 1000 $\mu\text{g PO}_4^{3-}\text{P}$). 10 ml of this solution was transferred to a 100 mL volumetric flask and made up to the mark with distilled water. (Here, 1 mL solution = 100 $\mu\text{g PO}_4^{3-}\text{P}$)

(e) Procedure

(i) Standard Curve

The proportion of 0.5, 1, 2, 4, and 8 ml intermediate phosphate solutions was taken in five different a 100 ml VF and made up to the mark with distilled water. Then, 2 mL standard sample, 5 mL NH_4VO_3 solution, 5 mL $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}$ solution, 5 mL H_2SO_4 was taken in a 50 mL volumetric flask. The absorbance was read against distilled water set at zero absorbance and A wavelength of 450 nm was used to obtain PO_4^{3-} ion absorbance to make a standard curve.

(ii) Absorbance of Sample

Following the same procedure, the absorbance of collected water samples was taken.

(iii) Calculation

The absorbance of samples and standard solution were taken at the wavelength of 450 nm. By using the absorbance, the concentration of samples was obtained directly from the standard curve.

3.5.5.5 Total Alkalinity: Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-) Ions

The concentration of carbonate and bicarbonate ion was determined in titration method.

i. Reagents

(a) Phenolphthalein Indicator

About 0.5 g phenolphthalein was taken in a 100 mL volumetric flask and 50% ethanol was added slowly. The solution was finally made up to the mark with 50% ethanol. After shaking, it was stored in a glass bottle.

(b) Methyl Orange indicator

About 0.5 g methyl orange was taken in a 100 mL volumetric flask and made up to the mark with deionized water. After shaking, it was stored in a glass bottle.

ii. Procedure

Exact 25 mL sample water was taken in a 250 mL conical flask. About 1-2 drops of Phenolphthalein indicator were added to the flask. No color was detected, indicated that carbonate ion (CO_3^{2-}) was absent in the water sample. Then, the same amount of sample water was taken in another flask. About 1-2 drops of methyl orange indicator were added to the flask and orange color was detected, indicated that bicarbonate ion (HCO_3^-) was present in the water sample. Then, the solution was titrated by 0.1N HCl until the color changed to pink.

iii. Calculation

$$\text{Total Alkalinity (CaCO}_3\text{, mg/L)} = \frac{A \times N \times 1000 \times 50}{V}$$

Here, A = Volume of HCl (mL)

N = Normality of HCl

V = Volume of water sample (mL)

3.6 Water Quality Assessment Tools

i) AWQI Method

The commonly used weighted arithmetic water quality index (AWQI) method was used to apprehend the existing water quality for domestic and drinking purpose uses. The calculation followed the equations:

$$WQI = \sum Qi Wi / \sum Wi \dots\dots\dots(1)$$

$$Qi = 100[(Vi - V_0) / (Si - V_0)] \dots\dots\dots(2)$$

Qi = The quality rating scale for each parameter.

Vi = Estimated concentration of *i* th parameter of analyzed water samples.

V₀ = the ideal value of this parameter in pure water

V₀ = 0 (except pH =7.0 and DO = 14.6 mg/l),

Si = recommended standard value of *i* th parameter.

$$Wi = K/Si \dots\dots\dots(3)$$

Wi = The unit weight for each water quality parameter.

K = proportionality constant

$$K = 1/\sum (1/Si) \dots\dots\dots(4)$$

Table 3.2 Water Quality Rating as per AWQI method

WQI value	Rating of water quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very Poor water quality	D
>100	Unsuitable	E

ii) IWQI Method

IWQI is a customary and mostly used method for irrigation water quality assessment, initially developed by Meireles *et al.*(2010). In the assessment EC, Na⁺, Cl⁻, HCO₃⁻ and Sodium Absorption Ratio (SAR) value of water was considered.

The calculation followed the equations:

$$q_i = q_{imax} - [(x_{ij} - x_{inf}) \times q_{iamp} / x_{amp}] \dots\dots\dots(1)$$

q_i = water quality index value

q_{imax} = maximum value of q_i for each class

x_{ij} = the observed value

x_{inf} = the lower value of the class to which the parameters belongs

q_{iamp} = represents the class amplitude

x_{amp} = corresponds to class amplitude which the parameter belongs.

Table 3.3 Parameter limiting values for quality measurement (q_i) calculation

q _i	EC (ds/cm)	SAR (meq/L)	Na ⁺ (meq/L)	Cl ⁻ (meq/L)	HCO ₃ ⁻ (meq/L)
85-100	0.2 ≤ EC < 0.75	2 ≤ SAR < 3	2 ≤ Na < 3	1 ≤ Cl < 4	1 ≤ HCO ₃ < 1.5
60-85	0.75 ≤ EC < 1.5	3 ≤ SAR < 6	3 ≤ Na < 6	4 ≤ Cl < 7	1.5 ≤ HCO ₃ < 4.5
35-60	1.5 ≤ EC < 3.0	6 ≤ SAR < 12	6 ≤ Na < 9	7 ≤ Cl < 10	4.5 ≤ HCO ₃ < 8.5
0-35	EC < 0.2 or EC ≥ 3.0	SAR < 2 or SAR ≥ 12	Na < 2 or Na ≥ 9	Cl < 1 or Cl ≥ 10	HCO ₃ < 1 or HCO ₃ ≥ 8.5

$$w_i = \frac{\sum_{j=1}^k F_j A_{ij}}{\sum_{j=1}^k F_j \sum_{i=1}^n A_{ij}} \dots\dots\dots(2)$$

Here, w_i = weight of the parameter

F = component 1 auto value

A_{ij} = explain ability for parameter i by factor j

i = number of physicochemical parameters

j = number of factors selected in the model varying from 1 to k.

Table 3.4 Weights for the IWQI parameters

Parameters	w _i
EC	0.211
Na ⁺	0.204
HCO ₃ ⁻	0.202
Cl ⁻	0.194
SAR	0.189
Total	1.000

The final equation: $WQI = \sum w_i q_i \dots\dots\dots(3)$ The index values were classified considering the risk of salinity and toxicity to plants as observed in the classifications presented Bernardo (1995) and Holanda and Amorim (1997).

Table 3.5 Restrictions to water use classes

WQI	Water use restriction	Recommendation for plants
85 ≤ 100	No restriction (NR)	No toxicity risk for most plants
70 ≤ 85	Low restriction (LR)	Avoid salt sensitive plants
55 ≤ 70	Moderate restriction (MR)	Plants with moderate tolerance to salts
40 ≤ 55	High restriction (HR)	plants with moderate to high tolerance to salts
0 ≤ 40	Severe restriction (NR)	plants with high salt tolerance

3.7 Secondary Data Collection

(i) Meteorological Data Collection

Secondary meteorological such as Temperature, Humidity and rainfall data of Kalapara station from 1975 to 2015 was collected from Bangladesh Meteorological Department (BMD).

(ii) Hydrological Data Collection

The hydrological such as sea water level of some tide gauge stations and salinity data of the previous few decades were taken from the Permanent Service of Mean Sea Level (PSMSL), Soil Resource Development Institute, and Bangladesh Water Development Board (BWDB).

3.8 Data Analysis

The experimental and collected secondary data were analyzed using various software's and the results were plotted in applicable figures, tables, diagrams and water quality indices.

3.9 Research Lab

The collected water samples were analyzed for various parameters in different laboratories including, the Central Science lab of the University of Rajshahi, Water Research Lab of the Institute of Environmental Science, University of Rajshahi, Bangladesh Chemical, Scientific and Industrial Research Lab, Soil Resource Development Institute lab of Rajshahi.

CHAPTER - 4

RESULTS AND DISCUSSION

The study collected some secondary meteorological and hydrological data of Khepupara (Present named Kalapara) station and some representative water samples of selected estuaries, rivers, canals, ponds and tube-wells of the study area. It analyzed the collected water samples and secondary data accordingly. Finally, the study assessed the impacts of climate change (i.e., meteorological and hydrological) on water quality of the areas. The detailed results of both the laboratory and secondary data analysis are interpreted and described in this chapter in several graphs, tables, charts and figures.

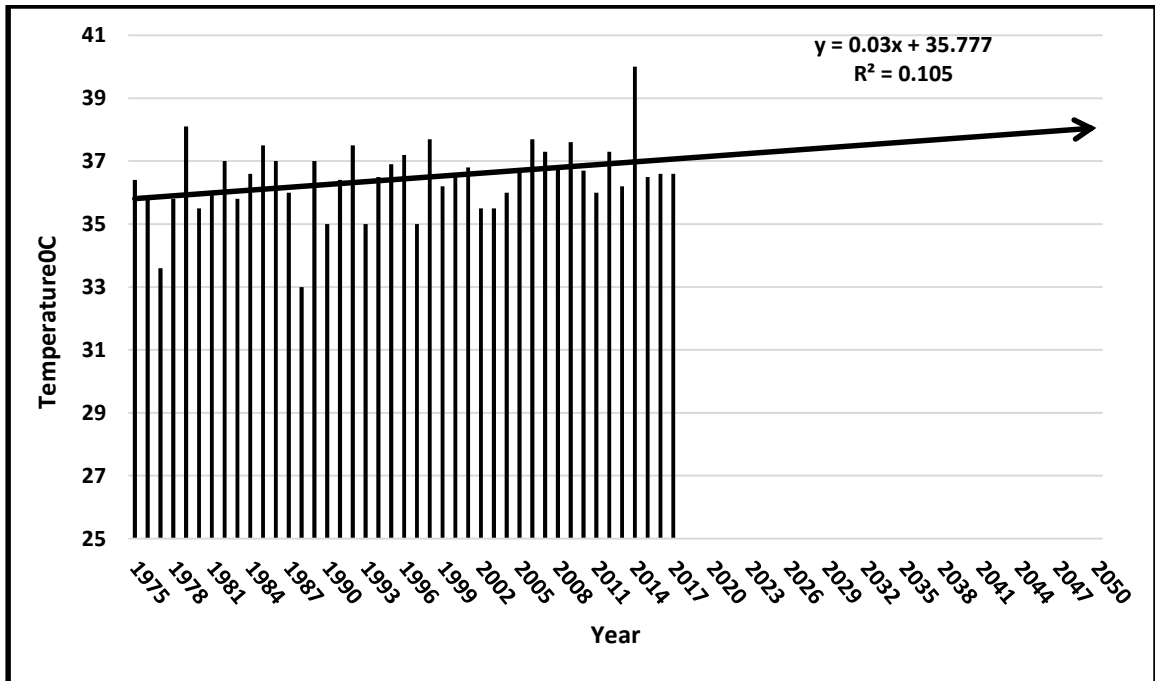
4.1 Meteorological Data Analysis

The long-term meteorological time-series data were recorded between 1975 and 2017 at Kalapara station which have been collected from the Bangladesh Meteorological Department (BMD). The study analyzed the annual maximum, minimum, average temperatures, humidity and rainfall data and the results are interpreted and discussed in the following sections.

4.1.1 Annual Maximum Temperature

The time-series data of the annual maximum temperature at Khepupara (Kalapara) station from 1975 to 2017 were plotted in Fig. 4.1.1. The highest annual maximum temperature was found to be 40°C in 2014 and the lowest annual maximum temperature was 38.1°C in 1987. Fig. 4.1.1 shows an increasing trend of the annual maximum temperature (0.03°C per year), though the magnitude of increasing trend is very low ($R^2 = 0.105$). Mondal *et al.* (2013) showed that the average maximum temperature raised about 0.037°C per year between 1980 and 2010 in the south-west coastal region of Bangladesh. Rahman *et al.* (2015) also studied the regional temperature variation in the coastal areas of Bangladesh and observed an increasing trend of the maximum temperature. Both the studies showed

the increasing trend of the maximum temperature that supports the results of the present study.



Data source: BMD, Dhaka

Fig. 4.1.1 Annual maximum temperature at Khepupara station from 1975 to 2017

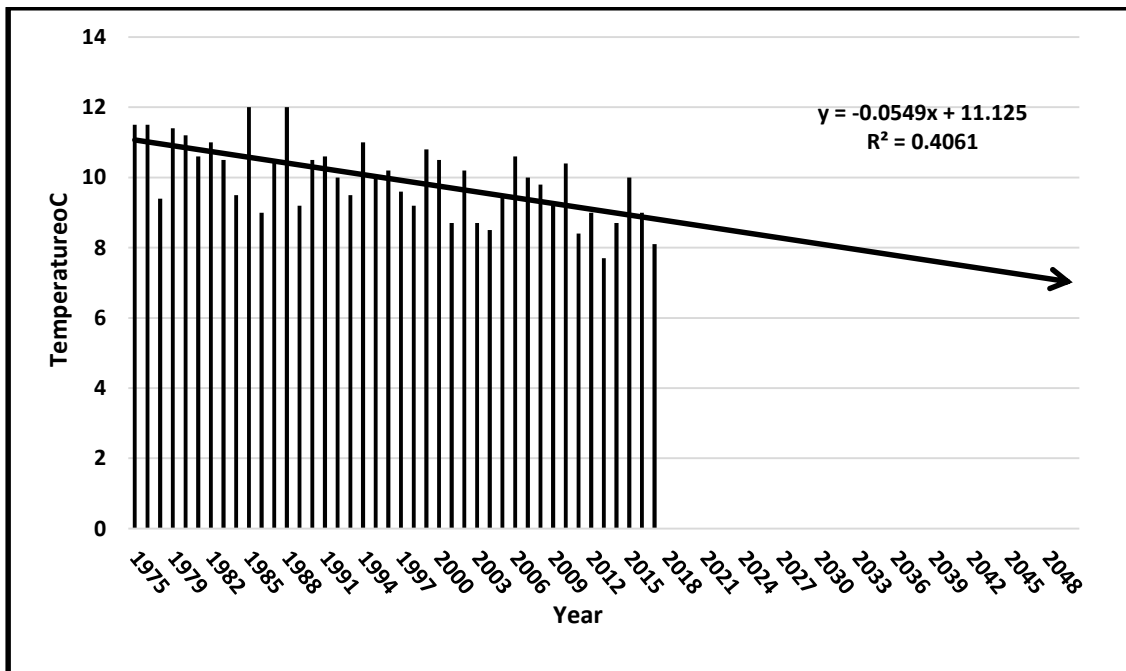
Table 4.1.1 shows that the annual maximum temperature increased about 1.29°C against the base year. The projected temperature in 2050 was estimated to be 2.3°C

Table 4.1.1 Mathematical study of annual maximum temperature at Khepupara station

Duration	Number of Years	Yearly Change (°C)	Total Change (°C)
1975-2017 (Data based)	43	0.03 (Fig. 4.1.1)	1.29
2018-2050 (Projected)	33		0.99
1975-2050 (Total)	76		2.28

4.1.2 Annual Minimum Temperature

The results showed that the highest annual minimum temperature was 12°C in 1985 and the lowest annual minimum temperature was 8°C in 2012. Fig. 4.1.2 shows a decreasing trend, though the magnitude was found to be insignificant ($R^2 = 0.4061$). Nasher *et al.* (2013) studied the changing trend of minimum temperatures from 1950 to 2002 in the northern and southern parts of Bangladesh and the results showed a decreasing trend that supports the present study.



* Data of 1978 is not available

Data source: BMD, Dhaka

Fig. 4.1.2 Annual minimum temperature at Khepupara station from 1975 to 2017.

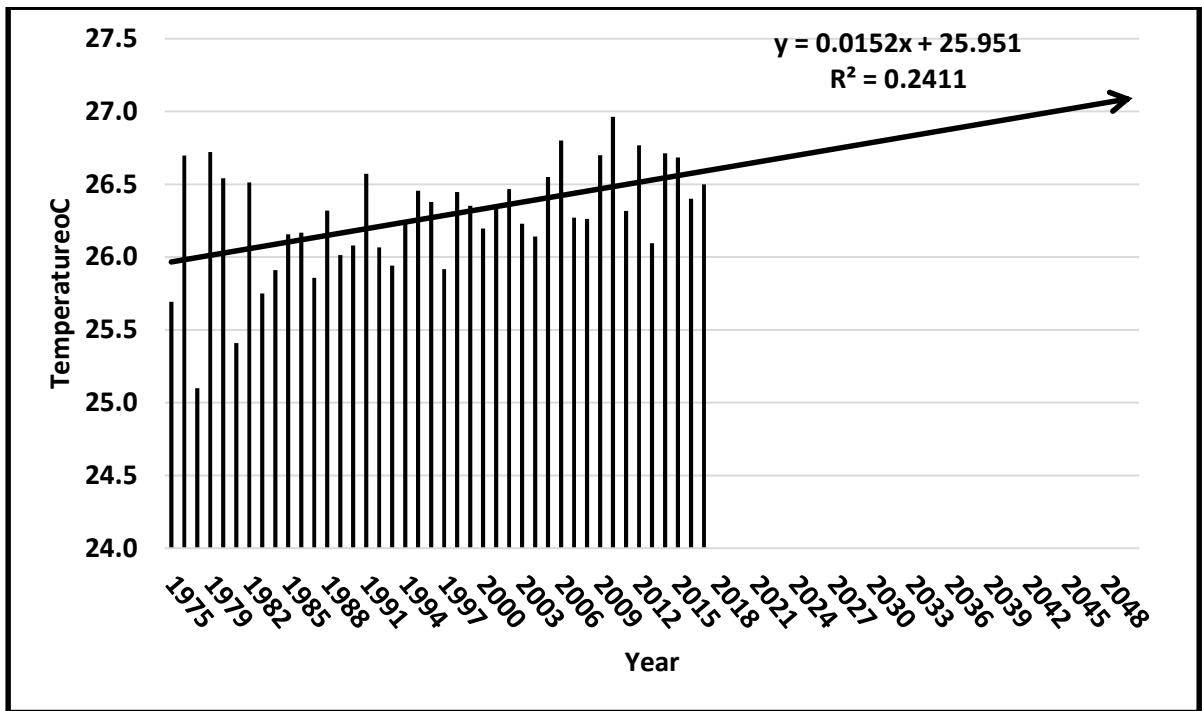
Table 4.1.2 shows that the annual minimum temperature decreased about 2.4°C between 1975 and 2017 and the temperature would be lessened about 4.2°C by the year 2050.

Table 4.1.2 Mathematical study of annual minimum temperature at Khepupara station

Duration	Number of Years	Yearly Change (°C)	Total Change (°C)
1975-2017 (Data based)	43	- 0.0549 (Fig. 4.1.2)	-2.4
2018-2050 (Projected)	33		-1.8
1975-2050 (Total)	76		-4.2

4.1.3 Annual Average Temperature

The recorded annual average temperatures at Khepupara station from 1975 to 2017 are shown in Fig. 4.1.3. The maximum annual average temperature was found to be 27°C in 2010 and the lowest was 25.1°C in 1977. It revealed an increasing trend nonetheless, the magnitude ($R^2 = 0.2403$) described an insignificant change. Rouf *et al.* (2011) studied on the past, present, and future climatic patterns of the north and southwestern parts of Bangladesh between 1979 and 2006, found an increasing trend in annual average temperature. Farooqi *et al.* (2005) used GCMs Climate Scenario generator MAGIC and Regional Climate Model RegCM2 for projected rainfall and temperature of Pakistan based on 1961-1990 data. The Results indicated a progressive change in temperature during the period, and Water quality would suffer from the projected impacts of climate change.



* Data of 1978 is not available

Data source: BMD, Dhaka

Fig. 4.1.3 Annual average temperature at Khepupara station from 1975 to 2017

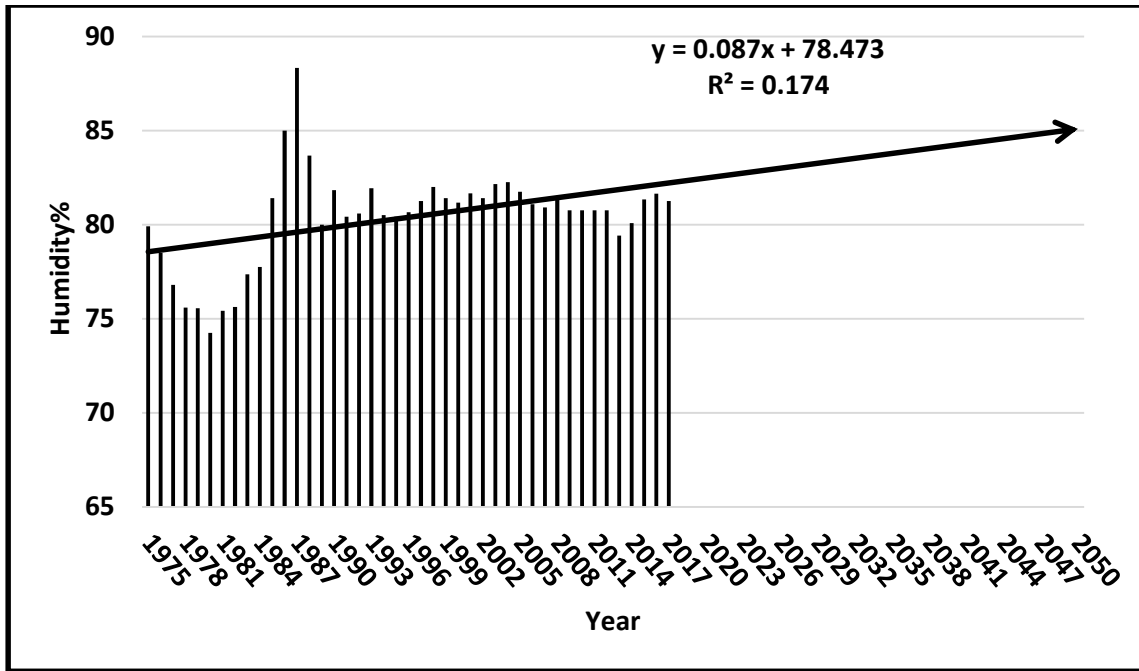
Table 4.1.3 shows that the annual average temperature raised about 0.7°C during 1975 to 2017 and it would be increased around 1.2°C by 2050.

Table 4.1.3 Mathematical study of average annual temperature at Khepupara station.

Duration	Number of Years	Yearly Change (°C)	Total Change (°C)
1975-2017 (Data based)	43	0.0152 (Fig. 4.1.3)	0.7
2018-2050 (Projected)	33		0.5
1975-2050 (Total)	76		1.2

4.1.4 Annual Average Relative Humidity

The annual average relative humidity values at Khepupara station ranges between 74.3-88.3% during 1975 to 2017. Fig.4.1.4 shows an increasing trend but the magnitude was found to be very insignificant.



Data source: BMD, Dhaka

Fig. 4.1.4 Annual relative humidity at Khepupara station from 1975 to 2017.

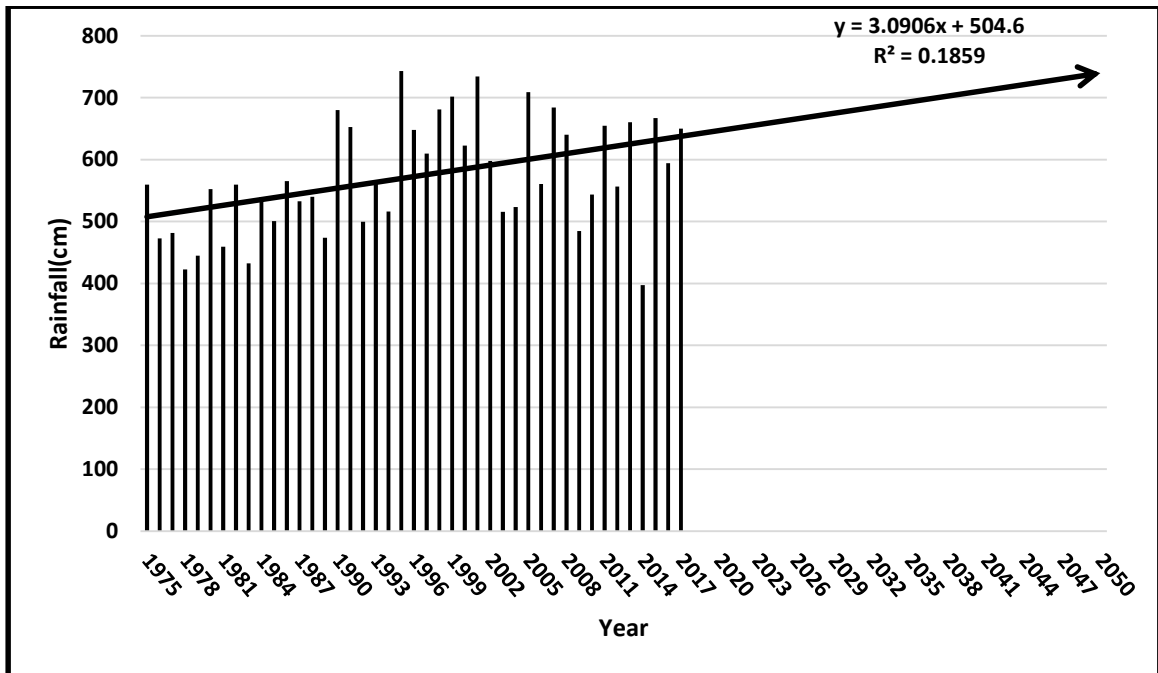
Table 4.1.4 shows that the annual relative humidity raised about 3.7% between 1975 and 2017 and about 6.6 % humidity would be increased by the year 2050.

Table 4.1.4 Mathematical study of annual average humidity at Khepupara station.

Duration	Number of Years	Yearly Change (%)	Total Change (%)
1975-2017 (Data based)	43	0.087 (Fig. 4.1.4)	3.7
2018-2050 (Projected)	33		2.9
1975-2050 (Total)	76		6.6

4.1.5 Annual Average Rainfall

The annual average rainfall data at Khepupara station from 1975-2017 is shown in Fig. 4.1.5. The highest annual average rainfall was found to be 743 cm in 1995 and the lowest was 397 cm in 2014. The trendline was found to be increased about 3.09 cm per year, though the degree was found very low ($R^2 = 0.1859$). Shamsuddin Shaid (2011) studied the variability of the extreme rainfall events in nine stations of Bangladesh during 1958 - 2007 and found a significant increase of annual average rainfall. Hossain *et al.*, (2014) studied the spatial and temporal variabilities of rainfall at eight stations over the south-west coastal areas of Bangladesh between 1940 and 2007 and found a positive increasing trend of annual average rainfall, which supports the findings of the present study.



Data source: BMD, Dhaka

Fig. 4.1.5 The annual average rainfall at Khepupara station from 1975 to 2017

Table 4.1.5 shows that the annual average rainfall raised about 132.8 cm compared 1975 to the study period and would be increased about 234.7 cm by the year 2050.

Table 4.1.5 Mathematical study of annual average rainfall at Khepupara station

Duration	Number of Years	Yearly Change (cm)	Total Change (cm)
1975-2017 (Data based)	43	3.09 (Fig. 4.1.5)	132.8
2018-2050 (Projected)	33		101.9
1975-2050 (Total)	76		234.7

The secondary meteorological data analysis results found some substantial but trivial changes in the annual maximum and minimum temperature, and the average temperature, humidity and rainfall, etc. The trend analysis demonstrates that all the selected meteorological parameters show an increasing trend except, the annual minimum temperature. The study predicted that a long-term meteorological changes could affect the hydrological regimes as well as water quality in the selected coastal areas of Bangladesh.

4.2 Secondary Hydrological Data Analysis

The collected secondary hydrological data such as the mean sea level and salinity of the last few decades were analyzed so that the study can assess the impacts meteorological changes on hydrological systems as well as water quality of the areas. The results and discussion are illustrated in the following sections.

4.2.1 The Mean Sea water Level Assessment

The study evaluated the changes of the seawater level adjacent to the coastal areas of Bangladesh and the neighbor Indian state, West Bengal with the purpose of assessing the impacts of such changes on existing water quality in the area. The study analyzed the collected tide-gauge records of four stations named Cox's Bazar, Khepupara, Hiron point in Bangladesh and Diamond Harbor in India. The analysis results is interpreted and discussed in the subsequent sections.

4.2.1.1 Annual Mean Sea Level at Khepupara Station

The available tide gauge data during 1979 to 2000 of Khepupara station (station ID -1454) plotted in Fig. 4.2.1, where the highest value was recorded to be 7.21 m in 2000 and the minimum was 6.66 m in 1980. It presents a positive increasing trend and the coefficient of determination signifies a strong changing magnitude.

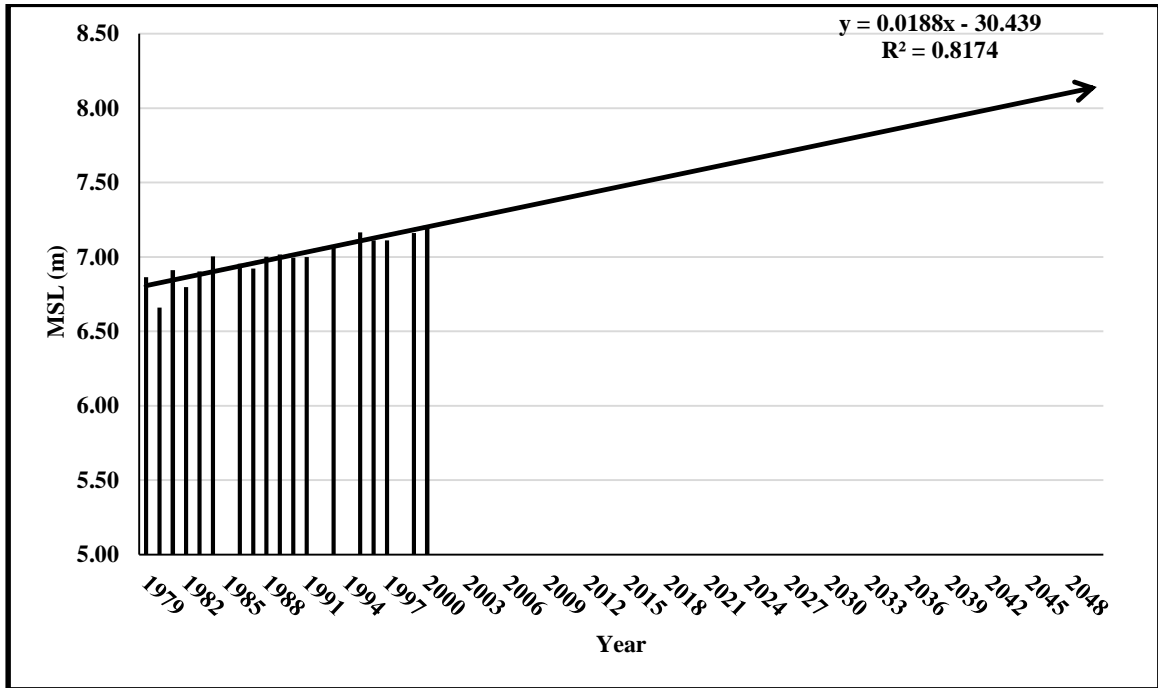


Fig.4.2.1 Tide gauge data at Khepupara station (ID -1454) (Data Source: PSMSL)

Table 4.2.1 describes that the water level of Khepupara station raised up about 0.041 m till 2000 and it would be raised of 1.35 m by the year 2050.

Table 4.2.1 Mathematical study of MSL at Khepupara station

Duration	Number of Years	Yearly Change (m)	Total Change (m)
1979-2000 (Data based)	22	0.0188 (Fig 4.2.1)	0.41
2001-2050 (Projected)	50		0.94
1979-2050 (Total)	72		1.35

4.2.1.2 Annual Mean Sea Level at Cox’s Bazar Station

The available tide gauge data at Cox’s Bazar station (station ID -1476) during 1979 -2000 are shown in Fig. 4.2.2. The maximum value was recorded to be 7.16 in 1985 and the minimum was 6.67 m in 1994. It demonstrates a positive increasing trend, though the degree of changes are found very low ($R^2 = 0.025$).

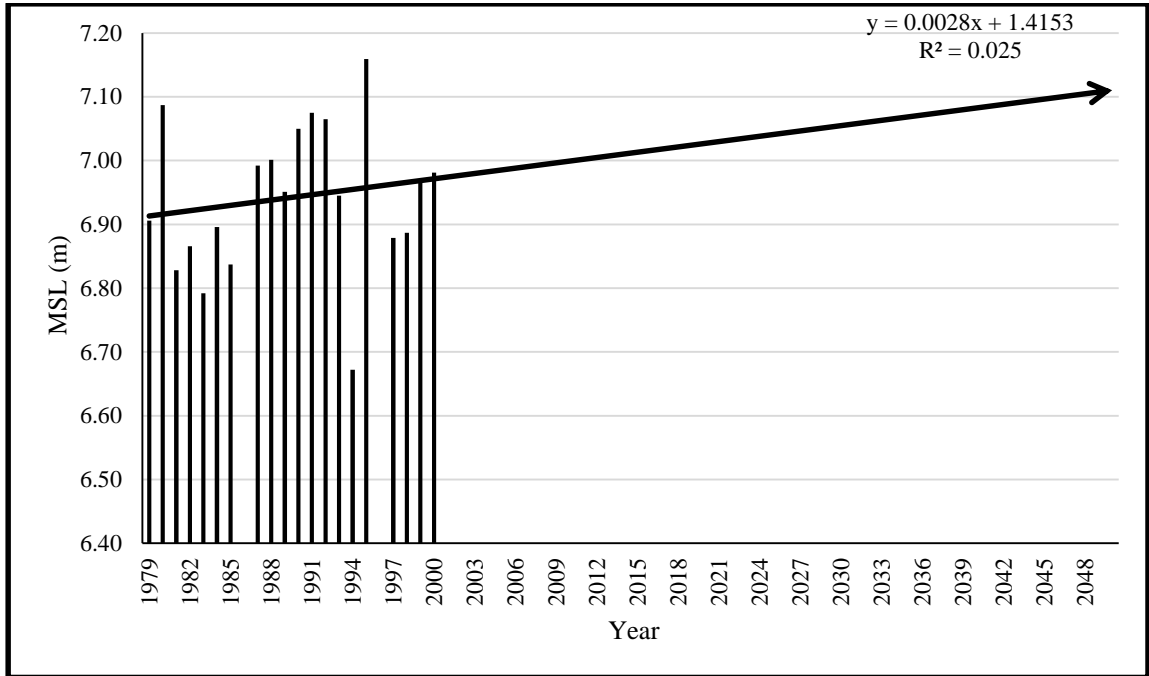


Fig. 4.2.2 Tide gauge data at Cox’s Bazar station (ID -1476) (Data Source: PSMSL)

The calculation table shows that the mean sea water level of Cox’s Bazar station raised up about 0.044 m till 2000 against the base year, 1979. Considering the same changes, the study projected that the mean sea level at Cox’s Bazar station would be raised up about 0.14 m by 2050. (Table 4.2.2)

Table 4.2.2 Mathematical study of MSL at Cox’s Bazar station.

Duration	Number of Years	Yearly Change (m)	Total Change (m)
1979-2000 (Data based)	22	0.002 (Fig 4.2.2)	0.044
2001-2050 (Projected)	50		0.1
1979-2050 (Total)	72		0.14

4.2.1.3 Annual Mean Sea Level at Hiron Point Station

The highest annual mean sea level at Hiron Point station (station ID -1451) recorded to be 7.23 m in 2001 and the lowest was 6.94 m in 1997. Fig. 4.2.3 shows a positive increasing trend, though the magnitude of the change is very insignificant ($R^2 = 0.1307$).

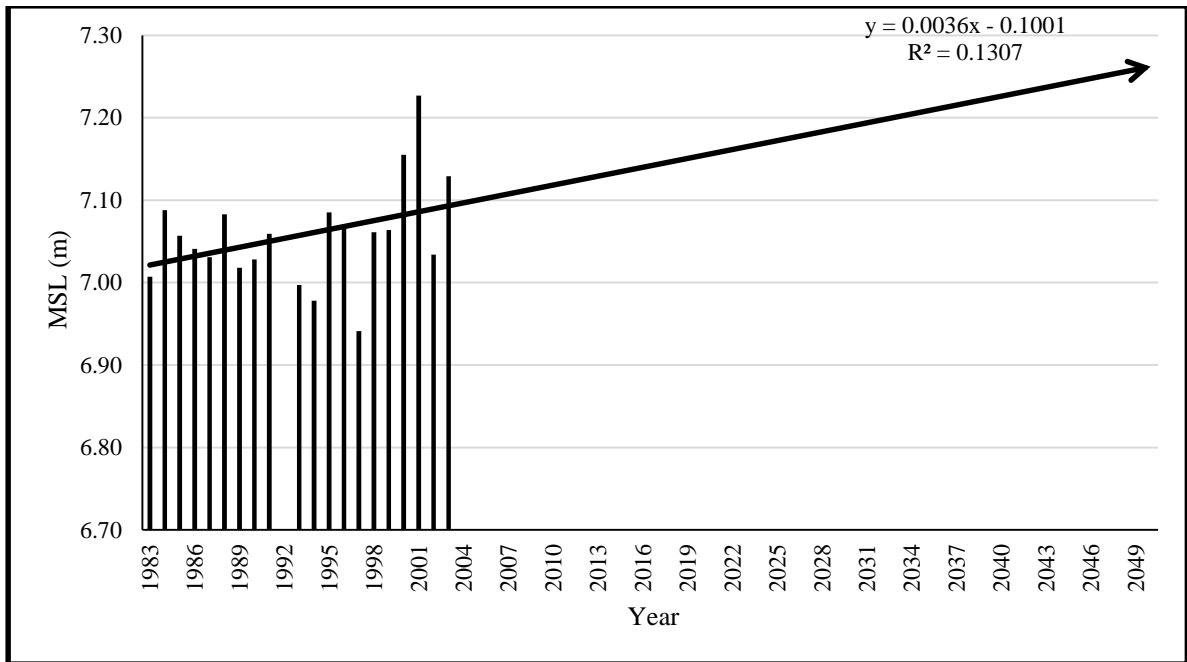


Fig. 4.2.3 Tide gauge data at Hiron Point station (ID -1451) (Data Source: PSMSL)

Table 4.2.3 presents that the mean sea water level of Hiron point station raised up about 0.075 m between 2003 and 2015. It predicts that it would be higher about 0.24 m by the year 2050.

Table 4.2.3 Mathematical study of MSL at Hiron Point station

Duration	Number of Years	Yearly Change (m)	Total Change (m)
1983-2003 (Data based)	21	0.0036 (Fig 4.2.3)	0.075
2004-2050 (Projected)	47		0.169
1983-2050 (Total)	68		0.244

4.2.1.4 Annual Mean Sea Level at Diamond Harbor Station

The tide gauge data at the Diamond Harbor station (station ID -543) during 1948 to 2013 were studied where the highest value was found to be 7.23 m in 2013 and the lowest was 6.88 m in 1963. The recorded data plotted in Fig. 4.2.4, where a positive increasing trend observed. The coefficient of determination is 0.7167 that signifies a strong changing magnitude.

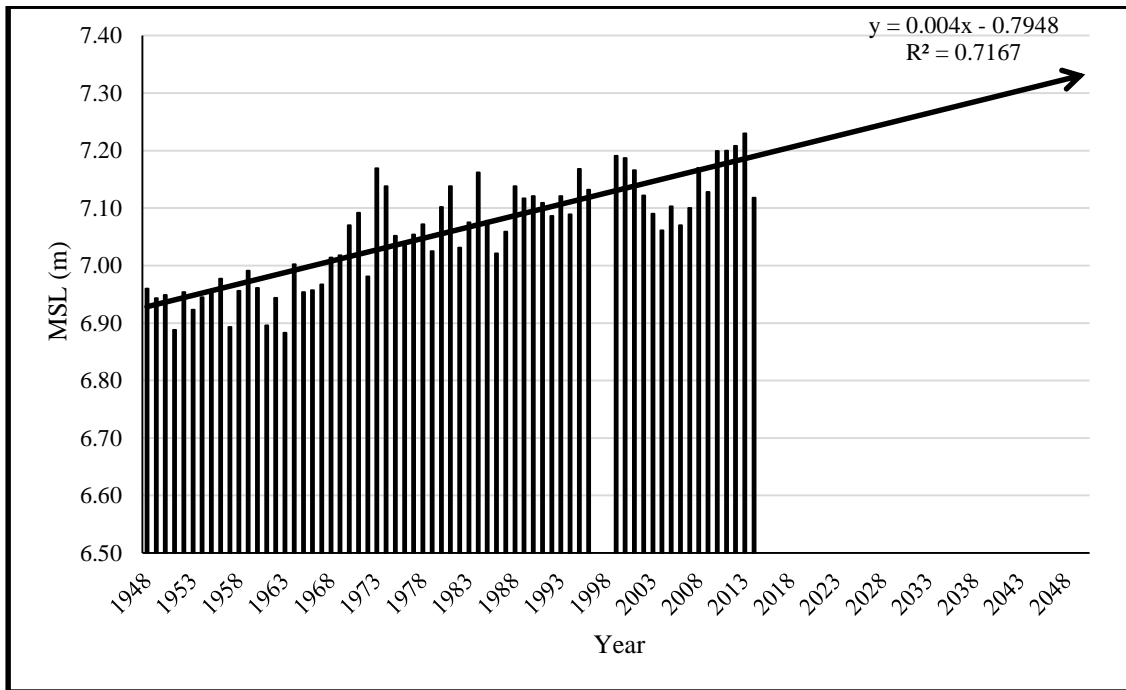


Fig. 4.2.4 Tide gauge data at Diamond Harbor station (ID - 543) (Source: PSMSL)

Table 4.2.4 shows that the water level at the Diamond Harbor station raised about 0.26 m till 2014 and the projected trend line to 2050 illustrates that a total of 0.4 m water level would be added by the year 2050.

Table 4.2.4 Mathematical study of MSL at Diamond Harbor station

Duration	Number of Years	Yearly Change (m)	Total Change (m)
1948-2014 (Data based)	67	0.004 (Fig 4.2.4)	0.26
2015-2050 (Projected)	36		0.14
1948-2050 (Total)	103		0.4

The mean sea water level is considered to be the most important hydrological parameter especially in the coastal areas, which can be influenced by the air temperature, melted ice waters and/or rainfall, etc. A study of McGranahan *et al.* (2007) stated that sea-level rise (SLR) poses a particular threat for the civilization because 10% of the world's population lives in low-lying coastal regions within 10 m elevation of the sea level. Now it is a common consensus amongst the scientists that sea water level is seriously affected with the increasing temperature (i.e., global warming). Global warming potentially affect both natural and anthropogenic changes to temperature, precipitation, sea level and other climatic conditions (FitzGerald *et al.*, 2008). The study found a positive increasing trend in the mean sea level at all the stations (Fig. 4.2.1 - 4) and the maximum change was observed at Khepupara station. It is predicted that the increased sea level would speed up the saline water intrusion to the coastal inland areas and exacerbate the surface and groundwater quality.

4.2.2 River Salinity Assessment

The study considered some secondary EC data during 2001- 2006 and 2012 - 2016 of the Andhermanik River water, (Sampling spot-5) collected by the Soil Resource Development Institute (SRDI), Bangladesh. The highest value was found to be 19.56 ds/cm in 2014 and the lowest was 14.02 ds/cm in 2002. The recorded data plotted in Fig.4.2.5 which shows a positive increasing trend, though the magnitude ($R^2= 0.1653$) is very low.

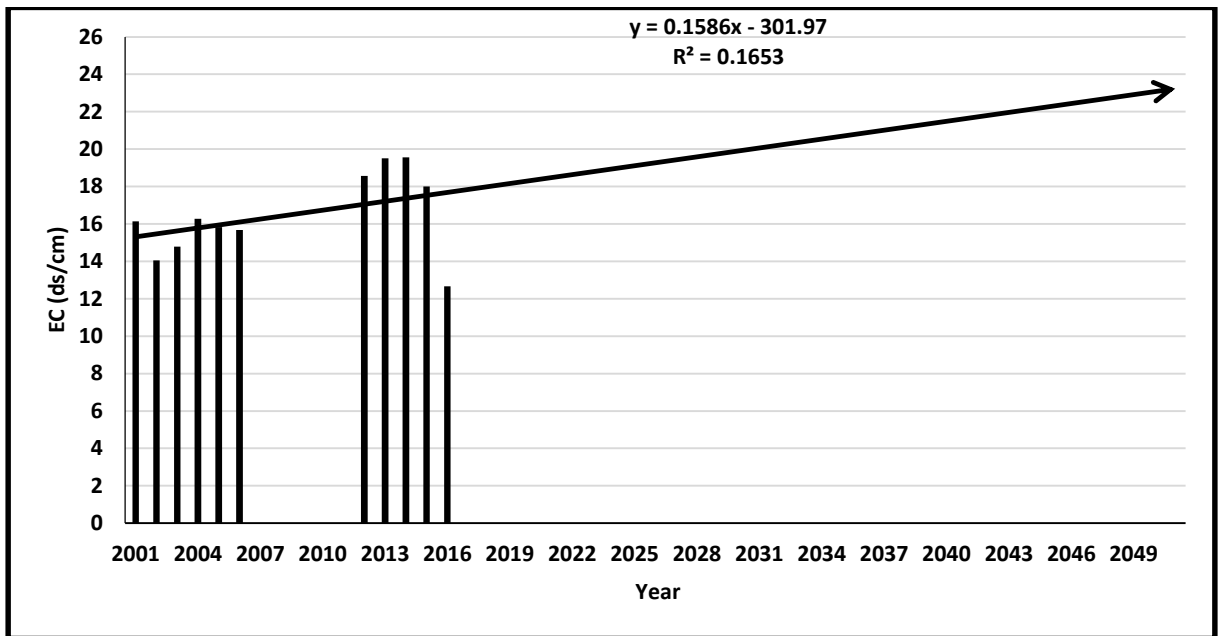


Fig 4.2.5 EC of Andhermanik River water at Kalapara (Data Source: SRDI)

Table 4.2.5 shows that the salinity of the selected river increased about 2.54 ds/cm compared to the base year, 2001. The projected salinity would be increased as 8.09 ds/cm by the year 2050.

Table 4.2.5 Mathematical study of EC value in Andhermanik River

Duration	No. of Years	Yearly Change	Total Change (ds/cm)
2001-2016 (Data based)	16	0.1586 (Fig 4.2.5)	2.54
2016-2050 (Projected)	35		5.55
2001-2050 (Total)	51		8.09

The study already observed some significant change in the meteorological and hydrological regimes during the last few decades in the selected coastal areas of Bangladesh. The study predicted that the climatic (i.e., meteorological and hydrological) change could seriously modify the surface and groundwater quality in the area. Hence, the existing water quality in the selected coastal areas of Bangladesh is elaborately discussing in the following sections.

4.3 Water Sample Analysis

The study analyzed the water samples in respects with some water quality parameters such as water temperature, DO, pH, EC, TDS, TSS, Na⁺, K⁺, Ca²⁺, Mg²⁺, Fe, Cu, Pb, Mn, As, Zn, Cl⁻, SO₄²⁻, NO₃⁻, HCO₃⁻, PO₄³⁻, etc. The observed values were compared to three selective standards followed by the Department of Environment (DoE), Bangladesh, World Health Organization (WHO) and Food and Agricultural Organization (FAO). The reading of water temperature, pH, EC and DO was taken in-situ in the spot and other parameters were examined in the laboratory using standard methods of analysis. The analysis results in different figures, tables, graphs are interpreted and discussed in the following sections.

4.3.1 Surface Water (Estuaries, Rivers and Canals) Samples Analysis

The surface water samples were collected from the selected estuaries, rivers and canals etc. Then, the samples were prepared in the laboratory and analyzed to detect some significant major physicochemical parameters. The analysis results are displayed and described in the subsequent sections.

4.3.1.1 Physical Parameters

The results of the physical parameters such as temperature, dissolved oxygen, pH, DO, EC, TDS and TSS are demonstrated as well as described in the following segments.

4.3.1.1.1 Water Temperature

Temperature is one of the most important factors of water quality, closely follows air temperature. The density of water is depended upon the water temperature. The surface water bodies such as the ponds and rivers or canals of low depth could stratify thermally. Temperature affects the geochemical and chemical reactions and influences the lives of aquatic environment. In the study, the maximum temperature of selected estuaries, rivers and canals was recorded as 33°C during the pre-monsoon season, 2016 and the minimum was 17°C during the post-monsoon season, 2016 (see Appendix 1.1). The highest mean temperature of surface water samples was found to be 31±1°C in the pre-monsoon season and the lowest was 19±0.8°C in the post-monsoon season during the study period. The mean temperature of the monsoon season was found to be 30.1±0.7°C, which was almost

the same as recorded in the pre-monsoon season (Table 4.3.1). The study found that the surface water temperatures were slightly varied with the air temperature in the pre-monsoon and monsoon seasons, whereas, a significant seasonal fluctuation observed during the monsoon to post-monsoon seasons. In the study, the surface water temperature was found to follow the order of pre-monsoon > monsoon > post-monsoon seasons. The study found that the mean temperature of three seasons were within the permissible limit of the DoE (Department of Environment, Bangladesh) standard. Rahman *et al.* (2013) studied on the physicochemical parameters of some coastal rivers in Khulna district during 2008-2009. The results found that the water temperature at four sampling stations ranged from 30 to 31°C in the rainy, 22 to 23°C in the winter and 30.6 to 31.1°C in the summer season. The highest temperature (31.1°C) was observed during the summer season, whereas the lowest temperature was found to be 19°C in winter season, as expected. The findings of the study is quite similar to the present study.

4.3.1.1.2 Dissolved Oxygen (DO)

Dissolved Oxygen is another important component for water quality due to aerobic inhalation and regulates the redox potential in water and sediment. It is considered as an important parameter for assessing water quality because of its influence on the organisms living in the waters. A variance of dissolved oxygen level can affect the water quality. When DO concentration is condensed, aquatic animals are forced to modify their breathing patterns which seriously affects their life cycle. In the fresh water systems such as the lakes, rivers and canals, dissolved oxygen concentrations are varied with seasons, rainfall, locations and water volume. The study recorded the maximum DO value of selected estuaries, rivers and canals to be 7.5 mg/L during the monsoon season 2017 and the minimum was recorded as 6.8 mg/L during the pre- and monsoon season, 2016 (see-Appendix 1.2). The highest mean value was found to be 7.3 ± 0.1 mg/L during the monsoon and post-monsoon season and the lowest was found to be 7.1 ± 0.1 mg/L during the pre-monsoon season (Table 4.3.1). During the study period, the mean DO values were followed the order of monsoon > post-monsoon > pre-monsoon. The observed values were found

within the range of the DoE and WHO standards (Table-4.1) indicating a good water quality in the consideration of dissolved oxygen. The study results found that the selected surface water was suitable for aquatic environment as well as aquatic lives. Rahman *et al.* (2013) studied on some physicochemical parameters of some coastal rivers in Khulna district during 2008-2009. The study result showed that the DO values at four sampling stations range 4.2-7.3 mg/L for the entire year that support the present study.

Table 4.3.1 Bi-yearly descriptive statistics of physical parameters of estuaries, rivers and Canals water in 2016 and 2017

Parameters	Count	Pre- monsoon	Monsoon	Post- monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WH O	FAO
WT ($^{\circ}$ C)	10	31 \pm 1.0	30.1 \pm 0.7	19.0 \pm 0.8	40	-	-
DO (mg/L)	10	7.1 \pm 0.1	7.3 \pm 0.1	7.3 \pm 0.1	6-8	6-8	-
pH	10	7.6 \pm 0.2	8.1 \pm 0.3	7.6 \pm 0.2	6.5-8.5	<8	6-8.5
EC (ds/m)	10	13.1 \pm 8.4	1.1 \pm 0.3	7.0 \pm 4.8	0.75	-	<3.0
TDS(mg/L)	10	11295 \pm 8006	977.9 \pm 257	6634 \pm 4356	1000	1000	2000
TSS(mg/L)	10	251.5 \pm 182	20.1 \pm 8.0	154.5 \pm 94.8	10	-	-

4.3.1.1.3 Total Acidity/Alkalinity (pH)

The pH of the coastal waters holds a remarkable importance to fisheries and coastal resources. Generally, it signifies the degree of acidity or alkalinity in the waters. The higher or lower pH values can modify the water quality. The maximum pH value of selected waters was recorded as 8.5 during the monsoon season, 2016 and 2017. The minimum was recorded as 7.2 during the pre-monsoon season, 2016 and 2017 (see- Appendix 1.3). The highest mean pH value of surface water samples was observed to be 8.1 \pm 0.3 during the

monsoon season and the lowest was 7.6 ± 0.2 during the pre- and post-monsoon seasons (Table 4.3.1). The pH value of selected waters followed in the order of monsoon > post-monsoon > pre-monsoon seasons. The results illustrated that all pH values of the surface water samples were found within the range of the DoE and FAO standards (Table 4.3.1). The existing pH values of selected water sample points are of good quality, which can be used as domestic or industrial or even irrigation purposes. Rahman *et al.* (2013) studied some physicochemical parameters of some coastal rivers in Khulna district during 2008-2009. The report found that the pH values of most the coastal river waters varies from 7.0 to 8.4 which is quite comparable with the present study.

4.3.1.1.4 Electro-Conductivity (EC)

Electro-conductivity (EC) is considered as the most important water quality parameter for measuring the salinity in aquatic ecosystem of the coastal areas. In general, the sea water has a higher sodium and chloride concentrations, so the inland coastal water system can be affected by increasing the concentration of dissolved salts. The maximum EC value of selected estuaries, rivers and canals was found to be 26.5 dS/m during the pre-monsoon season, 2017 and minimum was 0.7dS/m during the monsoon season, 2017 (see-Appendix 1.4). The highest mean EC value was found to be 13.1 ± 8.4 dS/m during the pre-monsoon season whereas the lowest was 1.1 ± 0.3 dS/m during the monsoon season. The mean EC value of the post-monsoon season was found to be 7.0 ± 4.8 dS/m (Table 4.3.1). The study results observed that the salinity started to increase from the beginning of November due to the cessation of the rains and consequent reduction of sweet water flows. Several studies on the coastal water quality found a higher salinity concentration during the pre- and post-monsoon seasons (Shalby *et al.*, 2020 ; Haque *et al.*, 2014; Rahman *et al.*, 2013.; Ladipo *et al.*, 2011) and the results were quite similar to the present findings. Shalby *et al.* (2020) implemented A 2-D hydro-ecological modeling for the lagoon using MIKE21FM. The proposed model was calibrated and validated against the collected water quality records, for two successive years (2011–2013), at twelve monitoring stations throughout the lagoon. The study results showed that climate change has the potential to alter the physical and chemical structure of Lake Burullus, and is expected to change the water temperature and

salinity. Haque *et al.* (2014) studied the water and soil salinity of the coastal rivers at Kalapara Upazila of Patuakhali district over the period from February to April, 2014. The study showed the highest salinity levels were found to be 35.1, 24.8, 38.1, 37.4 and 30.2 dS/m in the pre-monsoon season at the Kuakata sea beach, Tolatoli, Khapravanga, Sonatala and Andhermanik river waters, respectively. A study conducted by Rahman *et al.* (2013) on some physicochemical parameters of the Passur River in the Sundarbans, the world's largest mangrove forest and showed that the EC value widely varied from 4.11 to 33.2 dS/m and the maximum value was found in the pre-monsoon season. Ladipo *et al.* (2011) studied some selected waters of the Lagos Lagoon and found higher EC values during the pre-monsoon season in coastal rivers which was quite analogous to the present study. The results showed that the EC values of selected estuaries, rivers and canals followed the order of pre-monsoon > post-monsoon > monsoon season. The mean values of the pre-monsoon and post-monsoon seasons were found exceeding the permissible limit of the DoE and FAO standards. However, the EC value of the monsoon season was found within the permissible limit of the FAO standard, but it considerably exceeded the DoE standard. The study results indicate that during the dry seasons, the selected surface waters contained high concentration of EC value, so the waters are unusable for industrial, domestic or irrigation purpose usages.

4.3.1.1.5 Total Dissolved Solids (TDS)

Total dissolved solids measure the salinity refers to any minerals, salts, metals, cations and anions dissolved in waters. Generally, TDS are comprised of major inorganic components (i.e, sodium, magnesium, calcium, potassium, bicarbonate, chlorides and sulfates etc.), and some small amount of organic matter that dissolved in water. Brackish and brine waters generally contain TDS in a concentration ranging from 10000 mg/L, 35000 mg/L, respectively (Boyd, 2000). The results showed that the TDS values in selected seasons fairly followed the EC values. The maximum value was found as 25864 mg/L during the pre-monsoon season, 2017 and the minimum was 586 mg/L (Sample ID - 3RW) during the monsoon season, 2017 (see-Appendix 1.5). The highest mean value was found to be 11925 ± 8006 mg/L during the pre-monsoon season and the lowest was 978 ± 257 mg/L

during the monsoon season. The mean EC value of the post-monsoon season was found to be 6634 ± 4356 mg/L (Table 4.3.1). The results showed that the TDS values of selected estuaries, rivers, and canals followed the order of pre-monsoon > post-monsoon > monsoon season. The mean values of the pre- and post-monsoon seasons exceeded the permissible limit of the DoE, WHO and FAO standards and the values in the monsoon season were found within the permissible limit of selected standards. The study makes clear that the waters with higher EC values follow the higher TDS values and the prevailing values during the pre- and post-monsoon season prohibited for regular uses.

4.3.1.1.6 Total Suspended Solids (TSS)

Total Suspended Solids measure the dry weight of suspended particles that are not dissolved in water. A wide variety of materials such as silt, decaying plants and animal matter, industrial wastes and sewage etc. are included in total suspended solids (TSS). High concentration of TSS are problematic for stream health and aquatic lives. The analysis results illustrated the maximum TSS value of selected estuaries, rivers and canals was to be 509 mg/L during the pre-monsoon season, 2017 and minimum was 7 mg/L during the monsoon season, 2017 (see-Appendix 1.6). The highest mean value was found to be 251.5 ± 182 mg/L during the pre-monsoon season and the lowest was 20.1 ± 8 mg/L during the monsoon season. (Table 4.3.1). The results showed the seasonal abundance order of pre-monsoon > post-monsoon > monsoon season. The mean values during three seasons were found to exceed the permissible limit of the DoE standard. The study explicated that the water bodies of the coastal water system contain high concentration of TSS values (>10) due to tidal effects and continuous river or sea beach erosion. The waters with higher TSS values are filled with profuse fragments of soil and silts which impedes the light penetration and such water is unsafe for aquatic environment.

4.3.1.2 Chemical Parameters

The chemical parameters such as Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Bi-carbonate (HCO_3^-), Nitrate (NO_3^-), Phosphate (PO_4^{3-}) and Sulfate (SO_4^{2-}) were determined in the laboratory using standard scientific methods of analysis. The detailed results are interpreted and discussed in the following sections.

4.3.1.2.1 Sodium Ion (Na^+)

Sodium ion is found as the dominated ion in the seawater and estuarine coastal water. Naturally, the sea water contains approximately 3.5% sodium ion, though the concentration of Na^+ is largely varied with several factors such as sweet water runoff and precipitation. Sodium ion is an essential mineral for animals and plants. But, in the coastal aquatic system due to the exceeding the permissible limit sodium is accredited as the most water hazard. The present results showed that the maximum value of Na^+ ion in the selected estuaries, rivers and canals was 2884 mg/L during the pre-monsoon season, 2017 and the minimum was 71 mg/L during the monsoon season, 2016 (see-Appendix 1.7). The highest mean concentration of Na^+ in selected waters was found to be 1425.4 ± 993 mg/L during the pre-monsoon season and the lowest was 113.9 ± 21 mg/L during the monsoon season. During the post-monsoon season the mean concentration was found to be 572.4 ± 320.8 (Table 4.3.2). A similar study was conducted by Rahman *et al.* (2013) on some physicochemical parameters of the Passur River in the Sundarbans, the world's largest mangrove forest. The study results showed that during the rainy, winter and summer season the concentration of sodium (Na^+) range from 329 - 398 mg/L, 899.05 - 915.9 mg/L, 7948 - 8839 mg/L, respectively with an average of 3209.29 mg/L. The present results expose that during the pre-monsoon season, the EC values of selected surface water samples exceed the permissible limits of the DoE, WHO and FAO standards. But, in the course of the post-monsoon season the values crossed over the DoE and WHO standards whereas, throughout the monsoon season the values were found within the permissible limit of selected three standards. The mean concentration of Na^+ found to follow the order of pre-monsoon > post-monsoon > monsoon season. The study found that the coastal water bodies contain a

higher concentration of Na^+ which apparently follow the higher EC and TDS values that were described in the earlier sections. The values exceeded the standard permissible limits (Table 4.3.2) indicating unsuitable for domestic, industrial and irrigation purpose uses.

4.3.1.2.2 Potassium Ion (K^+)

Potassium is considered as one of the important minerals, plays a vital role in nerve functions of living organisms. Generally, the sea water contains about 400 ppm, but the rivers encompass only 2-3 ppm potassium. Through weathering process from oceanic basalts and granite, a large amount of potassium deposit to the sea water and makes the variance between the sea and rivers water. The results describe that the maximum concentration of K^+ in the selected estuaries, rivers and canals water found to be 66 mg/L during the pre-monsoon season, 2017 and the minimum was 2.8 mg/L during the monsoon season, 2016 (see-Appendix 1.8). The highest mean concentration of K^+ of selected waters was 37.1 ± 19 mg/L for the period of pre-monsoon and the lowest was 4.3 ± 1.2 mg/L throughout the monsoon season (Table 4.3.2). The mean concentration of potassium ion was found higher during the pre-monsoon season whereas, the lower concentration was observed in the monsoon season, as was expected. The mean values during the pre- and post-monsoon seasons surpassed the permissible limits of the DoE and FAO standards. But, in the course of the monsoon season, the values were found within the permissible limit of selected standards. The results showed that the selected surface water contained higher potassium (>10 mg/L) in the dry season and therefore, the waters were not suitable for irrigation uses in terms of K^+ ion.

Table 4.3.2 Bi-yearly descriptive statistics of chemical parameters of estuaries, rivers and canals water in 2016 and 2017

Parameters (mg/L)	Count	Pre- monsoon	Monsoon	Post- monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WHO	FAO
Na ⁺	10	1425.4 \pm 993	113.9 \pm 21	572.4 \pm 320.8	200	200	920
K ⁺	10	37.1 \pm 19	4.3 \pm 1.2	23.1 \pm 14	12	-	15
Ca ²⁺	10	45.4 \pm 30	17.0 \pm 4.4	29.2 \pm 18.6	75	-	400
Mg ²⁺	10	97.3 \pm 66	14.8 \pm 3.6	61.1 \pm 41.6	30-35	-	60
Cl ⁻	10	2435 \pm 1512	183 \pm 36.7	913.3 \pm 532.4	150-650	250	1065
SO ₄ ²⁻	10	366.8 \pm 245	21.1 \pm 5.7	88.2 \pm 58.4	400	250	960
NO ₃ ⁻	10	2.2 \pm 0.3	2.5 \pm 0.6	1.5 \pm 0.4	10	-	<10
HCO ₃ ⁻	10	187 \pm 37.6	274.3 \pm 12.9	109.3 \pm 5.2	200-500	-	610
PO ₄ ³⁻	10	0.8 \pm 0.1	1.5 \pm 0.2	1.2 \pm 0.2	-	-	2.0

4.3.1.2.3 Calcium Ion (Ca²⁺)

Calcium is naturally present in water, dissolves from the several rocks such as limestone, calcite, dolomite, etc. Generally, the sea water contains <400 ppm, but does not maintain the uniformities. The rivers water holds small amount of calcium such as 2-3 ppm. The higher concentration of calcium is categorized as hard water, creates problem in domestic and industrial uses. The present study measured the maximum concentration of Ca²⁺ as 92 mg/L during the pre-monsoon season, 2017 and minimum was 10 mg/L during the monsoon season, 2016 (see-Appendix 1.9). The highest mean concentration of Ca²⁺ of selected estuaries, rivers and canals found to be 45.4 \pm 30 mg/L during the pre-monsoon season and the lowest was 17.0 \pm 4.4 mg/L during the monsoon season (Table 4.3.2). So,

the mean concentration of calcium ion followed the order of pre-monsoon > post-monsoon > monsoon season. The mean values of three seasons found within the permissible limits of the DoE and FAO standards which indicates that the selected waters can be used in the domestic, industrial and irrigation purposes.

4.3.1.2.4 Magnesium Ion (Mg^{2+})

Magnesium, an alkali earth metal is naturally found as Mg^{2+} in water, dissolves from several rocks such as dolomite, magnetite, etc. Magnesium is washed from rocks and subsequently dissolved in water. The higher concentration of magnesium considered as hard water, can be problematic in domestic and industrial usages. The results observed that the maximum concentration of Mg^{2+} in selected estuaries, rivers and canals water found as 178 mg/L during the pre-monsoon season, 2017 and minimum was 9 mg/L during the monsoon season, 2016 (see-Appendix 1.10). The highest mean concentration of Mg^{2+} found to be 97.3 ± 66 mg/L during the pre-monsoon season and the lowest was 14.8 ± 3.6 mg/L during the monsoon season (Table 4.3.2). According to the abundance, the mean concentration of Mg^{2+} followed the order of pre-monsoon > post-monsoon > monsoon season. The mean values during the pre- and post-monsoon seasons found to exceed the permissible limits of the DoE and FAO standards, whereas during the monsoon season the values were found within the permissible limit of both standards. The study found that during the dry season, the coastal water bodies contained a higher concentration of magnesium. Throughout the period, the values considerably exceeded the nominated standards (Table 4.3.2) and therefore, the selected waters were not recommended for domestic, industrial and irrigation purpose uses.

4.3.1.2.5 Chloride Ion (Cl⁻)

Chloride ion is another major ion in the sea water and estuarine coastal waters. Naturally, the sea water contains approximately 35 ppt chloride ion, but the concentration can be largely differed due to fresh water runoff and huge precipitation. In water, chloride ion originates from the rock and soil and the ion can be found as various soluble salts in water. The seawater contributes very high amount of chloride, which mixes up with fresh water due to semi-diurnal tidal variation. In coastal aquatic system due to crossing the allowable limit, chloride ion is attributed as one of the most water hazard. The result showed that the maximum concentration of Cl⁻ in selected estuaries, rivers and canals water was 4327 mg/L during the pre-monsoon season, 2016 whereas the minimum was 114 mg/L during the monsoon season, 2016 (see-Appendix 1.11). The highest mean concentration of Cl⁻ found as 2435±1512 mg/L for the period of the pre-monsoon season and the lowest was 183±36.7 mg/L for the duration of the monsoon season. Throughout the post- monsoon season the mean concentration found as 913.3±532.4 mg/L (Table 4.3.2). Muhibbullah *et al.* (2005) observed 200, 550, 2800 and 7200 mg/L of dissolved chlorine in the river water of the Rupsha, Passur, Shippa, and Arpangasia rivers, respectively. Rahman *et al.*(2013) studied the chloride ion concentration in some coastal waters in Khulna district, Bangladesh. They found the annual mean chloride ion concentration of 13-4381 mg/L in Mongla, 13-4381 mg/L in Dangmari, 12.5 - 4672 mg/L in Koromjol rivers, and 11.99 - 4422 mg/L in Koromjol Creek . The findings of both studies quite comparable with the present study. The present result illustrates that the mean values during the pre-monsoon and post-monsoon seasons exceeded the permissible limits of the DoE, WHO and FAO standards. But, in the course of the monsoon season the values remain within the permissible limit of designated standards. The mean concentration of chloride ion followed the order of pre-monsoon > post-monsoon > monsoon season. During the dry season, the chloride ion concentration was gradually elevated due to dehydration. Throughout the summer, the values are increased up and reached to the highest level. So, during this period the selected waters are supposed to inappropriate for any domestic, industrial or even agricultural purpose uses.

4.3.1.2.6 Sulfate Ion (SO₄²⁻)

Sulfate is another major dissolved elements of water can be found almost all natural waters. The rocks and soil are the main source of sulfate is dissolved and found as SO₄²⁻ in water. The present results found the maximum concentration of SO₄²⁻ to be 705 mg/L during the pre-monsoon season, 2017 and minimum was 14 mg/L during the monsoon season, 2017 (see-Appendix 1.12). The highest mean concentration of SO₄²⁻ of selected estuaries, rivers and canals found to be 366.8±245 mg/L during the pre-monsoon season whereas the lowest was 21.1±5.7 mg/L during the monsoon season (Table 4.3.2). The mean concentration of sulfate ion followed the order of pre-monsoon > post-monsoon > monsoon season, respectively. Around the year, the mean values were found within the permissible limits of the DoE, WHO and FAO standards which indicate that the selected waters can be used in the domestic, industrial and irrigation purposes in term of sulfate ion.

4.3.1.2.7 Bi-carbonate Ion (HCO₃⁻)

Bi-carbonate is a basic dissolved ion in water that comes from the dissociation of carbon dioxide. In water, it controls the buffering capacity and measures the pH value or acidified concentration. The results found the maximum concentration of HCO₃⁻ in the estuaries, rivers or canals was 289 mg/L during the monsoon season, 2016 and minimum was 90 mg/L during the post-monsoon season, 2017 (see- Appendix 1.13). The highest mean concentration of HCO₃⁻ ion found to be 274.3±12.9 mg/L during the monsoon season and the lowest was 109.3±5.2 mg/L during the post-monsoon season (Table 4.3.2). In the study, the mean concentration of HCO₃⁻ followed the order of monsoon > post-monsoon > pre-monsoon seasons. The mean values during the pre-monsoon, monsoon and post-monsoon seasons were found within the permissible limits of the DoE and FAO standards indicating good quality in terms of bicarbonate ion.

4.3.1.2.8 Nitrate (NO₃⁻) and Phosphate (PO₄³⁻) Ions

The maximum concentration of NO₃⁻ found to be 3.5 mg/L during the monsoon season, 2016 and 2017, and the minimum was 1.0 mg/L during the post-monsoon season, 2017 (see-Appendix 1.14). The highest mean concentration of nitrate ion were 2.2±0.3, 2.5±0.6

and 1.5 ± 0.4 mg/L during the pre-monsoon, monsoon and post-monsoon seasons, respectively. The maximum concentration of PO_4^{3-} was found to be 1.9 mg/L during the monsoon season, 2016 and the minimum was 0.6 mg/L during the pre-monsoon season 2016. (See-Appendix 1.15). The highest mean concentration of phosphate ions were 0.8 ± 0.1 , 1.5 ± 0.2 and 1.2 ± 0.2 during the pre-monsoon, monsoon and post-monsoon seasons, respectively (Table-4.3.2). Around the year, the mean values of both ions were found within the permissible limits of both the standards. The study observed that nitrate and phosphate ion have trivial effect on the coastal waters.

Table 4.3.3 Bi-yearly descriptive statistics of trace elements of estuaries, rivers and Canals water in in 2016 and 2017

Parameters (mg/L)	Count	Pre-monsoon	Monsoon	Post-monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WHO	FAO
Fe (Total)	10	0.298 ± 0.279	0.094 ± 0.106	0.21 ± 0.1	0.3-1	0.3	5.0
Cu (Total)	10	0.101 ± 0.150	0.017 ± 0.017	0.05 ± 0.06	1.0	2.0	0.2
Pb (Total)	10	0.009 ± 0.150	0.005 ± 0.014	0.004 ± 0.002	0.05	0.01	5.0
As (Total)	10	0.002 ± 0.001	0.001 ± 0.00	0.002 ± 0.00	0.05	0.01	0.1
Mn (Total)	10	0.008 ± 0.001	0.002 ± 0.003	0.007 ± 0.007	-	-	0.2
Zn (Total)	10	0.008 ± 0.010	0.001 ± 0.001	0.005 ± 0.006	-	3.0	2.0

4.3.1.3 Trace Elements

The study examined some trace elements such as iron, copper, lead, arsenic, manganese, and zinc in surface water samples during 2016 and 2017. The maximum values of Fe, Cu, Pb, As, Mn and Zn were 0.907, 0.394, 0.043, 0.004, 0.029, 0.34 mg/L, respectively (See-Appendix 1.16-21). The maximum mean value of Fe, Cu, Pb, As, Mn and Zn found to be 0.298 ± 0.279 , 0.101 ± 0.150 , 0.009 ± 0.150 , 0.002 ± 0.001 , 0.008 ± 0.001 , 0.008 ± 0.010 ,

respectively (Table-4.3.3). In the study, the mean concentration of selected trace elements followed the order of pre-monsoon > post-monsoon > monsoon seasons, respectively. Throughout three seasons, the observed values were found within the permissible limit of the designated standards.

4.3.1.4 Water Type Assessment

Water type is an important factors of water quality that helps to assess the characteristics of water. The coastal water system is influenced by the mixed effect of saline and sweet waters. The estuarine as well as low lying area have an effect of tidal bores and sweet water pressure from the upstream regions. Therefore, study targeted to assess the water type of the study area. The Piper (1953) diagram is commonly used in determining the water type which recognizes the hydro chemical facies and describe the water type (Wen *et al.*, 2005).

(i) Water Type in Pre-monsoon Season

The estimated values of the cations and anions of the estuaries, rivers and canals water samples of the pre-monsoon season plotted in a Piper trilinear diagram (Fig. 4.3.1). The cation diagram shows that the major water samples contained higher $\text{Na}^+ + \text{K}^+$ than Ca^{2+} and Mg^{2+} . The concentration of Na^+ was found higher in all samples compare to K^+ , hence, Na^+ was the dominant cation. (Table 4.3.2). The anion diagram shows that the major water samples contained higher Cl^- than SO_4^{2-} and HCO_3^- and so, the dominance of Na^+ and Cl^- indicates Na-Cl water type in surface waters during the pre-monsoon season. A previous researcher of this Institute used the piper diagram to find out the water type of groundwater in Rajshahi City, Bangladesh and found Ca- HCO_3 water type (Helal Uddin *et al.*, 2013).

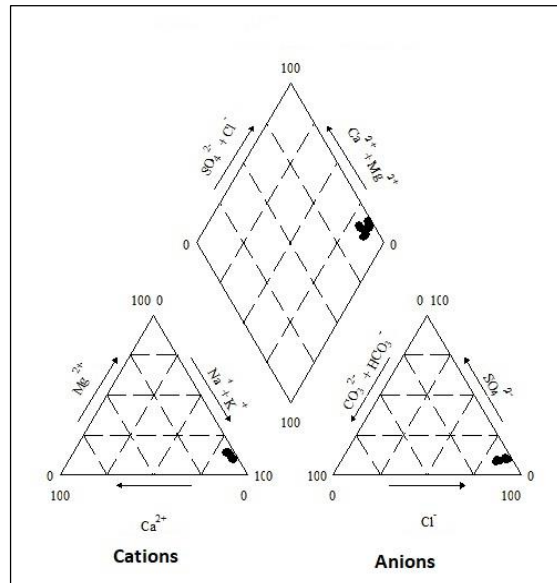


Fig. 4.3.1 Water type of the estuaries, rivers and canals in pre-monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$ and anions were $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{NO}_3^- > \text{PO}_4^{3-}$. Fig.4.3.2 shows the average concentration of the dominant ions.

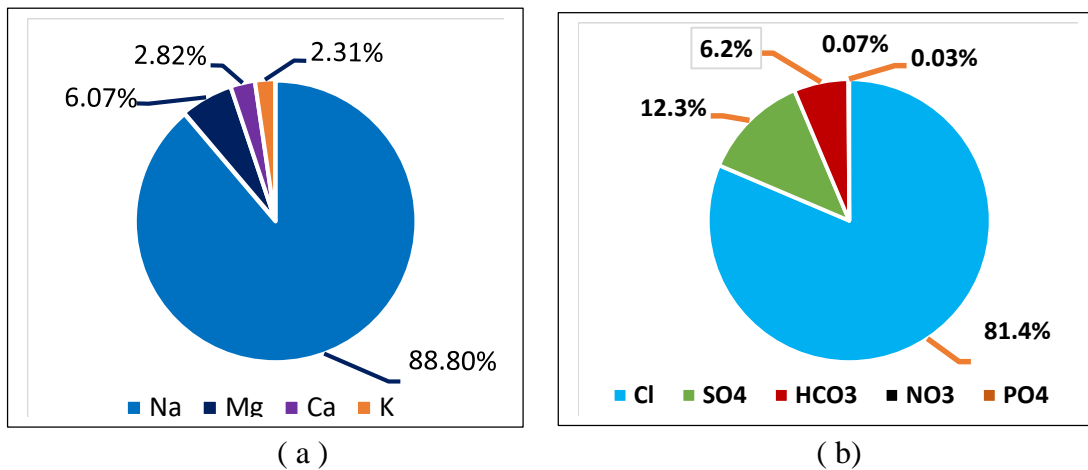


Fig.4.3.2 The proportion of major cations (a) and anions (b) in pre-monsoon season

(ii) Water Type in Monsoon Season

The values of the estuaries, rivers and canals water samples of the monsoon season plotted in a Piper trilinear diagram (Fig. 4.3.3). The cation diagram shows that the major water samples contained higher $\text{Na}^+ + \text{K}^+$ than Ca^{2+} and Mg^{2+} , Nevertheless, the concentration of K^+ found to be very low (Table 4.3.2). The anion diagram shows a mixed dominance of anions, i.e., Cl^- and HCO_3^- in water samples and so, the dominance of Na^+ in cations and $\text{Cl}^- + \text{HCO}_3^-$ in anions indicates Na-Cl- HCO_3 water type during the monsoon season.

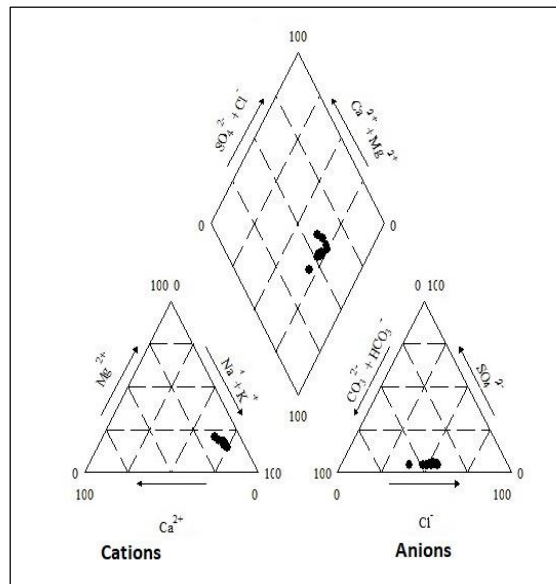


Fig. 4.3.3 Water type of the estuaries, rivers and canals in monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$ and anions were $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$. Fig. 4.3.4 shows the average concentration of the dominant ions.

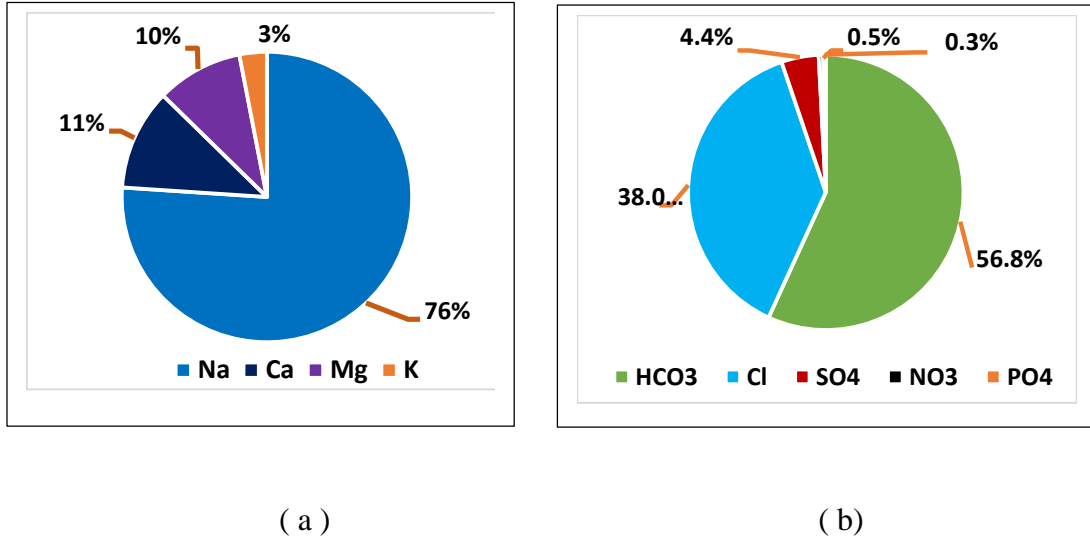


Fig.4.3.4 The proportion of major cations (a) and anions (b) in monsoon season

(iii) Water Type in Post-monsoon Season

The obtained values of the post-monsoon season plotted in a Piper trilinear diagram (Fig. 4.3.5). The cation diagram shows that the major water samples contain higher $\text{Na}^+ + \text{K}^+$ than Ca^{2+} and Mg^{2+} , though the concentration of K^+ found to be very low (Table 4.3.2). The anion diagram shows that the major water samples contained higher Cl^- than SO_4^{2-} and HCO_3^- ion and so, the dominance of Na^+ in cations and Cl^- in anions indicates Na-Cl water type during the post-monsoon season.

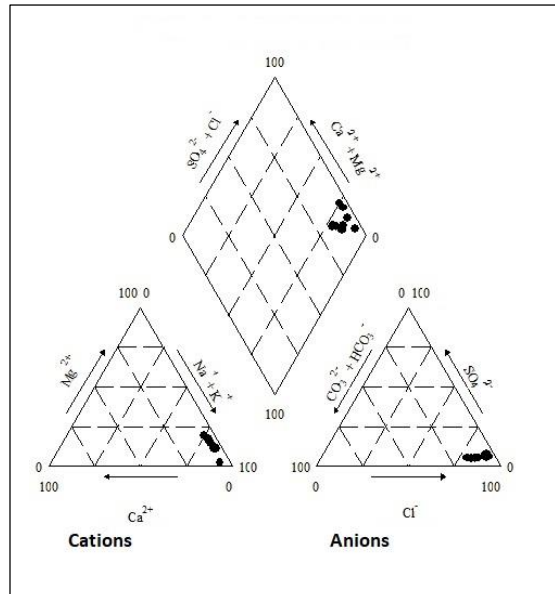
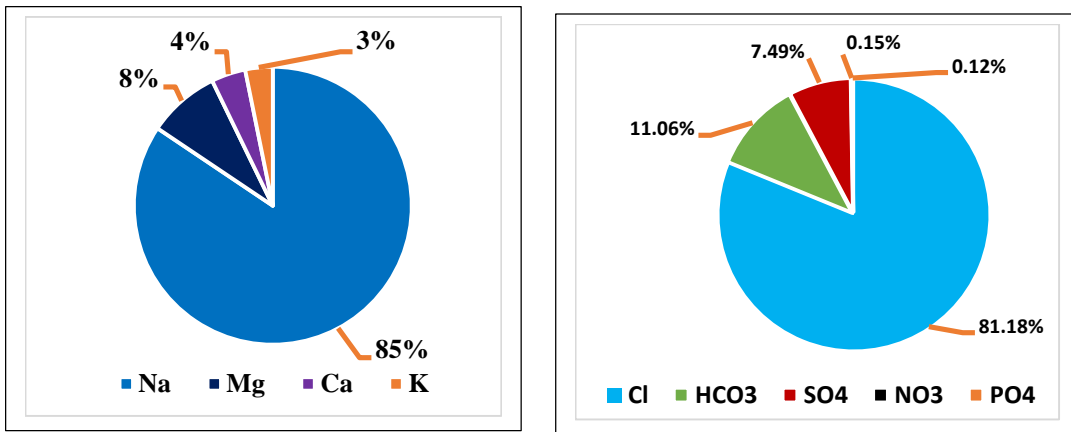


Fig. 4.3.5 Water type of the estuaries, rivers and canals in post- monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$ and anions $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$. Fig.4.3.6 shows the average concentration of the dominant ions.



(a)

(b)

Fig.4.3.6 The proportion of major cations (a) and anions (b) in post-monsoon season

The study explained that during the monsoon season, the concentration of chloride ion was decreased due to the increasing of precipitation and sweet water pressure from the upstream regions. So, a mixed water type was observed during the monsoon period. Again, during the pre-monsoon and post-monsoon season, the concentration of chloride ion was considerably increased due to evaporation and lower pressure of sweet water flows. Nonetheless, throughout the year except the rainy season, chloride ion was found as the predominant ion of total anions. So, throughout the pre-monsoon and post-monsoon seasons, the water type of the estuaries, rivers and canals were found to be Na-Cl and a mixed Na-HCO₃-Cl types observed especially during the monsoon season.

4.3.2 Surface (Ponds) Water Sample Analysis

The study collected ten pond water samples from the selected area and analyzed with a view to assess the existing water quality. The sample analysis results are illustrated and discussed in next sections.

4.3.2.1 Physical Parameters

The reading of some physical parameters such as temperature, dissolved oxygen, pH and EC were recorded in the spot. Other physical parameters such as TDS and TSS were measured in the laboratory by using evaporation method. The analysis results of the described parameters

4.3.2.1.1 Water Temperature

The maximum temperature of selected ponds was recorded to be 32°C during the monsoon season, 2016 and minimum was 18°C during the post-monsoon season, 2016 (see-Appendix 1.1). The highest mean temperature found to be 30.2±0.6 during the pre- and monsoon seasons and the lowest was 19±0.4°C during the post-monsoon season (Table 4.3.4). The recorded values found to be very close with the air temperature. The temperature of selected ponds followed the order of pre-monsoon > monsoon > post-

monsoon season. The mean temperature of three seasons were found within the permissible limit of the DoE standard.

4.3.2.1.2 Dissolved Oxygen

The maximum DO value of selected ponds was recorded to be 7.5 mg/L during the monsoon season, 2017 and minimum was 7.0 mg/L during the pre- and monsoon season, 2016 (see-Appendix 1.2). The highest mean value was found to be 7.2 ± 0.1 during the monsoon and post-monsoon season and the lowest was 7.1 ± 0.1 mg/L during the pre-monsoon season (Table 4.3.4). The mean DO values of selected ponds followed the order: monsoon > post-monsoon > pre-monsoon season. The values were found within the range of the DoE and WHO standards (Table 4.3.4) indicating a good quality for aquatic environment. However, the predicted increase in mean temperature may influence DO in the areas. Chang et al. (2015) assessed the impacts of climate change on the water quality of Hsinshan Reservoir, Taiwan, using CE-QUAL-W2 simulations. The study observed that the increased temperature enhanced the probability of deep-layer oxygen depletion and oversupply of nutrients leading to algae growth.

Table 4.3.4 Bi-yearly descriptive statistics of physical parameters of ponds water in 2016 and 2017

Parameters	Count	Pre-monsoon	Monsoon	Post-monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WHO	FAO
WT ($^{\circ}$ C)	10	30.2 \pm 0.6	30.2 \pm 0.8	19.3 \pm 0.4	-	-	-
DO (mg/L)	10	7.1 \pm 0.1	7.2 \pm 0.1	7.2 \pm 0.0	6-8	-	-
pH	10	7.7 \pm 0.1	7.9 \pm 0.6	7.6 \pm 0.3	6.5-8.5	<8	6-8.5
EC (ds/m)	10	1.2 \pm 0.2	0.6 \pm 0.04	0.9 \pm 0.0	0.75	-	<3.0
TDS (mg/L)	10	1076 \pm 182.6	595.0 \pm 41.1	852. \pm 31.4	1000	1000	2000
TSS (mg/L)	10	22.5 \pm 8.1	7.9 \pm 2.8	19 \pm 4.3	10	-	-

4.3.2.1.3 Total Acidity or Alkalinity (pH)

The maximum pH of selected ponds was recorded to be 8.4 during the monsoon season, 2016 and 2017. The minimum value recorded to be 6.3 during the monsoon season, 2016 (see-Appendix 1.3). The highest mean pH value of pond water samples observed to be 7.9 \pm 0.6 during the monsoon season and the lowest was 7.6 \pm 0.3 during the post-monsoon season (Table 4.3.4). The mean pH of selected ponds followed the order of monsoon > post-monsoon > pre-monsoon season. Around the year, the values were found within the permissible limit of three standards (Table 4.3.4) indicating a good quality in terms of pH.

4.3.2.1.4 Electro-Conductivity (EC)

The study results found that the maximum EC value of selected ponds was 1.6 dS/m during the pre-monsoon season, 2016 and minimum was 0.5 dS/m during the monsoon season, 2016 (see-Appendix 1.4). The highest mean value was found to be 1.2 \pm 0.2 during the pre-

monsoon season and the lowest was 0.6 ± 0.04 dS/m during the monsoon season (Table 4.3.4). In the study, the mean value of selected ponds followed the order of pre-monsoon > post-monsoon > monsoon season, as were expected. The results observed that the mean value of EC in the pre- and post-monsoon seasons were found to slightly exceed the permissible limit of the DoE standard, though the value of the monsoon season was found within the permissible limit. The study observed that a volume of sea water run over the dams and embankments and mixed with the inland ponds water during the tidal storms. Moreover, during high tide, some amount of salt water intruded to the inland water bodies through seepage. In the summer seasons, due to evaporation such ponds water showed higher EC value (< 2 ds/m). Nonetheless, these waters can be used as irrigation and domestic purposes in consideration of EC.

4.3.2.1.5 Total Dissolved Solids (TDS)

The TDS values of the selected ponds ranged between 520 - 1405 mg/L in 2016 and 2017 (see-Appendix 1.5). The highest mean value found to be 1076 ± 182.6 during the pre-monsoon season and the lowest was 852 ± 31.4 mg/L during the monsoon season (Table 4.3.4). The mean value of selected ponds followed the order of pre-monsoon > post-monsoon > monsoon season. The value of the pre-monsoon season was found to exceed the permissible limit of the DoE and WHO standards, but the values of the monsoon and post-monsoon seasons were found within the permissible limit of three standards indicating a good water quality in terms of TDS.

4.3.2.1.6 Total Suspended Solids (TSS)

The maximum value was found to be 36 mg/L during the pre-monsoon season, 2016 and minimum was 5 mg/L during the monsoon season, 2016 (see-Appendix 1.6). The highest mean value was found to be 22.5 ± 8.1 during the pre-monsoon season and the lowest was 7.9 ± 2.8 mg/L during the monsoon season (Table 4.3.4). The mean values of selected ponds followed the order of pre-monsoon > post-monsoon > monsoon season. During the pre- and post-monsoon season, the values exceeded the permissible limit of the DoE standard, whereas during the monsoon season, the values were found within the permissible limit.

The study showed that the water bodies with lower depth contained higher TSS values (>10mg/L) and the waters were influenced with profuse fragments of soil and silts which impedes the light penetration. Such water is unsafe for the aquatic environment.

4.3.2.2 Chemical Parameters

The chemical parameters such as Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Bi-carbonate (HCO_3^-), Nitrate (NO_3^-), Phosphate (PO_4^{3-}) and Sulfate (SO_4^{2-}) ions were determined in the laboratory using the standard method of analysis. The results are described in the following sections.

4.3.2.2.1 Sodium Ion (Na^+)

The maximum Na^+ of ponds water sample was found to be 197 mg/L during the pre-monsoon season, 2017 and minimum was 58 mg/L during the monsoon season, 2016 (see-Appendix 1.7). Following the EC values, the highest mean value was found to be 150.1 ± 25.5 during the pre-monsoon season and the lowest was 73 ± 4.7 mg/L during the monsoon season (Table 4.3.5). The mean value of selected ponds followed the order of pre-monsoon > post-monsoon > monsoon season. Throughout three seasons, the values were found within the permissible limits of the DoE, WHO and FAO standards indicating a good quality.

4.3.2.2.2 Potassium Ion (K^+)

The maximum concentration was found to be 8 mg/L during the pre-monsoon season, 2016 and 2017 and minimum was 4.0 mg/L during the monsoon season, 2017 (see-Appendix 1.8). The highest mean value was 7.0 ± 0.3 during the post-monsoon season and the lowest was 4.6 ± 0.3 mg/L during the monsoon season (Table 4.3.5). In the study, the mean values followed the order of post-monsoon > pre-monsoon > monsoon season and values were found within the permissible limit of DoE, WHO and FAO standards.

Table 4.3.5 Bi-yearly descriptive statistics of chemical parameters of ponds water in 2016 and 2017

Parameter s (mg/L)	Count	Pre- monsoon	Monsoon	Post- monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WH O	FAO
Na ⁺	10	150.1 \pm 25.5	73.0 \pm 4.7	87.1 \pm 3.4	200	200	920
K ⁺	10	6.8 \pm 0.8	4.6 \pm 0.3	7.0 \pm 0.3	12	-	15
Ca ²⁺	10	4.3 \pm 0.7	11.4 \pm 0.8	4.5 \pm 0.2	75	-	400
Mg ²⁺	10	9.6 \pm 1.8	9.8 \pm 0.7	10.6 \pm 0.4	30-35	-	60
Cl ⁻	10	227.3 \pm 38.4	111.1 \pm 53.2	133.9 \pm 5.2	150-600	250	1065
SO ₄ ²⁻	10	35.6 \pm 7.3	12.8 \pm 0.9	10.7 \pm 0.4	400	250	960
NO ₃ ⁻	10	2.6 \pm 0.3	2.3 \pm 0.4	1.5 \pm 0.4	10	-	<10
HCO ₃ ⁻	10	107.2 \pm 5	200.1 \pm 11.8	107.1 \pm 5.8	200-500	-	610
PO ₄ ³⁻	10	1.5 \pm 0.3	1.2 \pm 0.2	0.8 \pm 0.2	-	-	2.0

4.3.2.2.3 Calcium Ion (Ca²⁺)

The maximum concentration was found to be 14 mg/L during the monsoon season, 2017 and minimum was 3.6 mg/L during the post-monsoon season, 2016 (see-Appendix 1.9). The highest mean value was 11.4 \pm 0.8 during the monsoon season and the lowest was 4.3 \pm 0.7 mg/L during the pre-monsoon season (Table 4.3.5). In the study, the mean concentration of calcium ion followed the order of monsoon > pre- monsoon > post-monsoon season and the values were found within the permissible limits of DoE and FAO standards.

4.3.2.2.4 Magnesium Ion (Mg²⁺)

The maximum value was found to be 12 mg/L during the pre-monsoon season, 2017 and minimum was 7 mg/L during the pre-monsoon season, 2017 (see-Appendix 1.10). The highest mean value was found to be 10.6 \pm 0.4 mg/L during the post-monsoon season and

the lowest was 9.6 ± 1.8 mg/L during the pre-monsoon season (Table 4.3.5). In the study, the mean values followed the order of pre-monsoon > post-monsoon > monsoon season. The mean values during three seasons were found within the permissible limits of DoE and FAO standards.

4.3.2.2.5 Chloride Ion (Cl^-)

The maximum was found to be 303 mg/L during the pre-monsoon season, 2017 and minimum was 90 mg/L during the monsoon season, 2016 (see-Appendix 1.11). The highest mean value was found to be 227.3 ± 38.4 during the pre-monsoon season and the lowest was 111.1 ± 5.32 mg/L during the monsoon season (Table 4.3.5). In the study, the concentration of chloride ion were found to follow the order of pre-monsoon > post-monsoon > monsoon season and the values were found within the permissible limit of selected standards indicating a good quality in term of chloride ion.

4.3.2.2.6 Sulfate Ion (SO_4^{2-})

The concentration of sulfate ion ranged between 9.8 - 48 mg/L during 2016-17 (see-Appendix 1.12). The highest value was found to be 35.6 ± 7.3 during the pre-monsoon season and the lowest was 10.7 ± 0.4 mg/L during the post-monsoon season (Table 4.3.5). In the study, the mean concentration were found to follow the order of pre-monsoon > monsoon > post-monsoon season and the values were found within the permissible limits of DoE, WHO and FAO standards.

4.3.2.2.7 Bi-carbonate Ion (HCO_3^-)

The study results found the maximum concentration of HCO_3^- was to be 288 mg/L during the monsoon season, 2017 and minimum was 95 mg/L during the post-monsoon season 2016 and 2017 (see-Appendix 1.13). The highest value was found to be 200.1 ± 11.8 mg/L during the monsoon season and the lowest was 107.1 ± 5.8 mg/L during the post-monsoon season (Table 4.3.5). The mean values followed the order of monsoon > post-monsoon > pre-monsoon seasons and found within the permissible limits of DoE and FAO standards indicating good quality.

4.3.2.2.8 Nitrate ion (NO₃⁻) and Phosphate (PO₄³⁻) Ions

The maximum concentration of NO₃⁻ was found to be 3.5 mg/L during the pre-monsoon season, 2016 and minimum was 0.9 mg/L during the post-monsoon season, 2016 (see-Appendix 1.14). The mean concentration of Nitrate ion were 2.6±0.3, 2.3±0.4 and 1.5±0.4 mg/L during the pre-, monsoon and post-monsoon seasons, respectively. The maximum concentration of PO₄³⁻ was found to be 2.0 mg/L during the pre-monsoon season 2016 and 2017. The minimum was 0.2 mg/L during the post-monsoon season 2017. (See-Appendix 1.15). The mean concentration of phosphate ions found to be 1.5±0.3, 1.2±0.2 and 0.8±.2 mg/L during the pre-monsoon, monsoon and post-monsoon season, in the order (Table 4.3.5). The mean values of Nitrate and Phosphate ions were found within the permissible limits of selected standards.

4.3.2.3 Trace Elements

The study examined some trace elements such as iron, copper, lead, arsenic, manganese and zinc of ponds water samples during 2016 and 2017. The maximum value of Fe, Cu, Pb, As, Mn and Zn were found to be 0.856, 0.054, 0.006, 0.007, 0.022, and 0.024 mg/L, respectively (see-Appendix 1.16 - 21). The mean value of Fe, Cu, Pb, As, Mn and Zn were found to be 0.2 ±0.2, 0.01 ±0.014, 0.004±0.002, 0.002±0.002, 0.007±0.004, and 0.007±0.006, respectively (Table 4.3.6). In the study, the mean concentration of selected trace elements were found to follow the order of pre-monsoon > post-monsoon > monsoon seasons. Throughout the three seasons, the observed values were found within the permissible limit of selected standards.

Table 4.3.6 Bi-yearly descriptive statistics of trace elements of ponds water in 2016 and 2017

Parameters (mg/L)	Count	Pre-monsoon	Monsoon	Post- monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WHO	FAO
Fe (Total)	10	0.2 \pm 0.2	0.021 \pm 0.009	0.2 \pm 0.1	0.3-1	0.3	5.0
Cu (Total)	10	0.016 \pm 0.008	0.017 \pm 0.014	0.012 \pm 0.005	1.0	2.0	0.2
Pb (Total)	10	0.004 \pm 0.002	0.001 \pm 0.0	0.002 \pm 0.001	0.05	0.01	5.0
As (Total)	10	0.002 \pm 0.002	0.001 \pm 0.0	0.001 \pm 0.002	0.05	0.01	0.1
Mn(Total)	10	0.007 \pm 0.004	0.001 \pm 0.001	0.004 \pm 0.003	-	-	0.2
Zn (Total)	10	0.007 \pm 0.006	0.003 \pm 0.004	0.004 \pm 0.003	-	3.0	2.0

The study observed that the value of the most physicochemical parameters were found within the range of selected standards indicating good water quality. As the selected ponds are located inside the high embankments along the rivers of sea line, so, there was less possibility of mixing the saline water to the ponds water. However, a very few ponds water samples showed marginal higher EC values. The study found that such ponds water were affected with saline water during tidal storm. Besides, saline water may be intruded into ponds water through seepage or any leakage of the embankments. Except it, the ponds waters were found in a good quality which can be used as irrigation, domestic or industrial purposes.

4.3.2.4 Water Type Assessment

The study assessed the ponds water type of the study area using the Piper (1953) diagram and that are interpreted and discussed below.

(i) Water Type in Pre-monsoon Season

The estimated values of the cations and anions of the ponds water samples of the pre-monsoon season plotted in a Piper (1953) trilinear diagram (Fig.4.3.7). The concentration of Na⁺ found higher in all samples compare to K⁺, hence, Na⁺ was the dominant cation

(Table 4.3.5). The anion diagram shows that the major water samples contain higher Cl^- than SO_4^{2-} and HCO_3^- and so, the dominance of Na^+ and Cl^- indicates Na-Cl water type in surface waters during the pre-monsoon season.

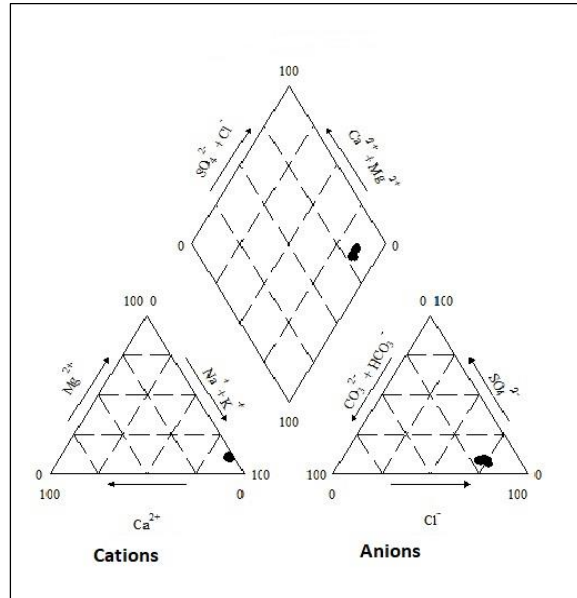


Fig. 4.3.7 Water type of ponds in pre-monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Mg}^{2+} > \text{K}^+ > \text{Ca}^{2+}$ and anions were $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$. Fig.4.3.8 shows the dominant ions in ponds water during the pre-monsoon season.

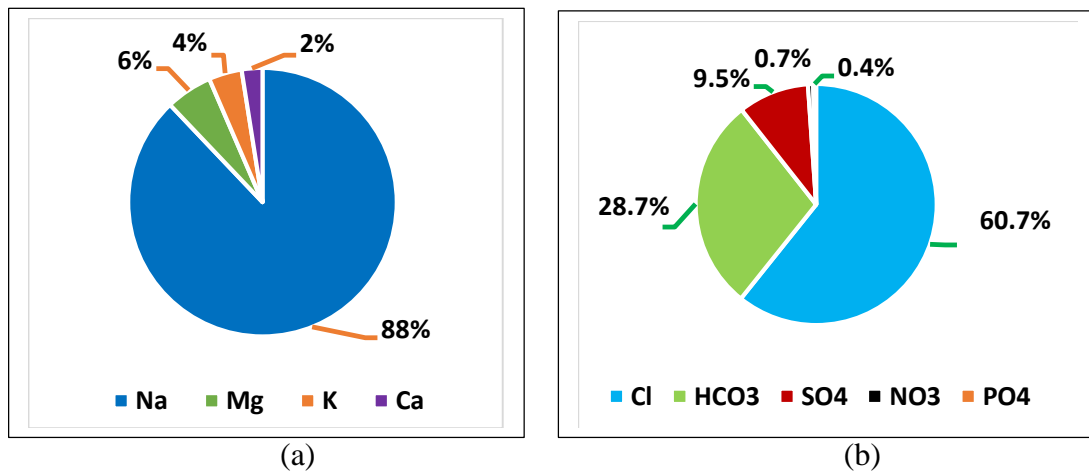


Fig.4.3.8 The proportion of major cations (a) and anions (b) in pre-monsoon season

(ii) Water Type in Monsoon Season

The values of the ponds water samples of the monsoon season plotted in a Piper trilinear diagram (Fig. 4.3.9). The cation diagram shows that the major water samples contained higher $\text{Na}^+ + \text{K}^+$ than Ca^{2+} and Mg^{2+} , Nevertheless, the concentration of K^+ found to be very low (Table 4.3.5). The anion diagram shows a mixed dominance of anions, i.e., Cl^- and HCO_3^- in water samples and so, the dominance of Na^+ in cations and $\text{Cl}^- + \text{HCO}_3^-$ in anions indicates Na-Cl- HCO_3 in ponds waters during monsoon season.

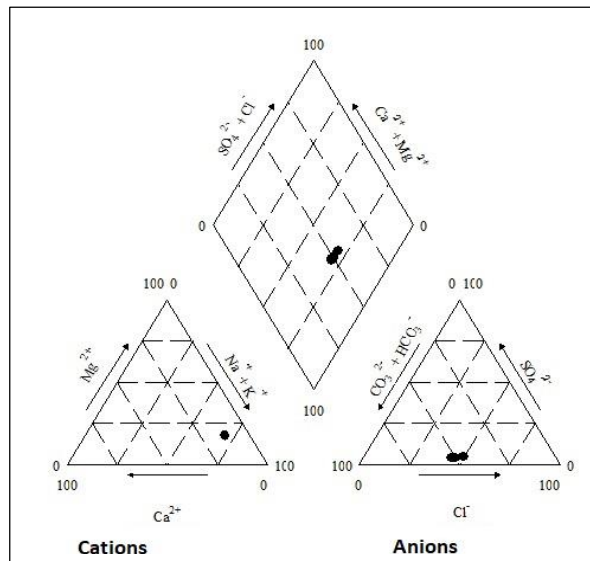


Fig. 4.3.9 Water type of ponds in monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ and anions were $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$. Figure: 4.3.10 shows the proportion of major ions in pond water samples.

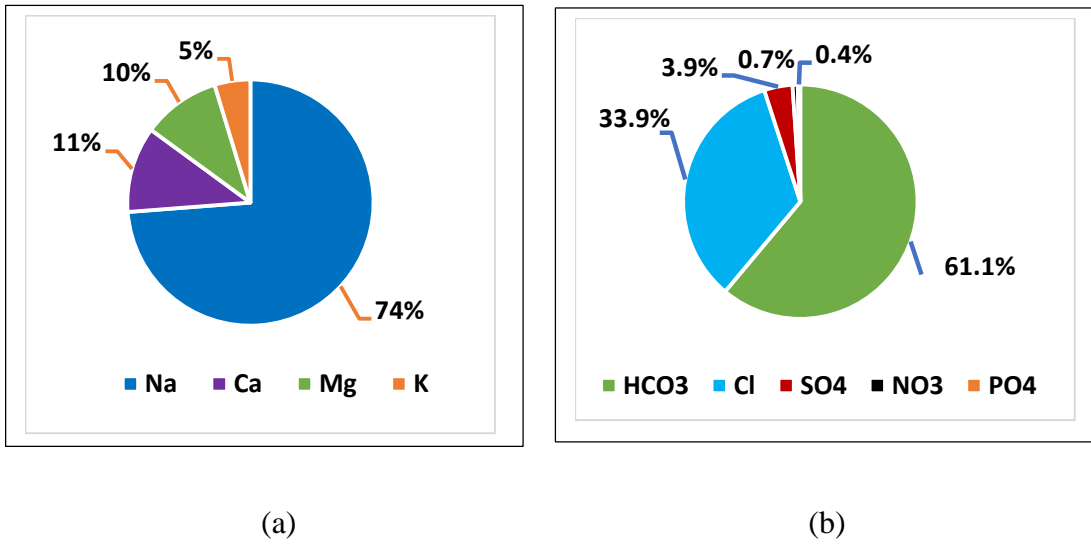


Fig.4.3.10 The proportion of major cations (a) and anions (b) in monsoon season

(ii) Water Type in Post-monsoon Season

The obtained values of the post-monsoon season plotted in a Piper trilinear diagram (Fig.4.3.11). The cation diagram shows that the major water samples contained higher $\text{Na}^+ + \text{K}^+$ than Ca^{2+} and Mg^{2+} , though the concentration of K^+ found to be very low (Table 4.3.5). The anion diagram shows that the major water samples contained higher Cl^- than SO_4^{2-} and HCO_3^- ion and so, the dominance of Na^+ in cations and Cl^- in anions indicates Na-Cl water type in ponds water during the post-monsoon season.

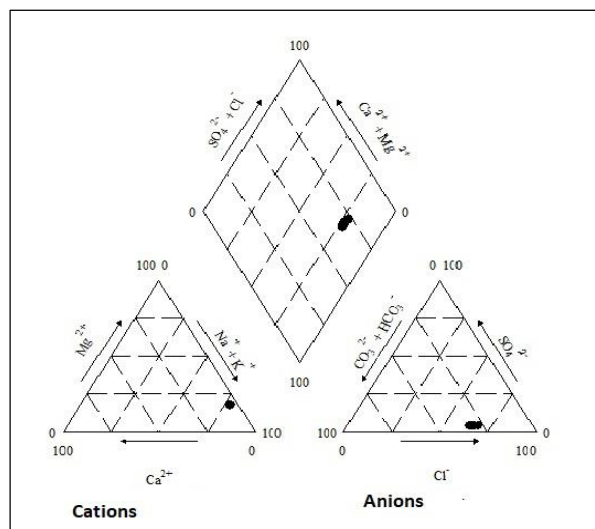


Fig. 4.3.11 Water type of ponds in post-monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Mg}^{2+} > \text{K}^+ > \text{Ca}^{2+}$ and anions were $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$. Fig. 4.3.12 shows the proportion of the dominant ions in ponds water during post-monsoon season.

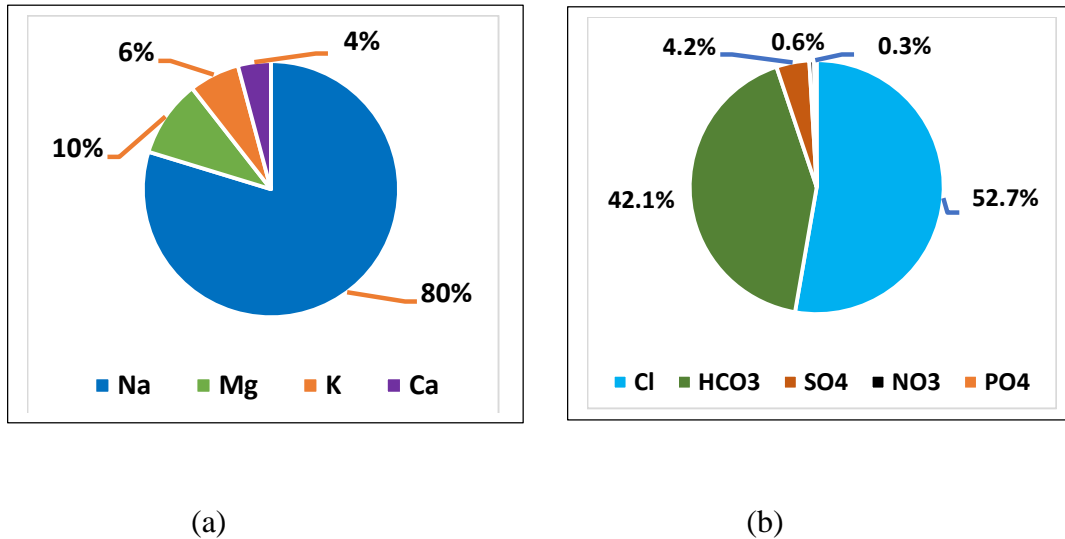


Fig.4.3.12 The proportion of major cations (a) and anions (b) in post-monsoon season

The study found that during the monsoon season, the concentration of chloride ion was decreased due to the increasing of precipitation. So, a mixed water type was observed during the monsoon period. Again, during the pre- and post-monsoon season, the concentration of chloride ion was considerably increased due to evaporation. Therefore, throughout the year except the rainy season, chloride ion was found as the predominant ion of total anions. So, throughout the pre- and post-monsoon seasons, the water type of the ponds were found to be Na-Cl and a mixed Na-HCO₃-Cl type was observed especially during the monsoon season.

4.3.3 Groundwater (Tube-well) Sample Analysis

The study collected ten groundwater, i.e., tube-wells water samples from the selected area with a view to assess the existing water quality. The samples were collected during the pre-monsoon, monsoon and post-monsoon seasons throughout 2016 and 2017. The samples were prepared in the laboratory and major physicochemical parameters, such as temperature, DO, pH, EC, TDS, TSS, Na⁺, K⁺, Ca²⁺, Mg²⁺, Fe, Cu, Pb, Mn, As, Zn, Cl⁻, SO₄²⁻, NO₃⁻, HCO₃⁻ and PO₄³⁻ were analyzed. The detailed results are illustrated and discussed in the following sections.

4.3.3.1 Physical Parameters

The reading of some physical parameters such as temperature, dissolved oxygen, pH and EC were recorded in the spot. Other physical parameters such as TDS and TSS were measured in the laboratory by using evaporation method. The analysis results are discussed in the next sections.

4.3.3.1.1 Temperature

The maximum temperature of selected tube-wells recorded to be 32°C during the pre-monsoon season, 2016 and minimum was 19°C during the post-monsoon season, 2016 and 17 (see-Appendix 1.1). The highest mean temperature found to be 30.5 ±0.6 during the pre-and monsoon seasons and the lowest was 19±0.2°C during the post-monsoon season (Table 4.3.7). The recorded values found to be very close with the air temperature. The temperature of selected tube-wells followed the order of pre-monsoon > monsoon > post-monsoon season. The mean temperature of three seasons were found within the permissible limit of the DoE standard.

4.3.3.1.2 Dissolved Oxygen

The maximum DO value of selected tube-wells recorded to be 7.5 mg/L during the monsoon season, 2017 and minimum was 6.9 mg/L during the pre- and monsoon season, 2016 (see-Appendix 1.2). The highest mean value found to be 7.3 ± 0.1 mg/L during the post-monsoon season and the lowest was 7.1 ± 0.1 mg/L during the pre-monsoon season (Table 4.3.7). The mean values of selected tube-wells followed the order of monsoon > post-monsoon > pre-monsoon season and were found within the permissible limit of the DoE and WHO standards indicating a good water quality in terms of DO.

Table 4.3.7 Bi-yearly descriptive statistics of physical parameters of tube-wells water in 2016 and 2017

Parameters	Count	Pre- monsoon	Monsoon	Post- monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WHO	FAO
WT(°C)	10	30.5 ± 0.6	29.5 ± 0.8	19.1 ± 0.2	-	-	-
DO (mg/L)	10	7.1 ± 0.1	7.2 ± 0.1	7.3 ± 0.1	6-8	-	-
pH	10	7.8 ± 0.1	8.0 ± 0.2	7.6 ± 0.2	6.5-8.5	<8	6-8.5
EC (ds/m)	10	1.6 ± 0.3	1.0 ± 0.1	1.3 ± 0.2	0.75	-	<3.0
TDS (mg/L)	10	1412 ± 235	951 ± 72	1238 ± 209	1000	1000	2000
TSS (mg/L)	10	8.4 ± 2.2	6.7 ± 1.4	9.0 ± 2.0	10	-	-

4.3.3.1.3 Total Acidity/Alkalinity (pH)

The maximum pH of selected tube-wells recorded to be 8.3 during the monsoon season, 2016 and 2017. The minimum value recorded to be 7.4 during the post-monsoon season, 2016 and 2017(see-Appendix 1.3).The highest mean pH value of tube-well water samples observed to be 8.0 ± 0.2 during the monsoon season and the lowest was 7.6 ± 0.2 during the post-monsoon season (Table 4.3.7). The mean pH of selected tube-wells followed the order of monsoon > post-monsoon > pre-monsoon season. Around the year, the values were found within the permissible limit of three standards (Table 4.3.7) indicating a good quality.

4.3.3.1.4 Electro-conductivity (EC)

The maximum EC value of selected tube-wells recorded to be 2.0 dS/m during the pre-monsoon season, 2017 and minimum was 0.8 dS/m during the monsoon season, 2016 and 2017 (see-Appendix 1.4). The highest mean value found to be 1.6 ± 0.3 during the pre-monsoon season and the lowest was 1.0 ± 0.1 dS/m during the monsoon season. The mean EC value in the post-monsoon season found to be as 1.3 ± 0.2 dS/m (Table 4.3.7). The EC values of the selected tube-wells followed the order of pre-monsoon > post-monsoon > monsoon season, respectively, as was expected. The mean values of three seasons found to exceed the permissible limit of the DoE standard. However, the values were found within the permissible limit of the FAO standard. The study observed that the salinity started to increase from the beginning of November due to the cessation of the rains and consequent reduction of sweet water flows.

Therefore, the tube-wells located in the estuarine areas were found to be saline during the pre-and post-monsoon season.

4.3.3.1.5 Total Dissolved Solids (TDS)

The maximum TDS value of selected tube-wells found to be 1768 mg/L during the pre-monsoon season, 2016 and the minimum was 794 mg/L during the monsoon season, 2016 (see-Appendix 1.5). The highest mean value found to be 1412 ± 235 during the pre-monsoon season and the lowest was 951 ± 72 mg/L during the monsoon season (Table 4.3.7). In the

study, the obtained values followed the order of pre-monsoon > post-monsoon > monsoon season and the values were found to exceed the permissible limit of the DoE and WHO standards.

4.3.3.1.6 Total Suspended Solids (TSS)

The maximum value found to be 18 mg/L during the pre-monsoon season, 2016 and the minimum was 4 mg/L during the monsoon season, 2016 (see-Appendix 1.6). The highest mean value was found to be 9.0 ± 2.0 during the post-monsoon season and the lowest was 6.7 ± 1.4 mg/L during the monsoon season (Table 4.3.7). The obtained mean values of selected tube-wells followed the order of pre-monsoon > post-monsoon > monsoon season and were found within the permissible limit of selected standard.

4.3.3.2 Chemical Parameters

The chemical parameters such as Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Bi-carbonate (HCO_3^-), Nitrate (NO_3^-), Phosphate (PO_4^{3-}) and Sulfate (SO_4^{2-}) ions were determined and the results are described in the following sections.

4.3.3.2.1 Sodium Ion (Na^+)

The maximum concentration found to be 245 mg/L during the pre-monsoon season, 2017 and the minimum was 98 mg/L during the post-monsoon season, 2017 (see-Appendix 1.7). Following the EC values, the highest mean concentration found to be 184.4 ± 28.3 during the pre-monsoon season and the lowest was $113. \pm 7.0$ mg/L during the monsoon season (Table 4.3.8). The obtained mean values of selected tube-wells followed the order of pre-monsoon > post-monsoon > monsoon season and were found within the permissible limit of selected standards indicating a good water quality in terms of EC values.

Table 4.3.8 Bi-yearly descriptive statistics of chemical parameters of tube-wells water in 2016 and 2017

Parameters (mg/L)	Count	Pre- monsoon	Monsoon	Post- monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WHO	FAO
Na ⁺	10	184.4 \pm 28.3	113.8 \pm 7.0	122.9 \pm 18.8	200	200	920
K ⁺	10	10.0 \pm 1.7	5.7 \pm 0.5	8.4 \pm 1.5	12	-	15
Ca ²⁺	10	13.9 \pm 1.9	15.2 \pm 1.4	13.6 \pm 1.6	75	-	400
Mg ²⁺	10	18.7 \pm 1.3	13.8 \pm 1.3	11.2 \pm 1.8	30-35	-	60
Cl ⁻	10	282.6 \pm 42.7	176.0 \pm 13.2	191.3 \pm 34.4	150-600	250	1065
SO ₄ ²⁻	10	45.0 \pm 7.8	21.2 \pm 1.6	16.8 \pm 3.3	400	250	960
NO ₃ ⁻	10	1.9 \pm 0.4	2.4 \pm 0.4	1.7 \pm 0.2	10	-	<10
HCO ₃ ⁻	10	192.8 \pm 14.5	297.4 \pm 5.8	167.8 \pm 13.9	200-500	-	610
PO ₄ ³⁻	10	1.2 \pm 0.3	1.1 \pm 0.2	0.9 \pm 0.2	-	-	2.0

4.3.3.2.2 Potassium Ion (K⁺)

The maximum concentration found to be 13 mg/L during the pre-monsoon season ,2017 and the minimum was 4.4 mg/L during the monsoon season, 2016 (see-Appendix 1.8). The highest mean concentration found to be 10 \pm 1.7 during the pre-monsoon season and the lowest was 5.7 \pm 0.5 mg/L during the monsoon season (Table 4.3.8). The obtained mean values of selected tube-wells followed the order of pre-monsoon > post-monsoon > monsoon season and were found within the permissible limit of selected standard.

4.3.3.2.3 Calcium Ion (Ca²⁺)

The maximum concentration found to be 19.2 mg/L during the monsoon season, 2017 and the minimum was 10 mg/L during the pre-monsoon season, 2016 and (see-Appendix 1.9). The highest mean value found to be 15.2±1.4 during the monsoon season and the lowest was 13.6±1.6 mg/L during the post-monsoon season (Table 4.3.8). The obtained mean values of selected tube-wells followed the order of pre-monsoon > post-monsoon > monsoon season and were found within the permissible limit of selected standards.

4.3.3.2.4 Magnesium Ion (Mg²⁺)

The maximum concentration of Mg²⁺ found to be 24 mg/L during the pre-monsoon season, 2017 and the minimum was 9 mg/L during the post-monsoon season, 2016 (see-Appendix 1.10). The highest mean value found to be 18.7±1.3 during the post-monsoon season and the lowest was 11.2±1.8 mg/L during the monsoon season (Table 4.3.8). In the study, the mean values followed the order of pre-monsoon > post-monsoon > monsoon season and the values were found within the permissible limits of the DoE and FAO standards.

4.3.3.2.5 Chloride Ion (Cl⁻)

The maximum concentration of Cl⁻ found to be 372.4 mg/L during the pre-monsoon season, 2017 and the minimum was 152 mg/L during the monsoon season, 2016 (see-Appendix 1.11). The highest mean value was 282.6±42.7 found during the pre-monsoon season and the lowest was 176±13.2 mg/L that was found during the monsoon season (Table 4.3.8). In the study, the mean concentration of chloride ion followed the order of pre-monsoon > post-monsoon > monsoon season, as were expected. During the pre-monsoon season, the mean value found to exceed the permissible limit of the WHO standard. But, during the monsoon and post-monsoon seasons the values were found within the permissible limit of the DoE and FAO standards (Table 4.3.8).

4.3.3.2.6 Sulfate Ion (SO₄²⁻)

The maximum concentration found to be 62 mg/L during the pre-monsoon season, 2017 and the minimum was 12.2 mg/L during the post-monsoon season, 2017 (see-Appendix 1.12). The highest mean values found to be 45±7.8 mg/L during the pre-monsoon season and the lowest was 16.8±3.3 mg/L during the post-monsoon season (Table 4.3.8). The obtained mean values of selected tube-wells followed the order of pre-monsoon > post-monsoon > monsoon season and that found within the permissible limit of selected standards.

4.3.3.2.7 Bicarbonate Ion (HCO₃⁻)

The maximum concentration found to be 310 mg/L during the monsoon season, 2017 and the minimum was 150 mg/L during the post-monsoon season, 2017 (see-Appendix 1.13). The highest mean concentration found to be 297.4±.8 during the monsoon season and the lowest was 167.8±13.9 mg/L during the post-monsoon season (Table 4.3.8). In the study, the mean values followed the order of monsoon > post-monsoon > pre-monsoon seasons and values were found within the permissible limits of DoE and FAO standards.

4.3.3.2.8 Nitrate (NO₃⁻) and Phosphate (PO₄³⁻) Ions

The maximum concentration of NO₃⁻ was found to be 3.3 mg/L during the monsoon season, 2016 and the minimum was 1.1 mg/L during the post-monsoon season, 2016 (see-Appendix 1.14). The mean concentration of Nitrate ion were 1.9±0.4, 2.4± 0.4 and 1.7±0.2 mg/L during the pre-, monsoon and post-monsoon seasons, respectively. The maximum value of PO₄³⁻ found to be 1.7 mg/L during the pre-monsoon season, 2017. The minimum concentration was 0.5 mg/L during the post-monsoon season, 2017 (see-Appendix 1.15). The mean concentration of phosphate ions found to be 1.2±0.3, 1.1±0.2 and 0.9±0.2 mg/L during the pre-, monsoon and post-monsoon seasons in that order (Table 4.3.8). The mean value of both ions were found within the permissible limit of the DoE and WHO standards.

4.3.3.3 Trace Elements

The study examined some trace elements such as iron, copper, lead, arsenic, manganese and zinc in tube-well water samples during 2016 and 2017. The maximum value of Fe, Cu, Pb, As, Mn and Zn were found to be 0.856, 0.054, 0.006, 0.007, 0.022, 0.024 mg/L, respectively (see-Appendix 1.16-21). The maximum mean value of Fe, Cu, Pb, As, Mn and Zn found to be 0.3 ± 0.1 , 0.027 ± 0.016 , 0.032 ± 0.005 , 0.003 ± 0.002 , 0.004 ± 0.003 , 0.005 ± 0.002 , respectively (Table 4.3.9). In the study, the mean concentration of selected trace elements observed to follow the order of pre-monsoon > post-monsoon > monsoon season and were found within the permissible limit of selected standards.

Table 4.3.9 Bi-yearly descriptive statistics of trace elements of tube-wells water in 2016 and 2017

Parameters (mg/L)	Count	Pre-monsoon	Monsoon	Post-monsoon	Standards		
		Mean \pm SD	Mean \pm SD	Mean \pm SD	DoE	WHO	FAO
Fe (Total)	10	0.3 ± 0.1	0.030 ± 0.01	0.2 ± 0.1	0.3-1	0.3	5.0
Cu (Total)	10	0.027 ± 0.16	0.017 ± 0.01	0.019 ± 0.012	1.0	2.0	0.2
Pb (Total)	10	0.01 ± 0.01	0.032 ± 0.005	0.042 ± 0.016	0.05	0.01	5.0
As (Total)	10	0.003 ± 0.001	0.002 ± 0.001	0.003 ± 0.002	0.05	0.01	0.1
Mn(Total)	10	0.004 ± 0.003	0.003 ± 0.002	0.004 ± 0.003	-	-	0.2
Zn (Total)	10	0.005 ± 0.002	0.003 ± 0.001	0.003 ± 0.001	-	3.0	2.0

4.3.3.4 Tube-well Water Type Assessment

The study assessed the tube-wells water type of the study area using the Piper (1953) diagram and that are interpreted and discussed below.

(i) Water Type in Pre-monsoon Season

The estimated values of the cations and anions of the tube-wells water samples of the pre-monsoon season plotted in a Piper (1953) trilinear diagram (Fig.4.3.13). The concentration

of Na^+ found higher in all samples compare to K^+ , hence, Na^+ was the dominant cation (Table 4.3.8). The anion diagram shows that the major water samples contains higher Cl^- than SO_4^{2-} and HCO_3^- and so, the dominance of Na^+ and Cl^- indicates Na-Cl water type in surface waters during the pre-monsoon season.

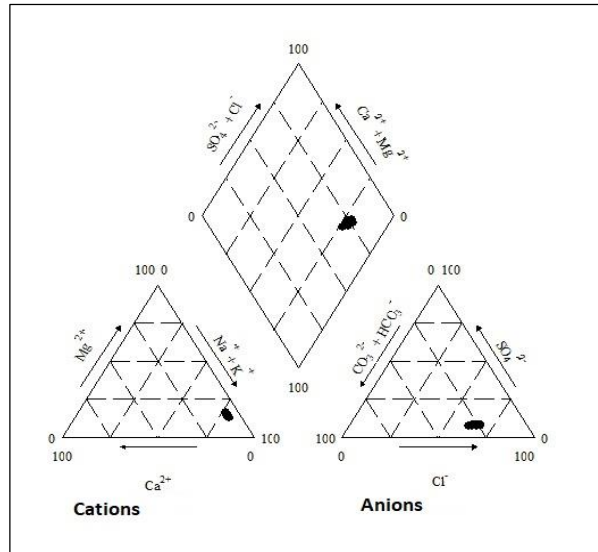


Fig. 4.3.13 Water type of tube-wells water during pre-monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Mg}^{2+} > \text{K}^+ > \text{Ca}^{2+}$ and anions were $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$. Fig. 4.3.14 shows the average concentration of the dominant ions in tube-wells water during pre-monsoon season.

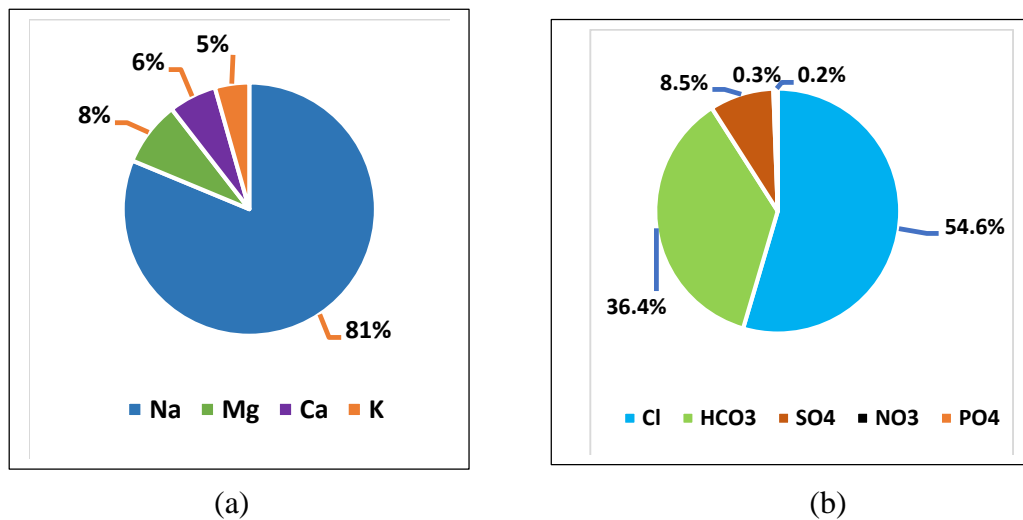


Fig.4.3.14 The proportion of Major cations (a) and anions (b) in pre-monsoon season

(ii) Water Type in Monsoon Season

The values of the tube-wells water samples of monsoon season plotted in a Piper trilinear diagram (Fig. 4.3.15). The cation diagram shows that the major water samples contains higher $\text{Na}^+ + \text{K}^+$ than Ca^{2+} and Mg^{2+} , though, the concentration of K^+ found to be very low (Table 4.3.8). The anion diagram shows a mixed dominance of anions, i.e., Cl^- and HCO_3^- in water samples and so, the dominance of Na^+ in cations and $\text{Cl}^- + \text{HCO}_3^-$ in anions indicates Na-Cl-HCO_3 water type in tube-wells water during the monsoon season.

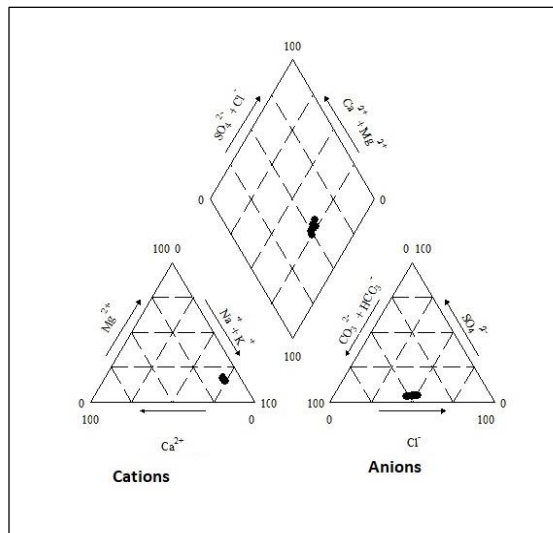


Fig. 4.3.15 Water type of tube-wells water during monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ and anions were $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$. Fig. 4.3.16 shows the proportion of dominant ions.

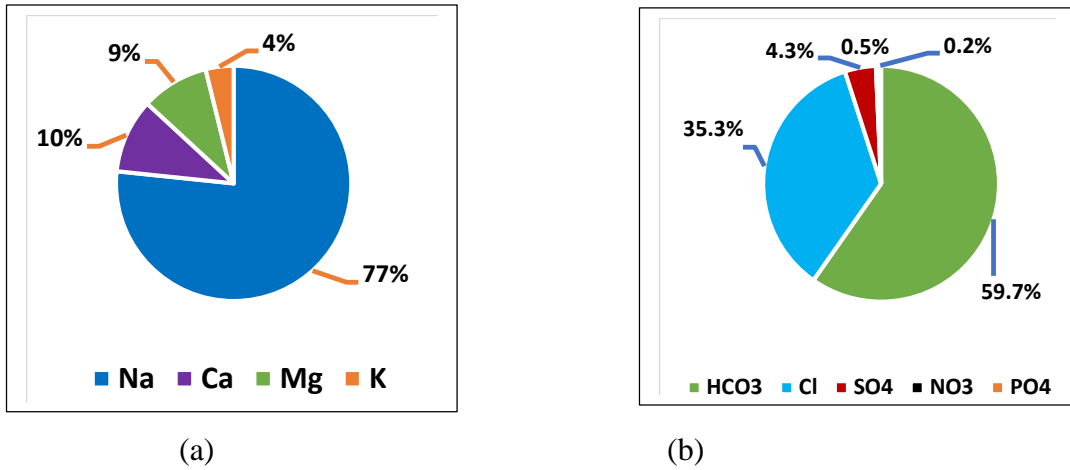


Fig. 4.3.16 The proportion of major cations (a) and anions (b) in tube-wells water in monsoon season.

(iii) Water Type in Post-monsoon Season

The obtained values of the post-monsoon season plotted in a Piper trilinear diagram (Fig.4.3.17).The cation diagram shows that the major water samples contain higher $\text{Na}^+\text{+K}^+$ than Ca^{2+} and Mg^{2+} , though the concentration of K^+ found to be very low (Table 4.3.8). The anion diagram shows that the major water samples contain higher Cl^- than SO_4^{2-} and HCO_3^- ion and so, the dominance of Na^+ in cations and Cl^- in anions indicates Na-Cl water type in tube-wells water during post-monsoon season.

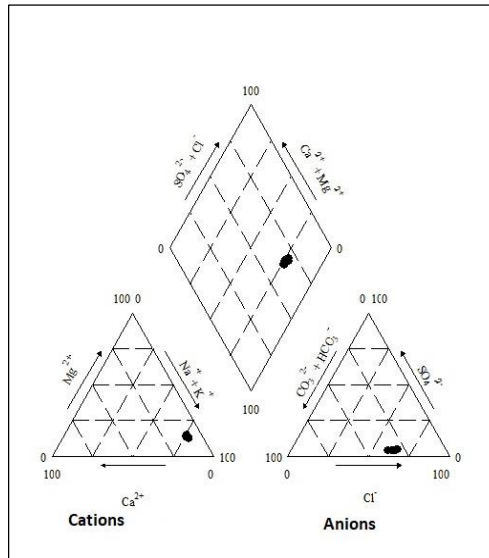


Fig. 4.3.17 Water type of tube-wells water during post-monsoon season

The major cations in water samples followed the order of $\text{Na}^+ > \text{Mg}^{2+} > \text{K}^+ > \text{Ca}^{2+}$ and anions were $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-}$. Fig.4.3.18 shows the proportion of dominant ions in tube-wells water during the post-monsoon season.

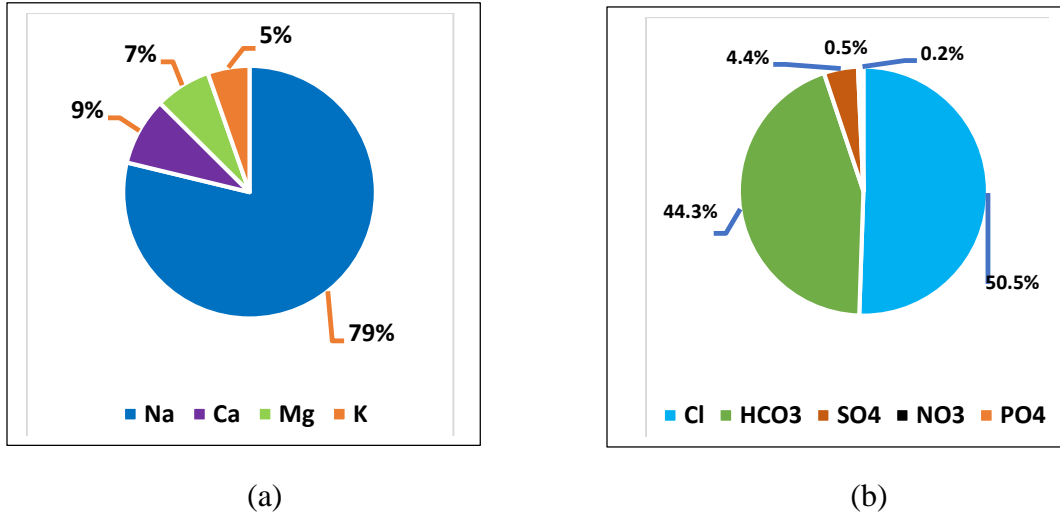


Fig. 4.3.18 The proportion of major cations (a) and anions (b) in tube-wells water in post-monsoon season.

The study found that the concentration of chloride ion found to decrease during the monsoon season and bicarbonate ion significantly increased. Therefore, the ground water of selected areas found to be Na-Cl type during the pre- and post-monsoon seasons, and that was changed to Na-HCO₃-Cl type during the monsoon season.

4.4 Water Quality Assessment

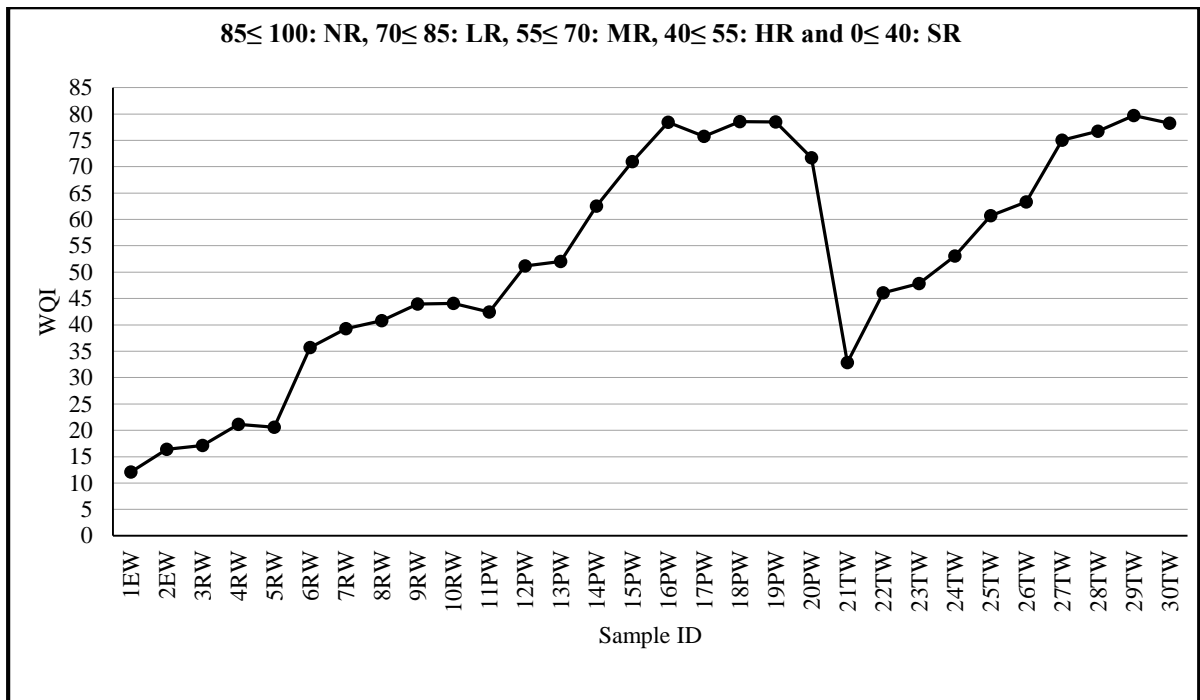
The study examined the existing water quality of the surface and groundwater in the study area during 2016 and 2017. The study considered the assessment of the water quality for specific uses such as irrigation, domestic and drinking purposes. It followed the Irrigation Water Quality Index (IWQI) method developed by Meireles *et al.* (2010) for the evaluation of irrigation water quality. The method considered some selective water quality measurement tools such as EC, Na⁺, Cl⁻, HCO₃⁻ and Sodium Absorption Ratio (SAR) values. Another water quality index named Weighted Arithmetic Water Quality Index (AWQI) method, developed by Brown *et al.* (1970) was considered to assess the water quality for drinking and domestic (e.g. bathing, washing, etc.) purpose uses. The method used some significant water quality measurement tools such as TDS, Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, HCO₃⁻ and NO₃⁻. The values of both indices were compared with the permissible limit of the DoE, Bangladesh, 2010 and FAO, 1985 standards.

4.4.1 Irrigation Water Quality Assessment in 2016 and 2017

The study examined the selected surface and groundwater samples to identify its suitability for irrigation purpose uses. The mostly used Irrigation Water Quality Index (IWQI) followed the index rating scores as 85 ≤ 100: No Restriction (NR), 70 ≤ 85: Low Restriction (LR), 55 ≤ 70: Moderate Restriction (MR), 40 ≤ 55: High Restriction (HR) and 0 ≤ 40: Severe Restriction (SR). The detailed assessment results are stated and discussed in the following sections.

4.4.1.1 Irrigation Water Quality Assessment in Pre-monsoon Season

The study results found that the water quality index values of the estuaries, rivers, canals, ponds and tube-wells water ranged between 12 and 80, indicating lower to severe restriction for irrigation purpose uses (see-Appendix 2.1).



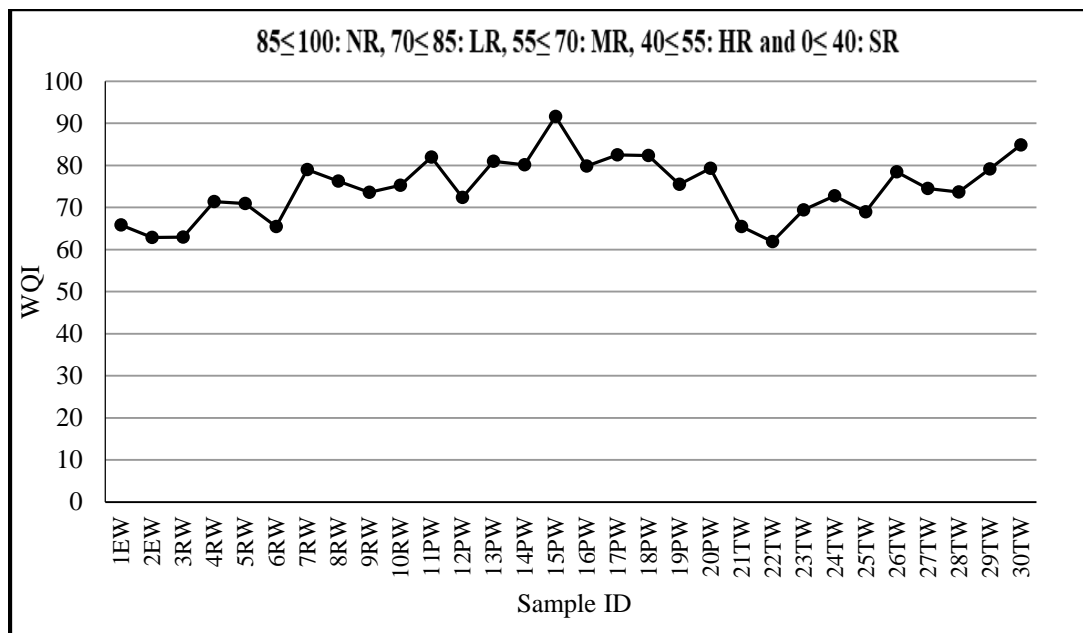
*EW: Estuary Water; RW: River Water, PW: Pond Water; TW: Tube-well Water

Fig. 4.4.1 Irrigation water quality index values in pre-monsoon season

Fig. 4.4.1 shows that most of the estuaries, rivers and canals waters (i.e., 6 of 10 samples) found in severe to high restriction, whereas ponds water found to be low restriction throughout the pre-monsoon season in 2016 and 2017. Some of the groundwater samples from the estuarine (i.e., Sample ID 21 TW–24 TW) marked for high restricted uses. Nonetheless, other groundwater samples were found as low to moderate restriction. The study observed that the water bodies dehydrated throughout the pre-monsoon season. During the season, due to the insufficient rainfall and back water effect, the upstream sweet water flow decreased and as a result, salt water penetrated or intruded to the inland waters. Thus, a higher concentrated saline water intruded to the inland estuarine waters and speeded up the deterioration of water quality.

4.4.1.2 Irrigation Water Quality Assessment in Monsoon Season

The study results found that the water quality index values ranged between 62 and 92 during the monsoon season, indicating as no restriction to moderate restriction for irrigation purpose uses (see-Appendix 2.1). During the season, most of the estuaries, rivers and canals, ponds and groundwater showed no restriction or low restriction. The groundwater samples collected from the estuarine area (i.e., Sample ID 21 TW-24 TW) marked as moderate restriction for irrigation purpose uses, though it was acceptable enough for uses. (Fig. 4.4.2). The study found that the water bodies were well recharged during the monsoon season due to the sufficient precipitation and sweet water pressure from the upstream regions. As a result, the concentration of saline water diluted and thus, a better water quality achieved in 2016 and 2017.

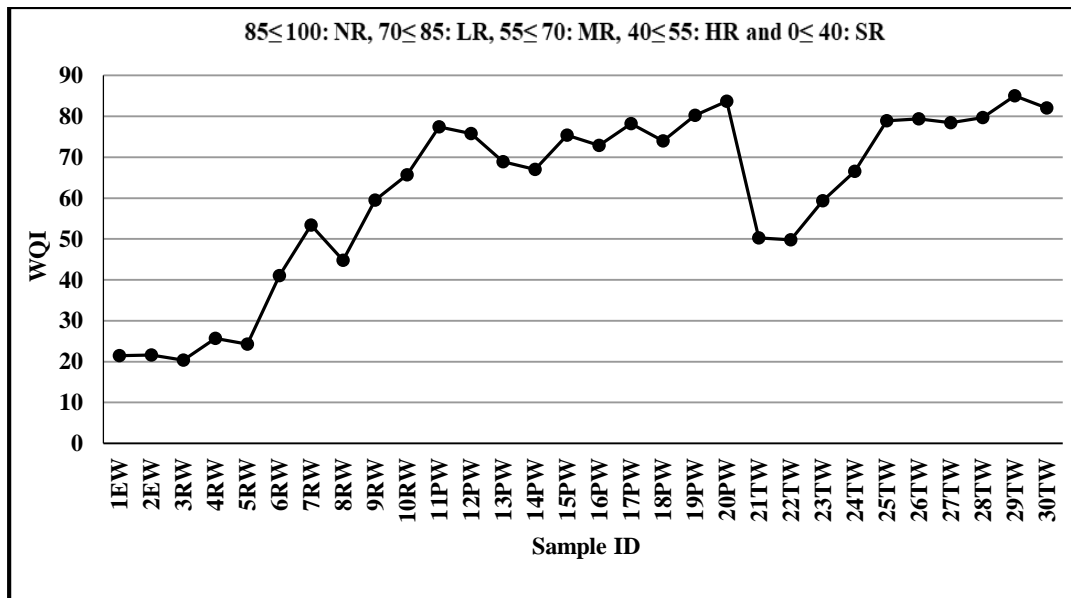


*EW: Estuary Water; RW: River Water, PW: Pond Water; TW: Tube-well Water

Fig. 4.4.2 Irrigation water quality index values in monsoon season

4.4.1.3 Irrigation Water Quality Assessment in Post-monsoon Season

The results found that the water quality index values ranged from 20 to 85 during the post-monsoon season, indicating a low to severe restriction for irrigation purpose uses (see-Appendix 2.1). Fig.4.4.3 shows that most of the estuaries, rivers and canals water (i.e., 5 of 10 samples) found in a severe to a high restriction, whereas the ponds water found to be low restriction. Some of the groundwater samples, located in the estuarine area (i.e., Sample ID 21 TW-23 TW) marked as the moderate to high restriction however, other groundwater samples found as low to moderate restriction for agriculture purpose uses. The study illustrates that the water bodies started to dry from the month of October and reached at the pick between April and May. During the dry season, due to the extreme evaporation and lacking of sweet water pressure, backwater effect introduced and hence, the saltwater penetrated or intruded into the inland water bodies. Thus, the water quality of the areas found to be worsened.



*EW: Estuary Water; RW: River Water, PW: Pond Water; TW: Tube-well Water

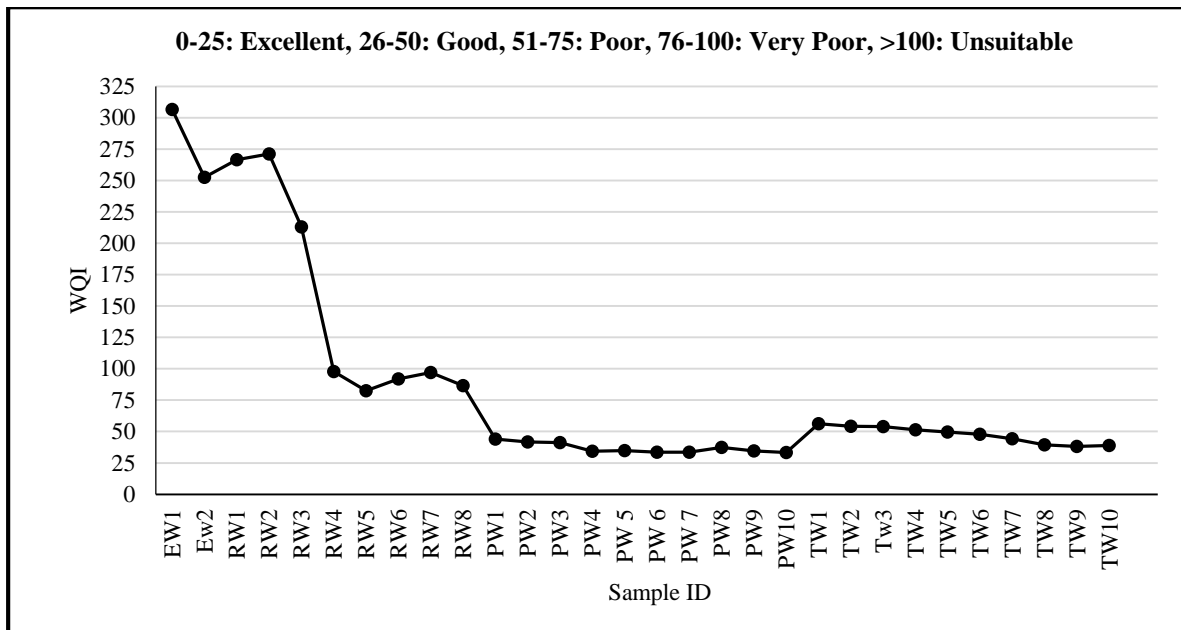
Fig. 4.4.3 Irrigation water quality index values in post-monsoon season

4.4.2 Domestic Water Quality Assessment in 2016 and 2017

The study examined the surface and groundwater samples to assess their appropriateness for domestic such as bathing, washing and industrial purpose uses. The customarily used arithmetic water quality index (AWQI) method was followed, where the index rating scores categorized as 0-25: Excellent, 26-50: Good, 51-75: Poor, 76-100: Very Poor, >100: Unsuitable uses. The assessment results are interpreted and described in the subsequent sections.

4.4.2.1 Domestic Water Quality Assessment in Pre-monsoon Season

The results showed that the water quality index values ranges between 33 and 307 during the pre-monsoon season, 2016-17 indicating a good to unsuitable quality for domestic purpose uses (see-Appendix 2.2). Throughout the season, most of the estuaries, rivers and canals waters (i.e. 6 of 10 samples) found to be unsuitable (scores: >100) whereas, ponds water showed good quality (Score range: 26-50). Some of groundwater samples (i.e. Sample ID 21TW-25TW) marked as poor ranking (Score range: 51-75) and other groundwater samples showed good quality (Fig. 4.4.4).



*EW: Estuary Water; RW: River Water, PW: Pond Water; TW: Tube-well Water

Fig.4.4.4 Domestic water quality index values in pre-monsoon season

4.4.2.2 Domestic Water Quality Assessment in Monsoon Season

Fig. 4.4.5 shows that the water quality index values ranges between 26 and 44 during the monsoon season, indicating good quality (see-Appendix 2.2). During the season, most of the estuaries, rivers and canals, ponds and groundwater samples showed good quality (Score range: 26-50).

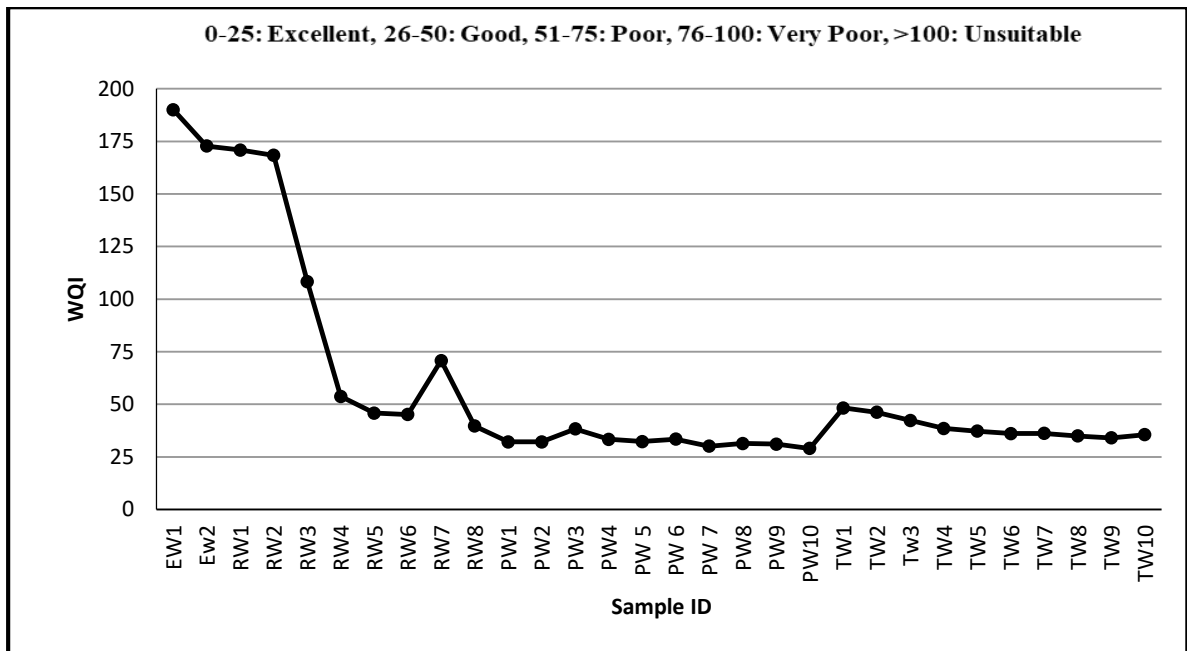


*EW: Estuary Water; RW: River Water, PW: Pond Water; TW: Tube-well Water

Fig. 4.4.5 Domestic water quality index values in monsoon season

4.4.2.3 Domestic Water Quality Assessment in Post-monsoon Season

The water quality index values ranges between 29 and 190 during the post-monsoon season, 2016-17 indicating good to unsuitable quality (see-Appendix 2.2). Throughout the season, most of the estuaries, rivers and canals water (i.e., 5 of 10 samples) found to be unsuitable (Score range: >100) whereas, ponds water found in a good quality (Score range: 26-50). Groundwater samples also showed a good quality in the described season (Fig 4.4.6).



*EW: Estuary Water; RW: River Water, PW: Pond Water; TW: Tube-well Water

Fig. 4.4.6 Domestic water quality index values in post-monsoon season

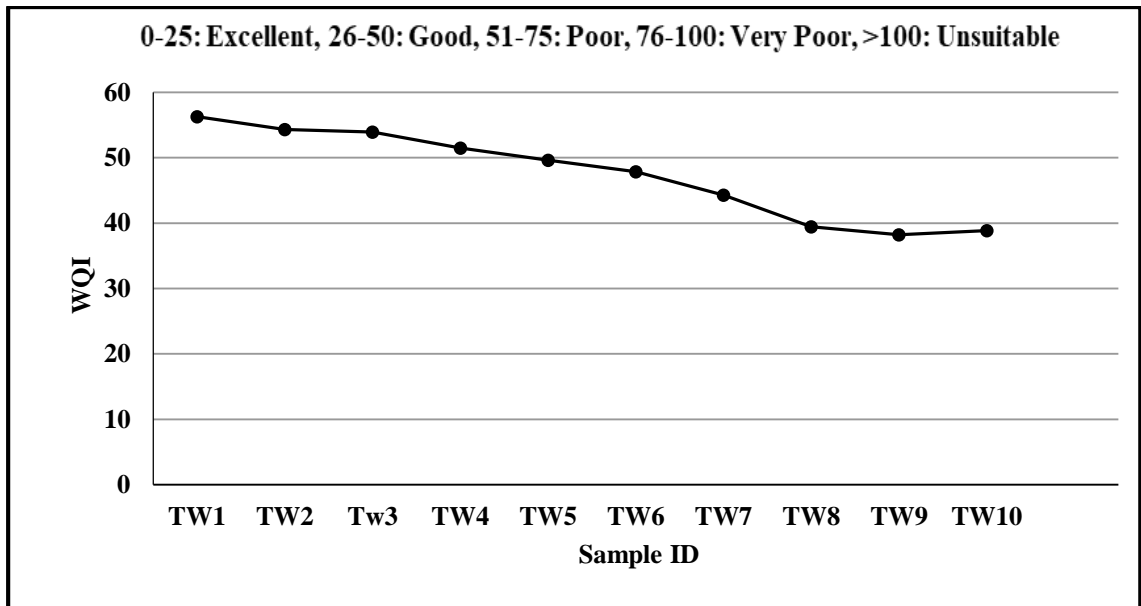
The study found that the water bodies desiccated during the pre- and post- monsoon period due to evaporation as well as the scarcity of rainfall. Again, sweet water pressure reduced from the upstream region and as a result, saline water concentrated and the water bodies found in a restricted condition for domestic purpose uses. But, during the monsoon season, the water bodies well-filled by sufficient rains. Again, sweet water pressure increased during the monsoon and as a result, the prevailing salt in water diluted and a better quality observed.

4.4.3 Drinking Water Quality Assessment in 2016 and 2017

The study examined only groundwater samples to identify its suitability for drinking purpose uses. To assess the water quality, the commonly used arithmetic water quality index (AWQI) was followed where the index rating scores were categorized as 0-25: Excellent, 26-50: Good, 51-75: Poor, 76-100: Very Poor and >100: Unsuitable for uses. The assessment results are stated and discussed in the following sections.

4.4.3.1 Drinking Water Quality Assessment in Pre-monsoon Season

The results found that the water quality index values ranges between 38 and 56, indicating as good to poor quality for drinking purpose uses (see-Appendix 2.3). Throughout the season, some of the groundwater samples (i.e., ID TW1- TW4 etc.) showed poor quality (Score range: 51-75) and another samples found in a good quality for drinking uses (Fig. 4.4.7).

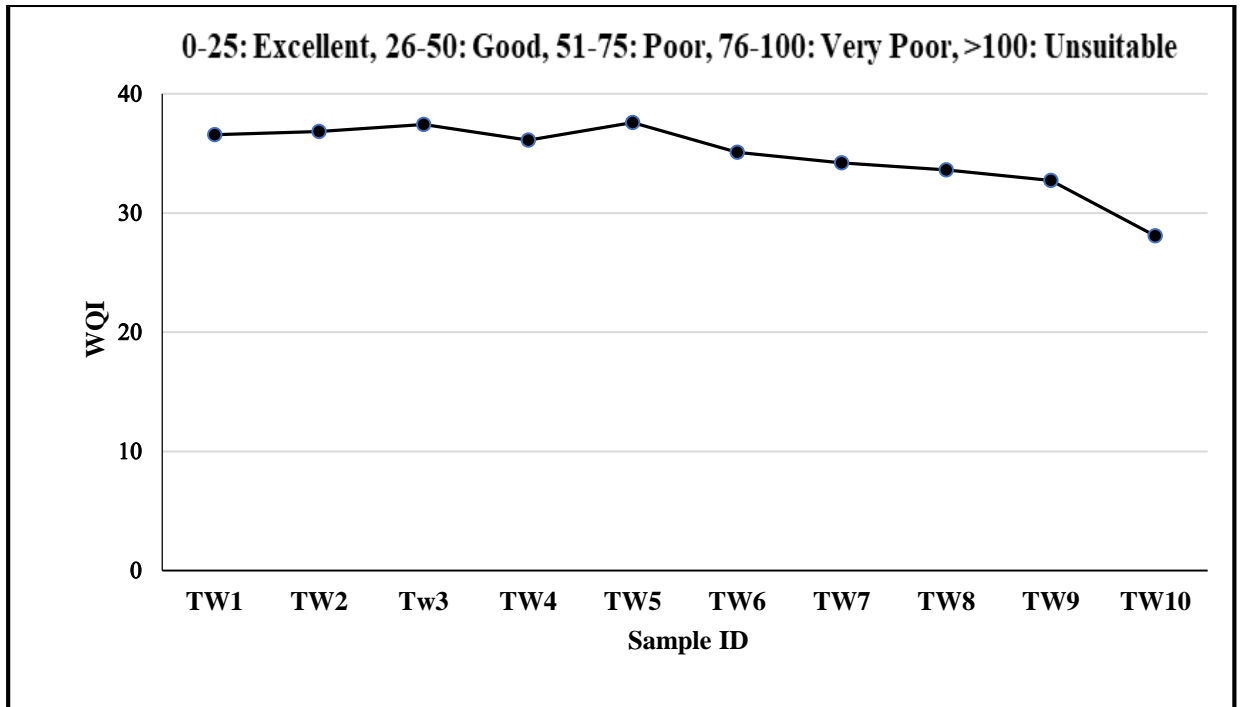


* TW: Tube-well Water

Fig. 4.4.7 Drinking water quality index values in pre-monsoon season

4.4.3.2 Drinking Water Quality Assessment in Monsoon Season

The study showed that the water quality index values ranges between 28 and 38 during the monsoon season, indicating as good water quality for drinking purpose uses (see-Appendix 2.3). Throughout the season, all of the selected groundwater samples showed good quality (Score range: 26-50) for drinking purpose uses during 2016 and 2017 (Fig-4.4.8).

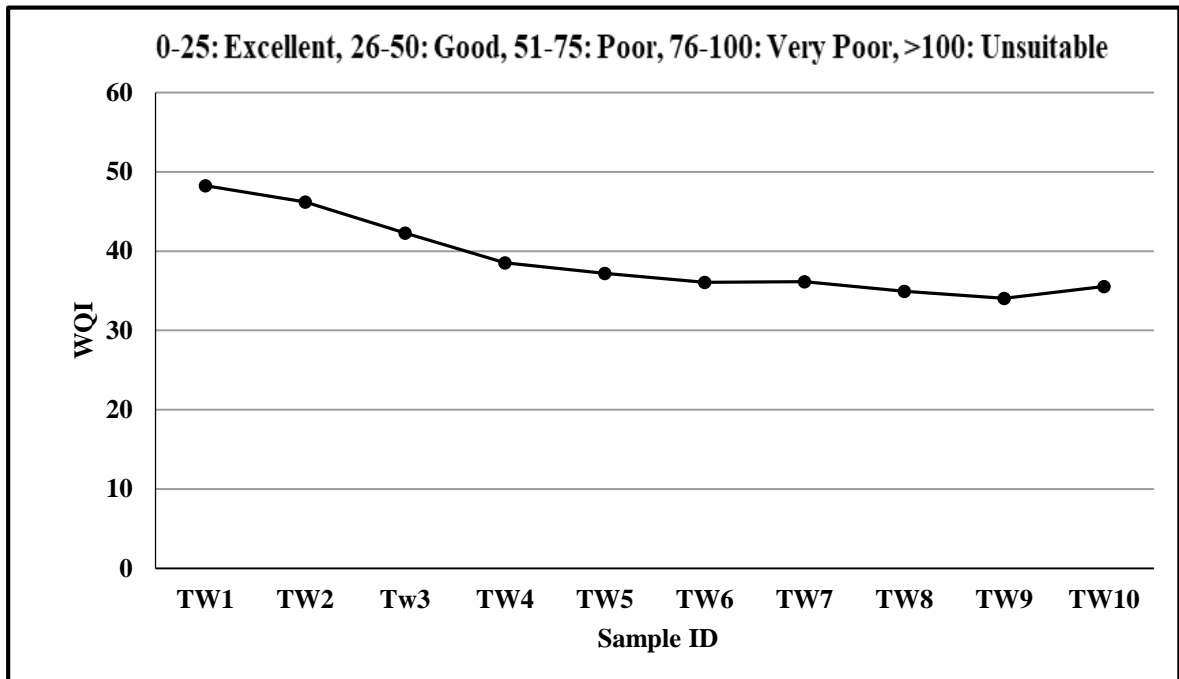


* TW: Tube-well Water

Fig. 4.4.8 Drinking water quality index values in monsoon season

4.4.3.3 Drinking Water Quality Assessment in Post-monsoon Season, 2016-17

The results showed that the water quality index values ranges between 34 and 48 during the post-monsoon season, indicating good water quality for drinking purpose uses (see-Appendix 2.3). Throughout the season, all groundwater samples showed good quality (Score range: 26-50) for drinking purpose uses during 2016 and 2017 (Fig-4.6.9).



* TW: Tube-well Water

Fig. 4.4.9 Drinking water quality index value in post-monsoon season

The study observed that the ground water bodies dried during the pre-monsoon and post-monsoon period due to the scarcity of rainfall. Again, sweet water pressure drastically reduced from the upstream region and as a result, saline water concentrated and the waters found in a poor condition for drinking purpose uses. But, during the monsoon season, the water bodies well-recharged with sufficient rain water. During the period, sweet water pressure increased and as a result, the prevailing salt diluted and thus, a better water quality observed. Nonetheless, the selected tube-wells water can be used as drinking purpose in terms of WHO guidelines.

4.5 Climate Change Impacts on Water Quality

Several studies have reported the impacts of global warming on climate change and its consequences on water quality. Bangladesh is one of the most vulnerable countries to climate change, and indeed there should be somewhat influences on the water quality and coastal watersheds in particular. Researchers are much involved in assessing the probable impacts of the mean temperature on watersheds using different software models. Climate change can affect the water bodies as well as water regimes especially in the coastal areas. The influences of long-term climatic change can alter or modify the water quality also. Climate change can convert the water quality directly or indirectly through various biochemical processes. Already the analysis results showed the changes of climatic factors as well as the deterioration of the existing water quality in the study area. Therefore, the study focused on assessing the impacts of climatic change (i.e., meteorological and hydrological) on water bodies that were liable for deteriorating the existing water quality of the areas.

4.5.1 Assessment of Meteorological Changes

The analysis results showed an increasing trend of the annual maximum, average temperature, humidity and rainfall. However, the annual minimum temperature showed a decreasing trend. The study estimated a projected trend line for the annual maximum and average temperature that would be raised about 2.3 and 1.3°C, respectively by the year 2050. Similarly, the annual average relative humidity and rainfall also increased by 6.6% and 234.7 cm for the same period (Table 4.5.1).

Table 4.5.1 The meteorological changes of Kalapara station from 1975 to 2050

Parameters (Annual)	Periods	
	Observed Changes (1975-2017)	Projected Changes (by 2050)
Maximum Temperature (°C)	1.3	2.3
Minimum Temperature (°C)	-2.4	-4.2
Average Temperature (°C)	0.7	1.2
Average Humidity (%)	3.7	6.6
Average Rainfall (cm)	132.8	234.7

The study predicted that the temperature rise would intensify the melting of the polar ice caps and the sea-level rise. A report of the Atlantic Climate Adaptation Solutions Association (ACASA), 2011 described that the warming of global temperatures will result in the thermal expansion of the world's oceans, as well as glacial melting that lead to sea-level rise. The report also showed that the global sea-level rise is expected to rise at an alarming rate for the next 100 years. Rahmstorf (2010) stated that the global sea-level rise is likely to be more than twice due to the raise in temperature. Such changes will certainly affect the coastal hydrological regimes that deteriorate the water quality. The temperature rise will also increase precipitation or rainfall that would inflate the overflow of the inland rivers. The heavy rivers flow would introduce floods, wash away the organic matters, salts, garbage's, chemicals and clay silts to the low land and estuarine areas and thus, the water quality would be declined. Zhou *et al.* (2015) stated that the heavy runoff carried high turbid particulate phosphorus and organic matters that seriously affected the water quality of the reservoirs.

4.5.2 Assessment of Hydrological Change

The annual average tide gauge data of four stations named Cox's Bazar, Khepupara, Heron point and Diamond Harbor showed a gradual increase in the mean sea level (Table 4.5.2). The highest change was found to be 1.35 m from 1979 to 2050 at Khepupara station.

Table 4.5.2 Mean sea level study

Station (ID)	Duration	Change/Year	Changes (m)
Khepupara (1454)	1979-2000	0.0188	0.41
	projected by 2050		1.35
Cox's Bazar (1476)	1979-2000	0.002	0.044
	projected by 2050		0.14
Heron Point (1451)	1983-2000	0.0036	0.044
	projected by 2050		0.14
Cox's Bazar (1476)	1948-2014	0.004	0.26
	projected by 2050		0.4

Table 4.5.2 shows the increasing trend in sea water-level at four tide gauge stations. The increased water level would intensify the intrusion of saltwater to the inland waters and therefore, the saline water gradually mixed with the sweet waters and hence, declined the water quality. The study analyzed the EC value of the Andhermanik (Study area spot-5) and Lohalia River located in the coastal district, Patuakhali (Table 4.5.3).

Table 4.5.3 EC values of the Andhermanik and Lohalia Rivers, Patuakhali

Period	Locations	Periods	Changes
EC (Annual)	Andhermanik River, Patuakhali	2001-2016	2.54 ds/m
		Projected by 2050	8.09 ds/m
EC (Pre-monsoon)	Lohalia River, Patuakhali	2001-2015	1.36 μ s/cm
		Projected by 2050	4.53 μ s/cm
EC (Post-monsoon))	Lohalia River, Patuakhali	2001-2015	0.45 μ s/cm
		Projected by 2050	1.51 μ s/cm

Table 4.5.3 shows that the EC values of the Andhermanik River found higher than that of the Lohalia River. The study observed that the Andhermanik River is closed to the the seashore line . It is expected that sea level rise primalily invaded the Andhermanik River.Thus, the higher salinity was found in the water of the Andhermanik River. Due to the long distance from the coast and comparatively higher elevation, a lower salinity concentration was observed in the water of Lohalia River. Nonetheless, the EC values of both rivers found to increase significantly during the pre- and post-monsoon seasons in the studied period.

4.5.3.2 Temperature and Rainfall

Generally, Temperature, humidity, and rainfall always maintain a linear relationship. The study assessed the correlation between recorded temperature and rainfall at Kalapara station from 1975 to 2017. Fig. 4.5.2 shows a positive relation between the variables indicate that the temperature rise would increase the rainfall in the areas.

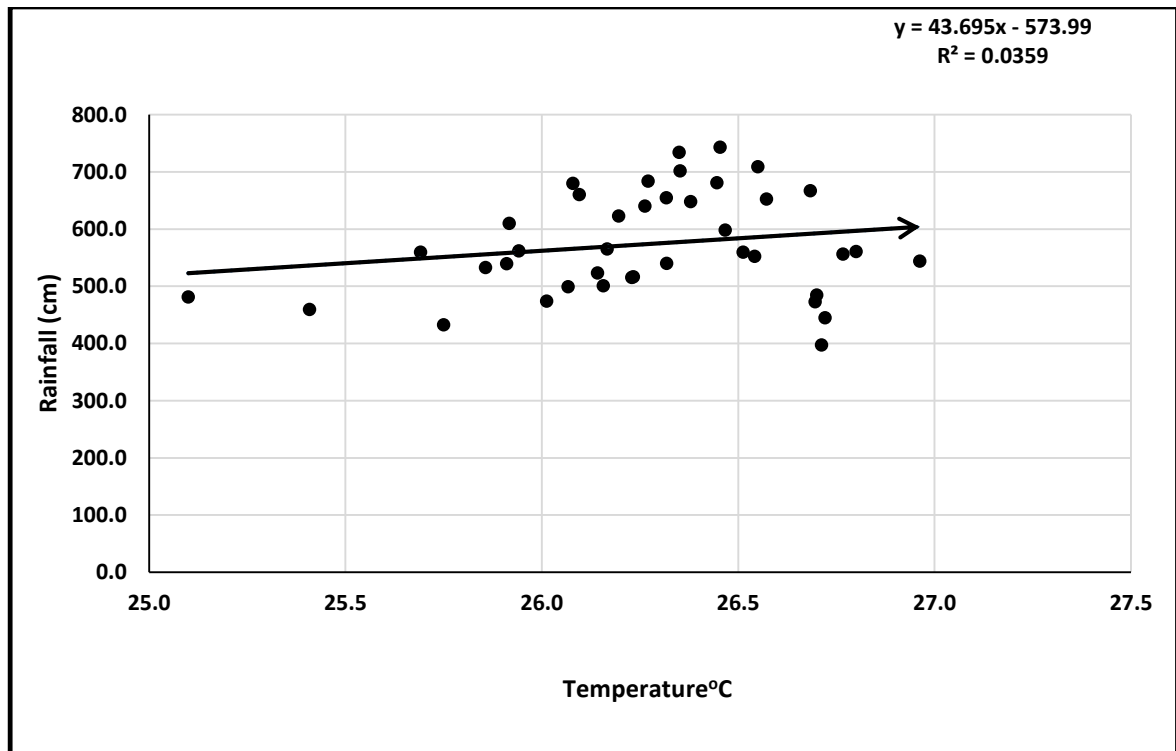


Fig. 4.5.2 Temperature and Rainfall of Kalapara station from 1975 to 2017

4.5.3.3 Relative Humidity and Rainfall

In hydrological cycle, relative humidity and rainfall always keep an equilibrium. The temperature rise as well as the increase of relative humidity would increase the rainfall. The study estimates the correlation between recorded relative humidity and rainfall of Kalapara station from 1975 to 2017. Fig. 4.5.3 shows a positive relationship between the variables indicating increased rainfall occurred in the areas. Nonetheless, the correlation statistics illustrated that the changes in relative humidity considerably unstable the rainfall patterns.

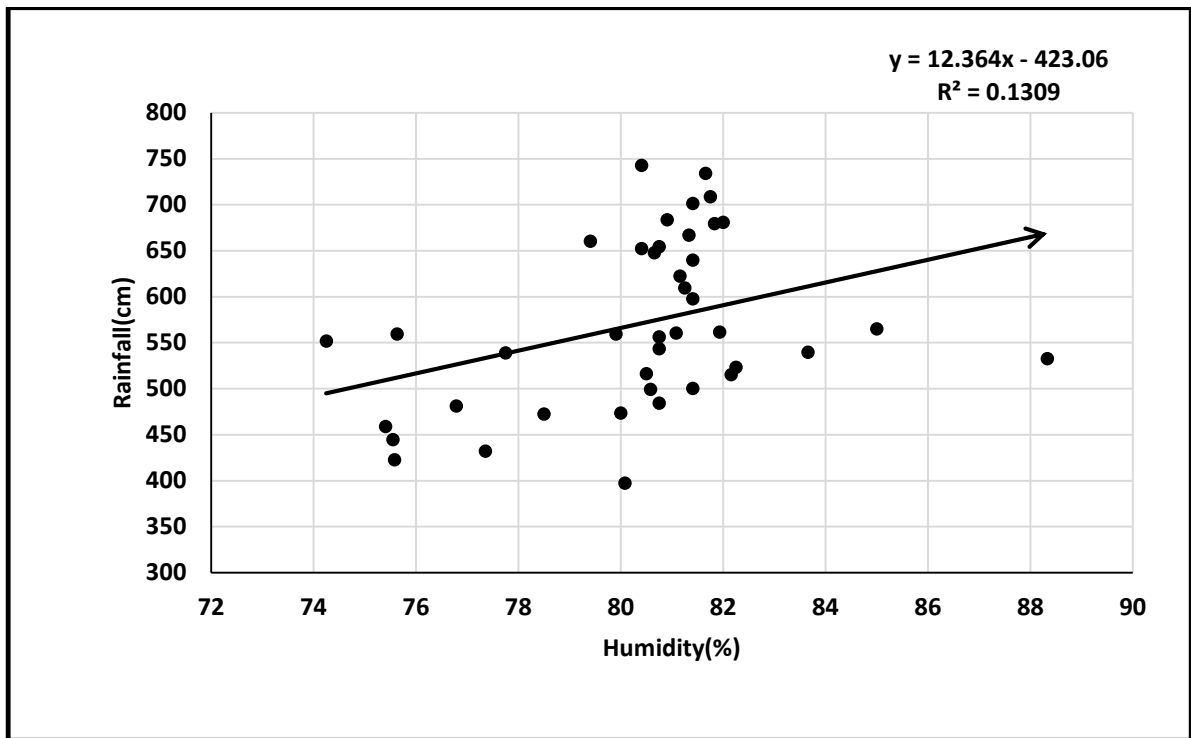


Fig. 4.5.3 Humidity and Rainfall of Kalapara station from 1975 to 2017

4.5.3.4 Temperature and Mean Sea Level

The seawater level can be raised by two different factors concerning climate change. Firstly, the seawater can expand due to raising the temperature, and secondly, the melting of polar ice caps would add extra water with the existing seawater. However, the study assessed the correlation between recorded temperature and mean sea level data at Kalapara

station from 1979 to 2000. The data plotted in Fig.4.5.4 that shows a positive correlation between the variables indicates that the increases of temperature would accelerate to the rises of the seawater level.

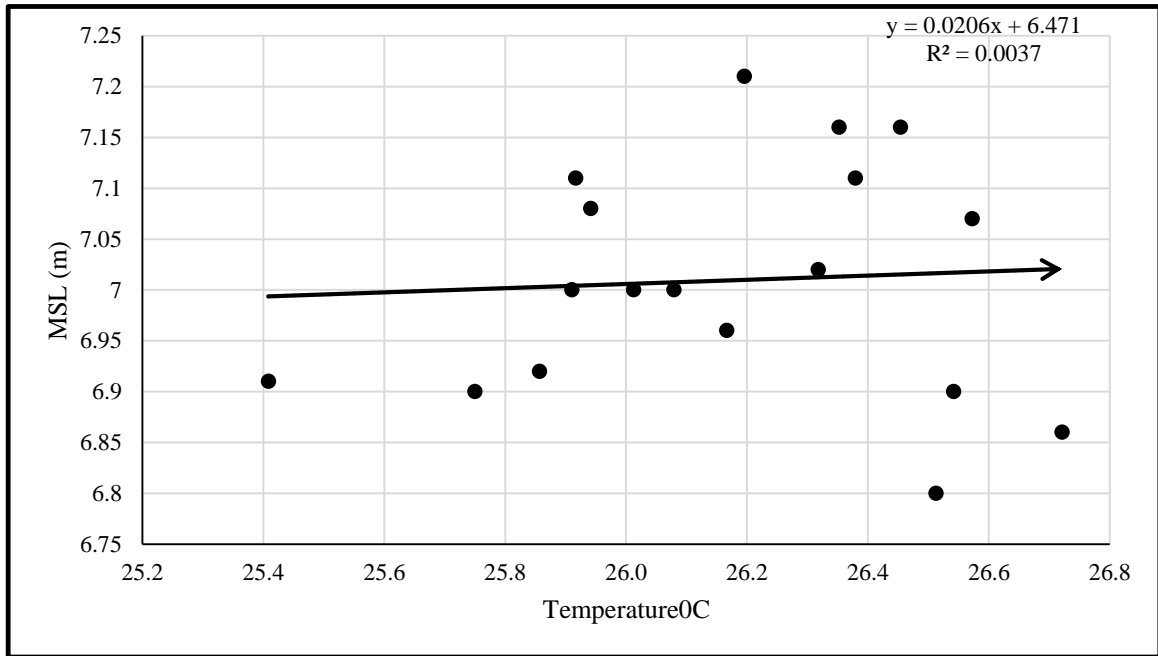


Fig. 4.5.4 Temperature and MSL at Kalpara station from 1979 to 2000

4.5.3.5 EC and Temperature

The electrical conductivity of waters considerably depends on the water temperature and salinity. The changes in water temperature can fluctuate the EC level of waters. Temperature also influences water density, which leads to an increase in the water volume and dissolution of ions. So, the changes in air temperature and EC values of water will influence the water quality. Therefore, the study evaluated the annual EC values (Andhermanik River, Kalapara) and temperature (Kalapara station) from 2001 to 2015 and found a positive relationship between the variables (Fig.4.5.5).

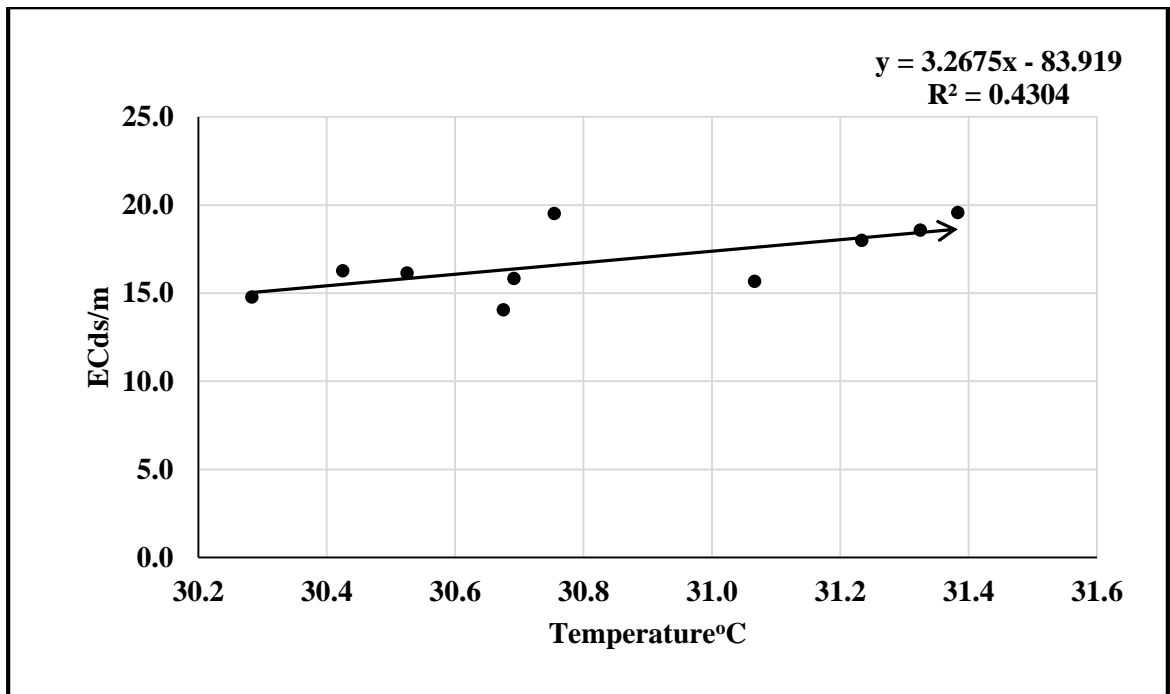


Fig. 4.5.5 EC and Temperature at Kalapara station from 2001 to 2015

Hayashi, M.(2003) studied the EC-temperature relation in a temperature range of 0-30°C of natural waters having different compositions and salinities. The study observed a linear relationship between EC and temperature. Mandal (2014) showed the effect of temperature on EC values in industrial effluents and sewages of Panjab, India and found a positive correlation between the variables. The results of the both studies fairly support the findings of the present study.

Many researchers are trying to predict the possible climate change impacts on watersheds using software models. A few are discussing to improve the understandability of this research findings. Farooqi et al. (2005) used GCMs Climate Scenario generator MAGIC and Regional Climate Model RegCM2 for projected rainfall and temperature of Pakistan based on 1961-1990 data. The Results indicated a progressive change in temperature during the period, and Water quality would suffer from the projected impacts of climate change. Another study conducted by Wang et al. (2018) focused on quantifying the impacts of climate change on nutrient losses from the two small watersheds from 2015 to 2099 with 30 years for each period against the historical nutrient estimation data from 1985 to 2008. The study used Water Erosion Prediction Project-Water Quality (WEPP-WQ) model and found that the combined effects of an increase of precipitation and air temperature on the water quality, especially the oversupply of nutrients, i.e., phosphorus and nitrogen in the watersheds. Chang et al., (2015) studied the impacts of climate change on the water quality of Hsinshan Reservoir, Taiwan, using CE-QUAL-W2 simulations. It observed that increased water temperatures would affect the chemical kinetics; and deteriorate the quality and ecological status of freshwater. The results indicated that the intensified thermal stratification caused by the rising temperature is the primary driver of water quality decline. The increased temperature enhanced the probability of deep-layer oxygen depletion and oversupply of nutrients leading to algae growth. Thus, it leads to an increase in a higher risk of algal blooms, i.e., eutrophication and a decline in the water quality. Whitehead *et al.* (2006b) used the INCA-N model to address the rising nitrate concentrations under climate change. The study showed that climate change could affect the magnitude, frequency, timing, variability, and direction of predicted changes in flow and water quality.

4.5.3.6 EC and Water Quality

In coastal water system, water quality largely depends on saline water intrusion. The results showed a higher EC value in water sample during the pre-monsoon and post-monsoon seasons (see-Appendix 1.4). The study already measured the water quality for specific uses such as irrigation, domestic, and drinking purposes. The results showed a poor to unsuitable quality for the users, especially during the pre-and post-monsoon seasons. Therefore, the study attempted to find out the relation between existing EC and WQI of the studied water samples.

4.5.3.6.1 EC and WQI (Pre-monsoon)

The study evaluated the correlation between existing mean EC and WQI values of selected surface and groundwater samples during the pre-monsoon season of 2016 and 2017. Fig.4.5.6 shows a strong positive relation of EC and WQI values of the studied water samples.

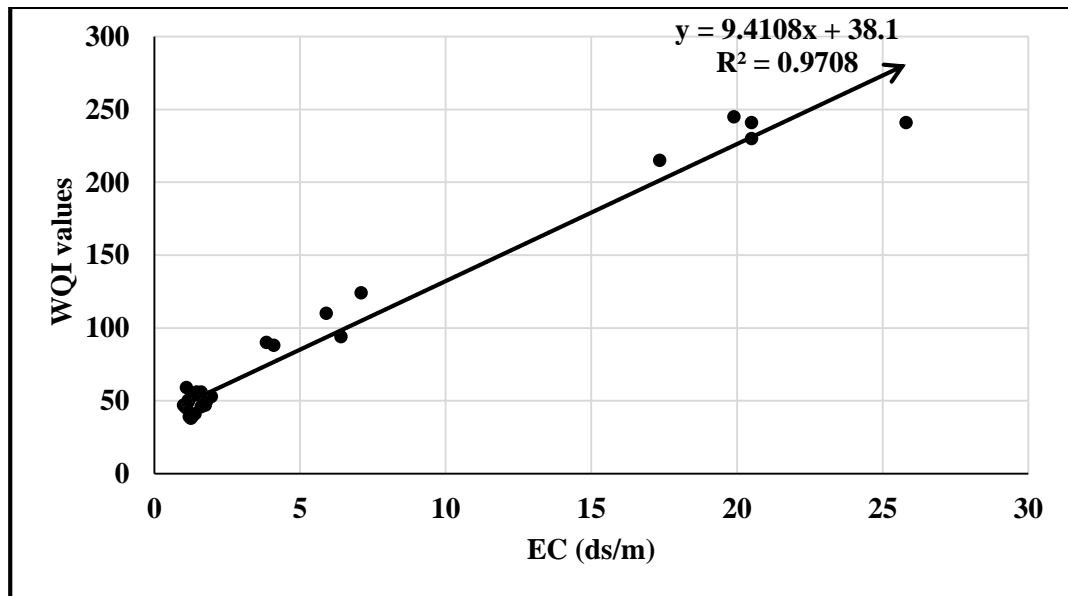


Fig. 4.5.6 EC and WQI values in pre-monsoon season

4.5.3.6.2 EC and WQI (Post-Monsoon)

The study also assessed the correlation between existing mean EC and WQI values of the selected surface and groundwater samples during the post-monsoon period of 2016-2017. Fig. 4.5.7 shows a strong positive correlation with EC and WQI of studied water samples.

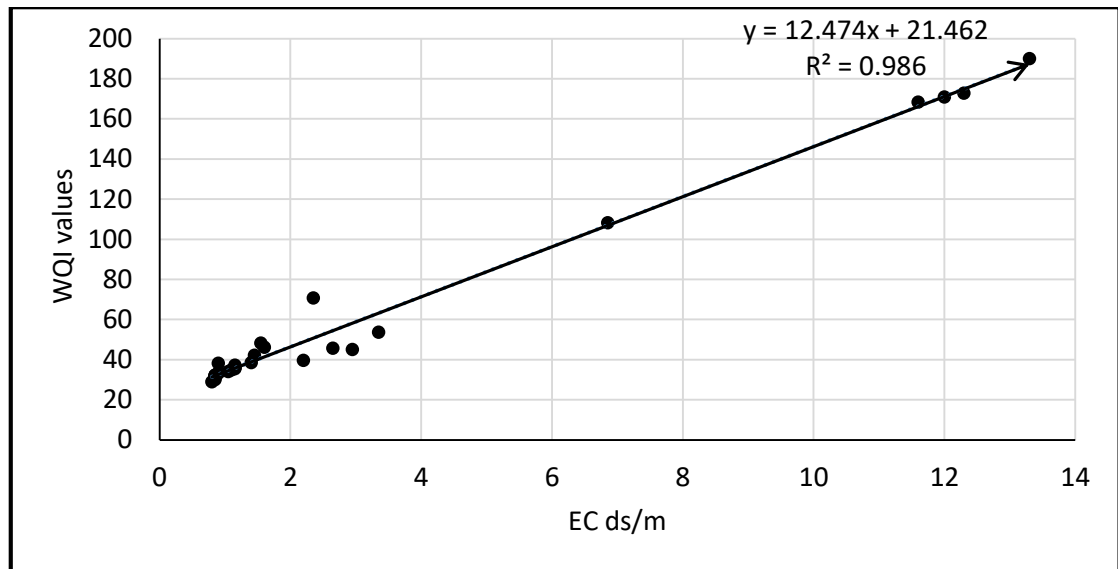


Fig. 4. 5.7 EC and WQI values in post-monsoon season

The study observed that the average temperature, humidity, rainfall, and sea-level rise are continuously increasing in the last forty years threatened the entire coastal areas of Bangladesh. The consequences of sea-level and temperature rise (global warming) have a great concern to the coastal water quality that may change the agricultural productivity, human life, and the entire environment of the areas. The EC value of the water increased with increased temperature is a general phenomenon, which leads to an increase in salinity. The analysis results of the estuaries, rivers, and canals water samples showed that the dominant cation and anion were Na and Cl ions, respectively, and the water type was Na-Cl. Besides, the rise of temperature would increase the rate of evaporation as well as the precipitation in the tropical areas.

The study showed that a good correlation between EC and WQI values has existed. Furthermore, it observed that an increasing trend in average temperature also increased the EC values in coastal watersheds. Furthermore, the sea-level rise would also increase the salinity; and submerge the low-lying areas near the seashore that degraded the water quality of entire coastal watersheds of Bangladesh. Hence, it can be said that the water quality of the coastal watersheds is degrading due to the increase in average temperature in the last few decades, i.e., climate change

CHAPTER-5

CONCLUSION

The study aimed to assess the impacts of climate change on water quality in Kalapara Upazila, the mid-coastal area of Bangladesh. Some secondary meteorological, such as temperature, humidity, and rainfall data of Kalapara station of Patuakhali district were collected from the BMD from 1975 to 2017, and the hydrological (e.g. mean sea level and salinity) data of the last few decades from the BWDB, SRDI, and PSMSL to interpret climate change and its impact on water quality of the area.

The water samples of the selected estuaries, rivers, canals, ponds, and tube-wells were collected for the years 2016 and 2017 to assess the surface and groundwater quality of the areas. Some major water quality parameters such as water temperature, DO, pH, EC, TDS, TSS, Na⁺, K⁺, Ca²⁺, Mg²⁺, Fe, Cu, Pb, Mn, As, Zn, Cl⁻, SO₄²⁻, NO₃⁻, HCO₃⁻, and PO₄³⁻ were analyzed. The observed values were compared with the selected standards, i.e., the DoE, WHO, and FAO. The water type of the study area was determined using the Piper trilinear diagram. In the study, the present water quality of the selected area was examined using two suitable water quality indices such as the Irrigation Water Quality Index (IWQI) and Arithmetic Water Quality Index (AWQI) methods.

The results showed some significant positive increasing trend of annual maximum, average temperature, relative humidity, and rainfall, whereas annual minimum temperature showed a decreasing trend. The annual average temperature increased to 0.7oC and the projected trend line is likely to raise 1.2oC by the year 2050. The annual relative humidity and rainfall also showed an increasing trend, and the projected relative humidity and rainfall will increase by 6.6 % and 234.7 cm, respectively by the same period. The study assessed the available secondary tide gauge data of four stations named the Cox's Bazar, Khepupara, Hiron point, and the Diamond Harbor, and found a positive increasing trend in all stations. The higher increasing trend was observed at Khepupara station, the study area in particular. The study results showed that the water level of Khepupara station would raise about 1.35 m by the year 2050. The analysis results showed that the salinity increased of the

Andhermanik river just about 2.54 ds/m from 2000 to 2015 and is expected to increase by 8.09 ds/cm by the year 2050.

The water samples of the estuaries, rivers, and canals showed higher EC, TDS, and TSS values during the pre-and post-monsoon seasons. The mean EC value of selected estuaries, rivers, and canals waters was found to be 13.1 ± 8.4 dS/m during the pre-monsoon season whereas the lowest was 1.1 ± 0.3 dS/m during the monsoon season. The mean concentration of Na^+ and Cl^- of selected estuaries, rivers, and canals waters were found to be 1425.4 ± 993 and 2435 ± 1512 mg/L, respectively during the pre-monsoon season. The major ions such as Na^+ , K^+ , Cl^- , SO_4^{2-} , and HCO_3^- were found to exceed the permissible limit of the DOE, WHO, and FAO standards during the period. The concentration of the cations followed the order of $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$ during the pre-and post-monsoon seasons and the order of $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ followed during the monsoon season. The anions followed the order of $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-}$ during the pre-and post-monsoon seasons and that was changed as $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$ during the monsoon season. The mean concentration of Na^+ and Cl^- of selected pond water was found to be 150.1 ± 25.5 and 227.3 ± 38.4 mg/L, respectively during the pre-monsoon season. The mean concentration of Na^+ and Cl^- of selected tube-wells water was found to be 184.4 ± 28.3 and 282.6 ± 42.7 mg/L, respectively during the pre-monsoon season. The major ions of both ponds and tube-wells water were found the permissible limit of the DOE, WHO, and FAO standards during the period. The major cations and anions of ponds and tube-wells water followed the similar order of the estuaries, rivers, and canals water. The estimated values of the cations and anions of the estuaries, rivers, and canals water samples of the pre-and post-monsoon seasons plotted in a Piper trilinear diagram and showed that the concentration of $\text{Na}^+ + \text{K}^+$ was higher than $\text{Ca}^{2+} + \text{Mg}^{2+}$ and the concentration of Cl^- was higher than SO_4^{2-} and HCO_3^- . Hence, the ionic dominance of Na^+ and Cl^- indicated Na-Cl water type that was found in surface waters during the pre-and post-monsoon seasons. However, a mixed Na-Cl- HCO_3^- water type was found in the monsoon season.

The study evaluated the water quality of the study area for specific uses such as irrigation, domestic, and drinking purposes. The assessment results showed that the water quality of the estuaries, rivers, and canals found to be poor (30%) and unfit (70%) for irrigation

purposes during the pre-monsoon season. However, the quality was found suitable (100%) in the monsoon season. During the post-monsoon season, only 20% of the samples showed good water quality. The selected pond water showed good quality for irrigation uses especially in the monsoon season, nevertheless, during the pre-and post-monsoon season, only 30 and 20% of the samples showed poor quality. The tube well water quality showed a marginal variance throughout the three seasons. Only 10% of the samples showed unfit quality during the pre-monsoon season though, 50 and 40% of the samples showed poor quality during the pre-and post-monsoon seasons, respectively. During the monsoon season, 40% of the water samples were found to be of poor quality for irrigation uses. The study results showed that about 50% of the water samples of the estuaries, rivers, and canals were found to be unfit quality for domestic purpose uses during the pre and post-monsoon seasons. However, the waters turned into good quality during the monsoon season. The statistics showed that around all the seasons, the pond water samples showed good quality, but about 40% of tube well water samples showed poor quality during the pre-monsoon season. The study results also showed that about 50% of groundwater samples showed poor quality. However, during the monsoon and post-monsoon seasons, the waters were found to have good quality. During the pre-monsoon season, the higher EC values in the coastal surface and groundwater, regulate the higher salinity concentration, whereas during the monsoon season the values were found reasonable. The study stated that the EC values of the selected estuaries, rivers, canals, ponds, and tube well waters started to saline prone during the dry season. It is caused due to less rainfall and sweet water pressure from the upstream regions. Throughout the summer, the values increased up and reached the highest level up to the starting of the next rainy season.

The humidity, rainfall, mean sea level, and EC data of the study area showed a positive correlation with temperature. The seawater level and salinity were remarkably influenced by the increasing temperature. The study exhibited a very good correlation with existing EC and WQI values, which signified that EC values greatly influence the water quality of the coastal areas. The study observed that higher EC values substantially affect coastal water quality. Hence, it can be said that the rise in EC Values is predominantly liable for deteriorating the water quality of coastal areas. The study also observed that the average

temperature, humidity, rainfall, and sea-level rise are continuously increasing in the last few decades that certainly deteriorate the coastal water quality. The study recommends the appropriate adaptation and mitigation options to reduce further degradation of the coastal water quality as well as the entire coastal environment.

Recommendations

The consequences of the rise in sea-level and temperature (global warming) have a great concern to the coastal water quality. The continuous water quality deterioration in low-lying coastal areas could initiate a vulnerable situation that makes a barrier to sustainable development. Geologically and geographically Bangladesh lies in a vulnerable situation in the context of climate change, and the coastal-dwellers have already faced the challenges of climate change impacts. The deterioration of the present status would be unbearable for the affected occupants of the coastal areas shortly. The study recommends some mitigation and adaptation measures that can help to minimize the losses of lives and properties.

- Adequate measures should be taken to ensure safe drinking water for all in the coastal areas of Bangladesh.
- Desalinization plants should be set up in the coastal areas to supply safe drinking water.
- Adaptation measures should be strengthened to improve public food distribution, disaster preparedness, management, and health care systems for reducing vulnerability.
- Saline water-tolerant varieties of crops should be encouraged in planting for better yield and cope with the new coastal environment.
- The local government authorities should be strengthened both technically and financially to conduct community-based adaptation and mitigation action programs.
- Capacity building programs for the local community should be initiated to reduce the knowledge gap in the understanding of climate change impacts and adaptation actions.
- Public awareness programs should have to be taken to minimize the loss of crop productivity, property, livestock, and humans.

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APPENDIX - 1

1.1 Water Temperature

Sample ID	2016			2017		
	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
1EW	31	29	19	30	29	19
2EW	31	30	19	30	29	20
3RW	31	31	19	30	31	19
4RW	29	30	17	30	30	18
5RW	30	30	17	30	29	19
6RW	31	30	18	30	29	19
7RW	33	30	19	32	30	20
8RW	32	32	18	31	29	20
9RW	33	32	18	31	30	21
10RW	33	32	19	31	29	21
11PW	30	29	19	30	30	21
12PW	31	31	18	30	31	19
13PW	31	32	19	31	30	20
14PW	31	28	19	30	29	19
15PW	30	30	18	30	30	20
16PW	29	31	19	29	31	20
17PW	29	30	19	31	30	19
18PW	30	32	19	31	30	20
19PW	29	31	19	30	29	20
20PW	31	31	18	30	29	20
21TW	32	28	19	30	29	19
22TW	30	30	19	29	29	19
23TW	30	30	19	29	29	19
24TW	32	28	18	29	29	20
25TW	32	28	18	29	29	20
26TW	32	30	18	30	30	20
27TW	32	30	18	30	30	20
28TW	32	30	19	30	29	20
29TW	32	30	19	29	31	19
30TW	31	31	19	30	30	19

1.2. Dissolved Oxygen

Sample ID	2016			2017		
	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
1EW	7.1	7.1	7.2	7.2	7.4	7.3
2EW	7.2	7.2	7.3	7.1	7.5	7.3
3RW	7.2	7.2	7.3	7.2	7.5	7.4
4RW	7.2	7.2	7.4	7.2	7.5	7.4
5RW	7.2	7.2	7.3	7.2	7.5	7.3
6RW	7.1	7.1	7.2	7	7.5	7.3
7RW	6.8	6.8	7	7	7.4	7.2
8RW	7	7	7.2	7	7.4	7.2
9RW	6.8	6.8	7	7	7.4	7.2
10RW	7.1	7.1	7.3	7.1	7.4	7.3
11PW	7.2	7.2	7.2	7.2	7.4	7.2
12PW	7.1	7.1	7.2	7.1	7.4	7.3
13PW	7.2	7.2	7.3	7	7.4	7.3
14PW	7	7	7.2	7.1	7.5	7.2
15PW	7.2	7.2	7.3	7.2	7.4	7.3
16PW	7.1	7.1	7.2	7.1	7.3	7.2
17PW	7	7	7.2	7.1	7.4	7.3
18PW	7	7	7.2	7	7.4	7.2
19PW	7.1	7.1	7.3	7.2	7.2	7.3
20PW	7	7	7.2	7.1	7.4	7.2
21TW	7.2	7.2	7.3	7.2	7.5	7.3
22TW	7.1	7.1	7.2	7.1	7.3	7.3
23TW	7.1	7.1	7.3	7.2	7.4	7.3
24TW	7	7	7.2	7	7.5	7.2
25TW	7	7	7.3	7.1	7.5	7.3
26TW	6.9	6.9	7.2	7.1	7.5	7.4
27TW	6.9	6.9	7.1	7	7.4	7.2
28TW	6.9	6.9	7.1	7	7.3	7.2
29TW	6.9	6.9	7.1	7.1	7.4	7.3
30TW	7.2	7.2	7.3	7.2	7.5	7.4

1.3. Total Acidity or Alkalinity (pH)

Sample ID	2016			2017		
	Pre-monsoon	Monsoon	Pre-monsoon	Pre-Monsoon	Monsoon	post-monsoon
1EW	7.9	8.2	7.8	7.7	8	7.7
2EW	7.2	7.7	7.3	7.2	7.5	7.3
3RW	7.3	7.8	7.4	7.5	7.8	7.4
4RW	7.8	8.2	7.7	7.8	8	7.8
5RW	7.3	8.2	7.8	7.2	8.3	7.8
6RW	7.9	8	7.5	7.8	7.9	7.5
7RW	7.9	8.5	7.9	7.5	8.5	8.1
8RW	7.5	8.4	7.9	7.9	8.4	8
9RW	7.6	8	7.6	7.7	8.2	7.6
10RW	7.8	7.8	7.4	7.9	7.8	7.4
11PW	7.7	7.8	7.4	7.8	7.6	7.4
12PW	7.7	7.7	7.3	7.7	7.9	7.3
13PW	7.7	7.5	7.1	7.7	7.6	7.1
14PW	7.8	8.4	7.8	7.6	8.3	8
15PW	7.5	8.1	7.7	7.6	8.2	7.7
16PW	7.8	7.9	7.5	7.8	7.9	7.5
17PW	7.9	6.3	7.9	7.8	6.5	7.9
18PW	7.8	8.3	7.9	7.8	8.3	7.9
19PW	7.8	8	7.6	7.7	8.1	7.6
20PW	7.8	8.3	7.8	7.6	8.4	7.9
21TW	7.8	8.1	7.5	7.8	8.1	7.7
22TW	7.8	7.9	7.4	7.7	7.8	7.4
23TW	7.8	7.8	7.4	7.9	7.9	7.4
24TW	7.6	8	7.5	7.9	8.1	7.6
25TW	7.6	8	7.6	7.9	7.9	7.6
26TW	7.8	7.9	7.5	7.8	7.9	7.5
27TW	7.7	8.1	7.5	7.9	8.2	7.7
28TW	7.9	8.3	7.9	7.9	8.2	7.9
29TW	7.8	8.2	7.8	7.8	8.3	7.8
30TW	7.9	8.2	7.7	7.9	8	7.8

1.4. Electro-conductivity (EC)

Sample ID	2016			2017		
	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
1EW	25.1	1.2	13.1	26.5	1.3	13.5
2EW	19.5	1.1	12.1	21.5	1	12.5
3RW	20.1	1.4	11.9	20.9	1.5	12.1
4RW	22.9	1.4	11.4	19.5	1.5	11.8
5RW	16.6	1.1	6.5	18.1	1.2	7.2
6RW	6.7	1.0	2.9	7.5	1	3.8
7RW	4	0.8	2.7	5.3	0.8	2.6
8RW	5.1	0.8	2.8	6.7	0.7	3.1
9RW	3.8	0.9	2.4	4.3	0.8	2.3
10RW	3.8	0.8	2.3	3.9	0.8	2.1
11PW	1.6	0.6	0.8	0.9	0.6	0.9
12PW	1.5	0.7	0.8	0.9	0.7	0.9
13PW	1.5	0.6	0.9	0.9	0.6	0.9
14PW	1.4	0.6	0.9	0.9	0.7	0.9
15PW	1.1	0.5	0.8	0.9	0.6	0.9
16PW	1.2	0.6	0.9	0.9	0.7	0.9
17PW	1.1	0.6	0.8	0.9	0.6	0.9
18PW	1.4	0.6	0.9	0.8	0.6	0.8
19PW	1.1	0.6	0.8	0.9	0.7	0.9
20PW	1.2	0.6	0.8	0.8	0.6	0.8
21TW	1.9	1.0	1.6	2	1.1	1.5
22TW	1.7	1.0	1.5	1.8	1.2	1.7
23TW	1.8	1.0	1.4	1.8	1	1.5
24TW	1.8	0.9	1.3	1.9	1	1.5
25TW	1.7	0.9	1.2	1.8	1.1	1.1
26TW	1.6	0.9	1.2	1.6	1	1.1
27TW	1.4	0.9	1.1	1.4	1	1.2
28TW	1.3	0.9	1.1	1.3	1	1.1
29TW	1.2	0.9	1.1	1.2	0.9	1
30TW	1.2	0.8	1.1	1.3	0.8	1.2

1.5. Total Dissolved Solid (TDS)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	22541	985	10548	25864	1028	12280
2EW	16120	986	10259	18560	992	10920
3RW	16856	1175	11942	19856	1286	11546
4RW	18845	1180	10589	16854	1267	12023
5RW	13606	980	7658	15906	1028	8745
6RW	6440	985	3198	6960	990	3746
7RW	3041	790	2689	5124	794	3001
8RW	3854	586	1987	3450	587	2875
9RW	2924	880	2090	3052	884	2546
10RW	3005	780	2007	3045	782	2035
11PW	1405	576	797.0	1415	580	890
12PW	1317	672	697.4	1245	673	894
13PW	1317	576	597.8	1245	575	892
14PW	1229	620	890.0	961	640	870
15PW	966	540	820.0	1050	520	895
16PW	1054	580	898.0	884.375	670	880
17PW	966	582	597.8	1098	573	890
18PW	1229	586	885.0	1050	570	791
19PW	966	610	697.4	972.8125	630	888
20PW	1054	560	786.0	1061.25	567	791
21TW	1768	992	1493	1756	1088	1596
22TW	1492	992	1487	1675	1078	1560
23TW	1580	992	1394	1598	995	1478
24TW	1589	893	1376	1612	992	1409
25TW	1524	893	1026	1548	1091	1214
26TW	1405	893	1036	1423	990	1184
27TW	1210	893	1096	1231	992	1124
28TW	1141	893	1054	1142	992	1096
29TW	1130	893	1085	1120	891	1021
30TW	1153	794	996	1140	798	1036

1.6. Total Suspended Solids (TSS)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
1EW	487	26	254	498	28	260
2EW	431	26	265	509	27	284
3RW	452	33	254	431	26	234
4RW	342	27	245	399	20	240
5RW	264	19	130	288	20	140
6RW	180	25	132	152	27	140
7RW	60	12	60	57	13	50
8RW	120	16	135	198	18	130
9RW	11	8	20	23	7	25
10RW	56	8	38	71	9	54
11PW	36	6	20	30	5	25
12PW	15	7	18	18	6	15
13PW	18	8	18	30	10	20
14PW	16	12	15	18	16	18
15PW	36	10	16	16	12	14
16PW	26	12	28	29	15	22
17PW	17	5	21	22	6	20
18PW	26	9	21	23	11	23
19PW	17	5	12	15	6	14
20PW	18	5	21	21	6	20
21TW	9	7	15	18	8	13
22TW	10	6	10	9	7	8
23TW	8	8	10	10	9	11
24TW	6	4	8	9	6	8
25TW	5	6	9	8	7	8
26TW	8	7	9	10	8	10
27TW	5	4	8	7	5	7
28TW	6	6	7	7	7	8
29TW	7	4	9	8	7	7
30TW	8	8	7	9	9	8

1.7. Sodium ion (Na⁺)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	2446	135	840	2884	140	850
2EW	2380	126	832	2470	130	912
3RW	2250	137	847	2675	140	934
4RW	1934	120	940	2023	121	895
5RW	1988	119	798	2403	126	875
6RW	802	120	359	820	124	385
7RW	479	96	225	512	100	260
8RW	356	71	275	450	75	386
9RW	425	99	201	456	105	235
10RW	286	93	198	464	97	201
11PW	192	70	84	197	72	88
12PW	180	82	84	165	83	89
13PW	180	73	95	175	72	90
14PW	168	70	95	163	82	89
15PW	132	58	84	144	70	89
16PW	144	70	95	124	82	86
17PW	132	71	84	144	71	88
18PW	168	69	95	126	72	78
19PW	132	68	84	132	82	85
20PW	144	69	84	147	72	78
21TW	228	119	145	245	120	155
22TW	207	120	145	205	122	156
23TW	198	122	135	201	118	145
24TW	196	107	126	194	119	144
25TW	190	110	116	192	131	106
26TW	192	105	116	194	119	107
27TW	168	107	106	173	119	116
28TW	148	108	106	160	119	117
29TW	144	106	106	158	107	97
30TW	144	98	106	152	100	107

1.8. Potassium ion (K⁺)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	65	4	40	66	5	43
2EW	49	4	38	54	4	40
3RW	50	5	37	57	6	39
4RW	57	5	34	54	6	38
5RW	42	4	20	43	4	23
6RW	17	4	9	20	4	12
7RW	17	3	10	18	3	8
8RW	19	3	9	20	3	10
9RW	21	3	7	21	4	8
10RW	20	2.8	8	21	3	8
11PW	8	4.4	7	8	4.5	7
12PW	8	5.2	6	7	5.3	7
13PW	8	4.4	7	7	4.0	7
14PW	7	4.4	7	6	5.3	7
15PW	6	5.0	6	7	4.0	7
16PW	6	4.4	7	5	5.3	7
17PW	6	4.4	6	6	4.5	7
18PW	7	4.4	7	6	4.5	6
19PW	6	4.4	6	7	5.3	7
20PW	6	5.0	6	6	4.0	6
21TW	12	6	10	13	7	10
22TW	10	6	10	12	8	11
23TW	10	6	9	12	6	10
24TW	11	5	8	12	6	10
25TW	10	5	8	11	6	7
26TW	10	5	8	11	6	8
27TW	9	5	7	10	6	8
28TW	8	5	7	8	6	7
29TW	7	5	7	8	6	6
30TW	7	4	7	8	5	8

1.9. Calcium Ion (Ca²⁺)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	75	16	58	80	17	56
2EW	67	15	54	72	17	52
3RW	69	22	38	81	25	46
4RW	79	24	48	92	26	49
5RW	57	16	30	60	18	30
6RW	23	16	16	25	18	19
7RW	14	13	14	41	15	11
8RW	19	10	10	24	12	13
9RW	13	14	11	27	15	11
10RW	13	13	11	15	15	9
11PW	5.5	9.6	3.6	5.4	12.0	5.0
12PW	5.2	11.7	4.0	5.0	14.0	5.0
13PW	5.2	10.0	4.5	4.8	13.0	5.0
14PW	4.8	10.0	4.5	4.1	14.0	5.0
15PW	3.8	8.3	4.0	4.1	12.0	5.0
16PW	4.1	10.0	4.5	4.0	14.0	5.0
17PW	3.8	10.0	4.0	4.1	12.0	5.0
18PW	4.8	10.0	4.5	4.1	12.0	4.4
19PW	4.0	10.0	4.0	3.7	14.0	5.0
20PW	4.1	10.0	4.0	4.1	12.0	4.4
21TW	15	15	16	18	17	16
22TW	16	16	14	14	19	18
23TW	15	16	15	14	16	13
24TW	15	14	14	15	16	16
25TW	16	13	12	14	18	12
26TW	14	14	14	14	16	13
27TW	13	14	12	15	15	12
28TW	14	14	11	12	16	13
29TW	10	14	12	11	14	12
30TW	12	12	12	10	12	14

1.10. Magnesium Ion (Mg²⁺)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	153	16	104	175	17	125
2EW	147	14	117	152	12	105
3RW	124	20	98	174	19	109
4RW	112	20	97	178	21	114
5RW	123	16	63	126	15	66
6RW	36	13	28	54	15	24
7RW	22	12	26	34	13	22
8RW	38	9	27	36	10	20
9RW	29	11	23	32	12	28
10RW	30	12	22	37	11	25
11PW	12	9	10	14	10	11
12PW	11	11	10	12	12	11
13PW	11	9	11	12	10	11
14PW	11	9	11	10	12	11
15PW	8	8	10	9	10	11
16PW	9	9	11	7	12	11
17PW	8	9	10	10	10	11
18PW	11	9	11	9	10	10
19PW	8	9	10	9	12	11
20PW	9	9	10	9	10	10
21TW	18	15	12	22	15	16
22TW	19	15	13	20	17	15
23TW	16	14	13	24	15	13
24TW	21	15	12	17	14	10
25TW	18	13	10	22	15	10
26TW	18	14	10	19	14	11
27TW	18	13	9	20	14	11
28TW	17	13	11	18	14	10
29TW	16	13	10	18	13	10
30TW	16	11	10	18	11	11

1.11. Chloride Ion (Cl⁻)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	4238	216	1458	4276	225	1429
2EW	3930	245	1348	4072	209	1468
3RW	4234	230	1372	3735	225	2005
4RW	4327	192	1296	3581	195	1210
5RW	3479	147	1293	3260	203	1109
6RW	1403	192	582	1451	200	598
7RW	1056	154	365	906	161	419
8RW	1055	114	446	1175	121	521
9RW	805	158	326	905	169	378
10RW	709	149	321	821	156	324
11PW	293	109	130	303	109	135
12PW	270	120	131	261	126	132
13PW	273	106	146	276	109	138
14PW	198	107	146	236	125	135
15PW	202	90	129	218	106	136
16PW	180	110	146	191	124	132
17PW	202	106	130	205	108	135
18PW	205	105	146	198	109	125
19PW	185	108	129	208	124	130
20PW	195	110	129	226	109	120
21TW	326	182	228	372	191	240
22TW	298	184	225	312	215	241
23TW	303	186	207	306	182	222
24TW	340	164	190	295	180	225
25TW	309	168	177	292	202	162
26TW	293	160	178	310	175	164
27TW	257	164	163	263	185	177
28TW	234	165	165	243	183	179
29TW	220	164	162	230	165	148
30TW	214	152	160	236	154	164

1.12. Sulfate Ion (SO₄²⁻)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	686	21	148	705	22	175
2EW	598	23	138	620	21	153
3RW	525	29	157	556	31	148
4RW	575	29	145	519	33	153
5RW	512	23	102	482	22	88
6RW	197	21	45	200	20	56
7RW	118	17	30	141	18	32
8RW	150	17	37	178	14	39
9RW	112	19	34	114	18	28
10RW	112	17	30	104	18	26
11PW	47	13	11	48	12	10
12PW	44	15	11	46	14	10
13PW	44	13	11	46	12	11
14PW	41	13	11	32	14	12
15PW	32	11	11	32	12	10
16PW	35	13	11	27	14	11
17PW	32	13	11	34	12	10
18PW	41	13	10	32	11	11
19PW	32	13	11	31	14	10
20PW	35	13	10	32	12	10
21TW	56	22	21	62	24	22
22TW	58	22	20	55	25	22
23TW	53	22	19	51	22	22
24TW	51	20	17	53	22	21
25TW	50	20	16	58	24	13
26TW	47	20	16	43	22	13
27TW	49	20	15	39	22	15
28TW	41	20	15	36	22	13
29TW	35	20	15	32	21	12
30TW	38	18	15	46	18	15

1.13. Bi-Carbonate Ion (HCO_3^-)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	232	270	110	239	267	114
2EW	210	289	112	215	282	108
3RW	215	289	112	220	285	104
4RW	190	270	100	198	268	90
5RW	185	270	110	196	263	116
6RW	200	289	108	196	286	112
7RW	186	251	110	196	247	116
8RW	178	289	113	187	288	109
9RW	109	270	110	112	268	114
10RW	132	270	110	137	269	110
11PW	110	197	104	115	267	108
12PW	118	195	108	112	282	112
13PW	114	210	103	104	285	98
14PW	105	178	108	108	268	113
15PW	108	195	110	98	263	112
16PW	102	178	95	107	286	99
17PW	108	197	100	95	247	106
18PW	103	201	110	100	288	120
19PW	104	214	107	100	268	101
20PW	105	220	110	108	269	116
21TW	218	298	185	210	305	189
22TW	220	289	184	215	301	186
23TW	205	298	184	198	302	182
24TW	198	287	178	190	288	176
25TW	196	290	162	190	298	166
26TW	178	288	160	183	297	165
27TW	175	286	162	180	302	160
28TW	186	295	156	190	302	152
29TW	170	301	154	180	310	150
30TW	184	303	152	190	308	153

1.14. Nitrate Ion (NO₃⁻)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	1.7	2.8	2.7	1.81	2.9	2.05
2EW	2.5	1.5	1.6	1.91	1.5	1.4
3RW	1.9	2	1.9	2.16	2.1	1
4RW	2.8	3.5	1.7	2.31	3.5	2.35
5RW	2.3	2.5	1.5	2.12	2.4	1.2
6RW	2.6	2.5	1.5	2.73	2.5	1.5
7RW	2	3	1.3	2.46	2.8	1.4
8RW	2.2	2	1.2	2.11	2	1.3
9RW	2.1	2.5	1.2	2.12	2.5	1.5
10RW	2.2	2.5	1.2	2.1	2.6	1
11PW	2.8	2.5	1.5	2.7	2.5	2.7
12PW	3	1.7	1.8	2.9	1.7	2.9
13PW	3.5	2.7	3.3	2.2	2.7	2.2
14PW	1.9	1.8	1	2.2	1.8	2.2
15PW	2.1	2.5	1.2	3.0	2.6	3.0
16PW	2.8	2.5	1.5	2.9	2.5	2.9
17PW	2.4	2.4	0.9	2.5	2.2	2.5
18PW	2.9	2.5	1.5	3.0	2.5	3.0
19PW	2.5	2.7	1.4	2.7	2.7	2.7
20PW	2	2	1.1	2.4	2.1	2.4
21TW	2	2.3	2.5	2.0	2.3	1.1
22TW	2.4	2	2	2.6	2.1	1.6
23TW	2.9	2.8	2.1	2.1	2.8	1.2
24TW	1.7	2.7	1.1	1.8	2.7	1.3
25TW	1.8	3.3	3	1.6	3.1	1.3
26TW	1.6	2.8	1.9	1.8	2.2	1.3
27TW	1.5	2.4	2.3	1.8	2.3	1.3
28TW	1.5	2.2	2.3	1.7	2.2	1.3
29TW	1.6	2.3	2.5	1.6	2.3	1.4
30TW	1.5	1.8	1.9	2.0	1.8	1.5

1.15. Phosphate Ion (PO₄³⁻)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	0.9	1.5	1.4	1	1.3	1.1
2EW	0.9	1.6	1.5	1.2	1.6	1.2
3RW	0.9	1.7	1.8	0.9	1.8	1.1
4RW	0.7	1.7	0.8	0.8	0.85	0.85
5RW	0.7	1.9	1	0.8	0.84	0.98
6RW	0.8	1.8	1.4	0.8	1.8	1.2
7RW	0.6	1.8	1.5	0.6	1.7	1.5
8RW	0.7	1.7	1.5	0.8	1.4	1.3
9RW	0.6	1.5	1.3	0.8	1.2	1
10RW	0.7	1.2	1.2	0.7	1	1
11PW	1.5	1.7	1.1	1.2	0.8	1
12PW	1.7	1.4	1	1.5	0.5	0.5
13PW	1.6	1.5	1	1.4	0.8	0.7
14PW	1.8	1.8	1.2	2	0.3	0.2
15PW	2	1.8	0.9	2	0.7	0.6
16PW	1.5	1.5	1.5	1.4	0.5	0.5
17PW	1.5	1.7	1.1	1.2	1	1
18PW	1.6	1.9	1.2	1.2	1.1	1
19PW	1.2	1.7	0.6	1.4	0.5	0.4
20PW	1.1	1.3	0.9	1	0.6	0.5
21TW	1.3	0.7	0.7	1.2	0.7	0.5
22TW	1.8	1.2	1.3	1.6	1.2	1
23TW	1.6	1.1	1.2	1.7	1.1	1
24TW	1.2	0.8	0.9	1.2	0.8	0.7
25TW	1.4	1.1	1.2	1.5	1.2	1.1
26TW	1	1.5	0.7	0.9	0.6	0.5
27TW	1	1.4	1.2	0.8	0.9	0.8
28TW	1	1.6	0.9	0.8	0.8	0.7
29TW	1	1.5	1.1	0.9	1	0.8
30TW	1	1.6	1.1	1	1	0.8

1.16. Iron (Fe)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	0.281	0.081	0.123	0.284	0.071	0.125
2EW	0.281	0.021	0.145	0.272	0.022	0.142
3RW	0.333	0.133	0.133	0.293	0.138	0.133
4RW	0.907	0.304	0.304	0.807	0.314	0.401
5RW	0.039	0.022	0.135	0.049	0.032	0.123
6RW	0.349	0.036	0.198	0.347	0.035	0.213
7RW	0.678	0.268	0.268	0.688	0.238	0.268
8RW	0.032	0.024	0.354	0.042	0.024	0.45
9RW	0.103	0.04	0.123	0.113	0.05	0.213
10RW	0.039	0.012	0.12	0.03	0.013	0.13
11PW	0.035	0.018	0.012	0.035	0.019	0.032
12PW	0.035	0.012	0.022	0.035	0.012	0.35
13PW	0.527	0.027	0.027	0.528	0.028	0.856
14PW	0.293	0.021	0.031	0.283	0.024	0.366
15PW	0.214	0.024	0.023	0.224	0.025	0.248
16PW	0.214	0.012	0.026	0.205	0.016	0.21
17PW	0.032	0.011	0.011	0.022	0.017	0.214
18PW	0.036	0.04	0.024	0.026	0.044	0.23
19PW	0.417	0.017	0.036	0.427	0.01	0.654
20PW	0.317	0.024	0.024	0.337	0.026	0.474
21TW	0.214	0.012	0.012	0.228	0.022	0.256
22TW	0.214	0.015	0.036	0.204	0.015	0.208
23TW	0.357	0.023	0.031	0.387	0.023	0.574
24TW	0.396	0.04	0.04	0.396	0.044	0.592
25TW	0.388	0.03	0.036	0.308	0.04	0.416
26TW	0.333	0.024	0.325	0.339	0.034	0.478
27TW	0.356	0.036	0.036	0.346	0.046	0.492
28TW	0.198	0.017	0.023	0.178	0.027	0.156
29TW	0.388	0.04	0.027	0.398	0.05	0.596
30TW	0.396	0.03	0.03	0.412	0.04	0.624

1.17. Copper (Cu)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	0.026	0.006	0.006	0.028	0.007	0.0238
2EW	0.026	0.002	0.039	0.027	0.003	0.02295
3RW	0.026	0.002	0.002	0.026	0.005	0.0221
4RW	0.036	0.019	0.019	0.038	0.02	0.0323
5RW	0.394	0.014	0.002	0.367	0.01	0.31195
6RW	0.045	0.003	0.015	0.048	0.003	0.0408
7RW	0.02	0.02	0.02	0.021	0.021	0.01785
8RW	0.017	0.015	0.003	0.017	0.016	0.01445
9RW	0.036	0.051	0.039	0.036	0.057	0.0306
10RW	0.394	0.039	0.029	0.384	0.034	0.3264
11PW	0.022	0.013	0.013	0.021	0.018	0.01785
12PW	0.022	0.014	0.002	0.03	0.021	0.0255
13PW	0.021	0.02	0.02	0.022	0.024	0.0187
14PW	0.018	0.002	0.003	0.011	0.003	0.00935
15PW	0.007	0.015	0.02	0.008	0.016	0.0068
16PW	0.007	0.014	0.002	0.008	0.014	0.0068
17PW	0.007	0.005	0.005	0.007	0.006	0.00595
18PW	0.008	0.051	0.015	0.009	0.054	0.00765
19PW	0.028	0.014	0.003	0.028	0.014	0.0238
20PW	0.021	0.015	0.015	0.021	0.016	0.01785
21TW	0.002	0.014	0.014	0.002	0.013	0.002
22TW	0.002	0.019	0.003	0.003	0.018	0.003
23TW	0.02	0.02	0.02	0.021	0.021	0.018
24TW	0.051	0.051	0.051	0.051	0.054	0.043
25TW	0.04	0.001	0.003	0.03	0.002	0.026
26TW	0.017	0.015	0.02	0.027	0.016	0.023
27TW	0.025	0.003	0.003	0.029	0.003	0.025
28TW	0.038	0.014	0.002	0.038	0.014	0.032
29TW	0.023	0.051	0.02	0.033	0.006	0.028
30TW	0.051	0.001	0.001	0.041	0.001	0.035

1.18. Lead (Pb)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	0.003	ND	0.002	0.003	ND	0.007
2EW	0.003	ND	0.001	0.003	ND	0.006
3RW	0.004	ND	0.001	0.001	ND	0.008
4RW	0.001	ND	0.003	0.036	ND	0.006
5RW	0.002	ND	0.004	0.013	ND	0.013
6RW	0.001	ND	0.002	0.013	ND	0.010
7RW	0.003	ND	0.002	0.003	ND	0.002
8RW	0.004	ND	0.002	0.043	ND	0.005
9RW	0.005	0.044	0.001	0.023	0.045	0.003
10RW	0.006	0.001	0.001	0.013	ND	0.004
11PW	0.004	0.002	0.002	0.002	0.001	0.001
12PW	0.003	0.001	0.003	0.003	0.001	0.002
13PW	0.002	0.002	0.001	0.004	0.001	0.003
14PW	0.002	0.001	0.001	0.003	0.001	0.001
15PW	0.002	0.001	0.002	0.004	0.001	0.002
16PW	0.004	0.001	0.003	0.004	0.001	0.002
17PW	0.006	0.002	0.002	0.004	0.001	0.004
18PW	0.003	0.001	0.001	0.005	0.001	0.001
19PW	0.002	0.002	0.002	0.002	0.001	0.002
20PW	0.002	0.001	0.003	0.014	0.001	0.003
21TW	0.067	0.020	0.083	0.078	0.030	0.085
22TW	0.056	0.035	0.044	0.064	0.020	0.028
23TW	0.074	0.025	0.031	0.087	0.042	0.044
24TW	0.080	0.044	0.021	0.068	0.021	0.034
25TW	0.074	0.044	0.028	0.057	0.042	0.043
26TW	0.061	0.035	0.044	0.059	0.031	0.053
27TW	0.068	0.036	0.034	0.085	0.021	0.034
28TW	0.057	0.037	0.043	0.068	0.026	0.043
29TW	0.083	0.038	0.053	0.067	0.014	0.043
30TW	0.058	0.044	0.035	0.058	0.029	0.026

1.19. Arsenic (As)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	0.002	0.001	0.002	0.000	0.002	0.002
2EW	0.004	0.001	0.002	0.000	0.001	0.002
3RW	0.003	0.001	0.002	0.004	0.002	0.001
4RW	0.002	0.002	0.002	0.002	0.002	0.002
5RW	0.003	0.001	0.001	0.004	0.003	0.002
6RW	0.002	0.000	0.001	0.004	0.001	0.001
7RW	0.001	0.001	0.002	0.001	0.001	0.002
8RW	0.003	0.002	0.003	0.003	0.004	0.001
9RW	0.001	0.001	0.002	0.001	0.001	0.002
10RW	0.003	0.001	0.002	0.004	0.001	0.001
11PW	0.002	0.001	0.001	ND	0.001	0.001
12PW	0.002	0.001	0.002	0.002	0.001	0.001
13PW	0.002	0.001	0.002	0.001	0.001	0.002
14PW	0.001	0.002	0.001	0.001	0.000	0.002
15PW	0.006	0.001	0.002	0.007	0.001	0.002
16PW	0.005	0.000	0.001	0.007	0.001	0.002
17PW	0.002	0.001	0.001	ND	0.001	0.002
18PW	0.002	0.002	0.001	N D	0.001	0.001
19PW	0.001	0.001	0.002	0.001	0.001	0.001
20PW	0.002	0.001	0.001	0.001	0.001	0.001
21TW	0.005	0.003	0.004	0.004	0.003	0.004
22TW	0.005	0.004	0.004	0.004	0.003	0.004
23TW	0.004	0.004	0.004	0.004	0.003	0.004
24TW	0.004	0.002	0.004	0.004	0.003	0.004
25TW	0.005	0.002	0.004	0.004	0.003	0.004
26TW	0.006	0.003	0.004	0.005	0.003	0.003
27TW	0.002	0.003	0.004	0.003	0.002	0.004
28TW	0.001	0.002	0.004	0.001	0.001	0.004
29TW	0.005	0.002	0.004	0.005	0.002	0.004
30TW	0.003	0.003	0.003	0.003	0.002	0.003

1.20. Manganese (Mn)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	0.003	ND	0.018	0.002	0.001	0.001
2EW	0.003	0.002	0.019	0.002	0.002	0.001
3RW	0.006	ND	0.001	0.007	ND	0.004
4RW	0.005	0.001	0.002	0.006	0.001	0.002
5RW	0.019	0.001	0.002	0.019	0.001	0.020
6RW	0.005	0.007	0.001	0.006	0.006	0.006
7RW	0.003	0.001	0.001	0.004	0.001	0.004
8RW	0.003	0.001	0.007	0.004	0.001	0.003
9RW	0.005	ND	0.001	0.004	ND	0.003
10RW	0.019	ND	0.02	0.029	0.009	0.029
11PW	0.002	0.001	0.002	0.003	0.002	0.003
12PW	0.001	0.001	0.001	0.004	0.001	0.001
13PW	0.005	0.003	0.003	0.006	0.003	0.005
14PW	0.011	0.002	0.002	0.022	0.002	0.020
15PW	0.005	0.001	0.001	0.006	0.001	0.005
16PW	0.005	0.001	0.006	0.006	0.001	0.006
17PW	0.006	0.002	0.002	0.007	0.001	0.005
18PW	0.005	0.002	0.001	0.004	0.001	0.003
19PW	0.007	0.001	0.007	0.004	0.001	0.004
20PW	0.005	0.001	0.001	0.006	0.001	0.005
21TW	0.002	0.001	0.001	0.003	0.002	0.003
22TW	0.002	0.001	0.007	0.006	0.002	0.005
23TW	0.001	0.001	0.001	0.002	0.001	0.002
24TW	0.002	0.002	0.004	0.004	0.004	0.003
25TW	0.009	0.003	0.007	0.012	0.009	0.013
26TW	0.004	0.001	0.001	0.003	0.002	0.001
27TW	0.007	0.007	0.007	0.006	0.005	0.003
28TW	0.001	0.001	0.002	0.002	0.001	0.002
29TW	0.001	0.004	0.003	0.002	0.001	0.001
30TW	0.003	0.001	0.003	0.002	0.003	0.002

1.21. Zinc (Zn)

Sample ID	2016			2017		
	Pre-monsoon	monsoon	post-monsoon	Pre-monsoon	monsoon	post-monsoon
1EW	0.018	0.001	0.018	0.002	0.001	0.001
2EW	0.018	0.003	0.019	0.019	0.002	0.020
3RW	0.015	0.001	0.001	0.025	0.001	0.020
4RW	0.022	0.002	0.002	0.034	0.002	0.003
5RW	0.001	0.002	0.003	0.002	0.001	0.001
6RW	0.001	ND	ND	0.001	0.001	0.002
7RW	0.001	0.001	0.001	0.001	0.001	0.002
8RW	0.001	ND	ND	0.002	0.001	0.001
9RW	0.001	0.000	0.001	0.001	0.001	0.002
10RW	0.001	0.001	0.001	0.001	0.001	0.003
11PW	0.018	0.002	0.002	0.019	0.024	0.020
12PW	0.018	0.002	0.003	0.008	0.002	0.001
13PW	0.009	0.006	0.006	0.009	0.009	0.005
14PW	0.003	0.003	0.003	0.002	0.003	0.000
15PW	0.001	0.001	0.005	0.003	0.001	0.004
16PW	0.001	0.002	0.001	0.001	0.001	0.002
17PW	0.003	0.001	0.001	0.002	0.001	0.002
18PW	0.003	0.000	0.002	0.003	0.003	0.001
19PW	0.009	0.002	0.003	0.008	0.002	0.004
20PW	0.006	0.002	0.002	0.008	0.002	0.003
21TW	0.003	0.002	0.002	0.005	0.002	0.005
22TW	0.003	0.002	0.001	0.004	0.003	0.002
23TW	0.005	0.005	0.005	0.005	0.005	0.002
24TW	0.004	0.004	0.000	0.001	0.004	0.001
25TW	0.009	0.001	0.002	0.005	0.003	0.003
26TW	0.004	0.003	0.003	0.006	0.004	0.003
27TW	0.007	0.002	0.002	0.005	0.003	0.004
28TW	0.007	0.002	0.001	0.009	0.002	0.001
29TW	0.008	0.004	0.006	0.004	0.001	0.004
30TW	0.001	0.001	0.001	0.007	0.001	0.003

APPENDIX -2

2.1 Water Quality Index Value for Agricultural Purpose Uses

Sample ID	Pre-monsoon	Monsoon	Post-monsoon
1EW	12	66	21
2EW	16	63	22
3RW	17	63	20
4RW	21	71	26
5RW	21	71	24
6RW	36	66	41
7RW	39	79	53
8RW	41	76	45
9RW	44	74	59
10RW	44	75	66
11PW	42	82	77
12PW	51	72	76
13PW	52	81	69
14PW	63	80	67
15PW	71	92	75
16PW	78	80	73
17PW	76	83	78
18PW	79	82	74
19PW	78	75	80
20PW	72	79	84
21TW	33	65	50
22TW	46	62	50
23TW	48	69	59
24TW	53	73	67
25TW	61	69	79
26TW	63	79	79
27TW	75	75	78
28TW	77	74	80
29TW	80	79	85
30TW	78	85	82

2.2 Water Quality Index Value for Domestic Purpose Uses

Sample ID	Pre-monsoon	Monsoon	Post-monsoon
1EW	307	37	190
2EW	253	27	173
3RW	267	38	171
4RW	271	44	168
5RW	213	34	108
6RW	98	31	54
7RW	83	29	46
8RW	92	26	45
9RW	97	27	71
10RW	87	27	40
11PW	44	29	32
12PW	42	29	32
13PW	41	29	38
14PW	34	28	33
15PW	35	29	32
16PW	33	30	33
17PW	34	28	30
18PW	37	29	31
19PW	35	31	31
20PW	33	27	29
21TW	56	37	48
22TW	54	37	46
23TW	54	37	42
24TW	51	36	39
25TW	50	38	37
26TW	48	35	36
27TW	44	34	36
28TW	39	34	35
29TW	38	33	34
30TW	39	28	36

2.3 Water Quality Index Value for Drinking Purpose Uses

Sample ID	Pre-monsoon	Monsoon	Post-monsoon
21TW	56	37	48
22TW	54	37	46
23TW	54	37	42
24TW	51	36	39
25TW	50	38	37
26TW	48	35	36
27TW	44	34	36
28TW	39	34	35
29TW	38	33	34
30TW	39	28	36

