DEVELOPMENT OF A GIS BASED MODEL TO EXPLORE SAFE WATER OPTIONS IN SOUTHERN COASTAL REGION

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DECLARATION

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

Mohammad Abdul Karim Khan

6 June 2020

CERTIFICTION OF APPROVAL

The thesis titled **"Development of a GIS Based Model to Explore Safe Water Options in Southern Coastal Region"** submitted by **Mohammad Abdul Karim Khan**, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **Master of Science** in **Civil Engineering (Environment)** in **June 2020**.

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ABSTRACT

Safe water scarcity is one of the most leading crises in coastal Bangladesh. Salinity intrusion in both surface and groundwater is alarmingly augmenting and creating acute drinking water and safe water paucity. This study was conducted to examine the existing condition of safe water availability in Mongla Upazila (3rd level administrative zone) of southern coastal area of Bangladesh based on both quantitative and qualitative approaches. Spatio-temporal variation of both ground and surface water quality parameters (EC, TDS, Cl^-) was determined by the Inverse Distance Weighted (IDW) method of Deterministic model. IDW was proved to be effective to determine spatial variation of these parameters in Mongla. From the spatial distribution of EC, TDS and Cl^-, it was revealed that areas within the acceptable limits were very negligible and temporal variation depicted that areas with higher concentration of these parameters increased substantially within the last 10 years. For depicting the availability of safe water at each union (4th level administrative zone) of Mongla Upazila, ranking based comparative analysis was carried out. Unions were ranked based on both quantitative and qualitative factors. This study considered water quality parameters as quantitative factors; and no. of households covered by tube well/tap water, no. of functioning PSFs, no. of RWHS, no. of functioning RO, presences of community based adaptation options and NGO activities were the selected six qualitative factors. From the spatial distribution, each water quality parameters were classified into five classes and given a rank on a scale of 1 to 5, where 1 meant very low and 5 meant very high availability of safe water. Based on water quality parameters, only Suniltala union showed moderate status and others showed low safe water availability. On the other hand, unions were provided rankings for six qualitative factors, which were found from the insights of FGDs and KIIs. Burirdanga union and Paurashava showed high availability of safe water which was mostly because of their geographic location (near the Mongla port); and socio-economic conditions and good connectivity with nearby developed regions. Chila and Sundarban, being located in the southern part of Mongla showed low availability of safe water and others showed moderate safe water availability. To resolve the acuteness of fresh water scarcity, community based sustainable options should be introduced by maintaining the integration between local government, NGOs and other relevant stakeholders. A total of 150 households were randomly surveyed from Mongla Upazila. After analyzing their responses, a community-based model was designed to provide safe drinking water for 50 households, which could be implemented in any place. After conducting in-depth field visit, FGDs, KIIs and questionnaire survey it seemed that usage of Rainwater Harvesting System (RWHS) and Reserve Pond (RP) could be good solutions for combating water salinity problems in the study area. RWHS and RP are very convenient and economical to install and maintain that will supply safe drinking water in a sustainable way.

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List of Abbreviations

BWDB: Bangladesh Water Development Board

BMD: Bangladesh Meteorological Department

CEGIS: Centre for Environmental and Geographic Information Services

DPHE: Department of Public Health Engineering

EC: Electrical Conductivity

FGD: Focus Group Discussion

GIS: Geographical Information System

IDW: Inverse Distance Weighted

KII: Key Informants Interview

PRA: Participatory Rural Appraisal

PO: Personal Observation

PSF: Pond Sand Filter

RO: Reverse Osmosis

RP: Reserve Pond

RWHS: Rain Water Harvesting System

SSF: Slow Sand Filter

TDS: Total Dissolved Solids

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The availability of safe drinking water has become one of the most basic well-being and financial advancement issues of the current world. Water plays a very significant role in improving human welfare. As the population of the globe is increasing, the demand for safe water is also augmenting every single day. The dispersion, allotment, and management of water resource is a significant issue. Particularly, in many water-stressed portions of the world, a crucial role is played by it in social, financial and political strategies (Arsel and Spoor, 2009). A study conducted by United Nations depicts that approximately one-third of the globe's population live in areas where water shortage is a crucial issue and within these areas around 1.1 billion people have no access to safe drinking water (Shaw and Thaitakoo, 2010). Bangladesh is not only one of the most densely populated countries of the world but also it is one of the prominent polluted countries. Every year the population of Bangladesh is increasing and imposing tremendous pressure on its scarce area and resources. The country is striving hard to balance between the rising demands and its limited resources. Out of various limited resources in Bangladesh, perhaps water plays the most significant and unparalleled role. With the increasing population and rate of urbanization, the stress on water resources is increasing very fast (Abedin et al., 2014).

Water-related problems are very high and acute in Bangladesh especially in the coastal areas (Hasan et al., 2019). There is a multitude of water-related issues that are creating a huge crisis in the availability of safe water in the coastal Bangladesh and Mongla Upazila of Bagerhat is one of the most vulnerable coastal areas of Bangladesh. In the coastal areas of Bangladesh, the scarcity of drinking water is very prominent since the freshwater aquifers are not found at reasonable depths and the surface water is extremely saline and turbid (Islam et al., 2014). Coastal people are vulnerable in terms of their living condition and livelihood pattern, due to the combined effects of both natural and anthropogenic reasons. Some of the natural reasons are critical geographical location, complex hydrogeological state, sea-level rise, increasing frequency and magnitudes of natural calamities, extreme level of salinity intrusion etc. Moreover, some unwise and unplanned human activities like irregular flow control of water by the neighboring country, improper and inadequate monitoring of water qualities and associated factors by the local Governmental Organizations and Non-Governmental Organizations (NGOs), excess cultivation of shrimp, and lastly lack of appropriate and efficient adaptation strategies, have made the situation worse. Coastal water supply is mainly based on the groundwater sources as saline concentration is very high in surface water sources. In recent years, water supply in the coastal Bangladesh has been undergoing a multitude of significant problems, especially arsenic sullying, declination of the water table, salinity intrusion and lack of reasonable aquifers (PDO-ICZMP, 2004). Hence it is very important to conduct in-depth research in this area in order to identify the existing state of water salinity and available safe water options. Also, only identification of areas according to the state of water quality is not enough alone. Proper adaptation strategies based on the present condition of water should be planned considering the future increasing degree of vulnerability.

Climate Change plays a significant role in deteriorating the existing situation of water in Mongla Upazila by reducing access to available freshwater and agricultural resources as well (Rahman and Islam, 2018). As the sea-level rise and other extreme conditions of weather events are induced by climate change and these pose a great threat to coastal zones in terms of inundating the regions by saline water. Since salinity intrusion in both surface and groundwater gets increasing thus critically acute drinking water and safe water availability problems are created. Though Bangladesh has abundant water resources, currently the bitter truth depicts that the country is facing a huge crisis in the availability of safe water particularly in the coastal zones. Therefore, along with in-depth research in the coastal zones of Bangladesh, it is very important to search for safe water options through proper adaptation strategies to combat water-related problems in coastal Bangladesh.

1.2 Objectives of the Study

Following objectives were set for the study:

- To explore the Spatio-temporal variation of water quality of Mongla Upazila using Deterministic model
- To identify the safe water availability in Mongla Upazila by comparative analysis on GIS platform among the unions considering associated factors
- To propose a community-based model to facilitate safe drinking water availability

1.3 Scope of the Study

Searching for safe water options is extremely crucial challenge for engineers, scientists and other professionals. This study explores the present conditions of water quality parameters of both groundwater and surface water sources. Among the water quality parameters, salinity indicators Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Chloride (Cl^-) concentration are focused here. So before conducting any sort of study for implementing any adaptation plans in future this research work may help by providing some detailed analysis and results obtained from this study.

This study examines the applicability of the Inverse Distance Weighted (IDW) method of Deterministic model to represent the spatio-temporal variation of both ground and surface water salinity parameters. Researchers may validate their results using other GIS based models by comparing with this study.

This study also provides an overview of safe drinking water scarcity at the unions of Mongla Upazila and presents a comparison among the unions. It examines the current water quality conditions, community perceptions and adaptation measures for safe drinking water scarcity and local people's expectations to overcome the water crisis. Finally, it suggests a community-based adaptability action plan at the local level to combat drinking water scarcity.

1.4 Limitations of the Study

There are some limitations in this study which are given below:

- The secondary data obtained from different GOs and NGOs was not very recent. Collected data was for the year of 2010.
- Due to complex geographical location and safety issues, accessibility to some places were very limited.

1.5 Thesis Structure

The structure of the thesis report is briefly mentioned below:

Chapter 1 of the book describes the background, objectives, scope and limitations of the study.

The literature review along with some relevant studies are elaborately described in Chapter 2.

Chapter 3 contains the description of the study area and detail of methodological approach including the data collection and analysis process.

Chapter 4 presents the outcomes of the deterministic model, comparative analysis done by GIS and contains the results regarding safe water availability in Mongla Upazila.

Chapter 5 contains the detail of the proposed community-based adaptation model.

Finally, Chapter 6 contains the summary of findings and conclusions with some recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter summarizes the reviewed literatures. Drinking and irrigation water scarcity scenarios in coastal areas of Bangladesh, especially in Mongla Upazila are discussed here. Health problems due to water salinity are also pointed out in this chapter. Moreover, some literatures focused on different types of GIS based model to explore spatial variation of water quality parameters, are also encapsulated.

2.2 Drinking Water Scarcity in Mongla

Drinking water scarcity is the most prominent problem in all the six unions of Mongla Upazila. People residing in Mongla Upazila are facing great threat due to lack of safe drinking water as because the intrusion of saline water is highly seasonal in Bangladesh (Abedin and Shaw, 2018). Drinking water sources in the coastal areas are getting contaminated at an alarming rate as long-term salinization augments the contamination risks in the coastal aquifers (Rakib et al., 2019). WHO (2004) found that the groundwater was highly inadmissible for human consumption due to high salinity in the southwestern region of the country especially in Khulna and Bagerhat district. In addition, Ali (2006) reported that, saline water intrusion caused a serious issue in terms of severely declining the supply of potable water. The quality of groundwater is greatly influenced during the months of January, March and May because of continuous decline in the head of both surface and groundwater (Mirza and Sarker, 2004). A large section of population is often exposed to various diarrheal diseases as they are not served by treated water. Shrimp farming has become a prominent industry in Bangladesh and increased salinity has created convenient environment for cultivation of shrimp (Haque et al., 2008). In the majority of the cases, saltwater from the water body is injected into the wetlands for the purpose of shrimp cultivation, and consequently, it leads to an augmentation of salinity of the engulfing water bodies and aquifers by seepage which leads to increase in drinking water scarcity in the region. Since majority of the population are poor and their income is lower than the GNI (Gross National Income), it becomes almost impossible for the people to afford fresh water from other sources. As the literacy rate is very low along with low income so these people are more hyper-sensitized. Because of a multitude of natural hazards like cyclone, sea-level rise, land erosion, flood etc., an influx of seawater into groundwater occurs and freshwater sources are turning into the saline water. Combination of financial insolvency along with lack of skilled manpower has made this Upazila extremely vulnerable to scarcity of safe drinking water.

Again the water which is being used by them for drinking purpose is not suitable for drinking in majority of the areas. A believe that persists in many participants is that their body has already adapted to saline water since they have been using the water for many years. People have developed both individual and community level adaptation strategies along with some institutional strategies as well but unfortunately it is becoming increasingly difficult to maintain those. Again PSF, RO and other technical solutions are also failing to combat the salinity problem in Mongla Upazila. Since economic conditions of people are poor in Mongla and majority of the people do not have tertiary education and skilled manpower, so PSF and RO systems are unsuitable for them. Thus, it is extremely important to identify the locations where water scarcity is high and develop sustainable means of using RWH and RP. Islam (2015) also reported that the rainwater harvesting system (RWHS) is an important innovative livelihood option for safe drinking water in the exposed salinity-prone coastal area. Both surface and groundwater have been polluted by saline in this area. For this, rainwater is the most suitable for meeting drinking water needs.

2.3 Water Scarcity for Irrigation in Mongla

The expansion of irrigation to meet growing demands is a major source of freshwater consumption. The key reasons behind freshwater scarcity are population growth, expansion of the industrial sector, water use in energy development, inter-annual climate variability, and climate change (Murshed and Kaluarachchi, 2018). Freshwater scarcity is a serious issue in the lower Ganges Basin known as the Ganges Delta of Bangladesh. Due to the absence of freshwater, irrigation activities got seriously hampered. The primary occupation of the coastal people is basically agriculture, which is one of the most disaster-affected sectors. Salinity is said to be the salient factor of crop production and 36.8% of arable lands in the coastal and off-shore area are seriously affected by varying degrees of salinity (Asib, 2011). Due to salinity intrusion and irrigation with saline groundwater, agricultural lands have lost their productivity which results in decline of net food production (Islam et al., 2012; SRDI, 2010). Researches have shown that salinity intrusion has significant negative impacts on the livelihood strategy of the local farmers and on crop production and yield (Baten et al., 2015; Haider and Hossain, 2013).

Shrimp farming has been increased drastically over the past two decades by essentially changing the local land use which adversely influencing the surface and groundwater resources (Datta et al., 2010). Agriculture contributes about 30% of the GDP in Bangladesh. However, the agricultural production is heavily dependent on irrigation, which in turn depends on the availability of water. The availability of water has been affected by the global environmental changes in the region since water flows are controlled by tri-state, Bangladesh, India and Nepal. It has been observed that out of total available water, agriculture alone withdraws 86% in which 73% comes from groundwater and the rest 27% from surface water sources in Bangladesh. In the case of total irrigated area, surface water covers 31% and groundwater covers 69% of irrigated area. Higher saline concentration in the surface water creates the scarcity of irrigation water and farmers are bound to irrigate their lands with saline water, resulting in less yield and higher production cost for affording freshwater and using gypsum to combat salinity problem (Baten et al., 2015; Islam et al., 2012; Khanom, 2016; Khanom and Salehin, 2012). Due to surface water contamination, people tend to use more and more groundwater for irrigation and drinking purpose, which exerts tremendous pressure on the groundwater source. Economic loss in terms of crop yield loss, loss in industrial production for using saline water to cool condenser or to keep turbine running, destructions of tree species and loss of soil fertility and productivity are the consequences of higher saline concentration in surface water (Basar, 2012; Baten et al., 2015; Khanom, 2016; Khanom and Salehin, 2012). There are certain techniques that can be applied to combat salinity by applying gypsum, manuring and composting, retention irrigation, multi-cropping/intercropping, changing irrigation techniques for conserving water and low water consuming cropping pattern (Ferdous et al., 2019).

2.4 Health Risk due to Water Salinity

Saline concentration in water sources has serious implications on human health and livestock if it is used for drinking purposes (Baten et al., 2015; Khan et al., 2011; Nahian et al., 2018). Khanom and Salehin (2012) identified that saline water consumption might cause diarrhea, fever, high blood pressure, gastric problem, skin problem, etc. It can also cause an increased rate of preeclampsia and gestational hypertension in pregnant women (Baten et al., 2015; Khan et al., 2011; Vineis et al., 2011). Saline water may also have connections with a kidney stone and Rheumatism (Baten et al., 2015). Nahian et al. (2018) found that both prehypertension and hypertension were significantly associated with drinking saline water. They found that women had a higher chance of being hypertensive than man and respondents aged 35 years and above were more likely to be hypertensive compared to below 35 years' age group (Nahian et al., 2018). The livestock sector is also affected by the salinity problem. The scarcity of freshwater has a significant impact on domestic cattle as it may cause deterioration of milk production and reproductive health (Baten et al., 2015).

2.5 Application of IDW to Explore Spatial Distribution of Water Quality Parameters

Availability of fresh water options can be assessed through examining the water quality parameters of both surface and groundwater sources. As it is very time consuming and costly to test samples from all the water sources, GIS based interpolation techniques is an effective way out. Both Geo-statistical and Deterministic models of interpolation have been proved to be efficient to predict unmeasured values from measured ones. Among the models, Inverse Distance Weighted (IDW) method of Deterministic model is also proven capable to predict unmeasured values.

Exploring spatial distribution of water quality parameters is an effective application of GIS based interpolation models, which has been employed by several researchers. Sumiya and Khatun (2016) used IDW to study the changing pattern of groundwater level in Bangladesh. Moghaddam et al. (2017) employed IDW to identify the spatial variation of groundwater quality parameters in Gonabad Plain, Iran and reported that IDW can predict spatial variation with lower error than other models. Geo-statistical methods are one of the most advanced techniques for the interpolation of groundwater quality. Therefore, study by geographic information system ArcGIS and GS^+, deterministic interpolation methods such as Inverse Distance Weighting (IDW), Global Polynomial Interpolation (GPI), and Local Polynomial Interpolation (LPI), with power ranging from 1 to 5, as well as Geo-statistical interpolation methods such as OK, SK, and UK, with exponential and rational Quadratic models, were used for studying the spatial distribution of water quality parameters such as Cl, EC, TDS, and anion. Then, based on cross-validation criteria such as MRE, RMSE, and R, the best interpolation method was selected. The results showed that the IDW method, with the powers of 3 and 4, had the lowest error and the most correlation compared to the GPI, LPI, OK, SK, and UK methods. Finally, the zoning maps and spatial distribution for the studied parameters were prepared based on the best interpolation method.

Jha et al. (2010) used IDW for interpolating water quality parameters of Port Blair Bay, Andaman and found that IDW method showed better matching between the measured and interpolated values. The surface water parameters like temperature, salinity, conductivity, dissolved oxygen, pH and turbidity of Port Blair bay, Andaman & Nicobar Islands were measured in situ over 104 sampling points using a digital multi-parameter water quality instrument and a Global Positioning System (GPS) during high tide. These parameters were subsequently interpolated over the entire bay using three methods, viz., Inverse Distance Weighted (IDW), Spline and Kriging. The interpolated values over the sampling points were compared with the corresponding measured values by means of three statistical indices: Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Index of Agreement. It was found that among the three interpolation methods, the IDW method showed better matching between the measured and interpolated values for four out of six parameters whereas the Kriging method showed better results for the remaining two parameters with lower MAE and RMSE values, and higher values of 'd'. That study described the details of interpolation methods and suitability to assess water quality parameters in the bay. In addition, it also highlighted the capability of GIS as a tool to model spatial changes in environmental systems.

Ogbozife et al. (2018) also worked on IDW model to assess and map the water quality of Kaduna river, Nigeria. Sapna et al. (2018) determined the spatial variation of river water quality parameters of Noyyal watershed of India using IDW. Spatial variations of various surface water quality parameters were studied using the Geographical Information System (GIS). Spatial interpolation methods are frequently used to estimate the values of physical or chemical constituents in locations where they are not measured. The study used water quality data from the Noyyal watershed and employed spatial interpolation technique, inverse distance weighting that incorporated output from a process-based water quality model.

Adhikary and Dash (2017) compared deterministic model and Geo-statistical models and found that IDW was capable of predicting spatial variation of groundwater depth more than 77% correctly. Javari (2016) modeled the spatial distribution of precipitation in Iran using IDW. Pre- and post-monsoon groundwater level data for the year 2006 from 110 different locations over Delhi were used. This paper presented a comparison of stochastic (OK, UK) and deterministic (IDW, RBF) interpolation methods for groundwater level prediction. The cross-validation measures were used to compare various interpolation methods. In Delhi, IDW, RBF, OK, and UK interpolation methods satisfactorily predicted the spatial variation of water table depth for both the seasons.

2.6 Application of GIS based Model in Bangladesh for Determining Spatial Distribution of Water Quality Parameters

Some researchers worked on interpolation models focusing on Bangladesh. Bhuiyan et al. (2016) used Geo-statistical model to analyze the spatial variation of groundwater quality in Lakshimpur district. They employed Ordinary Kriging and Semi-variogram models to interpolate the water quality parameters. A total of 70 groundwater samples were collected from wells (shallow to deep wells, i.e., 10–375 m) from the study area. Groundwater quality index revealed that 50 % of the water samples belong to good-quality water. The degrees of contamination, heavy metal pollution index, and heavy metal evaluation index presented diversified results in samples even though they showed significant correlations among them. The results of principal component analysis (PCA) showed that groundwater quality in the study area was mainly influenced by geogenic (weathering and geochemical alteration of source rock) sources followed by anthropogenic source (agrogenic, domestic sewage, etc.). Cluster analysis and correlation matrix also supported the results of PCA. The Gaussian semi-variogram models were tested as the best fit models for most of the water quality indices and PCA components. The results of semi-variogram models showed that most of the variables had weak spatial dependence, indicating agricultural and residential/domestic influences. The spatial distribution maps of water quality parameters provided a useful and robust visual tool for decision-makers toward defining adaptive measures. This study was an implication to show the multiple approaches for quality assessment and spatial variability of groundwater as an effort toward a more effective groundwater quality management.

Islam et al. (2018) also used Ordinary Kriging and Semi-variogram models to study the spatial variation of groundwater irrigation water in south-central Bangladesh. Bodrud-

Doza et al. (2016) determined the spatial distribution of groundwater quality parameters by exponential semi-variogram model in central Bangladesh. This study investigated the groundwater quality in the Faridpur district of central Bangladesh based on preselected 60 sample points. Water evaluation indices and a number of statistical approaches such as multivariate statistics and Geo-statistics were applied to characterize water quality, which was a major factor for controlling the groundwater quality in terms of drinking purposes. The study revealed that EC, TDS, Ca^{2+}, total As and Fe values of groundwater samples exceeded Bangladesh and WHO standards. Groundwater quality index (GWQI) exhibited that about 47% of the samples were belonging to good quality water for drinking purposes. The heavy metal pollution index (HPI), degree of contamination (Cd), heavy metal evaluation index (HEI) revealed that most of the samples belonged to a low level of pollution. However, Cd provided a better alternative than other indices. Principle Component Analysis (PCA) suggested that groundwater quality was mainly related to geogenic (rock–water interaction) and anthropogenic source (acrogenic and domestic sewage) in the study area. Subsequently, the findings of cluster analysis (CA) and correlation matrix (CM) were also consistent with the PCA results. The spatial distributions of groundwater quality parameters were determined by Geo-statistical modeling. The exponential semi-variogram model was validated as the best-fitted model for most of the index's values. It was expected that the outcomes of the study will provide insights for decision-makers taking proper measures for groundwater quality management in central Bangladesh.

Rahman et al. (2017a) studied the Ordinary Kriging and Semi-variogram models to interpolate groundwater quality of Gopalganj, Bangladesh. Rahman et al. (2017b) used Inverse Distance Weighted (IDW) model to represent the spatial variation of water quality in Satkhira region. This study investigated selected water quality parameters (EC, TDS and Cl^-), local people's perception of drinking water scarcity and how local people cope with safe drinking water scarcity. This research was conducted using local water samples, a questionnaire survey of 200 households and 4 focus group discussions (FDGs) in Shyamnagar and Tala sub-district of the Satkhira district. The average values of total dissolved solids (TDS), electrical conductivity (EC) and Chloride concentration ($Cl-$) were found 4044.12 mg/L, 7186.7 μS/cm, and 3143.6 mg/L respectively in Shyamnagar and 2313.60 mg/L, 4390.3 μS/cm, and 1402.1 mg/L respectively in Tala. The result of community perception revealed that local people were aware of the safe water scarcity and nearly all of them perceived that salinity was the main reason behind it. Even though there were a number of socio-economic factors, communities had their own adaptation technologies to cope with the problem. The study concluded with the development of a community-based model defining the key responsibilities of the stakeholders, including local and central government, NGOs and community people to work in a well-coordinated manner which might be effective for reducing the scarcity of safe drinking water.

Hussain et al. (2016) employed Ordinary Kringing and empirical Bayesian Kringing method to study the temporal and spatial variation of groundwater level in Mymensingh district. Spatiotemporal analysis of groundwater level fluctuations of 32 piezometric wells using Geo-statistical analysis was done for Mymensingh district. A total of nine years of weekly groundwater level data were used for the analysis. The semivariogram models called spherical, exponential and Gaussian models were fitted with the experimental semivariogram in ordinary kriging while semivariogram fitting is automatic in EBK. Model performances were tested using root mean square standardized error (RMSSE), root mean square error (RMSE) and average standard error (ASE). The cross-validation results indicated that EBK performed better compared to ordinary kriging in representing the spatial groundwater level fluctuation in the study area. The Geo-statistical analysis result showed that Phulbaria, Trisal, Muktagachha, Bhaluka, Gafargaon, and Mymensingh Sadar Upazila are comparatively more vulnerable than other parts of the district in terms of water scarcity.

2.7 Summary

Very few previous studies included both surface and ground water sources for exploring safe water options. Current study has examined the applicability of Inverse Distance Weighted (IDW) model to represent spatio-temporal variation of both ground and surface water quality parameters. There are only a few studies that have focused on severe water stressed regions and hardly any research that focused particularly on Mongla. This study has provided an overview of safe drinking water scarcity caused by salinity at the unions of Mongla Upazila. It has examined the current water quality conditions, community perceptions and adaptation measures for safe drinking water scarcity, the local people's expectations to overcome the water crises. This study has analyzed the rainfall pattern on Mongla and performs test on rainwater samples to evaluate the applicability of RWHS. It has also suggested a community based adaptability action plan at the local level to combat drinking water scarcity.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter has included the detailing of comprehensive research methodology including data collection and data analysis of the study, which has facilitated the completion of overall objectives. Study area has also been detailed in this chapter.

3.2 Study Area

Mongla Upazila of Bagerhat district, Khulna Division is one of the exposed-coast Upazilas among 44 Upazilas (Ministry of Water Resources, 2005). It is bounded by Rampal Upazila on the north, and the Bay of Bengal on the south (Fig. 3.1). Mongla Upazila is the largest among other Upazilas in Bagerhat District. The total area of the Upazila is 1461.22 sq. km. Area of Chandpai range (portion of the Sundarbans) is 1274.31 sq. km which is 87.2% of total Mongla Upazila. The Upazila is situated in the bank of Pasur river and the opposite side of the Sundarbans. There are 6 unions and a Paurashava in Mongla Upazila. Unions are named as Burirdanga, Chandpi, Chila, Mithakhali, Suniltala and Sundarban (Banglapedia, 2015).

The majority of the people (36.31%) in the study area depend on agriculture for their livelihood. People get drinking water from various sources, such as tube well (74.11%), tap (15.10%), pond (6.93%) and others (3.86%) (Banglapedia, 2015). Water-related problems are particularly acute in Mongla. As population growth and urbanization rates in Mongla rise rapidly, stress on the region's water resources is intensifying. The coastal zones of Khulna are highly vulnerable and one of the most serious issues in the coastal communities is increasing of salinity in water (Shammi et al., 2019). On the other hand, being a part of exposed coast, Mongla is very susceptible to cyclone and storm surge. Past cyclonic events (e.g. Sidr, Aila) caused damages to their houses and crops, increased their sufferings which made them poor/ultra-poor. Long term inundation by saline water caused more salinity intrusion and fresh water scarcity.

3.3 Methodological Approach

This study is an outcome of both qualitative and quantitative approaches and employed data were collected from both primary and secondary sources. Detail of data collection and data processing are given in following sections.

3.3.1 Primary Data Collection

In 2017, a reconnaissance survey was conducted to gather overview of the study area, which helped to finalize the methodological approach. In July 2019, another field visit was carried out to collect primary data from all the unions and Paurashava of Mongla Upazila. During field visit, water samples were collected from both groundwater and surface water sources. Tools of Participatory Rural Appraisal (PRA) such as Focus group discussion (FGD) and Key informant interview (KII) and Personal Observation (PO) were also used for qualitative data collection. In December 2019, some rainwater samples were collected from different types of storage in Mongla Upazila.

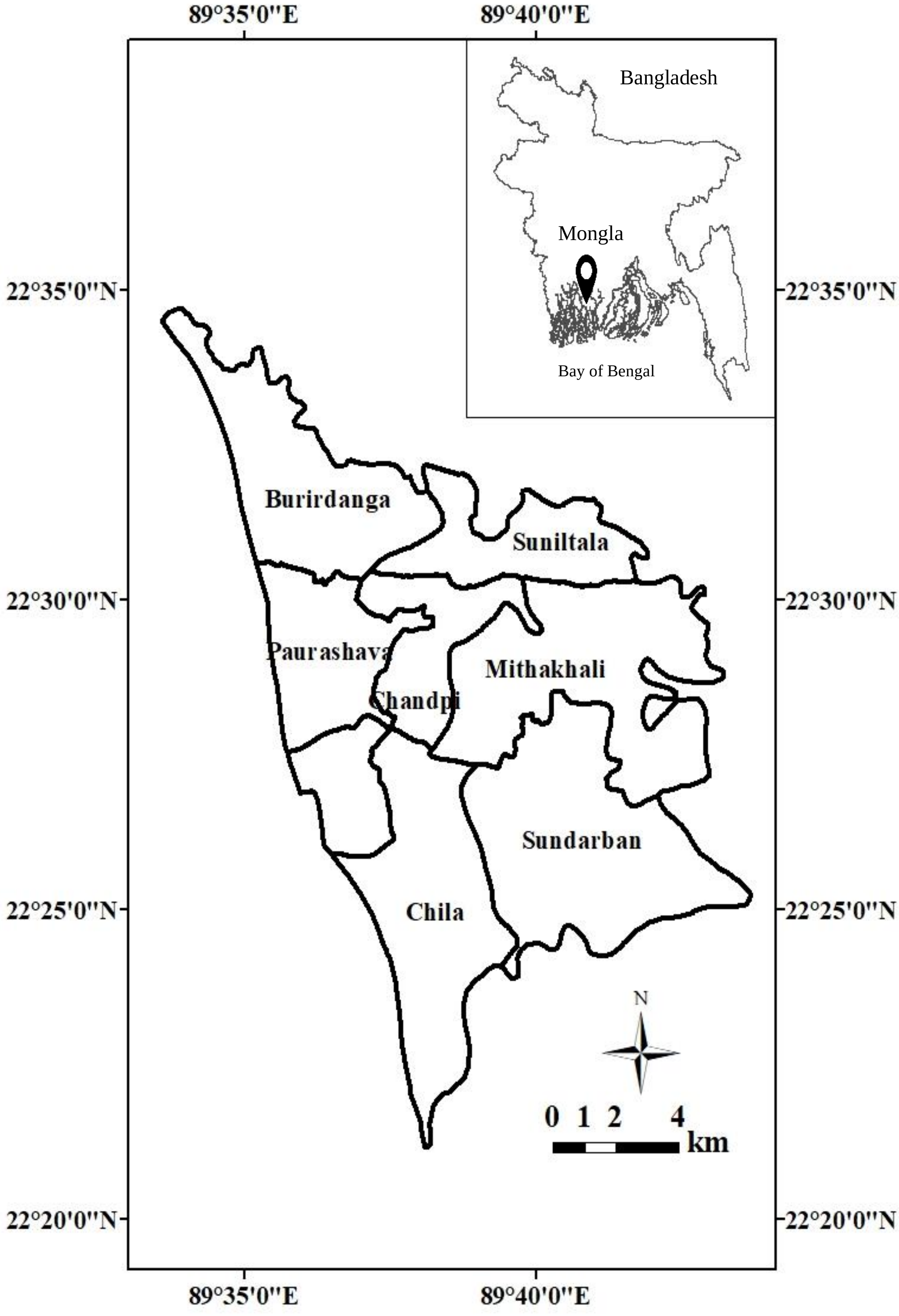


Fig. 3.1. Study Area Location (Mongla Upazila of Bagerhat District)

3.3.1.1 Water sample collection and testing

A total of 37 samples were collected randomly from groundwater and surface water sources within the short time of field visit during July of 2019 (Fig. 3.2). 17 samples were from surface water sources – rivers, ponds, shrimp gher etc. and remaining 20 samples were taken from groundwater sources (Fig. 3.3 and Fig. 3.4).

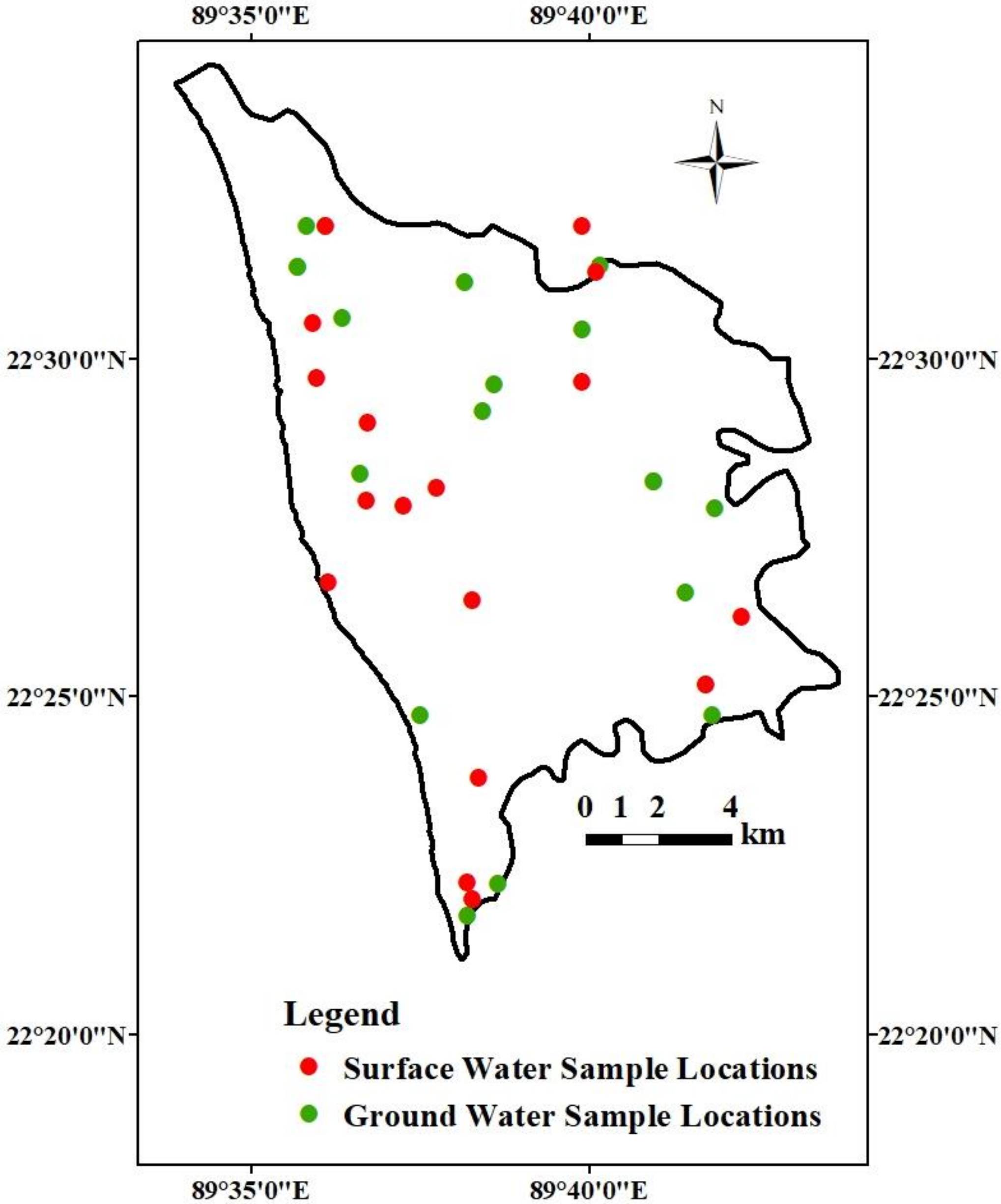


Fig. 3.2. Sample collection locations in Mongla Upazila

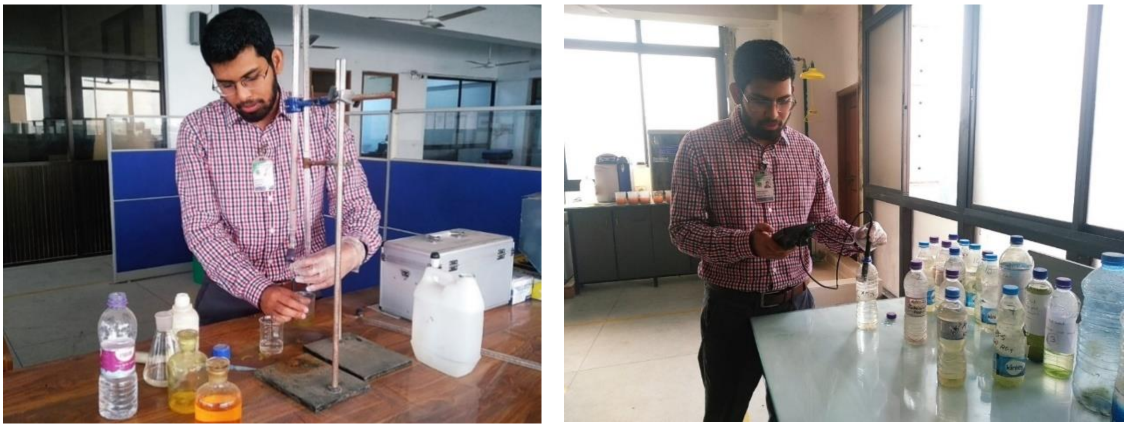
Environmental Multi-Meter was taken for on-spot testing of the Electrical Conductivity (EC) and Total Dissolved Solids (TDS) of water samples. Samples were also brought from those locations in sampling plastic bottles for performing laboratory test to find the Chloride (Cl^-) concentration. Sampling plastic bottles were washed with sample water three times before collecting water sample. Water sample bottles were marked properly for both ground & surface water sources.

(a) (b)

Fig. 3.3. Sample collection from surface water sources; (a) Shrimp gher, (b) pond

Collected water samples were tested in the Environmental Engineering Laboratory of Military Institute of Science & Technology (MIST) (Fig. 3.5). Chloride (Cl^-) concentration was measured in the lab by the Mohr Method. The Mohr Method uses silver nitrate for titration. The silver nitrate solution is standardized against standard chloride solution, prepared from sodium chloride (NaCl). During the titration, chloride ion is precipitated as white silver chloride. The indicator (potassium chromate) is added to visualize the endpoint, demonstrating presence of excess silver ions. In the presence of excess silver ions, solubility product of silver chromate exceeded and it forms a reddish-brown precipitate. This method is quite easy and convenient and gives reliable results.

Fig. 3.4 Sample collection from groundwater sources (Tube Wells); (a) Paurashava, (b) Burirdanga, (c) Mithakhali, (d) Suniltala, (e) Chandpi and (f) Sundarban



(a) (b)

Fig. 3.5. Testing the samples in Environmental Engineering Laboratory of MIST; (a) measuring Cl^- Concentration and (b) measuring EC and TDS

3.3.1.2 Focus Group Discussions (FGDs)

A total number of 10 FGDs were conducted in the six unions and Paurashava of Mongla Upazila during 9 to 15 July 2019 (Table 3.1). The FGDs were based on the following issues: Drinking water scarcity problems, surface water (SW) and ground water (GW) salinity conditions, community level safe water options, cyclone impact on water sources, health impacts due to salinity community-based adaptations.

Table 3.1. Detail of Focus Group Discussions

Date	Union	No. of FGDs	No. of participants
9th July 2019	Chandpi	1	13
10th July 2019	Chila	2	12
11th July 2019	Burirdanga	3	16
12th July 2019	Suniltala	1	8
13th July 2019	Mithakhali	1	14
14th July 2019	Sundarban	1	11
15th July 2019	Paurashava	1	10

A total of 118 participants participated in the discussions. The half-day long FGDs were conducted in some locations and some FGDs were conducted for about one-hour time through open discussion and in a participatory manner. After a brief introduction, the objectives and scope of FGDs were explained in details. A predesigned checklist was prepared in order to summarize the findings. The outputs of the FGDs were noted in the note book. An open discussion was conducted to discuss for finalization of FGDs' outcomes. The open discussion and documentation were concluded by giving thanks to the participating members for their support in the discussion. In the focus group discussion, secondary general information was collected from Upazila officers and some through a pre-designed questionnaire. The illustrations of FGD are shown in figure 3.6.

(a) (b) (c)

(d) (e) (f)

Fig. 3.6. Images from Focus Group Discussions (FGDs); (a) Burirdanga, (b) Chila, (c) Suniltala, (d) Mithakhali, (e) Chandpi and (f) Paurashava

3.3.1.3 Key Informants Interviews (KIIs)

KIIs were conducted in order to understand the perception of both local people and professionals. KIIs played a very crucial role to identify the authenticity of the information that was obtained from FGDs. The integration of the upshots from KIIs and FGDs assisted to develop a practical solution to the existing problems using a GIS-based model. The target group of professionals was:

- Principals of local union schools
- Professionals from DPHE
- Community clinic professionals
- Government officials
- NGO professionals
- Academicians and researchers
- BWDB Officials

Target people are selected on the basis of their experience and association with the water related issues. Key informants were interviewed by two interviewers using a semi-structured interview schedule developed in consultation with research team members. Potential participants were sent a Consent Information Letter (CIL) earlier before interview with verbal consent obtained prior to initiating the interview. At the initiation of each interview, participants were asked about their job titles and roles, their years of experience and some other relevant information. The information obtained during the interviews were noted properly (Fig. 3.7).

3.3.2 Secondary data collection

Secondary data were collected from BWDB, DPHE, CEGIS, and NGOs. Water quality parameters (EC, TDS and Cl^-) of 31 samples of Mongla Upazila with their GPS coordinates collected from these sources. Collected data was for the year 2010, which gives the opportunity to know the spatial variation of water quality in 2010 and compare the scenario of the year 2010 and 2019.

(a) (b) (c) (d) (e) (f)

Fig. 3.7. Images from Key Informant Interviews (KIIs); (a) Chila, (b) with Agricultural Officer, Mongla, (c) Mithakhali, (d) Sundarban, (e) Suniltala and (f) Chandpi

3.3.3 Data Analysis

For data analysis the spatio-temporal variation of water quality parameters was analyzed at the beginning and then the validation was done by using IDW method. After that both qualitative and quantitative analysis was done based on both secondary and primary data available.

3.3.3.1 Spatio-Temporal Variation of Water Quality Parameters

Collected primary and secondary data were analyzed in ArcGIS. Spatio-temporal variation of water quality parameters (EC, TDS, and Cl^-) was examined through the Deterministic Model. Inverse Distance Weighted (IDW) method of the deterministic model was employed. Measured values of water quality parameters with corresponding GPS coordinates were provided as point feature to map the spatial variation. Spatial distribution of each water quality parameters was classified into 5 classes. Areas under each class were calculated. The results of primary and secondary data sources were compared to explore the temporal changes between 2010 and 2019 (Fig. 3.8).

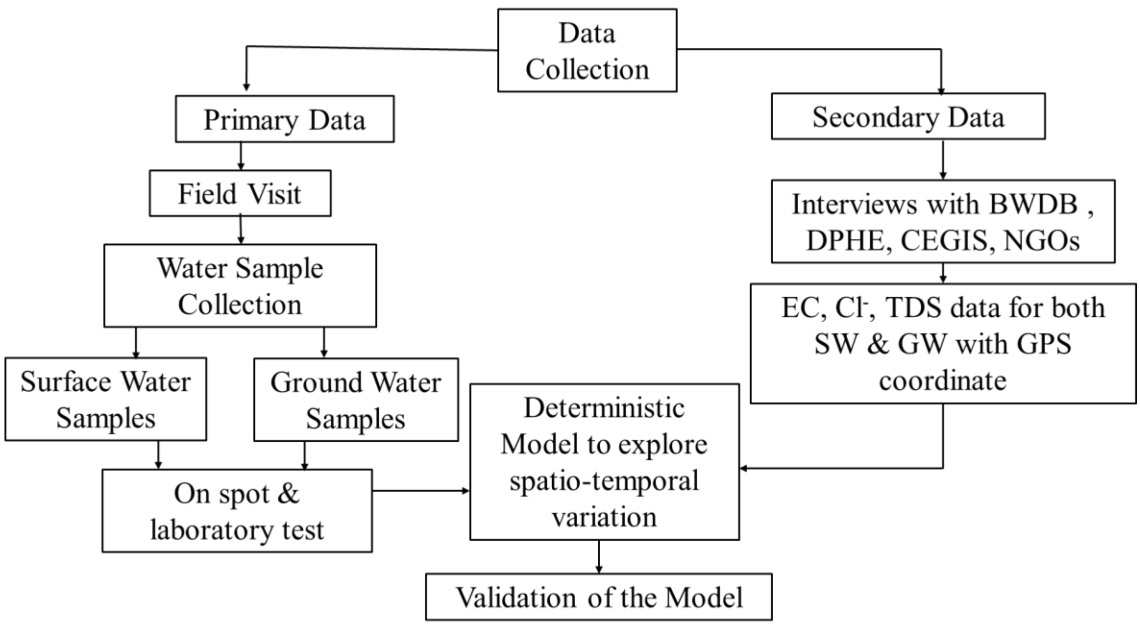


Fig. 3.8. Exploring Spatio-temporal variation of water quality of Mongla using IDW

For determining the spatial variation of groundwater quality, the whole Upazila was used as the extent but the spatial variation of surface water quality had been determined within the surface water part only. For this purpose, the surface water portion of Mongla Upazila of the year 2010 and 2019 have been demarcated from Landsat images. Mongla Upazila lies between 2 scenes (path/row – 137/44 and 137/45). Both of these scenes for the years 2010 and 2019 have been collected from the United States Geological Survey (USGS) website. From the Landsat images, surface water was demarcated using the most efficient remote sensing index named as Normalized Difference Water Index (NDWI). NDWI uses green and Near Infra-red bands of Landsat images and positive values of NDWI indicate water areas (McFeeters, 1996). After identifying the water areas for the year 2010 and 2019, the spatial distribution of surface water quality has been determined within those water areas only. One of the limitations of using NDWI is that it does not exclude waterlogged areas from surface water bodies.

3.3.3.2 Validation of IDW

The effectiveness of IDW was evaluated by computing r^2 and root mean square error (RMSE). 80% of primary and secondary data was used to run the model and the remaining 20% was kept for validation. After identifying the spatial distribution of water quality parameters from 80% of data, model data for the other 20% sample locations were extracted. Coefficient of Determination (r^2) was computed to know whether the deterministic model is fit for the study area or not. RMSE has also been calculated from the actual primary data and model data using the equation 3.1 (Chai and Draxler, 2014), as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(P_i - O_i \right)^2}{n}} \tag{3.1}$$

where Pi = Observed value, Oi = Model value and n = number of samples

RMSE tells how concentrated the data is around the line of best fit. The smaller the RMSE value, the better the model fits the data.

3.3.3.3 Analysis for safe water availability in unions of Mongla Upazila

This study was also aimed to identify the safe water availability in Mongla Upazila by comparative analysis on the GIS platform among the unions. For depicting the availability of safe water, ranking based comparative analysis was carried out among the Unions of Mongla Upazila. Unions are ranked based on both quantitative and qualitative factors. Water quality parameters are the quantitative factors and this study considered six qualitative factors, as follows:

1. No. of households covered by tube well/tap water
2. Condition of Pond Sand Filters (PSFs)
3. Condition of Reverse Osmosis (RO)
4. Usage of Rainwater Harvesting System (RWHS)
5. Presence of community-based adaptation practices
6. NGO activities

3.3.3.4 Investigating safe water availability based on quantitative factors

From the spatial distribution of water quality parameters, each parameter was classified into 5 classes and the classes were given ranks from 1 to 5, where 1 indicates the worst and 5 indicates the best quality. The standard acceptable value for EC, TDS and Cl^- are 1563 µs/cm, 1000 mg/l and 1000 mg/l respectively for Bangladesh (Rahman et al., 2017b). The higher the deviation from the standard value, the lower the rank. Table 3.2 presents the classes of water quality parameters and their associated ranks.

Table 3.2. Classification of water quality parameters and their ranks

Concentration of water quality parameters			**Rank**
EC (μs/cm)	**TDS (mg/l)**	**Cl^- (mg/l)**	
<1563	<1000	<1000	5
1563-2500	1000-1500	1000-1500	4
2500-5000	1500-3000	1500-3000	3
5000-10000	3000-6000	3000-6000	2
> 10000	> 6000	> 6000	1

Area under each class for all the parameters of a union was calculated and multiplied with associated ranks to find a weighted average rank for every Union, as shown in equation 3.2. Figure 3.9 shows a schematic diagram to represent how weighted average rank for each union for each water quality parameters were given. Detail calculation of weighted average ranking is given in Appendix A (Table A1 to A6). Figure 3.10 represents the framework for evaluating safe water availability in the unions based on water quality parameters.

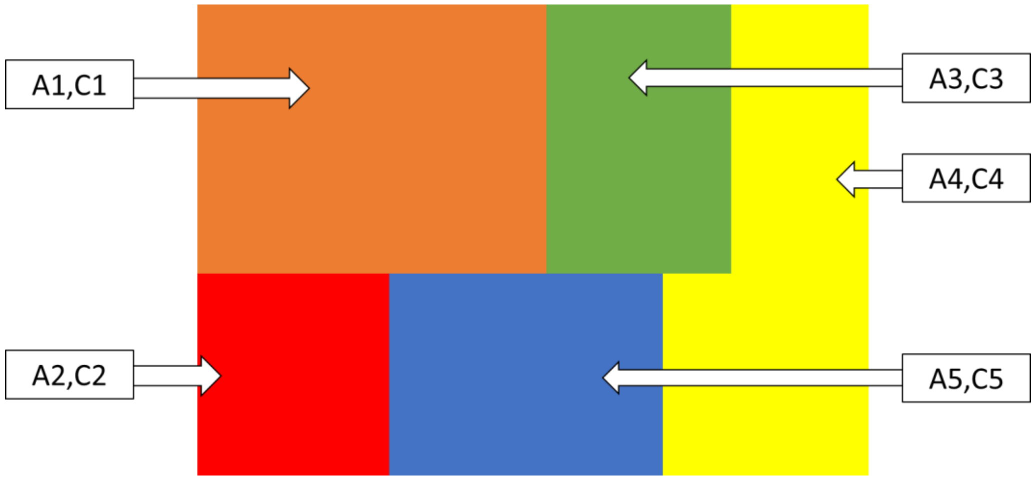


Fig. 3.9. Schematic diagram for calculating weighted average rank for each union

Weighted Average Rank = (A1*C1+A2*C2+A3*C3+A4*C4+A5*C5)/100……….(3.2)

Where, A= Percentage of the total area in each range, C= Rank

3.3.3.5 Investigating safe water availability based on qualitative factors

From the outcomes of FGDs and KIIs, each union has given a rank on a scale of 1 to 5, where 1 stand for very low and 5 stands for very high status for associative factors. Based on this ranking method, all the unions get ranks for six qualitative factors and finally, the average rank for each union was calculated to identify safe water availability. Figure 3.11 represents the framework.

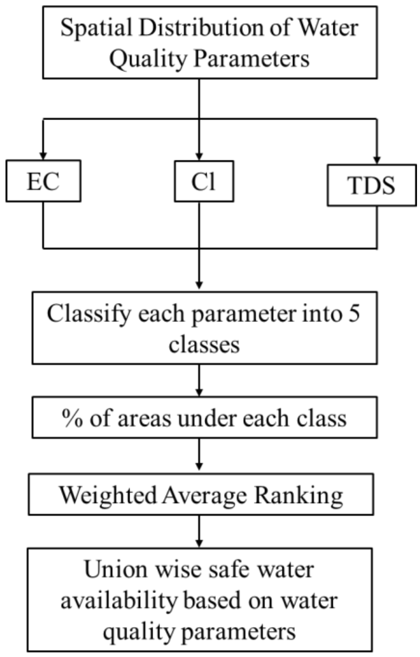


Fig. 3.10. Framework for exploring union wise safe water availability based on water quality parameters

3.3.3.6 Preparation of Community based model to facilitate safe drinking water availability

As safe drinking water is one of the scariest things in coastal area of Bangladesh, appropriate and affordable adaptation measures should be taken to supply safe water to local people. Considering the affordability and income level of coastal people, community-based solutions are the effective one. So, this study proposes a community-based model after investigating their preferences through a questionnaire survey. A total of 150 households were surveyed from Mongla Upazila and these households were selected randomly. Respondents were asked about their demographic conditions, their drinking water facilities, their preferences and willingness regarding community-based models, their problems regarding availing safe drinking water and adaptation measures taken at the individual level. The female participants were prioritized to select because they are mainly responsible for collecting drinking water in households.

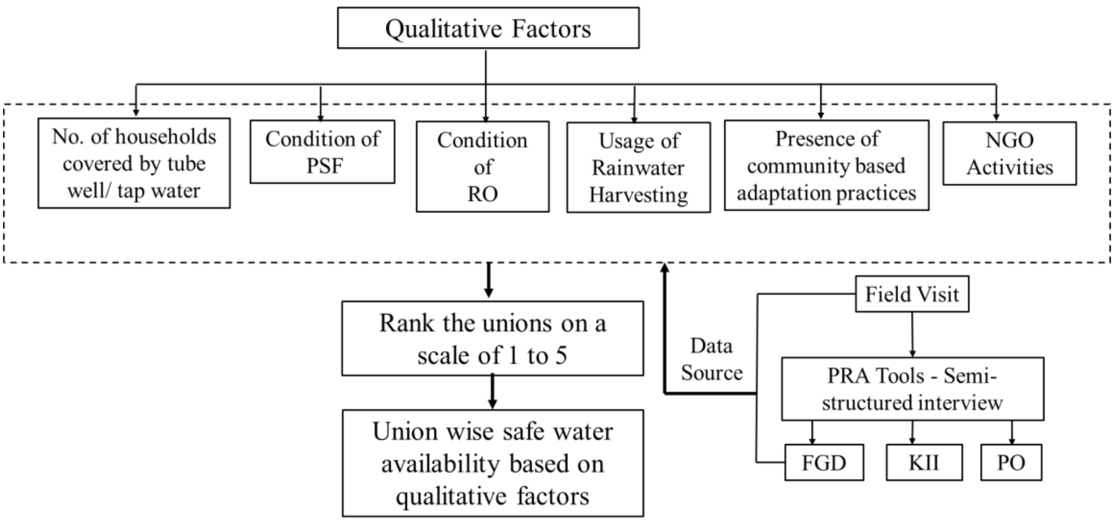


Fig. 3.11. Framework for exploring union wise safe water availability based on qualitative factors

After an analysis of their responses, a community-based model is designed to provide safe drinking water for 50 households, which can be implemented in any place. As rainwater is the most common and reliable source in coastal villages, the community-based model will also be based on rainwater harvesting but in an integrated and sustainable way. People were already using rainwater by storing them in different types of containers, which were subjected to be infected by pathogens. So, a total of 22 samples from different rainwater harvesting systems were collected to test them for identifying whether there was any pathogen in the stored water or not. Though the main field visit was carried out during July 2019, rainwater samples were collected during December 2019 to ensure that they are stored for some period. Rainwater samples were collected from different types of containers like – PVC, concrete, earthen pot (Local name Kolshi and Motka) etc. The samples were tested in the lab to count Total Coliform (TC) and Fecal Coliform (FC). From the test results, different types of storage containers were evaluated for their applicability. Finally, the most cost-effective and safe storage containers were used to design the model, which will supply safe drinking water to 50 households. Secondary data on the economic cost of the water supply options were obtained from the Department of Public Health Engineering (DPHE) office. The DPHE is responsible for water supply in the rural areas of Bangladesh. The construction and maintenance costs of RWHSs and PSFs were collected to calculate the economic cost of the systems. Figure 3.12 represents the framework of the proposed community-based model.

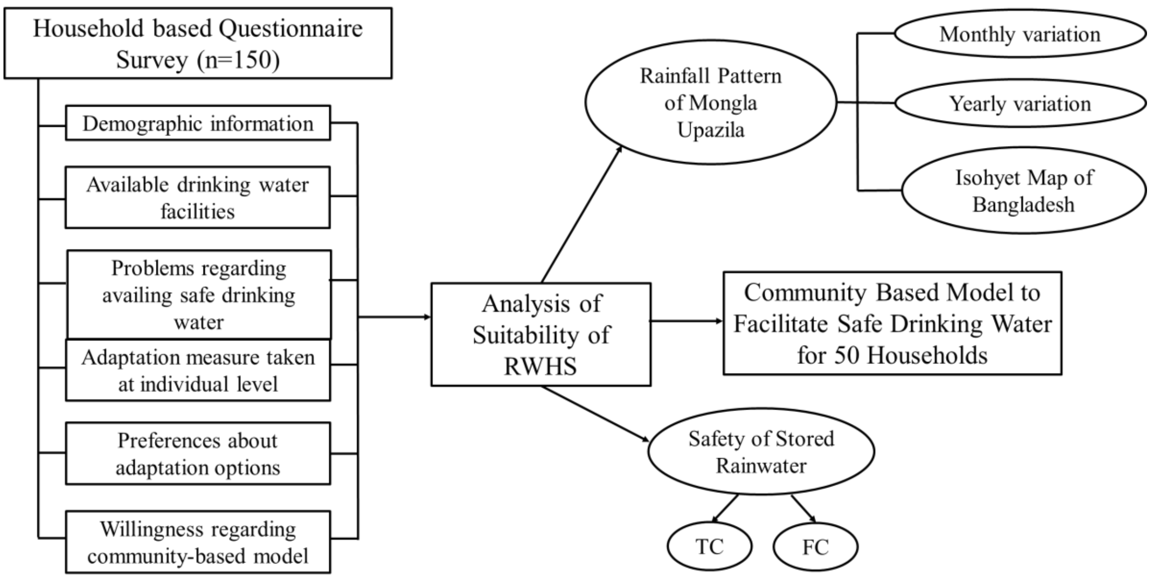


Fig. 3.12. Proposed Framework of community-based adaptation model for Mongla Upazila

CHAPTER 4

SAFE WATER AVAILABILITY IN MONGLA

4.1 Introduction

This chapter includes the outcomes of spatio-temporal variation which was analyzed using GIS model. Spatio-temporal variation of water quality parameters of both groundwater and surface water sources in Mongla Upazila are explained here. This chapter also includes the comparative scenario of the different unions of Mongla Upazila.

4.2 Spatio-temporal Variation of Groundwater Qualities in Mongla

The spatial distribution of groundwater qualities (EC, TDS, and Cl^-) was generated using the IDW method of the Deterministic Model. Higher concentrations of these parameters were found mostly in the southern portion, which is closer to the sea. Groundwater quality is quite good in the northeastern part of Mongla Upazila. From the analysis, it was found that areas within acceptable limits of EC, TDS and Cl^- (section 3.3.3.4) are very negligible. Temporal analysis was carried out to investigate the change in groundwater quality between 2010 and 2019. Analysis revealed that only 4% area of Mongla was within acceptable limit of EC (1563 µS/cm) in 2010, which reduced to less than 1% in 2019. About 8.75% area had EC of the range 1563 to 2500 µS/cm in 2010, which also reduced to 4% within last 10 years. In 2019, 13.82% area has EC level between 2500 to 5000 µS/cm, which was 34.7% in 2010. Around 44.47% areas had 5000 to 10000 µS/cm electrical conductivity and it increased to 62.88% in 2019. More than 8% areas had EC > 10000 µS/cm in 2010, which also increased to 18.32% within last 10 years. In a word, areas with lower EC decreased and areas with higher EC increased significantly within last 10 years (Fig. 4.1).

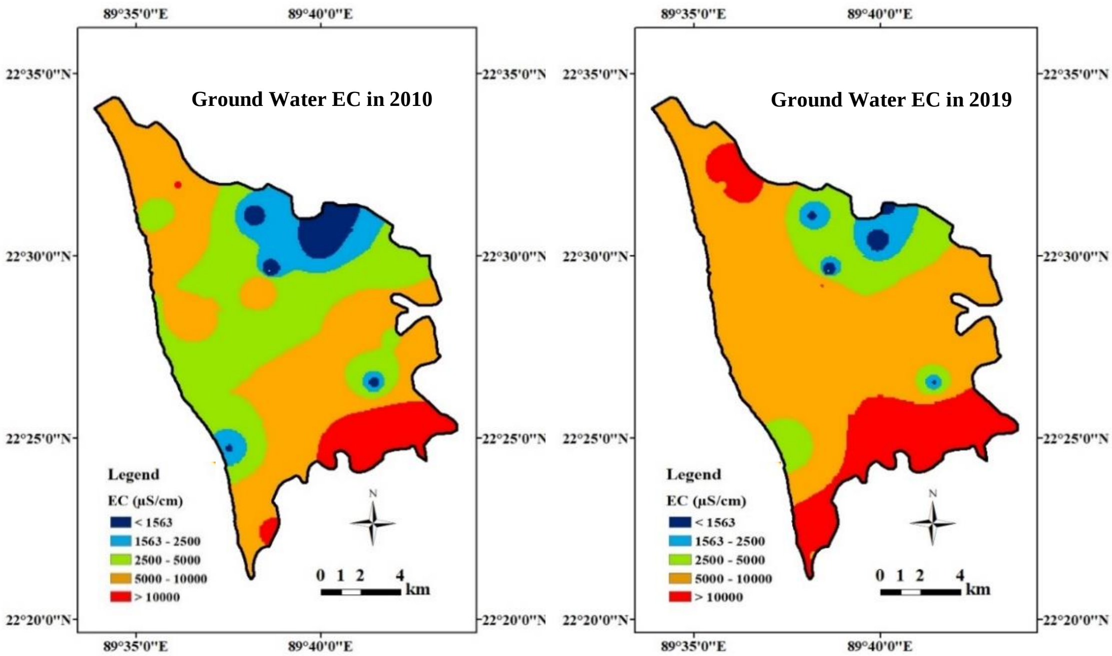


Fig. 4.1. Spatio-temporal distribution of EC in groundwater sources of Mongla Upazila

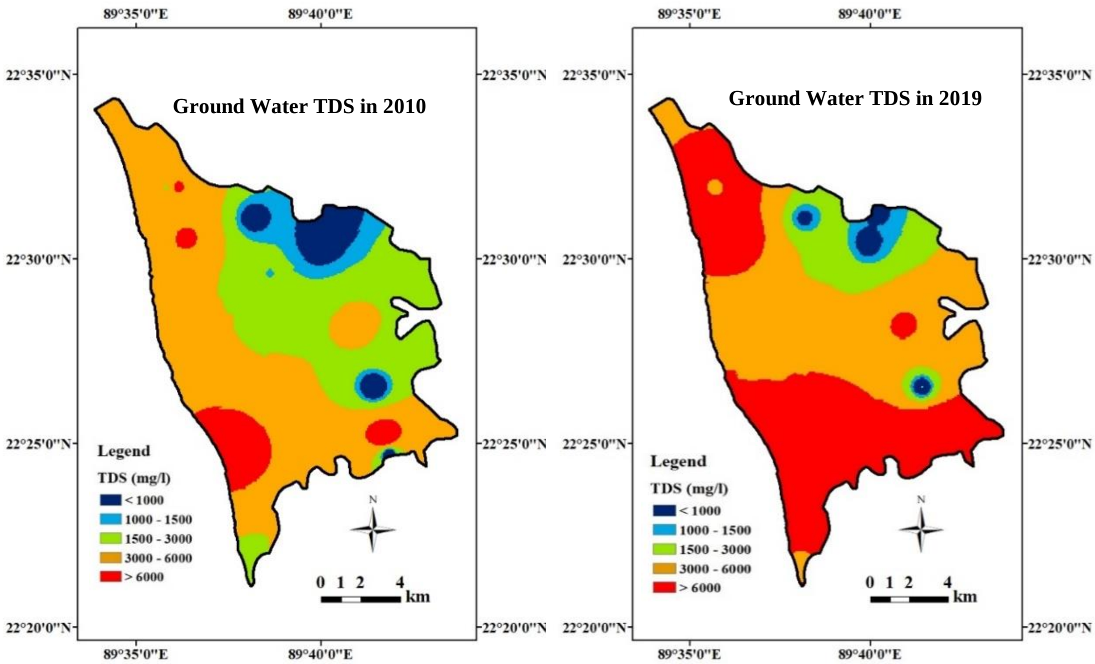


Fig. 4.2. Spatio-temporal distribution of TDS in groundwater sources of Mongla Upazila

Temporal analysis of TDS has shown that only 5.42% of areas had TDS within the acceptable limit (<1000 mg/l) in 2010, and in 2019 it was reduced to 1.89%. 31% of areas had TDS in the range of 1500-3000 mg/l, which reduced to 11.21% in 2019. Areas with TDS in the range of 3000 to 6000 mg/l also reduced from 51.08% to 42.82% within the last 10 years. On the other hand, only 6.54% of areas had TDS > 6000 mg/l in 2010, which drastically increased to 41.4% in 2019 (Fig. 4.2). Chloride distribution is similar to the distribution of EC and TDS. Areas with higher chloride concentration increased and areas with lower concentration decreased significantly between the last 10 years. Around 9.68% of areas had Chloride concentration within the acceptable limit (<1000 mg/l) in 2010, which decreased to only 2.07% in 2019. Areas with Chloride concentration in the range of 1000 to 1500 mg/l covered 6.48% of Mongla in 2010 and 4.96% in 2019. Areas with higher Chloride concentration (> 6000 mg/l) were only 9.74% in 2010, which drastically increased to 28.82% within the last 10 years (Fig. 4.3).

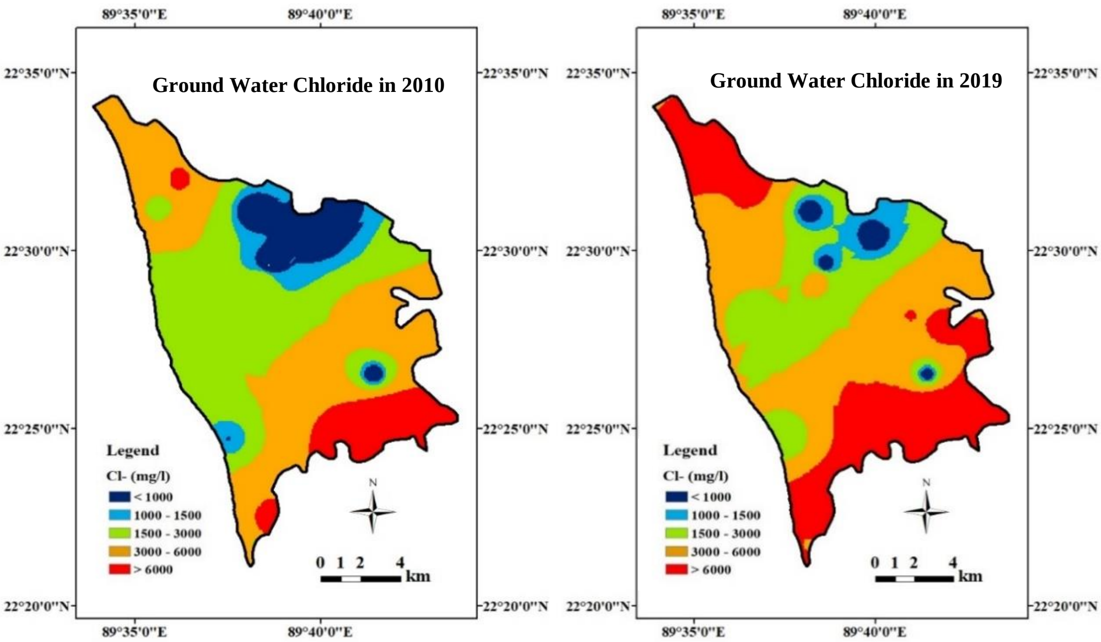


Fig. 4.3. Spatio-temporal distribution of Chloride concentration in groundwater sources of Mongla Upazila

4.3 Spatio-temporal Variation of Surface Water Qualities in Mongla

Spatial distribution of surface water qualities (EC, TDS, Cl^-) has shown within the surface water portion only, which was identified from Landsat images by imposing a threshold value of NDWI. More than 50% of the areas of Mongla Upazila are covered by surface water, mostly by shrimp farms. Spatial distribution of water quality parameters of surface water sources revealed that areas within the acceptable limit of EC, TDS and chloride concentration are very negligible both in 2010 and 2019. Surface water sources had already been contaminated by cyclone AILA in 2009 and excessive shrimp farming made the situation worse.

In 2010, most of the surface water bodies (95%) had EC > 5000 µS/cm and the remaining 5% areas had EC in the range of 1563 to 5000 µS/cm. After 10 years, water quality deteriorated more. In 2019, only 1.16% areas have EC < 5000 µS/cm and more than 80% areas have EC > 10000 µS/cm (Fig. 4.4). Temporal variation of TDS and Cl^- also showed similar results. Areas with acceptable TDS (< 1000 mg/l) are insignificant both in 2010 and 2019. About 18.27% areas had TDS < 3000 mg/l in 2010, which decreased to only 1.59% in 2019. Around 58% of areas had TDS in the range of 3000 to 6000 mg/l in 2010, which also reduced to 22.71% within 10 years. About 24% areas had TDS > 6000 mg/l, which substantially increased to 75.69% in 2019 (Fig. 4.5).

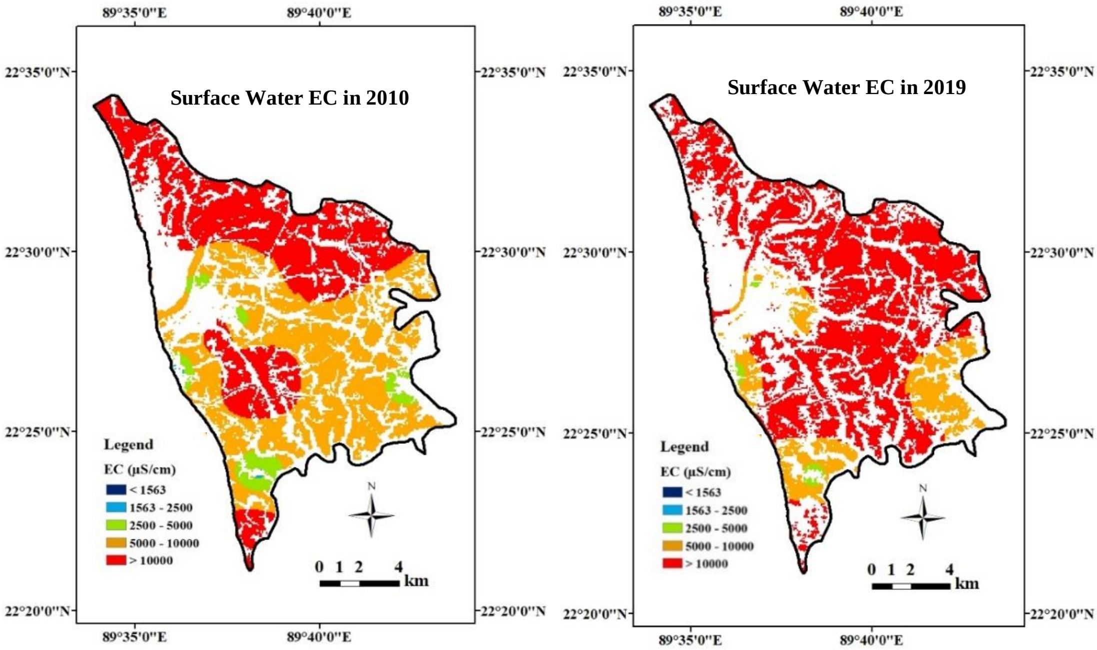


Fig. 4.4. Spatio-temporal distribution of EC in surface water sources of Mongla Upazila

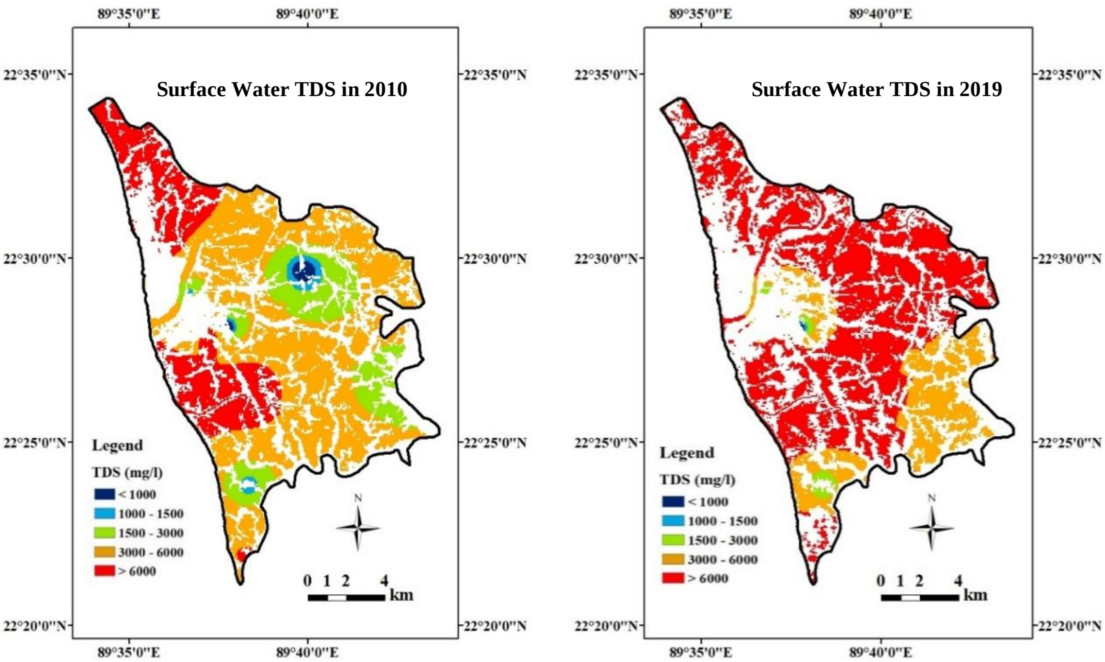


Fig. 4.5. Spatio-temporal distribution of TDS in surface water sources of Mongla Upazila

In 2010, 15.66% of areas had Cl^- concentration within 3000 mg/l, which reduced to only 8.6% in 2019. About 54.34% and 27.22% areas had chloride concentration in the range of 3000 to 6000 mg/l in 2010 and 2019 respectively. Chloride concentration was more than 6000 mg/l in 30% areas in 2010, which increased to 64.18% in 2019 (Fig. 4.6).

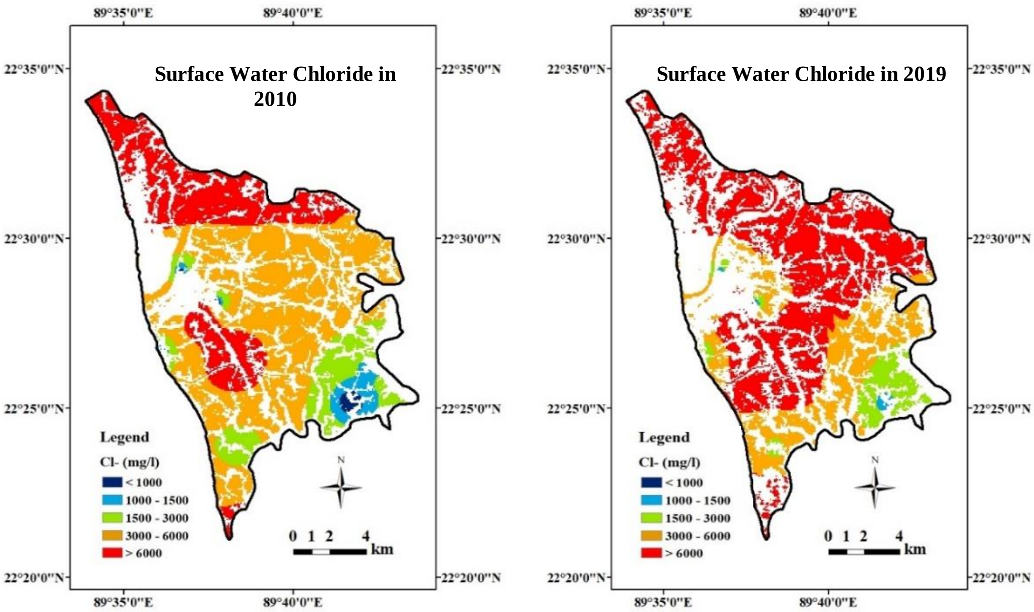


Fig. 4.6. Spatio-temporal distribution of Chloride concentration in surface water sources of Mongla Upazila

4.4 Validation of IDW

The efficiency of the IDW model to study the spatial variation of water quality parameters of coastal Bangladesh was evaluated by computing Coefficient of Determination (r^2) and Root Mean Square Error (RMSE). The IDW model showed a very good fit with primary data. R^2 values for distribution of EC, TDS and Cl^- concentration are 0.88, 0.86 and 0.83 respectively. On the other hand, RMSE values also indicated efficient modeling. RMSE for distribution of EC, TDS, Cl^- concentration is 4.19, 2.5 and 1.94 respectively, which is quite smaller comparing the range of data (Fig. 4.7).

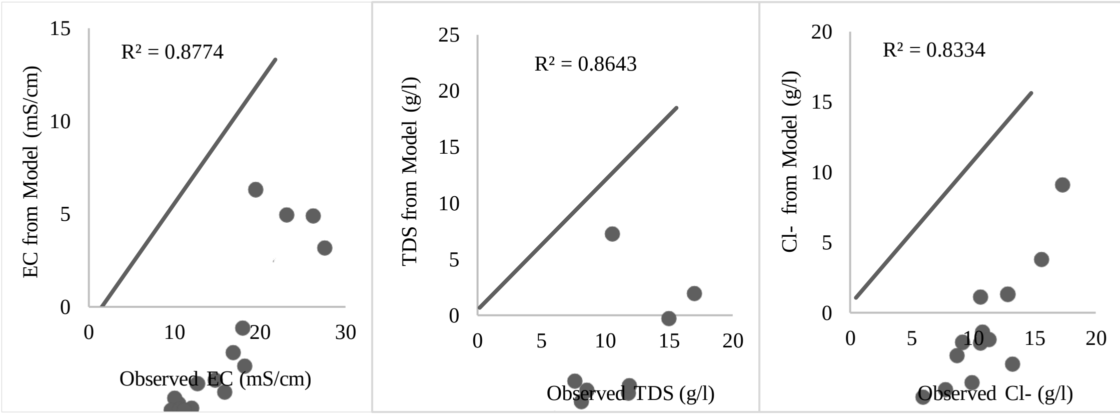


Fig. 4.7. Relationship between field data and model data

4.5 Union Wise Safe Water Availability based on Quantitative Factors

Comparative analysis was carried out among the unions and Paurashava based on the spatial distribution of water quality parameters (EC, TDS, Cl^-). Weighted average ranking on a scale of 1 to 5 was given to each union for each of the water quality parameters. Overall Water Quality was depicted by calculating the average of all ranks (Table 4.1).

Depending on the groundwater qualities, only Suniltala union showed comparatively good results. All other unions have moderate or low status regarding safe water availability. On the other hand, depending on the surface water qualities, most of the unions showed low status and Burirdanga and Suniltala had very low safe water availability. As mentioned earlier, surface water of Mongla Upazila is very much saline and cyclone AILA and high tidal surge made the situation worse. Considering all the water quality parameters of both groundwater and surface water sources, only Suniltala union showed moderate status and all other unions and Paurashava have low safe water availability (Table 4.1).

Table 4.1: Union-wise Rank for Safe Drinking Water Availability based on Quantitative Factors

Union Name	Quantitative Factors						Overall Water Quality Ranking	Status
	Water quality parameters							
	Surface Water			Ground Water				
	EC	TDS	Cl^-	EC	TDS	Cl^-		
Burirdanga	1	1	1	1.95	1.43	1.63	**1.34****	**Low**
Chandpi	1.39	1.27	1.48	2.3	2.07	2.94	**1.91**	**Low**
Chila	1.41	1.41	1.42	1.88	1.15	1.88	**1.53**	**Low**
Mithakhali	1.1	1.18	1.24	2.31	2.22	2.27	**1.72**	**Low**
Suniltala	1	1	1	3.46	3.5	3.64	**2.27**	**Moderate**
Sundarban	1.25	1.46	2.03	1.55	1.5	1.5	**1.55**	**Low**
Paurashava	1.5	1.57	1.96	2.01	1.74	2.33	**1.85**	**Low**

** Overall Water Quality Ranking = $\frac{1+1+1+1.95+1.43+1.63}{6}$ = 1.34

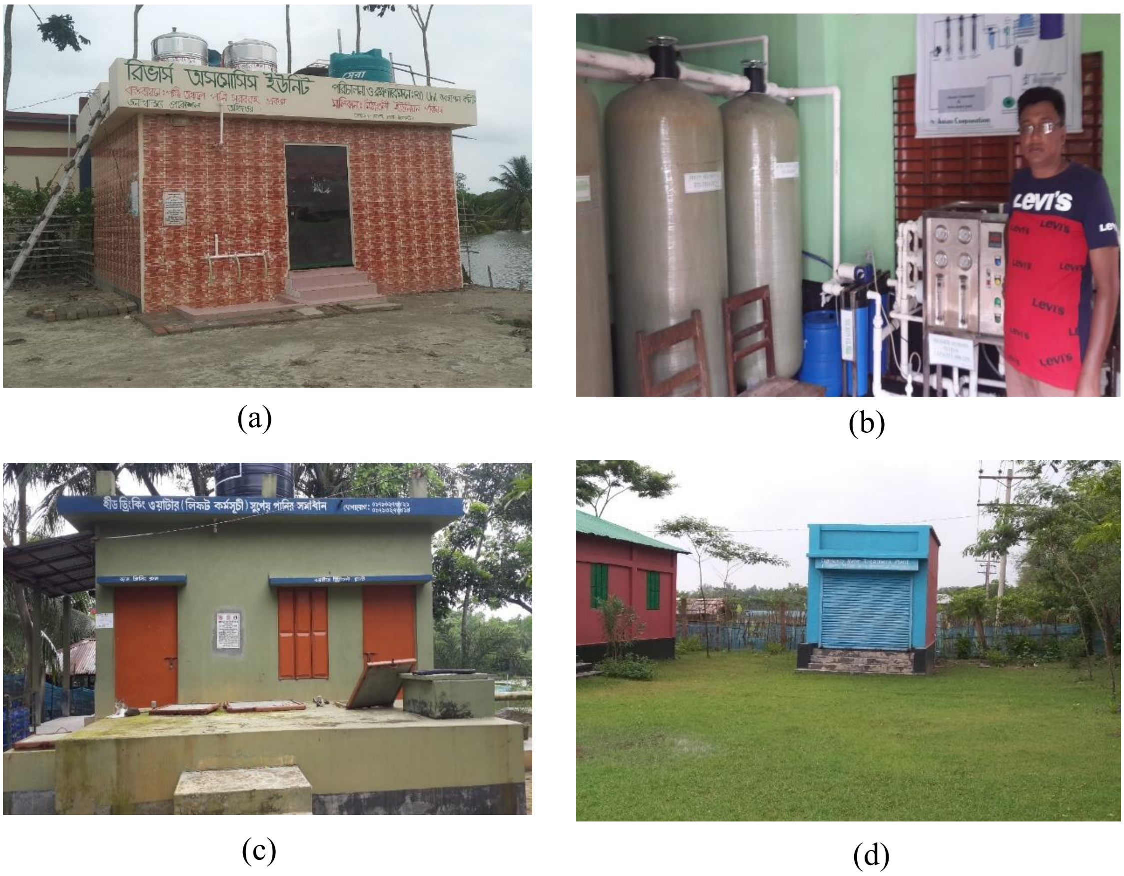
4.6 Union Wise Safe Water Availability based on Qualitative Factors

A total of 6 qualitative factors was considered to compare the unions for safe water availability. From the outcomes of FGDs, KIIs and personal observations, each union was given a rank on a scale of 1 to 5, where 1 stands for very low availability of safe water options. The following sections detail the outcomes of FGDs, KIIs and personal observations, which are the base of the ranking of qualitative factors.

4.6.1 Outcomes from FGDs and KIIs

Some predictions were already made by various researchers and professionals about Mongla Upazila. After conducting FGDs, the majority of the outcomes were found to be aligned with the anticipated predictions. A multitude of problems was identified as crucially significant from FGDs in each union. The salinity level of water bodies was extremely high and intolerable but astonishingly many participants replied that their body has already adapted with the high saline water level. Though the majority of the water sources were unsuitable for drinking still people were relying on saline water. Unfortunately, the condition of developed PSFs was very poor as maximum number of PSFs were totally out of order for usage (Fig. 4.8). According to the participants it was very difficult for the residents to operate and maintain the functionality of the system due to lack of skilled manpower and financial ability. The RO systems were not at all suitable for many parts of Mongla due to lack of skilled manpower. Though many NGOs developed some RO systems, the system collapsed due to lack of proper monitoring (Fig. 4.9). The major portion of the population was solely dependent on RWH (Fig. 4.10) and some (mostly in Paurashava and Burirdanga union) were dependent on supplied tap water. Community-based adaptations were developed in many portions of Upazila with the help of NGOs. The participation of NGOs to reduce salinity problems was very high but the main drawback was lack of proper maintenance.

Fig. 4.8. Pond Sand Filters (PSFs) in different unions of Mongla Upazila; (a) Chandpi, (b) Chila, (c) Sundarban, (d) Suniltala, (e) Mithakhali and (f) Burirdanga



(a) (b) (c) (d)

Fig. 4.9. Reverse Osmosis Systems (ROs) in different unions of Mongla Upazila; (a) Mithakhali, (b) Suniltala, (c) Chandpi and (d) Sundarban

(a) (b) (c) (d) (e) (f)

Fig. 4.10. Rainwater Harvesting System (RWHS) in different unions of Mongla Upazila; (a) Chandpi, (b) Chila, (c) Sundarban, (d) Suniltala, (e) Mithakhali and (f) Burirdanga

4.6.2 Outcomes from Fields Visits, FGDs and KIIs

After field visits and conducting in-depth FGDs and KIIs along with personal observations, it was observed that the majority of the population were deprived of tertiary education due to financial insolvency and lack of awareness. The average monthly income of the people was as low as BDT 6000-7000. Sources of drinking water were drastically decreasing with time. Though activities of NGOs were very high in quantity the maintenance state was far below average. People preferred RWH as the main drinking water source. Majority of the people were lacking in technical knowledge and so systems like PSF and RO are not at all working and unsuitable for use. The livelihood of people was shifting towards works related to shrimp farming. The agricultural productivity of the lands was constantly decreasing along with the worsening of water quality.

4.6.3 Ranking of Unions for qualitative factors

Many households in Burirdanga union and Paurashava had access to tube wells or supplied tap water. Some tube wells were also found in Mithakhali and Sundarban unions during the field visits. There were very few or no tube well and tap water supply option in other unions. There are plenty of Pond Sand Filters (PSFs) in Mongla Upazila but most of them were non-functioning. For this reason, every union was in bad condition based on ‘No. of functioning PSFs’ factor. Rainwater harvesting is very popular in coastal Bangladesh and Mongla is not an exception. People of every union used rainwater to some extent and RWHS was the very common and only way out in Mithakhali and Sundarban unions. According to personal observation, RWHS was less common in Paurashava as they had access to tap water/ tube wells (Fig. 4.11).

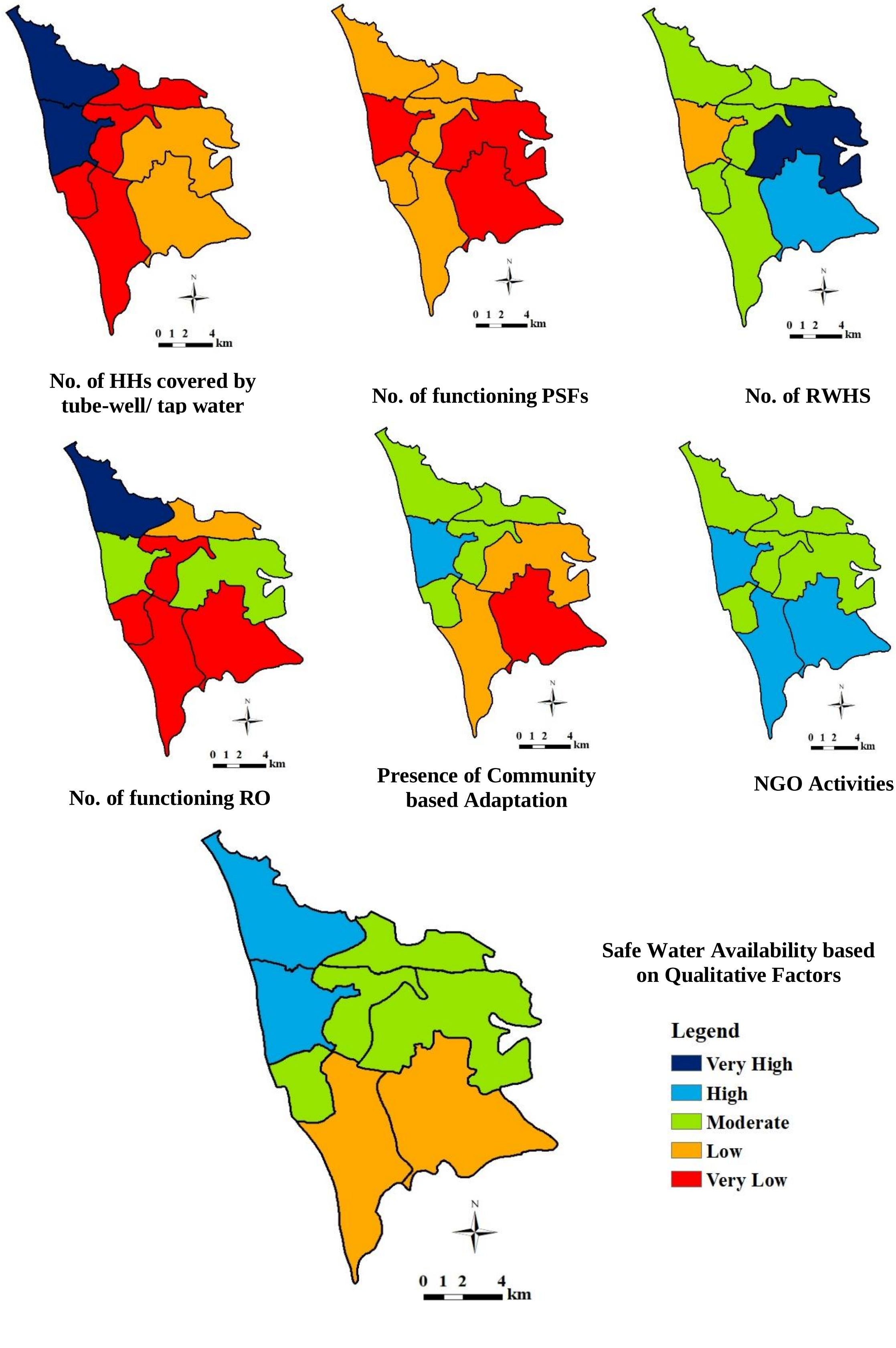


Fig. 4.11. Safe water availability in Mongla based on qualitative factors

Table 4.2: Union-wise Rank for Safe Drinking Water Availability based on Qualitative Factors

Union Name	Qualitative Factors						Overall Ranking of Safe Water Availability
	No. of HHs covered by tube-well/ tap water	No. of functioning PSF	No. of RWH system	No of functioning RO	Presence of Community based Adaptation Practices	NGO activities	
Burirdanga	5	2	3	4	3	3	**3.33****
Chandpi	1	2	3	1	3	3	**2**
Chila	1	2	3	1	2	4	**1.8**
Mithakhali	2	1	5	3	2	3	**2.6**
Suniltala	1	2	3	2	3	3	**2.2**
Sundarban	2	1	4	1	1	4	**1.8**
Paurashava	5	1	2	3	4	4	**3**

** Overall Ranking of Safe Water Availability = $\frac{5+2+3+4+3+3}{6}$ = 3.33

Reverse Osmosis (RO) was another well-known technique used in coastal areas of Bangladesh to combat salinity problems. Like PSFs, RO systems were also non-functioning in almost every union. Some RO systems of Paurashava and Mithakhali unions were functioning during the field visits. Community-based adaptation practice is somehow missing in Mongla. There were only one or two community-based systems in Paurashava. However, Non-Governmental Organizations (NGOs) were active in every union of Mongla. Considering all these issues, each union was given a rank on a scale of 1 to 5 and finally, overall ranking was calculated by averaging the ranks of six factors. It was found that Burirdanga union and Paurashava had high safe water options and Chila and Sundarban unions, the southern corner of Mongla had low safe water options. Other unions showed moderate status (Table 4.2 and Fig. 4.11).

CHAPTER 5

PROPOSED COMMUNITY BASED ADAPTATION MODEL

5.1 Introduction

This chapter includes detail information regarding the proposed community-based adaptation model for Mongla Upazila. Sustainability of such model is discussed here. Results of questionnaire survey and test reports of rainwater samples are also included here. Finally, the model is explained in detail with the guidelines for monitoring and maintenance.

5.2 Sustainability of Community-based Model

Over the years, the local people of the southern coastal areas of Bangladesh have adapted their water consumption behavior with varying levels of water availability. Ensure safe sources of water is one of the most important issues for human health and sustainable socio-economic development in these areas. Planning for effective water supply in rural coastal areas of Bangladesh requires an understanding of the existing water consumption patterns. In the WHO Guidelines for drinking-water quality, the Water Safety Plan is the central approach to safeguarding the health of the drinking water consumer. The findings of the present study may help in the planning and implementation of improved water supply facilities not only for the coastal areas in Bangladesh but also for other coastal areas with similar hydro-geological situations.

5.2.1 Socio-Economic and Demographic Profile of the Respondents

The socio-economic and demographic characteristics of the respondents were shown in Table 5.1. The mean age of the respondents was 37 years. The mean family size was 4.67

persons in a household. Nearly 33% of the respondents had no formal education. A large percentage of the households' income source was agriculture (37%) and most of the respondents (52%) were engaged in shrimp farming, others were daily laborers (6%) or in paid employment (4%). Approximately 53% of the participants reported monthly family income of less than BDT 5,000.

Table 5.1: Respondents' socio-demographic characteristics

Characteristics	Descriptive	Number	Percentage
Age	<30	42	28
	30–40	60	40
	>40	48	32
Education	No education	49	33
	Primary	44	28
	Secondary	53	36
	College	4	3
Family Size	1-4 people	80	53
	>5	70	47
Main Occupation	Agriculture	56	37
	Shrimp farming	78	52
	Daily labor	9	6
	Other Employment	6	4
Average monthly income (Tk.)	<5,000	80	53
	5,000–10,000	46	31
	>10,000	24	16

5.2.2 Drinking-Water Sources and Pattern of Water Use

Available drinking water sources are pond water, PSFs, RO, tube wells, tap water, and Rainwater. Most of the people were in the study area (86%) used multiple sources for collecting drinking water. 72% of respondents depended on RWHS but they stated that RWHS could not provide sufficient water for meeting their demand all the year-round. 12% of respondents got water from tube wells and tap water and these respondents were mainly from Burirdanga union and Paurashava. Only 6% got water from PSFs and RO systems as the majority of them are nonfunctioning. Remaining 10% of respondents stated that they collect their water from ponds (Fig. 5.1).

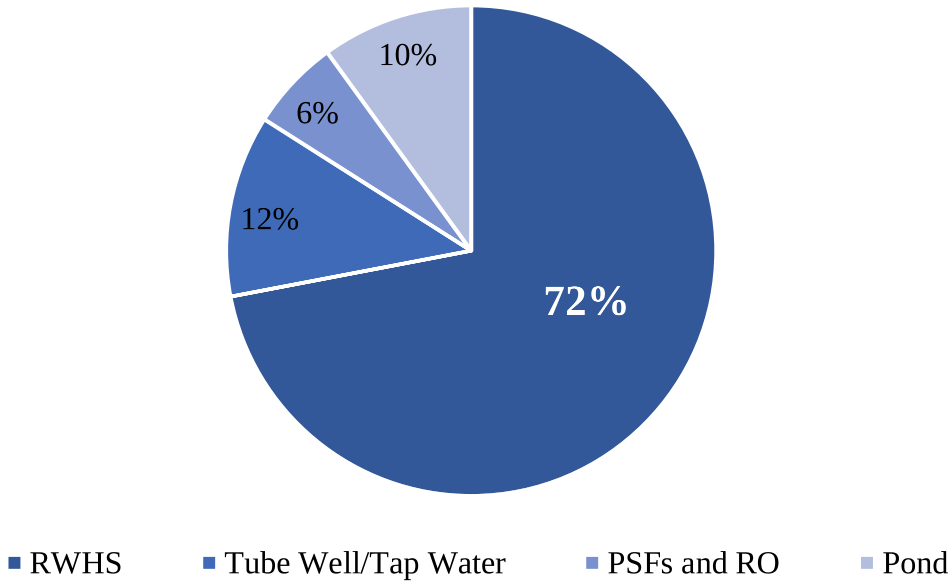


Fig. 5.1. Drinking water sources in Mongla Upazila

5.2.3 Problems in Collecting Safe Drinking Water

Respondents were told to identify their problems regarding safe drinking water. Seasonal variation was identified as a major problem. Respondents were asked if there were any effects of seasonal variation in their water consumption patterns. Most of them told that in monsoon they usually did not face any problem. In monsoon, they can collect water from ponds and rivers. When upstream heavy flow washes away saline waters in rivers, they can collect water from rivers. But in dry seasons, they face many obstacles as their stored rainwater is not sufficient for all the year-round and saline concentration of surface water sources increases during dry seasons.

On the other hand, their economic insolvency was another issue, for which they could not buy larger and permanent tanks to store rainwater. If they could build larger and sufficient storage for RWHS, they did not have to suffer during the dry season. Moreover, the erratic behavior of climatic elements like temperature and rainfall made the situation more problematic. The rainfall pattern sometimes showed anomalous behavior created problems in RWHS. They could not store enough water for themselves. Finally, respondents were also added that poor maintenance of PSFs and RO systems was another suffering. The majority of them were not functioning due to lack of proper maintenance. People there are bound to drink saline water sometimes during a year.

5.2.4 Preferences of Adaptation Options

Respondents were asked about their preferences about adaptation measures to combat the safe drinking water crisis. The majority of them preferred RWHS as they were accustomed to it and they were convinced that it was cheaper and safe for them. RWHS had already been a common and well-known concept in coastal areas of Bangladesh but the community-based approach was not so common and practiced one in Mongla. People responded that the community-based approach would be more suitable for them as they could not manage their own due to economic insolvency. Moreover, they did not prefer PSFs and RO systems as they required high maintenance and they were not very educated to handle these on their own.

5.2.5 Analysis of Suitability of RWHS

As RWHS was the most preferred adaptation option, suitability of RWHS should be evaluated. Rainfall pattern of Mongla Upazila was analyzed to find out the rainwater supply. On the other hand, stored rainwater samples were tested to investigate whether they were contaminated by any pathogens or not.

5.2.5.1 Rainfall Pattern of Mongla Upazila

The rainfall data of Mongla for the year 2001 to 2017 was collected from the Bangladesh Meteorological Department (BMD). Analysis of the total annual rainfall of Mongla Upazila from 2001 to 2017 showed that Mongla received more than 1900 mm water in a year (Fig. 5.2). Analysis of rainfall pattern of the year 2017 reveled that Mongla received a good amount (1773 mm) of rain from June to October (Fig. 5.3). Moreover, average total monsoon (June to September) rainfall was calculated for the year 2001 to 2017 and it was found that Mongla received around 1450 mm rainfall in monsoon period, which is sufficient for continuing rainwater harvesting at a large scale and in a sustainable way. Isohyet map also showed that Mongla receives on an average 2000 mm rainfall in a year (Fig. 5.4).

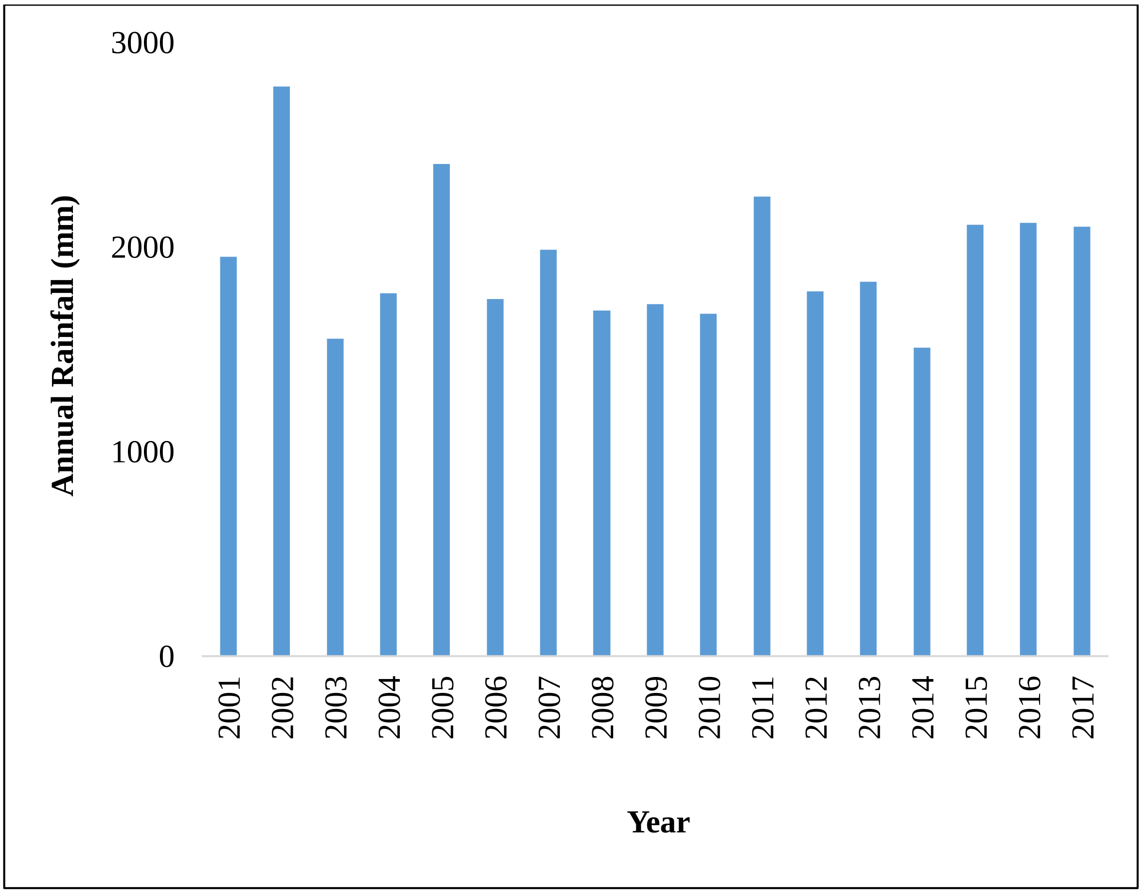


Fig. 5.2. Annual Rainfall of Mongla from 2001 to 2017 (Source: BMD, 2018)

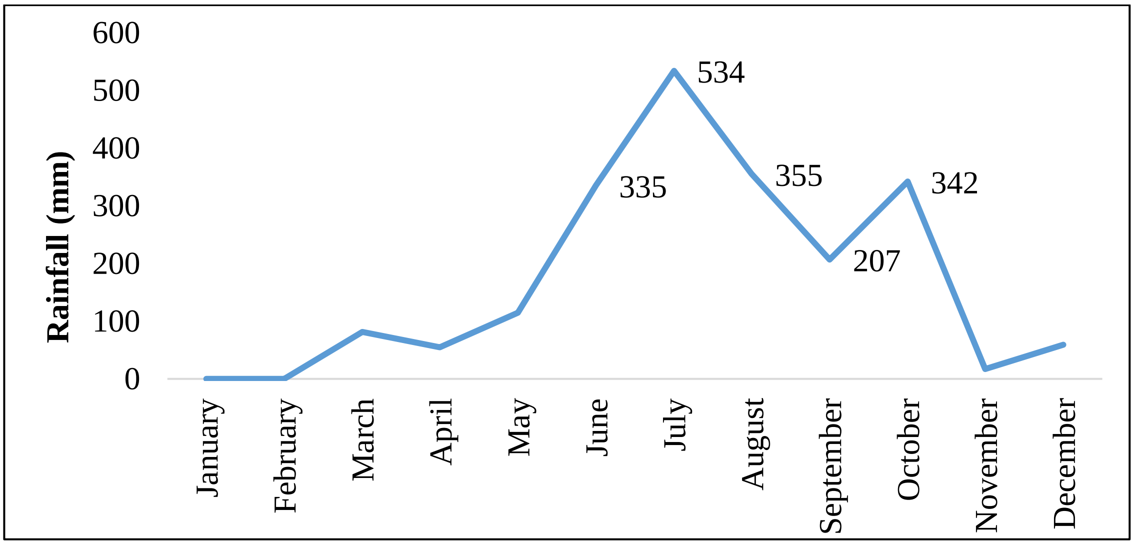


Fig. 5.3. Monthly Rainfall Pattern of Mongla Upazila in 2017 (Source: BMD, 2018)

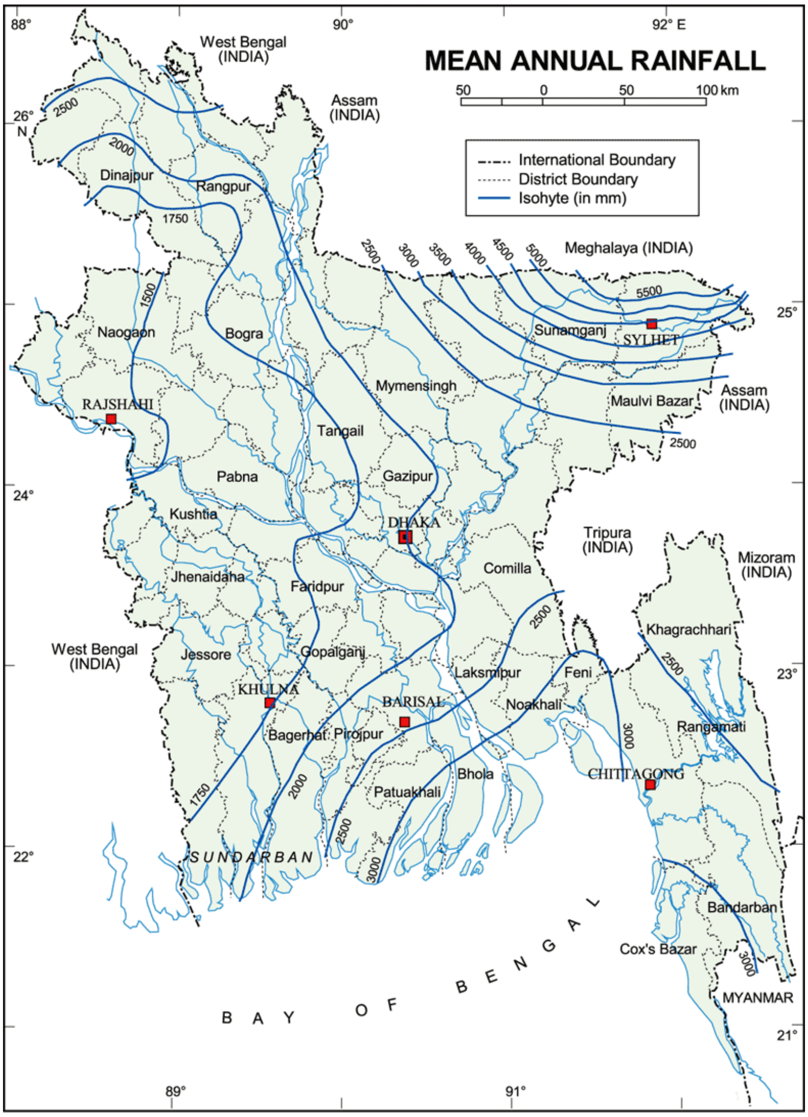


Fig. 5.4. Isohyet Map of Bangladesh (Brammer, 1996)

5.2.5.2 Safety of Stored Rainwater

As rainwater has to be stored for a longer period of time, by this time, pathogens can contaminate the water. For this reason, stored rainwater samples were tested to identify whether there were any coliforms or not. Though Fecal Coliform (FC) was not found in any sample, some of the samples were contaminated by non-fecal coliforms. It could be happened due to storage type and duration of water storage. Table 5.2 contains the detail information regarding tested rainwater samples.

Table 5.2: Result of TC and FC test of rainwater samples

SL	Union	Storage Type	TC (CFU per 100ml)	FC (CFU per 100ml)
1.	Chandpi	Cement Tank	26	0
2.		Motka (earthen pot)	0	0
3.		Cement Tank	0	0
4.		PVC Tank	0	0
5.	Chila	PVC Tank	0	0
6.		Drum	12	0
7.		Cement Tank	0	0
8.		PVC Tank	0	0
9.	Sundarban	Motka (earthen pot)	0	0
10.		PVC Tank	9	0
11.		Motka (earthen pot)	21	0
12.		Cement Tank	23	0
13.	Mithakhali	PVC Tank	10	0
14.		Plastic Container	25	0
15.		Motka (earthen pot)	0	0
16.	Suniltala	PVC Tank	0	0
17.		Cement Tank	33	0
18.		PVC Tank	7	0

SL	Union	Storage Type	TC (CFU per 100ml)	FC (CFU per 100ml)
19.	Burirdanga	PVC Tank	5	0
20.		PVC Tank	9	0
21.		PVC Tank	0	0
22.		Cement Tank	24	0

TC values of some samples exceeded the standard value (standard value is 0) but FC values did not exceed the standard value, which is a very good sign. Stored water in PVC tanks showed comparatively good results than other storage tanks. Moreover, PVC tanks are widely used in Bangladesh and they are made from food grade plastic, which is recommended by U.S. Food and Drug Administration (FDA). So, PVC water tanks can be used on a larger scale to promote community-based RWHS, as they are easy to install and maintain, comparatively cheaper and safer than other storage types.

5.3 Proposed Community-Based Models to Facilitate Safe Drinking Water

Community-based options are cost-effective as they do not pose a burden on individuals. The majority of coastal people have economic insolvency which makes them suffer more as they cannot afford adaptation measures to combat freshwater scarcity. However, a community-based option will provide them fresh drinking water at a minimum cost and it will be run sustainably by everyone’s effort. Some of the examples of community-based options practiced in coastal Bangladesh are given (Fig. 5.5).

(a) (b) (c)

Fig. 5.5. (a) Community-based Pond Sand Filter (PSF), (b) Rainwater Harvesting System (RWHS) and (c) Reverse Osmosis (RO) Plant

Respondents of this study have preferred RWHS over other options and RWHS is very convenient to install and maintain that PSFs and RO plants. This study proposes a community-based model for Mongla Upazila which can be installed anywhere and will provide safe drinking water for 50 households (around 200 people) year-round. The following is the detail calculation of the model.

- Drinking water demand of an individual per day is considered to be 3 liters. So, total monthly water demand for 50 households = 3*30*200 = 18,000 liters.
- Community people will catch and drink rainwater during monsoon (4 months, June to September). During this period, they can also collect water from surrounding water bodies as saline concentration remains low in monsoon.
- The community-based model will provide them drinking water for the remaining 8 months (October to May). They will collect water from the reserve pond for the first 4 months (October to January) and RWHS for the other 4 months (February to May). Water from reserve pond should be used first to prevent contamination in pond water.

5.3.1 Reserve Pond

For 4 months, 18,000*4 = 72,000 liters should be stored in the pond from rainwater. The pond size will be 5m*5m*4m, which can easily contain the required amount of water. It will serve 50 households for 4 months (October to January) after the monsoon period. Pond Sand Filter (PSF) will be installed near the reserve pond. Capacity of PSF will be 1000 liters and filtration rate will be 3 lit/hr (Sheikh and Islam, 2017). Barbed wire fencing will restrict the pond water from bathing and other usages. Dyke will prevent the pond water from inundation. Pond bed lining will prevent contamination from groundwater sources and other seepages. Community people will use this water after boiling (Fig. 5.6).

5.3.2 Rainwater Harvesting System (RWHS)

For the remaining 4 months (February to May), 18,000*4 = 72,000 liters should also be stored in RWHS. For this purpose, 8 PVC tanks of each 10,000 liters will be installed in the community-based RWHS to catch this water. 10,000 liter Gazi PVC tanks are available in market, which can be installed in the Primary Schools' ground field. Slow Sand Filter (SSF) will also be installed with RWHS to remove total coliform and other materials from rainwater (Fig. 5.7). In SSF, a fine sand is used and the designed rate of downward flow normally lies between 0.1 and 0.4 m^3/h per square meter of surface (Kamruzzaman and Ahmed, 2006). Capacity of SSF will be 1000 liters.

5.3.3 Estimated Water Demand v/s Available Rainwater

Yearly total water demand, Q = 18,000*12 liters = 216,000 liters = 216 m^3

Average rainfall during monsoon (June – September), R = 1.45 m

Runoff Coefficient, RC = 0.8

Catchment Area, A = Q/(R*RC) = 186.20 m2 = 2004 sft

So, a 2500 sft roof will be enough as a catchment. There are primary schools in every union of Mongla Upazila, which can be used as a catchment area and it will also minimize cost.

5.3.4 Estimated Cost

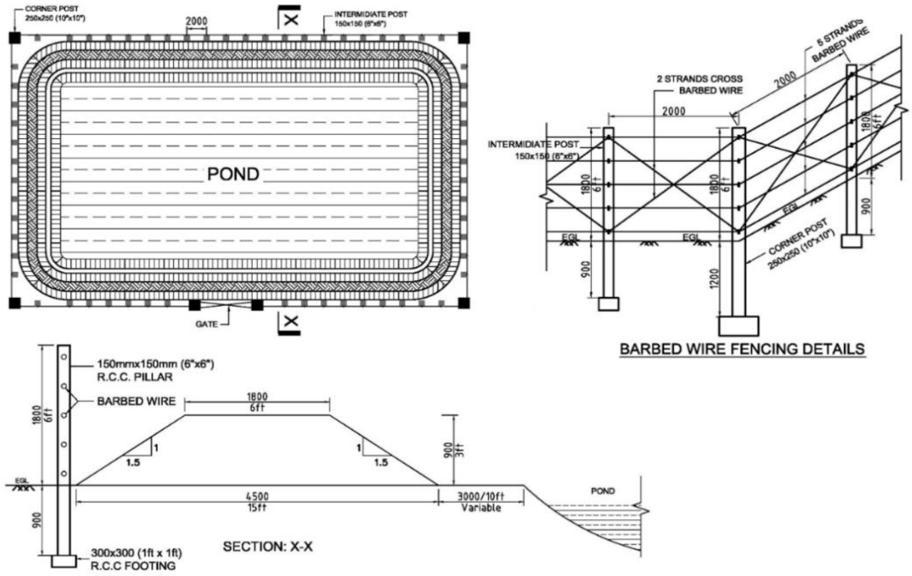
Installation Cost of

i. Reserve Pond – BDT 1,50,000 (Capacity 100 m^3)

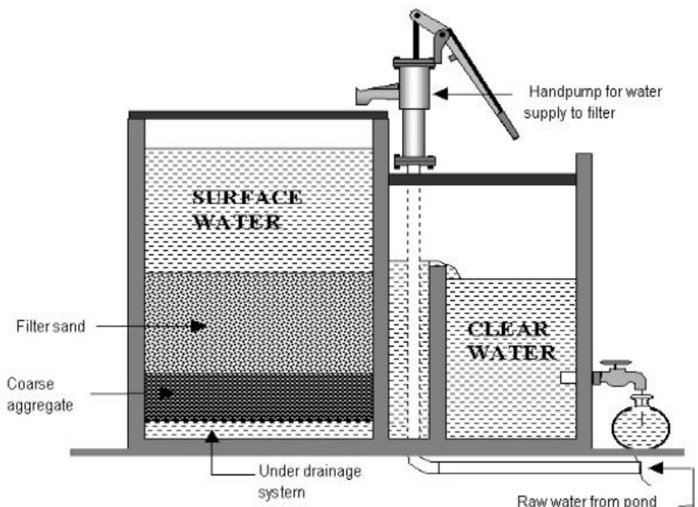
ii. Pond Sand Filter (PSF) – BDT 3,50,000 (Capacity 1000 liters)

iii. Rainwater Harvesting System (RWHS) – BDT 7,50,000 (PVC water tanks (80,000 liters) + plumbing + platform + slow sand filter and others)

iv. Monthly Maintenance Cost – BDT 5,000 (per family BDT 100 per month)

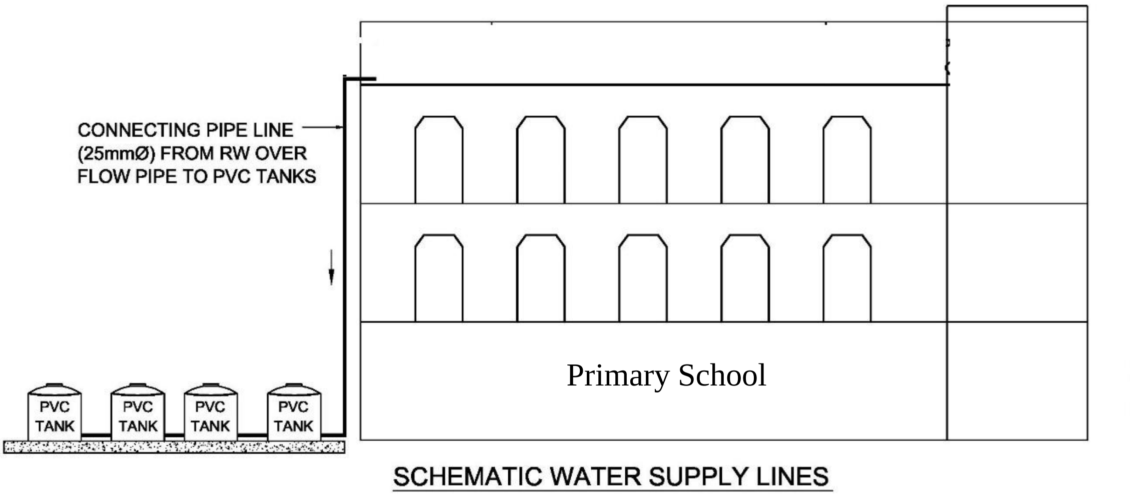


(a)

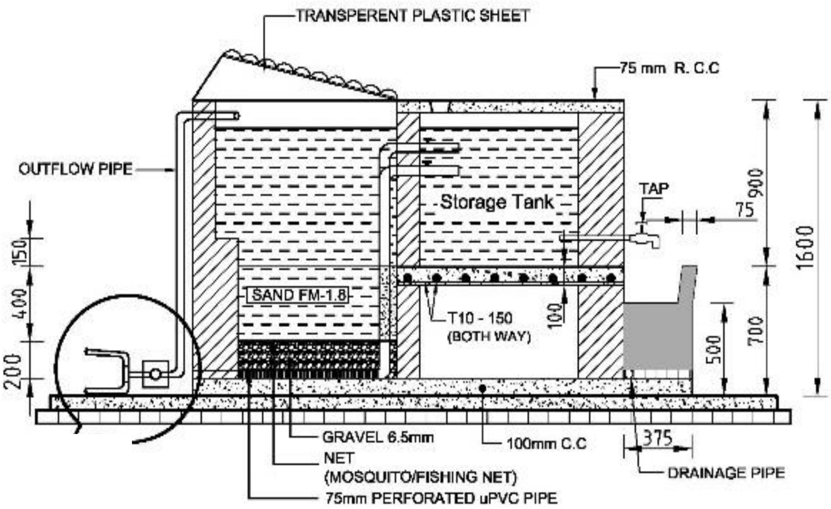


(b)

Fig. 5.6. (a) Proposed Reserve Pond (RP) with section and Barbed wire fencing details, and (b) Pond Sand Filter (PSF) (WaterAid, 2006)



(a)



(b)

Fig. 5.7. (a) Proposed Rainwater Harvesting System (RWHS) and (b) Slow Sand Filter installed in RWHS

5.3.5 Monitoring and Operation & Maintenance of Water Supply Systems

Rainwater is relatively free from impurities except those picked up by rain from the atmosphere, but the quality of rainwater may deteriorate during harvesting, storage, and use. Wind-blown dirt, leaves, fecal droppings from birds and animals, insects and contaminated litter on the catchment areas can be sources of contamination of rainwater, leading to health risks from the consumption of contaminated water from storage tanks.

Poor hygiene in storing water and abstracting water from tanks or at the point of use can also represent a health concern. However, risks from these hazards can be minimized by good design and practice.

5.3.5.1 Operation and Maintenance of RWHS

Following sections detail the operation and maintenance system for proposed RWHS (IMC Worldwide Ltd., 2015).

(a) **Rain Water Harvesting:** As designed, water from the roof area will flow through the drainpipe for rainwater harvesting. PVC Rain Water storage tanks on a platform will be connected with a pipe from the roof.

(b) **Cleanliness of Catchment Roof:** The quality of rainwater is directly related to the cleanliness of catchments, downpipe and storage tanks. Rooftop catchment surfaces collect dust, organic matter, leaves and bird and animal droppings, which can contaminate the stored water and cause sediment buildup in the tank. Care should also be taken to avoid materials or coatings that may cause adverse taste or odor, and some metals can be dissolved to give high concentrations in water. Regular cleaning of catchment surfaces and inlets/pipes should be undertaken to minimize the accumulation of debris. Wire meshes or inlet filters should be placed over the top of down-pipes to prevent leaves and other debris from entering storage tanks. These meshes and filters should be cleaned regularly to prevent clogging.

(c) **First Flush:** The first flush of rainwater carries most contaminants into storage. A system/ practice is, therefore, necessary to divert the contaminated first flow of rainwater from roof surfaces. Some devices and good practices are available to divert the first foul flush of rainwater. Even with these measures in place, storages will require periodic cleaning to remove sediment.

(d) **Rain Water Storage and Mosquito Control:** Storages without covers or with unprotected openings will encourage mosquito breeding and sunlight reaching the water will promote algal growth. Covers should be fitted, and openings need to be protected by mosquito-proof mesh. Cracks in the tank and withdrawing of water using contaminated pots can contaminate stored water.

(e) **Rain Water Use:** Storages should preferably be fitted with a mechanism such as a tap or an outlet pipe that enables hygienic abstraction of water. Some schools/ households incorporate cartridge filters or other treatments at the point of consumption to ensure a better quality of drinking water and reduce the health risk. Disinfection of rainwater should be practiced, when microbial contamination is detected or sanitary inspections indicate a likelihood of contamination. Disinfection with chlorine can make rainwater safe for drinking.

(f) **Operation Procedure:** The RW-Tank will be connected to a water point through a Mini-Slow Sand filter fitted with multiple taps to remove Total Coliform & E. Coli. Drinking water will be collected for school from the water-point attached to Tube well and PSF.

(g) **Cleaning of storage tanks:** PVC-Tanks and water point, platform, drain and surrounding places should be cleaned up at least every fortnight, and wastewater should be disposed of properly in adjacent agriculture fields or canal or making soak pit for recharging.

5.3.5.2 Operation and Maintenance of PSF

Following sections detail the operation and maintenance system for proposed PSF (IMC Worldwide Ltd., 2015).

(a) **Pond Sand Filter (PSF):** Immediately after installation of PSFs, proper operation & maintenance including regular monitoring will be necessary for the sustainability of the system. It is suggested to establish a PSF management committee for its proper O&M, where caretakers should play a critical role. Caretakers should have basic O&M training through DPHE or local NGO partners. For a properly constructed PSF, few items like filter material, water taps, lid etc. will require periodical replacement/repair. The filter material may be replaced as and when needed. The repair of the lid should follow PSF-guidelines by a competent local carpenter and mason. In the case of a hand-pump, the pump handle fulcrum pins should be greased regularly to prevent wearing.

(b) **PSF Management Committee:** Before construction/renovation of PSF, a PSF management committee consisting of 1-2 representatives from Union Parishad and Community users will be formed and be responsible to take necessary steps for regular operation and maintenance. Proposed PSF-management committee: UP Representative – 1 and Caretaker – 1.

(c) **Roles and responsibilities of the management committee:** The committee should have the following responsibilities:

   i. The committee will be responsible for proper operation & maintenance of the PSF through a "Care Taker".

   ii. The committee will seek necessary technical support and guidance from Upazila Engineer/DPHE/Local Mechanics if necessary.

iii. Maintain necessary records like-procurement related documents, income, expenditure, etc.

iv. Maintain a revolving "Maintenance Fund" through a grant from Union Parishad and collecting charges from Community Users.

(d) Operation Procedure: The PSF is a conventional technology for removing bacteria from pond water where turbidity level is less than 90 NTU (Nephelometric Turbidity Units), provided this is regularly monitored and maintained.

i. After the filter material is replaced, open the washout pipe of the filter chamber to drain accumulated water and then close the washout.

ii. Place bricks on top of the filter material under the dynamic roughing filter chamber to reduce disturbance and scouring of the filter material under the impact of water.

iii. Pump water until the filtered water enters the storage chamber.

iv. The initial filtered water should be drained out through the washout pipe of the storage chamber.

v. Close the washout pipe of the storage chamber. The water level in the storage chamber will raise to the level of the outlet pipe.

vi. Collect water from the storage chamber by opening the tap.

(e) Cleaning of PSF: The outside wall of PSF, platform, drain and surrounding places of PSF should be cleaned up at least twice a month, and wastewater should be disposed of properly in adjacent agriculture fields or canal or making soak pit for recharging.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Increasing of soil salinity in the coastal regions of Bangladesh has become one of the greatest costal threat and the condition is worsening with passage of time. Mongla is the largest Upazila of Bagerhat district and is undergoing severe water related problems and availability of safe water is alarmingly reducing. The deterministic model depicted that the water quality parameters like TDS, EC and Chloride concentration have exceeded the allowable limit to a great margin. Areas with lower concentration of these parameters decreased and areas with higher concentration increased substantially. Groundwater areas having EC, TDS and Cl- within allowable limit decreased by 77%, 65.13% and 78.62% respectively between 2010 and 2019. On the other hand, areas having EC more than 10000 µS/cm increased by 125.45% in groundwater and 75.61% in surface water sources. Higher concentration of TDS and Cl- (>6000 mg/l) covered more areas between this period and experienced 533.03% and 195.89% increment in groundwater; and 218.43% and 113.93% in surface water sources respectively. All the water bodies and most of the aquifers are contaminated by higher saline concentration, which caused acute drinking water scarcity in Mongla.

Union wise comparative analysis revealed that all the unions and Paurashava had low safe water availability except Suniltala, which had moderate safe water availability, based on water quality parameters of groundwater and surface water sources. However, different scenario is depicted considering the qualitative factors. Burirdanga and Paurashava showed high safe water availability and Chila and Sundarban showed low safe water availability and other unions have moderate status. Though the water quality of whole Upazila is far below the acceptable limits, some unions and Paurashava have managed to supply safe water to some extent by adaptation measures. On the other hand, unions at the southern part of Mongla have still no access to safe water and people lead miserable lives there. Both climate change factors (i.e. high temperature, cyclone, sedimentation, and sea-level rise) and anthropogenic causes (i.e. extensive shrimp cultivation, construction of Farakka barrage) are increasing salinity intrusion into the coastal regions of Bangladesh. To formulate a coastal zone management plan, an overall understanding of the community's exclusive perceptions and evaluation of their adaptive and proactive capacities are vital. Moreover, the role of existing stakeholders and governmental and non-governmental should be concentrated on the freshwater scarcity of coastal regions, especially in Mongla. Though the government and NGOs are working in different parts of the coordination of the coastal region is absence among them and there is no perspective of integration among community's adaptation measures and efforts of development organizations, which is compulsory for successful coastal hazard management programs and for ensuring safe drinking water for the coastal community.

Some socioeconomic factors (such as education level, income level) and geographical factors are causing the increase of vulnerabilities of coastal people's vulnerabilities to the drinking water crisis, though they are struggling to reduce their vulnerabilities by implementing different adaptation measures. It has been observed that approximately 33% of the participants had no education, 47% of them were living in a family of greater than 5 persons, 52% were involved in shrimp farming related occupations and most importantly 80% people were earning less than 5000 Tk per month. Considering all the findings and the existing socio-economic conditions, a proposal was made to develop a community-based model to provide safe drinking water to coastal people. In this regard, this study included a questionnaire survey to investigate their current level of adaptation measures and their preferences about adaptation options and their willingness regarding the community-based model. As local people are accustomed to RWHS and they are practicing that at the individual level and almost 72% of the respondents preferred it more than other options, the proposed community-based model is also based on RWHS. The proposed model will provide safe drinking water to 50 households at a reasonable cost. The model is designed to be cost-effective, easy to install and maintain and sustainable. Suitability of RWHS is also examined through analyzing the rainfall pattern of Mongla and testing the rainwater samples from different types of storage. Mongla receives a significant amount of rainfall during monsoon. So, RWHS will be sustainable. On the other hand, as samples from PVC tanks are less contaminated than other storage tanks, PVC tanks will be installed in the community-based RWHS.

6.2 Recommendations

- In order to explore safe water availability in Mongla Upazila only three parameters were considered. As, Mn and other heavy metals were not taken into considerations which can be used for future research.
- Since majority of the PSFs and ROs are non-functional, steps should be taken by the stakeholders, Local governments and NGO's in an integrated manner so that those systems can be made functional properly again.
- Awareness programs related to water, health and agricultural productivity should be conducted so that people can learn the ways to combat the water related problems.
- Bottom-up approach should be followed before developing any adaptation strategies in Mongla Upazila.
- The database containing water quality related information should be kept up to date so that there remains sufficient authentic data for conducting future research works.

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APPENDIX A

Table A1: Weighted average ranking of chloride concentration in surface water

Class (mg/l)	Rank	Percentage of areas under each class						
		Burirdanga	Suniltala	Chila	Chandpi	Sundarban	Mithakhali	Paurashava
< 1000	5	0	0	0	0.1	0	0	0
1000-1500	4	0	0	0	0.43	1.65	0	2.71
1500-3000	3	0	0	2.44	5.25	28.33	0.24	14.71
3000-6000	2	0	0	37.53	35.91	41.38	23.53	58.14
> 6000	1	100	100	60.03	58.31	28.65	76.23	24.43
Rank of Union		1	1	1.42	1.48	2.03	1.24	1.96

Table A2: Weighted average ranking of Total Dissolved Solids (TDS) in surface water

Class (mg/l)	Rank	Percentage of areas under each class						
		Burirdanga	Suniltala	Chila	Chandpi	Sundarban	Mithakhali	Paurashava
< 1000	5	0	0	0	0.38	0	0	0
1000-1500	4	0	0	0	0.57	0	0	0
1500-3000	3	0	0	5.98	3.01	0	0	8.14
3000-6000	2	0	0	28.54	17.49	45.6	18.31	41.18
> 6000	1	100	100	65.48	78.55	54.4	81.69	50.68
Rank of Union		1	1	1.41	1.27	1.46	1.18	1.57

Table A3: Weighted average ranking of Electrical Conductivity (EC) in surface water

Class (μS/cm)	Rank	Percentage of areas under each class						
		Burirdanga	Suniltala	Chila	Chandpi	Sundarban	Mithakhali	Paurashava
< 1563	5	0	0	0	0	0	0	0
1563-2500	4	0	0	0	0	0	0	0
2500-5000	3	0	0	3.63	2.87	0	0	6.33
5000-10000	2	0	0	33.4	33.52	25.42	10.2	37.33
> 10000	1	100	100	62.97	63.61	74.58	89.8	56.34
Rank of Union		1	1	1.41	1.39	1.25	1.1	1.5

Table A4: Weighted average ranking of chloride concentration in ground water

Class (mg/l)	Rank	Percentage of areas under each class						
		Burirdanga	Suniltala	Chila	Chandpi	Sundarban	Mithakhali	Paurashava
< 1000	5	2.57	12.88	0	4.51	0.82	1.37	0
1000-1500	4	1.8	39.64	0	9.49	0.86	2.43	0
1500-3000	3	4.94	45.83	21.92	61.47	2.68	30.32	32.93
3000-6000	2	36.95	1.65	44.47	24.53	38.92	53.89	67.07
> 6000	1	53.74	0	33.61	0	56.72	11.99	0
Rank of Union		1.63	3.64	1.88	2.94	1.5	2.27	2.33

Table A5: Weighted average ranking of Total Dissolved Solids (TDS) in ground water

Class (mg/l)	Rank	Percentage of areas under each class						
		Burirdanga	Suniltala	Chila	Chandpi	Sundarban	Mithakhali	Paurashava
< 1000	5	1.36	15.76	0	0.4	1.56	0.95	0
1000-1500	4	1.97	22.81	0	1.66	0.98	1.74	0
1500-3000	3	4.68	57.52	0	18.15	3.42	16.96	0.12
3000-6000	2	22.77	3.92	15.32	64.03	33.74	79.1	73.81
> 6000	1	69.22	0	84.68	15.76	60.3	1.24	26.06
Rank of Union		1.43	3.5	1.15	2.07	1.5	2.22	1.74

Table A6: Weighted average ranking of Electrical Conductivity (EC) in ground water

Class (μS/cm)	Rank	Percentage of areas under each class						
		Burirdanga	Suniltala	Chila	Chandpi	Sundarban	Mithakhali	Paurashava
< 1563	5	0.56	7.19	0	1.51	0.1	0.58	0
1563-2500	4	2.93	33.53	0	4.73	1.2	5.81	0
2500-5000	3	6.38	57.23	12.86	16.59	3.45	18.04	0.93
5000-10000	2	71.06	2.05	62.77	77.09	44.26	75.58	99.07
> 10000	1	19.07	0	24.37	0.07	50.99	0	0
Rank of Union		1.95	3.46	1.88	2.3	1.55	2.31	2.01