ASSESSMENT OF THE VARIABILITY IN NUTRIENT CONTENT OF DEPOSITED SEDIMENT AND CROP DIVERSITY IN SELECTED TIDAL BASINS OF BANGLADESH

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A Thesis by

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CERTIFICATE OF APPROVAL

The thesis titled **'Assessment of the Variability in Nutrient Content of Deposited Sediment and Crop Diversity in Selected Tidal Basins of Bangladesh'**, submitted by Nureza Hafiz, Roll No. 0416282051P, Session April, 2016, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M. Sc. in Water Resources Development on 16 November, 2022.

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

NUREZA HAFIZ

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Nureza Hafiz

Dedicated to

My Beloved Mother – Nilufar Rahman

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ABSTRACT

In Bangladesh, coastal polders have been constructed since 1960s to protect the land from floods as well as to intensify crop production. However, the polders altered the sensitive river-floodplain sediment balance and resulted in river siltation, drainage congestion and waterlogging. Therefore, Tidal River Management (TRM) was introduced to solve the waterlogging problem while ensuring sedimentation in the low-lying tidal basins and increasing the potential for crop production. This study has been conducted to assess the variation in nutrient content and composition of the deposited sediment and water quality in selected tidal basins, along with the socio-economic and institutional factors for crop production and diversity in the basins in relation to the level of success in TRM operations in Beel Bhaina (successful TRM), East Beel Khuksia (partially successful TRM) and Beel Pakhimara (unsuccessful TRM). The level of success of a TRM operation is understood by how the local community perceived the TRM operation results considering the extent of reduced waterlogging and drainage congestion problems and the depth of sedimentation inside the beel. Different physical and physicochemical properties of soil e.g., soil texture, pH, electrical conductivity (EC), organic matter (OM) and available nutrient elements such as Ca, Mg, Fe, P, S and Cl were determined for assessing the deposited sediment quality. For understanding the water quality, pH, EC, total dissolved solid (TDS), total suspended solid (TSS), Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-}, PO_4^{3-}, NO_3^- and NO_2^- were measured. Sodium adsorption ratio (SAR), sodium percentage (Na%), potential salinity (PS), magnesium ratio (MR), calcium-magnesium ratio (Ca: Mg), permeability index (PI), and Kelly's index (KI) were calculated to evaluate the suitability of the water for agricultural purposes. The soil and water quality parameters were analyzed following the established methodologies. Participatory Rural Appraisal tools like Focus Group Discussions, Group Discussions, Key Informant Interviews, individual interviews, and field observations were used to gather useful information regarding the socio-economic and institutional factors for crop production and diversity in the study areas. The field data were collected through several visits to the study areas and relevant organizations including upazila agriculture offices, upazila agricultural extension offices and Bangladesh Water Development Board.

Soil texture showed similar pattern in the three basins. Among the three beels, the EC of East Beel Khuksia was the lowest which may be one of the reasons for good harvest. The pH of the soils fell under a slightly alkaline class. All the soil parameters were higher in winter than that of monsoon, except for OM. The plant residues from crop production during winter may have increased the OM content in monsoon. Ca was the dominant cation in the basins because it is less susceptible to leaching. As salt affected soils tend to increase the available Fe under waterlogging conditions, Fe was higher in winter than in monsoon. All the water sources (beel, river and GW) from the three basins were suitable for irrigation purpose in terms of pH. The water salinity of Beel Pakhimara was better than the two other beels. The EC of GW in East Beel Khuksia was permissible for irrigation which could be the reason for higher crop production. The highest TDS and TSS were found in winter in the three basins, except for Beel Pakhimara having the highest TSS in monsoon. The water of Beel Bhaina and East Beel Khuksia was categorized as 'permissible' and 'unsuitable', respectively whilst that of Beel Pakhimara was categorized as 'good' in winter for irrigation purpose considering available TDS. The most dominant cation was Na in almost all the water samples due to the seawater influence, evaporation or crystallization and other hydrogeochemical processes. In Beel Bhaina and East Beel Khuksia, severe sodium toxicity was present in water whilst there was no sodium toxicity

in Beel Pakhimara. The most dominant anion was Cl^- in Beel Bhaina and East Beel Khuksia, whereas it was HCO_3^- in Beel Pakhimara. The HCO_3^- dominance could be due to the weathering from calcite parent materials and dissolution of limestone and dolomite. The water from the three beels was categorized as ‘severe’ for Cl^- toxicity. The SO_4^{2-} and HCO_3^- contents were found to be ‘satisfactory’ in both the seasons. Very low amounts of PO_4^{3-}, NO_3^- and NO_2^- were present in the water samples compared to other available anions in the three basins. For Beel Pakhimara, all the SAR values fell under ‘excellent’ category for crop production in both the seasons. Considering PS, the water of Beel Bhaina was ‘unsuitable’ and that of East Beel Khuksia and Beel Pakhimara was ‘suitable’ in both the seasons.

The dominant cropping pattern in Beel Bhaina, East Beel Khuksia and Beel Pakhimara was fish-fish-boro rice. The yields of boro rice were 7.2, 7.7 and 6.4 ton/ha in Beel Bhaina, East Beel Khuksia and Beel Pakhimara, respectively. Beel Bhaina and East Beel Khuksia being two adjacent tidal basins, similar crop varieties were also observed on gher embankments, for example beans, spinach, cucumber, and tomato. Moreover, beans were cultivated in abundance during winter and monsoon in Beel Bhaina. In East Beel Khuksia, tomatoes were cultivated in winter and cucumbers in monsoon at a large scale. In Beel Pakhimara, no farming was seen during monsoon. The farmers cultivated boro rice in the elevated lands in winter. The farmers of the three tidal basins reported that they were getting higher crop yield and economic return after the TRM operation. The profit margin in Beel Bhaina, East Beel Khuksia and Beel Pakhimara is found to be 53.6%, 50% and 43.7%, respectively. The variation in crop variety was also due to market competition, economic return and extension services. However, similar scenarios were found considering, access to capital, access to market, and competition in agricultural markets in the three beels regardless of the TRM success.

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ABREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrometer
AEZ	Agro Ecological Zones
BADC	Bangladesh Agricultural Development Corporation
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BINA	Bangladesh Institute of Nuclear Agriculture
BMD	Bangladesh Meteorological Department
BOD	Biological Oxygen Demand
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
COD	Chemical Oxygen Demand
DAE	Department of Agricultural Extension
DOE	Department of Environment
dS/m	deci-Siemens per meter
EC	Electrical Conductivity
EDTA	Ethylene-Di-amine Tetra Acetic acid
EGIS	Environmental and Geographic Information Services
FAO	Food and Agriculture Organization

FGD	Focus Group Discussion
g/L	Gram per Liter
GD	Group Discussion
GW	Groundwater
ha	hectare
HYV	High Yielding Variety
IWM	Institute of Water Modeling
KI	Kelly's Index
KII	Key Informant Interview
KJDRP	Khulna-Jashore Drainage Rehabilitation Project
LGED	Local Government Engineering Department
LGI	Local Government Institution
meq/L	Milliequivalents per Liter
Mha	Million hectare
MR	Magnesium Ratio
µS/cm	micro-Siemens per centimeter
Na%	Sodium Percentage
OM	Organic Matter
PI	Permeability Index
ppm	Parts per million
PRA	Participatory Rural Appraisal

PS	Potential Salinity
SAR	Sodium Adsorption Ratio
SMEC	Snowy Mountain Engineering Corporation
SRDI	Soil Resource Development Institute
STW	Shallow Tube Well
SWMC	Surface Water Modelling Centre
T. AMAN	Transplanted Aman
TDS	Total Dissolved Solid
TRM	Tidal River Management
TSS	Total Suspended Solid
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WFP	World Food Program
WMA	Water Management Association
WMF	Water Management Federation
WMG	Water Management Group
WMO	Water Management Organization

CHAPTER ONE
INTRODUCTION

1.1 Background

Bangladesh being a part of the world's largest delta, the Ganges-Brahmaputra delta (Figure 1.1) (Minnen, 2013), is adorned with hundreds of rivers, khals, canals, swamps, haors, lakes and tidal basins. The major rivers- the Ganges, the Brahmaputra and the Meghna - discharges into the Bay of Bengal (Die, 2013) joining about a few kilometers upstream of its mouth, along 380 kilometers of delta front (Allison, 1998). The Ganges-Brahmaputra river system transports vast amount of sediments, at least one billion tons of sediment load per year (the highest annual sediment load) and settles down sediment-borne water on the delta (Gain et al., 2017; Die, 2013; Allison, 1998). It was observed by Coleman (1969) that the sediment load of the Ganges-Brahmaputra is consisted of silt (>70%), fine sand (10%) and little amount of clay (Allison et al., 2003; Allison, 1998). The alluvial deposits rich in nutrients form almost the entire delta, approximately about 80% of Bangladesh (Gain et al., 2017; FAO, 2011). Due to the diverse and complex physiographical setting (Brammer, 2014), the coastal region faces multiple threats such as land subsidence, tidal floods, extreme cyclonic events, storm surge, and salinity intrusion (Gain et al., 2017; Islam et al., 2013).

The south-western coastal Bangladesh is covered by the districts- Khulna, Jashore, Satkhira, and Bagerhat (Figure 1.2). Being prone to cyclones in the pre-monsoon (March-May) and post-monsoon (October -November) (Islam et al., 2013), before 1960 this region was not only hit by 19 severe cyclones but also flooded by saline water during high tides (Talchabhadel et al., 2016). Therefore, coastal polders have been constructed since the mid-1960s to protect the land from floods as well as to intensify agricultural production (Masud et al., 2018; Gain et al., 2017; Cardno, 2017).

However, the polders altered the sensitive river-floodplain sediment balance and resulted in river siltation, drainage congestion and waterlogging in both rivers and canals (Masud et al., 2018; Khadim et al., 2013). Consequently, Tidal River Management (TRM) was introduced to solve the waterlogging problem while ensuring sedimentation in the low-lying tidal basins (Amir et al., 2013; Kibria, 2011). The deposited sediment rich in nutrient content improves the soil fertility and increases the potential for crop production (Kibria, 2011; Ikeda et al., 2009), which is particularly beneficial for the poor people primarily dependent on the natural resources and agriculture-based livelihoods (Rasel et al., 2013). Salinization affects the metabolism of the organisms present in the soil, drastically reduces soil fertility and increases water proofing of the deeper layers (Rahman et al., 2014). Widespread nutrient deficiencies of N, P, Zn and Cu have been observed in the coastal regions (Haque, 2006; Karim et al., 1990). However, a successful TRM can reduce the above problems of the coastal regions.

Significant increase in the livelihood opportunities related to agriculture and fisheries as a result of improved drainage was observed in Beel Bhaina after successful sediment management in the tidal basin (Paul et al., 2013; Tutu, 2005), whereas partially successful TRM in East Beel Khuksia resulted in uneven sedimentation in the tidal basin leading to livelihood loss, human displacement, conflicts and social unrest. According to IWM (2017), the sediment deposition appears to be unevenly distributed in Beel Pakhimara under an ongoing TRM scheme. This may result in a sediment and nutrient distribution different from the other tidal basins. It is evident that operational disparities of different TRM projects have caused different levels of success. This may have also caused different sediment and nutrient distributions, and varied impact on crop production. In addition, other socio-economic and institutional factors play significant role in crop diversity and production. Therefore, it is important to understand how the sediment and nutrient distributions vary in different tidal basins, and how they are related to the TRM operation and crop production.

1.2 Main Research Questions

The following research questions were formulated to address the central question, i.e., how do the sediment and nutrient distributions vary in different tidal basins (with TRM) in the southwest coastal delta of Bangladesh?

i. What is the quality of the water and soil in and around the study areas?

ii. Before TRM, what were the cropping pattern and crop yield in the beels?

iii. What is the socio-economic and institutional situation in the basin areas?

1.3 Objectives

The following specific objectives were formulated in response to the research questions:

i. To assess the variation in nutrient content and soil composition of the deposited sediment, along with the water quality in the selected tidal basins; and

ii. To assess the socio-economic and institutional factors for crop production and diversity in the tidal basins in relation to the level of success in TRM operation.

1.4 Importance of the Study

The study investigated the deposited sediment and water qualities in three tidal basins where TRM operation was implemented. Through the assessment of nutrients in the deposited soil and water, the study aimed to identify the potential benefits of such operation on crop production and diversity in the study areas. Moreover, the study assessed the socio-economic and institutional factors that could affect the success of TRM operation.

This study sheds light on the importance of understanding the effect of TRM oprations on the deposition of sediment and the associated implications for crop production and diversity. The findings of this study could be signicant for coastal communities, and farmers who rely on crop production for their livelihoods. There is no significant information regarding sediment and water nutrients for the selected tidal basins, thus the insights gained from this study could contribute to the development of effective policies and strategies for sustainable management of coastal areas in Bangladesh.

1.5 Scope and Limitations

As the TRM operation was implemented differently in different tidal basins, it is noticeable that the sedimentation rate and distribution varies with time and place, therefore the variation in the nutrients may also vary. The sediments carried by the river inside the tidal basins are full of nutrients important for crop production, so nutrient analysis for deposited sediment as well as water is done in this study. The soil and sediment samples were collected carefully in the dry and wet seasons and further analysis was done. The research was conducted with the following limitations:

i. The river systems as well as the locations of the study beels are different. Besides, TRM was operated at different times in different beels. Synchronous TRM operation on two or more adjacent beels may help further defining of nutritional variance.

ii. Stakeholder consultations and interviews could not be carried out extensively because of time and resource constraints.

iii. Underdeveloped road and transportation system hindered the sampling process and movement to access some important sites.

iv. Due to severe accessibility problems in the study areas, most of the samples were collected near the riverbanks and embankments, thus actual representation of deposited sediment or soil data of the entire area may not be possible.

v. From a sampling site, deposited sediment or soil sample was collected from only one spot at two depth ranges. It would have been more representative if collection of separate samples from different spots at different soil depths were done.

vi. Unavailability of secondary data or limited dataset hampered the socio-economic and institutional analysis of this thesis work.

vii. Analysis of some parameters, such as BOD, COD, B, As, Mo, Cd, and Hg in water and Na, K, Cu, Cr, Cd, Mo, and Hg in the deposited sediment or soil could lead to more exemplary understanding of the qualities for both the elements.

viii. For more precise evaluation of TRM impact, nutritional findings of the study beels may be compared with that of non-TRM beels and the nearby highlands.

1.6 Organization of the Thesis

This thesis consists of six chapters namely Introduction, Literature Review, Study Area, Methodology and Data Collection, Results and Discussions, and Conclusions and Recommendations. A brief outline of each chapter is given below.

Chapter 1, the **Introduction**, provides the background of the study as well as an overview of the research problems. Later, the objectives of the study and some research questions in relation to meeting the objectives of the study are mentioned. Finally, the expected outcomes are mentioned and how the total thesis is organized is outlined.

Chapter 2, **Literature Review**, establishes the linkage between the thesis work and the previous research works by accumulating and analyzing the previous research methodologies, outcomes and applications.

The Chapter 3, **Study Area**, identifies the study area which is three tidal basins in the south-western Bangladesh and describes the areas with respect to their climate, topography and hydrology. The cropping situation as well as socio-economic context regarding crop production and diversity is also included in this chapter.

In the Chapter 4, **Methodology**, discussion on methodological issues regarding sample collection and preparation, data collection and laboratory analysis are stated.

After the methodology section, Chapter 5, **Variations in Sediment and Water Quality**, deals with the final output of the laboratory analysis of the collected sediment and water samples, presentation of the obtained results and relationship among deposited sediment composition and quality and water quality.

In the Chapter 6, **Socio-economic and Institutional Factors for Crop Diversity and Production,** discussion on various socio-economic and institutional factors regarding crop diversity and production are included.

The final chapter, Chapter 7, **Conclusions and Recommendations**, summarizes the important features of the thesis work- research objectives, methodology and the findings of the work. It also includes the contributions in the field of work and the limitations of the study. An overall conclusion is drawn by identifying new areas of future research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of the polders and tidal basins of the south-western coastal Bangladesh, including the water related problems, water and sediment quality, cropping status and some factors related to crop diversity, based on a review of relevant literature.

2.2 Polders and Tidal Basins in Coastal Bangladesh

In this section, general information regarding the coastal polders and tidal basins of Bangladesh is described briefly.

2.2.1 Polders in Coastal Bangladesh

The coastal zone of Bangladesh consists of tidal rivers, facing the tidal influence twice a day. The local communities developed an indigenous knowledge system of water and river basin management uniquely adapted to the diurnal tidal process. They used to construct temporary earthen embankments, low dikes and wooden sluice gates around the areas to protect the arable land from saline water intrusion (Rouf, 2015; Amir, 2010). In the rainy season, farming communities exchanged saline water of their fields with river water when it became almost sweet. Sweet water normally minimizes the salinity of the land. Thus, they got a good crop harvest and a variety of fish. It was based on a local practice called doser badh (embankment construction by community) or ostomasi badh (embankment for eight months), and effective and innovative management of tidal flow and sediment, for agricultural production and land formation (Rouf, 2015; Minnen, 2013; Amir, 2010). The process allowed the sediment carried by tidal flow to deposit on the beels or wetland basins. The deposited sediment raised the land level of the wetlands. Due to this traditional indigenous knowledge based community practice, there was a balance between sedimentation and land subsidence in the area.

After abolishing the landlord system in 1951, gradually the structures became practically useless due to lack of managing authority and required maintenance (Amir, 2010). The coastal people of Bangladesh were frequently suffering because of the daily tidal saline water inundation and seasonal cyclone or storm surge floods, earlier in the 1960s. They were facing drainage congestion and water logging problems resulting from reduced drainage capacity in the rivers due to active channel sedimentation (Khadim et al., 2013). Thus, the area became unsuitable for agriculture, and the farmers could not produce crops.

To reduce the people's sufferings, a water master plan was prepared by BWDB in 1964, introducing a compartmentalized polder or enclosure system in the south-west tidal areas. According to Maliha (2016), Polder is a Dutch term which means a reclaimed landmass with engineering interventions to grow more food by protecting coastal land from saline water intrusion caused by tidal flooding. A polder is a tract of land, surrounded by dykes in which the discharge and supply of surface water are artificially controlled. Illustrations of a typical polder are given in Figure 2.1, Photo 2.1, and Figure 2.2.

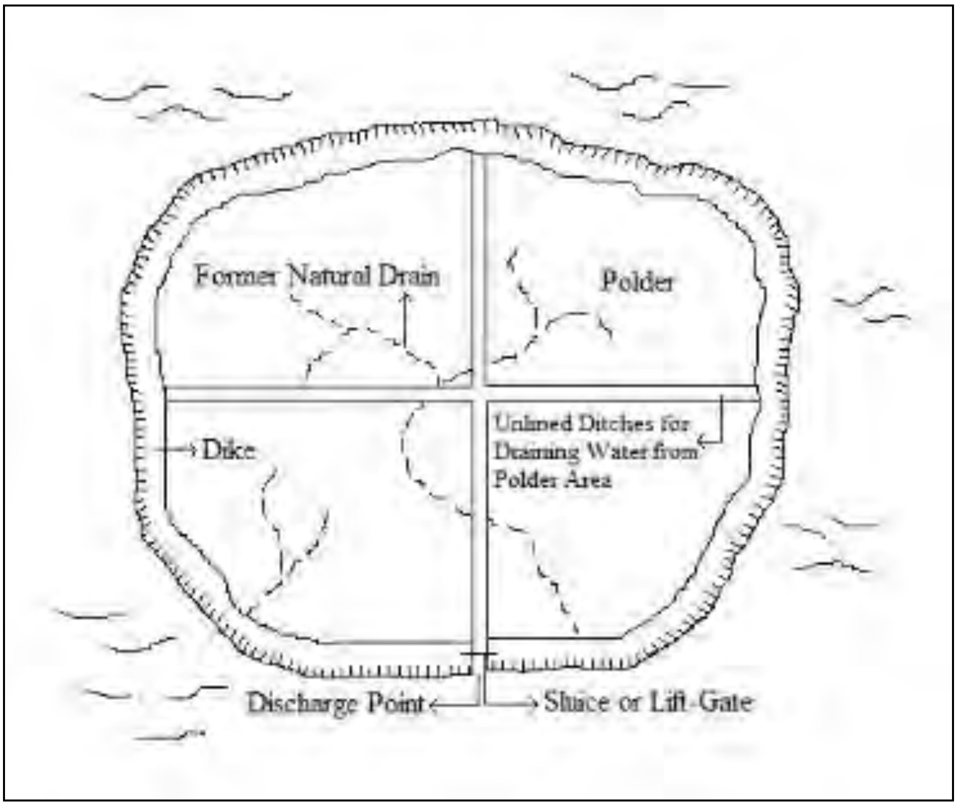

Figure 2.1: A Typical Polder Structure (modified from Rouf, 2015)

Photo 2.1: A Dike in Beel Bhaina of Polder 24

The polder system was developed and implemented to promote cultivation of high yielding variety (HYV) crops in dry lands with controlled irrigation (Adnan, 2006). During the 1960s and 1970s, about 37 polders were constructed around 1.2 Mha of the agricultural lands of the coastal zone of Bangladesh (Mondal et al., 2015). There were also 1566 km of embankments and 282 numbers of sluice gates constructed in the area with funding from USAID to prevent the intrusion of saline water from sea and recover more land for cultivation of HYV crops.

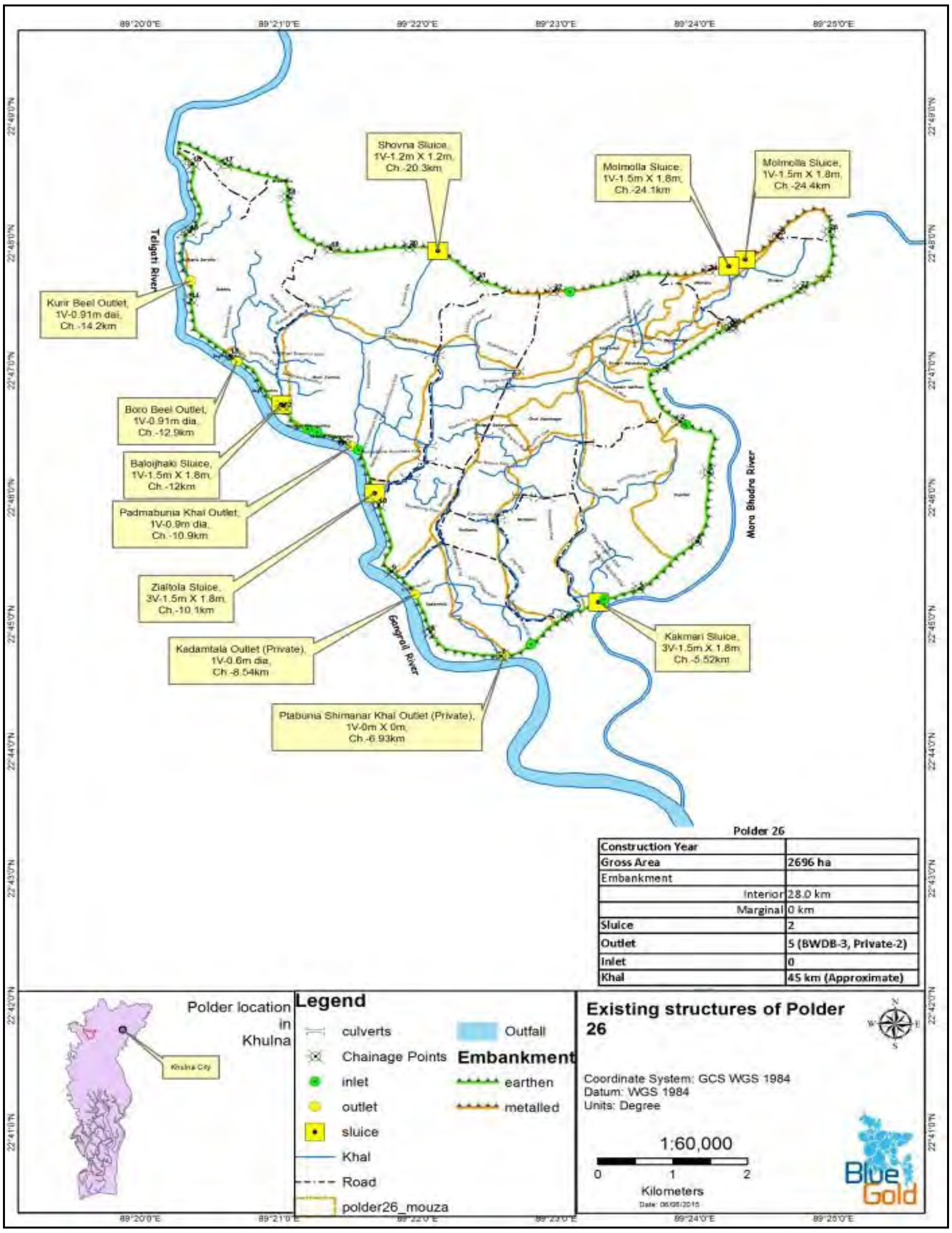

Figure 2.2: The Map of a Real Polder with Structures in Khulna, Bangladesh (Source: Blue Gold, 2015)

The projects undertaken in the sixties performed well till the 1980s with increased cropping intensity (mostly HYV rice), but reduced the production of local crop varieties and biodiversity (Adnan, 2006). Also the phenomena, such as siltation, drainage congestion, water logging, salinity intrusion and land use conflict, were blooming. In 1984, for the first time Beel Dakatia (part of polder 25) became water-logged due to siltation of the Solmari, Hamkura and Hari rivers. Gradually, this problem spread to more polders and had led to waterlogging of an area of more than 100,000 ha in Khulna, Jessore and Satkhira districts (Gain et al., 2017; Awal, 2014).

2.2.2 Tidal Basins in South-western Bangladesh

A beel is a natural depression in the flood plains that generally contains water throughout the year (Karim & Mondal, 2017; Wester & Brons, 1998). According to Banglapedia (2014), the term 'beel' (a Bengali word) is used for a relatively large surface, static water body that accumulates surface run-off water through an internal drainage channel. Amir et al. (2013) described beel as 'The Bengal basin repeatedly deposits sediment close to the river bank raising the land level. The land is thus kept low in between the two rivers and such a low-lying land is called "beel". Another definition for beel is stated as, 'A beel is a billabong or a lake-like wetland with static water (as opposed to moving water in rivers and canals - typically called khals), in the Ganges - Brahmaputra flood plains of the eastern Indian states of West Bengal and Assam and in the country of Bangladesh.' (Wikipedia, 2018).

A tidal basin is a naturally formed, depressed low-lying area or a beel adjacent to the sediment-laden tidal rivers. Depressions in the plains are formed by various causes such as subsidence of topsoil, subsidence caused by tectonic movement and non-destructive floods depositing sediment close to the riverbank. There are about 35 beels in the Khulna-Jessore-Satkhira districts of Bangladesh (Masud et al., 2018; Gain et al., 2017). Among them, 12 beels (Beel Barulia-Partha, Beel Dakatia, Beel Bhaina, Beel Kedaria, East Beel Khuksia, Beel Kapalia, Beel Boruna, Beel Bharter, Beel Golner, Beel Bahadurpur, and Beel Magurkhali) have been under TRM operation. At first, the polder of Beel Dakatia was breached in four places in September 1990 to resolve waterlogging and drainage congestion problem. On 29 October 1997, the people in Beel Bhaina also cut their embankments, and following its success Beel Kedaria and East Beel Khuksia were also transformed into tidal basins. A figure of the beels and tidal basins in the KJDRP Area is attached below (Figure 2.3).

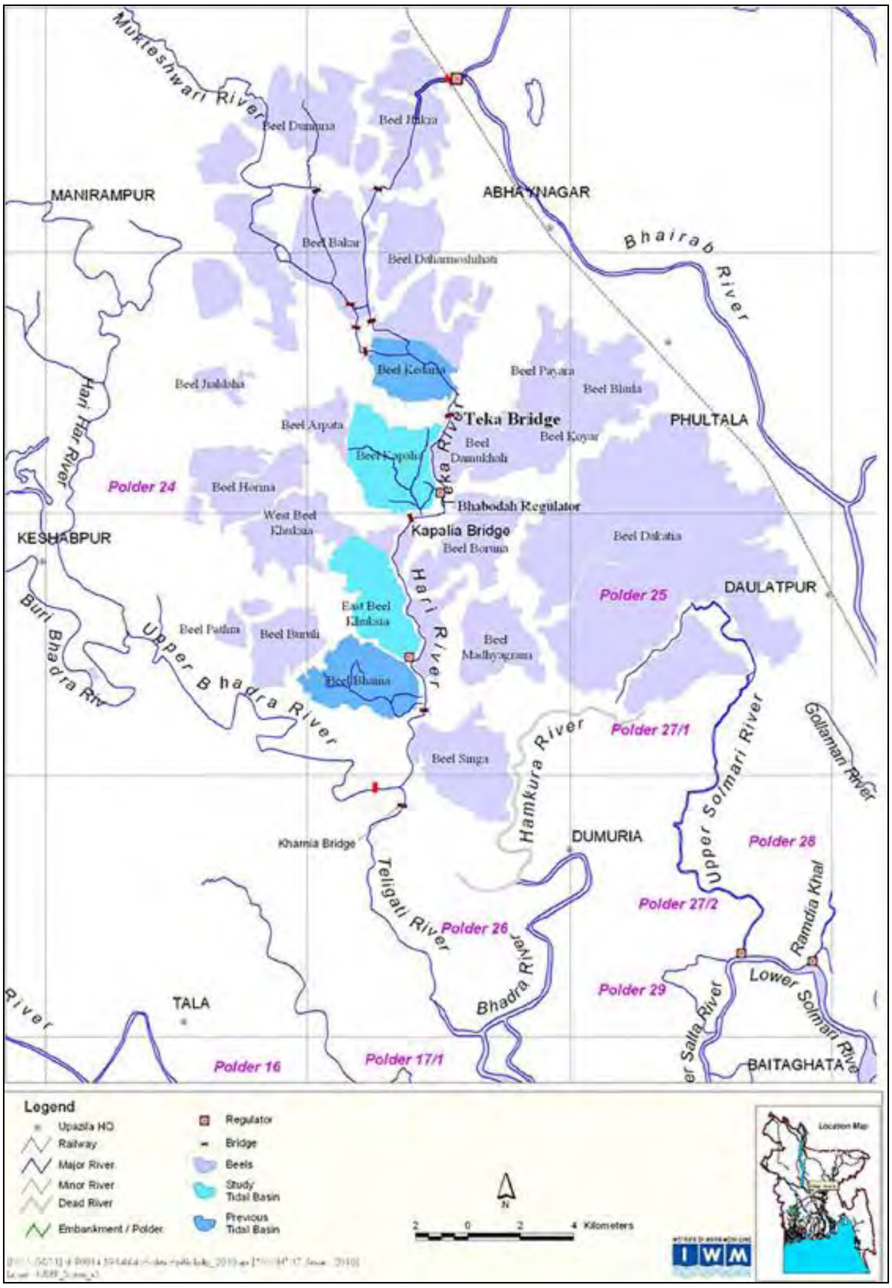

Figure 2.3: Beels and Tidal Basins in the KJDRP Area (Source: IWM)

2.3 Tidal River Management (TRM) Operation and Its Effects in Some Tidal Basins

In this part, the concept of tidal river management, its reason for introducing, positive and negative impacts, some examples of TRM operation in our country, etc. are briefly included.

2.3.1 Definition of Tidal River Management (TRM)

The idea of "Tidal River Management (TRM)" was first mentioned in the final report of the Khulna Coastal Embankment Rehabilitation Program (KJDRP) without using the term "TRM". The concept "TRM" was first literally stated in the Environmental Impact Assessment performed by CEGIS (1998). According to Kibria (2011), a mechanism was developed by local communities in the 1990s to solve the severe drainage congestion which is known as TRM (Paul et al., 2013). Karim and Mondal (2017) defined TRM as the tidal storage basin which allows natural tidal flows up and down in the river system which is applied on a beel. According to Die (2013), from the local farmers and villagers' perspectives, tidal river management is a practice that redirects water and sediment into a selected beel where the sediment settles and thereby gradually raises the land level of the low-lying beel. TRM has been considered as an effective approach for addressing and managing the complex problems, for instance, siltation, salinity, waterlogging and drainage congestion, in the south-western coastal zone of Bangladesh (Nowreen et al., 2014; Auerbach et al., 2015; Staveren et al., 2016; Gain et al., 2017).

During high tide, sediment laden tide is allowed to enter into the tidal basin (a low lying polder area) and with time, the area is filled with settled sediment due to reduction of velocity and flocculation due to high salinity. During low ebb tide, water is drained out containing a very little amount of sediment load, eroding the downstream of riverbed. Thus, the flood and ebb tides along the river and tidal basin prevent sediment deposition on the riverbed and ensure the proper drainage capacity and smooth navigation in the river channel (Masud et al., 2018; Jakarya et al., 2016; Paul et al., 2013; Kibria, 2011). The width of the river would increase by 2-3 times within only two to three years of TRM operation (Gain et al., (2017), and its depth would consequently get increased about 10-12 m at downstream of the basin (Jakarya et al., 2016).

TRM is done taking the help of natural tide movement in the rivers, with very little human interventions. Though this water management process requires less human interferences, it needs strong participation and consensus, along with enormous sacrifice by the stakeholders for a specific period (3 to 5 years or even more) depending on the tidal volume and the area of the beel (Gain et al., 2017; Amir, 2010; Rahman, 2008). The basic tools required for the implementation of successful TRM are mentioned by Karim and Mondal (2017), which are embankment enclosure, effective planning and operation of TRM, consultation with the community people, provision for compensation to the affected landowners, and sustained provision for operation and maintenance. The mechanism of tidal river management is illustrated in Figure 2.4.

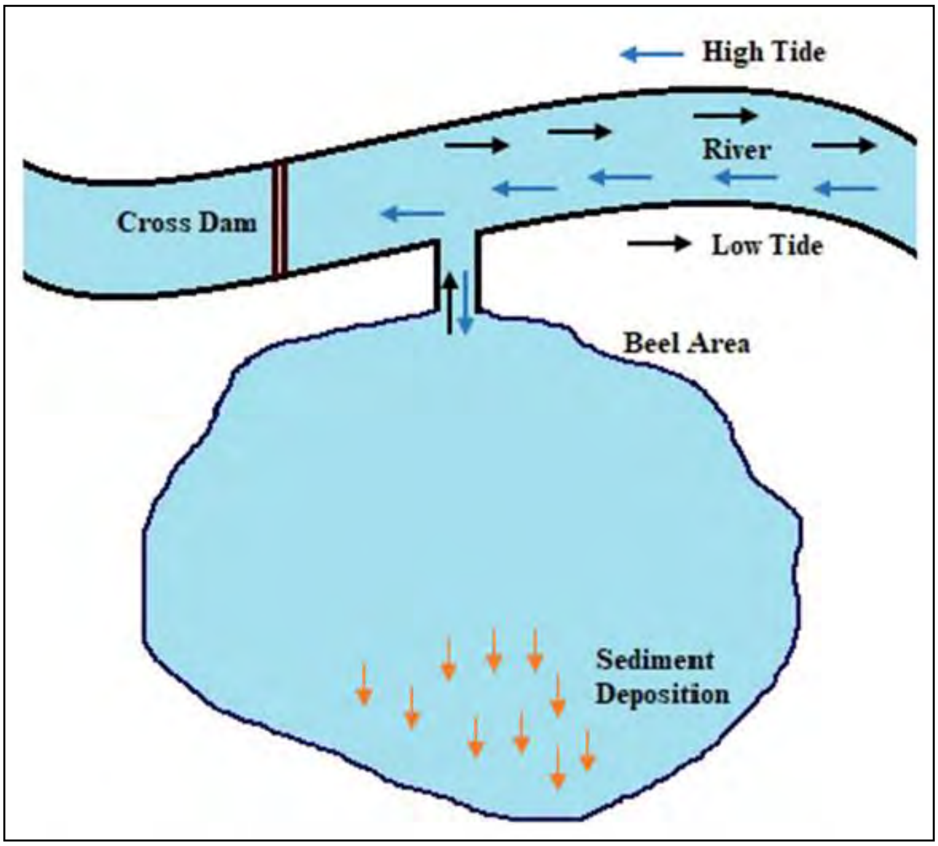

Figure 2.4: Tidal River Management Mechanism (modified from Paul et al., 2013)

2.3.2 Necessity of TRM

Due to polderization, water was restricted from entering into the floodplains, so the volume of tidal water stored in them was decreased significantly. A decrease in volume of stored water, in other words tidal prism, thus led to a decrease in river discharge and flow velocity following an increase in sedimentation (Tareq, 2016; and Die, 2013). The gradual settlement of sediments lowered the depth of riverbed causing drainage congestion and water logging in the southwest delta specially in Jashore, Khulna and Satkhira districts. Waterlogging had become an extreme event due to several factors, such as excessive monsoon rains, inadequate drainage system, mismanagement and lack of maintenance of the embankments, increased amount of sediment and siltation of rivers, restricted river flows due to embankments built for shrimp farming, and the release of water from barrages in India specially the Farakka Barrage and the Durgapur or Damodar Barrage (WFP et al., 2011). Ahmed et al. (2007) mentioned that in recent years the waterlogging phenomenon caused forced displacement of an estimated 80,000 inhabitants from several southwestern districts. Major displacement occurred as they were facing extreme poverty due to unavailability of land for agriculture based livelihoods which aggravated economic hardship, triggered hunger, severe health care scarcity and loss of lives. Waterlogging has largely affected biodiversity and environment in the southwest coastal Bangladesh. Salinity intrusion increased at a higher rate which resulted in killing of almost all types of vegetation, dramatic reduction in agricultural production, and condition unsuitable for homestead vegetation and cattle rearing (Tareq, 2016). At the beginning of the waterlogging problem, it was occurred for a few months in each year, but at present it prevails around the whole year. So, implementation of TRM becomes a crying need to solve these problems.

2.3.3 Positive and Negative Impacts of TRM

TRM operation has both positive and negative consequences on the study area. The benefits of the TRM process includes: it carries large amount of sediment from adjacent rivers to fill the beel bed and raises land from 1-2 meters leading to removal of waterlogging problems (Masud et al., 2018; Gain et al., 2017; Jakarya et al., 2016; Paul et al., 2013; Amir, 2010; Tutu, 2005); helps restoring the navigability of the rivers (Masud et al., 2018; Gain et al., 2017; Paul et al., 2013; Amir, 2010); after completion it protects agricultural lands, homesteads and infrastructures from inundation (Gain et al., 2017), helps increasing agricultural productivity, livelihood options and economy activities (Masud et al., 2018; Gain et al., 2017; Jakarya et al., 2016; Khadim et al., 2013; Amir, 2010; Tutu, 2005), growing biodiversity with strengthening environmental condition of the coastal region (Masud et al., 2018).

TRM operation came along with multidimensional negative sides. The negative consequences include: if unplanned, uneven sedimentation occurs inside the beels causing drainage congestion and permanent waterlogging in some parts of the beel (Gain et al., 2017; Rouf, 2015; Paul et al., 2013); increases the possibility of riverbank erosion near the embankment cut-points (Masud et al., 2018; Gain et al., 2017); agricultural fields remain under water so economic activity becomes impossible during the operational stage (Masud et al., 2018; Gain et al., 2017); disruption of internal communication due to inundation (Masud et al., 2018; Gain et al., 2017); delay in paying the compensations can hamper the future TRM implementation (Masud et al., 2018; Gain et al., 2017; Rouf, 2015; Paul et al., 2013); and non-acceptance of TRM may trigger conflicts among different stakeholders to carry it on from one beel to another (Masud et al., 2018; Gain et al., 2017; Rouf, 2015; Die, 2013; Kibria, 2011).

2.3.4 Effects of TRM in Some Tidal Basins of Bangladesh

Beel Dakatia: Beel Dakatia is situated in Khulna, polder no. 25. TRM operation in Beel Dakatia was implemented in mid-September 1990 by local people. Four Public cuts were made in the polder embankment to reduce drainage congestion and improve the water quality of the beel (Die, 2013; Amir, 2010). Only in the public cut no. 04, significant sedimentation was noticed and sediment deposit inside the beel extended outwards in a delta formation style over an area of about 900 ha out of 18000 ha (Amir, 2010; SMEC, 2002). The Hamkura River became 300 feet wide and 30 feet deep at the new highway bridge on the Khulna-Chuknagar Road after the breaching of the polder.

However, people's sufferings were not fully diminished due to inundation around about 10000-12500 ha of areas, lack of freshwater, reduced fish production, death of trees due to salinity and loss of dry season crops due to higher prevailing water levels (Die, 2013;

Amir, 2010). Waterlogging widespread around the Bhabodah area, so the people there tried the TRM concept from the lesson learnt from the Dakatia Beel and the experiments in Bharter beel, Golner beel, Bahadurpur beel, and Magurkhali beel were successful (Amir, 2010).

Beel Bhaina: In October 1997, the embankment of polder no. 24 (Jashore) was cut to connect the Hari River and Beel Bhaina by local people's initiative. The TRM operation was ended in December 8, 2001. It was led by the Paani Committee (Water Management Organization) and Uttaran without any effective government action. The land was raised by 1 m around almost 600 ha area until it was closed. But the sedimentation was not uniform inside the tidal basin, thus drainage congestion started to occur in the north-western part of the beel (Amir, 2010). It was reported that after closing the TRM operation, the bed level of the Hari River rose by more than 6 m within 8 months (Die, 2013). Gain et al. (2017) reported that regular agricultural practices have been carried out on the settled sediments in parts of Beel Bhaina, whilst there is still waterlogging in north-western section of the beel.

Beel Kedaria: The TRM operation in Beel Kedaria (Jashore) was started on 31 January 2002 and ended in January 2005. After completion of the project, it was evident that Beel Kedaria performed as an effective tidal basin during the operational period. The fact was stated confidently because the tidal basin helped Hari River maintaining its design drainage capacity at Ranai point (Amir, 2010). However, severe water-logging problem was prevailed in the Bhabodaho area from October 2005-November 2006 due to the discontinuation of TRM operation of Beel Kedaria (Paul et al., 2013; Kibria, 2011). The reason behind this was that severe sedimentation took place in the Hari River raising the bed level up to 3.5 m (Die, 2013; IWM, 2010). The sediment deposition took place almost over the whole area (514 ha), but the deposition was non-uniform with respect to time and place. In this case, the deposition was about 1 m higher near the link canal mouth in comparison to other distant areas.

East Beel Khuksia: East Beel Khuksia is in Jashore district of Bangladesh. The operational period of TRM for East Beel Khuksia was 2006-2013. It was actually expected to be completed by 2008, but due to compensation related issues and conflicts among different user groups the operation extended up to 2013. During the 5 months (December 2006-April 2007) of operation, about 0.9 million m^3 siltation took place in the basin (Gain et al., 2017) and also the conveyance of the Hari River at Ranai increased from 125 $m^{8/3}$ to 338 $m^{8/3}$ (Amir, 2010; IWM, 2007). According to Minnen (2013), the measurement in November 2012 showed that the ground level was raised by approximately 2 m near the beel cut, and 1.5-0.5 m further away from the cut point (Gain et al., 2017; Die, 2013). In this case it was also noticed that the siltation occurred mainly near the cut point. The reason behind this was the presence of ghers (fishing infrastructures) around the beel. It is claimed that TRM in East Beel Khuksia was mainly unsuccessful as waterlogging problem was not solved. But people were satisfied with the elevated land and crop production got increased, so it can be considered as a partially successful TRM.

Beel Pakhimara: Beel Pakhimara is situated in polder nos. 6-8, Tala upazila of Shatkhira district. The recently completed TRM project in Beel Pakhimara was planned to be implemented in 2011, but due to conflicts between local people and government land office, the TRM operation started in 2015 and ended in April 2021. From the field visits, we learnt that uneven siltation took place after TRM operation. About 1-1.5 m bed level increased at the cut point in 2018, whereas at the furthest part a very little sedimentation occurred and the waterlogging still hampering their daily life.

A pilot TRM in Krishnakathi village, Jalalpur union is claimed to be a successful TRM. The TRM operation started in 2011 continuing till 2013. About 400 ha of land were formed during this period. People were satisfied about the land formation as there was no water logging problem. When the soil was ready for cultivation, it became suitable for double cropping practice, whereas people only could cultivate single crop before the TRM operation. Thus, the TRM operation in Krishnakathi was an effective effort.

2.4 Impact of Waterlogging and Salinity Intrusion on Soil and Water

Due to the construction of polders along the rivers, tidal flow into the wetlands was obstructed; therefore, excessive silt deposited on the riverbed. Thus, the bed level of the river got raised in comparison to the nearby wetlands or beels. This caused permanent drainage congestion and waterlogging inside the polder areas creating catastrophic consequences. The aftershocks of water logging create socio-economic consequences, for instance, reduced food productivity, low income, unemployment, low level of utility services and migration (Masud et al., 2018).

Livelihood of the people and environment were seriously imperiled due to the inundation of massive areas under stagnant water. Water became polluted as human wastes, dead animals and trees were thrown into the water (Tutu, 2005). Scarcity of pure drinking water resulted in epidemic of waterborne diseases like diarrhea, scabies etc. (Islam and Kibria, 2006; Tutu, 2005). Masud et al. (2014) described that the study area suffers from environmental degradation and biodiversity loss in terms of reduced plants, livestock, birds, wild animals and fisheries due to water logging. According to Islam and Kibria (2006), vast areas of agricultural land lost its fertility as salinity increased at a large scale due to the capillary action. The increasing salinity in the root zone depth due to drainage congestion and waterlogging (Rahman et al., 2014; Abedin, 2010) is the main obstacle to intensify crop production in the coastal areas. As cultivable lands were submerged and salinity of the soil was increased, farmers had to shift to fisheries to earn their wages.

Though tidal river management was introduced to solve the waterlogging problem in the south-west region, due to lack of proper management and maintenance the purpose was not fully served. The farthest part of the beels remains waterlogged throughout the year (at least 6 months) and in the monsoon the problem is more acute. Salinity intrusion builds up during the dry season and even in April the salinity levels seem to be increasing in Khulna (Winterwerp and Giardino, 2012).

2.5 Deposited Sediment and Water Parameters and Their Analysis

2.5.1 Sediment and Water Quality

Sediment is the loose sand, silt, clay and other soil particles that settle down at the bed level of a water body (Shaha et al., 2013; Davies and Abowei, 2009). Sediment deposited on the banks and flood plains of a river is often rich in minerals and suitable for agricultural activities. Thus, sediment analysis is important in evaluating qualities of total ecosystem of a water body in addition to water sample analysis, as it reflects the long-term quality situation independent of the current inputs (Adeyemo et al., 2008).

The term 'water quality' and its parameters may vary with reference to the quality of water required for different human uses, such as drinking, agricultural and industrial purposes. In King et al. (2003), a modern approach was stated in that water quality is the combined effect of the physical attributes and chemical constitutes of the water body as well as all aspects of the aquatic environment. According to UNEP (2000), "water quality" is a term used to describe the physical, chemical, and biological characteristics and conditions of water and aquatic ecosystems.

It is essential to compare the laboratory data with standard nutrient value for determining the deposited sediment and water quality. The following tables (Table 2.1 and Table 2.2) are of standard soil quality nutrient values and water content standard values usual range in irrigation for agriculture.

Table 2.1: Standard Soil Quality Nutrient Values

Element	Unit	Low	Medium	High
Nitrogen	ppm	<75	76-150	151-300
Phosphorus	ppm	<12	13-25	26-75
Sulfur	ppm	<12	13-25	26-75
Iron	ppm	<20	21-40	41-200
Calcium	ppm	<40	42-80	82-360
Magnesium	ppm	<9.7	9.8-24	25-110
Potassium	ppm	<78.2	78.2-156.4	160.3-586.5

(Source: SRDI, 2003)

Table 2.2: Standard for Common Irrigation (Surface) Water Quality Evaluation

Water Parameter	**Symbol**	**Unit**	**Usual Range in Irrigation Water**
Electrical Conductivity	EC	dS/m	0 – 3
Total Dissolved Solids	TDS	ppm	0 – 2000
Calcium	Ca^{2+}	meq/L	0 – 20
Magnesium	Mg^{2+}	meq/L	0 – 5
Sodium	Na^{+}	meq/L	0 – 40
Carbonate	CO_3^{2-}	meq/L	0 – 0.1
Bicarbonate	HCO_3^{-}	meq/L	0 – 10
Chloride	Cl^{-}	meq/L	0 – 30
Sulphate	SO_4^{2-}	meq/L	0 – 20
Nitrate-Nitrogen	NO_3-N	ppm	0 – 10
Phosphate-Phosphorus	PO_4-P	ppm	0 – 2
Potassium	K^{+}	ppm	0 – 2
Boron	B	ppm	0 – 2
Acid/Basicity	pH	1–14	6.0 – 8.5

(Source: Ayers and Westcot, 1985)

2.5.2 Parameters Regarding Sediment Quality in Bangladesh

Sediment is the key factor for land formation. The primary source of sediment in the Bengal delta is the Bay of Bengal. During flood tides, sediments containing silt and clay are transported upstream of the Bay of Bengal and sedimentation occurs in the coastal zone. In the study area, sediment concentration is higher in the dry season and lower in the wet season (Rouf, 2015). The mineral particles of sand, silt and clay provide nutrients to the soil, but for sufficient soil fertility it also requires a good amount of organic matter which holds the particles together and provides structure (Maliha, 2016). The sediments of the Hari River contain calcium, copper, magnesium, manganese and sulphur (Rouf, 2015; CEGIS, 1998).

According to SRDI (2018), in Khulna division different soil parameters were measured as pH (6.4-7.9), organic matter (0.54%-2.42%), total nitrogen (0.027%-0.121%), phosphorus (0.13 ppm-90.65 ppm), potassium (0.20 meq/100g soil- 0.42 meq/100g soil), sulphur (0.03 ppm-258.09 ppm), zinc (0.68 ppm-9.2 ppm) etc.

Shaha et al. (2013) conducted a research to assess the soil, sediment and water quality of the Mayur River. They reported that the different parameters of the Mayur River's sediments were found to be pH (7.5-8.2), EC (2-11.96 dS/m), available nitrogen (112.98-386.76 ppm), available phosphorus (4-19 ppm), potassium content (0.3-1.2 ppm), available sulfur (0.008-0.346 ppm), available calcium (0.2-0.34%), available magnesium (0.12-0.24%), iron content (8.64-143.79 ppm), bicarbonate (0.006-0.03%) etc.

According to Rouf (2015), the soil type in Beel Dakatia and Beel Bhaina is peaty-clay and sandy-clay-loamy soil, respectively, which would become more abundant in nutrient contents with time and contribute to increased agricultural productivity. The soil of the Mayur River contains pH (7.8-8.1), EC (1.9-11.13 dS/m), nitrogen content (46.06-390 ppm), phosphorus content (2.5-29.37 ppm), available potassium (0.368-1.364 ppm), available magnesium (0.04-0.14 %), available iron (0.223-110 ppm), chloride content (0-0.019%) etc. (Shaha et al., 2013).

The soil type near Bangshi River is silty-clay-loam, and the average values of different nutrients were found to be N (0.104 %), P (5.15 ppm), K (0.29 C mol/kg), Ca (13.66 C mol/kg), B (0.35 ppm), Cu (6.08 ppm), Fe (432 ppm), Zn (2.28 ppm) etc. (Rahman, 2009).

2.5.3 Parameters Regarding Water Quality in Bangladesh

The freshwater reduction, especially during the dry season, led to increased salinity of the surface water, groundwater and soils, which in turn affects rural and urban water supplies, crop and fish production, and the ecosystem (Winterwerp & Giardino, 2012). The water salinity starts rising in November and continuing the rising up, hits the maximum point in May. Rouf (2015) reported that during the year 2001 at both the points of Ranai and Dohori along the Hari River, the surface water salinity was about 4 gram/litre (g/l), which increased to 13 g/l in mid-May and then decreased to 5 g/l by the end of June. It was also reported that salinity levels in the rivers Lower Sholmari, Gangrail, Telegati, etc. vary from 15-20 g/l, whilst the maximum salinity is between 25 g/l and 30 g/l in the Bay of Bengal (CEGIS, 1998; SMEC, 2002).

According to Ayers et al. (2017), in the period March-May 2013, the salinity in the tidal channels surrounding the polder no. 32 was on average 15 ppt, exhibiting slightly higher salinity during the flood tides (17-19 ppt) and slightly lower salinity during the ebb tides (10-13 ppt) and with time in the monsoon season the salinity reaches as low as 0.15 ppt and remains low until October.

In a research work, at different sampling points of Mayur River, pH (6.88-7.4), EC (0.77-1.67 dS/m), available nitrogen (0.98-23.89 ppm), available phosphorus (0-1.5 ppm), available calcium (0.24-0.42%), available magnesium (0.2-0.6%), bicarbonate content (0.024-0.067%) etc. of water were found (Shaha et al., 2013).

In the polder no. 32, arsenic (As) concentrations in tidal channel water were higher than the global average river water as concentration of 0.83 μg/L in both wet and dry seasons (Vaughan, 2006) and about 43% of fresh water ponds exceeds As concentration of 10 μg/L (Ayers et al., 2017).

A research conducted on the Bangshi river, the average values of different parameters in water from polluted site of the river were found as pH (9.65), EC (2.57 dS/m), Cl (585.5 ppm), Na (561.5 ppm), Ca (22 ppm), Mg (6.7 ppm), Cu (0.275 ppm), Fe (2.15 ppm), Zn (0.12 ppm), Cd (0.07 ppm), As (0.055 ppm) etc. (Rahman, 2009).

In 2015, the salinity of the Kobadak River at Pakhimara and Baliaghat points was measured as 21.8 ppt and 20.6 ppt, respectively. It was also reported that the sodium and chloride content was found around 38.78 ppt and 634 ppt in Pakhimara and 49.94 ppt and 765 ppt in Baliaghat, respectively (Tareq, 2016).

2.5.4 Methods for Analyzing Different Parameters in Bangladesh

There are various methodologies for determining different parameters of soil and water. In this research work we tried to follow the worldwide established standard methodologies which are most suitable as well as commonly used.

SRDI (2018) conducted a research on 35 districts under 8 divisions to determine the nutrient content as well as pH and organic matter in order to evaluate the fertility status of farmers' soil samples. Nitrogen and sulfur were determined by Micro Kjeldahl method and Turbidimetric method, respectively. Phosphorus was determined by Bray and Kurtz method (if pH is <7.0) or Olsen method (if pH is >7.0) and organic matter was measured by Walkley and Black Wet oxidation method.

Shaha et al., (2013) have measured various chemical parameters for their research work. The pH was determined electrochemically by glass electrode pH meter as suggested by Jackson (1973). The EC of the soil was measured at a soil: water ratio of 1:2.5 with the help of EC meter (USDA, 2004). Available N was measured by colorimetric method suggested by Baethgen and Alley (1989). Available P and K were determined by Olsen's method and flame photometry method respectively, described by Jackson (1967). The Ca^{2+} and Mg^{2+} contents were measured by titrimetric method mentioned by Ramesh and Anbu (1996). Chloride was determined by the titrimetric method as described by Jackson (1973).

Maliha (2016) in her research work determined soil pH using pH meter (Huq and Alam, 2005), EC by EC meter, total N by Kjeldahl method, K by cold extraction method, Ca and Mg by complexometric titration using EDTA (Ethylene-Di-amine Tetra Acetic acid) method, P by Molybdophosphoric blue color method.

Bahar and Reza (2010) conducted a research on the hydro-chemical characteristics and quality of shallow groundwater in the southwest Bangladesh. By using portable pH and EC/TDS meter the pH, EC, TDS and temperature were measured just after the sampling.

Sodium and potassium were measured using flame photometer. Calcium and magnesium were determined titrimetrically using standard EDTA. Chloride was determined by ion selective electrode method. Bicarbonate concentrations of the groundwater were determined by potentiometric titration method. Nitrate was measured by using ion selective electrode methods.

A research on the impact of the Bangshi River water quality on rice yield was done by Rahman (2009). He measured pH, EC and DO of the river water by using portable pH meter, EC/TDS meter and digital oxygen meter, respectively. Cl of water samples was measured by titrimetric method (Huq and Alam, 2005) and NH_4-N by colorimetric method with Nessler's reagent (Ramesh and Anbu, 1996). Ca, Mg, Fe and Zn were determined through Atomic Absorption Spectrometer (AAS) and Na by Flamephoto meter (Petersen, 2002). Heavy metals, such as Cu, Mn, Pb, Cd, Ni, Cr and As, of water samples were determined by both Inductively Coupled Plasma-Mass Spectrometer (Aydinalp et al., 2005) and AAS (Petersen, 2002). The EC and pH of the soils were measured by using conductivity meter and glass electrode meter, respectively (Petersen, 2002). The Ca and Mg contents were determined through AAS and K by Flamephotometer from soil extraction done by using ammonium acetate extracted solution (Petersen, 2002). N, P and S contents were measured by Kjeldahl method, Olsen's method, calcium biphosphale extraction method, respectively (Petersen, 2002). The heavy metals, such as Cu, Fe, Mn, Zn, Pb, Cd, Ni and Cr, were determined by DTPA extraction method through AAS (Petersen, 2002), on the contrary, As was determined by nitric acid digestion method through AAS (Saha and Ali, 2007).

Morshed (2001) has researched on the physico-chemical characteristics of soils from different agro ecological zones of Bangladesh. Glass electrode pH meter was used to determine the soil pH. The organic carbon was measured by using Walkley and Black's (1934) wet oxidation method (Jackson, 1973). Available P from acid soils were extracted by dilute acid fluoride (Bray and Kurtz, 1945) and soils having greater pH (>6.5) were extracted with 0.5 $NaHCO_3$ at pH 8.5 (Olsen et al., 1954). Available S was determined by using the method as described by Page et al. (1982). Exchangeable Ca, Mg and Zn were determined by ammonium acetate extraction method using atomic absorption spectrometer.

2.6 Overall Cropping Situation in the Study Area

The major sector of Bangladesh's economy is agriculture, and overall economic growth largely depends on the performance of this sector. More than 30% of the cultivable land of Bangladesh is situated in the coastal zone (Moslehuddin et al., 2015). The coastal and off-shore lands consist of 2.86 million ha, where about 1.056 million ha of arable lands are affected by varying degrees of salinity (SRDI, 2010). The agricultural land use and cropping patterns of the coastal zone are generally dominated by the paddy and other crops suited to the coastal and saline condition (Maliha, 2016).

Although Bangladesh has made impressive strides towards achieving food security, crop production in coastal areas is rapidly declining. Farmers are reluctant to cultivate HYV rice varieties as they are easily submerged and damaged by tidal fluctuations. Therefore, they mostly grow low yielding traditional rice varieties only during the monsoon season. Water salinity results in soil salinity which decreases the agricultural production and brings extensive pressure on food security (Tehsin, 2019; Basar, 2012). In the dry (Boro) and pre-monsoon (Aus) seasons, most of the lands remain fallow due to high soil and water salinity and lack of good quality irrigation water (Karim et al., 1990).

Presently, around one-third of the farmers in the coastal areas are cultivating only one crop in a calendar year, for example Aman rice during the monsoon season, while most of the cultivable lands remain almost fallow in the dry season (Uddin et al., 2019; Hossain, 2016). According to Saha (2016), the dominant crop in the coastal areas is Aman rice with small to medium cultivation of dry season crops. In the saline areas most of the farmers follow the cropping patterns of Fallow – Aman rice – Fallow, Fallow – Aman rice – Pulses, and Fallow – Aman rice – Chili/Maize/other Rabi crops (Uddin et al., 2019). Also, in the south-western coastal region, people traditionally culture shrimp and fish extensively to semi-intensively by trapping them in low lying coastal areas with construction of polders (Tareq, 2016). After the introduction of formal TRM, a new agro-fishery mixed production pattern is showing up in the study area (Mutahara, 2018; Ferdous, 1997). Due to polderization, changes in land use pattern can be stated as: from fallow to agricultutal land; after that from low yield variety to high yield variety paddy; and very recently from paddy cultivation to shrimp farming (Saha, 2016; Ferdous, 1997).

In 2013-2015, a study in Beel Bhaina, East Beel Khuksia and Beel Kedaria showed that single crop lands occupy around 4-14% of the entire study area, whereas double crop and triple crop lands occupy about 50-98% in the areas (Mutahara, 2018). According to Rashid et al. (2017), the average cropping intensity of the country was 179% in 2007-08, whereas it is 128-147% in the southern districts (BBS, 2014). The cultivable lands are not effectively utilized for agricultural production due to morphological change, water logging, salinity, decreasing nutrients etc. Thus, such low cropping intensity is observed in the coastal areas. From 1996 to 2008, there was 5.87% increase in the net cultivable land in Bangladesh, whereas 5.89% loss of net cultivable land was observed in 16 out of 19 coastal districts (Saha, 2016; Mishu and Zaman, 2013). Various hydrological, morphological, environmental, socio-economic, and institutional factors play vital role in the reduction of the net cultivable land as well as the agricultural crop production in the south-western coastal region.

2.7 Socio-economic and Institutional Situations Regarding Crop Diversity

The south-western region of Bangladesh is located in a climate–vulnerable area with a sensitive socio-economic system, which mainly depends on the land and water resources of the delta (Mutahara, 2018). Agricultural diversification means a shift from the regional dominance of one crop to regional production of a number of crops (cereals, pulses, vegetables, fruits, oilseeds, fibers, fodders and grasses, fuel etc.) in order to meet the increasing demand (Rahman and Kazal, 2015; Singh, 2011). The institutional arrangements such as credit facilities, marketing system, short- and long-term agricultural investment, production, farmer's income, employment etc. are affected by the land ownership condition (Tahan, 1982), which has direct impact on agricultural production. Rashid et al. (2017) and Hajong et al. (2020) stated that climate, soil type, rainfall, insect pressure, availability of irrigation, transportation, marketing and transit infrastructure all impact crop growth and change in Khulna and Satkhira districts of Bangladesh.

According to Pandey (2013) ethnicity, religion of the household, number of ecosystems/production domains available, size of cultivable land area, sex of the household decision maker in crop production, education of the household decision maker etc. were the independent variables affecting crop diversity in Nepal. A study showed that socio-economic factors such as age, marital status, educational level, household size, farm size, occupation, land acquisition, access to credit, extension services, social participation etc. are the important factors affecting agricultural productivity level in Nigeria (Zalkuwi, 2015). Dube and Guveya (2016) found that the variables that significantly and positively influence crop diversification by farmers are gender of the head of household, number of household members with secondary education, number of livestock units, access to irrigation, membership to a farmers group, access to markets, farming experience, farm terrain, farmer to farmer extension, routine extension, agro-ecological zone and household income. According to Maru et al. (2022), crop diversity was positively and significantly related to household farm size, animal size and composition, annual income, and the location's altitudinal gradient, whereas lack of road infrastructure and market connections constrained farmers' crop diversification options in Southern Ethiopia. From the above learning, we can conclude that the socio-economic and institutional factors affecting crop diversity are more or less the same all over the world.

CHAPTER THREE
STUDY AREA

3.1 Introduction

In this chapter, brief description of the study area, which is three selected tidal basins in the south-western Bangladesh, is given. The climate, topography, hydrology, cropping situation of the study sites, as well as socio-economic context of the study areas are also included in this chapter.

3.2 Field Sites

The tidal influence is a daily phenomenon in the coastal Bangladesh. Thus, the sediments as well as water containing various nutrients spread along the coastal areas. Therefore, assessing the nutrient contents of the water and deposited sediment is crucial. For conducting the research work, three tidal basins in the southwest coastal region have been selected as the study area. These are selected in terms of the level of success in Tidal River Management (TRM) operation. The selected basins are Beel Bhaina (successful TRM), East Beel Khuksia (partially successful TRM) and Beel Pakhimara (unsuccessful TRM). Figure 3.1 shows location map of the study area.

Beel Bhaina is situated inside the polder no. 24, near the Hari River in the Jashore district and comprises about 600 ha of area. It covers three blocks, namely Gourighona, Bharat Bhaina and Verchi under Dohori mouza of Keshabpur upazila. Keshabpur upazila is bounded by Monirampur upazila on the north, Tala and Dumuria upazilas on the south, Dumuria upazila on the east, and Kalaroa upazila on the west. The locations of the sampling sites in the Beel Bhaina are shown in Figure 3.2.

East Beel Khuksia (East) is also situated in the polder no. 24, along the Hari River, Jashore district and the area is about 1100 ha. It consists of the villages named Arua, Kismat Santola, Goda Khal, and Dayer Khal of Monirampur upazila. Monirampur upazila is bounded by Jashore Sadar upazila on the north, Kalaroa, Keshabpur and Dumuria upazilas on the south, Abhaynagar upazila on the east, and Jhikargachha upazila on the west. Beel

Bhaina and East Beel Khuksia are under the Mukteswari - Teka - Hari river catchment. The locations of the sampling sites in the East Beel Khuksia are shown in Figure 3.3.

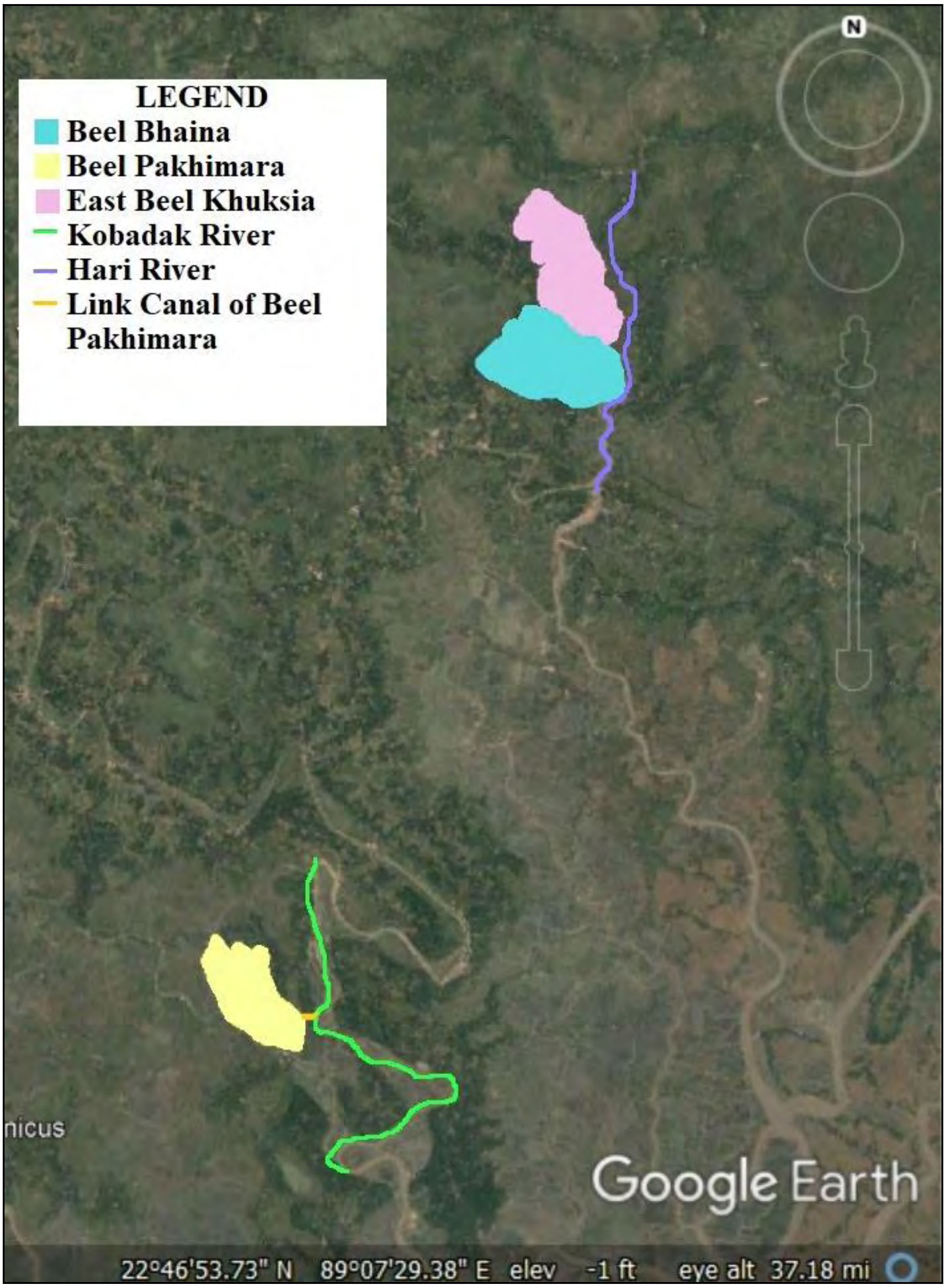

Figure 3.1: Location Map of the Study Areas

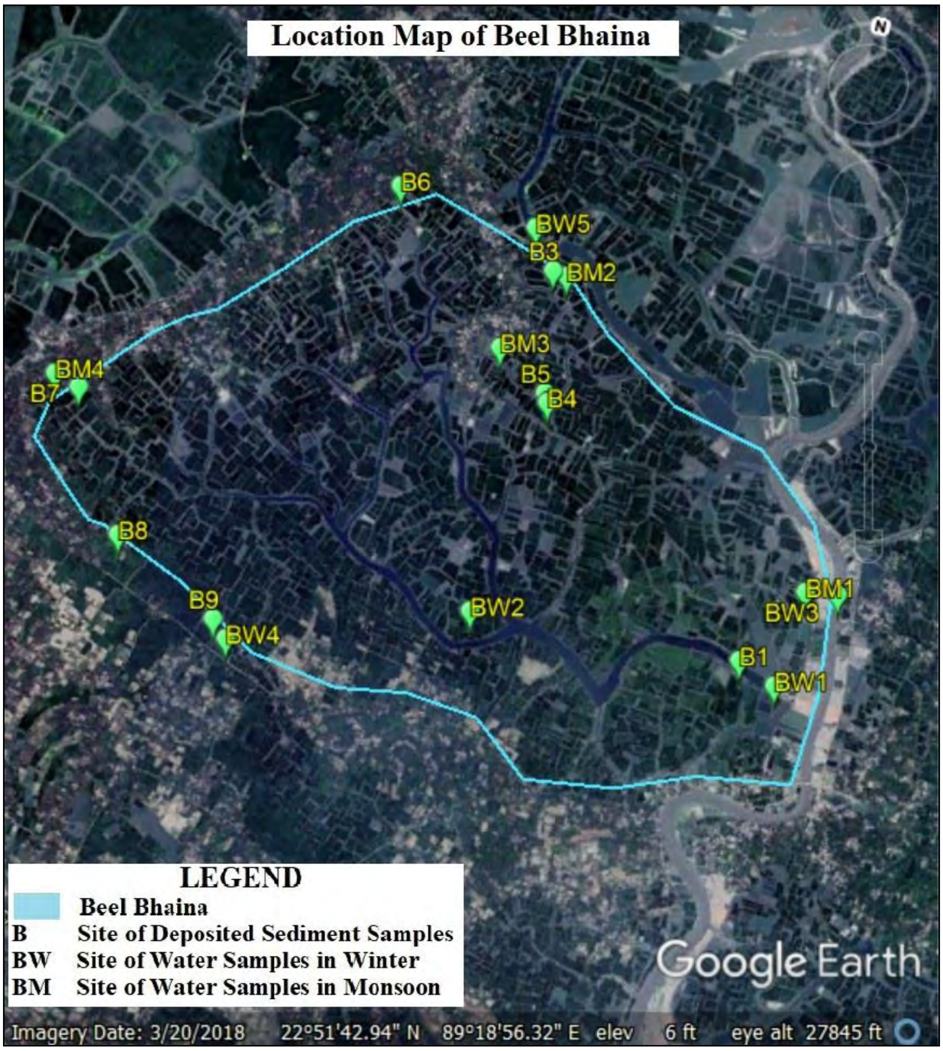

Figure 3.2: Location Map of Beel Bhaina

Beel Pakhimara is located inside the polder nos. 6-8, beside the Kobadak River in Tala Upazila, Shatkhira with a total size of about 700 ha. This beel covers seven villages, namely Dohar, Goutomkathi, Teghoria, Madra, Baliya, Merogacha and Kolagachi under the unions of Jalalpur, Kheshra and Magura of Tala upazila. Tala upazila is surrounded by Kalaroa, Keshabpur and Dumuria upazilas on the north, Assasuni upazila on the south, Dumuria and Paikgachha upazilas on the east, and Satkhira Sadar upazila on the west. The locations of the sampling sites in the Beel Pakhimara are shown in Figure 3.4.

Figure 3.3: Location Map of East Beel Khuksia

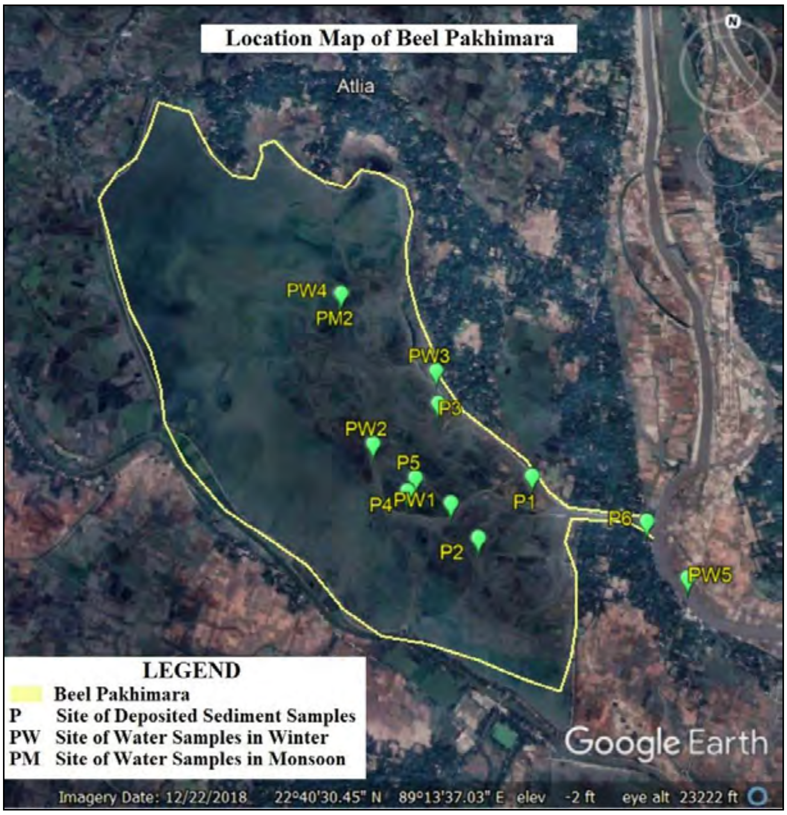

Figure 3.4: Location Map of Beel Pakhimara

3.3 Climate

The study area is situated in two neighboring districts- Jashore and Satkhira. The climate condition of the area can be stated as typical monsoon with a warm and dry season from March to May. The summer is hot and humid (March-June) followed by the rainy season (June-October) and then comes the cool and dry winter season (November-February). The values of normal maximum temperature, normal minimum temperature and monthly normal humidity represent that non-significant variations in these climatic factors is present. The climate is favorable for various agricultural activities throughout the year (Amir, 2010). The temperature, humidity, rainfall, wind speed and sunshine hour of the districts are described in the following sections.

3.3.1 Temperature

The normal maximum temperature varies from 25.6°C to 35.6°C in Jashore and 26.0°C to 35.2°C in Satkhira. The highest temperature is observed in April at Jashore.

The highest value for normal minimum temperature is 26.3°C, observed in June at Satkhira, whereas, the lowest value for normal minimum temperature is 11.2°C and observed in Janauary at Jashore. The normal maximum temperature and minimum temperature of Satkhira and Jashore are shown in Table 3.1

Table 3.1: Normal Maximum Temperature and Minimum Temperature of Satkhira and Jashore

Station	Normal Maximum Temperature (°C)											
	Months in 2016											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jashore	25.6	28.5	33.3	35.6	34.9	33.3	32.0	32.1	32.5	32.3	30.0	26.5
Satkhira	26.0	28.8	33.2	35.2	34.9	33.4	32.0	32.0	32.2	32.3	30.2	20.0
Station	**Normal Minimum Temperature (°C)**											
	Months in 2016											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jashore	11.2	14.4	19.5	23.6	24.9	25.9	25.9	25.9	25.4	23.2	18.0	12.4
Satkhira	12.2	15.6	20.6	24.3	25.3	26.3	26.0	26.0	25.6	23.6	18.5	13.2

Source of data: BMD

3.3.2 Humidity

In Jashore, monthly normal humidity ranges from 69% to 87%. For Satkhira, the value varies between 69% and 86% which is almost the same as Jashore. The minimum humidity observed during winter and maximum humidity observed during summer (Nandi, 2011). Monthly normal humidity of the study area is given in Table 3.2.

Table 3.2: Monthly Normal Humidity of Jashore and Satkhira

Station	Monthly Normal Humidity (%)											
	Months in 2016											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jashore	77	72	69	72	77	84	87	86	86	83	79	78
Satkhira	74	71	69	72	75	82	85	85	86	82	77	75

Source of data: BMD

3.3.3 Rainfall

The amount of rainfall is higher in Satkhira than Jashore (maximum average normal rainfall is in July, 375.4 mm in Satkhira). Almost 70-80% rainfall occurs in the monsoon season. The lowest rainfall is recorded as 11.4 mm in December, Satkhira. Average normal rainfall in Jashore and Satkhira is shown in Table 3.3.

Table 3.3: Average Normal Rainfall in Jashore and Satkhira

Station	Average Normal Rainfall (mm) Months in 2016											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jashore	14.8	26.1	44.6	75.4	169.9	298.7	304.1	291.8	236.9	107.9	29.0	15.8
Satkhira	13.7	40.1	37.6	86.5	152.4	296.6	375.4	297.3	280.1	120.6	31.2	11.4

Source of data: BMD

3.3.4 Wind Speed

The maximum normal wind speed is recorded as 6.25 m/s in May, Jashore and 3.75 m/s in April, Satkhira. From March to September, wind speed seems to get stronger than the dry months. Wind speed in Jashore and Satkhira is given in Table 3.4.

Table 3.4: Wind Speed in Jashore and Satkhira

Station	Normal Wind Speed (m/s) Months in 2016											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jashore	1.38	1.85	3.42	6.00	6.25	5.41	4.84	4.29	3.37	1.71	1.19	1.11
Satkhira	1.54	1.81	2.50	3.75	3.72	3.16	2.83	2.56	2.05	1.51	1.40	1.47

Source of data: BMD

3.3.5 Sunshine Hour

The sunshine hour ranges from 4 to 8.5 hours/day depending on the cloud cover (Newton, 2018; NWMP, 2004). Amir (2010) reported that the mean monthly sunshine hour at Keshabpur station varies between 4 hours and 8.1 hours.

3.4 Hydrology

The coastal zone of Bangladesh is characterized by semi-diurnal tidal rivers, creeks and canals providing drainage for the polders. The main river systems of the study area are Mukteshwari-Teka-Hari River and Kobadak River. These rivers are only rain-fed (Amir, 2010).

According to BWDB (2001), in Beel Bhaina two local cuts on the embankment, one in Agarhati village and another 1.5 km north of the Agarhati were cut along the Hari River. Initially, the cuts were narrow, but by May 1999, the cross sectional area of the Agarhati local cut had become more than 200 m^2 and the second cut was about 50 m^2. The tidal volume entering the beel was 4 Mm^3 which caused erosion of the bed and bank of the Hari River.

The maximum amplitude difference of mean maximum daily high water was 0.7 m at Bhabodaho and 1.6 m downstream of East Beel Khuksia in 1997-2000 (EGIS, 2001). In May 2007, during TRM in East Beel Khuksia, the tidal volume of the Hari River was over 5 Mm^3. In 2012, the tidal volume became about 16 Mm^3 (Mutahara, 2018).

3.5 Soil Condition

The south-western region of Bangladesh is under the agro ecological zones (AEZs) of the Ganges Tidal Floodplain, High Ganges River Floodplain, Lower Ganges River Floodplain and Gopalganj-Khulna Beels. The soil types of the High Ganges River Floodplain and Lower Ganges River Floodplain include silt loams and silty clay loams on the ridges and silty clay loam to heavy clays on lower sites having neutral to slightly alkaline reaction. The Ganges Tidal Floodplain region contains heavy silt clay soil. The soils of the Gopalganj-Khulna Beels are heavy clay-peaty, acidic, medium fertile.

Due to saltwater inundation, the soil condition of these areas ranges from very low saline to very high saline. In Beel Bhaina and East Beel Khuksia, soil salinity ranges from very slightly saline (non-saline at some points) to moderately saline, whereas in Beel Pakhimara it ranges from moderately saline to strongly saline round the year. After laboratory analysis, I found that the soil pH ranges from 6.7 to 8.01 in Beel Bhaina, 6.84-

8.03 in East Beel Khuksia, and 7.45-8.05 in Beel Pakhimara. The fertility status of the Khulna division ranges from very low to medium fertile (SRDI, 2018). In most of the saline soils, the dominant cation preponderance decreased in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and for the soils of prolonged brackish water shrimp cultivated areas, it is like $Na^+ > Mg^{2+} > Ca^{2+} > K^+$, whereas the anion preponderance decreased in the order of $SO_4^{2-} > Cl^- > HCO_3^-$ and $Cl^- > SO_4^{2-} > HCO_3^-$ (SRDI, 2010). In Beel Pakhimara, clay, clay loam and silty clay loam are the dominant soil textures, while in Beel Bhaina and East Beel Khuksia silty loam and silty clay loam are the dominant soil textures.

3.6 Cropping Pattern

The term "cropping pattern" refers to the annual sequence of crops cultivated in a particular proportion of land. The level of agricultural production is determined by the cropping patterns. The cropping pattern of a zone is determined by various factors namely soil type, rainfall, temperature, climate, willingness of the farmers, agrarian policy, availability of agricultural inputs, technology etc. In this region, the crop production is mainly rice based and the cropping patterns are Fallow- T. Aman (Local)- Fallow, Fallow- Fallow- Boro (HYV), Fallow- T. Aman (Local)- Boro (HYV), and Fallow- T. Aman (HYV)- Boro (HYV) (Newton, 2018; Uttaran, 2013). The available cultivable lands mostly remain fallow due to waterlogging, unsuitable soil and water condition, excessive salinity, scarcity of irrigation water etc. Agricultural land use of Keshabpur, Monirampur and Tala upazilas are shown in Table 3.5.

In dry season, major crops cultivated in the study areas are boro rice, wheat, maize, green chili, eggplant, cucumber, tomato, lentil, cauliflower etc. In the pre-monsoon season the lands are kept mostly fallow, and during the monsoon season aman rice is mostly cultivated due to low land level and long term waterlogging. After the introduction of formal TRM, a new agro-fishery mixed production pattern was shown up in the study area (Mutahara, 2018). The dominant cropping pattern in Beel Bhaina, East Beel Khuksia and Beel Pakhimara was fish-fish-boro rice. The saline water shrimp, fresh water shrimp and other fishes were cultivated in Beel Bhaina and East Beel Khuksia.

Table 3.5: Agricultural Land Use of Keshabpur, Monirampur and Tala Upazilas, 2014-15

Upazila	**Keshabpur**	**Monirampur**	**Tala**
Area of upazila (ha)	25903	44499	33726
Annual Cropped Area (ha)	990	570	830
Single Cropped Area (ha)	6000	2500	4010
Double Cropped Area (ha)	8300	15800	13270
Triple Cropped Area (ha)	4560	16200	4390
Quadruple Cropped Area (ha)	0	1000	0
Others (ha)	190	100	230
Net Cropped Area (ha)	20040	36170	22730
Cropping Intensity (%)	188	242	198
Source	Dewan et al. (2017)	Dewan et al. (2017)	Rashid et al. (2017)

3.7 Socio-Economic Context

People in the area are mostly dependent on natural resources for livelihood and live under poverty line. Most of the people of the study area are involved in agricultural production, fishery, farming, day labouring, small and medium businesses, government and non-government jobs etc. The socio-economic condition is defined by long term poverty, malnutrition, illiteracy and vulnerability (Saha, 2016). Before TRM operation livelihood was mainly driven by crop cultivation and capturing fish in the beel area, whereas people in the beels have taken up more fish culture than agriculture after the TRM implementation.

During running the TRM in the beels, significant loss in the livelihood was noticed in the surrounding villages. In Beel Bhaina, significant production in vegetables and mixed culture of rice and fisheries has been noticed after completion of the TRM operation. In case of East Beel Khuksia, rice and shrimp culture occupied the recently developed land areas (Mutahara, 2018). As for Beel Pakhimara, being under an ongoing TRM project in 2018, it was noticed that there was no crop production in monsoon period and people were trying to cultivate boro rice during dry season; also one-third of the beel area was under fish and shrimp production.

A majority of the landless and marginal farmers work as agricultural laborers while farmers with medium and large size land holdings mostly cultivate their own lands (Amir, 2010). As people face scarcity of continuous employment and sit idle for almost four to six months, currently they are trying to work as rickshaw pullers, day laborers in earth cutting, road and embankment construction and rehabilitation works, and migrant workers in other nearby villages and cities. It is noticed that conflicts among the agricultural farmers, fish and shrimp cultivators are present in the study area, because saline water shrimp cultivators deliberately cut the polders to intrude saline water which results in loss in agricultural production as well as fish production. Nowadays people are becoming aware of sustainable utilization of land and willing to use their lands for agricultural activities instead of saline water shrimp farming during the dry season (Saha, 2016). At present, parents are more aware of importance of education and send their children to schools because they suffered a lot to get the compensation for land acquisition and most of the people could not get the compensation due to lack of proper documentation. Therefore, the awareness and education may help them to improve their socio-economic condition.

CHAPTER FOUR
METHODOLOGY

4.1 Introduction

In this chapter, the methodologies of the study regarding sample collection and preparation, data collection and laboratory analysis are discussed briefly.

4.2 Deposited Sediment Sample Collection

As the land formation in the study area is made through sediment deposition, the term ‘deposited sediment’ is used for both soil and sediment. Deposited sediment samples were collected from the river bed, beel bed and crop land in both winter and monsoon seasons. Sample collection was done by using hand auger, spade and scoop. About 550-600 g of sample was taken in a plastic zipper bag labeled with the sample identification number. At each sampling point, 2 samples (at 0-15 cm and 16-30 cm from the soil surface) were generally collected, except for soil profile points. Total sampling points in Beel Bhaina, East Beel Khuksia and Beel Pakhimara were 9, 8 and 6, respectively. While handling the samples, proper caution was taken so that sample remains free from contamination and unwanted material. The samples were kept in a cool and dry place and taken to the Khulna University laboratory. Photo 4.1 shows a view of soil sample collection.

4.3 Deposited Sediment Sample Preparation

After taking the deposited samples to the laboratory, the samples were spread on separate plastic plates with proper labeling. It was air-dried for 15-30 days to remove all the moisture from the sediments. After that, the air-dried samples were broken and grounded by a wooden hammer. Each of the grounded samples was sieved through a 2 mm sieve and about 500 g sample was kept into a plastic zipper bag and ensured proper lock. Each bag was labeled according to the field label and then was stored in a cool dry place for the analysis.

Photo 4.1: View of Deposited Sediment Sample Collection near East Beel Khuksia

4.4 Water Sample Collection

Water samples from the river, beel, and groundwater (GW) sources were collected for each of the tidal basins in both dry (January 2018) and wet (July-August 2018) seasons. Water sample was collected in a 500 ml plastic bottle. At first, the bottle and the cap were cleaned thoroughly with the river water to be sampled before sampling. From the river and beel, samples were taken from around 1 feet depth below the water surface by hand. The opening of the bottle and allowing water to fill in and also the closing of the bottle mouth with the cap were done under water (Rahman, 2009; Jaji et al., 2007). Samples from GW source were collected after pumping the tube well for a few minutes. Immediately after sampling, sample bottles were labeled properly and also temperature and pH of the water were measured. The samples were stored in an icebox and then sent to the laboratory for further analysis. Photo 4.2 shows a view of water sample collection.

Photo 4.2: View of Water Sample Collection

4.5 Laboratory Analysis

Water samples were analyzed in the laboratory for some physical and physicochemical parameters such as pH, salinity, total suspended sediment and total dissolved solids. Grain size distribution and organic contents (using loss by ignition method) in the soil samples were assessed following the established methodologies (Wright et al., 2008; Hoogsteen et al., 2015). Both soil and water samples were analyzed to assess the nutrient contents. For water, Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-}, PO_4^{3-}, NO_3^- and NO_2^- were measured. Available nutrients in the soil such as Ca, Mg, Fe, P, S and Cl were assessed. I focused on the available soil nutrients because plant only can absorb the available contents from the soil. S, P, and Fe were assessed by spectrophotometry, whereas K was assessed using flame photometry on extraction method (CAFT, 2012). The titrimetric method

(EDTA) on extraction (Cash, 2008) was used to assess the Ca and Mg contents. Photos 4.3 and 4.4 show the views of laboratory analysis.

Photo 4.3: Understanding the Flame Photometer

Photo 4.4: Analyzing the Soil Parameters in the Laboratory

The methods of water and deposited sediment quality analysis are listed as below (Table 4.1).

Table 4.1: Methods of Analysis of Water and Deposited Sediment Quality Parameters

Deposited Sediment Quality	
Parameters	**Method of Analysis**
Grain size analysis	Sieve analysis and hydrometer method
pH	pH meter
Salinity	EC meter
Organic matter	Loss by ignition
Ca, Mg	Titrimetric method on extraction
Cl	Titration by silver nitrate
P, S, Fe	Spectrophotometry on extraction
Water Quality	
Parameters	**Method of Analysis**
pH	pH meter
EC	EC meter
TDS	TDS meter
Ca^{2+}, Mg^{2+}	Titrimetric method
Na^{+}, K^{+}	Flame photometer
HCO_3^-	Alkanity test
Cl^-	Titration by silver nitrate
NO_3^-, NO_2^-, PO_4^{3-}, SO_4^{2-}, Fe^{2+}	Spectrophotometry

Sodium Adsorption Ratio (SAR):

Irrigation water containing excess sodium in relation to calcium and magnesium promotes soil dispersion as well as structural breakdown. When sodium concentration is high in water, it results in infiltration problem and supplies less water to the crop field. SAR is calculated as:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

In this equation, Na, Ca and Mg are in meq/L.

Sodium Percentage (Na%):

The alkaline hazard occurs when Na concentration is high and is mainly related with the absolute and relative concentration of the cations in irrigation water. If the proportions of Ca and Mg are high the alkaline hazard is low, and conversely, if Na is predominant, the hazard is high (Sundaray et al., 2009). Na% is calculated as:

$$Na\% = \frac{(Na + K)}{(Ca + Mg + Na + K)} \times 100$$

Here, Na, K, Ca and Mg are in meq/L.

Potential Salinity (PS):

The suitability of irrigation water is not dependent on the amount of soluble salts because salts having low solubility precipitate in the soil and accumulate with successive irrigations, while the concentrations of highly soluble salts increase the salinity of the soil (Subbarao and Reddy, 2018; Doneen, 1964). PS is calculated from the following formula

$$PS = Cl + \frac{1}{2}SO_4, \text{units in meq/L}$$

Permeability Index (PI):

The long-term use of irrigation water can affect the soil permeability where the concentration of Na, Ca, Mg and HCO_3 has influence on it (Singh et al., 2020). PI is a vital parameter to assess the quality of irrigation water in relation to soil for improvement in agricultural sector (Singh et al., 2020; Thilagavathi et al. 2012). PI is calculated by using the following formula:

$$\mathrm{PI} = \frac{\mathrm{Na} + \sqrt{\mathrm{HCO_3}}}{(\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na})} \times 100$$

Where, concentration of cations and anions are in meq/L. Waters can be classified as Class I, II and III (Doneen, 1964), where Class I and II waters are categorized as good for irrigation with 50–75% or more (>75%) of maximum permeability and Class III waters are unsuitable with 25-50% of maximum permeability.

Kelly's Index (KI):

The hazardous effect of sodium on water quality for irrigation purpose is determined by Kelly's Index (Subbarao and Reddy, 2018; Kelly 1963). KI was calculated from the formula given as the following equation and all concentrations were expressed in meq/L.

$$\mathrm{KI} = \frac{\mathrm{Na}}{(\mathrm{Ca} + \mathrm{Mg})}$$

KI of >1 indicates excessive sodium in water. Therefore, waters with KI <1 are suitable, while those with a ratio >1 are unsuitable for irrigation use.

Magnesium Ratio (MR):

Generally, calcium and magnesium maintain an equilibrium state in most water bodies. In equilibrium, more magnesium in the water may adversely affect crop yields (Sundaray et al., 2009). The MR was introduced by Paliwal (1972) as the following formula:

$$MR = \frac{Mg}{Mg + Ca} \times 100$$

Where, concentrations of cations are in meq/L. If the MR value is more than 50%, the soil would become more alkaline and affect the crop yield. MR value less than 50% is considered to be satisfactory for agricultural production.

4.6 Socio-economic and Institutional Information Collection

The overall condition of the study area was acquired by using Participatory Rural Appraisal (PRA) tools such as Focus Group Discussions (FGDs), Key Informant Interviews (KIIs), Group Discussions (GDs) and individual interviews.

The information regarding socio-economic and institutional factors such as changes on land use, crop varieties, cropping pattern, soil properties, water quality, impact of polderization, available facilities, living status, etc. was gathered. Relevant data were collected from six field visits to the three tidal basins and to relevant governmental and non-governmental organizations. About 3 FGDs with the farmers and displaced people; and 4 GDs with the local people were conducted. Recent data was collected over phone and through a field visit in 2022. Photo 4.5 and Photo 4.6 show the views of a discussion with a key informant and a focus group discussion with farmers, respectively.

Photo 4.5: View of a Discussion with a Key Informant

Photo 4.6: Focus Group Discussion with the Farmers

4.7 Selection of Tidal Basins in Terms of Success

The selection of tidal basins considering the TRM success is very critical. Various socio-economic, technical, operational, and financial factors are needed to be considered to determine the success level of any TRM operation. Initially, the TRM reduced the waterlogging as well as increased the navigability of the rivers in the operational areas. Besides, the elevated lands created great opportunities for crop production. When the people of the beel areas are satisfied with the reduced waterlogging and drainage congestion problems and increased land level for cultivation, it is considered as a successful TRM project. The success of TRM is dependent on factors like duration of operation, location and length of link canal, regulator management, incorporation of local knowledge, land acquisition and requisition, conflicts among users and authorities, and compensation.

During the KJDRP, 507 Water Management Groups (WMG), 9 Water Management Associations (WMA), 58 Water management Committees (WMC), 48 Fisher Folk Groups, 58 Landless Groups and one Water Management Federation (WMF) were established by BWDB. During the TRM operations in Beel Bhaina and East Beel Khuksia, the institutions were ineffective and did not play any interactive role. As mentioned earlier, local people started the TRM operation in Beel Bhaina in October 1997, without a peripheral embankment and BWDB was against it. A conflict between management authority and community became extreme and turned to a socio-political violence and BWDB had taken legal action against 300 villagers in 1997 (Mutahara, 2018). However, people were determined to carry on the process with the support of local NGOs and Paani Committee (Mutahara, 2018). As community people were united (no major social conflicts among landowners, farmers and fish cultivators), there was no compensation disputes with the government and local people’s knowledge was taken in account to operate such action, they were satisfied with the sediment deposition and mitigated water logging and drainage congestion problems. Thus, the TRM operation was perceived as successful to the people as well as BWDB.

In East Beel Khuksia, TRM operation was a formal approach implemented by BWDB with financial support from Asian Development Bank, World Bank and the Dutch government (Mutahara, 2018). The ministry of water resources was another decision making authority. Other major stakeholders included government agencies such as Local

Government Engineering Department (LGED), Department of Fisheries (DOF), Department of Environment (DOE), Union Parishad, Upazila and District administrative authorities, WMG, WMA, WMF; research organizations- IWM and CEGIS, community and local stakeholders included landowners and landless people, farmers (agro-farmers and shrimp farmers), fishermen, day labourers, and NGOs (Mutahara, 2018). Social conflicts were evident in East Beel Khuksia after 2-3 years of operation, some people wanted to stop the TRM operation to utilize the elevated land for crop production whilst another group wanted TRM to elevate their land properly. There were also conflicts among landless people, crop farmers, shrimp farmers, fishermen, day labourers and brickfield owners having different personal interests. Lack of coordination among different stakeholders such as BWDB, DAE, DOE, LGED, LGI and water Management Organizations (WMO) resulted in institutional conflicts. Another conflict between the BWDB and a local government authority became visible over the issues related to tendering and the use of money in embankment construction (Mutahara, 2018). The government promised for compensation for land under TRM operation but due to its complex mechanism only 30-40% landowners had received compensation, thus conflicts among farmers, government and local government occurred. People expressed their dissatisfaction with the compensation both in term of process and amount (Mutahara, 2018). In 2012, around the issue of closing the TRM intervention in East Beel Khuksia and initiation of TRM in Beel Kapalia, the most severe conflict happened among community people, social activists, political groups, police, BWDB and parliament members. Although people were happy with the uniformly silted (about 50%) land for crop production, their discontentment regarding compensation and other conflicts were evident in East Beel Khuksia. Therefore, it can be considered as a partially successful TRM.

In Beel Pakhimara, the Paani Committee and the Beel committee (led by Uttaran) acting as negotiator among the actors such as BWDB and LGED, the Landless people, share-cropper, land owners and shrimp gher owners including villagers on the impact zone of TRM. The TRM operation was planned to start in 2011, but small farmers, landless and day labourers were instigated by few powerful and corrupted elite of the community and against starting the TRM because it would deprive them of aquaculture and daily wages who. Then the paani committee and Uttaran came forward and motivated them by informing the future prospects of TRM operation and promised for compensation by

BWDB. Although the TRM operation in Beel Pakhimara was undertaken with the support from most of the local people, conflicts arose regarding compensation and land acquisition during implementation period in 2015. The small and marginal land owners were affected the most because land was lost permanently for excavating link channel to connect the beel with the Kobadak River. About 35 families lost their home and resettled by the authorities at the bank of the Kobadak River. The compensation mechanisms also created conflicts among the community people and the government in this beel. They got the compensation once instead of twice during the implementation period. Many landowners do not apply for compensation to avoid the hassle that in most cases a very small amount remains after attending all the formalities. As there were many conflicts and problems and only about 30% of the beel has uniformly silted up and people were not as happy as that of Beel Bhaina and East Beel Khuksia with the elevated land. Thus it can be stated as an unsuccessful TRM. A table representing different contexts of TRM operation in the beels is given below (Table 4.2).

Table 4.2: Different Contexts of TRM Operation in the Three Beels

Contexts	**TRM Operations**		
	Beel Bhaina (1997-2001)	**East Beel Khuksia (2006-2012)**	**Beel Pakhimara (2015-2021)**
Operational Strategy	Informal, no technical planning	Formal, planned and approved by BWDB	Formal, planned and approved by BWDB
Proposed Time Frame	Not defined	4 years	4 years
Operating Time Frame	4 years	> 6 years	> 5 years
Cut Point	Chosen by local people	Decided by BWDB and other implementing authorities without considering local people’s suggestion	Decided by BWDB and other implementing authorities without considering local people’s suggestion
Internal Sediment Management	Existing internal channels (khals) were used automatically	Existing internal khals without operation and maintenance	A link canal was excavated to connect the beel with the river and existing internal khals without operation and maintenance
Siltation	> 60% uniform sediment deposition	About 50% uniformly filled	About 30% uniformly silted
Conflict	Less conflict	Multi level conflicts	Multi level conflicts
Compensation	No issue of compensation	30-40% recieved	Compensation stopped after two years
Level of Success	Successful TRM	Partially Successful TRM	Unsuccessful TRM

(Source: Mutahara, 2018 & Field Visit)

CHAPTER FIVE
VARIATIONS IN SEDIMENT AND WATER QUALITY

5.1 Introduction

In the 'Variations in Sediment and Water Quality' chapter, the final outputs of the laboratory analysis of the collected samples, and the results and relationships among the deposited sediment composition and quality, water quality are described.

5.2 TRM Operation and Sediment Distribution in the Basins

The main purpose of TRM operation is to allow suspended sediment deposition to raise coastal lands for improving agricultural production, along with increasing the depth of the river and mitigating waterlogging problems (Talchabhadel et al., 2016). It was stated in chapter 2 that local people of Beel Bhaina cut the embankment of polder 24 in 1997, therefore sediment was deposited inside the beel. Through focus group discussions and key informant interviews, I found that people were happy with the result of TRM operation in Beel Bhaina despite uneven sedimentation took place there. The sediment deposition inside Beel Bhaina is illustrated in Figure 5.1.

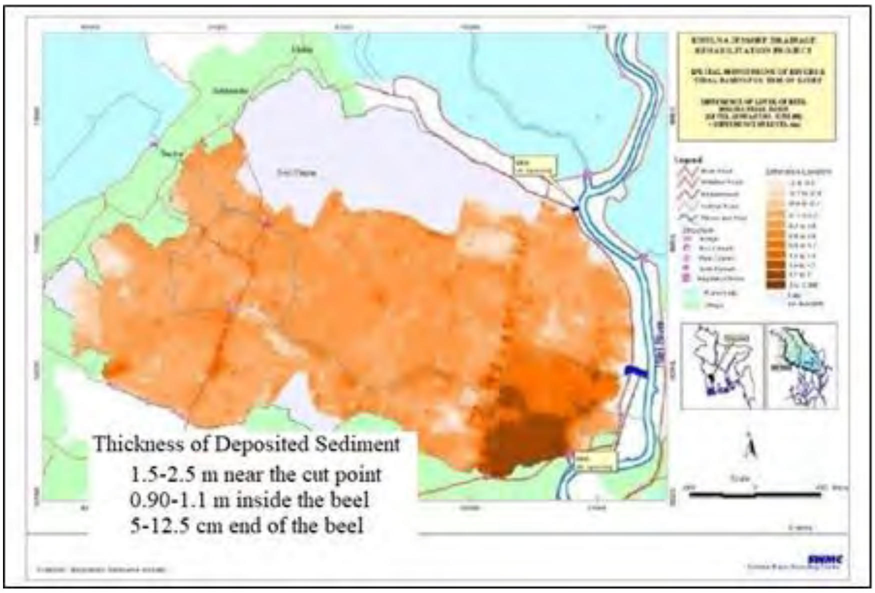

Figure 5.1: Sediment Deposition in Beel Bhaina (Source: SWMC)

According to BWDB (2001), sedimentation depth inside the Beel Bhaina was about 0.10 to 1.95 m, having volume of 4.70 Mm^3. According to the local people, about 1.53-2.13 m of silt deposition occurred from the cut point to 2-3 km inside the beel, after that around 0.91-1.07 m deposition took place, and at the furthest locations about 5-12.5 cm of silt deposition was observed. Despite not getting any compensation for the land under TRM operation, people claimed it as a successful attempt because waterlogging problem was solved and people could use their land for crop production and fish farming.

After the successful TRM operation in Beel Bhaina, government came forward and BWDB started TRM operation in East Beel Khuksia in April, 2006. In this case, the authority promised the local people to compensate for their land and settlement by a regular amount of money. After 7 years of operation, it was observed that about 1.8-2.5 m of silt deposition took place near the link canal, around 0.60-1.82 m deposition occurred inside the beel and elevation was 15-38 cm to the end of East Beel Khuksia. The TRM operation in East Beel Khuksia can be stated as partially successful because people were satisfied with the elevated land containing good quality sediments for crop production but expressed their dissatisfaction with the compensation amount as well as the whole process. The sediment deposition inside East Beel Khuksia is shown in Figure 5.2.

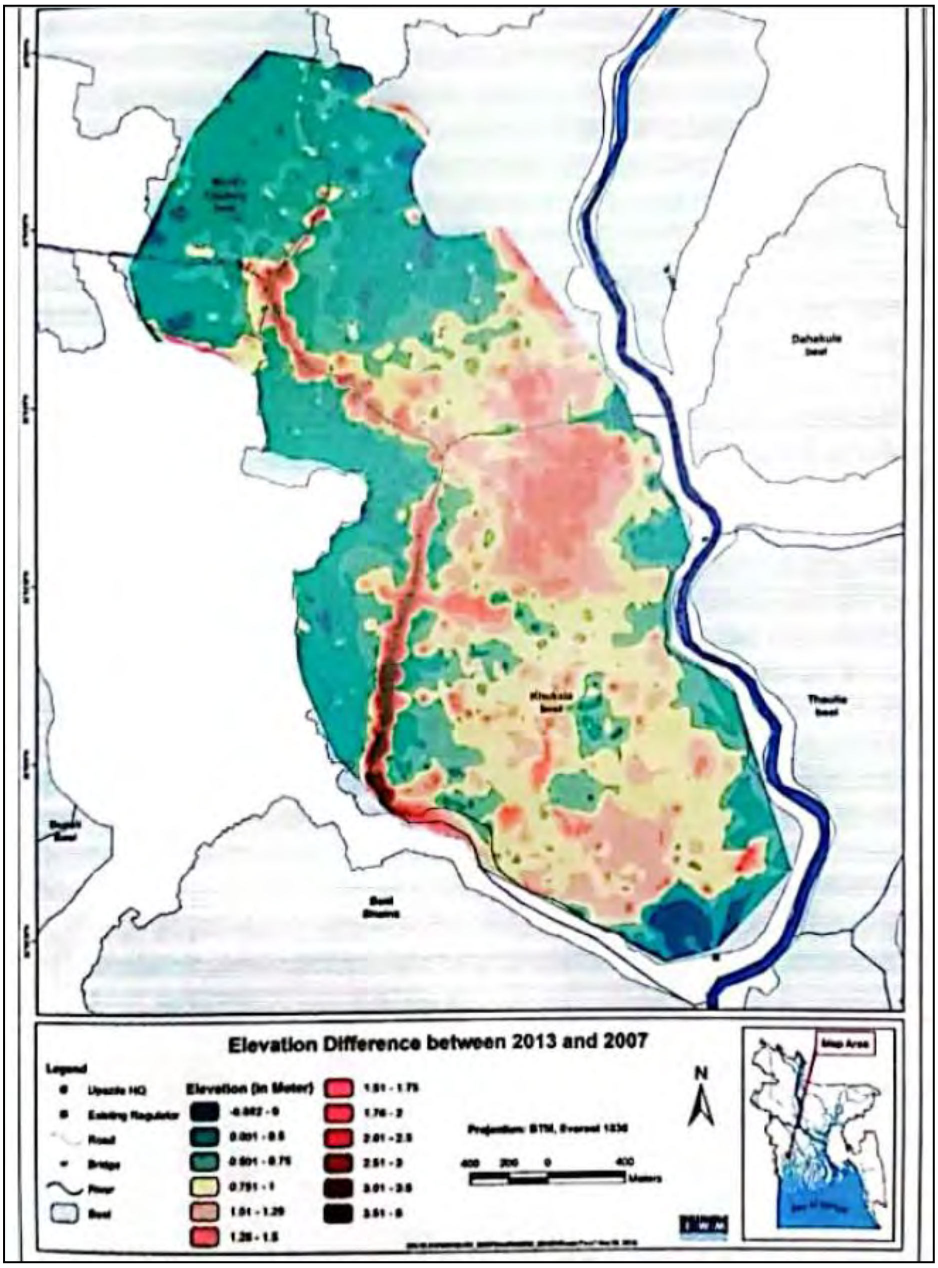

Figure 5.2: Sediment Deposition inside East Beel Khuksia (Source: IWM)

In Beel Pakhimara, local inhabitants breached the embankment to connect the beel with the Kobadak River. Later on BWDB engaged with the process and TRM operation formally started in 2015. Personnel from Uttaran informed that after operating for 2 years, they measured about 76 cm of sedimentation near the cut point in May, 2017 whereas 58.5 cm of sediment deposition was measured at the middle of the beel. The elevation near the cut point doubled within 2 years, and measured as 1-1.5 m. In 2019, it was found that at the middle of the beel about 91.5 cm of deposition occurred and at the furthest areas around 5-7.62 cm of siltation took place. The sediment deposition inside Beel Pakhimara during 2017-2019 is shown in Figure 5.3.

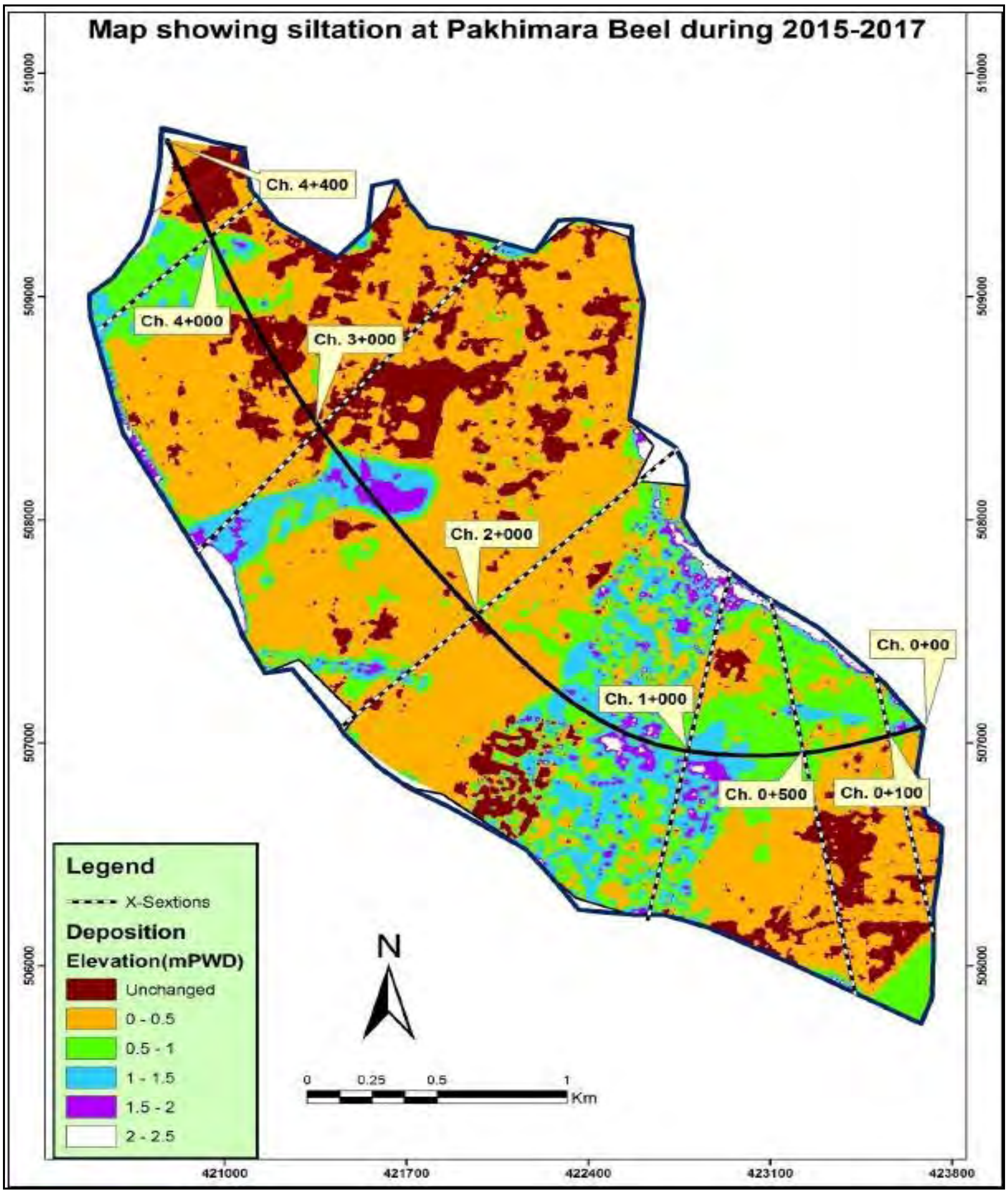

Figure 5.3: Sediment Deposition in Beel Pakhimara in 2015-2017 (Source: IWM)

5.3 Variations in Soil Composition in the Tidal Basins

Soil is the uppermost layer of the Earth's surface which serves as the reservoir of water and nutrients. It is also the medium in which life is sustained through plant growth, the recycling of matter and nutrients. Without good quality soil and water, crop production is hampered. Thus, understanding the soil and water condition of an area is a must for crop production.

Soil composition refers to the type and quantity of substances found in soils. Soil is usually composed of minerals (45%), organic matter (5%), water (20-30%) and air (20-30%). In terms of particle size, soil is classified into 4 different types: such as clayey soil, silty soil, sandy soil and loamy soil. In this study, I focused on organic matter and soil texture for analyzing variations in soil composition of the tidal basins. The spatial variations in soil composition of the three tidal basins are described in the following sections.

5.3.1 Beel Bhaina

Soil Texture:

Soil texture determines the relative penetration of plant roots in the soil. It also determines the ability of soil to hold nutrients and water for plant use which influences soil fertility. I considered the vertical profile at B2 site to understand the depth wise variation in soil texture in Beel Bhaina. I chose the point as it was near the link canal and undisturbed for a while. For understanding the spatial variations, samples were taken from different sites in winter. The soil inside the basin ranges from clay loam to silty loam at different depths. From Table 5.1, it is observed that soil has medium texture at 0-20 cm depth and from 20-70 cm depths soils are of moderately fine textures. So, soils are getting finer with the increasing depth from the top surface in Beel Bhaina. This was probably due to salinity and flocculation rate during the sedimentation process.

Table 5.1: Textural Class of Soils at Different Depths in Beel Bhaina

Samples at site B2	**Depth from Surface (cm)**	**Textural Class**
1	0-15	Silty Loam
2	15-20	Silty Loam
3	20-30	Silty Clay Loam
4	30-45	Clay Loam
5	45-70	Clay Loam

In Beel Bhaina, it is observed that at 15-30 cm depth in winter, soil texture was same and classified as clay at B3, B6-B9 sites. Other sites contained silty loam, silty clay loam and clay loam soils. Spatial variations in soil texture at different sites of Beel Bhaina are tabulated below (Table 5.2).

Table 5.2: Spatial Variations in Soil Texture in Beel Bhaina

Sampling Sites	Texture
B1	Silty Loam
B2	Silty Clay Loam
B3	Clay
B4	Silty Clay Loam
B5	Clay Loam
B6	Clay
B7	Clay
B8	Clay
B9	Clay

Organic Matter:

Organic matter (OM) is a major contributor to soil health which is made up of dead, living and decomposed plants, small animals and microorganisms. OM in soil helps retaining moisture and contains a reservoir of essential nutrients that are slowly released over time to make the soil conditions favorable for good crop growth. A figure illustrating the spatial and seasonal variations of OM in Beel Bhaina is given below (Figure 5.4).

Generally soils should contain about 5% OM, otherwise nutrient toxicity may occur, and it may be challenging to maintain a balanced ecosystem. Soils having 3%-6% OM is considered as healthy and rich soil. In Beel Bhaina the lowest OM was 0.874% in site B3 (0-15 cm) in winter whereas the highest OM was 3.631% in site B3 (15-30 cm) in monsoon. From Figure 5.4, it can be observed that in all the sampling points OM was higher in monsoon than that of winter season for samples from 0-15 cm depth. Samples taken from 15-30 cm depths have showed fluctuating pattern. Average OM content of this beel was below 3% (2.09%), which means the soil is unsuitable for agricultural production because decrease in OM may cause decrease in nutrient holding capacity.

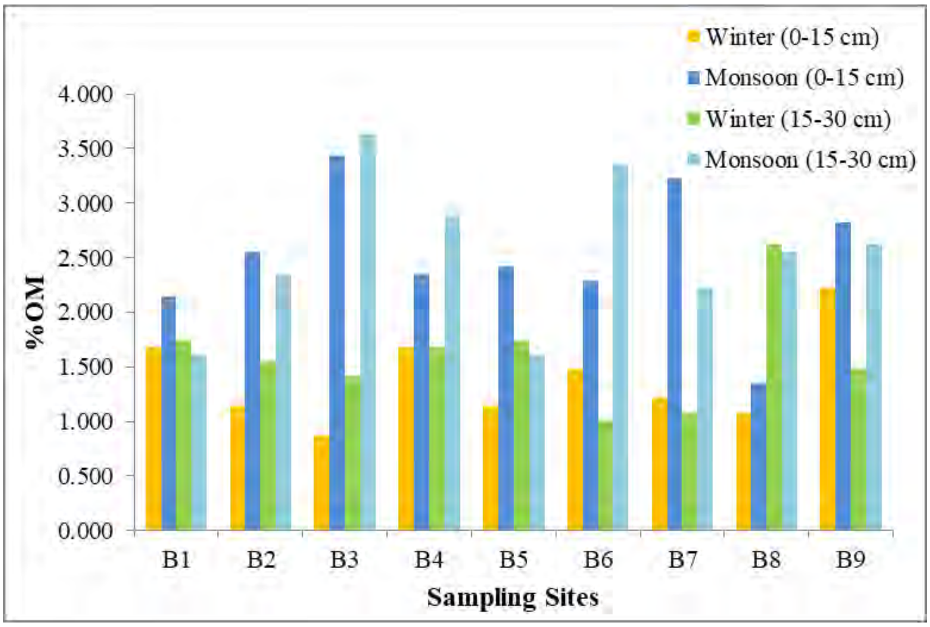

Figure 5.4: Spatial and Seasonal Variations of OM in Beel Bhaina

5.3.2 East Beel Khuksia

Soil Texture:

Sampling site K3 (undisturbed site) was considered to understand the depth wise variation in soil texture in East Beel Khuksia. I took 7 samples from 0-100 cm depth in winter. The soils inside the basin were found to be clay, silty clay, silt loam and silty clay loam at different depths. It is observed that in East Beel Khuksia the soil texture is found as medium to fine with increasing depth from the top surface. Table 5.3 shows the soil textures at different depths of East Beel Khuksia.

In East Beel Khuksia, soil was classified as clay, silty clay loam and silty loam at different sites. About 50% of the soil samples were of clay texture in this beel. Spatial variations in soil texture at different sites of East Beel Khuksia are tabulated below (Table 5.4).

Table 5.3: Textural Class of Soils at Different Depths in East Beel Khuksia

Samples at site K3	**Depth from Surface (cm)**	**Textural Class**
1	0-15	Silty Loam
2	15-30	Silty Clay Loam
3	30-45	Silty Clay Loam
4	45-60	Silty Clay Loam
5	60-75	Silty Clay Loam
6	75-90	Silty Clay
7	90-100	Clay

Table 5.4: Spatial Variations in Soil Texture in East Beel Khuksia

Sampling Sites	**Texture**
K1	Silty Clay Loam
K2	Silty Clay Loam
K3	Clay
K4	Silty Loam
K5	Silty Loam
K6	Clay
K7	Clay
K8	Clay

Organic Matter:

According to Figure 5.5, in East Beel Khuksia the minimum OM was 1.143% in site K2 (0-15 cm) whereas the maximum OM was 3.631% in site K3 (0-15 cm), both the values were found in monsoon. It can be observed that in all the sampling points OM was higher in monsoon than that of winter season for the samples from 15-30 cm depth. This may be due to the decomposition of the residue from winter crops. Samples collected from 0-15 cm depths have showed the similar result, except for the sites K2, K4 and K7 where OM was higher in winter. The average OM content of this beel was about 2.42% (<3%).

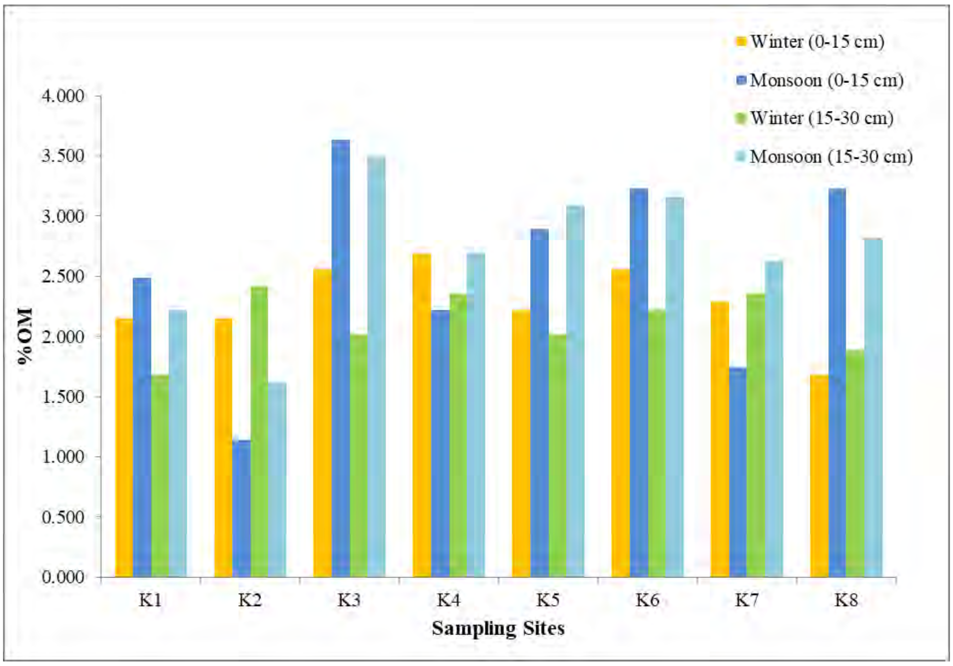

Figure 5.5: Spatial and Seasonal Variations of OM in East Beel Khuksia

5.3.3 Beel Pakhimara

Soil Texture:

Sampling sites P1 and P2 were considered to understand the depth wise variations in soil texture in Beel Pakhimara because they were undisturbed. In winter, I took 5 samples from each of the sites. The soils inside the basin were found to be clay, silty clay loam, clay loam, loam, sandy loam at different depths. In site P1, the soil texture is found as moderately fine to fine with the increasing depth from the top surface. In case of site P2, soil texture is classified as moderately fine to moderately coarse with the increasing depth from the top surface. Table 5.5 shows the soil textures at different depths of Beel Pakhimara.

Table 5.5: Textural Class of Soils at Different Depths in Beel Pakhimara

Sampling Sites	Sample No.	Depth from Surface (cm)	Textural Class
P1	1	0-15	Silty Clay Loam
	2	15-30	Clay
	3	30-50	Clay
	4	50-70	Clay Loam
	5	70-90	Clay
P2	1	0-15	Clay Loam
	2	15-30	Clay Loam
	3	30-50	Loam
	4	50-70	Sandy Loam
	5	70-100	Sandy Loam

In Beel Pakhimara, soil texture was found to be clay and clay loam at different sites. The soil particles were mostly finer in this beel. This may be due to the Kobadak River conveying more finer particles into the beel. Spatial variations in soil texture at different sites of Beel Pakhimara are shown as following (Table 5.6).

Table 5.6: Spatial Variations in Soil Texture in Beel Pakhimara

Sampling Sites	Texture
P1	Clay
P2	Clay Loam
P3	Clay Loam
P4	Clay Loam
P5	Clay
P6	Clay Loam

Organic Matter:

According to Figure 5.6, in Beel Pakhimara the minimum OM was 0.403% in site P5 (15-30 cm) in winter whereas the maximum OM was 3.9% in site P2 (0-15 cm) in monsoon. It can be observed that in all the sampling points OM was higher in monsoon than that of winter season for the samples from 0-15 cm depth, except for site P1. Samples collected from 15-30 cm depths have shown the similar result, except for the sites P1 and P2. The average OM content of this study area was about 2.35% (<3%).

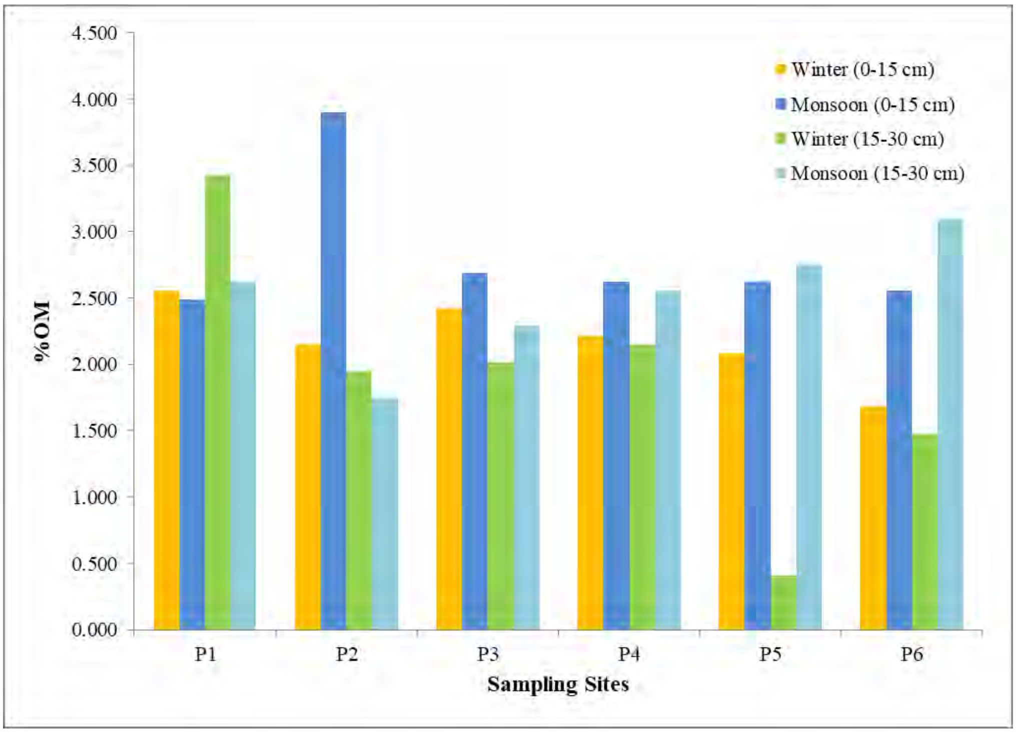

Figure 5.6: Spatial and Seasonal Variations of OM in Beel Pakhimara

5.4 Spatial and Seasonal Variations in Soil Nutrients and Quality in the Tidal Basins

Soil quality determines crop species and agricultural production of an area. I considered pH, EC, available calcium (Ca), available magnesium (Mg), available iron (Fe), available phosphorus (P), available sulphur (S), and available chlorine (Cl) of the tidal basins to assess the soil (deposited sediment) nutrients and quality. The spatial and seasonal variations in soil nutrients and quality of the tidal basins are discussed in the following sections.

5.4.1 Beel Bhaina

Soil pH:

The average pH for Beel Bhaina is 7.72 and 7.56 in winter and monsoon, respectively. The highest pH (8.01) is observed in site B1 in winter whereas the lowest pH (6.70) is found in site B8 in monsoon; both the samples were taken from 15-30 cm depth. Soil pH was found to be slightly alkaline ranging 7.06-7.95 for 8 sites. Only at site B8 the soil was very slightly acidic in monsoon. The seasonal and spatial variations in pH in Beel Bhaina are shown in Figure 5.7.

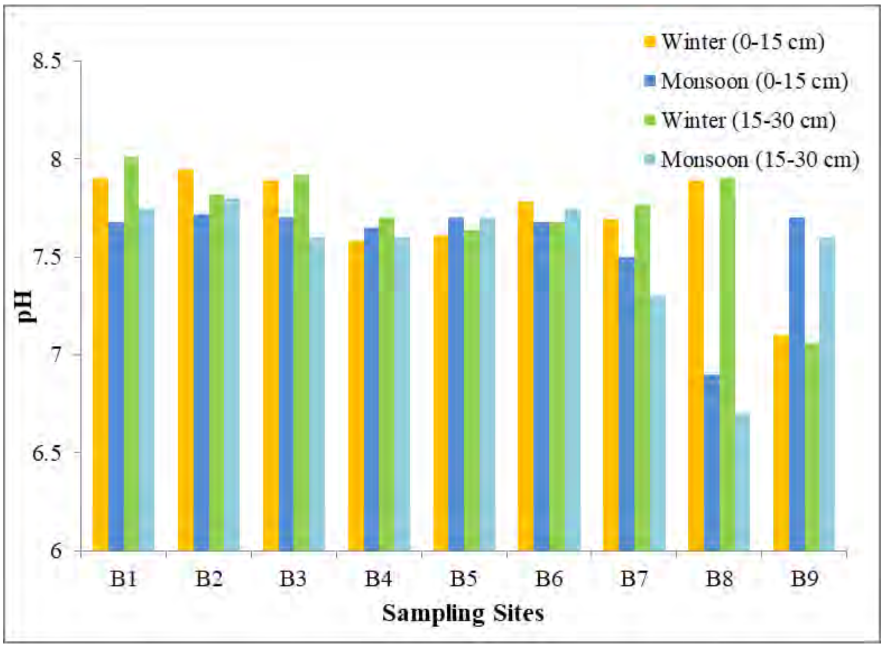

Figure 5.7: Spatial and Seasonal Variations of Soil pH in Beel Bhaina

Electrical Conductivity:

Electrical Conductivity (EC) is the measure of the amount of salts present in soil. In agriculture, EC has been used mainly as a measure of soil salinity; also helps in determining soil texture, soil depth and soil fertility. Soil is classified into 5 categories based on EC- Non saline (<2 dS/m), slightly saline (2-4 dS/m), moderately saline (4-8 dS/m), very saline (8-16 dS/m) and extremely saline (>16 dS/m) (SRDI, 2017). The average EC for Beel Bhaina was about 9.9 dS/m indicating very saline soil in winter whereas 5.87 dS/m indicating moderately saline soil in monsoon. In site B3, the highest EC (23.84 dS/m) was calculated in winter, whereas the lowest EC (0.60 dS/m) was found in site B8 in monsoon; both the samples were collected from 0-15 cm depth. The soils were found to be slightly saline to extremely saline in Beel Bhaina. Spatial and seasonal variations of soil EC in Beel Bhaina is illustrated in Figure 5.8.

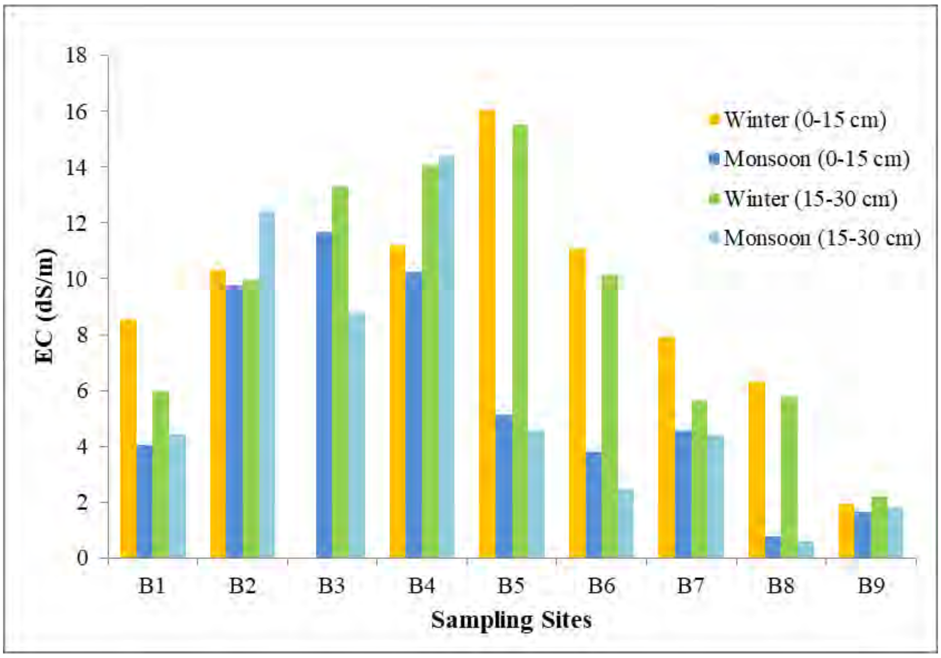

Figure 5.8: Spatial and Seasonal Variations of Soil EC in Beel Bhaina

Available Calcium:

In Beel Bhaina, the average available Ca was 20.51 meq/100g soil and 22.96 meq/100 g soil in winter and monsoon, respectively. The lowest and highest available calcium (Ca) values are about 11.6 meq/100 g soil at site B7 and 30.8 meq/100 g soil at site B6 respectively, both the values were measured for samples taken from 0-15 cm depth in monsoon. Among 9 sites, available Ca was higher in monsoon than that of winter except for site B7. If a soil contains extractable calcium > 10 meq/ 100 g soil, it is assumed to have high fertility in terms of Ca content. All the values were above 11 meq/ 100g soil, therefore the soils have high fertility in Beel Bhaina. Variations in Available Ca in Beel Bhaina are illustrated as follows (Figure 5.9).

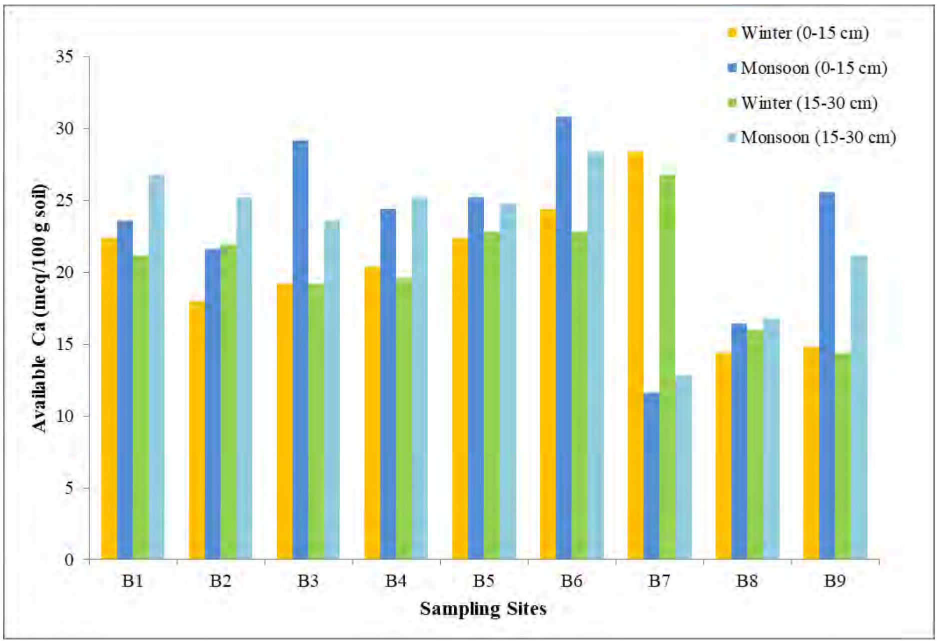

Figure 5.9: Spatial and Seasonal Variations in Available Calcium in Beel Bhaina

Available Magnesium:

Sufficient amount of magnesium (Mg) can be found in alkaline soils. According to Horneck et al. (2011), Mg content of a soil is said to be low, medium and high when extractable Mg is about <0.5 meq/ 100 g soil, 0.5-2.5 meq/100 g soil and > 2.5 meq/100 g soil, respectively. In Beel Bhaina, average Mg was found to be 8.22 meq/100g soil in winter and 7.96 meq/100g soil in monsoon. In 9 sites in Beel Bhaina, the lowest available Mg was about 3.6 meq/ 100 g soil in site B2, whereas the highest available Mg was 12.8 meq/ 100 g soil in site B7; both the values are measured at 0-15 cm depth in monsoon. Like Ca content, season wise decrease or increase in Mg content cannot be found. Figure 5.10 shows spatial and seasonal variations in available magnesium in Beel Bhaina.

Available Iron:

Available iron (Fe) at the sampling sites in Beel Bhaina can be illustrated by a graphical presentation (Figure 5.11). The average Fe content was about 94.68 ppm in winter and 6.96 ppm in monsoon, respectively. The available Fe for all the samples was higher in winter and the highest value was around 332.66 ppm in site B2 for sample at 15-30 cm.

The lowest value of available Fe was 1.42 ppm in Site B8 (0-15 cm) and B9 (15-30 cm) in monsoon. According to SRDI, the standard value of Fe in soil is classified as low (<20 ppm), medium (21-40 ppm), and high (41-200 ppm). In monsoon, Fe content of all the samples fell under low category indicating suitable for agricultural purpose, except for the sample collected from 15-30 cm depth at site B4. Samples fell under medium, high to excessive categories considering available Fe in winter, thus may hamper crop yield of some species.

Available Phosphorus:

According to SRDI, in terms of Phosphorus content, soil is classified as- low (<12 ppm), medium (13-25 ppm), and high (26-75 ppm). From Figure 5.12, the average available P was 39.59 ppm in winter and 33 ppm in monsoon for Beel Bhaina. The highest available phosphorus (P) value is 119.4 ppm at site B9 in winter (15-30 cm) and the lowest available P value is 19.6 ppm at site B8 in monsoon (15-30 cm). The available P in all the sites were found to be medium to high in both winter and monsoon, except at site B9 in winter (15-30 cm) where excessive P content was present.

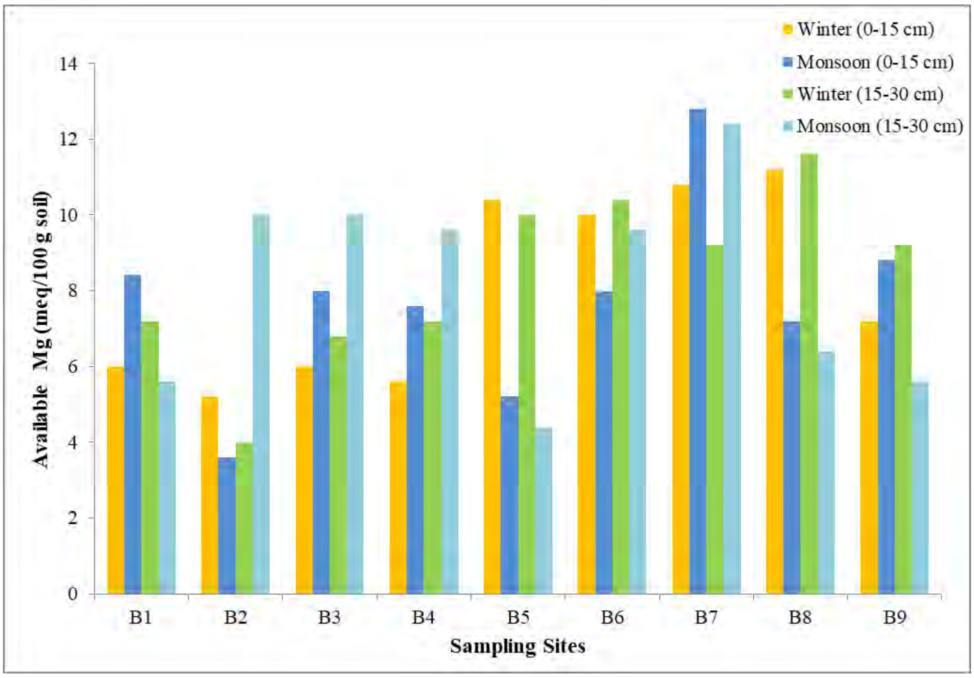

Figure 5.10: Spatial and Seasonal Variations in Available Magnesium in Beel Bhaina

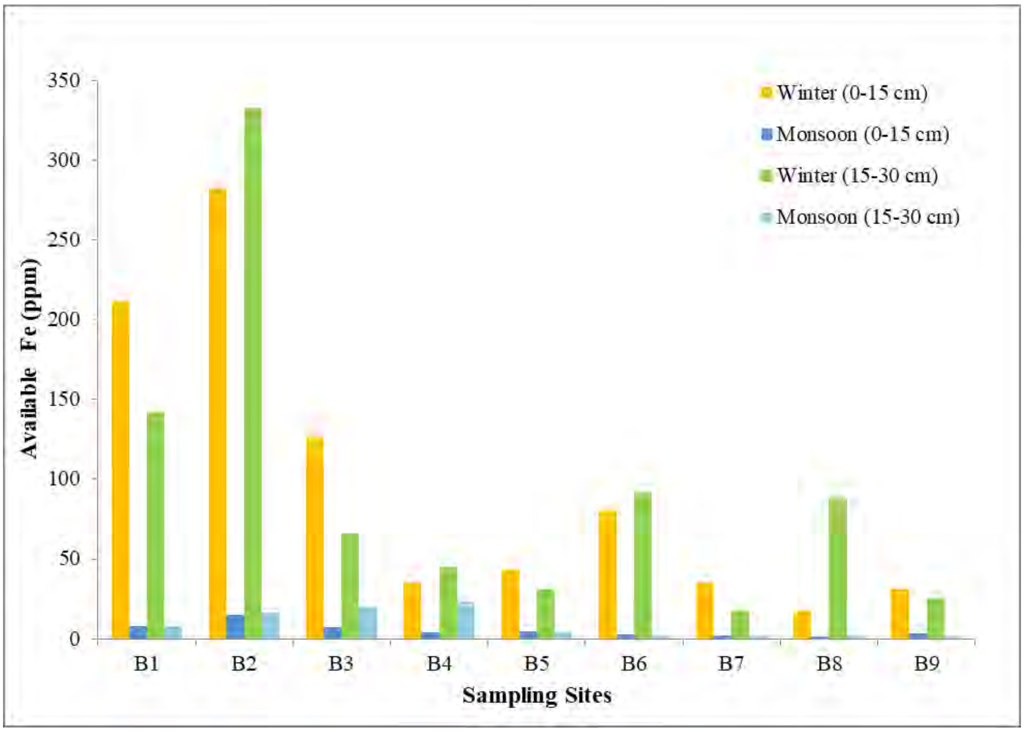

Figure 5.11: Spatial and Seasonal Variations in Available Iron in Beel Bhaina

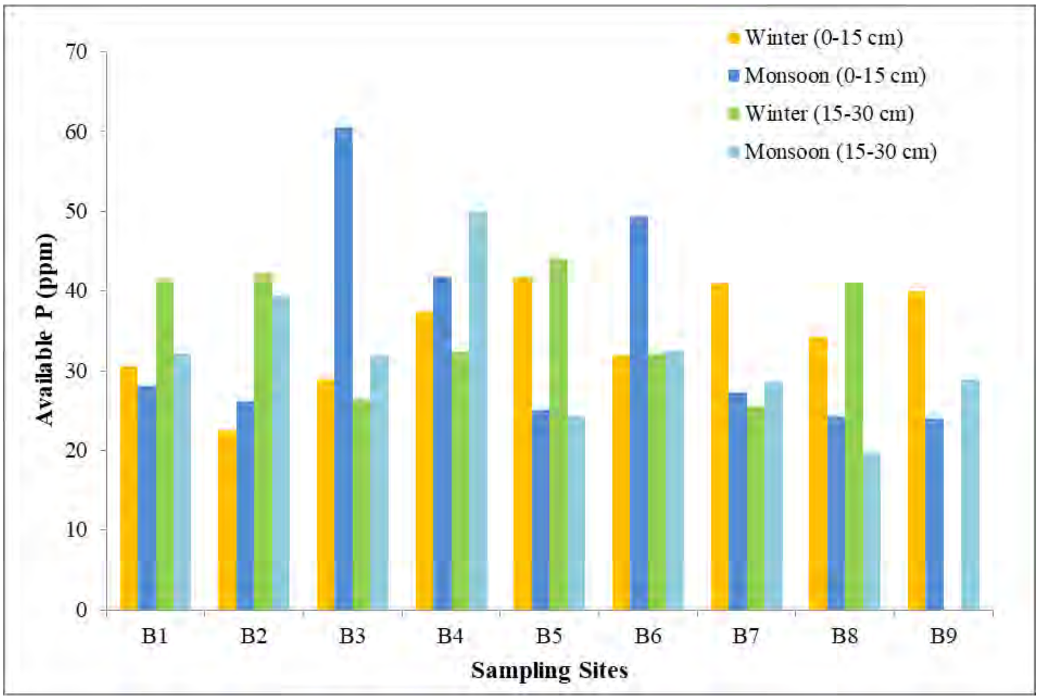

Figure 5.12: Spatial and Seasonal Variations in Available Phosphorus in Beel Bhaina

Available Sulphur:

Available sulphur (S) at the sampling sites in Beel Bhaina can be shown by a graphical presentation (Figure 5.13). There was significant change in the values in monsoon and winter seasons. Average available S was about 441.79 ppm in winter whereas 140.79 ppm in monsoon in case of Beel Bhaina. The highest available S was about 1085 ppm at site B5 in winter (15-30 cm) whereas the lowest available S was about 15.4 ppm at site B9 in monsoon for both 0-15 cm and 15-30 cm soil samples. The S content at 5 sites was higher in winter than monsoon season, except for the site B3 and site B4. According to SRDI, the standard value of S in soil is classified as low (<12 ppm), medium (13-25 ppm), and high (26-75 ppm). Excessive amount of S was present in all the samples in winter making it unsuitable for agricultural use. In monsoon, samples from the sites B2-B4 contained excessive S. Also sites B1, B5-B9 contained medium to high S concentration indicating it may hamper crop production.

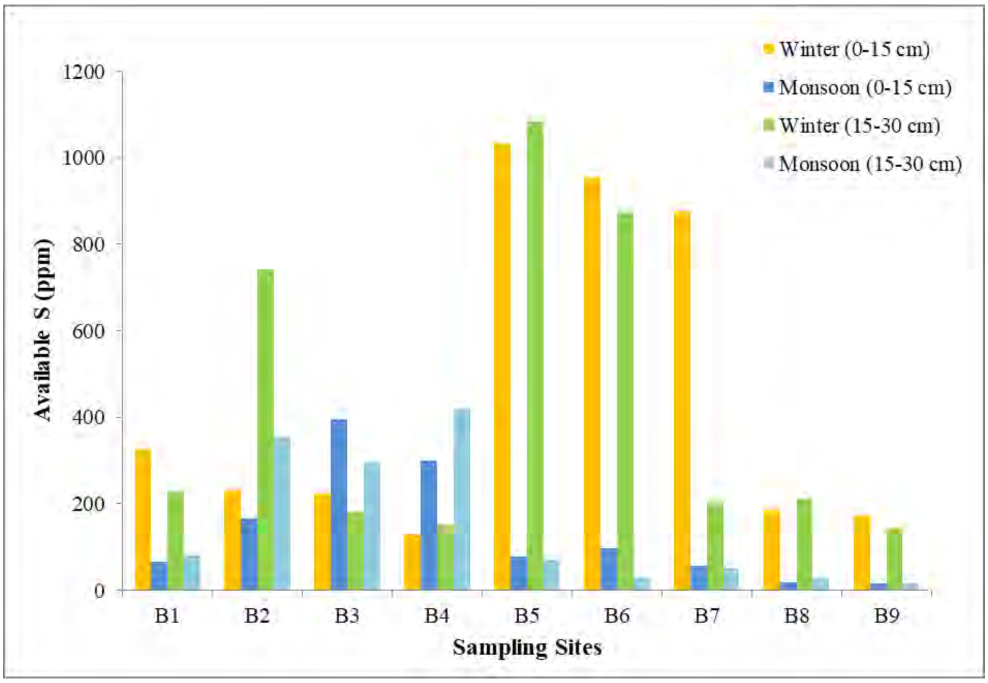

Figure 5.13: Spatial and Seasonal Variations in Available Sulphur in Beel Bhaina

Available Chlorine:

The average available Cl content was 1439.72 ppm and 1299.69 ppm in winter and monsoon, respectively, for Beel Bhaina. In monsoon, the available Cl was ranged between 497 ppm and 2094.5 ppm. In winter, the available Cl was found about 35.5 ppm to 3621 ppm. Spatial and seasonal variations in available Cl in Beel Bhaina are shown in Figure 5.14.

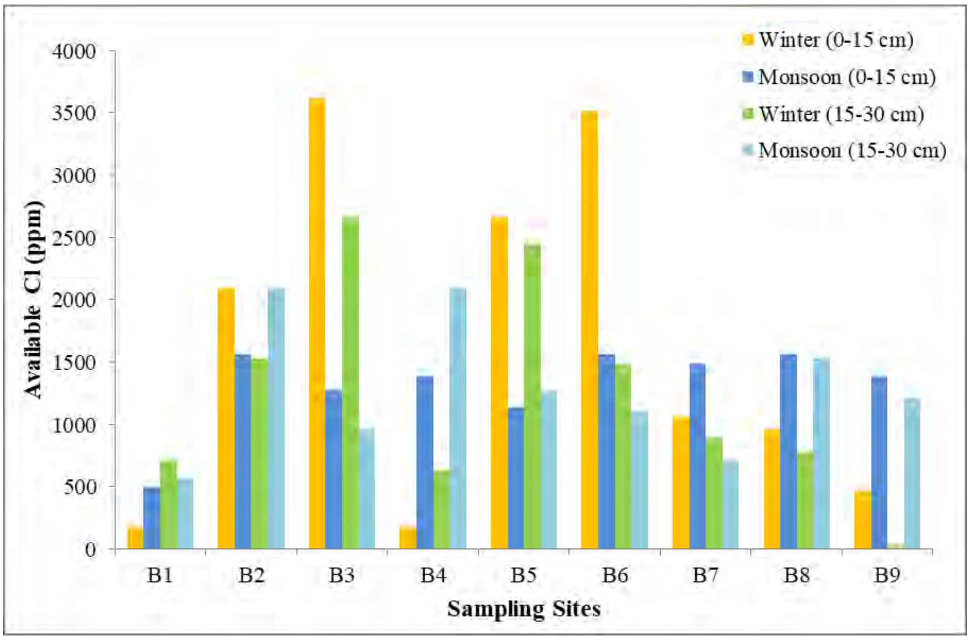

Figure 5.14: Spatial and Seasonal Variations in Available Chlorine in Beel Bhaina

5.4.2 East Beel Khuksia

Soil pH:

The seasonal and spatial variations in pH in East Beel Khuksia are shown in Figure 5.15. The average pH for East Beel Khuksia was 7.79 and 7.28 in winter and monsoon, respectively. The maximum pH is 8.03 at site K7 in winter, whereas the minimum pH is 6.84 at site K6 in monsoon; both the samples were from 0-15 cm soil depth. Soil pH was found to be slightly alkaline at almost all the sites.

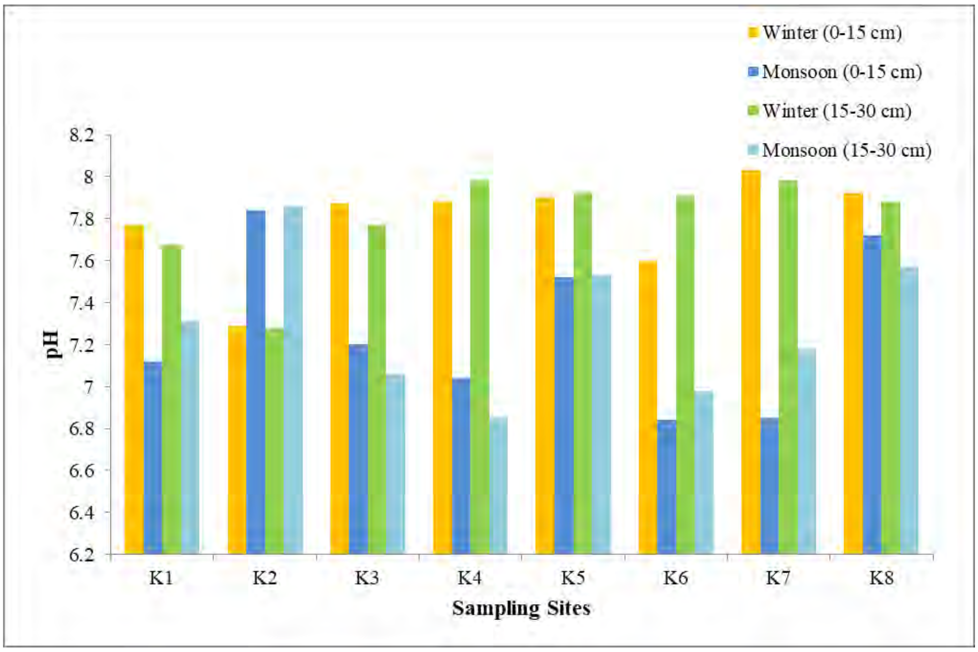

Figure 5.15: Spatial and Seasonal Variations of Soil pH in East Beel Khuksia

Electrical Conductivity:

The average EC for East Beel Khuksia was about 6.23 dS/m in winter whereas 4.59 dS/m in monsoon. The highest EC (12.86 dS/m) and the lowest EC (1.64 dS/m) was found at site K1 and site K7 in winter; both the samples were collected from 0-15 cm depth. The soils were found to be non-saline to very saline in East Beel Khuksia. Spatial and seasonal variations of soil EC in East Beel Khuksia is given in Figure 5.16.

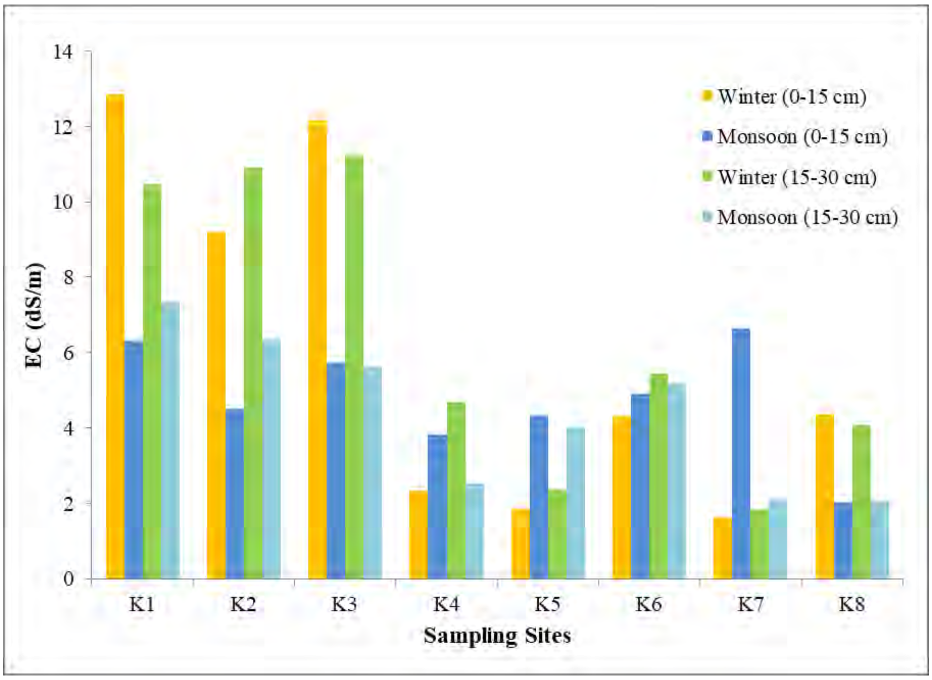

Figure 5.16: Spatial and Seasonal Variations of Soil EC in East Beel Khuksia

Available Calcium:

In East Beel Khuksia, the average Ca content was 21.73 meq/100g soil in winter and 24 meq/100g soil in monsoon, respectively. The highest and lowest available Ca value is about 28.8 meq/100 g soil at site K8 in monsoon and 14.8 meq/100 g soil at site K6 in winter, respectively; both the samples were taken from 0-15 cm depth. Soil containing calcium > 10 meq/ 100 g soil is assumed to have good fertility. Ca concentration of all the samples was above 14 meq/ 100g soil, therefore the soils have high fertility in East Beel Khuksia. Variations in available Ca in East Beel Khuksia are illustrated as follows (Figure 5.17).

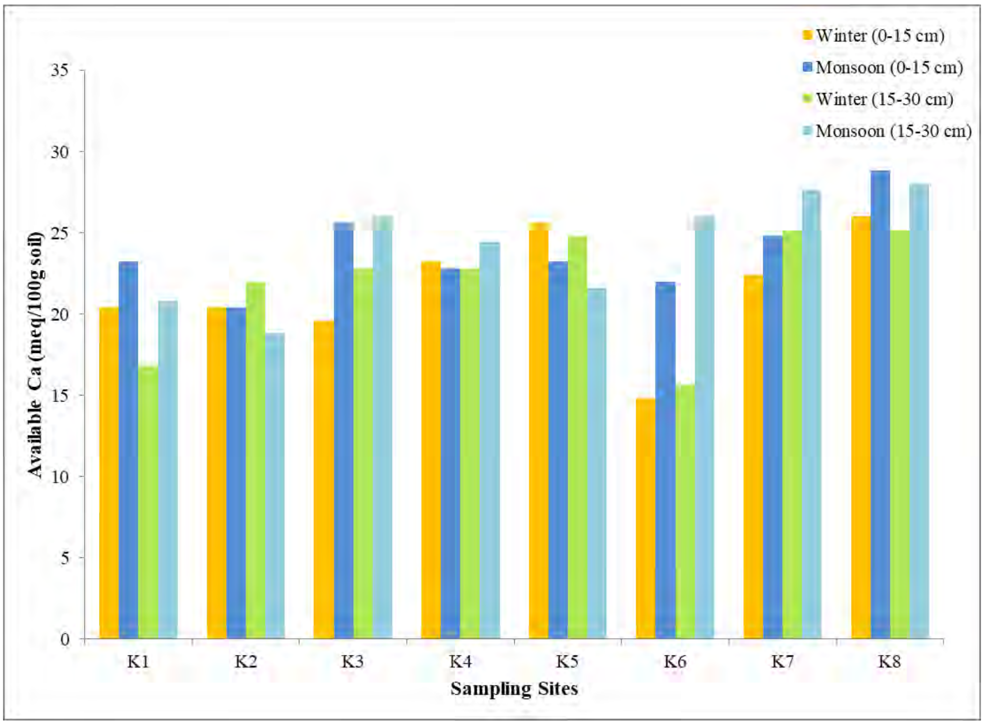

Figure 5.17: Spatial and Seasonal Variations in Available Calcium in East Beel Khuksia

Available Magnesium:

Figure 5.18 describes spatial and seasonal variations in available magnesium in East Beel Khuksia. The average available Mg was about 6.08 meq/100 g soil in winter whereas the value was 5.78 meq/100 g soil in monsoon. Both the highest and lowest values of Mg content were found for the samples from 0-15 cm depth at sites K6 and K2, in monsoon. Sufficient amount of Mg was found to be present in East Beel Khuksia. Almost all the samples were under high (>2.5 meq/100 g soil) category in terms of Mg concentration, except for three samples.

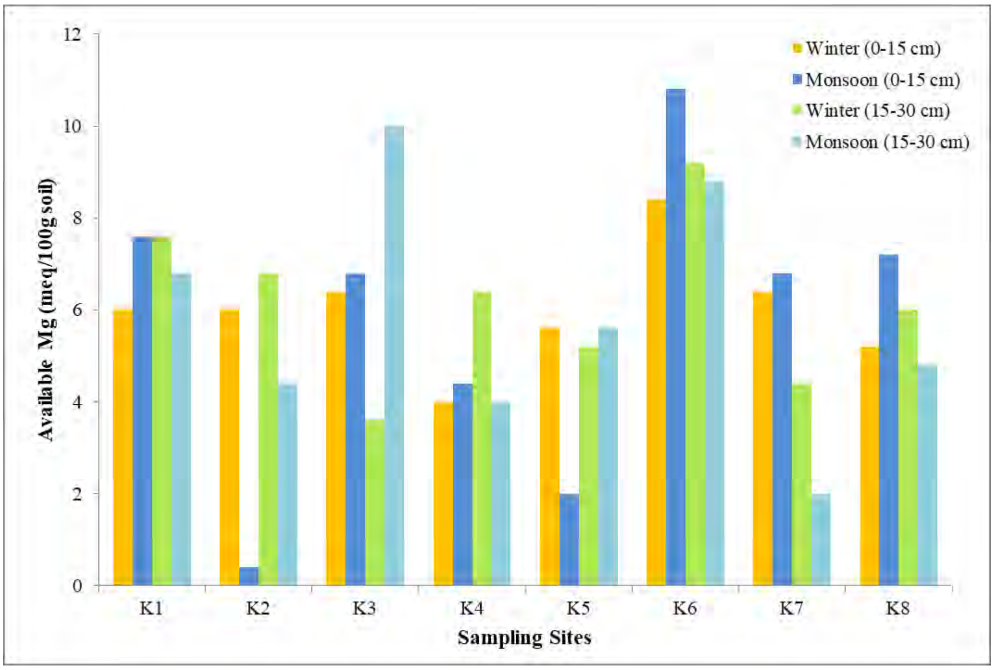

Figure 5.18: Spatial and Seasonal Variations in Available Magnesium in East Beel Khuksia

Available Iron:

In East Beel Khuksia, considering season and depth, noticeable variations in available Fe are demonstrated in Figure 5.19. At sites K7 and K8 very little seasonal and spatial change in Fe concentration was found, this may happen as these sites are situated at the furthest part of the beel. The Fe value was higher in winter than monsoon for all the samples. The average available Fe in winter was 109.18 ppm and in monsoon it was about 21.97 ppm, for East Beel Khuksia.

Available Phosphorus:

In East Beel Khuksia, the average available P was 44.11 ppm and 57.12 ppm in winter and monsoon, respectively. The highest available P is measured as 192.05 ppm at site K7 (0-15 cm) and the lowest available P value is 25.36 ppm at site K3 (15-30 cm); both the values were found in monsoon. Available P showed fluctuating pattern in both the seasons.

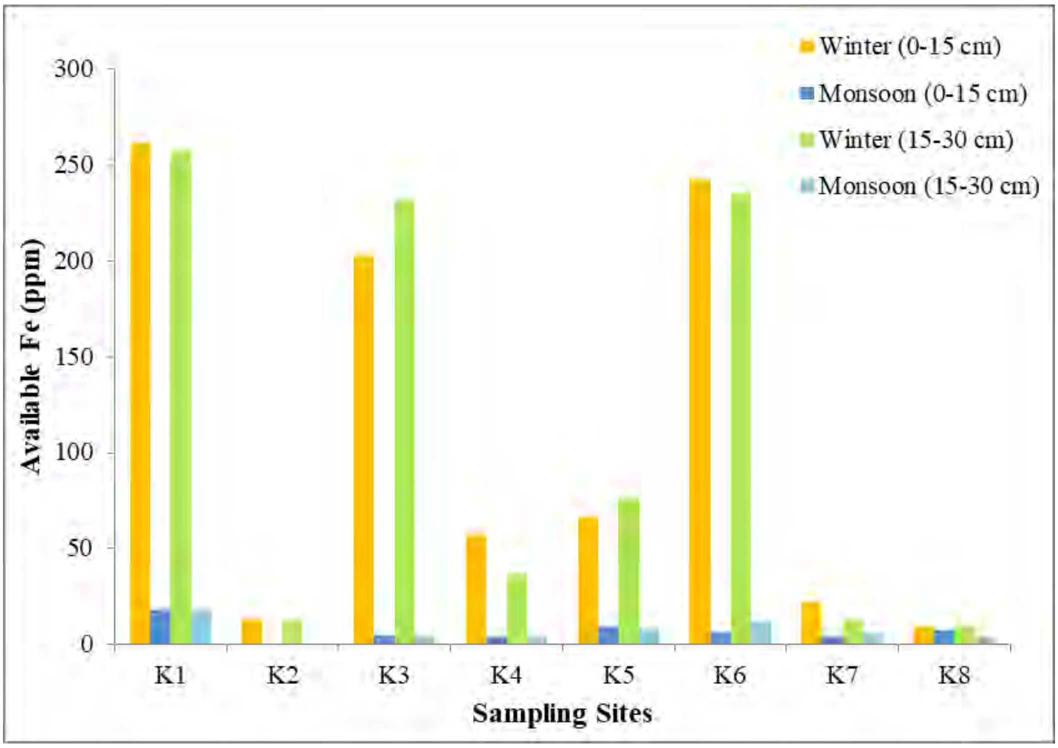

Figure 5.19: Spatial and Seasonal Variations in Available Iron in East Beel Khuksia

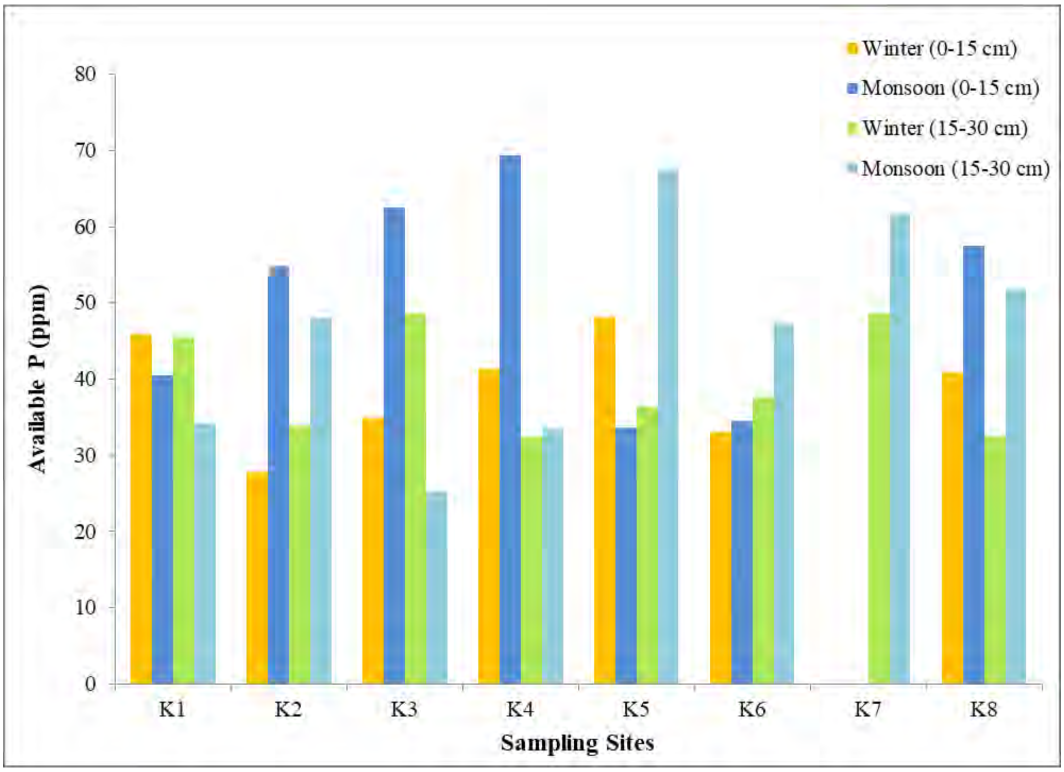

Figure 5.20: Spatial and Seasonal Variations in Available Phosphorus in East Beel Khuksia

Available Sulphur:

Available S at the sampling sites in East Beel Khuksia is shown by a graphical presentation (Figure 5.21). Significant variations in the S concentration were noticed regarding season and depth. The average available S in winter was 582.61 ppm and in monsoon it was 193.08 ppm, for East Beel Khuksia. The highest available S was about 777.151 ppm at site K1 (0-15 cm) in winter whereas the lowest available S was about 12.576 ppm at sites K7 (15-30 cm) and K8 (0-15 cm) in monsoon.

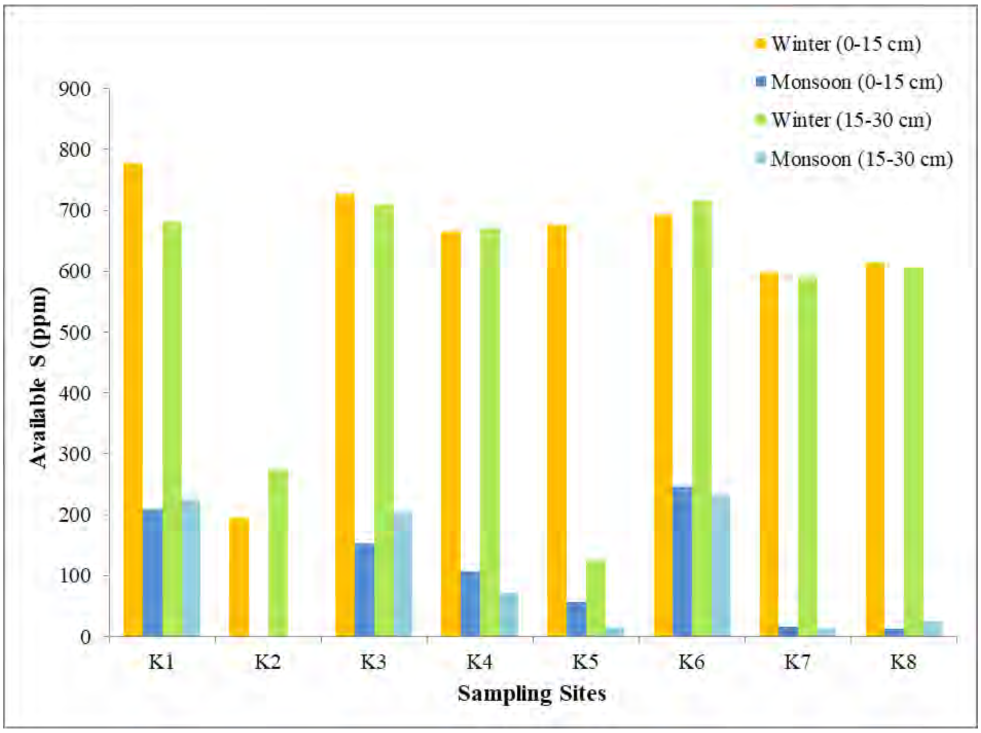

Figure 5.21: Spatial and Seasonal Variations in Available Sulphur in East Beel Khuksia

Available Chlorine:

The average available Cl was 1213.66 ppm and 1131.56 ppm in winter and monsoon, respectively, for East Beel Khuksia. In winter, the available chlorine (Cl) was ranged between 284 ppm and 3266 ppm. In monsoon, the available Cl was found to be 426 ppm to 1775 ppm. Spatial and seasonal variations in available Cl in East Beel Khuksia are shown in Figure 5.22.

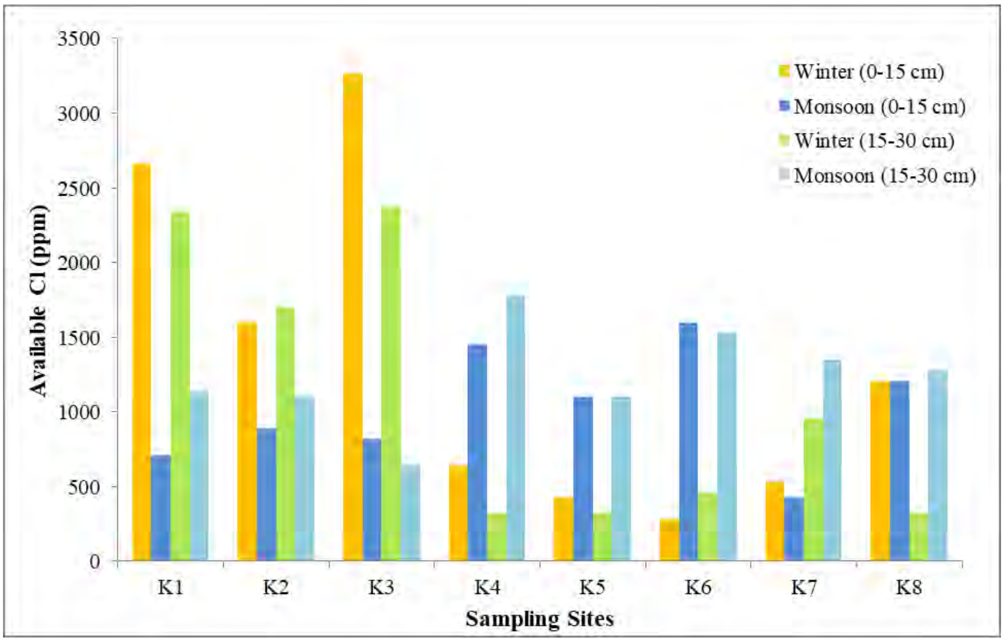

Figure 5.22: Spatial and Seasonal Variations in Available Chlorine in East Beel Khuksia

5.4.3 Beel Pakhimara

Soil pH:

The seasonal and spatial variations in pH in Beel Pakhimara are demonstrated in Figure 5.23. The average pH in Beel Pakhimara was 7.63 in winter and 7.87 in monsoon. Soil pH was measured between 7.45 and 8.05. The highest and lowest values were at site P6 (15-30 cm), found in monsoon and winter, respectively. All the samples were found to be within the permissible range and alkaline in nature. The pH values were higher in monsoon than in winter.

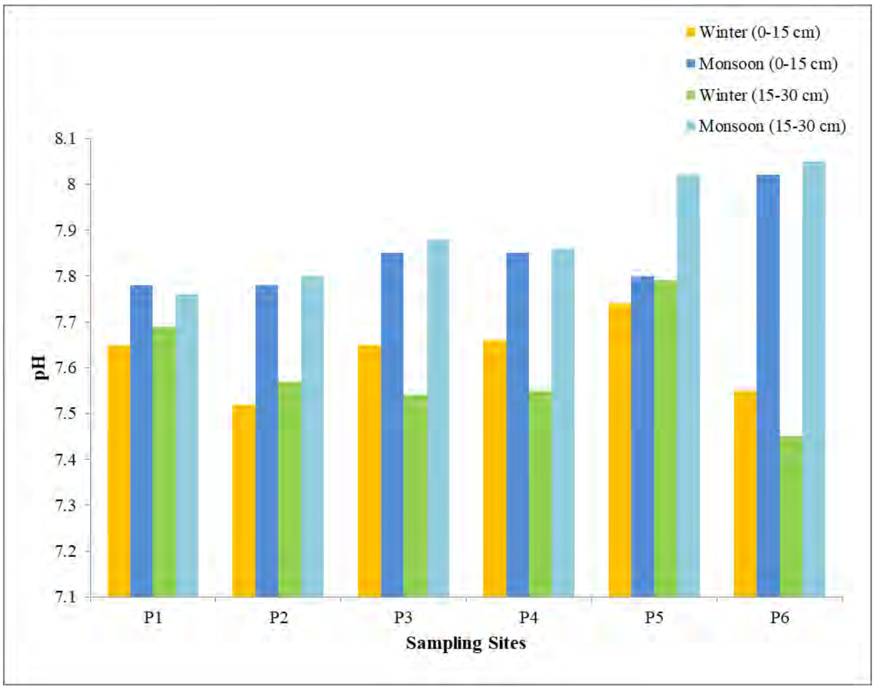

Figure 5.23: Spatial and Seasonal Variations of Soil pH in Beel Pakhimara

Electrical Conductivity:

In Beel Pakhimara at site P4 (15-30 cm) the highest EC (14 dS/m) in winter was found, whereas the lowest EC (4.57 dS/m) was found at site P6 (0-15 cm) in monsoon. The soils were found to be slightly saline to very saline in Beel Pakhimara. The average EC for Beel Pakhimara was about 10.99 dS/m indicating moderately saline soil in winter whereas 8.33 dS/m (slightly saline soil) in monsoon. Spatial and seasonal variations in Soil EC in Beel Pakhimara are shown in Figure 5.24.

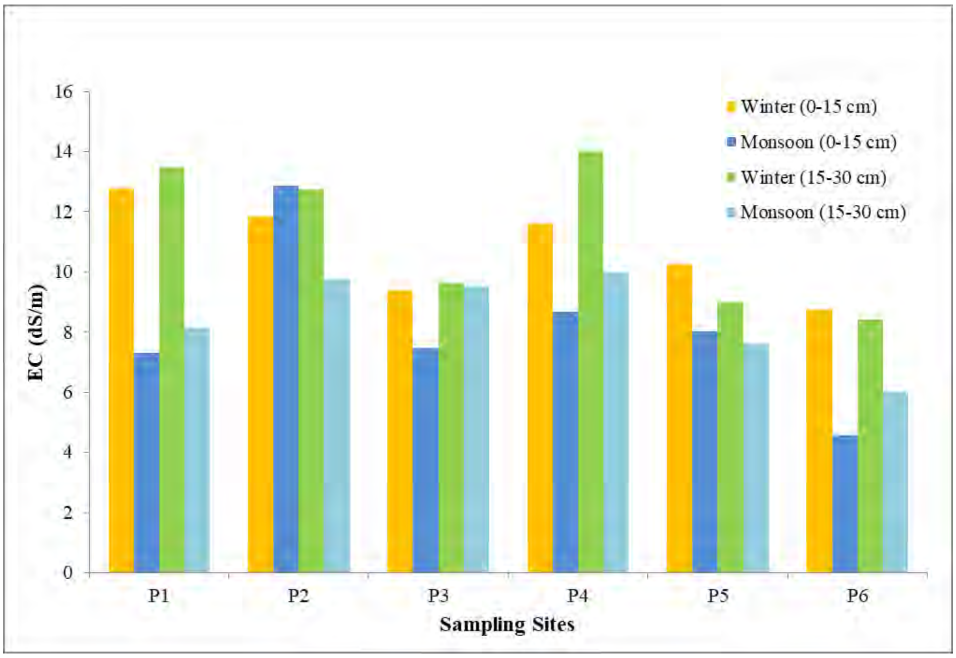

Figure 5.24: Spatial and Seasonal Variations of Soil EC in Beel Pakhimara

Available Calcium:

Variations in available Ca in Beel Pakhimara are illustrated in Figure 5.25. In Beel Pakhimara, the average available Ca was 21.27 meq/100g soil and 23.43 meq/100 g soil in winter and monsoon, respectively. The lowest available calcium (Ca) value was 17.20 meq/100 g soil at site P5 (15-30 cm) in winter. The highest Ca content was about 28.40 meq/100 g soil at site P5 in monsoon and at site P6 in winter, respectively, both the values were measured for the samples taken from 0-15 cm depth. Considering seasons, fluctuating Ca values were found in both monsoon and winter. All the values were above 17 meq/ 100g soil, therefore the soils have high fertility in Beel Pakhimara.

Available Magnesium:

In Beel Pakhimara, the average Mg was found to be 6.73 meq/100g soil in winter and 7.77 meq/100g soil in monsoon. The lowest available Mg was about 2.4 meq/ 100 g soil at site P4, whereas the highest available Mg was 12 meq/ 100 g soil at site P3; both the values are measured at 0-15 cm depth in monsoon. Like Ca concentration, season wise decrease or increase in Mg content was not present. Figure 5.26 shows spatial and seasonal variations in available magnesium in Beel Pakhimara.

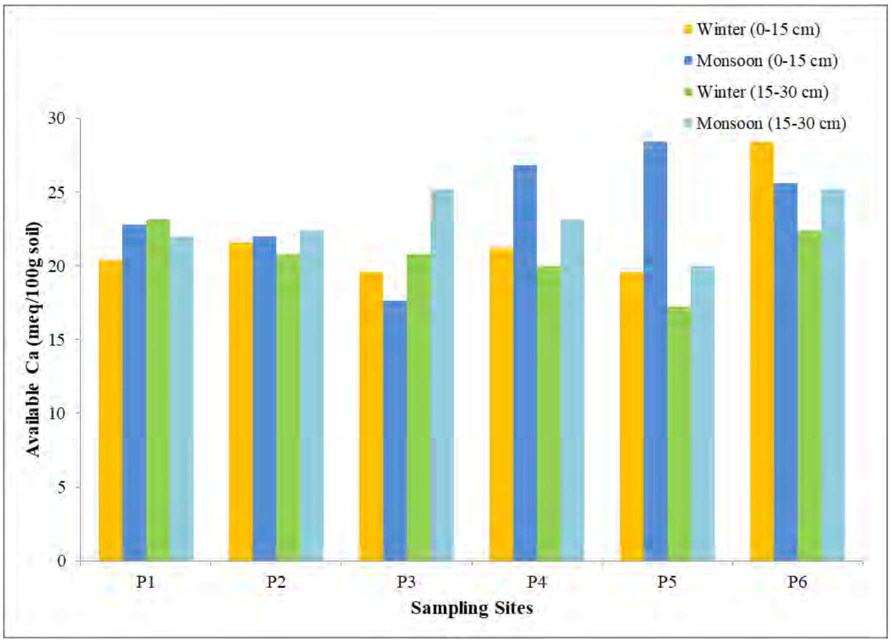

Figure 5.25: Spatial and Seasonal Variations in Available Calcium in Beel Pakhimara

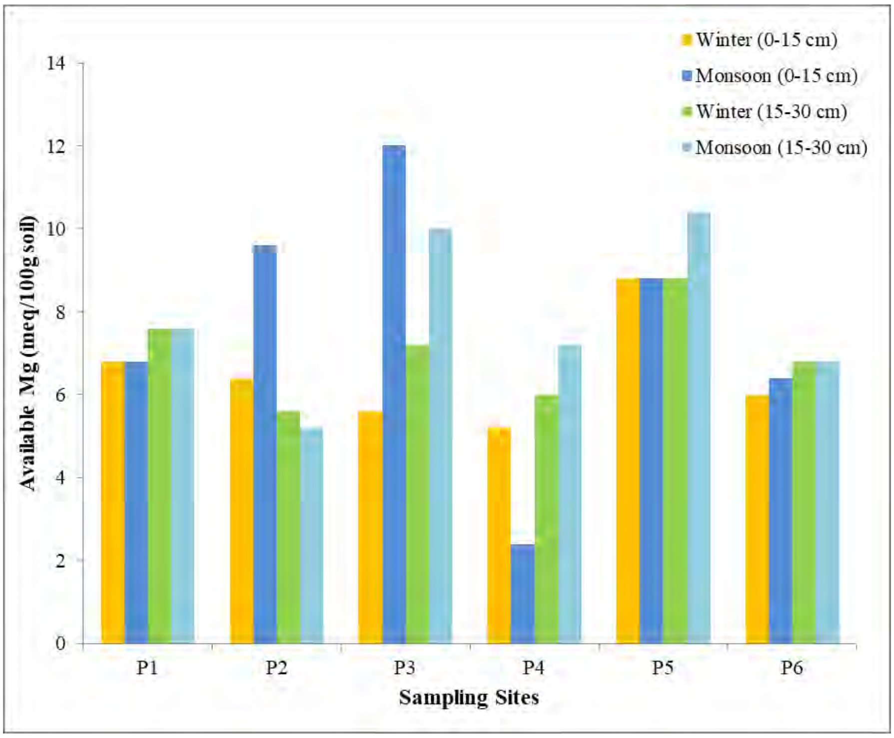

Figure 5.26: Spatial and Seasonal Variations in Available Magnesium in Beel Pakhimara

Available Iron:

In Beel Pakhimara, the average Fe content was about 185.70 ppm in winter and 13.38 ppm in monsoon, respectively. A drastic change in Fe content is demonstrated considering the seasons and depths (Figure 5.27). At site P6, little seasonal and spatial change in available Fe was found. At the sites P1 to P5, Fe content was extremely higher in winter than that of monsoon.

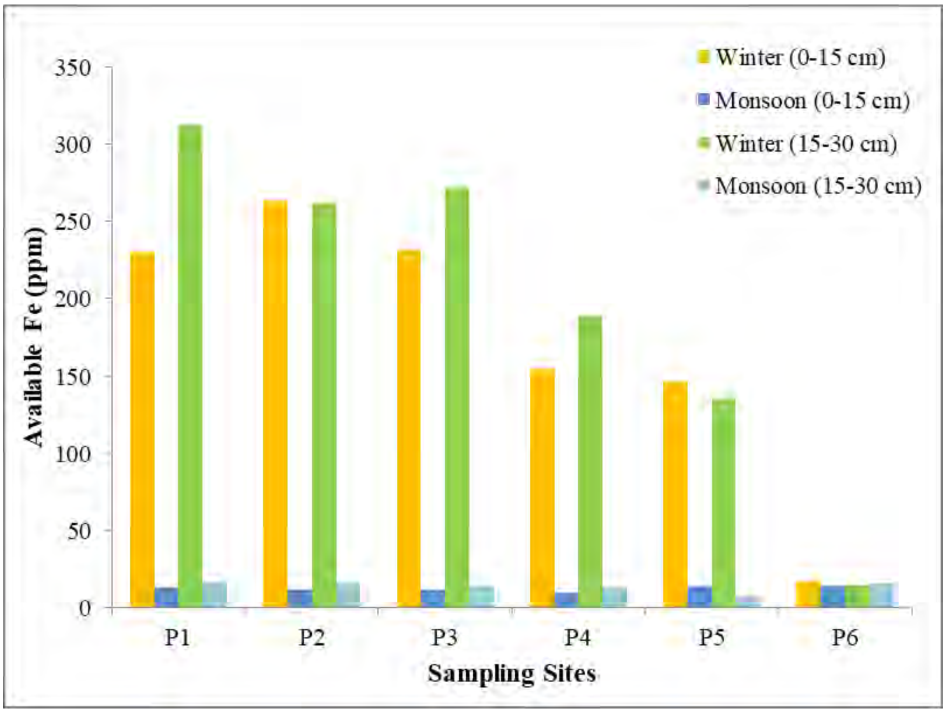

Figure 5.27: Spatial and Seasonal Variations in Available Iron in Beel Pakhimara

Available Phosphorus:

The average available P was 36.96 ppm in winter and 37.64 ppm in monsoon for Beel Pakhimara. According to Figure 5.28, the highest available P value is 46.824 ppm at site P2 and the lowest available P value is 20.859 ppm at site P6, both the samples were collected in winter at 15-30 cm soil depth. In Beel Pakhimara, the available P in all the sites was found to be medium to high in both monsoon and winter (SRDI, 2003).

Available Sulphur:

Available S at the sampling sites in Beel Pakhimara is shown by a graphical presentation (Figure 5.29). Significant change in the availability of S content was found considering season and depth. Average available S was about 754.28 ppm in winter whereas 258.64 ppm in monsoon in case of Beel Pakhimara. The highest available S was 864.49 ppm at site P1 in winter whereas the lowest available S was 123.22 ppm at site P6 in monsoon; both the samples were taken from 15-30 cm soil depth. The S content at all the sites was higher in winter than winter.

Available Chlorine:

Spatial and seasonal variations in available Cl in Beel Pakhimara are illustrated in Figure 5.30. The average available Cl content was 2014.63 ppm and 1452.54 ppm in winter and monsoon seasons, respectively, for Beel Pakhimara. The maximum available Cl was measured as 3195 ppm at site P1 (15-30 cm) in winter. The minimum available Cl was found to be 887.5 for both the depths at site P1 in monsoon.

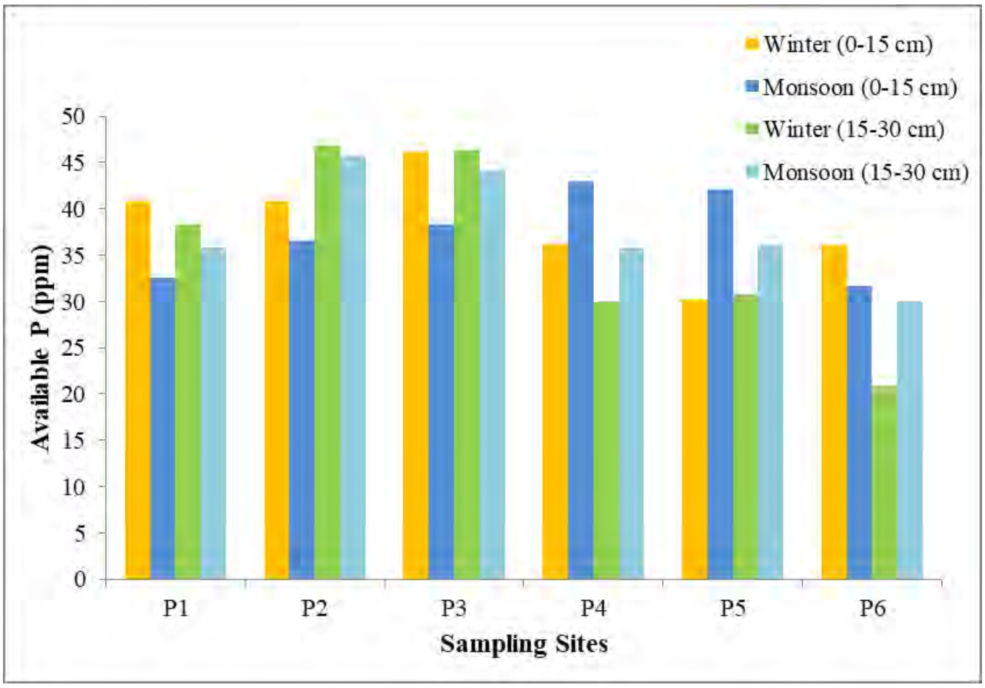

Figure 5.28: Spatial and Seasonal Variations in Available Phosphorus in Beel Pakhimara

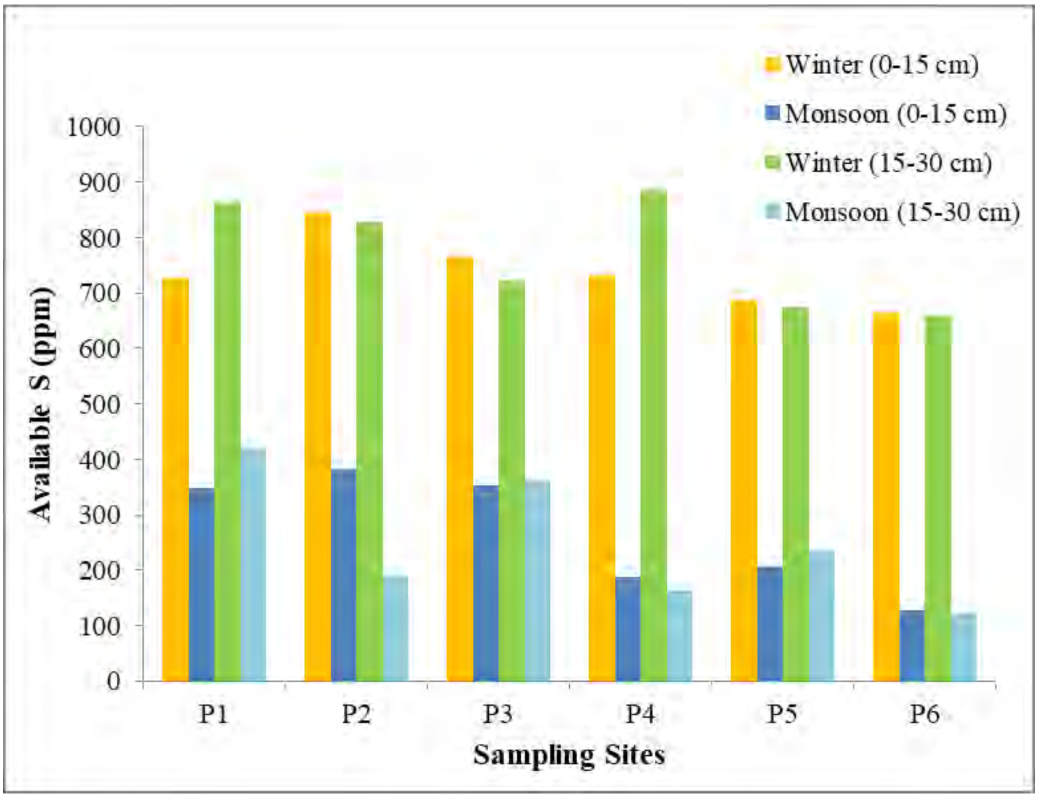

Figure 5.29: Spatial and Seasonal Variations in Available Sulphur in Beel Pakhimara

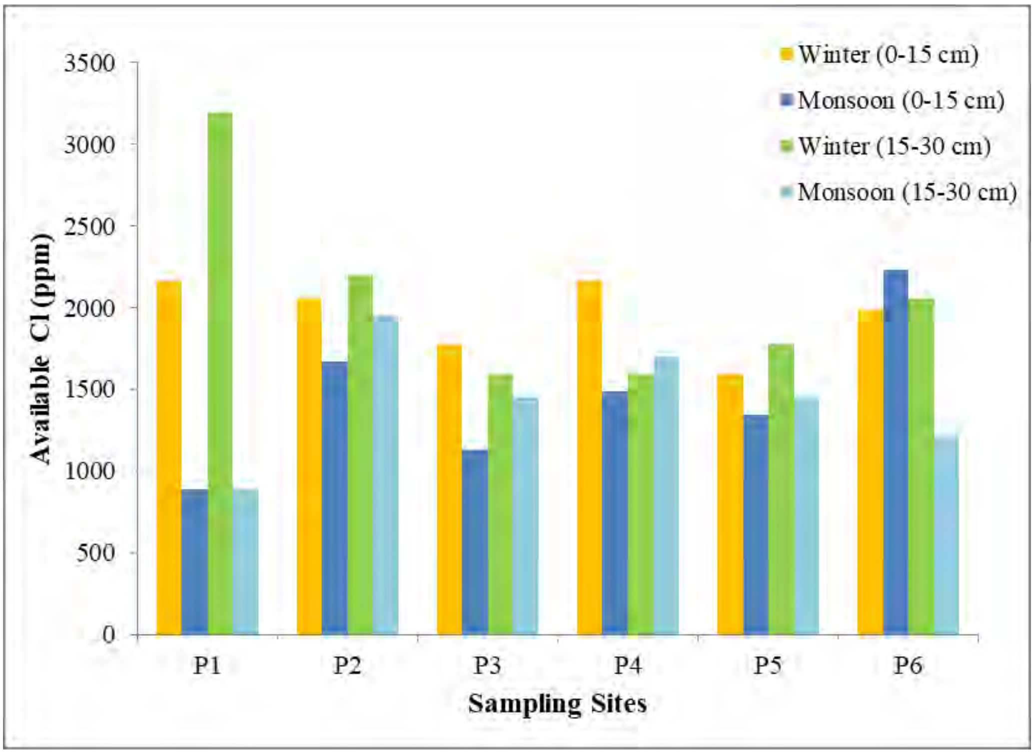

Figure 5.30: Spatial and Seasonal Variations in Available Chlorine in Beel Pakhimara

5.5 Spatial and Seasonal Variations in Water Quality in the Tidal Basins

Water quality plays a vital role in agricultural activities. The suitability of irrigation water depends on various parameters such as pH, EC, TDS, TSS, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), sulfate (SO_4^{2-}), phosphate (PO_4^{3-}), nitrate (NO_3^-) and nitrite (NO_2^-). The suitability class for each parameter determines the water quality for irrigation purpose. In this study sodium adsorption ratio (SAR), sodium percentage (Na%), potential salinity (PS), magnesium ratio (MR), calcium-magnesium ratio (Ca: Mg), permeability index (PI) and Kelly's index (KI) were calculated to evaluate the suitability of the water quality in the selected tidal basins. For understanding water quality, I took samples from different water sources (river, beel, GW) in both the winter and monsoon seasons. The spatial and seasonal variations in water quality of the study areas are discussed in the following sections.

5.5.1 Beel Bhaina

pH:

pH plays a vital role in agricultural production. It may cause a nutritional imbalance or contain ion toxicity in the irrigation water if the pH values are outside the permissible range (Ayers and Westcot, 1994). Table 5.7 shows that all pH values of the sites BW1-BW4 and BM1-BM5 were within the tolerance range (6.5-8.5) for irrigation in Bangladesh (BADC, 2007). In Beel Bhaina, the water from the Hari river, beel and GW sources were suitable for irrigation purposes.

EC:

Electrical conductivity (EC) determines the water salinity and is considered as one of the most important parameters to assess the suitability of water for agricultural use. The highest EC (19.21 dS/m) was measured for the Hari River at site BW1 in winter and the lowest EC (1.61 dS/m) was found for beel water at site BM1 in monsoon. Table 5.9 shows that the water from beel and GW at sites BM1-BM3 had permissible EC, except for a doubtful EC at site BM4 (GW) in monsoon. In winter, water from all sources was unsuitable for irrigation, except for site BW4 (GW) having a doubtful EC value. This could be the reason for using groundwater for irrigation in the beel.

Total Dissolved Solid and Total Suspended Solid:

Total dissolved solid (TDS) is the fraction of particles and ions, including metals, minerals and salts dissolved in water. Total suspended solid (TSS) is the fraction of particles floating in the water and takes longer period of time to settle down and also helps determining the clarity of water. The highest TDS (9600 mg/L) and TSS (2099 mg/L) were measured at site BW3 (Hari River) in winter whereas the lowest TDS (815 mg/L) and TSS (59 mg/L) were at site BM1 (beel) in monsoon. The values for TDS and TSS were higher in winter for all the sites than that of monsoon (Table 5.7). It was observed that in winter water from Hari River and beel was unsuitable for irrigation use in Beel Bhaina (Table 5.9). The TDS of GW sources were within the permissible limit and used for irrigation purposes.

Cations:

The most dominant cation is Na^+ in all sampling sites irrespective of seasons in Beel Bhaina. The sodium toxicity is difficult to diagnose, typically shows symptoms such as leaf burn, scorch and dead tissue at the outer edges of the older leaves. Higher amount of Na^+ is found in water from Hari River and beel than that of GW in winter. As per Table 5.9, all the samples fall under 'severe' class indicating that the water is unsuitable for irrigation.

The usual range for Ca^{2+} in irrigation water is 0-20 meq/L. The available Ca^{2+} at all the sites was recorded within 2.1-8.4 meq/L, which means irrigation water is suitable for crop production (Table 5.8). The highest Mg^{2+} was recorded to be 40 meq/L at site BW2 (Beel) in winter whereas the lowest Mg^{2+} was at BM1 (Beel) in monsoon. The permissible range for Mg^{2+} in irrigation water is 0-5 meq/L. In monsoon, water samples collected from beel and GW sources were suitable for irrigation. On the contrary, samples collected in winter from Hari river and beel were not suitable for agricultural purpose, except for site BW4 (GW). Thus GW sources were suitable for irrigation purposes.

The value of Ca: Mg ratio above 1 indicates that the water is calcium dominant. If the ratio is near or below 1, it indicates soil is rich in exchangeable Mg causing infiltration problem (Ayers and Westcot, 1994). In Beel Bhaina, the highest Ca: Mg ratio was measured at site BM4 (Boring) in monsoon and the lowest value was recorded at site BW5 (Beel) in winter (Table 5.8).

The permissible K^+ in irrigation water is ranged between 0 and 2 ppm. In monsoon, K^+ was suitable for irrigation at sites BM1-BM3, except for at site BM4 (2.5 mg/L). In winter, K^+ was unsuitable for irrigation at sites BW1-BW4 in Beel Bhaina, except for at site BW5 (1.62 mg/L).

The values of Na^+, K^+, Ca^{2+}, Mg^{2+} were higher in winter than that of monsoon, except for Fe^{2+}, which was found to be same (0.005 mg/L) at all sites in both the seasons.

Anions:

The spatial and seasonal variations in anions were significant in Beel Bhaina. The most dominant anion is found to be Cl^- in winter season, except for site BW4 (GW). In monsoon, the most dominant anion is calculated as HCO_3^-, except for site BM1 (Beel). Chloride is not adsorbed by soils and moves readily with the soil-water. It is one of the important micronutrients for plants. The most common toxicity in irrigation water occurs due to excessive chloride concentration. As per the guideline for specific ion toxicity (Table 5.8), the water from all the sites irrespective of season fall under 'severe' class indicating that the water is not suitable for irrigation, except for site BW4 (GW) categorized 'moderate' for irrigation purposes.

Alkalinity in water occurs due to the dissolved carbonate and bicarbonates. The usual range of HCO_3^- in irrigation water is 0-10 meq/L. Higher amount of HCO_3^- was found in monsoon than that of winter. The value of bicarbonate at all the sites was found satisfactory except for at site BM4 (GW) (Table 5.8).

The values of NO_3^-, NO_2^- and PO_4^{3-} were very low compared to other available anions. The highest and the lowest nitrate values were measured at site BW3 (beel) and site BW5 (GW), respectively in winter (Table 5.7). According to ion toxicity guideline (Table 5.8), the water from the sources falls under 'no problem' and 'moderate' classes indicating that it is suitable for irrigation.

The permissible range for SO_4^{2-} in irrigation water is 0-20 meq/L. From Table 5.8, in Beel Bhaina SO_4^{2-} was within the permissible limit in monsoon, whereas the waters from Hari River and beel exceeded the range in winter.

The $PO_4^{3-}$of water should be within 0-2 ppm for irrigation use. For all the sites, the water samples were suitable for irrigation in terms of available PO_4^{3-} in both monsoon and winter seasons (Table 5.7).

Sodium Adsorption Ratio (SAR):

SAR gives a reliable assessment of irrigation water quality with respect to sodium hazard. The highest and the lowest SAR value were measured as 47.73 and 7.45 in winter, at sites BW3 (Beel) and BW5 (GW), respectively. From Table 5.9, the water from GW (BW5 and BM2 sites) sources were classified as 'excellent', whereas the waters from Hari River and beel (BW1 and BW3 sites) fall under 'unsuitable' category for irrigation purposes.

Sodium Percentage (Na%):

The Na% of the samples from Beel Bhaina ranges between 57.58 and 85.44. Considering Na% in water samples, the water from BW1, BW3, and BW4 sites were under 'unsuitable' category in winter, moreover, samples from the sites BM1-BM4 in monsoon were 'doubtful' for irrigation (Table 5.9).

Potential Salinity (PS):

In Beel Bhaina, the PS of the water samples ranges from 8.29-145.12 meq/L. Both the highest and the lowest values were found in winter at sites BW3 (beel) and BW4 (GW), respectively. It suggests that the PS in all samples of the study area nearly is high (>10) in both seasons except for the site BW4 (GW), making the water unsuitable for irrigation usage (Table 5.9).

Permeability Index (PI):

In Beel Bhaina, water samples for both the seasons were under the Class I and II categories and thus are good for irrigation purposes (Table 5.9). In terms of PI, the water from Hari River, beel and GW sources were suitable for irrigation in Beel Bhaina.

Kelly's Index (KI):

In the present study, all the samples were unsuitable for irrigation in terms of KI (Table 5.8). The highest KI was 5.79 at site BW4 (GW) and the lowest KI was 1.36 at site BW5 (GW), for Beel Bhaina.

Magnesium Ratio (MR):

If the MR value is more than 50%, the soil would become more alkaline and affect the crop yield. In Beel Bhaina, the maximum MR was around 87% at site BW2 (Beel) in winter, on the other hand the minimum value was about 41.95% at BM4 (GW) in monsoon (Table 5.8).

Table 5.7: Water Quality Parameters in Beel Bhaina

Season	Sampling Sites with Source	pH	EC (dS/m)	TDS (mg/L)	TSS (mg/L)	Fe^{2+} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	PO_4^{3-} (mg/L)	NO_3^- (mg/L)	NO_2^- (mg/L)	SO_4^{2-} (mg/L)	HCO_3- (mg/L)	Cl^- (mg/L)
Winter	BW1 (Hari River)	6.79	19.21	9600	2099	0.005	5014.00	113.65	168.34	442.35	0.68	2.75	0.004	2519.00	159.0	3722.25
	BW2 (Beel)	7.46	18.98	9490	1513	0.005	3871.20	109.00	120.24	486.10	0.34	5.30	0.004	1969.00	140.3	4112.10
	BW3 (Beel)	7.01	17.51	8770	1243	0.005	4786.00	115.65	136.27	379.16	1.28	6.70	0.004	1915.00	220.0	4431.00
	BW4 (GW)	7.96	2.94	1425	288	0.005	747.00	16.50	64.13	29.17	1.17	2.90	0.004	121.81	366.0	248.50
	BW5 (GW)	7.44	3.08	1546	332	0.005	471.00	1.62	158.32	87.50	0.41	0.50	0.004	451.39	384.3	833.08
Monsoon	BM1 (Beel)	7.10	1.61	815	59	0.005	357.28	1.67	42.10	29.17	0.18	1.31	0.006	141.52	220.0	390.00
	BM2 (GW)	7.90	1.70	849	175	0.005	342.00	1.47	68.14	30.38	0.30	1.30	0.004	88.30	421.0	389.00
	BM3 (GW)	7.62	1.75	873	159	0.005	370.00	1.67	42.10	34.00	0.18	1.00	0.006	110.00	415.0	390.00
	BM4 (GW)	7.41	2.11	1054	251	0.005	485.00	2.50	72.15	31.68	0.80	5.74	0.004	58.74	659.0	391.00

*The Hari River data was unavailable in monsoon

Table 5.8: Calculated Parameters to Evaluate Water Quality in Beel Bhaina

Season	Sampling Sites with Source	Na^+ (meq/L)	K^+ (meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	Cl^- (meq/L)	SO_4^{2-} (meq/L)	HCO_3^- (meq/L)	SAR	Na%	PS (meq/L)	PI	KI	MR	Ca:Mg
Winter	BW1 (Hari River)	218.000	2.914	8.417	36.407	105.148	52.479	2.606	46.048	83.132	131.388	83.559	4.863	81.222	0.231
	BW2 (Beel)	168.313	2.795	6.012	40.008	116.161	41.021	2.299	35.088	78.805	136.671	79.236	3.657	86.936	0.150
	BW3 (Beel)	208.087	2.965	6.814	31.207	125.169	39.896	3.605	47.726	84.735	145.117	85.323	5.473	82.079	0.218
	BW4 (GW)	32.478	0.423	3.207	2.401	7.020	2.538	5.998	19.397	85.439	8.289	91.708	5.792	42.816	1.336
	BW5 (GW)	20.478	0.042	7.916	7.202	23.533	9.404	6.298	7.448	57.579	28.235	64.580	1.355	47.637	1.099
Monsoon	BM1 (Beel)	15.534	0.043	2.105	2.401	11.017	2.948	3.605	10.349	77.563	12.491	86.991	3.448	53.283	0.877
	BM2 (GW)	14.870	0.038	3.407	2.500	10.989	1.840	6.899	8.652	71.619	11.908	84.210	2.517	42.327	1.363
	BM3 (GW)	16.087	0.043	2.105	2.798	11.017	2.292	6.801	10.274	76.687	12.163	89.064	3.281	57.070	0.752
	BM4 (GW)	21.087	0.064	3.608	2.607	11.045	1.224	10.800	11.962	77.290	11.657	89.273	3.393	41.954	1.384

Table 5.9: Water Quality Classes of Beel Bhaina Water for Agricultural Use

Parameter	**Rate of hazard**	**Water class**	**Sampling Sites**	
			Winter	**Monsoon**
pH	6.5–8.4	No problem	BW1-BW5	BM1-BM4
	5.1–6.4 and 8.5–9.5	Moderate	-	-
	0–5.0 and 9.5+	Severe	-	-
EC (dS/m)	<0.25	Excellent	-	-
	0.25-0.75	Good	-	-
	0.75-2.00	Permissible	-	BM1-BM3
	2.00-3.00	Doubtful	BW4	BM4
	>3.00	Unsuitable	BW1-BW3, BW5	-
TDS (mg/L)	<450	Good	-	-
	450-2000	Permissible	BW4, BW5	BM1-BM4
	>2000	Unsuitable	BW1-BW3, BW5	-
Cl^- (meq/L)	< 4	No problem	-	-
	4–10	Moderate	BW4	-
	> 10	Severe	BW1-BW3, BW5	BM1-BM4
Na^+ (meq/L	<3	No problem	-	-
	3-9	Moderate	-	-
	>9	Severe	BW1-BW5	BM1-BM4
NO_3-N (mg/L)	< 5	No problem	BW1, BW4, BM5	BM1-BM3
	5–30	Moderate	BW2, BW3	BM4
	> 30	Severe	-	-
	> 180	Very hard	-	-
Na%	< 20	Excellent	-	-
	20–40	Good	-	-
	40–60	Permissible	BW5	-
	60–80	Doubtful	BW2	BM1-BM4
	> 80	Unsuitable	BW1, BW3, BW4	-
SAR	<10	Excellent	BW5	BM2
	10-18	Good	-	BM1, BM3, BM4
	18-26	Doubtful	BW4	-
	>26	Unsuitable	BW1-BW3	-

5.5.2 East Beel Khuksia

pH:

Table 5.10 shows that all pH values of the sites KW1-KW5 and KM1-KM5 were within the tolerance range for irrigation in Bangladesh (BADC, 2007). Therefore, the available water sources in East Beel Khuksia are good for irrigation purposes (Table 5.12). In East Beel Khuksia, the lowest pH (6.66) was found in monsoon at site KM3 (Beel) and the highest pH (8.0) was measured in winter at site KW2 (Beel).

EC:

In East Beel Khuksia,the maximum (18.90 dS/m) and minimum (0.60 dS/m) values of EC were found at site KW1 (Hari River) and site KM4 (GW) (Table 5.10). The waters from Hari river and beel were 'unsuitable' for irrigation purposes in winter. The water samples collected in monsoon from the sites KM1-KM5 were categorized under 'good', 'permissible' and 'doubtful' classes (Table 5.12). In general, groundwater had better quality than river and beel water. This could be the reason for using groundwater for irrigation in this beel.

TDS and TSS:

The amount of TDS and TSS present in water determines the suitability of irrigation water. The lowest values of TDS and TSS were calculated in monsoon, 301 mg/L at site KM4 (GW) and 38 mg/L atsite KM5 (GW), respectively. The highest value of TDS was 9450 mg/L and TSS was 8679 mg/L, found at site KW1 (Hari River) in winter. According to Table 5.12, in terms of TDS, the water from Hari river and beel at sites KW1-KW3 were unsuitable, on the contrary the samples from the sites KM1 (Hari River), KM4 (GW) and KM5 (GW) were found to be good for irrigation use.

Cations:

Just like Beel Bhaina, the most dominant cation is found to be Na^+ in all sampling sites in East Beel Khuksia, both in monsoon and winter. As per the guidelines for specific ion toxicity (Table 5.12), the water from the sites KW1-KW4 in winter and the sites KM2, KM3 in monsoon fall under 'severe' class indicating the water is unsuitable for irrigation in terms of sodium toxicity. The remaining sites fell under 'moderate' class indicating some crops may show injury.

The available Ca^{2+} at all the sites in East Beel Khuksia was about 1.50-8.42 meq/L, which was within the permissible limit. Therefore, the sources of irrigation water were suitable for crop production considering Ca^{2+} (Table 5.11). The highest Mg^{2+} (30.4 meq/L) was found at site KW1 (Hari River) in winter, whereas the lowest Mg^{2+} (1.193 meq/L) was found at site KM4 (GW) in monsoon. The amount of Mg^{2+} in all the water sources was within the usual limit in East Beel Khuksia, except for the sites KW1-KW3 in winter (Table 5.11).

In East Beel Khuksia, the highest Ca: Mg ratio was measured as 2.35 at site KM4 (GW) in monsoon and the lowest ratio was recorded as 0.28 at site KW1 (Hari River) in winter (Table 5.11).

In winter, K^+ at all the sites were above the permissible limit (0-2 ppm), thus found unsuitable for irrigation. The amount of K^+ at sites KW3 (Beel) and KW5 (GW) in winter and at site KM5 (GW) in monsoon was found suitable for irrigation in East Beel Khuksia (Table 5.10).

The values of Na^+, K^+, Ca^{2+}, Mg^{2+} were higher in winter for river, beel, and GW sources than that of monsoon, except for Fe concentration, which was found to be the same (0.005 mg/L) at all sites in both the seasons. In monsoon, I found two GW sources containing minimum amount of cations than river and beel water. Therefore, the GW sources were suitable for agricultural purposes than the surface water sources in East Beel Khuksia.

Anions:

In East Beel Khuksia, the spatial and seasonal variations in anions were significant. High amount of Cl^- and SO_4^{2-} was present in winter season, apart from the site KM5 (GW). As per the guidelines for specific ion toxicity (Table 5.12), the water from the sites KW4, KW5, KM1 and KM4 fell under 'moderate' class indicating some crops may show injury considering Cl^-. The remaining sites fell under 'severe' class indicating that the water is not suitable for irrigation in terms of chloride toxicity, except for a 'no problem' site KM5 (GW).

From Table 5.11, in East Beel Khuksia the amount of SO_4^{2-} was within the permissible limit in monsoon, whereas water samples from the sites KW1 (Hari River) and KW2 (Beel) contained SO_4^{2-} exceeding the permissible range (0-20 meq/L) in winter. The value of bicarbonate at all the sites in East Beel Khuksia was found to be satisfactory in both seasons, except for at site KW4 (GW) in winter (Table 5.11).

Very low amount of NO_3^-, NO_2^- and PO_4^{3-} was present in the water samples compared to other available anions.The maximum and minimum NO_3^- were measured at site KM3 (Beel) and KM5 (GW) in monsoon, respectively (Table 5.10). According to ion toxicity guideline (Table 5.10), water from all the sources were suitable for irrigation in East Beel Khuksia, apart from the sites KM3 (Beel) and KW1 (Hari River) falling under 'moderate' class in terms of nitrate content. The highest value of PO_4^{3-} in East Beel Khuksia was 1.60 ppm in winter and the lowest value of PO_4^{3-} was 0.10 ppm in monsoon. Thewaters were within the permissible range, thus were suitable for agricultural purposes in both seasons regarding PO_4^{3-} (Table 5.10).

Sodium Adsorption Ratio (SAR):

The highest SAR value was measured as 58.77 at site KW2 (Beel) in winter and the lowest value was found to be 3.01 at site KM4 (GW) in monsoon. From Table 5.12, water from GW was classified as 'excellent' (KW4 and KW5) and water from river and beel were 'unsuitable' (KW1-KW3) for irrigation in winter. In monsoon, water from GW and river were 'excellent' whilst water from beel (KM2 and KM3) were 'good' for crop production.

Sodium Percentage (Na%):

The Na% of the samples from East Beel Khuksia ranges between 48.63 and 88.62. Considering Na% in water samples, in winter water from GW was classified 'permissible' (KW5) and 'doubtful' (KW4) whereas the water from river and beel were 'unsuitable' (KW1-KW3) (Table 5.12). Water samples from GW (KM4 and KM5) were categorized as 'permissible' whilst that from river and beel (KM1-KM3) were 'doubtful' and 'unsuitable' in monsoon for crop production.

Potential Salinity (PS):

In East Beel Khuksia, the PS of the water samples ranges from 0.73 meq/L to 7.35 meq/L. The minimum and maximum values were found at site KM4 (GW) and site KM2 (Beel) in monsoon, respectively. It suggests that the PS in all samples of the study area is low (<10 meq/L) in both seasons making the water suitable for irrigation usage (Table 5.11).

Permeability Index (PI):

In East Beel Khuksia, the PI values of water samples for both the seasons fell under the Class I and II categories and thus were good for irrigation purposes. The minimum PI value (69.28%) was measured at site KM5 (GW) in monsoon and the maximum value (89.13%) was found at site KW2 (Beel) in winter (Table 5.11).

Kelly's Index (KI):

In East Beel Khuksia, all the samples were unsuitable for irrigation in terms of KI, except for water at site KM5 (GW) where KI was calculated as 0.94 in monsoon (Table 5.11).

Magnesium Ratio (MR):

In East Beel Khuksia, the maximum value of MR was 78.32% at site KW1 (Hari River) in winter, whereas the minimum value was about 29.84% at KM4 (GW) in monsoon (Table 5.11). Generally, water from river and beel were unsuitable considering MR, thus GW was used for irrigation purposes in the beel.

Table 5.10: Water Quality Parameters in East Beel Khuksia

Season	Sampling Sites with Source	pH	EC (dS/m)	TDS (mg/L)	TSS (mg/L)	Fe^{2+} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	PO_4^{3-} (mg/L)	NO_3^{-} (mg/L)	NO_2^{-} (mg/L)	SO_4^{2-} (mg/L)	HCO_3^{-} (mg/L)	Cl^{-} (mg/L)
Winter	KW1 (Hari River)	7.28	18.90	9450	8679	0.005	4709	108.00	168.34	369.44	0.36	5.90	0.004	3010.26	171.0	4360.35
	KW2 (Beel)	8.00	15.48	7740	1223	0.005	5167	112.00	152.31	262.50	0.10	4.40	0.004	3011.75	159.0	4112.10
	KW3 (Beel)	7.34	4.12	2060	623	0.005	1738	1.82	120.24	72.92	0.70	4.00	0.004	945.69	159.0	709.00
	KW4 (GW)	7.18	1.66	831	224	0.005	290	2.31	52.10	38.88	0.34	0.40	0.004	113.00	677.0	301.00
	KW5 (GW)	7.41	1.11	548	218	0.005	183	1.47	58.10	30.38	0.37	0.35	0.004	113.00	360.0	177.25
Monsoon	KM1 (Hari River)	6.85	0.84	422	349	0.005	145	4.20	36.10	23.08	1.60	0.80	0.003	121.81	214.0	177.25
	KM2 (Beel)	7.26	2..09	1061	470	0.005	461	15.20	52.10	36.45	0.34	1.10	0.004	202.62	189.0	549.48
	KM3 (Beel)	6.66	2.18	1088	972	0.005	381	11.54	30.00	31.59	1.48	14.79	0.004	232.19	189.0	392.00
	KM4 (GW)	7.43	0.60	301	79	0.005	98	3.26	56.11	14.50	0.15	0.70	0.004	902.00	336.0	243.60
	KM5 (GW)	7.93	0.73	367	38	0.005	113	0.60	56.11	29.17	0.30	0.20	0.004	110.00	268.4	70.90

Table 5.11: Calculated Parameters to Evaluate Water Quality in East Beel Khuksia

Season	Sampling Sites with Source	Na^+ (meq/L)	K^+ (meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	Cl^- (meq/L)	SO_4^{2-} (meq/L)	HCO_3^- (meq/L)	SAR	%Na	PS (meq/L)	PI	KI	MR	Ca:Mg
Winter	KW1 (Hari River)	204.739	2.769	8.417	30.407	123.174	62.714	2.802	46.470	84.239	3.928	84.747	5.274	78.320	0.277
	KW2 (Beel)	224.652	2.872	7.616	21.605	116.161	62.745	2.606	58.774	88.619	3.703	89.126	7.688	73.938	0.352
	KW3 (Beel)	75.565	0.047	6.012	6.002	20.028	19.702	2.606	30.832	86.290	2.033	88.126	6.290	49.957	1.002
	KW4 (GW)	12.609	0.059	2.605	3.200	8.503	2.354	11.095	7.401	68.576	7.224	86.564	2.172	55.125	0.814
	KW5 (GW)	7.957	0.038	2.905	2.500	5.007	2.354	5.900	4.840	59.660	4.254	77.724	1.472	46.258	1.162
Monsoon	KM1 (Hari River)	6.304	0.108	1.805	1.900	5.007	2.538	3.507	4.632	63.381	3.946	81.698	1.702	51.277	0.950
	KM2 (Beel)	20.043	0.390	2.605	3.000	15.522	4.221	3.097	11.973	78.474	7.354	85.009	3.576	53.524	0.868
	KM3 (Beel)	16.565	0.296	1.500	2.600	11.073	4.837	3.097	11.570	80.440	4.578	88.676	4.040	63.415	0.577
	KM4 (GW)	4.261	0.084	2.806	1.193	6.881	18.792	5.506	3.013	52.071	0.732	79.995	1.066	29.843	2.351
	KM5 (GW)	4.913	0.015	2.806	2.401	2.003	2.292	4.399	3.045	48.629	1.748	69.276	0.944	46.114	1.169

Table 5.12: Water Quality Classes of East Beel Khuksia Water for Agricultural Use

Parameter	Rate of Hazard	Water Class	Sampling Sites	
			Winter	Monsoon
pH	6.5–8.4	No problem	KW1-KW5	KM1-KM5
	5.1–6.4 and 8.5–9.5	Moderate	-	-
	0–5.0 and 9.5+	Severe	-	-
EC (dS/m)	<0.25	Excellent	-	-
	0.25-0.75	Good	-	KM4, KM5
	0.75-2.00	Permissible	KW4, KW5	KM1
	2.00-3.00	Doubtful	-	KM2, KM3
	>3.00	Unsuitable	KW1-KW3	-
TDS (mg/L)	<450	Good	-	KM1, KM4, KM5
	450-2000	Permissible	KW4, KW5	KM2, KM3
	>2000	Unsuitable	KW1-KW3	-
Cl^- (meq/L)	< 4	No problem	-	KM5
	4–10	Moderate	KW4, KW5	KM1, KM4
	> 10	Severe	KW1-KW3	KM2, KM3
Na^+ (meq/L)	<3	No problem	-	-
	3-9	Moderate	KW5	KM1, KM4, KM5
	>9	Severe	KW1-KW4	KM2, KM3
NO_3-N (mg/L)	< 5	No problem	KW2-KW5	KM1, KM2, KM4, KM5
	5–30	Moderate	KW1	KM3
	> 30	Severe	-	-
	> 180	Very hard	-	-
Na%	< 20	Excellent	-	-
	20–40	Good	-	-
	40–60	Permissible	KW5	KM4, KM5
	60–80	Doubtful	KW4	KM1, KM2
	> 80	Unsuitable	KW1-KW3	KM3
SAR	<10	Excellent	KW4, KW5	KM1, KM4, KM5
	10-18	Good	-	KM2, KM3
	18-26	Doubtful	-	-
	>26	Unsuitable	KW1-KW3	-

5.5.3 Beel Pakhimara

pH:

In Beel Pakhimara, theminimum pH (6.83) was found in monsoon at site PM5 (Beel) and the maximum pH (7.98) was measured in winter at site PW2 (Beel). The pH values of the sites PM1-PM5 and PW1-PW4 were within the tolerance range for irrigation in Bangladesh (BADC, 2007). Therefore, the available water sources in Beel Pakhimara are suitable for irrigation purposes (Table 5.13).

EC:

In Beel Pakhimara, the highest (1.28 dS/m) and lowest (0.55 dS/m) EC was found at site PW4 (Beel) and site PM5 (Beel), respectively (Table 5.14). The water from the sites PW1-PW4 were 'permissible' for irrigation use, thus were suitable for crop production in winter. The water samples collected in monsoon from the sites PM1-PM5 were categorized under 'good' and 'permissible' classes (Table 5.15). Thus, the water quality in Beel Pakhimara was better than the other two beels.

TDS and TSS:

In Beel Pakhimara, the lowest values of TDS and TSS were 2276 mg/L at site PM5 (Beel) in monsoon and 110 mg/L at site PW4 (Beel) in winter, respectively. The highest value of TDS was 639 mg/L at site PW4 (Beel) and TSS was 1395 mg/L at site PM1 (Kobadak River). According to Table 5.15, in terms of TDS, the water collected in winter from the sites PW1-PW4 were 'permissible' for irrigation use, on the contrary the samples collected in monsoon from the sites PM1-PM5 were under 'good'class.

Cations:

The cations such as Na^+, Ca^{2+}, Mg^{2+}, K^+ and Fe^{2+} were measured to understand the suitability of irrigation water in Beel Pakhimara. Just like Beel Bhaina and East Beel Khuksia, in Beel Pakhimara the most dominant cation is found to be Na^+ almost in all the water samples, except for the sites PM3 and PW4 where dominant cation was Ca^{2+}. The highest Na^+ was 11.22 meq/L in winter and the lowest Na^+ was 1.05 meq/L in monsoon, for Beel Pakhimara. As per Table 5.15 considering Na toxicity, water samples collected in winter mostly fell under 'moderate' class.In monsoon, water samples from sites PM3 and PM5 were under 'no problem' category whereas samples from PM1, PM2 and PM4 were classified as 'moderate' in terms of sodium toxicity. Thus water was permissible in both the seasons for irrigation purposes except for the water from Kobadak River in winter considering Na^+.

The highest was (5.61 meq/L) and the lowest (1.61 meq/L) Ca^{2+} was found in winter in Beel Pakhimara. The available Ca^{2+} at all the sites irrespective of seasons was within the permissible limit (0-20 meq/L) in the beel, showing similar result as Beel Bhaina and East Beel Khuksia. Therefore, the sources of irrigation water were suitable for crop production (Table 5.14). The highest Mg^{2+} (3.19 meq/L) was found at sites PW3 (Beel) and PW4 (Beel) in winter, whereas the lowest Mg^{2+} (0.40 meq/L) was at site PM5 (Beel) in monsoon. Mg^{2+} of all the water samples was within the usual limit (0-5 meq/L) in Beel Pakhimara (Table 5.14), thus waters were suitable for irrigation usage. In Beel Pakhimara, the maximum Ca:Mg ratio was 5.50 at site PM1 in monsoon and the minimum value was recorded as 0.75 at site PW3 in winter (Table 5.14).

In Beel Pakhimara, The amount of K^+ at all the sites was above the permissible limit (0-2 ppm) in both monsoon and winter, thus found to be unsuitable for irrigation purposes (Table 5.13). Fe concentrations were found to be the same (0.005 mg/L) at all sites in both the seasons, except for the site PM5 (0.2 mg/L).

Anions:

In Beel Pakhimara, the spatial and seasonal variations in anions were significant. High amounts of Cl^- and HCO_3^- were present in winter than in monsoon. As per the guidelines for specific ion toxicity (Table 5.15), majority of the water samples in this area were under 'no problem' class indicating that the water is suitable for irrigation, apart from the sites PM1, PM3 and PW4 falling under 'moderate' indicating some crops may show injury in terms of chloride toxicity. The value of SO_4^{2-} and HCO_3^- were found to be satisfactory at all the sites in both seasons (Table 5.14).

Very low amount of NO_3^-, NO_2^- and PO_4^{3-} was present in the water samples compared to other available anions just like two other study areas. The maximum NO_3^- was found at site PM4 (Beel) in monsoon, whereas the minimum NO_3^- was found at PW3 (Beel) in winter (Table 5.14). The PO_4^{3-} of all the water samples was within the permissible limit (0-2 ppm) in both winter and monsoon monsoon, thus the water was suitable for agricultural purposes (Table 5.13). According to ion toxicity guideline (Table 5.15), water from all the sources was permissible for irrigation in Beel Pakhimara.

Sodium Adsorption Ratio (SAR):

In Beel Pakhimara, the maximum SAR value was measured at site PW1 (Kobadak River) in winter and the minimum value was found at site PM3 (Beel) in monsoon, the values were 8.36 and 0.69 respectively (Table 5.14). From Table 5.15, all the water samples were classified as 'excellent' for crop production.

Sodium Percentage (Na%):

The Na% of the samples from Beel Pakhimara ranges between 20.67 and 76.06. Thelowest value was found in monsoon at site PM3 (beel) and the highest value was found in winter at site PW1 (Kobadak River). Considering Na% in water samples, the samples from the sites PM3 (Beel) was classified 'good' in monsoon whereas the samples from the sites PW1 (Kobadak River) and PW2 (Beel) were categorized 'doubtful' in winter and others were under 'permissible' class (Table 5.15).

Potential Salinity (PS):

In Beel Pakhimara, the PS of the water samples ranges from 2.06 meq/L to 14.28 meq/L. Both the lowest and highest values were found at site PM1 (Beel) in monsoon and site PW4 (Beel) in winter, respectively. It suggests that the PS in almost all samples of the study area is low (<10 meq/L) in both seasons making the water suitable for irrigation usage (Table 5.14).

Permeability Index (PI):

In Beel Pakhimara, the PI values of water samples for both the seasons fell under the Class I and II categories and thus were good for irrigation use. The minimum PI value (53.95%) was measured at site PM3 in monsoon and the maximum value (86.36%) was found at site PW1 in monsoon (Table 5.14).

Kelly's Index (KI):

In Beel Pakhimara, The highest KI was 3.11 at site PW1 in winter and the lowest KI was 0.23 at site PM3 in monsoon. Almost all the samples were suitable (<1) for irrigation in terms of KI, except for the sites PM4, PW1 and PW2 (Table 5.14).

Magnesium Ratio (MR):

In Beel Pakhimara, maximum MR was around 57.04% at site PW3 (Beel) in winter, whereas the minimum MR was about 15.39% at site PM5 (Beel) in monsoon (Table 5.14). MR<50% means the soil would become less alkaline and suitable for crop yield. All the water samples were suitable for irrigation except for the samples collected from the sites PW1 and PW3.

Table 5.13: Water Quality Parameters in Beel Pakhimara

Season	Sampling Sites with Source	pH	EC (dS/m)	TDS (mg/L)	TSS (mg/L)	Fe^{2+} (mg/L)	Na^{+} (mg/L)	K^{+} (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	PO_4^{3-} (mg/L)	NO_3^- (mg/L)	NO_2^- (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)	Cl^- (mg/L)
Winter	PW1 (Kobadak River)	7.11	0.98	489	358	0.005	258.00	9.17	32.10	24.30	0.30	0.60	0.004	141.52	153.00	141.80
	PW2 (Beel)	7.98	1.11	552	382	0.005	120.00	10.00	40.10	14.58	0.30	0.52	0.004	153.00	146.40	177.25
	PW3 (Beel)	7.15	1.07	533	644	0.005	98.00	9.27	48.10	38.80	0.30	0.50	0.004	153.00	165.00	159.53
	PW4 (Beel)	7.10	1.28	639	110	0.005	100.00	10.60	112.22	38.80	0.70	1.68	0.007	142.00	695.40	453.18
Monsoon	PM1 (Kobadak River)	6.85	0.81	406	1395	0.200	70.66	4.80	52.10	20.66	1.50	1.39	0.004	34.26	378.00	145.35
	PM2 (Beel)	7.18	0.68	342	180	0.005	70.42	5.18	46.00	17.00	0.37	1.80	0.004	32.29	220.00	95.71
	PM3 (Beel)	7.08	0.77	388	316	0.005	24.20	5.77	52.10	24.30	0.07	1.30	0.003	153.00	244.00	177.25
	PM4 (Beel)	6.94	0.84	417	229	0.005	113.30	5.90	44.10	18.22	0.10	2.90	0.007	153.00	232.00	124.00
	PM5 (Beel)	6.83	0.55	276	741	0.005	50.14	3.76	44.00	4.86	0.96	0.79	0.004	24.40	195.20	63.81

* The Groundwater data was unavailable for Beel Pakhimara

Table 5.14: Calculated Parameters to Evaluate Water Quality in Beel Pakhimara

Season	Sampling Sites with Source	Na^+ (meq/L)	K^+ (meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	Cl^- (meq/L)	SO_4^{2-} (meq/L)	HCO_3^- (meq/L)	SAR	Na%	PS (meq/L)	PI	KI	MR	Ca:Mg
Winter	PW1 (Kobadak River)	11.217	0.235	1.605	2.000	4.006	2.948	2.507	8.355	76.058	5.480	86.362	3.112	55.479	0.803
	PW2 (Beel)	5.217	0.256	2.005	1.200	5.007	3.188	2.399	4.121	63.071	6.601	80.337	1.628	37.441	1.671
	PW3 (Beel)	4.261	0.238	2.405	3.193	4.506	3.188	2.704	2.547	44.554	6.100	59.895	0.761	57.041	0.753
	PW4 (Beel)	4.348	0.272	5.611	3.193	12.802	2.958	11.396	2.072	34.413	14.281	58.725	0.494	36.271	1.757
Monsoon	PM1 (Kobadak River)	3.072	0.123	2.605	1.700	4.106	0.714	6.195	2.094	42.600	4.463	75.378	0.714	39.495	1.532
	PM2 (Beel)	3.062	0.133	2.300	1.399	2.704	0.673	3.605	2.251	46.340	3.040	73.371	0.828	37.824	1.644
	PM3 (Beel)	1.052	0.148	2.605	2.000	5.007	3.188	3.999	0.693	20.674	6.601	53.946	0.228	43.431	1.303
	PM4 (Beel)	4.926	0.151	2.205	1.500	3.503	3.188	3.802	3.619	57.816	5.097	79.669	1.330	40.479	1.470
	PM5 (Beel)	2.180	0.096	2.200	0.400	1.803	0.508	3.199	1.912	46.682	2.057	83.024	0.838	15.385	5.500

Table 5.15: Water Quality Classes of Beel Pakhimara Water for Agricultural Use

Parameter	Rate of Hazard	Water Class	Sampling Sites	
			Winter	Monsoon
pH	6.5–8.4	No problem	PW1-PW4	PM1-PM5
	5.1–6.4 and 8.5–9.5	Moderate	-	-
	0–5.0 and 9.5+	Severe	-	-
EC (dS/m)	<0.25	Excellent	-	-
	0.25-0.75	Good	-	PM2, PM5
	0.75-2.0	Permissible	PW1-PW4	PM1, PM3, PM4
	2.0-3.0	Doubtful	-	-
	>3.0	Unsuitable	-	-
TDS (mg/L)	< 450	Good	-	PM1-PM5
	450-2000	Permissible	PW1-PW4	-
	> 2000	Unsuitable	-	-
Cl^- (meq/L)	< 4	No problem	-	PM2, PM4, PM5
	4–10	Moderate	PW1-PW3	PM1, PM3
	> 10	Severe	PW4	-
Na^+ (meq/L)	< 3	No problem	-	PM3, PM5
	3-9	Moderate	PW2-PW4	PM1, PM2, PM4
	> 9	Severe	PW1	-
NO_3-N (mg/L)	< 5	No problem	PW1-PW4	PM1-PM5
	5–30	Moderate	-	-
	> 30	Severe	-	-
	> 180	Very hard	-	-
Na%	< 20	Excellent	-	-
	20–40	Good	PW4	PM3
	40–60	Permissible	PW3	PM1, PM2, PM4, PM5
	60–80	Doubtful	PW1, PW2	-
	> 80	Unsuitable	-	-
SAR	< 10	Excellent	PW1-PW4	PM1-PM5
	10-18	Good	-	-
	18-26	Doubtful	-	-
	> 26	Unsuitable	-	-

5.6 Summary of Deposited Sediment and Water Quality of the Tidal Basins

In the study areas, soil EC was higher in winter than in monsoon. Among the three beels, the lowest soil salinity was found in East Beel Khuksia which may have resulted in good crop production. In the three beels, soil was slightly alkaline which is good for crop. OM is higher in monsoon than that of winter. The plant residues and organic manure used in crop production in winter may increase the OM in monsoon. The mineral particles of sand, silt & clay provide nutrients but the soil lacks fertility without OM holding the particles together and providing structure. Average OM content of the study areas was below 3% which means the soil condition is unfavorable for agricultural production because decrease in OM may cause decrease in nutrient holding capacity of the soil.

Sufficient amounts of Ca and Mg were present in the soil. Ca was dominant than Mg in soils of Beel Bhaina, East Beel Khuksia and Beel Pakhimara. The reason behind this is Mg^{2+} ions are not absorbed as strongly by clay and organic matter as Ca^{2+} ions in soil. Also, Mg^{2+} ions are more susceptible to leaching than Ca^{2+} ions.

Available Fe was found to be higher in monsoon than in winter in the three tidal basins. According to Srivastava and Srivastava (1993), salt affected soils are likely to increase the available Fe content under waterlogging conditions.

The available P in the beels was found to be medium to high. Among the three beels, the highest average P was found in East Beel Khuksia. The phosphate fertilizer applied for crop production could have resulted in the higher available P.

In Beel Bhaina and East Beel Khuksia, the amount of available S in soils was about medium to excessive and in Beel Pakhimara soil had excessive S content making it unsuitable for crop in both the seasons. The higher S content might be due to salinity, soil texture, fertilizer having higher zinc and phosphate. Soils having clayey and clay loam textures are believed to contain a higher amount of S than that of sand and sandy loam soils. Such variation is mainly due to the textural differences and also partly from the association of organic matter with clay colloids.

Among the three beels, I found Kobadak River and beel water was better in Beel Pakhimara than the other two beels. Considering EC, the Hari River water and beel water was unsuitable for agricultural purposes in Beel Bhaina and East Beel Khuksia, thus GW sources were used for crop cultivation. Na^{+} was the most dominant cation in water. The most dominant anion was Cl^- in Beel Bhaina and East Beel Khuksia whereas higher amount of HCO_3^- was present in Beel Pakhimara. In general, the rainfall dominated water had Na^+ and Cl^- as major ions; the weathering dominated water had high Ca^{2+} and HCO_3^- concentrations; and the evaporation or crystallization dominated water was characterized with high Na^+ and Cl^- (Meybeck. 2003; Gibbs, 1970). A study conducted in Khulna showed that salinity, total hardness and sodium percentage (Na %) of most of the ground water samples are not suitable for irrigation as well as drinking purposes and suggested that the brackish nature in most of the ground water is due to the seawater influence and hydrogeochemical processes (Bahar and Reza, 2010). The HCO_3^- dominance can be due to weathering from calcite parent materials and dissolution of limestone and dolomite. Very low amounts of PO_4^{3-}, NO_3^- and NO_2^- were present in the water samples compared to other available anions in the three basins.

5.7 Success of TRM and Its Impact on Soil, Water and Crop Yield

The perception of success of TRM operation is a complex issue. I chose three tidal basins- Beel Bhaina (successful), East Beel Khuksia (partially successful) and Beel Pakhimara (unsuccessful) to understand the impact of TRM operation on soil and water quality and crop yield. Beel Bhaina and East Beel Khuksia are situated in the upstream while Beel Pakhimara is far from these tidal basins and situated in the downstream. However, through laboratory analysis, I found that each of the beels shares some common properties in terms of sediment and water quality. With medium to high concentration of P and S, the deposited sediment contains excessive amount of Ca and Mg. The sediment is rich in other nutrients as well. The seasonal variation in nutrients and other parameters of water is significant; therefore, water in winter is unsuitable for crop production in the tidal basins except for Beel Pakhimara. In Beel Bhaina and East Beel Khuksia, severe sodium toxicity was present in water in both seasons, whilst water from Beel Pakhimara was categorized as ‘no problem’ and ‘moderate’ showing no sodium toxicity. In the three beels, water was categorized as ‘severe’ for Cl toxicity, indicating it ‘unsuitable’ for irrigation.

Although uniform sedimentation is yet to be achieved throughout the area, indeed, TRM has facilitated tremendous stride in crop production in the area. After discussing with local experts and farmers, I found that the major crop in the beels is boro rice and the yield has increased after TRM operations. The yield was higher in the three beels after TRM operation. The reason behind this would be soil containing high amount of Ca and Mg making them fertile for crop production. The change in yield of boro rice in the tidal basins is shown in Table 5.16.

Table 5.16: Change in Yield of Boro Rice in the Tidal Basins

Tidal Basin	Boro Rice Yield (ton/ha)	
	Before TRM Operation	After TRM Operation
Beel Bhaina	4.5	7.2
East Beel Khuksia	5.0	7.7
Beel Pakhimara	4.5	6.4

Undoubtedly, addressing the technical and operational aspects as well as the social conflicts among various local stakeholders like farmers, fishermen, landowners, and tenants, the government authorities (BWDB, DAE) can ensure a higher achievement of the TRM operations. In addition, coordination among different government agencies, water management associations, and local government institutions should be ensured to minimize the institutional conflicts in the study areas. Further, local expertise such as experienced farmers, elderly people, NGOs and water users' associations can play a significant role in ensuring a higher success of the TRM project.

CHAPTER SIX
SOCIO-ECONOMIC AND INSTITUTIONAL FACTORS FOR CROP DIVERSITY AND PRODUCTION

6.1 Introduction

The crop production and diversity depend on various physical, environmental, ecological, socio-economic, institutional and other factors present in a specific area. In this chapter I assessed the socio-economic and institutional factors that can affect crop production and crop diversity in relation to the success of TRM operations in the study area.

6.1.1 Access to Land

Access to land is governed through land tenure systems. Land tenure systems determine who can use what resources, for how long and considering what conditions, and are classified as private, communal, open access and state owned lands. The rights of access to land can be classified as- use rights, control rights, and transfer rights. In these polder areas, people are mostly farmers having small to large farmlands and a few of them are also landless. The landless people work as day laborer in the crop fields and ghers. People have good access to the communal and open access grazing lands in the selected areas. Mostly, when the TRM is in operation, the landless and landowning mass people remain deprived of availing aquatic resources, e.g., fish, from the beels as the corrupted and political elites of the community try to control people's access inside the beels. The land owners and local people should be allowed to collect the resources from the beel during TRM operation. Sometimes the large farmers and political elites influence the small and landless farmers to move against the TRM operation. Because of such action there was delay in TRM implementation in Beel Pakhimara. Sometimes they also initiate protests against the implementing authorities to stop the TRM operation. During TRM practice, the influential people try to establish ghers inside the beel area which hinder proper sediment deposition. After TRM operation, they sometimes force the small and tenant farmers to lease their lands to them for shrimp farming and thus the land for agriculture is lost.

6.1.2 Land Distribution in Terms of Ownership

Distribution of land ownership is considerably uniform in all the study beels. In this study, land holding has been classified into three broad groups: small (0.05 to 2.49 acres), medium (2.50 to 7.49 acres) and large (7.50 acres and above) in terms of ownership. Medium and large farmers usually take lease of land to increase their farm size, whereas small farmers lease their land to the medium and large investors and work as day labourers. In Beel Pakhimara, 72% of the surveyed farmers are small farmers, while 24% are medium farmers and only 4% are large farmers. In Beel Bhaina, the distribution of farmers is similar, with 60% being small farmers, 36% medium farmers and rest large farmers. However, in East Beel Khuksia, the situation is different with 48% of the surveyed farmers being small farmers, 40% being medium farmers and 12% being large farmers. East Beel Khuksia is distant from the locality compared to the other two beels. Thus, the land owners tend to lease their lands to medium or large farmers in this beel. The land distribution in terms of ownership in the three beels is shown in Figure 6.1.

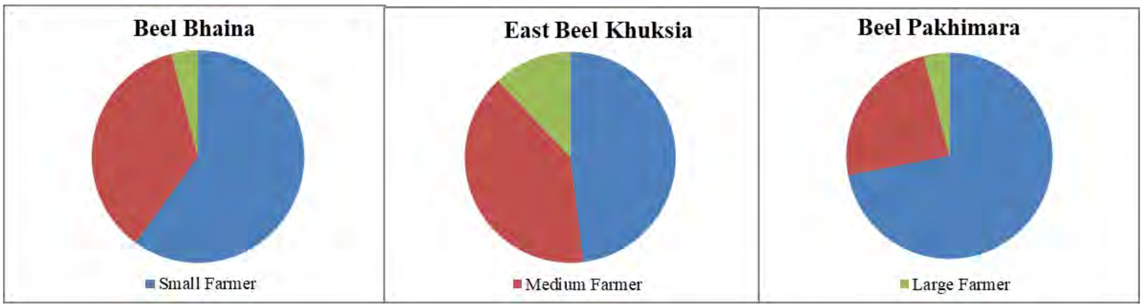

Figure 6.1: Land Distribution in Terms of Ownership in the Three Beels

6.1.3 Land Distribution in Terms of Investment

In this study, I have classified land distribution in terms of investment in three broad segments: small investor (2 lacs), medium investor (2-10 lacs), and large investor (more than 10 lacs). In Beel Bhaina, approximately 44% land is occupied by small investors while 40% and 16% are occupied by medium and large investors, respectively. However, In East Beel Khuksia, only 12% land is occupied under medium investment. Most of the land, about 75% is under large investment, while the rest 13% is occupied by small investors in this beel. In Beel Pakhimara, 60% land is in capture of small scale investors, while 35% and 5% are occupied by medium and large scale investors, respectively. In the areas where large scale investors dominate, there may be less diversity in crops grown, as their focus is primarily on a single crop that is economically profitable. The land distribution in terms of investment in the three beels is shown in Figure 6.2.

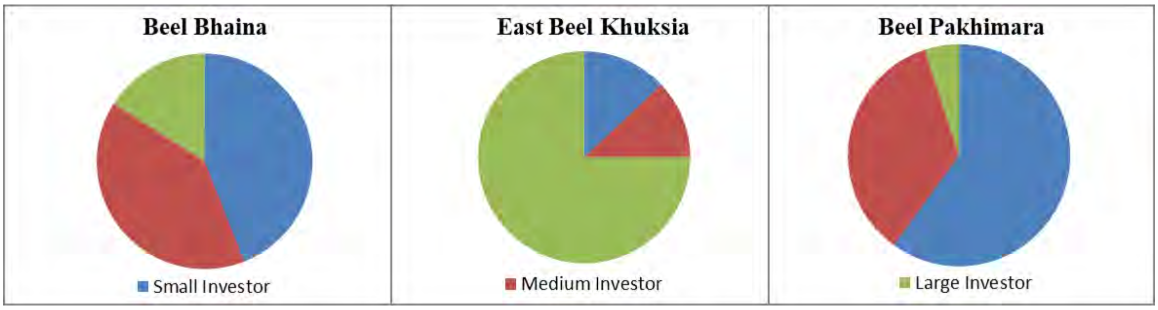

Figure 6.2: Land Distribution in Terms of Investment in the Three Beels

6.1.4 Literacy Level

The literacy level of farmers in the study areas can also have an impact on crop production and crop diversity. Out of the 75 farmers surveyed in the three beels, 45 (60%) had no formal education, 17 (23%) completed primary level education, and the remaining 13 (17%) completed secondary level education.

Low levels of literacy can limit farmers' ability to access information and knowledge about new agricultural techniques and technologies, as well as market information and trends. This can impact their ability to make informed decisions regarding crop selection, planting and management practices, and marketing strategies. This can result in a lack of diversity in crop production and reduced ability to adapt to changes in market demand or environmental conditions.

On the other hand, higher levels of education can increase farmers' access to information and knowledge, enabling them to make informed decisions about crop selection, planting and management practices. It is important for the government and other stakeholders to implement programs to increase the level of education and access to information among farmers in the area.

6.1.5 Access to Capital

Access to capital is a crucial factor in the success of agricultural operations including crop diversity and production. In the three coastal beels, mainly two types of financial institutions operate their activities: banks and macro finance institutions (NGOs). After discussing with local people, I found that large farmers and politically influential people have enough access to capital in the three basins. Very few farmers can opt for bank loans because proper documentation for their property is unavailable. A key informant reported that after 2012 in East Beel Khuksia, Bangladesh Krishi Bank is supporting small and medium farmers as well as tenant farmers with loans and microloans having flexible terms and conditions. The same scenarios can be observed in Beel Bhaina and Beel Pakhimara.

Among the surveyed farmers in the beels, 50 (60%) are members of NGOs and use them as a source of loan if necessary, while 10 (13%) have no access to either banks or NGOs. The preference of small farmers for NGOs over banks can be attributed to the procedural complexity of obtaining loans from banks. Very few farmers can opt for it because proper documentation for their property is unavailable. NGOs are usually perceived as more accessible and flexible in terms of loan requirements and procedures. This can increase the ability of small farmers to obtain capital for agricultural operations, enabling them to diversify their crop selection and increase crop production.

It is important for the government and the other stakeholders to provide increased access to capital and financial services to farmers in the selected beels to support sustainable and diverse crop production. The availability of credit can affect farmers' ability to invest in new crop varieties or technologies that may be more resilient to the impact of TRM operations.

6.1.6 Access to Market

The ability of farmers to sell their crops and access markets can affect their ability to adopt new crop varieties or technologies that may be more resilient to the impact of TRM operations. After field surveys, I found that the roads and infrastructures of Beel Bhaina and East Beel Khuksia are under-developed. Most of the roads are constructed with mud and brick, a few concrete made yet damaged roads were seen there. In case of Beel Pakhimara, roads, culverts and bridges were more developed than the other two study areas. The farmers expressed that in Beel Bhaina, before TRM, they faced market access problems due to poor transportation system, especially during monsoon the roads became unusable and thus they mostly were dependent on the riverine transport. After the TRM operation in 2002, new roads and culverts were constructed and varieties of transport modes were introduced and therefore it took less time and easy accessibility to various services was possible. Moreover, they get better market price of the products than previous time. In Beel Pakhimara, people sell their fish and crop products at two nearby markets, namely Dorhati Notun Bazar and Jethuar Bazar. In Beel Bhaina, farmers purchase and vend products at three markets; they are Verchi Bazar, Bharat Bhaina Bazar, Sholgatia Bazar. For vending agricultural and fisheries products, the farmers of East Beel Khuksia go to Kolagachi Bazar and Katakhali Bazar.

6.1.7 Competition in Agricultural Market

In the three tidal basins, the agricultural markets are competitive because there are many sellers and buyers existing in the markets and they are well informed about the price and quality of the products. As mentioned earlier, one of the reasons behind getting lower prices for their products before TRM operation in Beel Bhaina is the deterioration of the products during handling and transporting. In Beel Bhaina and East Beel Khuksia, currently prevailing competition in the markets is also due to crop types and varieties, production etc. All their goods are sold at the local markets. Only a few farmers can afford to bring their products to the nearby cities and Dhaka by their own pickup vans to compete in the national market.

6.1.8 Economic Return

The production practices in the three beels have significant implifications for the economic returns of farmers in this region. While shrimp production is considered more profitable than crop production, during boro season farmers tend to cultivate boro rice to ensure food security. The practice of rotating between shrimp and boro rice production can increase crop diversity and increase soil quality. This allows farmers to utilize the deposited sediment for crop production and helps minimize risks. The high profit margin from boro rice cultivation further provides an economic incentive for farmers to continue this practice. From Table 6.1, it can be seen that the profit margin is the highest in East Beel Khuksia among the beels. This may be due to the better soil quality (EC and OM) of East Beel Khuksia than the other two beels. Yearly economic return from boro rice production in the three beels is tabulated below (Table 6.1).

Table 6.1: Yearly Economic Return from Boro Rice Production in the Three Beels

Tidal Basin	Yield (Ton/ha)	Cost of Production (Tk/ha)	Revenue (Tk/ha)	Profit Margin (%)
Beel Bhaina	7.2		194000	53.6
East Beel Khuksia	7.7	90000	180000	50.0
Beel Pakhimara	6.4		160000	43.7

Further, the practice of cultivating vegetables on the embankment of the ghers during shrimp production can also increase crop diversity and improve economic return. By utilizing otherwise unused land for crop production, farmers can increase their overall crop yields and improve their economic return. While collecting sediment and water samples during winter, I observed the farmers cultivating boro rice, beans, pulses, brinjal, spinach, mustard, raddish, etc. in the Beel Bhaina. In the monsoon, I witnessed the cultivation of red amaranth, beans, string beans, okra and jute as well in the same area.

Moreover, I observed a somewhat similar farming scenario in the East Beel Khuksia. Farmers cultivate boro rice, plum, tomato, brinjal, malabar spinach, arum, bottle gourd, etc. in winter as well as cucumber, pumpkin, arum, etc. in monsoon.

On the other hand, during my study period, TRM operation was on development in the Beel Pakhimara area. Although no farming was seen during monsoon, I observed the farmers cultivating boro rice in the elevated lands in winter.

A key informant from East Beel Khuksia stated that during 2016-17, he cultivated plum and got about 2-3 lac taka in return. In Beel Bhaina and East Beel Khuksia, beans, tomato and cucumbers grew at a large scale and the farmers earned a good amount of money. Also, in Beel Pakhimara, the farmers seemed okay with the return they got from boro cultivation. According to the farmers and agricultural officers the production variation largely depends on the economic return potentiality of the crops.

I found that most of the soils in the study areas fell under clay, silty clay, silt loam and silty clay loam classes. Clay soil is suitable for paddy, cabbage, cauliflower, bean, pea, squash and pumpkin, whilst loamy soil is good for cultivating wheat, tomatoes, green beans, cucumbers, onions, radish, eggplant, spinach, etc. During sediment sample collection, I observed that beans, cucumbers and tomatoes grew in abundance in Beel Bhaina and East Beel Khuksia. If green beans and cucumbers are picked frequently, they tend to provide more yields. Also, tomatoes can be harvested 8-10 times in a year, which result in good economic return. From the above discussion, it can be concluded that the farmers were aware of the soil quality and chose the crops accordingly to improve their livelihoods.

By promoting a diverse range of agricultural practices and encouraging sustainable farming methods, it may be possible to increase the resilience of agricultural system and promote the crop diversity and economic return in this region.

6.1.9 Access to Extension Services

Agricultural extension includes the services designed to help rural people to increase access to latest agricultural practices. It includes the transfer of knowledge generated by agricultural research as well as other possible sources. Recently, government agricultural agencies like BRRI, BINA and BARI have introduced various flood and salt tolerant rice, maize and vegetable cultivars which are generally not available at the community level. Though saline tolerant varieties result in higher production and economic return, the seeds were not easily available in the local markets.

In the study areas, different stakeholders facilitate training and help farmers know the latest development in farming. The large holding farmers in East Beel Khuksia mentioned that they were given training under the project ‘National Agricultural Technology Project’ after completion of the TRM operation in 2012. The farmers from the Beel Bhaina stated that they used to get support from their upazila agriculture officer, agriculture extension officer, and block supervisors. The farmers from both of the beels further informed that occassionally training facilities are provided by the NGOs and other technology and fertilizer companies.

With increasing success of TRM operations, along with agricultural extension offices, other NGOs have increased their services in the study beels. However, for a number of reasons, still the small farmers hardly have regular communication with these service providers. Instead they depend largely on local expertise in making decisions regarding crop selection and other related agricultural practices. This study found that government offices and other NGOs do not have enough manpower to extend their network to an extent that includes a greater segment of farmers. They actually are connected with medium to large farmers.

In addition, the study found that the farmers believe that reaching the government services is difficult. For crop production and other agricultural practices, farmers seek advice from large investors and local retailers of agricultural products like seeds, fertilizers, pesticides etc. A number of reasons are behind such reluctance in seeking government services. Government extension offices do not have enough manpower to reach a greater segment of farmers. In addition, the ease of getting government services is yet to be increased. Further, local businesses try to have a hand in current production trends.

This dependence on a limited number of sources for information and decision making can limit the exposure of small farmers to new and innovative agricultural practices and technologies. This can result in minimal crop diversity and decreased crop production, as farmers may not be aware of the latest developments and may continue to use traditional and outdated practices.

To improve this situation, the government and NGOs should increase their outreach efforts to small farmers and provide them with information and training on new and innovative agricultural practices. They must ensure that the local people are constantly upgraded with the latest developments. Local organizations and farmers’ associations can also play a critical role in ensuring that the farmers have access to the information and support they need.

CHAPTER SEVEN
CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

Tidal River Management (TRM) is an eco-technological concept introduced to solve the waterlogging problem while ensuring sedimentation in the low-lying tidal basins and improving the environment. The study was designed to assess the variation in nutrients and quality of the deposited sediment and water of the selected tidal basins. The samples were collected from Beel Bhaina, East Beel Khuksia and Beel Pakhimara in the monsoon and winter seasons and laboratory analysis was done to obtain necessary data. The impact of TRM operation on crop production was assessed based on the information collected from the local people and experts who helped identify the socio-economic and institutional factors regarding crop diversity and yield. Based on the collected data, the analysis was done for the study areas and some conclusions were drawn.

7.2 Conclusions

7.2.1 Findings Regarding Deposited Sediment Composition and Quality

- The vertical profiling of soil texture in the three basins showed similar pattern having silty clay, silty loam and silty clay loam classes.

- The average organic matter (OM) content of the soils was 2.09%, 2.42%, and 2.35% in Beel Bhaina, East Beel Khuksia and Beel Pakhimara, respectively.The OM values were higher in monsoon than in winter for the three beels. East Beel Khuksia has the highest OM which may have resulted in better crop production.

- Generally, soil pH of the study areas was higher in winter than that of monsoon, classified as slightly alkaline. The average pH values were 7.72, 7.79 and 7.63 in winter and 7.56, 7.28 and 7.87 in monsoon, for Beel Bhaina, East Beel Khuksia and Beel Pakhimara, respectively.

- The soils were found to be slightly saline to extremely saline in Beel Bhaina.The average EC for Beel Bhaina was about 9.9 dS/m (very saline soil) in winter whereas it was 5.87 dS/m (moderately saline soil) in monsoon. In case of East Beel Khuksia, soils fell under non-saline to very saline classes. The average EC was found to be 6.23 dS/m in winter whereas 4.59 dS/m in monsoon, indicating moderately saline soil. For Beel Pakhimara, the soils were classified as slightly saline to very saline, having average EC of 10.99 dS/m in winter and 8.33 dS/m in monsoon.

- High amounts of Ca and Mg were present in the soils of the three basins, making them highly fertile for crop production.

- Significant seasonal variation in Fe content in soil was found in the three beels. In Beel Bhaina, East Beel Khuksia and Beel Pakhimara, the average Fe content was 94.68 ppm, 109.18 ppm and 185.70 ppm in winter whereas the values were 6.96 ppm, 21.97 ppm and 13.38 ppm in monsoon, respectively.

- In Beel Bhaina and Beel Pakhimara, available P was found to be medium to high in both monsoon and winter, having average values of 39.59 ppm and 36.96 ppm in winter, and 33.00 ppm and 37.64 ppm in monsoon, respectively. In East Beel Khuksia, available P at all the sites were found to be high in both monsoon and winter, having average values of about 44.11 ppm and 57.12 ppm in winter and monsoon, respectively.

- Generally, the S content at all the sites was higher in winter than in monsoon for the three basins. In Beel Bhaina, East Beel Khuksia and Beel Pakhimara, the average available S content was 441.79 ppm, 582.61 ppm and 754.28 ppm in winter whereas the values were 140.79 ppm, 193.08 ppm and 258.64 ppm in monsoon, respectively. In Beel Bhaina and East Beel Khuksia, the amount of S concentration was about medium to excessive. The soils of Beel Pakhimara were found to be unsuitable for crop production having excessive S content in both the seasons.

- The highest Cl content was found in monsoon in the tidal basins. In Beel Bhaina, East Beel Khuksia and Beel Pakhimara, the average available Cl was 1439.72 ppm, 1213.66 ppm and 2014.63 ppm in winter whereas the values were 1299.69 ppm, 1131.56 ppm and 1452.54 ppm in monsoon, respectively.

7.2.2 Findings Regarding Water Quality

- All the water sources from the three tidal basins were suitable for irrigation purpose in terms of pH.

- In winter, the water from all the sources was unsuitable for irrigation where Hari River in Beel Bhaina had the highest EC; in monsoon, all the sources had 'doubtful' EC for irrigation. In East Beel Khuksia, Hari River and beel were 'unsuitable' for irrigation purposes and GW was categorized as 'good' in winter and beel water had 'doubtful' EC in monsoon. In Beel Pakhimara, the beel and Kobadak River water were 'permissible' in monsoon and were 'good' and 'permissible' in winter considering EC values.

- The highest TDS and TSS were measured in winter in the three tidal basins, except for Beel Pakhimara having the highest TSS in monsoon. In Beel Bhaina, the water was categorized as 'permissible' and 'unsuitable' in winter and 'permissible' in monsoon considering TDS. In East Beel Khuksia, TDS was found to be 'permissible' and 'unsuitable' whilst in monsoon the sites fell under 'good' and 'permissible' categories in winter. In Beel Pakhimara, water was categorized as 'good' in winter and 'permissible' in monsoon considering available TDS. This may be the reason for higher crop production in East Beel Khuksia.

- Like Beel Bhaina and East Beel Khuksia, in Beel Pakhimara the most dominant cation was found to be Na^+ in almost all the water samples. In Beel Bhaina and East Beel Khuksia sodium toxicity was present in water in both the seasons. In Beel Bhaina, the water was categorized as 'severe' whilst in East Beel Khuksia the water was 'moderate' and 'severe' sodium toxicity. In Beel Pakhimara, the water was categorized as 'no problem' and 'moderate' showing no sodium toxicity.

- In Beel Bhaina, K^+ was 'unsuitable' for irrigation in winter and 'suitable' for irrigation in monsoon. In case of East Beel Khuksia and Beel Pakhimara, K^+ was 'unsuitable' for irrigation in both the seasons.

- The most dominant anion was Cl^- in Beel Bhaina and East Beel Khuksia whereas in Beel Pakhimara higher amount of HCO_3^- was present. The water from the three beels was categorized as 'severe' for Cl^- toxicity. The SO_4^{2-} and HCO_3^- were found to be 'satisfactory' for the study areas in both the seasons. Very low amount of NO_3^-, NO_2^- and PO_4^{3-} was present in the water samples compared to other available anions in the three basins.

- The SAR values of water were categorized as 'good' and 'excellent' in monsoon, whilst 'doubtful' and 'unsuitable' in winter in Beel Bhaina. Similar situation was observed in East Beel Khuksia. For Beel Pakhimara, all the SAR values fell under 'excellent' category for crop production in both seasons.

- The sodium percentage (Na%) of the water from Beel Bhaina was 'permissible' to 'unsuitable' in winter and 'doubtful' in monsoon. In East Beel Khuksia, the water was 'permissible' to 'unsuitable' both in winter and monsoon. In case of Beel Pakhimara, the waters were 'permissible' and 'doubtful' in winter and 'good' and 'permissible' in monsoon considering Na%.

- In both the seasons, water was 'suitable' in East Beel Khuksia and Beel Pakhimara considering potential salinity (PS). The water was 'unsuitable' in Beel Bhaina in both winter and monsoon.

7.2.3 Findings Regarding Socio-economic and Institutional Factors

- People have good access to land being mostly small and medium farmers, few of them were large farmers. The highest land holders were small farmers having 72% in Beel Pakhimara, 48% in East Beel Khuksia, and 60% in Beel Bhaina. Land holdings could not play any major role in cropping pattern.

- Similar scenarios regarding access to capital, access to market, and competition in agricultural markets were observed in the three beels.

- In Beel Bhaina, beans were found to be cultivated in almost every corner of the embankments in both the seasons, whereas tomato, plum and cucumber were cultivated at a large scale in East Beel Khuksia. The variation in land use and crop varieties was mainly due to suitability of water for irrigation, lack of awareness, market competition and economic return.

- The dominant cropping pattern in the three tidal basins was fish-fish-boro rice. The yields of boro rice were 7.2, 7.7 and 6.4 ton/ha in Beel Bhaina, East Beel Khuksia and Beel Pakhimara, respectively. Although people are getting higher crop yields, politically powerful and elites want to do fish farming to get higher economic return.

7.3 Recommendations

Based on the experience gained during the course of this study, the following recommendations are made:

- Since the deposited sediment and water quality in the study areas share some uncommon properties, further studies should be conducted on other TRM operational areas for having more comprehensive idea about the changes in sediment and water quality.

- Incessant investigation of spatial and seasonal changes in deposited sediment and water quality for a period of 2-3 years may indicate actual impact on seasonal crops.

- Analysis of some parameters, such as BOD, COD, B, As, Mo, Cd and Hg in water and Na, K, Cu, Cr, Cd, Mo and Hg in deposited sediment or soil should be included as it could lead to better understanding of the environmental qualities of the tidal basins.

- Government and NGOs should provide more extension services to the farmers of the tidal basins so that they can introduce new crop varieties and improve their livelihood and socio-economic conditions.

- With the help of achieved data regarding deposited sediment and water quality, experts should work more on HYV and salt tolerant crop varieties for the coastal areas. Moreover, farmers should be encouraged to cultivate them through training, field demonstration, exposure visits, etc.

- Unavailability of secondary data or limited primary data hampered the socio-economic and institutional analysis of this thesis work. Thus, extensive field work and questionnaire survey should be conducted to better understand the actual situation.

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