Ministry of Water Resources

Bangladesh Water Development Board

Coastal Embankment Improvement Project, Phase-I (CEIP-I)

Long Term Monitoring, Research, and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)

Groundwater Resource Assessment and Impact of Climate Change in Coastal Area

March 2022

DHI Deltares Enabling Delta Life IWM Water Environment & Climate CU Columbia University

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Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone

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Memo No: CEIP/LTMRA/0322/152 14 March 2022

Project Management Unit
Coastal Embankment Improvement Project, Phase-I (CEIP-I)
House No.15, 4tn Floor, Road
No.24(CNW) Gulshan, Dhaka-1212

Attn: Mr. Syed Hasan Imam, Project Director

Dear Mr Imam,

Subject: Submission of Groundwater Assessment and Impact of Climate Change in Coastal Area (Component 4D)

It is our pleasure to submit herewith five copies of the Report on "***Component 4D: Groundwater Assessment and Impact of Climate change in Coastal Area***". The report covers assessment of extent of groundwater salinity and the impact of climate change in the coastal region of Bangladesh.

This report contains 10 chapters which include background information, review previous studies, data collection and processing, extent of groundwater salinity, GW level conditions, GW salinity model, and application of GW salinity model for different scenarios.

Thanking you,

Yours sincerely,

Dr Ranjit Galappatti
Team Leader

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Table of contents

1 Introduction 1
1.1 Background 1
1.2 Specific objectives of (this report) 1
1.3 Report Structure 1

2 Review of Previous Studies 3

3 Description of the Study Area 11
3.1 Location 11
3.2 Climate 13
3.3 Geomorphology and Hydrogeological setting 13
3.3.1 Tectonic Setting 13
3.3.2 Topography 14
3.3.3 Soil Formation 15
3.3.4 Hydrogeology 16
3.4 Land-use 18
3.5 Physiography 19
3.6 River System 20
3.7 Soil Salinity 20

4 Data Collection, Processing and Analyses 21
4.1 Introduction 21
4.2 Field Visit 21
4.3 Water quality data Collection 21
4.4 Hydro-metrological Data Collection 26
4.4.1 Rainfall 26
4.4.2 Evaporation 26
4.5 Hydro-geological Investigation 27
4.5.1 Geological Section 27
4.5.2 Groundwater Level 29

5 Aquifer Properties and extent of the study area 31
5.1 Introduction 31
5.2 Lithological Characterization and Hydro stratigraphic Classification 31
5.3 Aquifer Properties in Coastal Areas 31
5.3.1 Hydraulic Conductivity 32
5.3.2 Transmissivity 33
5.3.3 Specific yield 33

6 Hydro-Chemical Investigation and Extent of Salinity 35
6.1 Introduction 35
6.2 Groundwater Salinity 35
6.3 Surface water Salinity 38
6.4 Electroconductivity of Groundwater 39

7 State of Groundwater Resources 41
7.1 Assessment of groundwater level 42
7.1.1 Groundwater Level Trend of Jessore 42
7.1.2 Groundwater Level Trend of Satkhira 43
7.1.3 Groundwater Level Trend of Khulna 44
7.1.4 Groundwater Level Trend of Barisal 45

7.1.5 Groundwater Level Trend of Barguna 46
7.1.6 Groundwater Level Trend of Pirojpur 47
7.1.7 Groundwater Level Trend of Patuakhali 48
7.2 Spatial distribution of groundwater well 48
7.2.1 Spatial distribution of groundwater level in dry season 48
7.2.2 Spatial distribution of groundwater level in wet season....50
7.2.3 Changes of groundwater level in dry season (from 2008 to 2018) 52
7.3 Changes of groundwater level in wet season (from 2008 to 2018)....53

8 Updating Groundwater Salinity Model 55
8.1 Introduction 55
8.2 Initial Condition 57
8.3 Boundary Condition 57
8.3.1 Surface Water Level 57
8.3.2 Groundwater Level 59
8.3.3 Surface water salinity 59
8.4 Inflow/outflow 60
8.4.1 Rainfall 60
8.4.2 Evapotranspiration....62
8.5 Calibration and Validation of model....62

9 Application of Groundwater Salinity Model 65
9.1 Generation of Rainfall and Temperature under Climate Change....65
9.1.1 Climate Change Projections 65
9.1.2 Rainfall & Evapotranspiration 66
9.1.3 Sea Level Rise....66
9.1.4 **Formulation of Scenarios**....66
9.2 Model Setup for Different Scenarios....67
9.3 Analysis and Evaluation of Simulated Scenarios 68
9.3.1 Scenario I....70
9.3.2 Scenario II....72
9.3.3 Scenario III....74
9.4 Comparison of the scenarios....76
9.4.1 Comparison of the Scenarios with Base Condition 76

10 Refences.... 77

List of Figures

Figure 3-1: Tectonic setting of Bangladesh 14
Figure 3-2: Topography of Bangladesh 15
Figure 3-3: Soil type of Coastal Zone 16
Figure 3-4: Land use map of coastal zone....19
Figure 4-1: Water Sampling at Field and Quality Measurement....22
Figure 4-2: Locations of Water sampling 24
Figure 4-3: Locations of Water sampling in model study area....25
Figure 4-4: Monthly average rainfall of different districts in study area 26
Figure 4-5: Monthly Average Evaporation of Khulna and Jessore 27
Figure 4-6: Geological Cross-Sections of the Study Area 28
Figure 4-7: Hydro-stratigraphic cross section at F-F'' and K-K' 29
Figure 4-8: Location of BWDB observation well 30
Figure 5-1: Hydraulic conductivity (Kh) in deeper aquifer(left) and in shallow aquifer(right) 32
Figure 5-2: Transmissivity for deeper aquifer(left) and shallow aquifer(right) 33
Figure 5-3: Specific yield in deep aquifer(left) and in shallow aquifer(right) 34

Figure 6-1: 1ppt groundwater salinity line in Coastal area 36
Figure 6-2: GW salinity in coastal areas in monsoon and post monsoon season 38
Figure 6-3: Comparison of surface water salinity 39
Figure 6-4: Electroconductivity of Groundwater for coastal areas of Study Area 40
Figure 7-1: Locations of groundwater observation well in the Study Area 41
Figure 7-2: Groundwater level hydrograph of Abhaynagar, Jessore 43
Figure 7-3: Groundwater level hydrograph of Manirampur, Jessore 43
Figure 7-4: Groundwater level hydrograph of Assusani union, Satkhira 44
Figure 7-5: Groundwater level hydrograph of Dacope union, Khulna 44
Figure 7-6: Groundwater level hydrograph of Phultola union, Khulna 45
Figure 7-7: Groundwater level hydrograph of Hizla union, Barisal 45
Figure 7-8: Groundwater level hydrograph of Banaripara union, Barisal 46
Figure 7-9: Groundwater level hydrograph of Barguna Sadar, Barguna 46
Figure 7-10: Groundwater level hydrograph (2008-2018) for Bhandaria, Pirojpur 47
Figure 7-11: Groundwater level hydrograph (2008-2018) for Nesarabad, Pirojpur 47
Figure 7-12: Groundwater level hydrograph (2008-2018) for Mizanganj, Patuakhali 48
Figure 7-13: Spatial distribution of groundwater level in dry season, 2008 49
Figure 7-14: Spatial distribution of groundwater level in dry season, 2018 50
Figure 7-15: Spatial distribution of groundwater level in wet season, 2008 51
Figure 7-16: Spatial distribution of groundwater level in wet season, 2018 52
Figure 7-17: Changes of groundwater level in dry season (2008 to 2018) 53
Figure 7-18: Changes of groundwater level in wet season (2008 to 2018) 54
Figure 8-1: Model study area 56
Figure 8-2: Initial Condition of Hydraulic Head (left) and Mass conc. (right) 57
Figure 8-3: Location of Surface water level boundary 58
Figure 8-4 : Location of Hydraulic Head Boundary 59
Figure 8-5 : Location of surface water salinity boundary 60
Figure 8-6: Thiessen Polygon in the study area 61
Figure 8-7: Location of calibration well 62
Figure 8-8: Comparison of GW Level in the calibration wells 63
Figure 8-9: Comparison of GW salinity distribution from (a) field data and (b) model 63
Figure 9-1: Groundwater Salinity for Scenario-0 69
Figure 9-2: Groundwater Salinity in Shallow Aquifer for Scenario-I (May 2050) 71
Figure 9-3: Salinity of Groundwater in shallow aquifer for model scenario 2 (May 2050) 73
Figure 9-4: Salinity of Groundwater in shallow aquifer for model scenario III (May 2050) 75

List of Table

Table 3-1: Upazila wise Distribution of the Study Area 11
Table 3-2: Comparison of Aquifer Systems of Bangladesh 18
Table 4-1: List of Field Visits 21
Table 4-2: Locations of collected groundwater and surface water sampling 22
Table 4-3: List of Evaporation Stations 27
Table 6-1: Area wise distribution of groundwater salinity in Coastal area 37
Table 8-1: List of SWL boundary stations 58
Table 8-2: List of groundwater level stations used for boundary of model 59
Table 8-3: List of Rainfall Stations 60
Table 9-1: Groundwater Salinity in Shallow Aquifer for Scenario-0 68
Table 9-2: Groundwater Salinity in Shallow Aquifer for Scenario-I (May 2050) 70
Table 9-3: Groundwater Salinity in Shallow Aquifer for Scenario-II (May 2050) 72
Table 9-4: Groundwater Salinity in Shallow Aquifer for Scenario-III (May 2050) 74
Table 9-5: Comparison among three Scenarios 76

ACRONYMS AND ABBREVIATIONS

BoB	Bay of Bengal
BWDB	Bangladesh Water Development Board
CEIP-	Coastal Embankment Improvement Project
CEIP-	Coastal Embankment Project
DEM-	Digital Elevation Model
FM-	Flexible Mesh
GBM	Ganges, Brahmaputra and Meghna
HD-	Hydrodynamic
IWM-	Institute of Water Modelling
EC -	Electroconductivity
SLR-	Sea Level Rise
SSC-	Suspended Sediment Concentration
SWRM-	South West Region Model
TRM	Tidal River Management
WL	Water Level

1 Introduction

1.1 Background

Groundwater is the largest natural resources of freshwater in Bangladesh. It plays an important role for sustaining agriculture, industrial uses, wetlands and ecosystem in our country. At present, about 80% of the people in rural Bangladesh rely on groundwater as their primary drinking sources. Groundwater also contributes largely to irrigation and 72% of the total coverage is provided by groundwater (Banglapedia). It is also an essential part of the hydrologic cycle. In the coming years, the ground water utilization is likely to increase for expansion of irrigated agriculture and to achieve targets of food production. Although the groundwater is annually replenishable resource, its availability is non-uniform in space and time. Hence, precise estimation of ground water resource and irrigation potential is a prerequisite for planning its development (Kumar, Singh).

Bangladesh is a low-lying delta country which is prone to many natural disasters like draught, flash flood, cyclones etc. Though groundwater level is recharged due to rain every year. The drastic over abstraction of groundwater for irrigation, drinking and industrial purposes is causing groundwater depletion thus ultimately results in serious water scarcity in some areas of Bangladesh. In other regions of Bangladesh, due to human intervention and climate change, the groundwater quality is deteriorating at an alarming rate. Every year cyclones of different magnitude hit us in the coastal region. These cyclones destroy our habitat and natural resources. Huge population density works as a multiplier of these disasters. Due to climate change and global warming, the intensities of these cyclones are increasing, and sea level is rising. Flood occurring from these cyclones and sea level rising causes salinity intrusion thus results in destroying the fresh water sources. That causes water scarcity.

However very little has been known about water availability and climate change effect on groundwater resources in the coastal region of Bangladesh. Thus, there are urgent need to address the climate change effect on groundwater salinity intrusion and groundwater resources.

1.2 Specific objectives of (this report)

The main objective of this report is groundwater resource assessment and to assess the climate change impact on groundwater salinity in the coastal region of Bangladesh.

1.3 Report Structure

This report consisting of 10 chapters.

Chapter 1: contains background, objectives, scope of works, outputs and limitations of the study.

Chapter 2: describes the review of previous studies and relevant reports and findings related to the present study

Chapter 3: provides the setting of the project area.

Chapter 4: describes data collection and processing

Chapter 5: highlights the aquifer properties

Chapter 6: assesses the extent of groundwater salinity in the study area.

Chapter 7: describes the GW level conditions over the study area.

Chapter 8: describes the updating of GW salinity model.

Chapter 9: focuses on the application of developed GW salinity model for different scenarios.

Chapter 10: References

2 Review of Previous Studies

Over the last few decades, various studies and development activities have been undertaken in the area relating to water resources development and salinity. Reports pertaining to the present study have been reviewed to gain an understanding of the salinity problem and its extent. A brief of the review of the relevant studies are presented below.

Bangladesh Land and Water Resources Sector Study (WB, 1972)

The study titled 'Bangladesh Land and Water Resources Sector Study' was carried out by World Bank. The study was based mostly on data collected prior to March 1971. The general objective of this study was to assess the agricultural development potential of Bangladesh. In this respect, it has reviewed over all water resource potential of Bangladesh and given in volume-VII which is comprised of four technical reports, TR No. 21-23, of which technical report-20 has dealt with overall water resource potential and technical report-21 with the groundwater potential. These later two reports have been reviewed.

Technical Report – 20

It is reported that "*Analysis of rainfall, runoff and surface conditions drawing together all available data, leads to conclusions that with the exception of limited areas near the western border and in the extreme south, the recharge potential would be to sustain intensive irrigated agriculture from groundwater withdrawals over most areas*".

It is generalized comment based on data and reports about groundwater conditions as on 1971. Studies of reports as on to-date about groundwater resources have indicated that the entire coastal areas of Bangladesh are not favourable for large scale groundwater developments. It is mainly due salinity problem.

It has been reported that over most of Bangladesh, there are groundwater aquifers which are suitable for groundwater development for irrigation, water supply for municipal, industry, and domestic uses. intrusion of salt water through rivers and inundation of lands by saline tide water is the limiting factor to full development of agriculture in the southern region of Bangladesh. Withdrawal of fresh water upstream will reduce the prospects of irrigation by pumping fresh water from coastal rivers and creeks.

Technical Report – 21

Aquifer properties and thickness have been determined from the bore holes and bore logs of production wells within the depth of 100m. Below the depth of 100m, aquifer extent is unknown in major areas of Bangladesh. Areas surrounded by saline estuaries have poor quality water in major areas.

Aquifer types, size and thickness has been determined from the test bore-holes and bore logs of thousands of production wells. Below the depth of 100m aquifer geometry was unknown in major areas of Bangladesh. Areas surrounded by saline estuaries had poor water quality near the surface; however, in several areas shallow wells provided good to brackish domestic water. In some areas at the coastal zone shallow groundwater is unsuitable for domestic consumption and well depths of 200 to 300m depth are required to obtain fresh water.

Regional extension of this deep aquifer and recharge conditions was yet to be known. So, development of potential resource was unknown, moreover this deep aquifer was sandwiched between the saline water layers at the top and below. Therefore, it was not advised to develop these deep aquifers by irrigation wells in the coastal zone unless recharge potential of the deep aquifers is known.

In brief, it may be said that the IBRD Document contains valuable data and information and analyzed results about water resources available at that time. It is an important study-report about water resources, although past findings and conclusions need to be revisited with present data and analysis.

Khulna Water Supply Project (DPHE, 1981)

The feasibility study on Khulna water supply project was done by HASKONING B.V, Consulting Engineers & Architects and IWACO B.V, International Water Supply Company in 1981 to identify the possible groundwater sources in and around the Khulna city in order to cover the projected total water demand.

A comprehensive field data collection programme consisted of 19 reconnaissance drilling and electric borehole logging, 35 geo-electrical sounding, 3 aquifer tests, 43 groundwater quality analyses have been carried out during the study period. From those surveys, it was found that the saline shallow aquifer is encountered between a depth of approximately 31m and 121 m, having the transmissivity of approximately 2300 m^2/day at Khalishpur. A pumping test in deep aquifer was carried out near Gollamari indicated a transmissivity of 2500m^2/day. However, it did not mention whether the correction factor for brackish/saline water is considered or not. In general, the study found that in Khulna and surroundings thick clay layers and lenses occur which restrict vertical flow of groundwater which gives the aquifer a multistore character while gully-like clay deposits might restrict also even the horizontal flow. The aquifer is partially confined by means of silty and clayey top-layers, which reach a thickness of over 60 m near Khulna. In the northern part the aquifer locally is nearly unconfined.

Data regarding groundwater quality in the upper aquifer indicates that water is brackish to saline in the Khulna region. It was found in the study that the fresh-saline groundwater interface lays at depth between 200 m and 300 m. The Chloride contents in the deep aquifers ranging from less than 25 ppm to 100 ppm at Dumuria. In the south of Dumuria, the water quality in the aquifer gradually deteriorates.

Ground-Water Survey (BWDB, 1982)

The study was conducted by BWDB and funded by UNDP focusing the activities of groundwater investigation along with previous data/information on groundwater. Results of groundwater investigations were presented graphically. The report stated that transmissivity of Khulna region in the range of 1000 m^2/day to 2000 m^2/day in the main aquifer.

Geohydrological Investigation in Khulna (DPHE, 1985)

Due to expansion of groundwater-based drinking water supply system, a study entitled Khulna Geohydrological Investigation was carried out. Since the deep aquifer is overlain by brackish groundwater, it has been ascertained that freshwater recharge by direct infiltration from rainwater or floodwater close to Khulna cannot be possible. Carbon-14 analysis (isotopic dating) of waters from wells in deep aquifer indicated that about 10,000 years has elapsed since the water has entered the groundwater reservoir. In some instances, the investigation termed those waters as fossil water and its abstraction has been considered as non-renewable. However, the study was lacking in conducting any monitoring campaign in the

Khulna region. Therefore, groundwater abstraction in Khulna is mainly a mining process of the fresh groundwater resources.

Groundwater Resources (MPO, 1986)

Technical Report no 5 of MPO has presented countrywide groundwater resources assessment based on the then available hydro-geological data and information and primary data collected from detailed 8 eight specific study areas.

Country wide contour map of transmissivity has been prepared using data of existing tube well's development tests data and aquifer test data. In the study area the transmissivity value has been estimated around 1000 m^2/day; for thin aquifer it may vary from 200-700 m^2/day. Contour map of specific yield has also been prepared using bore log and aquifer test data assuming that specific yield value increases linearly with the increase of depth from ground surface due to increase of sand content in the aquifers. The average value of specific yield for the study area is in the range of 2% to 5%. It is agreed that, this value depends on the accuracy of identification of aquifer materials as shown the bore-log.

Salinity Distribution Study (FAP 4, 1993)

The southwest region water management project aimed to provide a management plan for land and water resources. One of the key elements of the plan is groundwater which is a major source of potable water and irrigation. The study tried to relate freshwater and groundwater interactions at a conceptual state not in detail. The study shows the following points:

Presence of saline front and lenses of fresh water in the upper aquifer,

Presence of saline wedge in the main aquifer, and

Existence of hydraulic conductivity between surface aquifers and rivers.

In the upper aquifers the position of the saline fronts can be controlled by regional flow of groundwater towards the sea and prevailing recharge conditions. In addition, freshwater lenses may occur, overlying the saline water. Under natural conditions only minor seasonal changes take place in these relationships between fresh and saline waters. The over abstraction of groundwater for irrigation at upstream, for example, the unconfined aquifers of Khustia-Jessore areas will tend to move the saline front inland. Similarly, over abstraction or badly planned abstraction of water from the freshwater lenses will cause up-coning of saline water with the effect of turning the wells saline. These problems have already occurred in Khulna region.

Study on Salinity Management Techniques (BRRI, 2001)

BRRI conducted a research program entitled "Development of Suitable Management Techniques and their Environmental Impact Assessment on the Coastal Ecosystem of Bangladesh" in association with Bangladesh Agricultural Research Council (BARC). The greater Khulna district alone contributes about 23% of the total coastal ecosystem. Generally, four categories of salinity exist in the coastal areas ranging from S1 (2-4 dS/m) to S4 (>16 dS/m) as mentioned by Karim et al (1990). The extent of salinity level of most of the soils (68%) in the greater Khulna district is S2 category (4-8dS/m), 13% area is under each S1 and S3 (8-16dS/m) categories and only 6% area is under S4 category.

From the study it was known that the salinization process of both surface water and groundwater mainly depends on the hydrodynamic balance between fresh and saline water interface. If the freshwater pressure in river or underground layer is more, the salinity penetration or intrusion will be less into the groundwater. In many places of the coastal area, groundwater salinity ranges from 1.5-2.0 dS/m during the dry season (Mondal, 1977).

Khulna-Jessore Drainage Rehabilitation Project (BWDB, 2002)

This study has been conducted to examine the tidal dynamics in rivers and tidal basin for tidal management. Bangladesh Water Development Board engaged IWM to carry out the study. The study includes extensive hydro-morphological data collection activities, development of a database system and finally development of a mathematical model. In addition, measurements of surface water salinity, groundwater level and groundwater salinity have also been carried out during the project period. The developed model has been used to understand the tidal dynamics and physical process in the rivers and tidal basins.

In order to monitor tidal basin operation on groundwater, observation wells were installed at different locations inside the project area. Groundwater level varies from 0 mPWD in dry period to 2.0 mPWD in wet season. The salinity level in the groundwater reaches its maximum when groundwater level is lower, in general salinity level varies from 1.0 to 1.5 ppt. Similar temporal variation of groundwater level and groundwater salinity has been found but no significant spatial variations.

Southwest Area Integrated Water Resources Management Project (WARPO, 2004)

Groundwater is the main source of water for domestic uses and drinking water. South of Jessore and Khulna saline intrusion through the surface water channels make this resource less and less usable. Potential recharge for Abhaynagar upazila was estimated to be 35.37 Mm^3 with an available recharge of 20.5 0 Mm^3.

Saline Water Quality Assessment (SRDI, 2009)

High salt content is limiting crop intensification in the coastal zones of Bangladesh. Salt enters inland through rivers and channels during the later part of the dry season when the downstream freshwater flow becomes low. Salt also enters the soil by flooding with saline river water to concentrate in the surface water layers through evaporation. River water causes an increase in salinity of groundwater and possibly makes it unfavourable environment over prevailing hydrological condition, to restrict intensive crop production throughout the year. Thus, the soil and groundwater salinities are making winter crop cultivation difficult during November to May. The irrigation coverage in the coastal zone is only 30% of the net cropped area, compared to 50 % of the country (PDO-ICZMP, 2004).

Implications of Climate Change for Fresh Groundwater Resources (WB, 2010)

The study mainly focused on understanding the salinization process in the coastal zone, implication of climate change on the coastal groundwater and evaluation of the consequences of climate change and means of mitigating the negative impacts. The study identified three main ways of salinization in the coastal aquifer, (i) intrusion of saline sea water in the coastal groundwater due to sea level rise and/or falling ground water level, (ii) downward vertical movement of saline surface water to the aquifer. This saline surface water could be brought towards inland by storm surges or coastal flooding, (iii) migration of pre-existing pockets of saline water in the subsurface.

The rate of saltwater intrusion in coastal aquifer may be accelerated with increased pumping of groundwater from the aquifer, rise in sea level, increased incidence of storm surges etc. The study observed that vertical downward movement of saline water could be quicker than lateral saltwater intrusion, particularly if the surface inundation events are frequent. The study finding suggests that direct impact of sea level rise through inundation of coastal land and increased incidence of storm surges are of great concern than the traditional lateral salinity intrusion. The study suggested for undertaking scientific studies supported by appropriate modelling tools, survey and data collection for properly understanding the salinization process and formulating mitigation measures.

Forecasting Saline Water Intrusion, Water Quality and Water Logging (BADC, 2011)

BADC undertook a GW salinity monitoring program during 2009-10 and 2010-11 fiscal years in the southern region of Bangladesh. The monitoring program covered May-June of 2009 and November-December of 2010. Salinity data was collected at every 10 feet interval from 130 locations distributed over the Khulna, Dhaka, Barisal and Chittagong division in southern part of Bangladesh. The report made a comparison of the salinity status of the two periods on a district basis.

As to the causes of salinity expansion in the coastal region the report noted that decrease of upstream flow due to Farrakka Barrage on the Ganges River is one of the main reasons for salinity expansion in the region. Other contributing factors include horizontal expansion of shrimp farms and Coastal Embankment Project implemented during the 1960s. The report apprehended that salinity expansion may be exacerbated by climate change and sea-level rise.

About lateral extent of salinity in the coastal region the report states that saline soils occur in the river deltas along the sea coast, a few kilometers to 180 kilometers. According to salinity survey findings and salinity monitoring information, about 1.02 million ha (about 70%) of the cultivated lands are affected by varying degrees of soil salinity. About 0.282, 0.297, 0.191, 0.450 and 0.087 million hectares of lands are affected by very slight, slight, moderate, strong and very strong salinity respectively. Cropping intensity may be increased in very slight and slightly alkaline areas by adopting proper soil and water management practices with introduction of salt tolerant varieties of different crops.

The report recommended for intensive salinity data collection program, particularly using auto logger, in the coastal region to monitor the trend of salinity movement and to formulate mitigation and adaptation measures to cope with the impending climate change threat.

Joint Action Research on Saltwater Intrusion in Groundwater in the Coastal Area (IWM-DPHE, 2015)

The main objective of this study was assessment of salinity extent, aquifer vulnerability and salinity intrusion and freshwater pockets in the study area that covers three districts Khulna, Jessore and Satkhira.

To fulfil the objectives of the study, 45 groundwater observation wells were installed under this study. GW level data was collected by using auto recorders and used from 7 observation wells. Data on topographic, hydro-geologic, hydrometric, hydro-chemical and bathy were also used for model development. For assessment of GW quality parameters, i.e., EC, temperature, pH, TDS and chloride from 350 selected tubewells have been collected comprising both shallow and deep tubewells in three different periods (December 2011, October 2012 and April 2013). In order to ensure reliability of field test results of water quality, 10% water samples were analyzed in the renowned laboratories. Correlation equation was used in case of chloride data due to limitation in field value particularly at low range.These data were used in the model development, addressing salinity extent, preparation of vulnerability map and identification of water pockets in the study area.

In order to understand the salinity intrusion process in the coastal aquifer density dependent groundwater modelling tool FEFLOW was used. This model was also coupled with river model, developed using MIKE 11 modelling software. Besides this, the boundary conditions of river model for future scenarios ware extracted from GBM and BoB model.

In this study it is found that, Shallow aquifer is more saline than deep aquifer with exception of Paikgacha, where shallow aquifer is relatively less saline. In major cases salinity of shallow aquifer exceeded allowable limit of 1000 mg/l. At the base condition, the low salinity zone (< 1000 ppm) lies along the western part of the study area and the high salinity zone (> 1000 ppm) lies along the southern and eastern sides. In the study area groundwater salinity for shallow aquifer varies from 250 mg/L to 3500 mg/L. Water pockets (fresh/saline) within the study area were identified based on primary data supported by findings from FGD and KII.

Mathematical Modelling Study (Groundwater and Surface water) to Assess Upazila wise Surface Water and Groundwater Resources and Changes in Groundwater Level Distribution due to Withdrawal of Groundwater in the Study Area

The study mainly focused on assessing the surface water as well as groundwater resources for the two pilot areas of the coastal belt of Bangladesh. The pilot area-1 was of 4867 sq km lies in 15 Upazilas of the districts of Barisal, Patuakhali, Barguna, Pirojpur and Jhalokhati and Pilot area-2 was spread over 946 sq km of Chittagong District.

In order to achieve the study objectives, a mathematical modelling study supported by comprehensive data collection program has been carried out. Major activities of the study include cross section survey, hydrometric data collection, computation of water demand, model calibration and validation. The models developed under this study are based on MIKE-11 for surface water model and MIKE-SHE for groundwater model. Existing river systems and updated topographic features have been included in surface water model setup while hydro-geological setting, aquifer properties, DEM, land use pattern, etc are incorporated in groundwater model. Both the models have been integrated and simulated dynamically. The coupled model has been calibrated using the data for period of 2000 to 2005 and validated for the period of 2006 to 2009. The validated model was simulated for base condition and climate change conditions. Surface water resources at some key locations have been assessed based on average year. Groundwater resources have been assessed considering yield criteria of 6m and 7m depth from ground surface, and potential recharge. Useable recharge is considered as 75% of the potential recharge to account for various uncertainties inherent in different assumptions.

The study identified three possible ways of salinization in the coastal aquifer, (i) intrusion of saline sea water in the coastal groundwater due to sea level rise and/or falling ground water level, (ii) downward vertical movement of saline surface water to the aquifer. This saline surface water could be brought inland by storm surges or transgression of the coast, (iii) migration of pre-existing pockets of saline water in the subsurface. This may happen due to withdrawal of groundwater for drinking or other purposes.

The rate of saltwater intrusion in coastal aquifer may be accelerated with increased pumping of ground water from the aquifer, rise in sea level, increased incidence of storm surges etc. The study observed that vertical downward movement of saline water could be quicker than lateral saltwater intrusion, particularly if the surface inundation events are frequent. The study finding suggests that direct impact of sea level rise through inundation of coastal land and increased incidence of storm surges are of great concern than the traditional lateral salinity intrusion. The study suggested to undertaking scientific studies supported by appropriate modelling tools, survey and data collection to properly understand the salinization process and formulating mitigation measures.

3 Description of the Study Area

3.1 Location

The study area covers South Western region of Bangladesh which is approximately in between 88.787746° E to 91.032903° E longitudes and 21.887773°N to 23.156002°N latitude. Within the study area, there are 12 Districts like Jessore, Gopalganj, Narail, Barisal, Khulna, Bagerhat, satkhira, Pirojpur, Jhalkathi, Patuakhali and Barguna. Under these districts, there are 66 Upazillas and the study area covers total 23714 km^2. The upazillawise coverage within the study area is given in Table 3-1.

Table 3-1: Upazila wise Distribution of the Study Area

Sl No.	District	Upazilla Name	Upazilla wise coverage (Sqkm)
1	Satkhira	Kalaroa	229
2		Tala	335
3		Satkhira Sadar	399
4		Debhata	171
5		Assasuni	377
6		Kaliganj	329
7		Shyamnagar	1969
8	Jessore	Chaugachha	276
9		Bagher Para	272
10		Kotwali (Jessore Sadar)	435
11		Jhikargachha	312
12		Sharsha	340
13		Abhaynagar	249
14		Manirampur	444
15		Keshabpur	257
16	Narail	Lohagara	293
17		Narail Sadar	384
18		Kalia	305
19	Khulna	Batiaghata	238
20		Paikgacha	378
21		Dacope	1050
22	Bagerhat	Mollahat	205
23		Chitalmari	196

Sl No.	District	Upazilla Name	Upazilla wise coverage (Sqkm)
24		Fakirhat	160
25		Bagerhat Sadar	267
26		Kachua	126
27		Rampal	322
28		Morrelganj	439
29		Mongla	1502
30		Sarankhola	825
31	Pirojpur	Nazirpur	222
32		Nesarabad (Swarupkati)	184
33		Pirojpur Sadar	262
34		Kawkhali	80
35		Bhandaria	165
36		Mathbaria	350
37	Gopalganj	Muksudpur	310
38		Kashiani	288
39		Gopalganj Sadar	377
40		Kotali Para	363
41		Tungi Para	129
42	Jhalokati	Jhalokati Sadar	189
43		Nalchity	235
44		Rajapur	160
45		Kanthalia	158
46	Barisal	Gaurnadi	142
47		Hizla	343
48		Muladi	229
49		Agailjhara	163
50		Wazirpur	248
51		Babuganj	158
52		Mehendiganj	414
53		Banari Para	135
54		Barisal Sadar (Kotwali)	308
55		Bakerganj	407

Sl No.	District	Upazilla Name	Upazilla wise coverage (Sqkm)
56	Barguna	Betagi	168
57		Bamna	99
58		Amtali	565
59		Barguna Sadar	378
60		Patharghata	311
61	Patuakhali	Bauphal	476
62		Patuakhali Sadar	441
63		Mirzaganj	177
64		Dashmina	304
65		Galachipa	1202
66		Kala Para	492

3.2 Climate

The study area experiences a tropical humid monsoon climate. In summer the mean maximum temperature is well above 35˚C whereas in winter the mean minimum temperature is around 10˚C. The cool weather begins in December and continues up to the end of February. The average highest rainfall occurred in the month of July (372mm) while the average lowest (6 mm) occurred in December. The average annual rainfall of coastal area for the period of 2000-2018 has been recorded as 2000 mm and about 88% rainfall occurs in May to September. The post-monsoon period (October to November (Fall/Autumn)), is warm and humid. The relative humidity in the study area varies from 43% to 86%. The potential evapotranspiration is the lowest in December.

3.3 Geomorphology and Hydrogeological setting

Hydrogeological parameters of an area are generally governed by the lithostratigraphy and prevailing tectonic activities of that area which is a part of regional geological setting, physiography and geomorphology. Geomorphology is the scientific study of the origin and evolution of topographic and bathymetric features created by physical, chemical or biological processes operating at or near the Earth's surface. In this part of study, soil formation, land use pattern, topography, soil quality such as salinity, underground water situation such as aquifer etc. has been discussed.

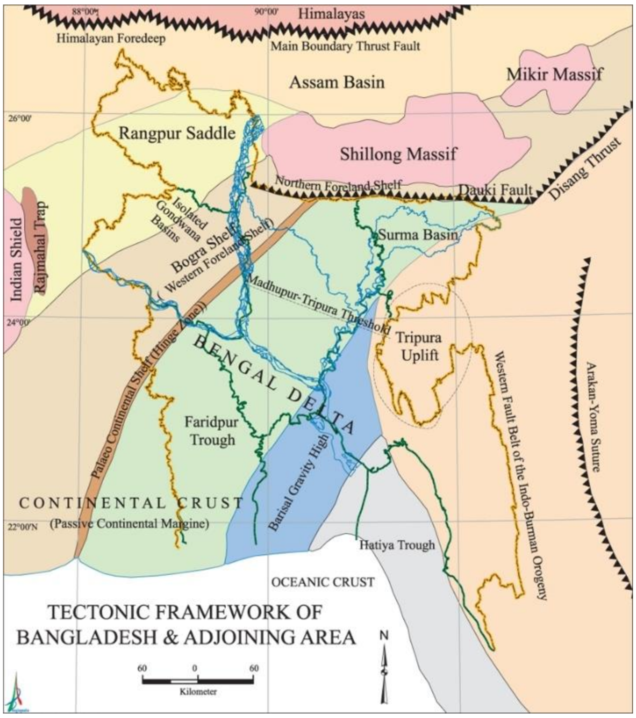
3.3.1 Tectonic Setting

Tectonics are the processes that control the structure and properties of the Earth's crust and its evolution through time. Tectonic Framework refers to the basic structural frame on which Bangladesh stands. It is essential to have a clear conception about the tectonic framework of Bangladesh in order to evaluate the prospect of mineral water including oil and natural gas. [Sifatul Quader Chowdhury].

Bangladesh is divided into two major tectonic units: i) Stable Pre-Cambrian Platform in the northwest, and ii) Geophysical basin in the southeast. There is also a third unit, a narrow northeast-southwest trending zone called the hinge zone. Hinge zone separates the above two units almost through the middle of the country. This hinge zone is currently known as paleo continental slope. The tectonic setting of Bangladesh is shown in Figure 3-1.

For the study area the 2nd tectonic unit is applicable, that is the geophysical basin in the southeast. It has three divisions, Faridpur trough, Barisal gravity high and Hatiya trough.

If we observe the tectonic settings of the study area. Khulna, Satkhira, Bagerhat, Jessore, Narail and Gopalganj falls on the Faridpur Trough and rest of the area falls on the Barisal Gravity High plate.



***Source: Banglapedia*

Figure 3-1: Tectonic setting of Bangladesh

3.3.2 Topography

The topography of the study area has been collected from SRTM, which has the resolution of 30m. From the topography map, it has been observed that, coastal region is mostly flat land. 76% of the area has the elevation of 0-2m. There is not much undulation at the topography of the study area. Upper portion of the study area which means Jessore, Narail and Upper portion of Barisal has the higher elevation which ranges from 5 mPWD to 10 mPWD. The elevation of the mangrove forest is less than 1 mPWD. The topography of the study area is shown in Figure 3-2.

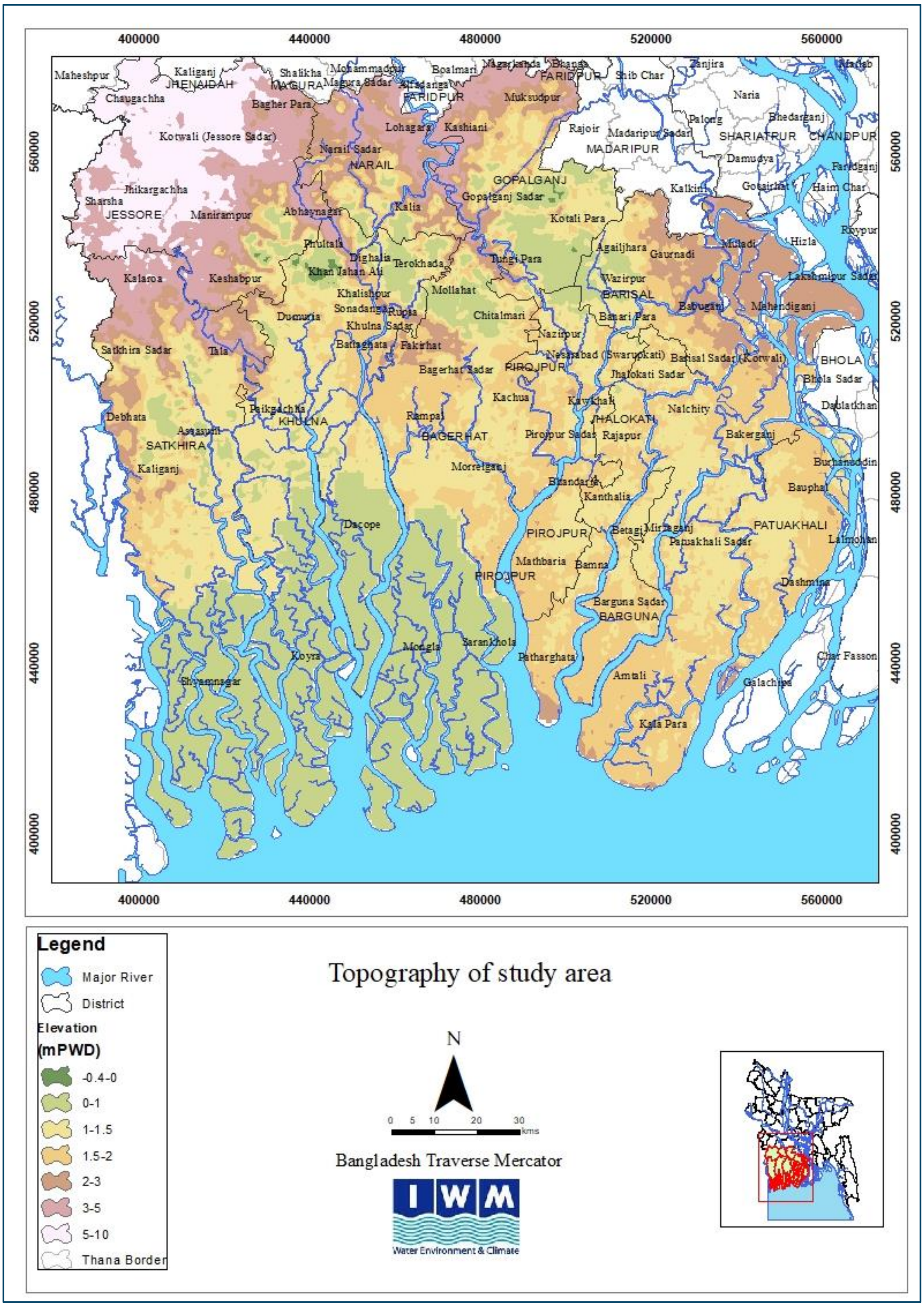


Figure 3-2: Topography of Bangladesh

3.3.3 Soil Formation

Mainly three major types of soil govern the coastal area. These are grey floodplain soil (silt loam & clay), acid sulphate soil and brown floodplain clay. Beside this, peat and calc. alluvium soil also exist in the study area.

Part of Satkhira, Khulna, Barguna, Pirojpur, Patuakhali and some regions of Barisal etc districts contain grey floodplain soil along with silt, loam & clay. In Jessore and the rest of the Barisal districts, the soil type is calcareous dark, grey and calcareous brown floodplain soil. The Sundarbans area contain acid sulphate soils. Whole Bhola district contain calc. alluvium soil. The soil type of the coastal zone is shown in Figure 3-3.

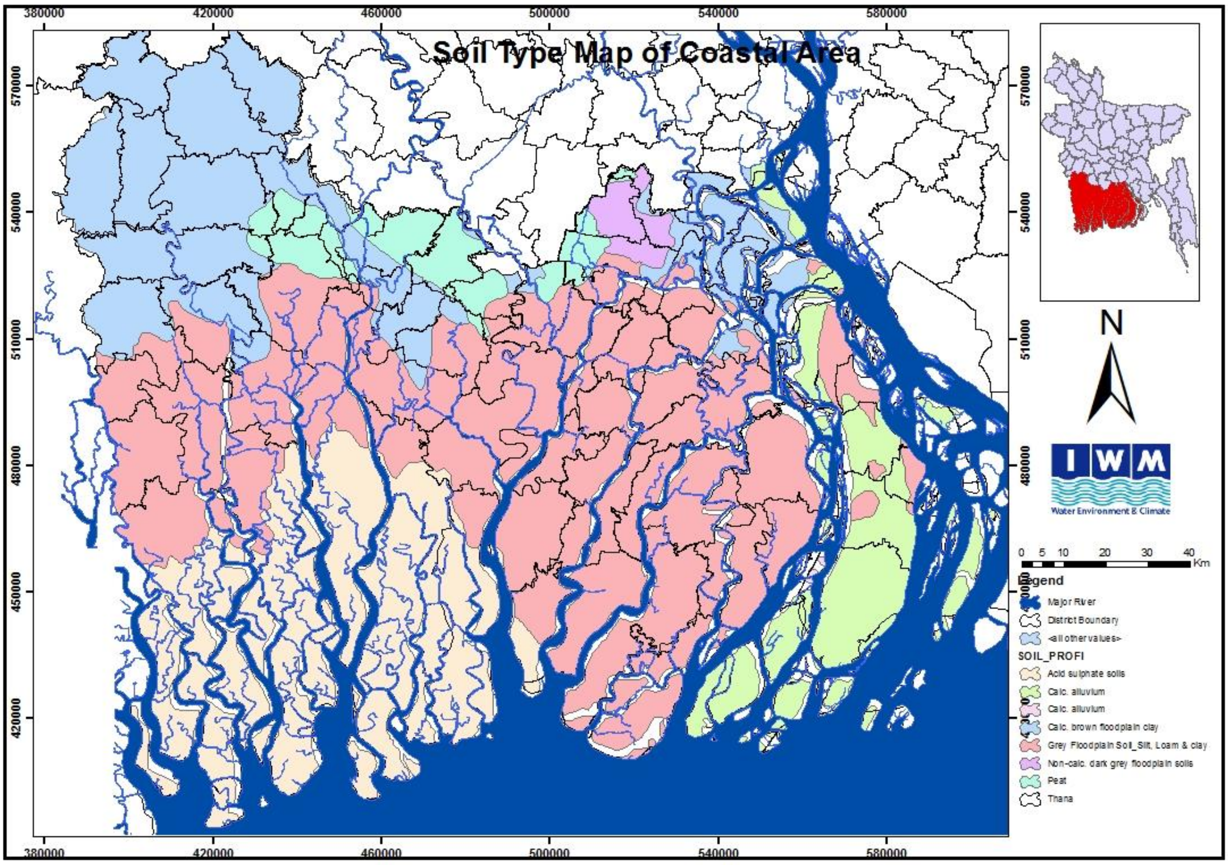


Figure 3-3: Soil type of Coastal Zone

3.3.4 Hydrogeology

Existing information on aquifer formation have been collected from various secondary sources. It gives an idea about the depth and variable thickness of the aquifer in the study area. Tectonically Bangladesh occupies the major part of Bengal Basin and forms the largest delta complex in the world. It is bounded by the Indo-Burma ranges in the east, in the west by the Indian shield, in the north by the Shillong massif and the Himalayan thrust fault and in the south it is open towards the Bay of Bengal for a considerable distance. The delta development activities are still going on in the south by deposition of the major river system. Quaternary sediments deposited mainly by the river Ganges, Brahmaputra and Meghna, which covers about three-quarters of Bangladesh with exception of Tertiary folded belts. Rangpur platform, Bogra shelf, Hinge zone, Trough area and Tripura-Chittagong folded belt are the major regional elements of the country.

The geology of the study area can be attributed to Quaternary alluvial sequence, which is a part of the Ganges flood plain. According to Davies (1989, 1994), Davies &Exley (1992), Monsur (1995) and Umitsu (1993) the study area lies in the Faridpur trough of Bengal Foredeep considering the tectonic setting. The quaternary climatic fluctuations were the controlling factors in the deposition of recent sediments and the late Quaternary sedimentary sequences. At the peak of last glaciation, the sea levels, and thus the base level for rivers, were about 100m to 130m below the present Mean Sea Level. This led to the erosion of previously deposited Plio-Pleistocene sediments and the river channels cut narrow and further deeply incised valleys through the underlying sediments. Again, the sea level began to rise at the beginning of Holocene, the hydrodynamic conditions of the river system were changed, and the Holocene deposits filled up the incised valleys. The thick lobes of coarse sand and gravels were deposited in the incised channels and larger cobbles and boulders were brought down sporadically from the Himalayas far away towards the south due to strong hydrodynamic conditions. Lastly, fine-grained sediments were deposited when the sea level has become higher. This pattern of deposition has resulted in a complex array of coarse sand and gravel channel-fills followed by intercalated fine sand and silt layers of alluvial and deltaic floodplain deposits. Thus, the sedimentary environment changed from braided streams (sandy gravel deposits) and meandering rivers to flood plains with the deposition of first sand and gravels and later finer silty sediment.

The Quaternary alluvium and deltaic deposits of Bangladesh generally constitute the aquifer system in the country with good hydraulic characteristics in terms of transmissivity and storage coefficient. Annual rainfall and flooding are the main sources of recharge to groundwater aquifer. Thick semi-consolidated to unconsolidated fluvio deltaic sediments constitute the aquifers of the country. The sandy aquifers generally exist within 350 meters depth. The general groundwater flow trend of the country is from the northwest to the south-southeast direction. Considering the groundwater investigation and hydro-geological studies by different agencies the aquifer system of the country is categorized into four different major aquifer systems. The depth locations of these aquifer systems are variable to sediment deposits and general topography. Brief descriptions of these four aquifer systems are:

Upper shallow aquifer system:

The upper shallow aquifer generally exist within 50m below ground level consisting mostly of heterogeneous assemblage of sand, silt and clay.

Lower shallow aquifer system:

Unconfined to mainly semi-confined aquifers generally exist between 50m – 150m below ground level, consist of medium to coarse sand with occasional fine sand and silt.

Deep aquifer system:

This deeper aquifer is more than 250m below ground level. By depth, 150m is the boundary of deep aquifer as adopted in the BGS & DPHE (2001). In the coastal region, deep aquifer was defined as aquifer containing fresh water and occurring in the depth range of 220 to 350m (DANIDA/DPHE, 2001). It generally consists of fine to medium sands and mostly of confined to semi confined in nature. The aquifer exists below main aquifer in reasonable depth with confined nature and sufficient hydrostatic pressure can be termed as deep aquifer. Table 3-2 presents the summary of the aquifer system of Bangladesh.

Table 3-2: Comparison of Aquifer Systems of Bangladesh

UNDP (1982)	Aggarwal et. al. (2000)	BGS & DPHE (2001)	JICA (2002)	GWTF (2002)
Upper/Composite Aquifer	1st Aquifer	Upper Shallow Aquifer	Upper Aquifer	Upper Holocene Aquifer
Main Aquifer	2nd Aquifer	Lower Shallow Aquifer	Mid Aquifer	Middle Holocene Aquifer
Deep Aquifer	3rd Aquifer	Deep Aquifer	Deep Aquifer	Late Pleistocene-Holocene Aquifer

3.4 Land-use

The land use map of the coastal zone is shown Figure 3-4. The crop land type pattern governs almost all area of the coastal zone except the south western part of the study area. Southern portion of Satkhira and Khulna is covered by regularly flooded forest type land pattern which is the mangrove forest Sundarbans. According to land use map, part of Khulna, Satkhira, Bagerhat have closed to open broadleaved forest regularly flooded (fresh-brackish water), closed broadleaved forest permanently flooded (saline-brackish water).

Barguna, Patuakhali, Pirojpur, Jessore and the rest of Satkhira, Khulna, Bagerhat consist of irrigated, rainfed and mosaic cropland. Besides this, these coastal areas also contain some water body and deciduous forest. Deciduous forest discretely lies on Jessore and Satkhira, Khulna.

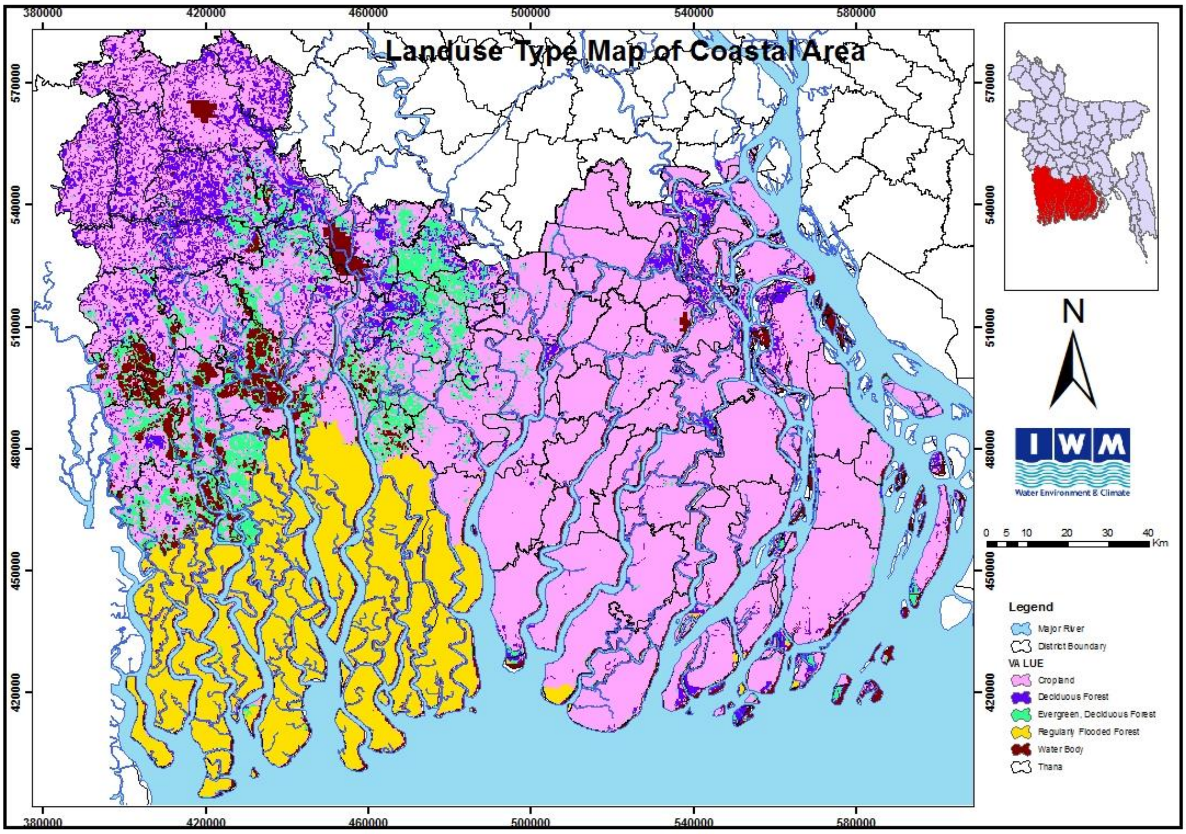


Figure 3-4: Land use map of coastal zone

3.5 Physiography

Physical geography (also known as physiography) is one of the two fields of geography. Physical geography is the branch of natural science which deals with the study of processes and patterns in the natural environment such as the atmosphere, hydrosphere, biosphere, and geosphere, as opposed to the cultural or built environment, the domain of human geography. The physiography of the country has been divided into 24 sub-regions and 54 units.

The study area falls in three physiographic unit, Unit 8: Ganges Flood Plain, Unit 9: Ganges Tidal Flood Plain, Unit 10: The area is criss-crossed by innumerable number of rivers and creeks whose banks generally stand generally less than 1 meter above the adjoining basin. The whole of this unit is lies within the cyclone zone.

The study area also falls in three agro ecological zones (AEZ 11, 13 &14) of the country. Ganges Tidal Flood Plain covers most of the area followed by High Ganges Flood Plain. The soil in the Ganges flood plains is Calcareous silt loams to silty clays.

The land of AEZ 11, High Ganges Flood Plain, is composed of some high land and some medium high land with patches of some low land in the form of beels. The land in the AEZ 13, Ganges Tidal Flood Plain, is mostly medium highland with some patches of low land. The land in AEZ 14-unit Gopalganj-Khulna Beels makes part of peat basins and is comprised mainly medium low land followed by low land with some area under medium high land and patches low and very low land.

3.6 River System

Large number of rivers crisscrossing the study area in the coastal zone. The most prominent rivers are Rupsha, Passur, Sholmari, Shibsa, Bhadra, Kobadak. These rivers are all tidal and undergo semidiurnal tidal fluctuation. These rivers along with large number of creeks influence the hydrology of the Study area. But study area is within polders of BWDB coastal embankment. The upper part in Jessore is outside polders. The surface water resource area includes some beels and large number of ponds.

The area is affected by the withdrawal of the Ganges in the dry season. The dry season flow which was used to reach Khulna through Gorai-Madhumati now remains cut off from the Ganges and therefore the dry season salinity of Rupsha at Khulna has increased three folds over what was before commissioning of the Farakka Barrage. The increase in salinity and reduction in flow has brought significant morphological changes in the area; notably in Bhadra River.

3.7 Soil Salinity

The most of the study area is salt affected. The soil salinity of the area increases from north towards the southern part. The soil salinity decreases significantly during the monsoon season. The rainfall leaches down the soil salinity from the surface to the deep substratum. The severely saline soils become slightly saline and slightly saline soils turns into non saline soils during the monsoon season, mainly due to dilution of saline water with more fresh water from rainfall. The dry season soil salinity in the area ranges from 2.0 ds/m to 8.0 ds/m. Paikghacha upazila is the most highly saline and Abhaynagar upazila is the least saline area within the study area (SRDI, 2010). Presence of high salinity in the soil and non-availability of fresh water for irrigation during the dry season has restricted the growth/increase of Boro crops in the area. The salt affected soil are supporting T. Aman crop in kharif season. The practice of shrimp farming in the area is increasing soil salinity (IWM, 2010). Salinity has also severely affected other socio-economic activities and environmental setting of the area.

4 Data Collection, Processing and Analyses

4.1 Introduction

For groundwater resource assessment in the coastal region, different types of data have been collected from both the primary as well as from secondary sources. Since available data from secondary sources was limited, data collection at field level has been undertaken. Primary sources data include water quality data (pH. EC and salinity) of groundwater and surface water. Secondary sources data includes hydro geologic data, aquifer properties, topographic data, groundwater and surface water level & salinity, Rainfall and evapo-transpiration data. These data have been collected to fulfil the requirement of the study. a brief description of the collected data is presented in the following sub-sections.

4.2 Field Visit

For collection of data and information from the field, so far three field visits have been conducted during September’2019, January’2020 and October’2020. The main objectives of the field visits were water sampling from different hand tube wells and river for measuring the water quality.

The field visit during October’2020 was conducted to collect groundwater sample for salinity measurement in the model study area for validation of model. The list of the field visits is given in Table 4-1.

Table 4-1: List of Field Visits

SL No	Team Members	Period	Activities
1.	Md. Tarikul Islam Arnob Barua	2nd Sep'19 to 11th Sep'19	Collection of Groundwater and Surface water samples at different selective locations
2.	1. Arnob Barua	11th Jan'20 to 20th Jan'20	Collection of Groundwater and Surface water samples at different selective locations
3.	1. Arnob Barua	28th October to 31th October	Collection of Groundwater samples at different selective locations within model study area

4.3 Water quality data Collection

In order to have a clear picture about the spatial and temporal variation of water quality, water samples have been collected from 25 different selective locations of the study area during monsoon, post-monsoon season. The locations of sampling have been selected in such a way that it represents the whole study area. In order to get the surface water quality, surface water sample have also been collected at two different locations.

Accordingly, the team from IWM collected water samples (Figure 1) from the selective locations. Groundwater samples have been collected from the existing hand tube wells. The positions of each sampling have been recorded with hand held GPS. Before sampling, sufficient water has been pumped out so that, any impurities that might have entered through the outlet of tubewell is washed out. The list of the selective locations for water sampling is given in Table 4.2 and shown in Figure 4.2. From the collected water samples, pH, EC and salinity have been measured.

Figure 4-1: Water Sampling at Field and Quality Measurement

Table 4-2: Locations of collected groundwater and surface water sampling

Sl No.	Sample ID	Address	Well Depth (m)	UTM_X	UTM_Y
1	GW01	Jessore New Market, Khajura Bus Stand Petrol Pump (Prantik Petrol Pump), Jessore Sadar, Jessore.	24.39	726768	2564886
2	GW02	Monirampur Adarsha Primary School, Monirampur, Jessore.	259	728425	254785
3	GW03	Besides Talikarkhana, Mouza-Sripotipur, Kalaroa, Satkhira.	37	710133	2529607
4	GW04	Satkhira Sadar, Kasim Super Market, Satkhira.	128	712640	2513038
5	GW05	Nalta Union Parisad, Kaliganj (Shamim Cloth Store), Satkhira.	64	707336	2490879
6	GW06	MM Plaza, Shyamnagar, Badhoghata, Shatkhira	64	716802	2472302
7	GW07	Bidhan Chandra Sana's House, Shibbati Bridge, Shibbati, Paikgacha, Khulna	28.74	737028	2499177
8	GW08	Darus Sunnah Salafia Madrasa (Abu Naser Hospital Mor), BN School	34.48	759414	2529420

Sl No.	Sample ID	Address	Well Depth (m)	UTM_X	UTM_Y
9	GW09	Darus Sunnah Salafia Madrasa (Abu Naser Hospital Mor), BN School, Khulna Sadar, Khulna	273	759414	2529420
10	GW10	Bismillah Hotel, Katiarangla Bazar, Batiaghata, Khulna	273	759837	2509480
11	GW11	Bhagarbazar Mor, Rampal, (Behind Liton's House), Bagerhat	245	771709	2502872
12	GW12	Behind Md Alam Sikder's Hotel, Morelganj Ferri ghat, Morrelganj Bagerhat	35	794459	2487363
13	GW13	Abdullah Villa, Holding No#57, Baleswar Bridge, Pirojpur	20	804652	2498986
14	GW14	Singair mosque Tubewell, Bagerhat Sadar, Bagerhat.	290	781826	2509894
15	GW15	Mollahat Thana Masjid, Mollahat, Bagerhat.	25	788099	2538363
16	GW16	128 No Purbo Barashur Govt Primary School, Kashiani, Gopalganj Near Batiapara Mor	183	777526	2569701
17	GW17	Bypass Helipad Agaijhara, Bakal Union Barisal	260	208771	2543184
18	GW18	CnB Road, Kazipara (in front of Molla Pharmacy) Barisal Sadar, Barisal	275	227872	2513854
19	GW19	Al Hasan store in front of Betagi Bus stand Mosque, Betagi Bus stand, Barguna.	275	208621	2481006
20	GW20	Char Colony Road, House of Piara Begum, Barguna Town Hall, Barguna Sadar, Barguna	305	203523	2453585
21	GW21	Bainchotki Ferrighat beside Md Ashraf Ali's Shop, Bainchotki, Barguna	366	196140	2453445
22	GW22	Beside Bauphal Thana, in a Madrasa, Patuakhali	305	248675	2480984
23	GW23	Panna Commisioner's House, Patuakhali Sadar,	290	212959	2434382
24	GW24	Abu Huraira Mosque, central mosque of amkhola Bazar, Golachipa, Patuakhali	290	231682	2461636
25	GW25	Kolapara Bus Stand, Bismillah Filling Station	336	212958	2434381
Surface Water sample					
26	SW01	Katiarangla ghat, Poshur River, Batiaghata Khulna		759913	2509480
27	SW02	Morelganj Ferri ghat, Morrelganj Bagerhat		794361	2487337

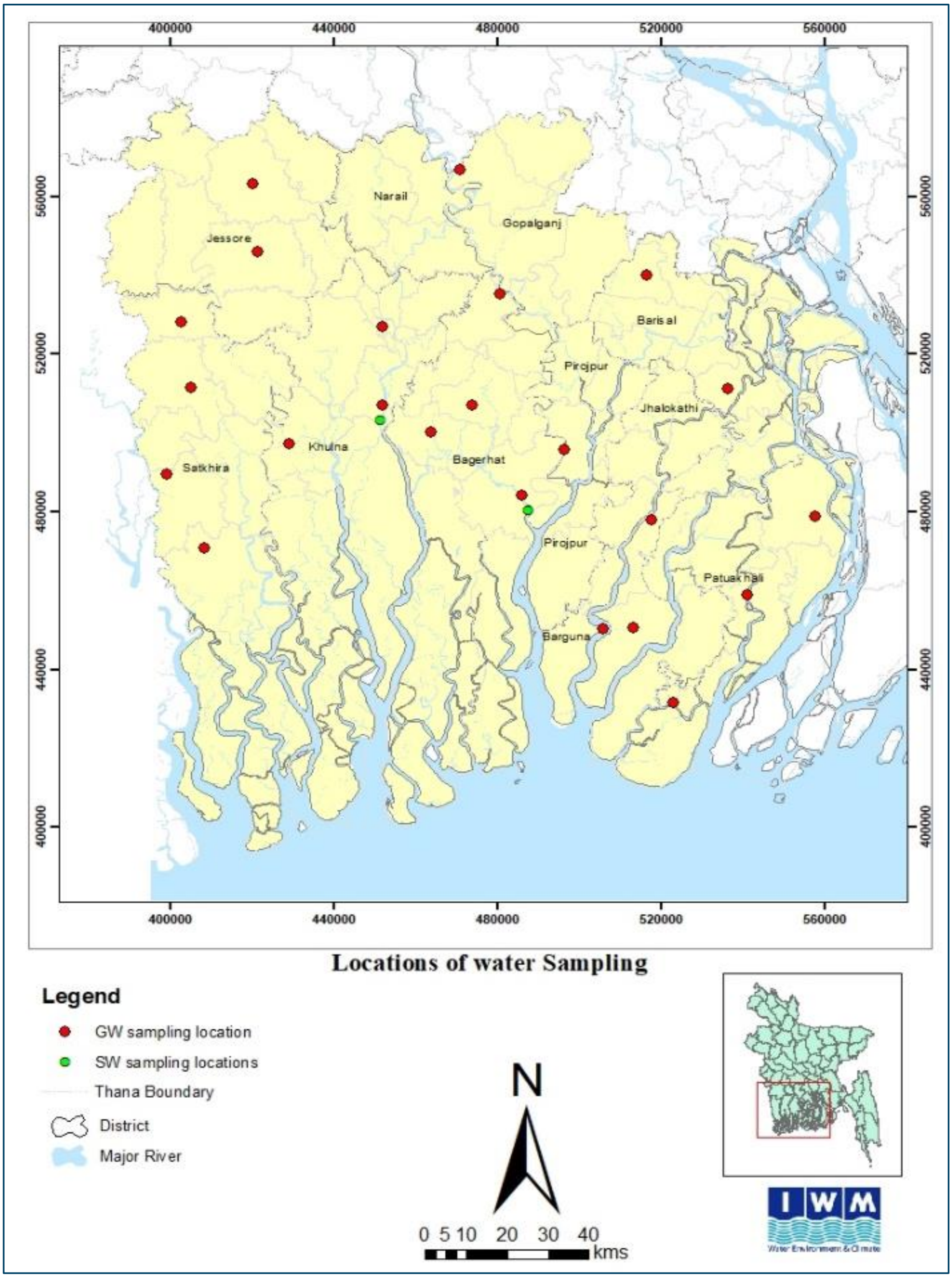


Figure 4-2: Locations of Water sampling

For validation of GW salinity model, GW samples from shallow aquifer from 44 locations have also been collected during 28 to 31 October'2020. The locations of samples have been given in Figure 4-3.

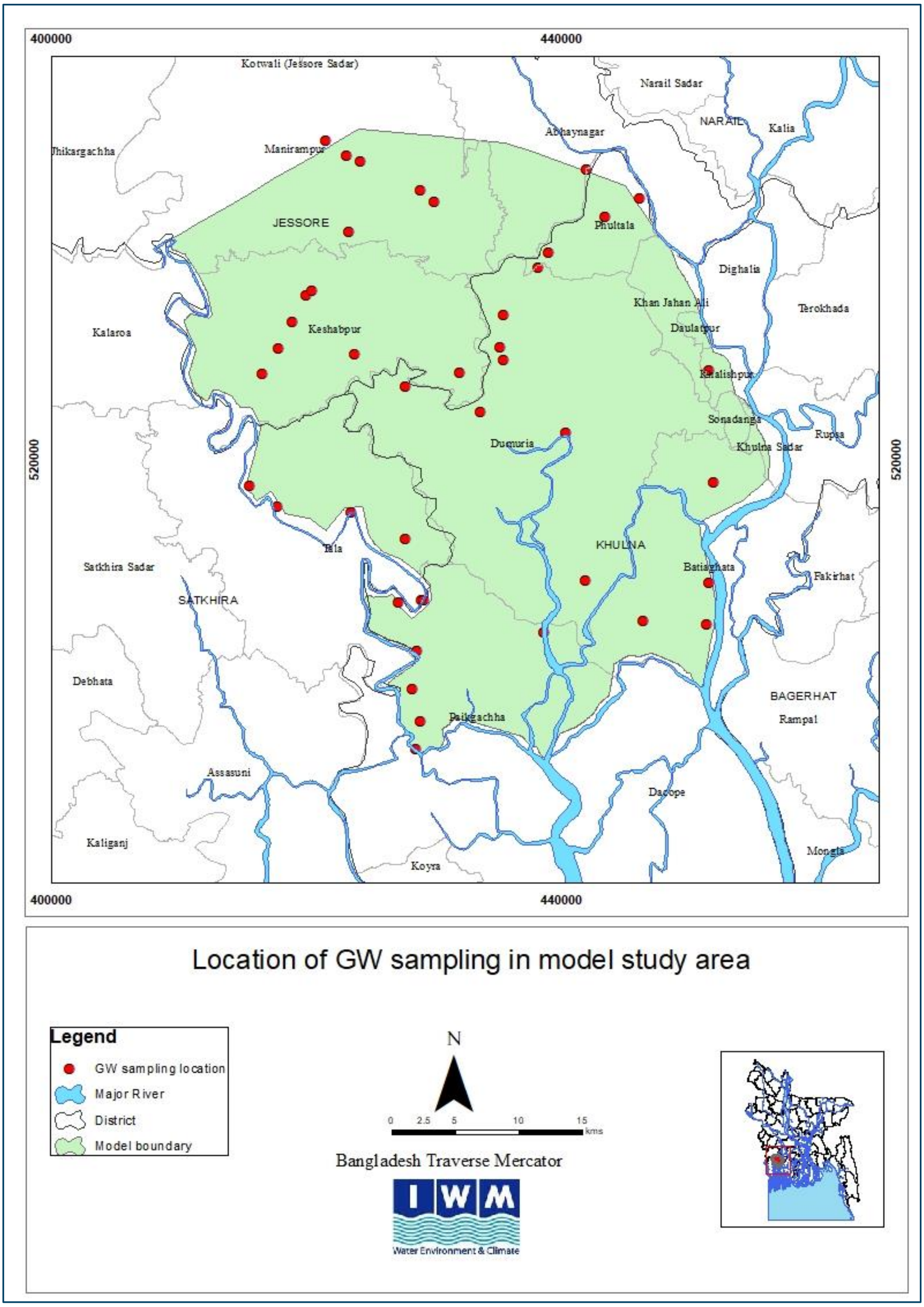


Figure 4-3: Locations of Water sampling in model study area

4.4 Hydro-metrological Data Collection

4.4.1 Rainfall

Rainfall data of 63 stations situated in and around the study area was collected from BWDB for the duration of 1985-2019. The collected data were checked for quality control by visual inspection of the plot of rainfall data. Monthly average rainfall for the stations of Khulna and Jessore have been shown in Figure 4-4. It is observed that highest rainfall occurs in July. It is also noticed that the annual average rainfall is about 2000mm and 80% of its total rainfall occurs during monsoon. It is also noticed that there is an increasing trend of rainfall from west to eastern side within the study area.

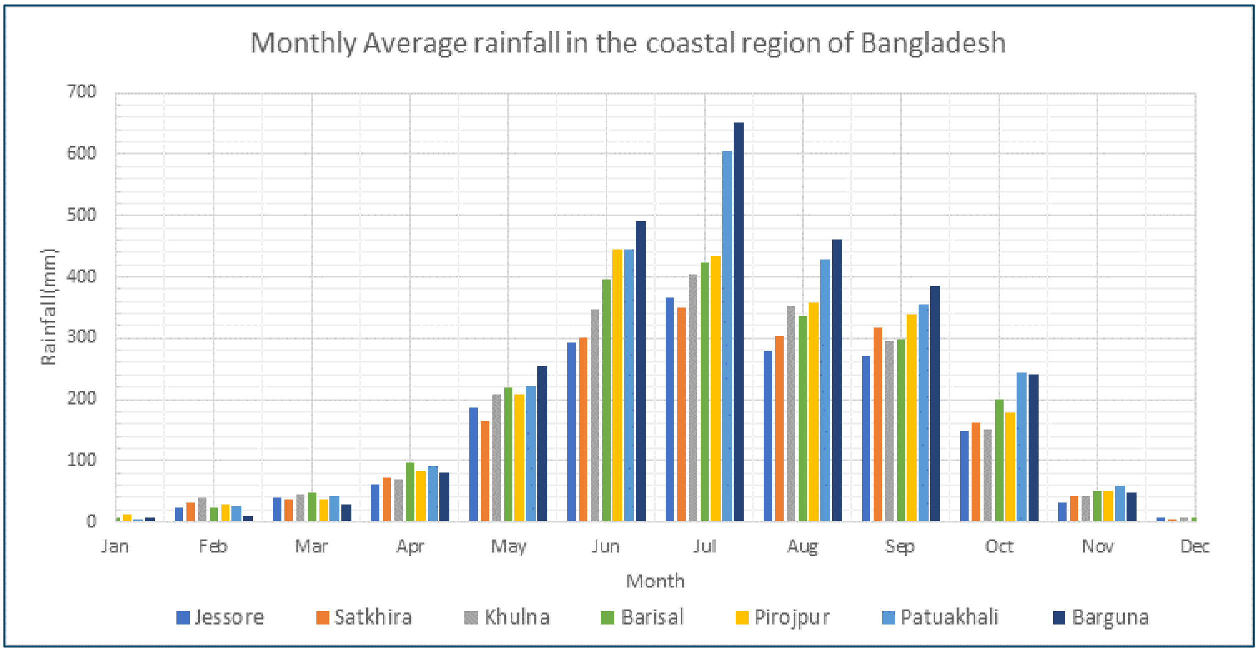


Figure 4-4: Monthly average rainfall of different districts in study area

Among these stations, rainfall data of seven stations in Jessore, Khulna and Satkhira district have been used for updating the model, considering its locations.

4.4.2 Evaporation

Potential evapotranspiration data of 2 stations located in and around the study area which are installed and maintained by BWDB, have been collected from BWDB for the duration of 2013-2019. The collected data has been checked to assess their quality following the standard data processing manual of IWM. List of the evaporation stations is given in Table 4-3 and the monthly average evaporation is shown in Figure 4-5.

Table 4-3: List of Evaporation Stations

Sl No	Station Name	Station ID	District	Upazila
1	Jessore	CL456	Jessore	Kotwali
2	Khulna	CL510	Khulna	Khalishpur

It has been observed that higher evaporation occurs during April to June. It suggests that the temperature in these months are higher than other months of the year. It is also noticed that the evaporation in Jessore is higher than Khulna during dry months. The monthly average evaporation varies from 40mm to 140mm.

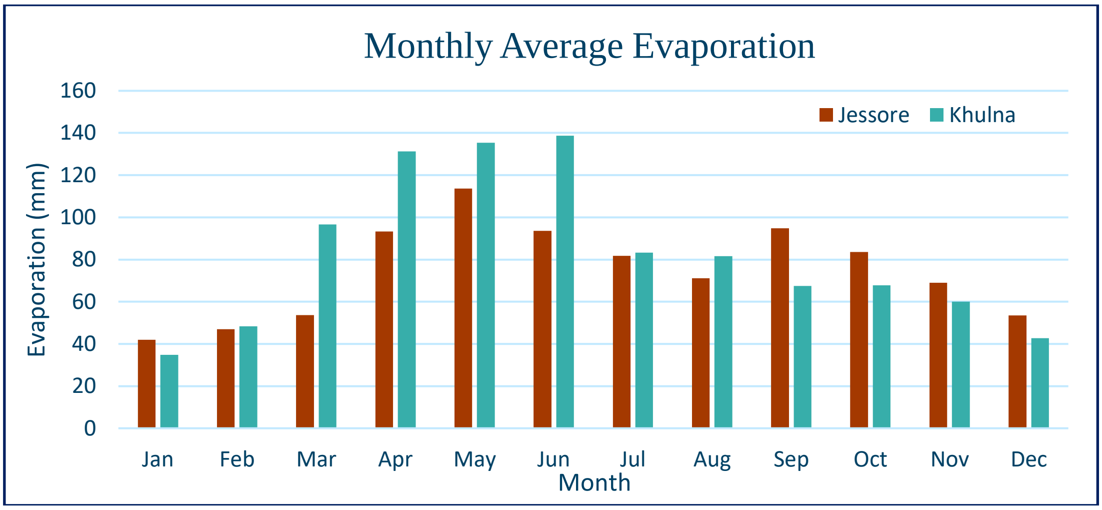


Figure 4-5: Monthly Average Evaporation of Khulna and Jessore

4.5 Hydro-geological Investigation

4.5.1 Geological Section

In order to identify the extent of different geological layers, lithological data of boreholes have been collected from different relevant sources like DPHE and BWDB, for the study area. A total of 1737 lithological data have been collected. The collected were checked and processed. For determining the vertical and lateral extent of aquifer, 14 nos of hydro-stratigraphic cross sections have been prepared traversing through the study area in different directions using Rockworks15 tool (Figure 4-6). Among them, 6 nos. of these cross sections (A-A’ to F-F’) are traversing from West to East direction and remaining sections (G-G’ to N-N’) are traversing from North to South direction. The horizontal extent of these cross section varies from 100km to 170km. The hydro-stratigraphic sections for F-F’ and K-K’ are shown in Figure 4-7.

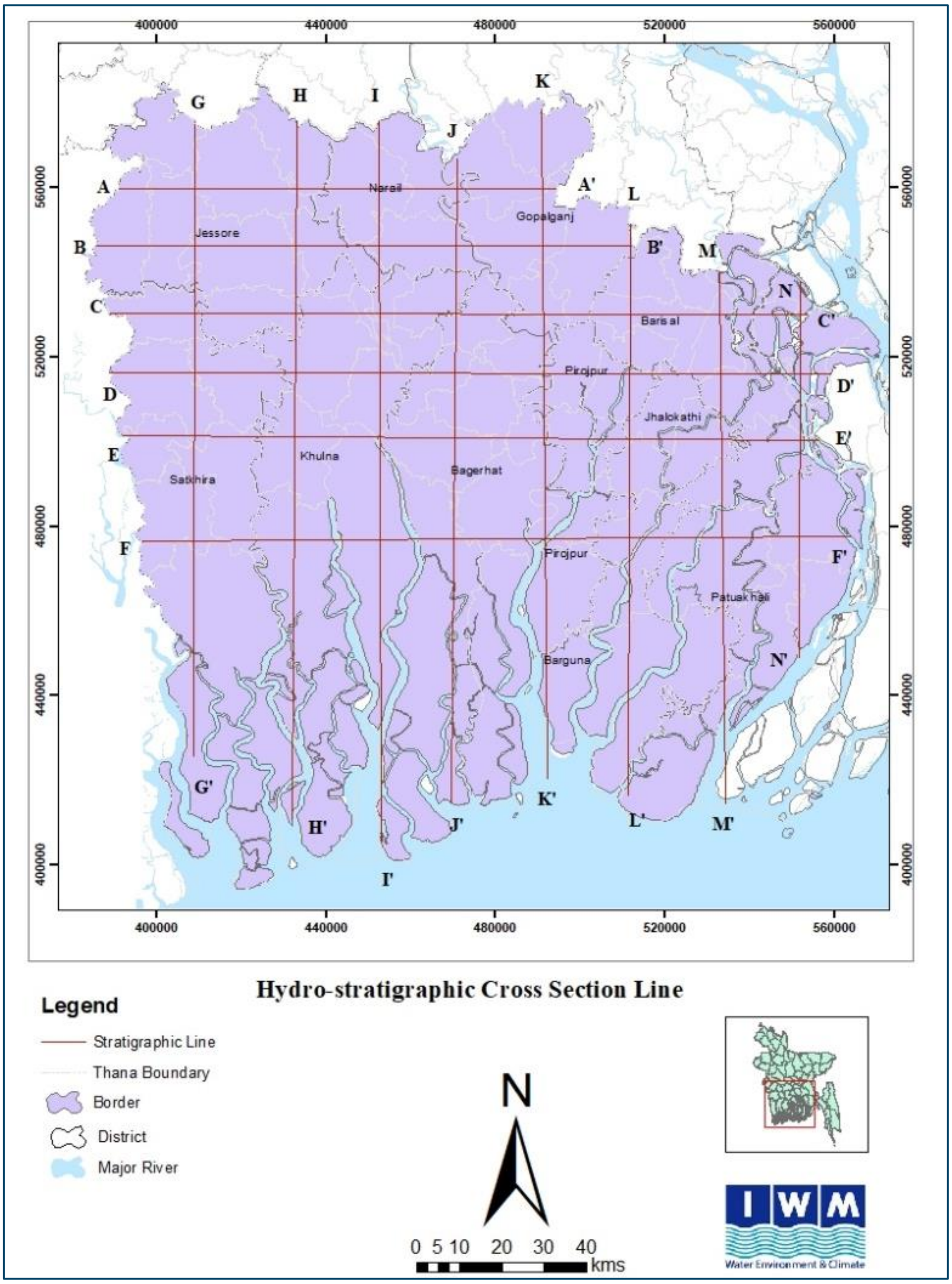


Figure 4-6: Geological Cross-Sections of the Study Area

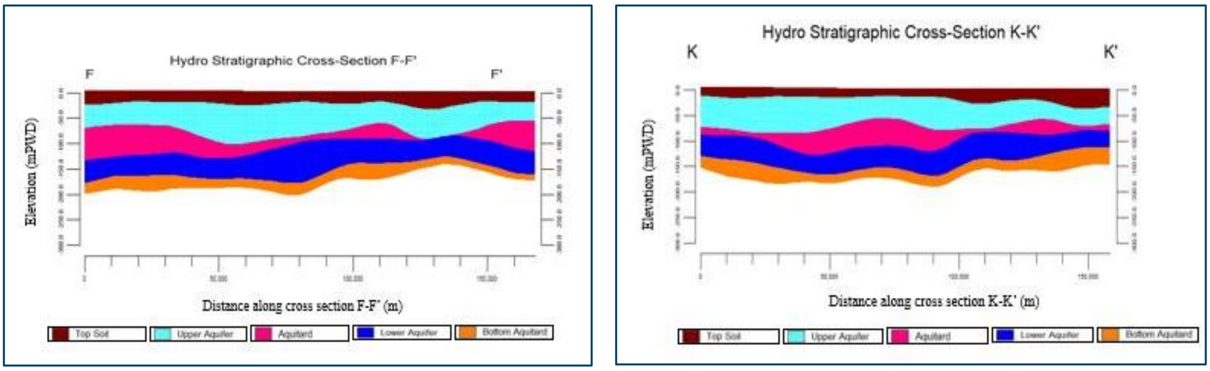


Figure 4-7: Hydro-stratigraphic cross section at F-F'' and K-K'

Subsurface sediment formations have been classified into five different units considering the lithological variations and groundwater flow capacity. These are:

- Topsoil
- Upper Aquifer
- Aquitard
- Lower Aquifer
- Bottom Aquitard

It is observed from the hydro-stratigraphic analysis that, within the exploited depth two different aquifer units exists in the study area, upper aquifer and lower aquifer. Upper aquifer lays beneath the clay layer. The upper aquifer layer consists of fine to very fine sand and the lower aquifer consists of fine to medium sand. The lower aquifer is considered principal sources of groundwater.

4.5.2 Groundwater Level

Groundwater level data from 95 observation wells have been collected from Bangladesh water Development Board (BWDB) for the duration of 2013-2018. The location of these observation wells are shown in Figure 4.4. The collected data has been checked for quality by visual inspection of the groundwater level hydrograph, prepared using the data. Groundwater level hydrograph has been prepared to see the historical trend of groundwater level as well as the quality of the data. Spatial maps of groundwater level for different years for both dry and wet seasons have also been prepared to see the spatial distribution as well as temporal variation.

These Groundwater level have also been used to update the groundwater level salinity model developed under the JAR Project (2014).

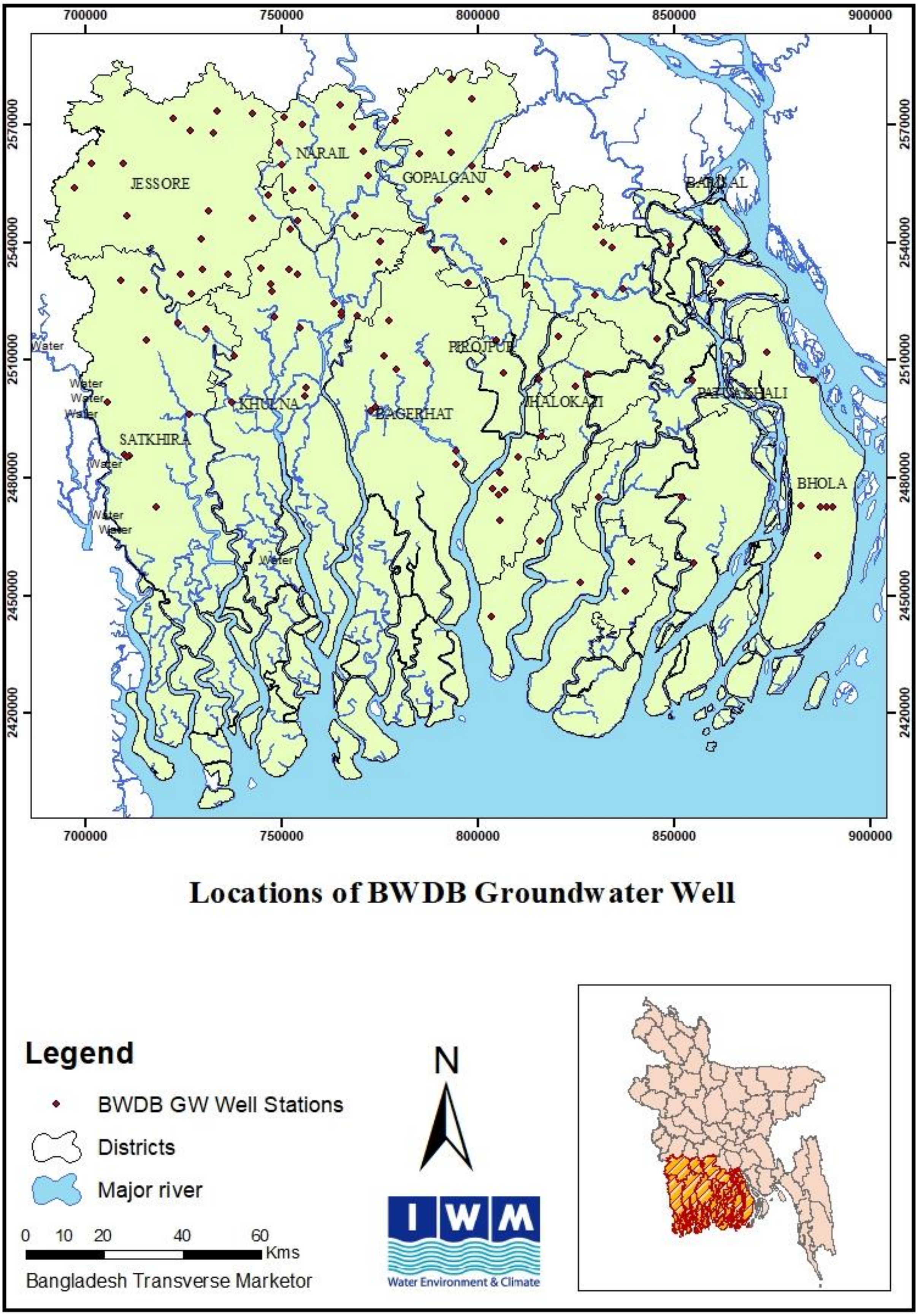


Figure 4-8: Location of BWDB observation well

5 Aquifer Properties and extent of the study area

5.1 Introduction

To assess the groundwater resources and for understanding its recharge characteristics as well as for understanding the salinity intrusion mechanism, and modelling purposes, it is very important to have a clear idea about the number of geological layers, its horizontal and vertical extent and finally the properties of different layers or units.

5.2 Lithological Characterization and Hydro stratigraphic Classification

It is observed from the hydro-stratigraphic analysis that, within the exploited depth two different aquifer exists in the study area, upper or shallow aquifer and lower or deeper aquifer. Upper aquifer lays beneath the clay layer and the aquitard exists between the upper & lower aquifer. The layers of the study area has been defined as continuous layer but in real the layers are discontinuous. These aquifers are interconnected in the coastal region.

The extent along with the properties of the layers are described below:

a) *Upper Aquifer*: The upper aquifer is found 40-50m below the ground level. It consists of fine to medium coarse sand occasionally interbedded with silt and clay. The thickness of upper aquifer varies from 20m to 80m. Dug wells and hand pumped wells are generally used to withdraw water from these aquifers. The estimated transmissivity of this main aquifer ranges from 222 m^2 /d to 2300 m^2/d.

b) *Aquitard*: From the hydro stratigraphic cross sections, it has been observed that, the thickness of aquitard beneath the Sundarbans and eastern part of Barisal is higher than the other parts of coastal region. And the thickness ranges from 50m to 200m. On the other hand, in Bagerhat, Patuakhali, Barguna, Jashore district the thickness of the aquitard is less. The aquitard consists of clay and silty clay.

c) *Lower Aquifer*: This aquifer occurs at or more than about 150 m below ground level. It generally consists of fine to medium sands and is mostly confined to semi-confined in nature. The thickness of this fresh aquifer is variable. So far limited number of tube wells are installed in this aquifer to cater to the needs of Pouroshava water supply and rural water supply. The estimated transmissivity of this main aquifer ranges from 430 m2 /d to 2900 m2 /d.

5.3 Aquifer Properties in Coastal Areas

Aquifer properties (Hydraulic Conductivity, Transmissivity and Specific yield) data have been collected from the relevant secondary sources e.g. BWDB and IWM's previous study. These data have been collected from both deep and shallow aquifers. From these data, maps have been prepared to determine the extent of hydraulic conductivity for both aquifers. The details of these are described in the following sections.

5.3.1 Hydraulic Conductivity

Hydraulic conductivity is a physical property which measures the ability of the material to transmit fluid through pore spaces and fractures in the presence of an applied hydraulic gradient. The spatial distribution of horizontal hydraulic conductivity (K_h) for upper or shallow aquifer and lower or deeper aquifer is shown in Figure 5-1. From the analysis, it is observed that the K_h for shallow aquifer varies from 11 to 40 m/day and for deeper aquifer, it varies from 23 to 115 m/day. It is also noticed that in most of the area of shallow aquifer, the horizontal hydraulic conductivity is in the range of 20-28 m/day.

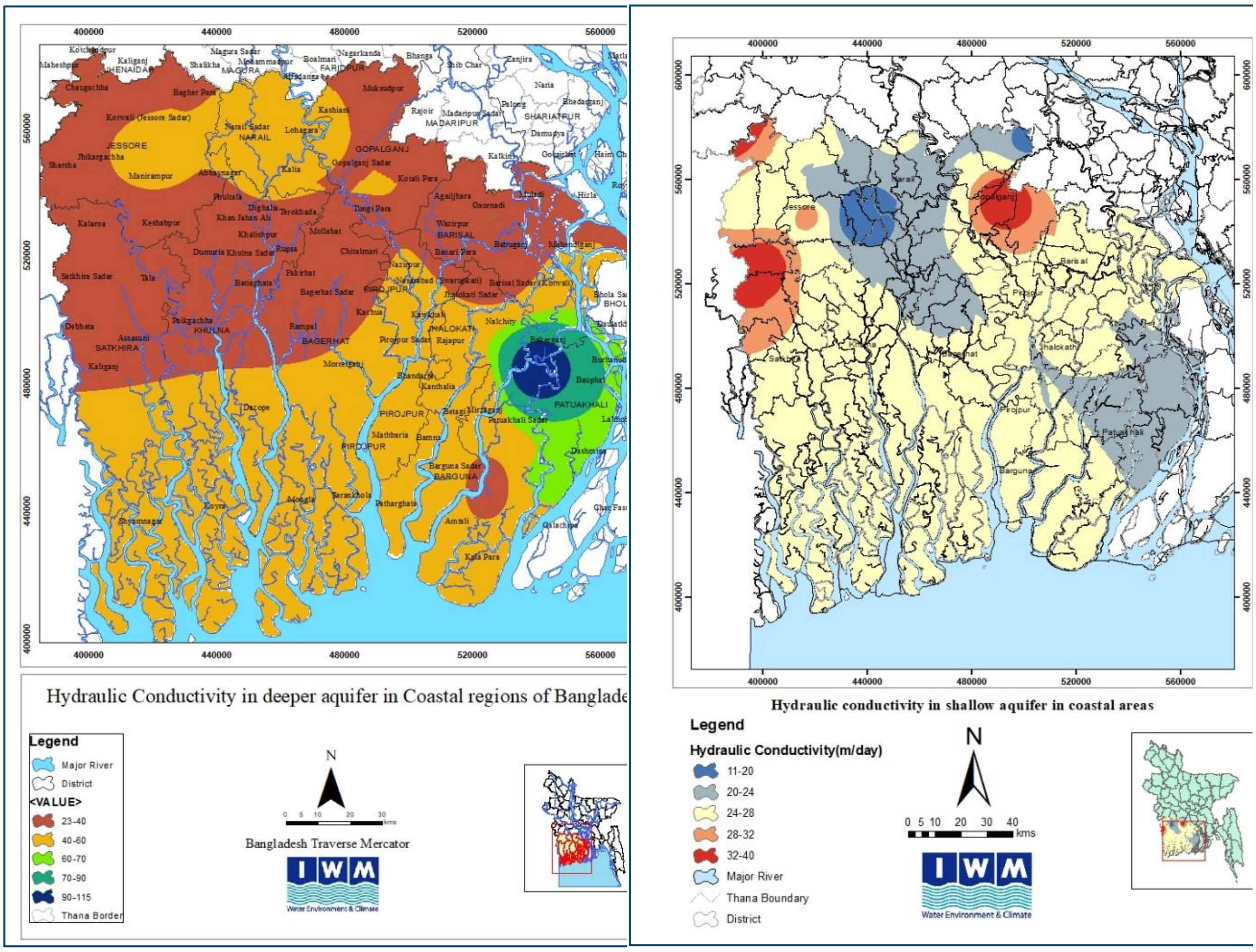


Figure 5-1: Hydraulic conductivity (Kh) in deeper aquifer(left) and in shallow aquifer(right)

It is also cleared from the figure that the hydraulic conductivity in deep aquifer is higher than that of shallow aquifer. That means, the velocity of groundwater flow is higher in deeper aquifer than that of shallow aquifer. Hydraulic Conductivity in deeper aquifers varies from 23 m/day to 115 m/day. It can be seen that the hydraulic conductivity of deeper aquifer at some places of Patuakhali and Barguna Area is in the range of 77-114 m/day.

5.3.2 Transmissivity

The transmissivity (T) describes the ability of the aquifer to transmit groundwater throughout its entire saturated thickness. It is defined as the product of the hydraulic conductivity K (m/day) and the saturated thickness D(m), in the direction normal to the base of the aquifer and may expressed as T = KD (m^2/day).

The spatial distribution of transmissivity for shallow and deeper aquifer is shown in Figure 5-2. In the study area, the transmissivity for deeper aquifer varies from 430-2900 m^2/day and for shallow aquifer, varies from 222-2300 m^2/day. In shallow aquifer, most of the areas have the transmissivity of 950-1200 m^2/day.

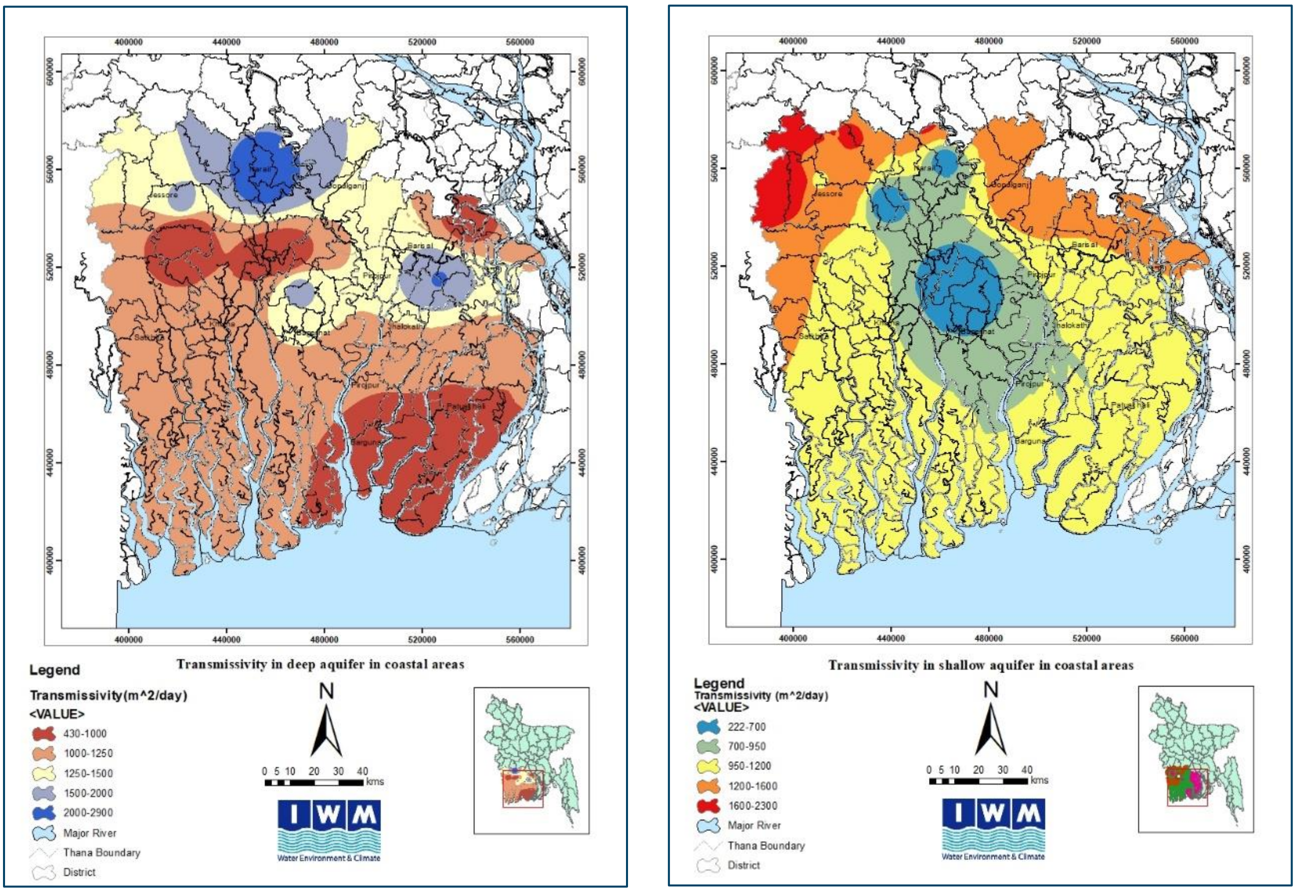


Figure 5-2: Transmissivity for deeper aquifer(left) and shallow aquifer(right)

5.3.3 Specific yield

Specific yield (Sy)is defined as the volume of water released from storage by an unconfined aquifer per unit surface area of aquifer per unit decline of the water table. . Specific yield of soils differs from each other in the sense that some soil types have strong molecular attraction with the water held in their pores while others have less. It is found experimentally that cohesionless soils have higher specific yield than that of cohesive soils because the former has significantly less molecular attraction then the latter.

The spatial distribution of Sy for shallow and deeper aquifer for the study area is shown in Figure 5-3. It is observed for the analysis of the data that, specific yield in deeper aquifers varies from 0-0.036 where in shallow aquifer, the range of specific yield is 0-0.13. It has been observed that, specific yield in the deeper aquifer is less than that of shallow aquifer.

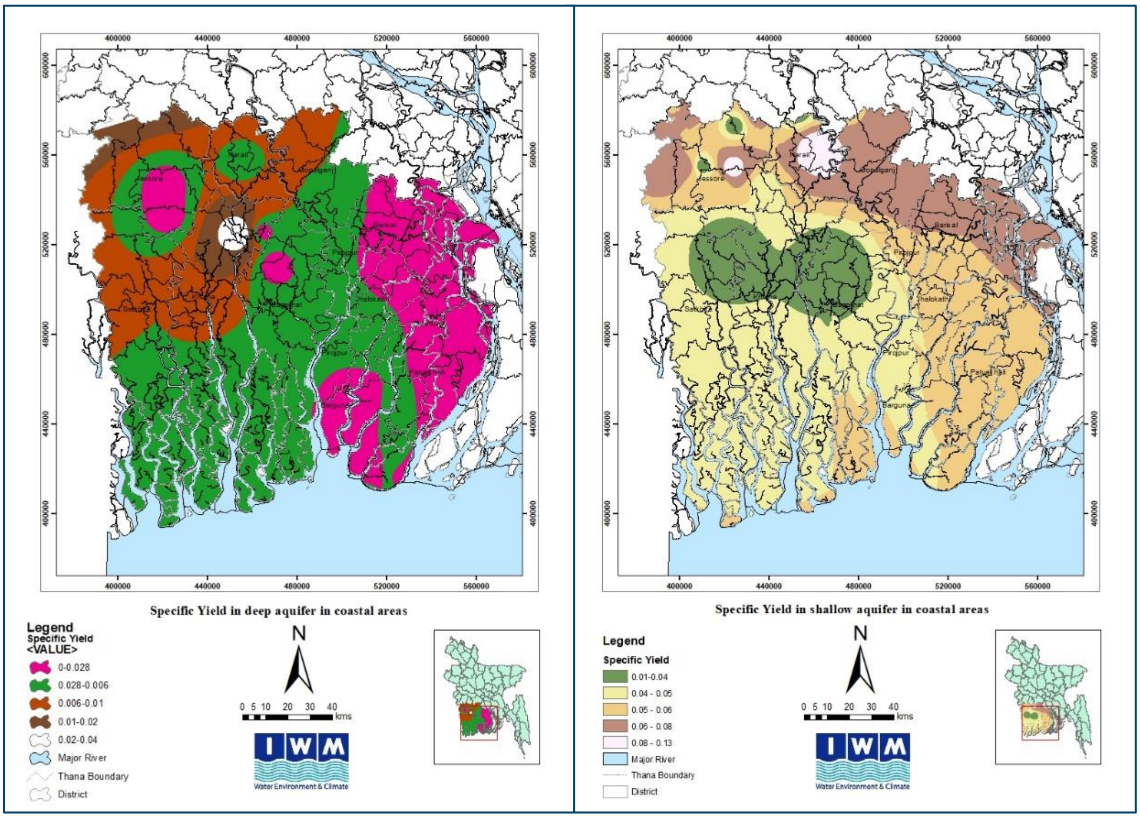


Figure 5-3: Specific yield in deep aquifer(left) and in shallow aquifer(right)

6 Hydro-Chemical Investigation and Extent of Salinity

6.1 Introduction

Salinity in water is a big problem for the coastal zone of Bangladesh. Salinity in water hampers a lot for agriculture as well as for drinking purposes. The salinity in water is not uniform for all over the coastal zone as well as for all the time in a year. That’s why it is very important to have a clear idea about the spatial as well as temporal distribution of salinity in the coastal zone. To address this issue, the water quality data were collected from some selective locations for different times. The details are described in the following sub-sections.

6.2 Groundwater Salinity

Groundwater salinity is the biggest problem in terms of water scarcity in the coastal zone. In coastal area of Bangladesh, it is observed that the groundwater salinity becomes highest during April/May and lowest during December/January. Due to heavy rainfall during monsoon, a large volume of freshwater infiltrates in the subsurface which decreases the salinity of groundwater and reaches lowest salinity during December/January. Then the salinity of the groundwater begins to rise again due to the decreased upstream flow in the dry period as well as very little rainfall and becomes highest during April/May. The tidal flow of coastal rivers and storm surge are also responsible for the salinity of groundwater.

Under this study, primarily it was planned for groundwater sampling from 25 selective locations for three times i.e. at January, April and September to see the spatial as well as temporal distribution of salinity in the groundwater in the coastal zone but due to pandemic covid situation, sampling were done only during Sep’19 and Jan’20. It is also mentionable that the groundwater samplings were done from the existing hand tube wells installed by private or public initiative which are at varying depth from place to place. Based on these surveyed data, the analysis of groundwater salinity has been done. As in Bangladesh, the salinity limit for drinking purposes is considered as 1 ppt, especially for coastal zone of Bangladesh, 1 ppt groundwater salinity line for both January and September were generated and is shown in Figure 6-1. It is observed that, total area under 1 ppt line during January 2020 is less than that of September 2019.

It may occur because freshwater from the rainfall of the monsoon season took time to infiltrate to dilute the saline water. Thus, the impact of rainfall in monsoon is observed in the post monsoon period. This may also happen due to elongated rainfall in 2019. Here it is observed that, part of Satkhira, Khulna, Bagerhat, Narail and Pirojpur district falls under 1 ppt line for both September 2019 and January 2020. That means in those areas, the groundwater salinity is more than 1 ppt in both seasons. Though in September 2019, Jhalokathi District was under 1 ppt line, in January 2020 season, the groundwater salinity was out of this line.

It is also observed that, salinity intrusion in the south west part of the coastal areas is higher. In the eastern region, the salinity intrusion is less. This happens due to the huge freshwater flow from the upstream of Meghna. This huge flow restricts the tidal flow of saline river in the eastern part of the study area. Also, due to the huge abstraction and rapid urbanization the salinity of the South west region is increasing. The area wise distribution of groundwater salinity was also estimated and is given in Table 6-1.

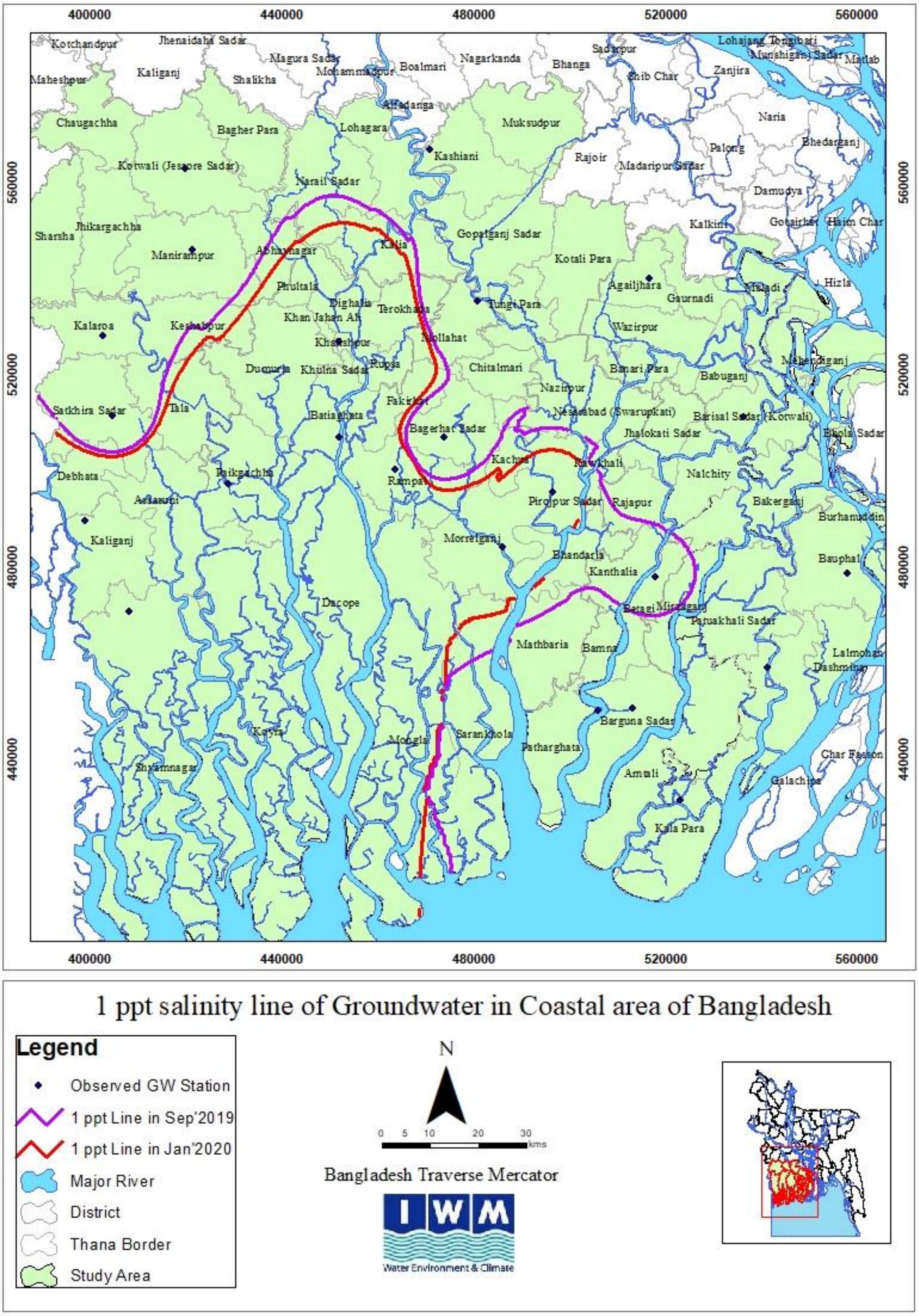


Figure 6-1: 1ppt groundwater salinity line in Coastal area

Table 6-1: Area wise distribution of groundwater salinity in Coastal area

Zone	Salinity (mg/l)	Area (km^2) under different salinity during	
		Sep’19	January’20
Fresh water Zone<1000 mg/l	<600	3489	5013
	600-1000	9861	9636
Saline zone >1000 mg/l	1000-1200	2565	2488
	1200-1600	2731	2363
	1600-2000	1899	1809
	2000-2500	1598	1400
	2500-3300	1054	686
	3300-4700	515	319

Though the salinity in surface water have been increased in January,2020 with respect to September 2019. The groundwater salinity seems to be decreased in January with respect to September. This may happen due to the elongated period of Monsoon season in 2019 in Bangladesh. It is observed that saline zone (>1000 mg/L) has been decreased at 12.53% in January 2020 with respect to September 2019.

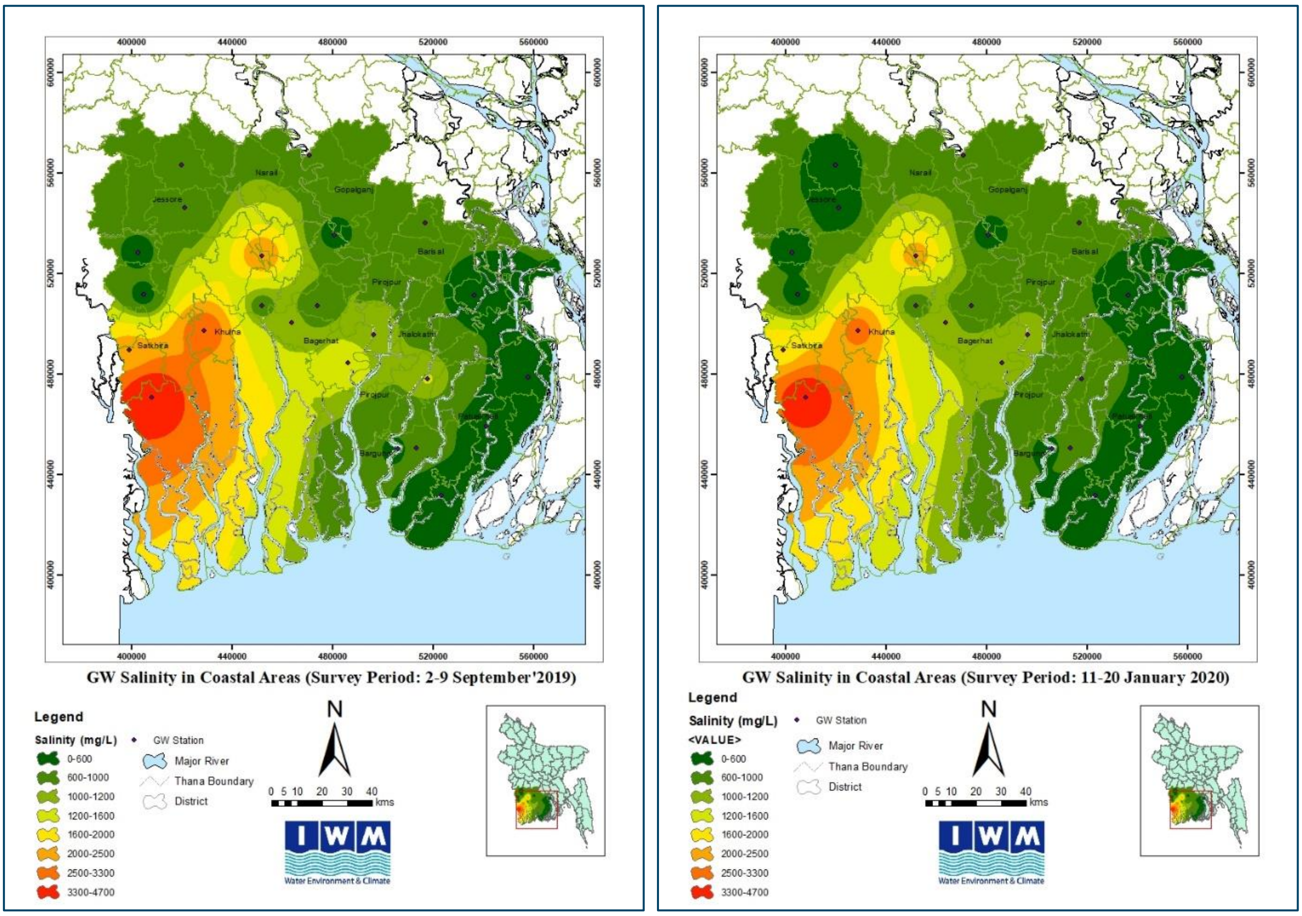


Figure 6-2: GW salinity in coastal areas in monsoon and post monsoon season

From the spatial distribution it is observed that, salinity in groundwater is found most at South western zone in Coastal areas. In Satkhira, Bagerhat and Khulna District, the salinity value is >1000 mg/L. In Barisal, Jhalkathi, Pirojpur, Patuakhali, Barguna districts are in the fresh water zone (<1000 mg/L).

6.3 Surface water Salinity

To see the temporal variation of surface water salinity, surface water salinity was also measured at locations namely Katianangla bazar, Khulna and at Mollarhat, Bagerhat during September 2019 and January 2020. The comparison of the salinity for these two stations is shown in Figure 6-3. It is observed that, salinity in surface water has been increased in January'2020 than salinity in September'2019. In Katianangla bazar, Khulna station the salinity has been found 1680 mg/l whereas in September it was only 176.8 mg/l. Though in Bagerhat, the salinity has not been increased as much as Khulna. This may occur due reduction in freshwater flow from the upstream in January 2020. It is mentionable that for modelling purposes the historical surface water salinity data at different locations available from the secondary sources were collected and used. This measured have not been used for modelling or other purposes, considering it insufficiency.

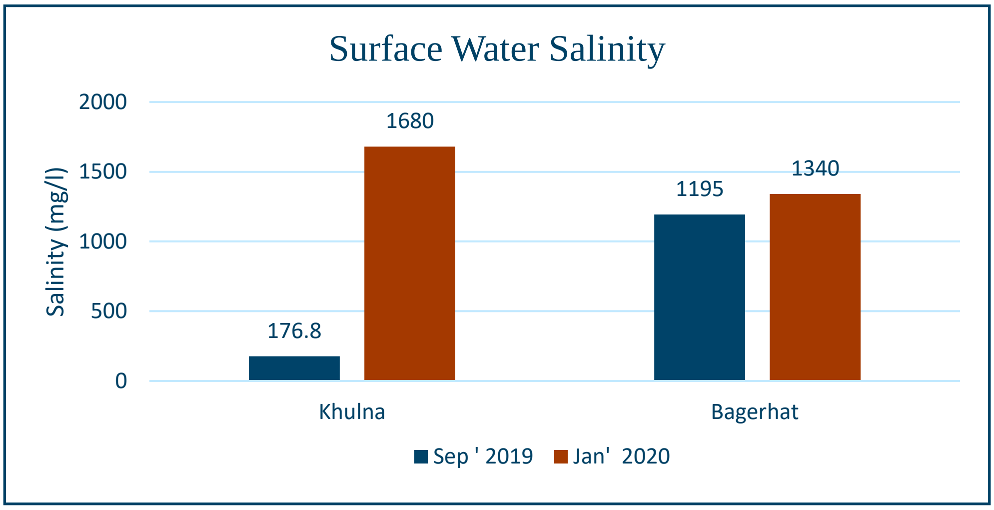


Figure 6-3: Comparison of surface water salinity

6.4 Electroconductivity of Groundwater

Electroconductivity is a measure of water’s capability to pass electrical flow. This ability is directly related to the concentration of ions in the water. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds. The more ions that are present, the higher the conductivity of water. Likewise, the fewer ions that are in the water, the less conductive it is. That means higher electroconductivity indicates higher impurities. Distilled or deionized water can act as an insulator due to its very low (if not negligible) conductivity value. Sea water, on the other hand, has a very high conductivity.

In this study, Electroconductivity data has also been measured from the collected groundwater sample. Using the measured data, the spatial distribution maps for the electroconductivity of groundwater have been prepared and is shown in Figure 6-4. It is observed that, in Satkhira, Khulna districts, the range of EC is higher than the other districts. In January 2020, EC has been decreased as well with respect to September 2019 like salinity. The value of EC varies here from 500-9000 µS/cm.

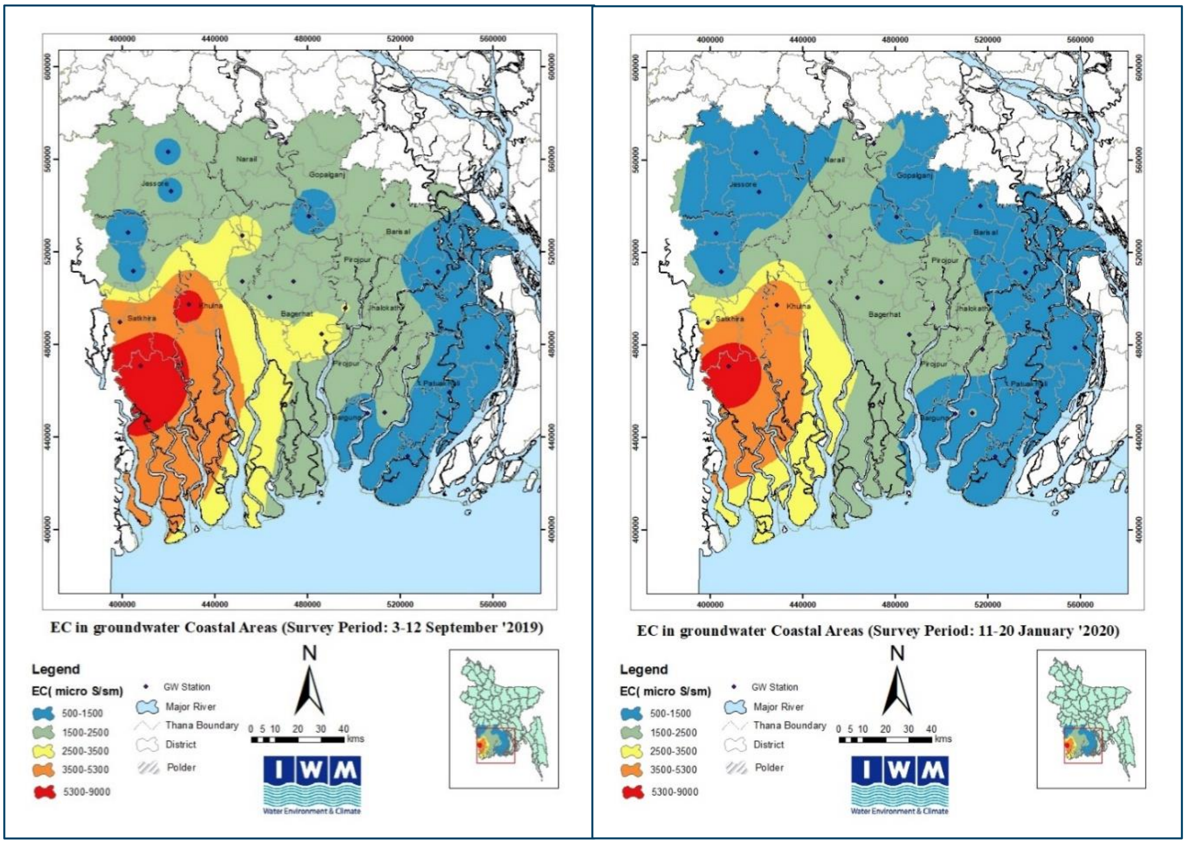


Figure 6-4: Electroconductivity of Groundwater for coastal areas of Study Area

7 State of Groundwater Resources

For understanding the state of groundwater resource, groundwater level analysis is an essential part. The trend analysis of groundwater level gives a clear picture about the change of abstraction and groundwater recharge conditions. To have a clear idea about the changes of groundwater level both spatially as well as temporarily, spatial distribution maps of groundwater level for different seasons & for different years have been prepared. To see the long-term trend, groundwater level hydrographs have also been prepared and analysed. For this purpose, the groundwater level data from 96 stations, maintained and monitored by Bangladesh Water Development Board (BWDB) within the study area, have been collected for the duration of 2008 to 2019. The locations of the groundwater monitoring stations are shown in Figure 7-1.

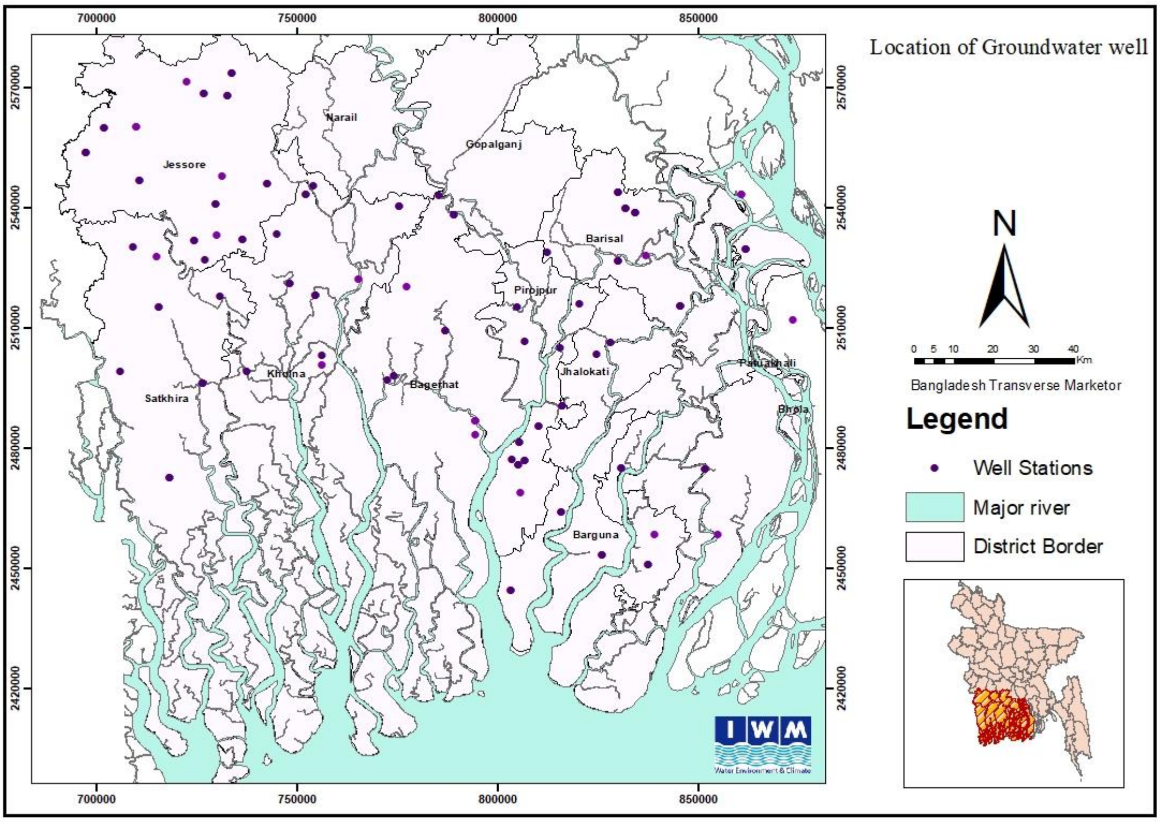


Figure 7-1: Locations of groundwater observation well in the Study Area

7.1 Assessment of groundwater level

To have a clear idea about the historical trend of groundwater level, Hydrographs for the representative stations of each district has been prepared and analysed. It also gives the ideas about the seasonal changes of groundwater level. For these purposes, hydrographs of all the stations have been prepared and consistency checking has been performed for all the data. It has been observed that there are a lots of uncertainties and anomalies in the observed data. In most of the cases the data is measured and recorded manually. So, it is very natural to have a mistake during measuring the data or recording the data. The error may also happen for shifting the well and absence of establishment of new RL for the shifted well. The error may also occur due to negligence of the reader, normally it occurs when their activities are not monitored regularly. The data which are inconsistent have been discarded. Only those data which are consistent have been used both for modelling as well trend analysis. In spite of checking the data, there may also some error in the data.

From the analysis of groundwater level hydrograph, it is observed that minimum groundwater tables are found during (March/April) dry season and maximum groundwater table during (August) monsoon. This is mainly occurring due to abstraction of groundwater and recharge from rainfall. In the monsoon, the aquifer is recharged from rainfall and groundwater level reaches its peak during the monsoon and due to abstraction, groundwater level decreases gradually during the dry season.

Groundwater declination happens when the outflow (including abstraction and lateral outflow) of groundwater from aquifer is higher than that of recharge. Groundwater recharge depends on a number of factors, e.g. rainfall along with its intensity, duration, seepage & percolation rate, soil typs, land sloe, land use type etc. Urbanization of an area which leads to increase of constructed area hindrance the recharge of groundwater also due to increases of paved or cemented area. In the study area, the long term trend of groundwater levels have been analysed for the last ten years in different districts. District wise groundwater level hydrograph analysis has been conducted which are described in the following sub sections.

7.1.1 Groundwater Level Trend of Jessore

The representative groundwater level hydrograph of Jessore district is shown in Figure 7-2 and Figure 7-3. From the analysis of the historical data, it is observed that groundwater level trend in Jessore shows a slightly declining trend, especially after 2016. The peak groundwater level in both dry and wet seasons is showing declining rate in all the stations in Jessore district. It may happen due to heavy extraction of groundwater for irrigation or industrial supply, scarcity of rainfall etc.

It is also observed that groundwater level of Abhayanagar, Jessore fluctuates about 4.5m (-1.5 mPWD to 3 mPWD) and is Manirampur the fluctuation is also about4.5m ((-1 mPWD to 3.5 mPWD). The land of this area is favourable for agriculture, on the other hand the groundwater salinity quite less. That’s why, large volume of groundwater is abstracted for irrigation purposes. This may be the main causes of this fluctuation.

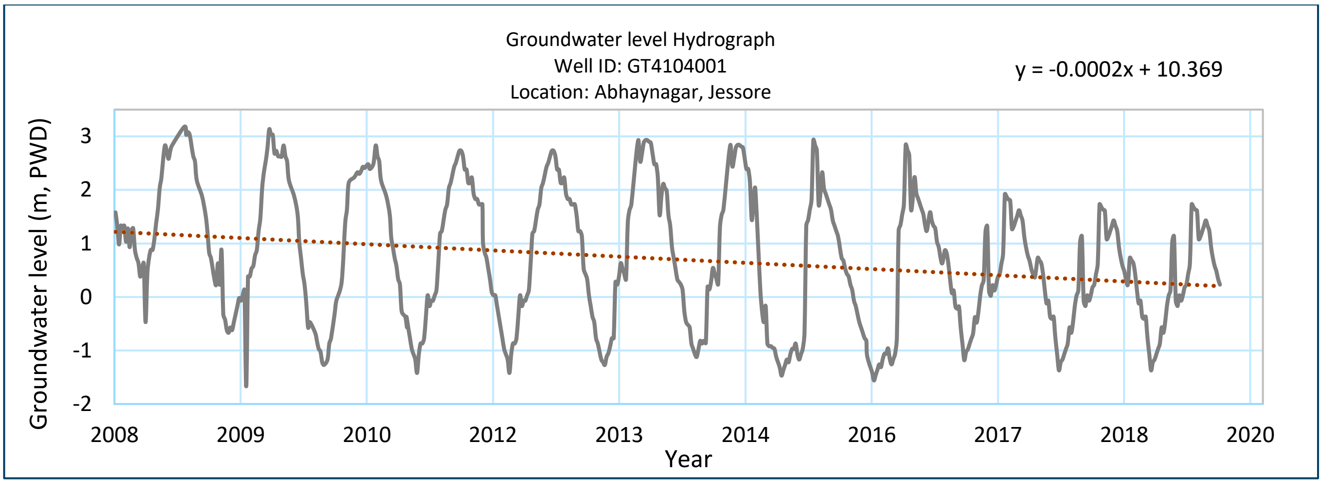


Figure 7-2: Groundwater level hydrograph of Abhaynagar, Jessore

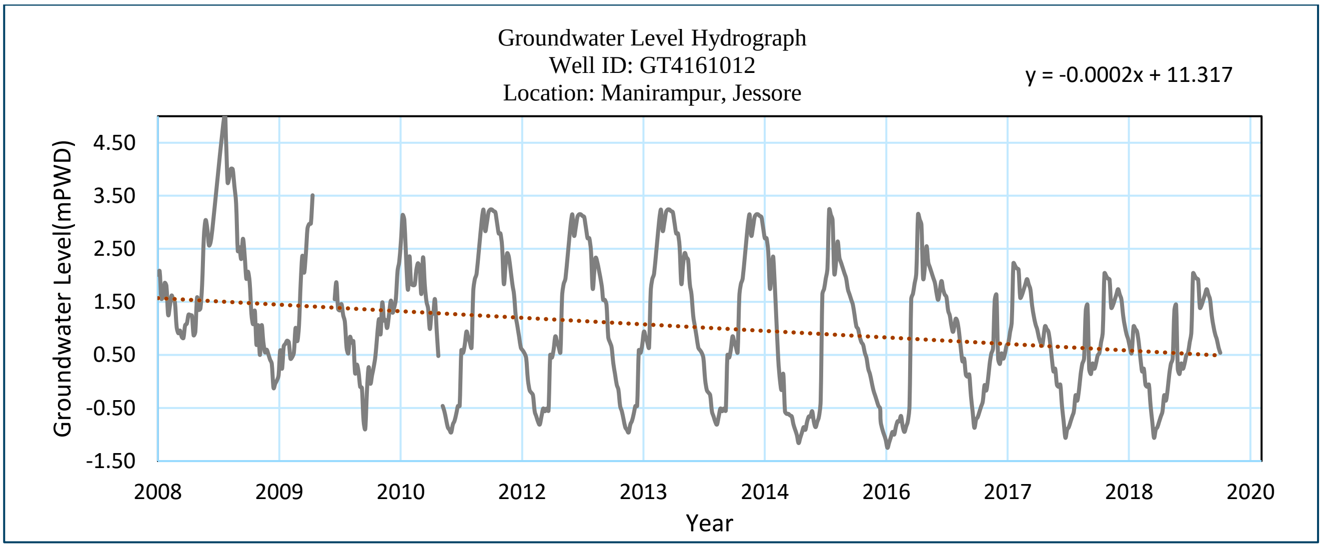


Figure 7-3: Groundwater level hydrograph of Manirampur, Jessore

7.1.2 Groundwater Level Trend of Satkhira

The representative groundwater level hydrograph of Satkhira district is shown in Figure 7-4. From the analysis of the historical data, it is observed that groundwater level trend in Satkhira more or less stable. It may happen due to very less amount of groundwater is abstracted for irrigation or domestic purposes as the groundwater salinity is comparatively higher and most of the land in this area is used for shrimp culture. The GWL fluctuation is also less in Satkhira district ranges from -1mPWD to 2.00m.

It may happen due to less abstraction because of salinity at this area. Due to good recharge, the upper peak in the monsoon period stays the same.

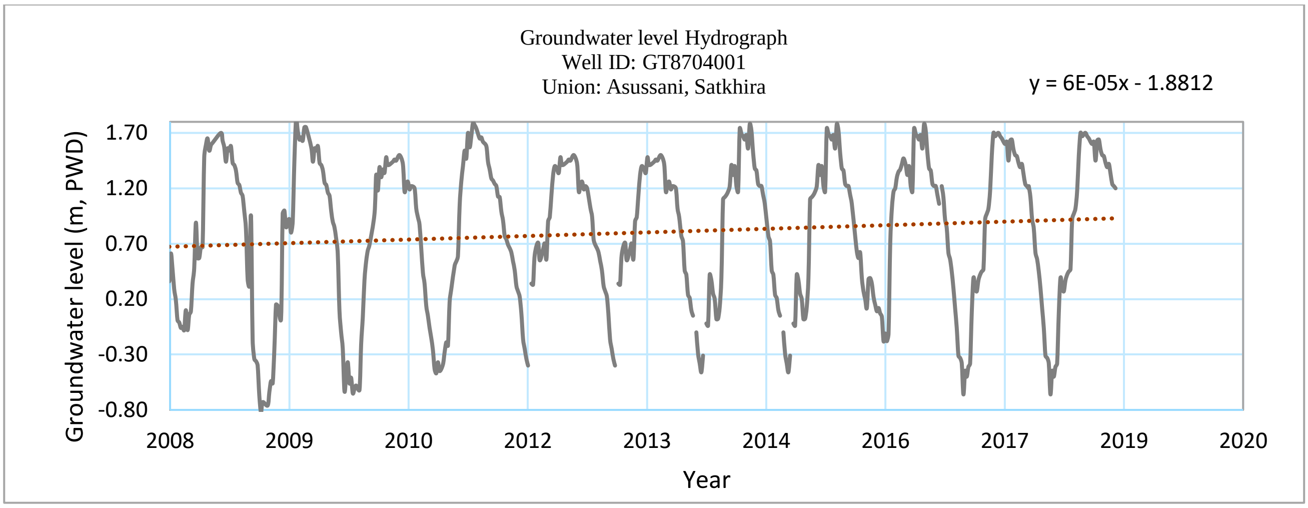


Figure 7-4: Groundwater level hydrograph of Assusani union, Satkhira

7.1.3 Groundwater Level Trend of Khulna

The GWL hydrograph of Dacope and Phultala of Kuhlna district is shown in Figure 7-5 and Figure 7-6 respectively. From the analysis of GWL hydrograph in Khulna district, it is observed that the GWL trend in Khulna show slightly declining trend specially after 2016. This may happen due to higher abstraction and low recharge of Groundwater. Rapid urbanization and increase of pavement area may be the causes of this scenario, specially at Phultal of Khulna district.

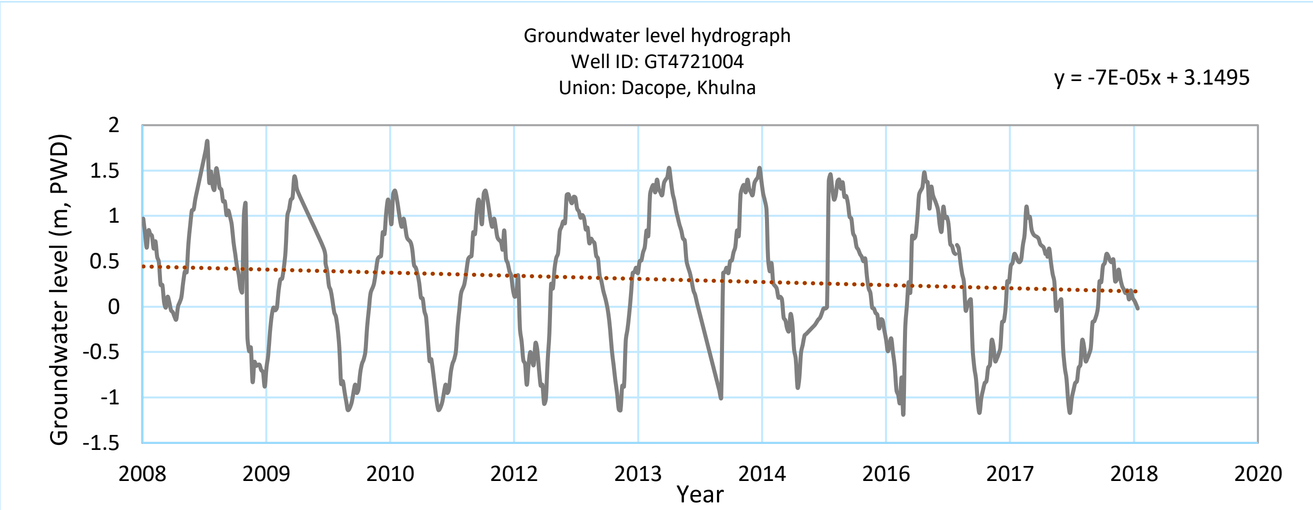


Figure 7-5: Groundwater level hydrograph of Dacope union, Khulna

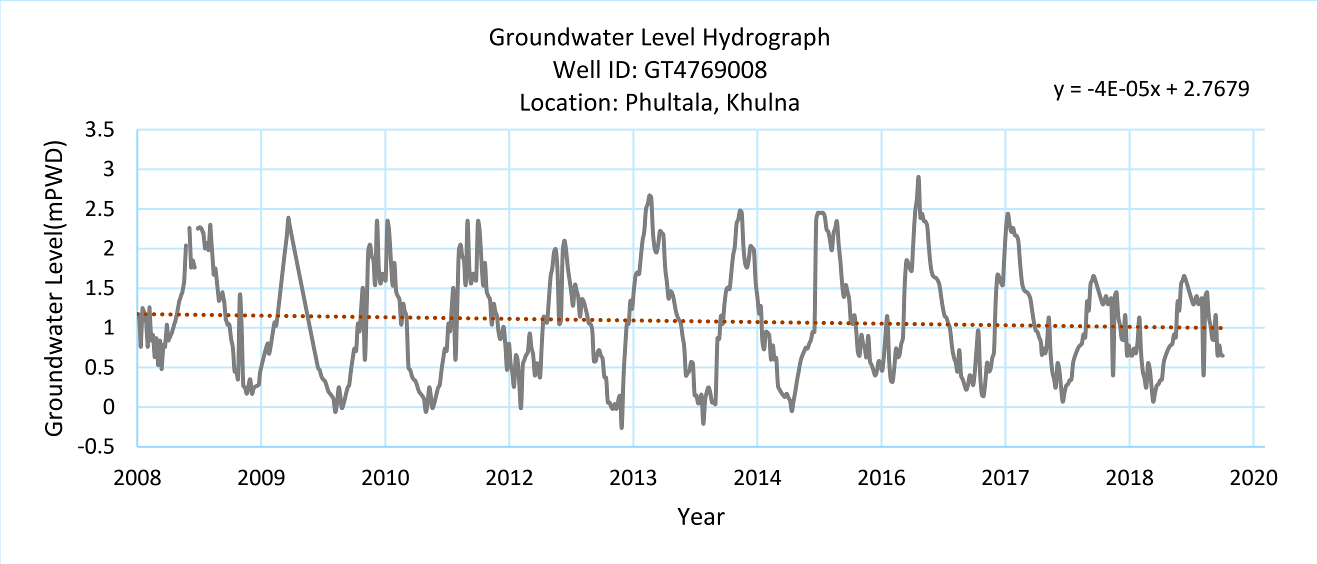


Figure 7-6: Groundwater level hydrograph of Phultola union, Khulna

According to water level hydrograph of Dacope union of Khulna (Figure 7.5), it seem that the seasonal recovery of the groundwater table is less in recent years. The groundwater level of Phultala shows a stable trend upto 2017 but after that the trend is declining. The fluctuation range of GWL at Phultala station is in the range of 0.0mPWD to 3mPWD.

7.1.4 Groundwater Level Trend of Barisal

The GWL hydrograph for Hizla and Banaripara union of Barisal district is shown in Figure 7-7 and Figure 7-8 respectively. From the analysis of groundwater data of Barisal district, it is seen that groundwater level is more or less steady over the last ten years in Barisal, indicating good amount of recharge in Barisal District

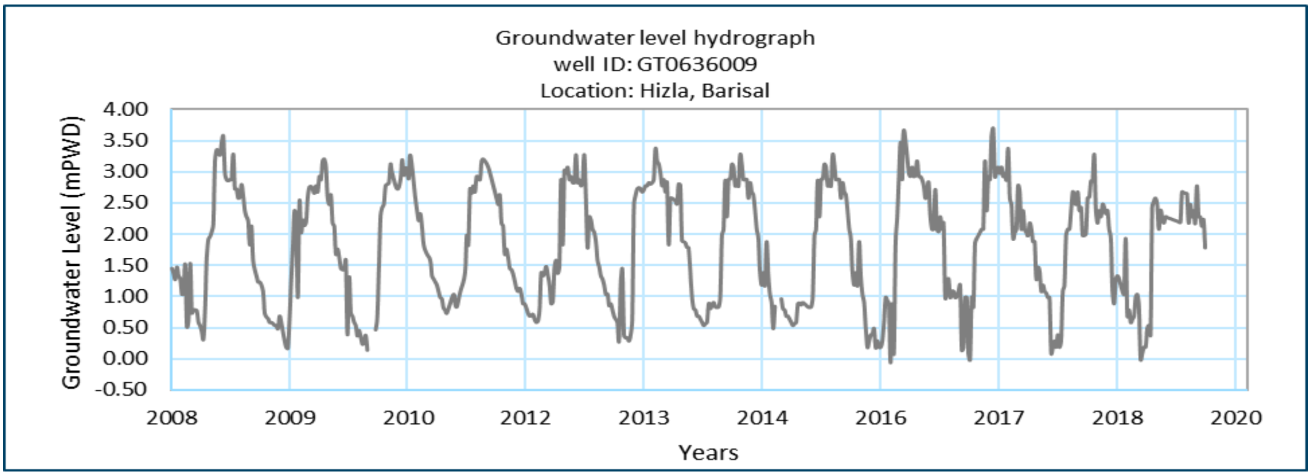


Figure 7-7: Groundwater level hydrograph of Hizla union, Barisal

For Banaripara union, the groundwater level fluctuates from -0.75 m PWD during dry season to 1.25 m PWD during wet season.

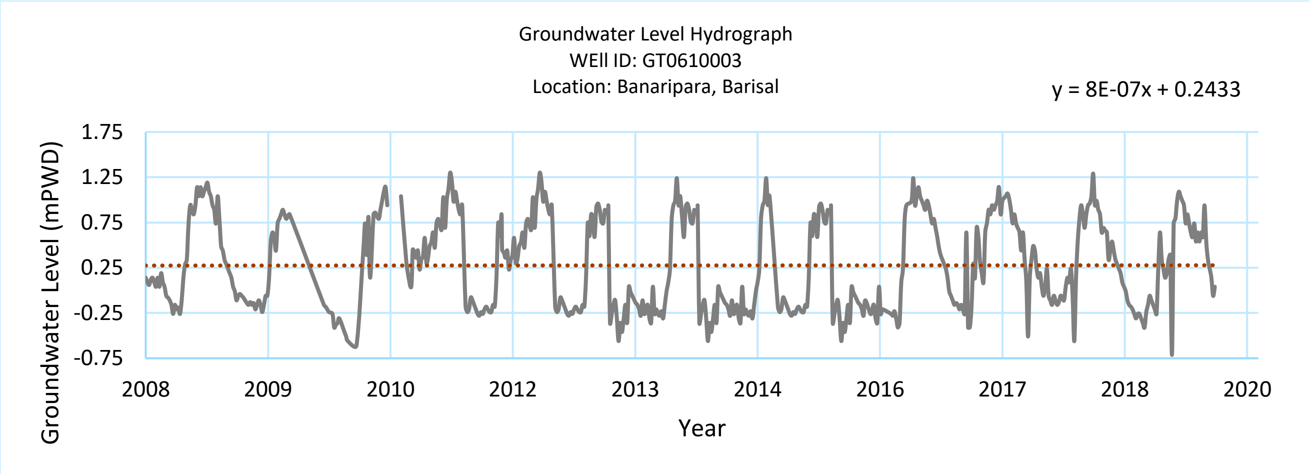


Figure 7-8: Groundwater level hydrograph of Banaripara union, Barisal

7.1.5 Groundwater Level Trend of Barguna

There are 5 groundwater monitoring wells in Barguna District that has been collected from BWDB. The highest peak of the groundwater level is found in the month of August/September and the lowest in April or May. Figure 7-9 shows the groundwater level hydrograph for Barguna sadar. It is observed that groundwater level trend is stable and slightly increade for the recent 4 to 5 years. The fluctuation of groundwater table is also very less, only 1-1.2 m.

This may happen due to very less amount of groundwater abstraction only for drinking/domestic purposes and no abstraction for irrigation purposes due its high salinity. The increase in water table for the recent year though it is very minor scale, may be due to increase of sea level rise.

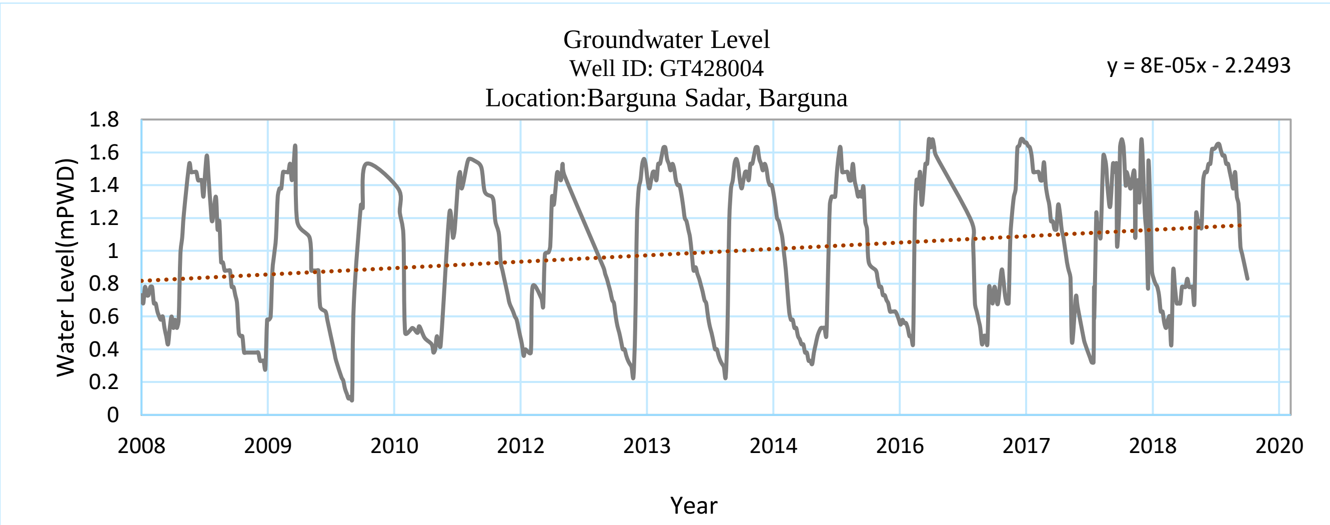


Figure 7-9: Groundwater level hydrograph of Barguna Sadar, Barguna

7.1.6 Groundwater Level Trend of Pirojpur

There are eleven groundwater wells in Pirojpur district installed and maintained by BWDB. These wells are in Bhandaria, Mathbaria, Nazirpur, Swarupkathi and pirojpur Sadar upazilla. In Pirojpur district, all the wells are showing similar trend of groundwater level.

In Bhandaria, the water level here ranges from 1.00 mPWD to 2.40 mPWD. The water level trend of this area shows a steady trend, not declining or inclining. Figure 7-10 and 7-11 shows the representative groundwater level for Pirojpur.

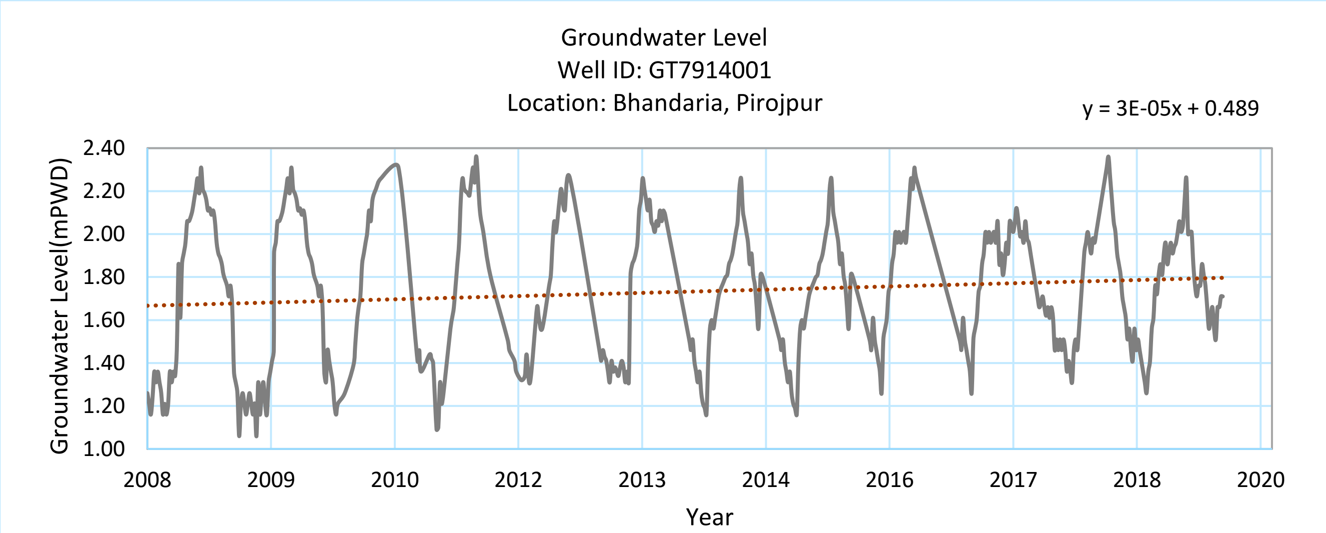


Figure 7-10: Groundwater level hydrograph (2008-2018) for Bhandaria, Pirojpur

In Nesarabad, the groundwater level fluctuates from 0.00 mPWD to 1.80 mPWD. The trend of water level is steady throughout last 10 years. The groundwater usage here has remained unchanged. This area is saline prone area, and the population density is also less and no significant urbanisation is observed in this area. This may be the reason of no change in groundwater table in this area.

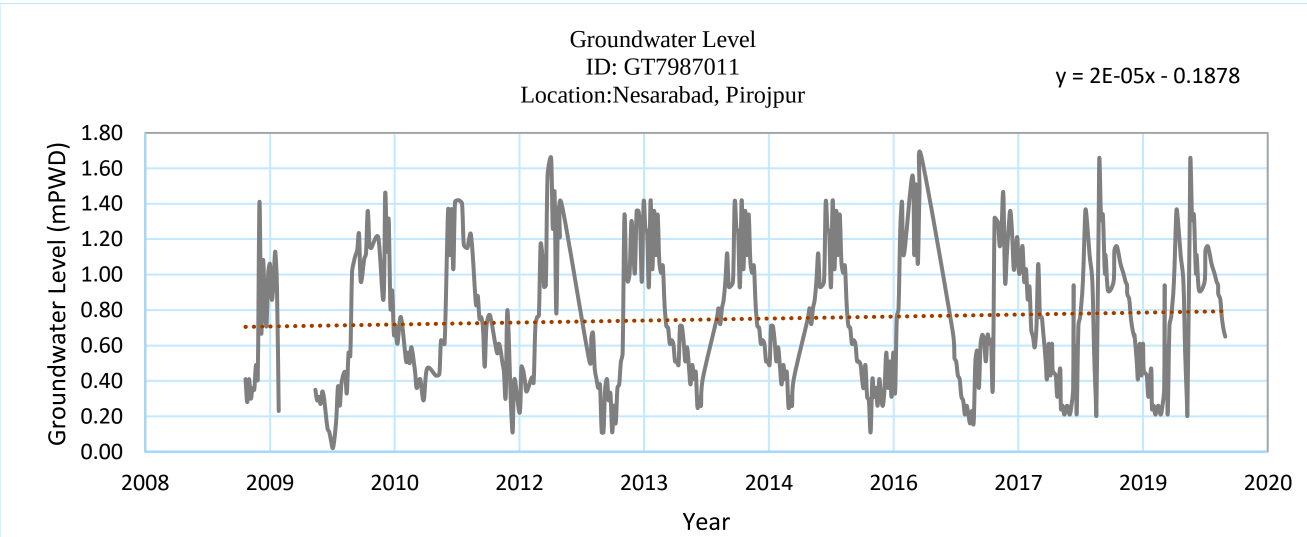


Figure 7-11: Groundwater level hydrograph (2008-2018) for Nesarabad, Pirojpur

7.1.7 Groundwater Level Trend of Patuakhali

In Patuakhali District, there are three observation wells which are constructed and maintained by BWDB. Those are in Galachipa, Mirzaganj and Patuakhali Sadar Upazilla. The groundwater level trend shows a slightly increasing. There is also a chance of shifting error of groundwater level data which may have occurred during the year 2016.

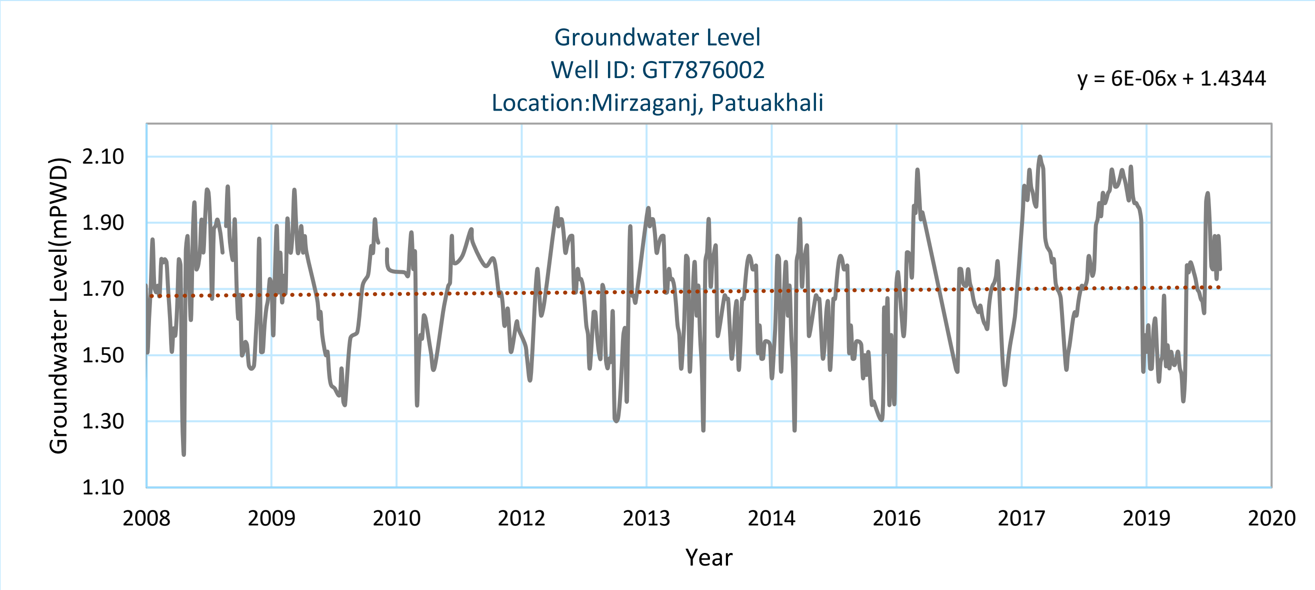


Figure 7-12: Groundwater level hydrograph (2008-2018) for Mizanganj, Patuakhali

In the Figure 7-12, it is observed that, the upper peak in the groundwater level has increased with respect to the year 2008. This may happen due to the surface water level rise in the monsoon season. Though, in Patuakhali Sadar, the groundwater level in recent year is declining, It may occur due to urbanization in Patuakhali.

7.2 Spatial distribution of groundwater well

For getting a clear picture of the groundwater level at different areas within the study area, spatial distribution maps of groundwater level have been prepared covering both the dry and west season and at the same time in different year also to have an idea about the changes in groundwater level with the passing of years. For this purpose, inverse distance weighted (**IDW**) tool of ArcGIS has been used where the interpolation determines cell values using a linearly weighted combination of a set of sample points.

7.2.1 Spatial distribution of groundwater level in dry season

From the analysis of groundwater level data, it has been observed that groundwater level attains the lowest level within the study area during March, that’s why the groundwater level data of March have been used for preparing the spatial distribution maps of groundwater level during dry season. At the same time, to see the temporal variation of the groundwater table with the passage of time, the maps have been prepared both for dry season in 2008 and 2018. The groundwater level maps of dry season in 2008 and 2018 is shown in Figure 7-13 and in Figure 7-14 respectively.

From the analysis of spatial distribution maps of the groundwater level at dry season in 2008, it is observed that the groundwater table is in the ranges of 0.o to 1.0 mPWD at around 51% of the study area. These areas are mainly lower & middle part of Satkhira-Khulna, Upper part of Jessore, Narail, Gopalganj, Barisal and, Barguna. Lower part of Khulna and a major part of Pirojpur, Bagerhat andJhalokathicover around 24.56 % area having groundwater level from 1.0 to1.5 mPWD. The upper part of Satkhira-Khulna and lower part of Jessore cover 14.40% area having the groundwater level from -1.0 to 0.0 mPWD.

It is also noticeable that the groundwater level was comparatively higher in the northern part of coastal zone than that of southern part.

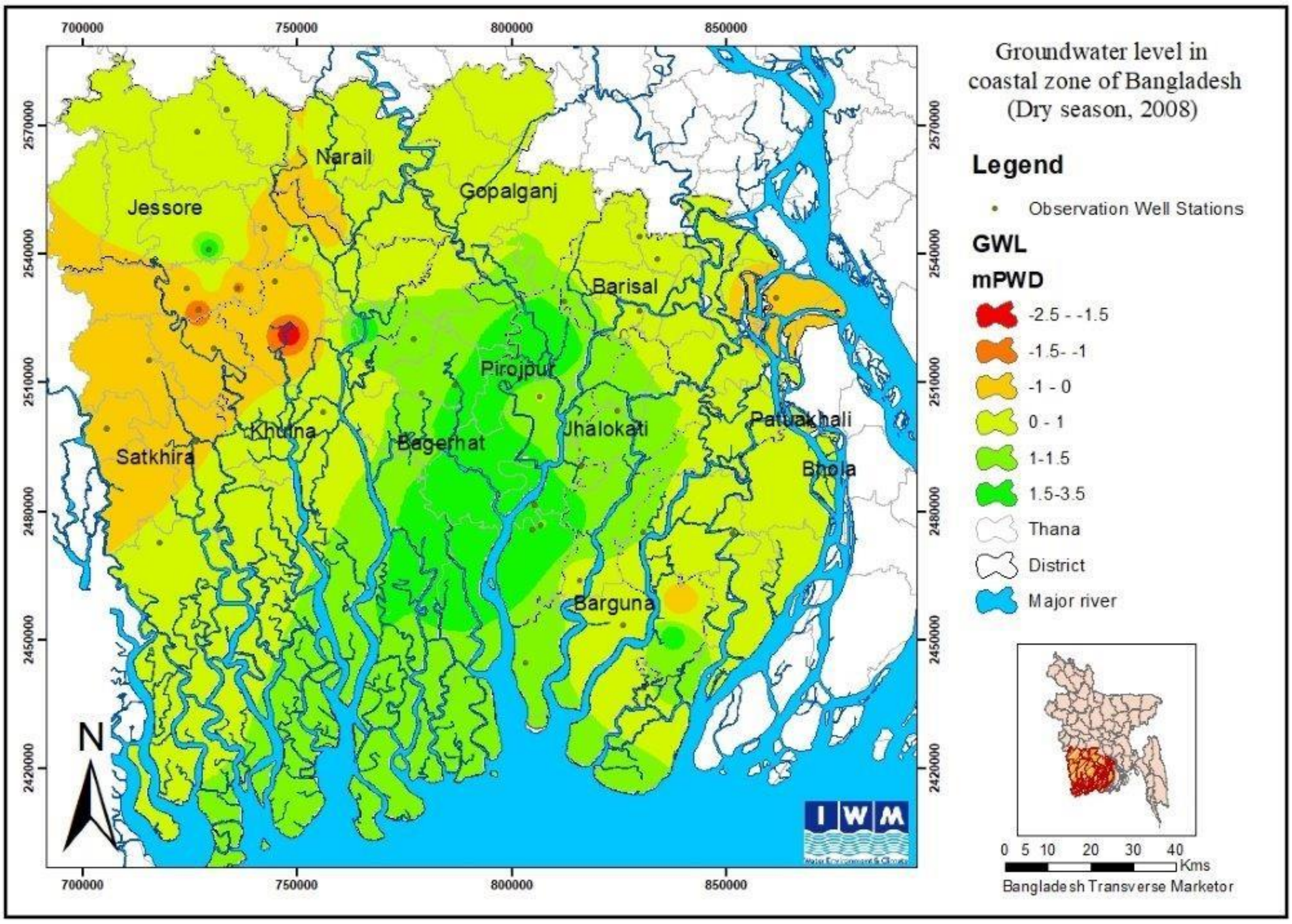


Figure 7-13: Spatial distribution of groundwater level in dry season, 2008

From the analysis of dry season groundwater level during 2018, it is seen that around 56.29% of the whole coastal zone were in the ranges of 0.0 to 1.0 mPWD. These areas were mainly major part of BagerhatPriojpur, Barguna, Patuakhali, Barisal, Gopalganj and Jhalokathi. Satkhira, Khulna, Narail and Jessore (North-western part) covers around 26.29 % area having the groundwater level from -1.0 to 0.0 mPWD.

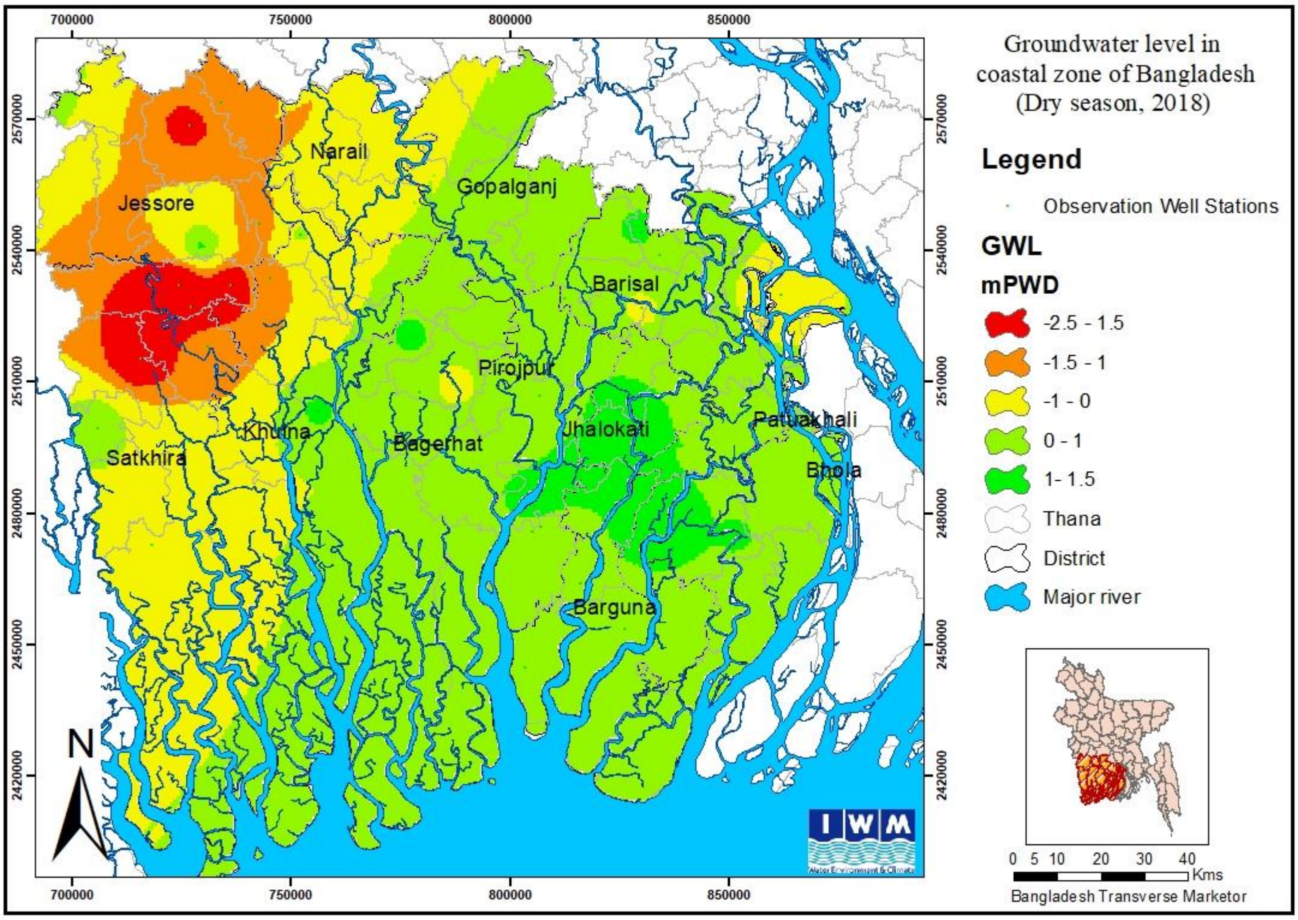


Figure 7-14: Spatial distribution of groundwater level in dry season, 2018

7.2.2 Spatial distribution of groundwater level in wet season

From the analysis of groundwater level data, it has been observed that groundwater level attains the highest level within the study area during October, that's why the groundwater level data of October have been used for preparing the spatial distribution maps of groundwater level during wet season. At the same time, to identify the temporal variation of the groundwater table with the passage of time, the maps have been prepared both for wet season during 2008 and 2018. The groundwater level maps of wet season during 2008 and 2018 is shown in Figure 7-15 and in Figure 7-16 respectively.

From spatial distribution of the groundwater level during 2008, it is seen that around 38.60% of the whole coastal zone were in the ranges of 2.5 to 3.0 mPWD. These areas were mainly Khulna, lower part of Satkhira, Bagerhat, Narail and Gopalganj. Barisal, Jhalokathi, Barguna, Patuakhali and southern part of Bagerhat cover around 35.56% area having groundwater level from 1.5 to 2.5 mPWD. Besides this, some part of Jessore, upper part of Satkhira,Bagerhat and Pirojpur cove 17.33 % of area having groundwater level from 3.0 to 3.5 mPWD. It is also noticeable that the groundwater level in 2008, was comparatively higher in the north side of coastal zone as the elevation of the southern part of Bangladesh becomes lower gradually.

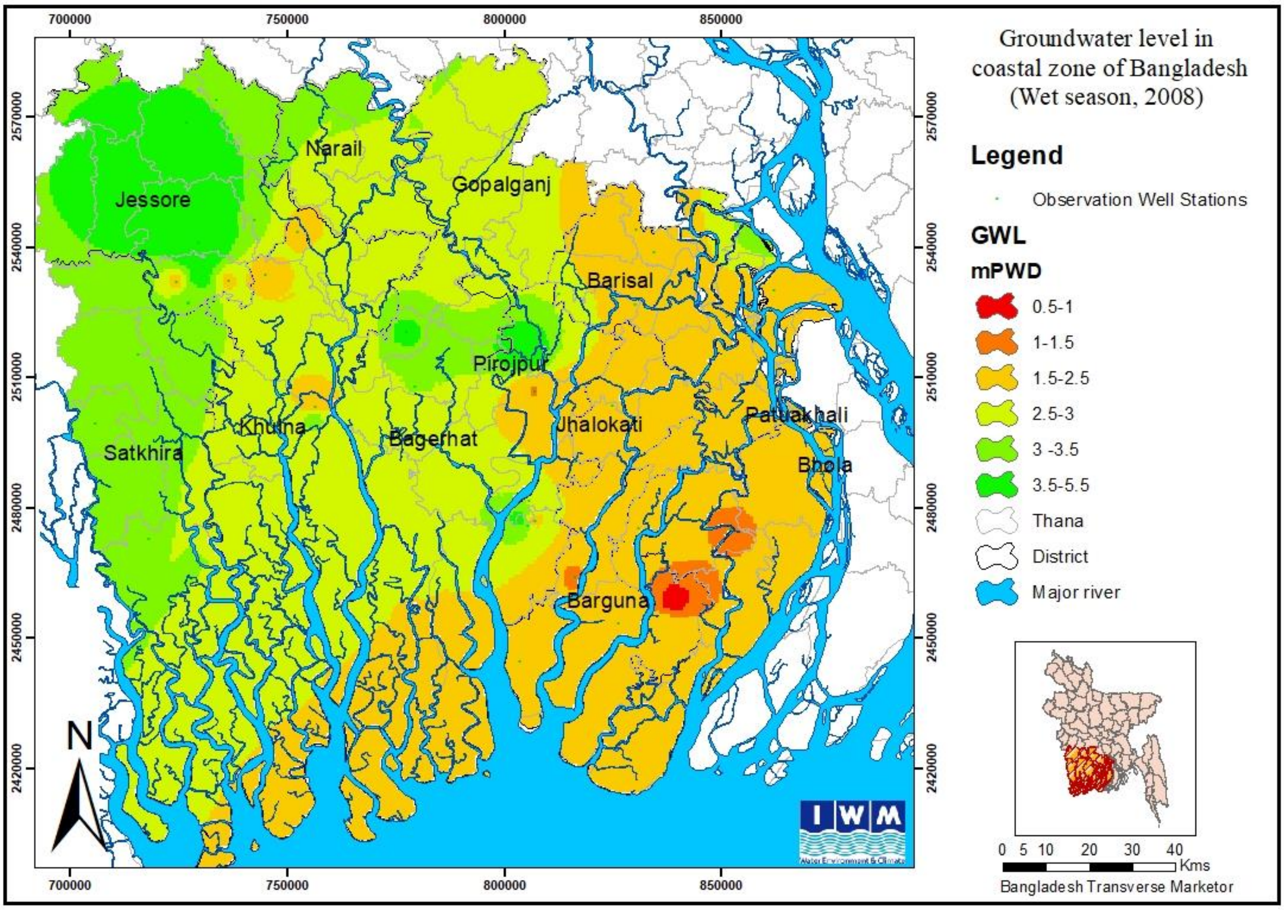


Figure 7-15: Spatial distribution of groundwater level in wet season, 2008

From spatial distribution of the groundwater level during 2018, it is seen that around 57.92% of the area, the groundwater level ranges from 1.5 to 2.0 mPWD. These areas were mainly Major part of Satkhira, Khulna, Jhalokathi, Barisal, Bagerhat, Barguna and Pirojpur. Some part of Khulna, Satkhira, Narail and Bagerhat cover around 25.92% area having the groundwater level ranges from 2.0 to 2.5 mPWD. The upper part of Jessore and Bagerhat cover around 9.45 % of area having the groundwater level ranges from 2.5 to 3.5 mPWD.

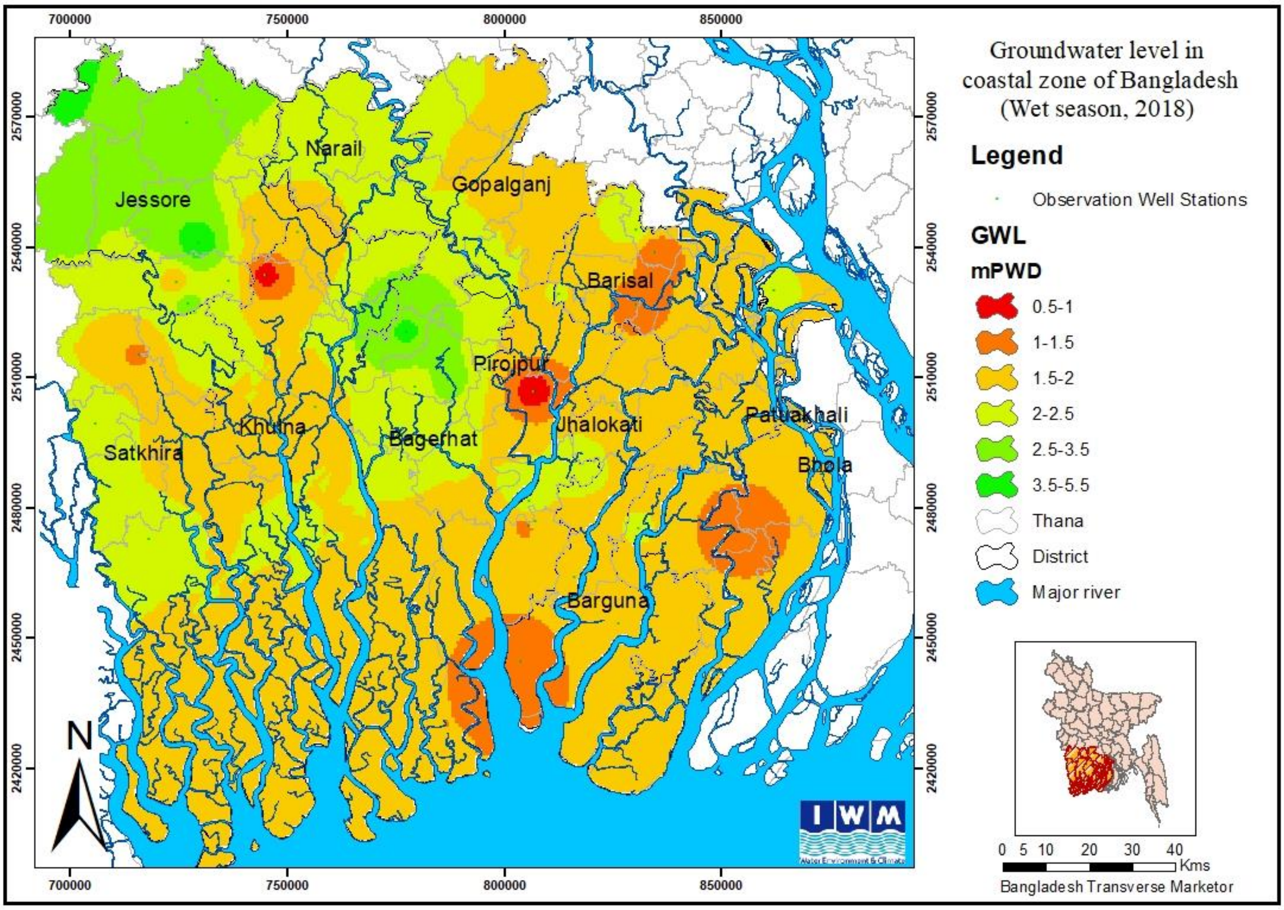


Figure 7-16: Spatial distribution of groundwater level in wet season, 2018

7.2.3 Changes of groundwater level in dry season (from 2008 to 2018)

The changes of groundwater level during dry season 2008 to 2018 is shown in Figure 7-17. It is observed that in some places of of Barisal, Patuakhali, Bhola and Barguna; the groundwater level has risen. This may happen due to the impact of sea level rise or may be due to data error. This scenario is observed around in 2.0% of the study area.

On the other hand, groundwater level in the major areas have decreased due to abstraction of groundwater for agriculture or domestic purposes. Depletion of groundwater happens more that 1.0 m in major part of Jessore which is mainly due to abstraction for agriculture purposes. About 20.54% area faces more than 1.0 m, 43.05% 0.5 to 1.0 m and 17.56% area less than 0.5 m depletion.

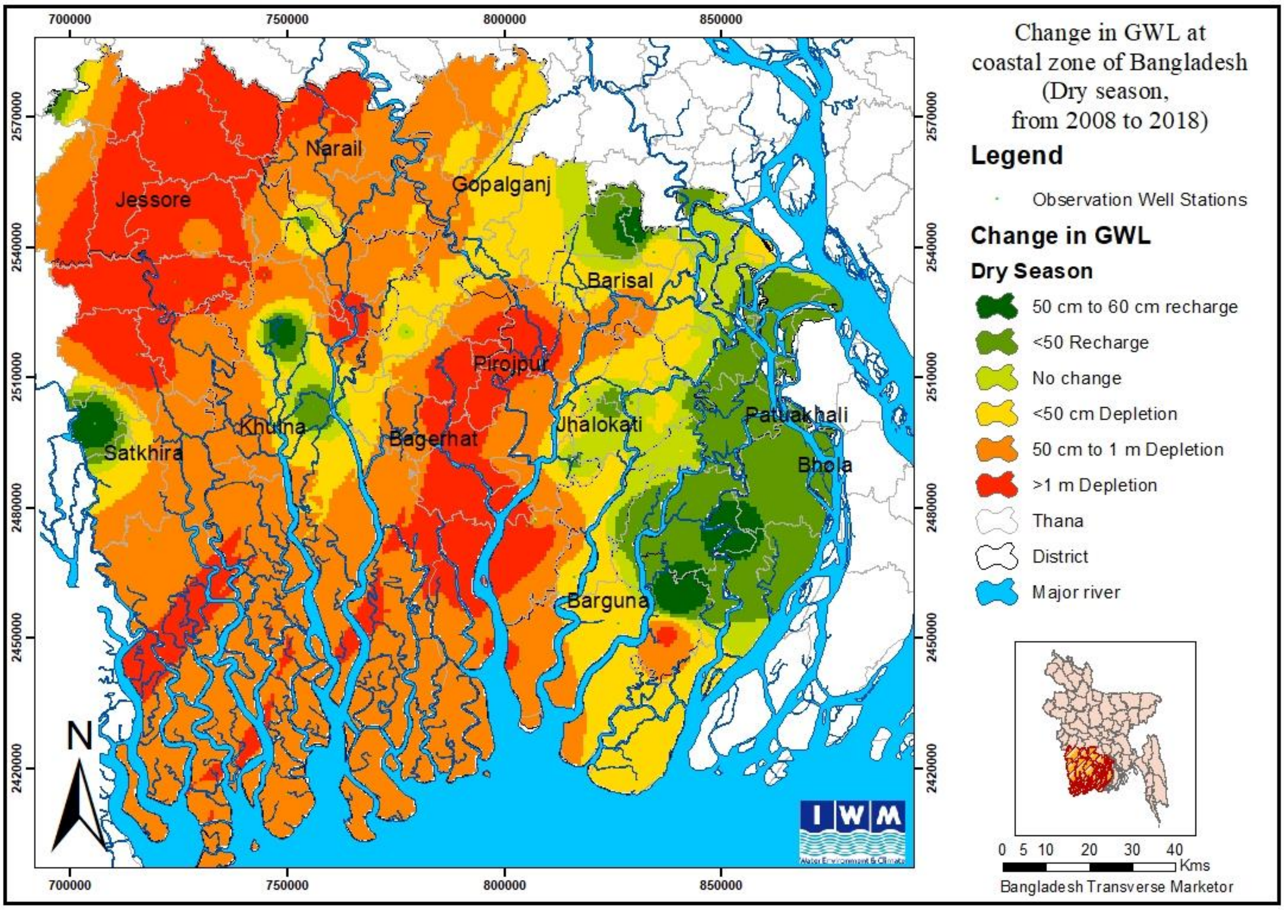


Figure 7-17: Changes of groundwater level in dry season (2008 to 2018)

7.3 Changes of groundwater level in wet season (from 2008 to 2018)

The changes of groundwater level during wet season 2008 to 2018 is shown in Figure 7-18. It is observed that some part Barguna and Patuakhali shows increased groundwater level which may be due to sea level rises.This scenario is seen at about 1.9% of the study area.

On the other hand, groundwater level has decreased in part of the study areadue to higher abstraction. Depletion of groundwater happens more than 1.0 m in some part of Jessore, satkhira and Pirojpur which is around 16.24% of the study area. Around 57.18% area faces 0.5 m to 1.0 m depletion, 19.78% area faces less than 0.5 m depletion.

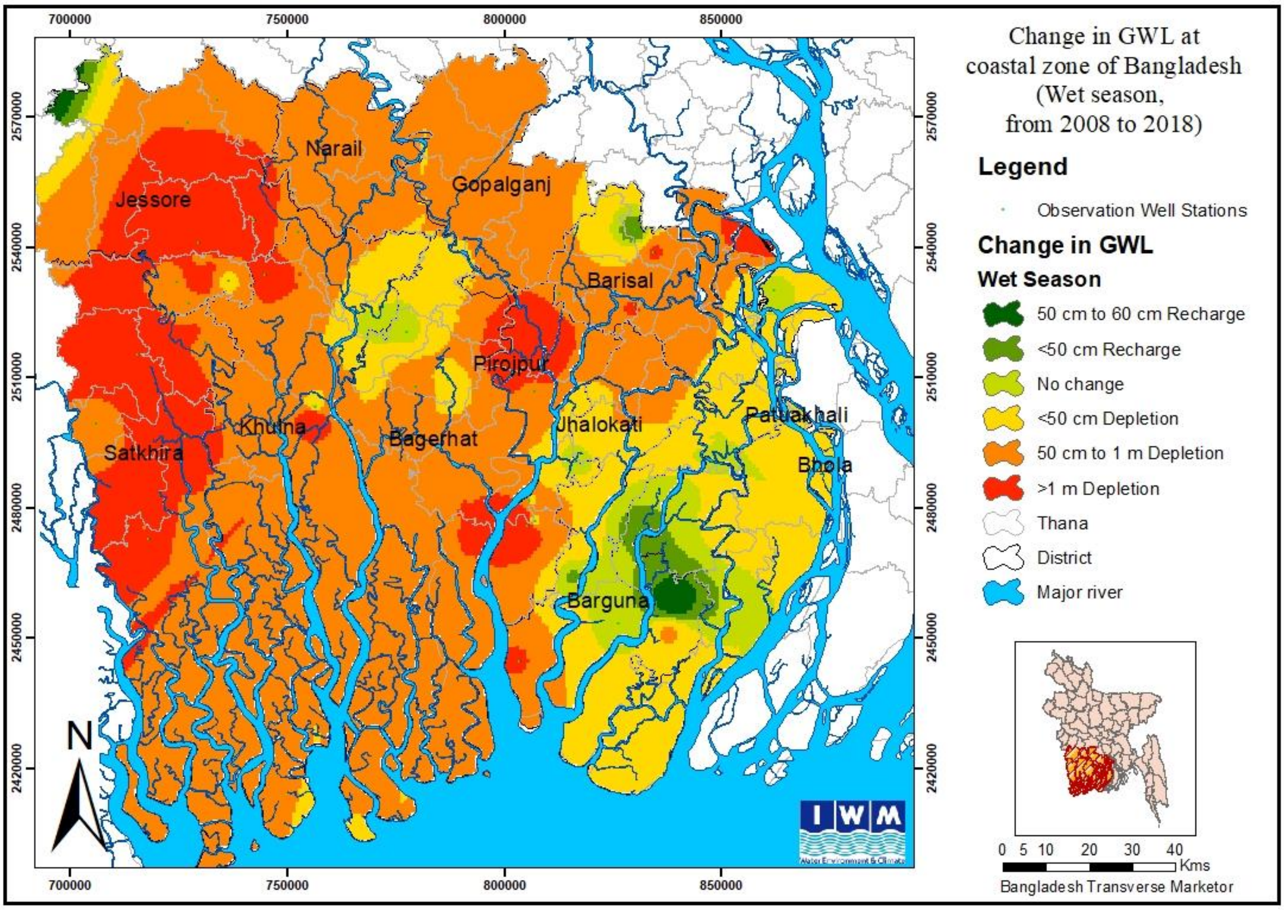


Figure 7-18: Changes of groundwater level in wet season (2008 to 2018)

From overall analysis, we can say that groundwater level has been depleted for the major part of Jessore and at city areas. The main reason behind this may be higher abstraction of groundwater for agriculture, domestic and other purposes. But in Barguna, Bhola, Jhalokathi and Patuakhali, the groundwater has risen slightly. It may be due to less abstraction of groundwater because of salinity or due to the impact of sea level rise. To have the clear picture more investigation in details level is required.

8 Updating Groundwater Salinity Model

8.1 Introduction

In the coastal region, salinity is one of the biggest problems in relation to water use and water management. So, it is necessary to assess the groundwater salinity dynamics including impact of climate change andhuman intervention. For this purpose, the groundwater salinity model that was developed under “Joint Action Research on Saltwater Intrusion in Groundwater in the Coastal Area” has been updated under this project. In this study, the groundwater salinity model has been updated for Jan’2013 to Dec’2018 to observe the change in salinity and effect of climate change in groundwater salinity. For the climate change impact assessment, the effect of rainfall, increase in surface water salinity and sea level rise have been considered.

The different input files have updated and the model has been calibrated for the period from 2013-2018 and validated against the salinity for the year 2020. The model area (Figure-6) is about 1534 km^2 covers thirteen upazilas of Khulna, Jessore and Satkhira districts. The model area is bounded on the north by groundwater observation wells, on the west by the Kobadak river, on the east by the Rupsha river and on the south by a channel connecting Kobadak and Rupsha.

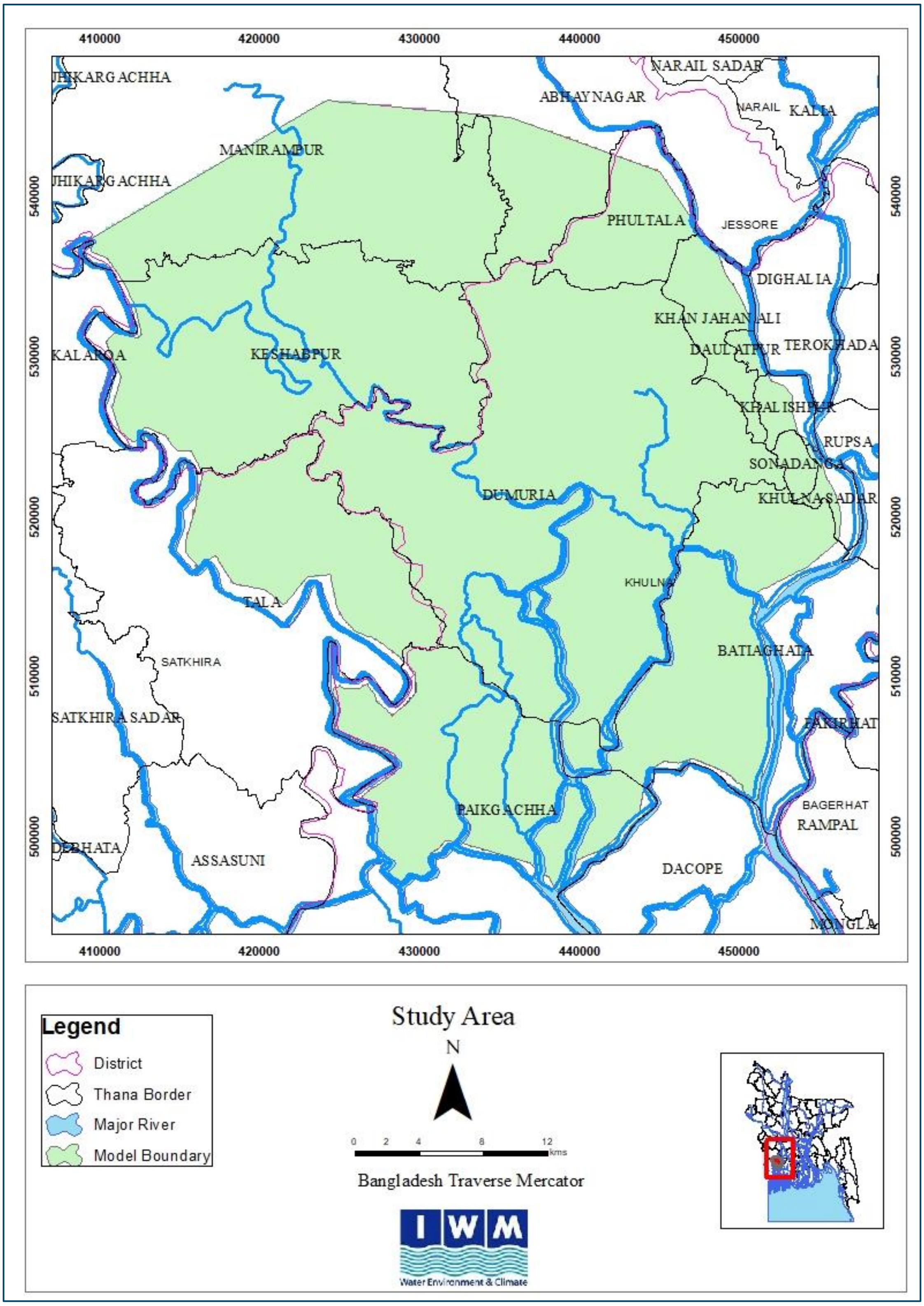


Figure 8-1: Model study area

8.2 Initial Condition

Initial conditions in terms of hydraulic heads of groundwater have been specified in the model. Groundwater level of the observation wells have been used to generate initial condition for both shallow and deep aquifer. Initial conditions of groundwater level have been prepared using the groundwater level data from 15 March 2013.

The initial conditions in terms of mass concentrations have also been specified. Here groundwater salinity data collected under JAR project have been used. The initial condition of hydraulic head and mass concentration have been shown in Figure 8-2.

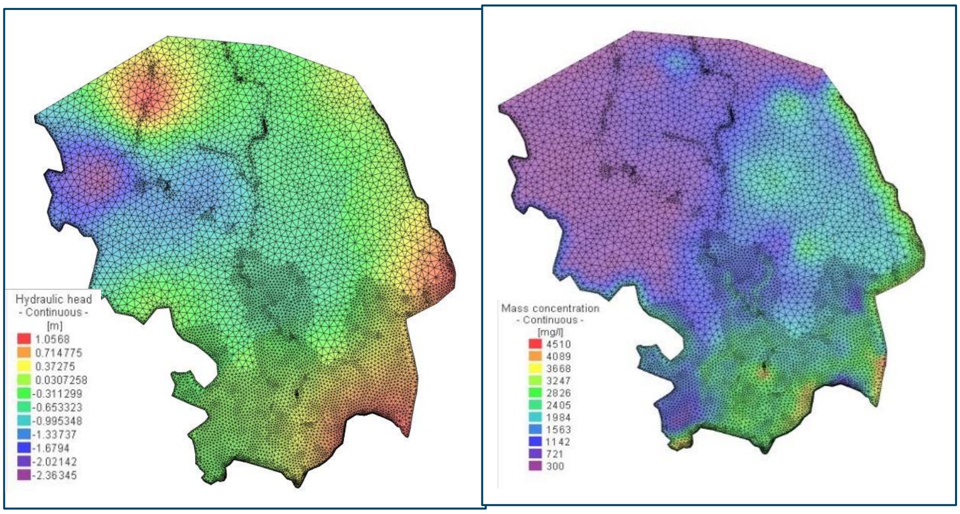


Figure 8-2: Initial Condition of Hydraulic Head (left) and Mass conc. (right)

8.3 Boundary Condition

For updating the boundary conditions, following time series data have been updated for the duration of 2013 to 2018.

- Groundwater Level
- Surface Water Level
- Surface water Salinity

8.3.1 Surface Water Level

Surface water level of 15 stations along the rivers have been generated from result file of South West regional model of IWM, for the period 2013-2018. Then the water level has been incorporated with the model as fluid transfer boundary in slice 1 and 2 (Figure 8-3). Remaining nodes along the river have been interpolated. List of surface water level station is given in Table 8-1.

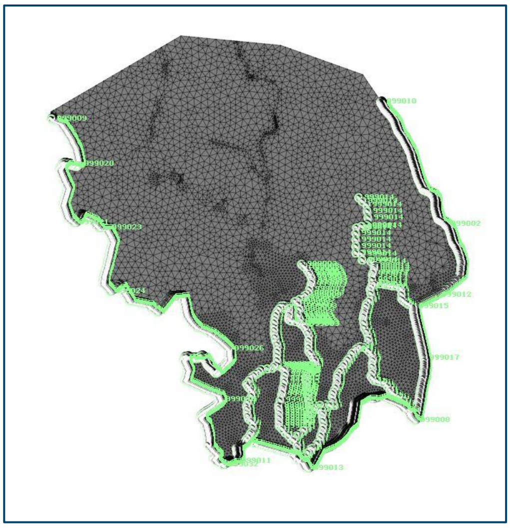


Figure 8-3: Location of Surface water level boundary

Table 8-1: List of SWL boundary stations

SL No	River	Chainage	BTM_X	BTM_Y
1	Bhadra	1000	438040	520010
2	Buri-Bhadra	0	412720	532580
3	Minajnadi	991	429010	495788
4	Sibsa	7250	438780	496480
5	Kazibacha	0	451670	514160
6	Kazibacha	6800	452194.5	509676.6
7	Kazibacha	12000	451530	502800
8	Kobadak	107946	412037.9	524231.4
9	Kobadak	120046	415164	523419.6
10	Kobadak	128146	415583	516881.2
11	Kobadak	149800	429270.8	509762.5
12	Kobadak	169400	428196.9	505065.5
13	Kobadak	180000	428300	497310
14	Kobadak	94246	412213	531492.7
15	Kobadak	86946	409434.8	536949.7

Here, surface water level from different chainage from the main rivers in Bhadra, Buri-Bhadra, Sibsa, Kazibacha and Kobadak has been incorporated. The water level data was in the interval of six hours. All the data were properly checked for quality assurance.

8.3.2 Groundwater Level

Groundwater level data has been collected for the period 2013-2018 from BWDB in and around the study area. Six stations have been used as boundary of hydraulic head for modelling purpose. The remaining nodes at the border of the study area has been interpolated. The interval of the data is 7 days. Groundwater level data has been checked and pre-processed for quality. The list of the groundwater level stations used as boundary is given in Table 8-2. The locations of the groundwater head boundaries nodes are shown in Figure 8-4.

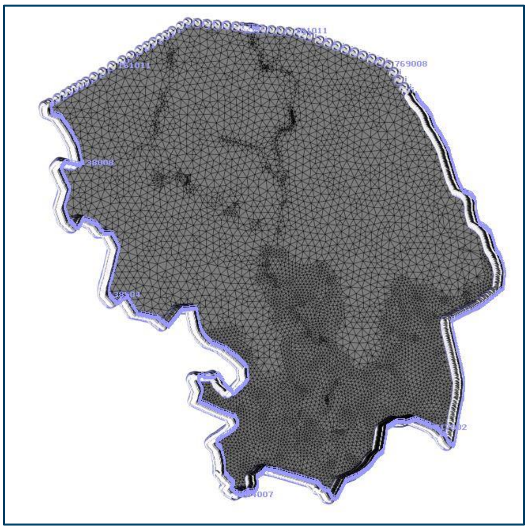


Figure 8-4 : Location of Hydraulic Head Boundary

Table 8-2: List of groundwater level stations used for boundary of model

SL No	Well_ID	District	Thana	Village
1	4161011	Jashore	Manirampur	Kadlapara
2	4138008	Jashore	Keshabpur	Altapur
3	4138504	Jashore	Keshabpur	Keshabpur
4	4769008	Khulna	Phultala	Sikirhat
5	4717002	Khulna	Dacope	Chalnabazar
6	4764007	Khulna	Paikgachha	Batikhali

8.3.3 Surface water salinity

Surface water salinity has been collected from Rupsa, Sibsa, Kobadak, Gangril River. The salinity data has been incorporated as mass transfer boundary condition. In the Figure 8-5, the location of the salinity boundary nodes and time series of salinity in Rupsa River is shown.

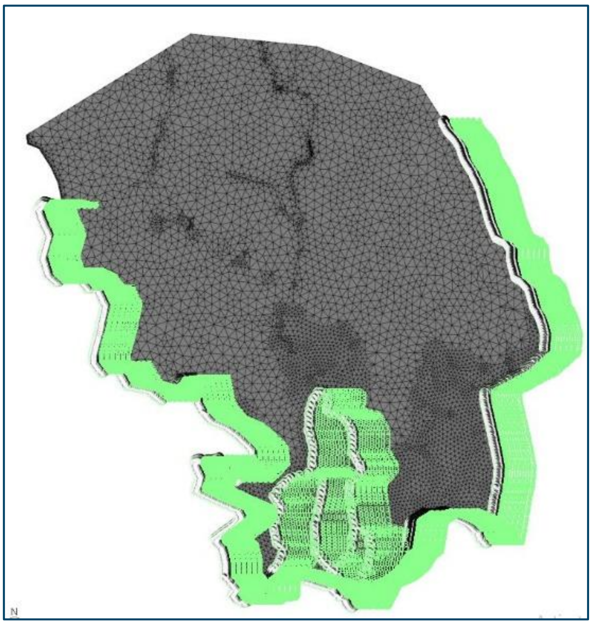


Figure 8-5 : Location of surface water salinity boundary

8.4 Inflow/outflow

Rainfall and Evapotranspiration (ET) have been considered as input and a sink, respectively. As rainfall facilitates the recharge it is considered as inflow and ET is considered a loss.

8.4.1 Rainfall

BWDB collects daily data for rainfall and evaporation. Rainfall data have been collected from seven BWDB stations, situated in and around the model area. Location of available rainfall stations is given in Table 8-3.

Table 8-3: List of Rainfall Stations

Sl No	Station Name	Station ID	District	Upazila
1	Khulna	R510	Khulna	Khalishpur
2	Keshabpur	R459	Jessore	Keshabpur
3	Chalna	R503	Khulna	Dacope
4	Dumuria	R504	Khulna	Dumuria
5	Islamkati	R505	Sathkira	Tala
6	Kapilmuni	R509	Khulna	Paikgacha
7	Paikgacha	R515	Khulna	Paikgacha

The collected data has been checked for quality. Missing data were filled by using data from the nearby station. The quality of the rainfall data has been checked by visual inspection of the hyetograph as well as through double mass curves analysis. The double mass curves of the rainfall data is given in Appendix-A. The spatial distribution of the rainfall for various stations has been described by means of Thiessen polygons and is shown in Figure 8-8.

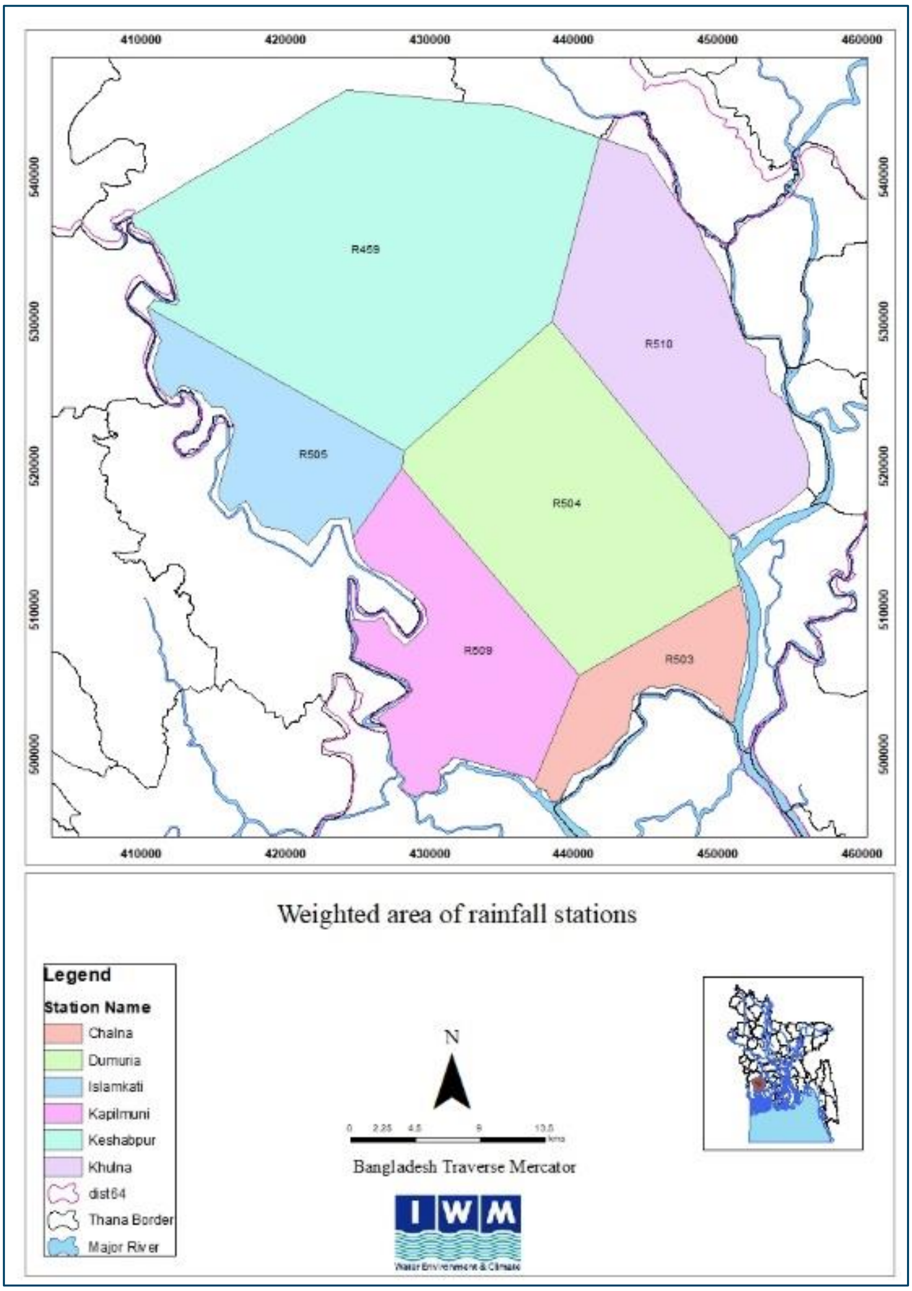


Figure 8-6: Thiessen Polygon in the study area

Here, for different stations, different percentage of rainfall has been considered as infiltrated. As the urbanization in Khulna Sadar and Chalna is higher, the percentage of rainfall that infiltrates is considered 10%. For remaining stations, the percentage has been considered as 15%. Only for Keshabpur, the percentage is considered as 20% of total rainfall.

8.4.2 Evapotranspiration

Evapotranspiration for the study area has been collected from Bangladesh Meteorological Department (BMD). 23% of Evapotranspiration has been considered as outflow on all the areas of the model area.

8.5 Calibration and Validation of model

The groundwater salinity model has been calibrated against groundwater levels. The % of inflow and outflow were adjusted within a reasonable range, during the calibration period to match the simulated groundwater level with the observed one. Model results have been compared at certain key locations where observed water level data are available. The model results have been calibrated against three wells shown in Figure 8-7, due to a limited number of wells within the model area.

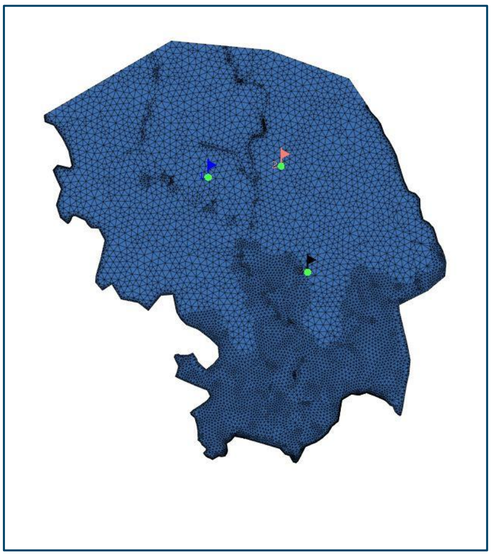


Figure 8-7: Location of calibration well

Comparison of groundwater level between simulated and observed is shown in Figure 8-8. The dots show the observed values and the continuous line is for the simulated groundwater level. From calibration plot of GW level, it is observed that the simulated groundwater level mostly matched with observed values. So, we can say that the calibration of the model is quite satisfactory.

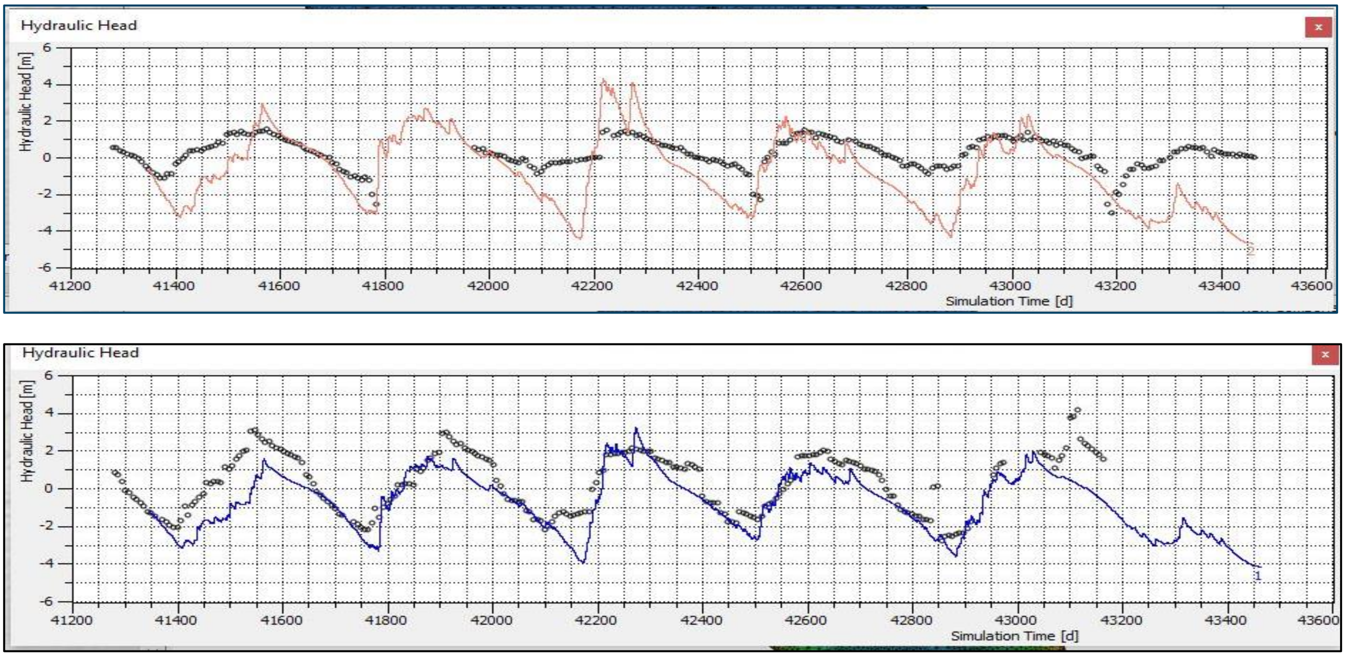


Figure 8-8: Comparison of GW Level in the calibration wells

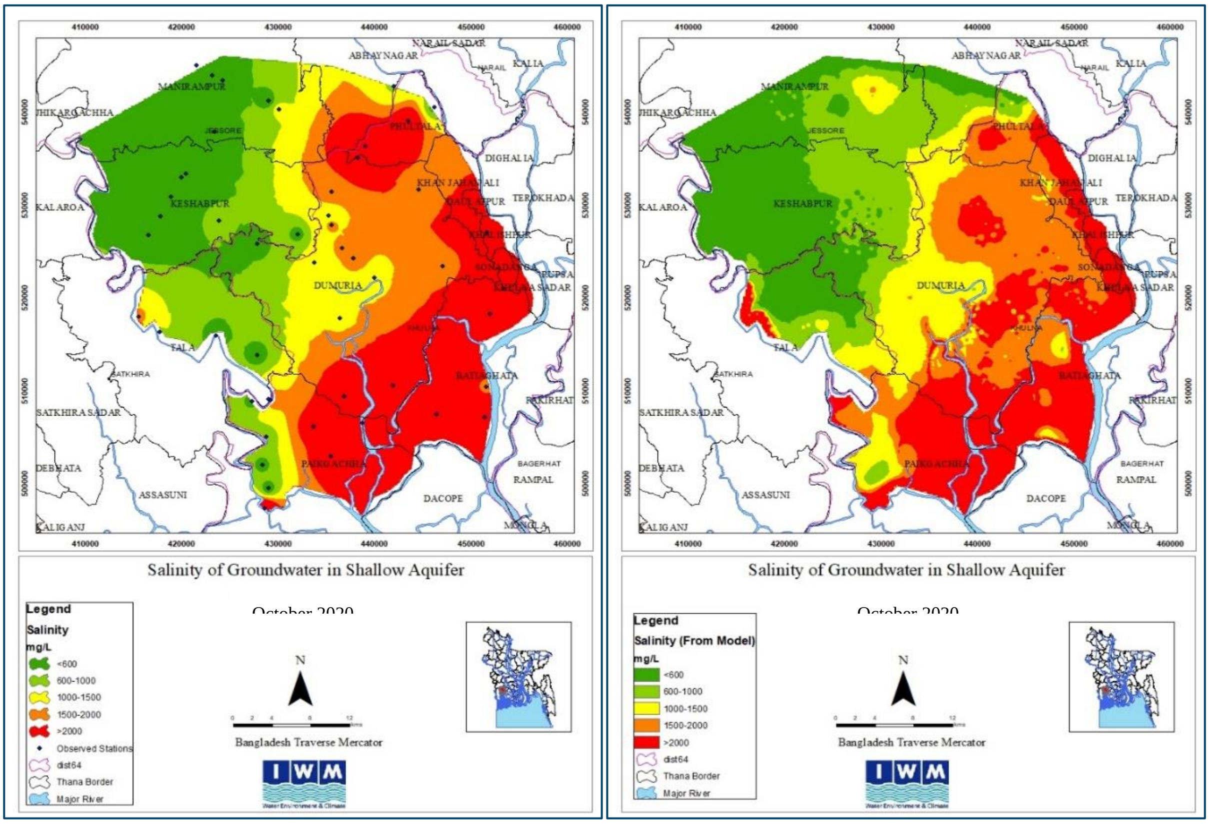


Figure 8-9: Comparison of GW salinity distribution from (a) field data and (b) model

Comparison of GW salinity distribution is shown in Figure 8-9. Here, in October 2020, Groundwater from 44 locations in shallow tube well has been collected and spatial distribution has been made. A good agreement of spatial distribution of salinity is seen between the observed and simulated results. The low salinity zone (< 1000 ppm) lies along the western part of the study area and the high salinity zone (> 1000 ppm) lies along the eastern side.

9 Application of Groundwater Salinity Model

In order to evaluate the impact of different options on GW salinity distribution, GW salinity model has been developed as mentioned in Chapter-8. This chapter mainly deals with application of the salinity model to simulate different options and evaluation of option results. It also briefly describes other activities e.g. assessment of water demand, generation of climatic parameters such as rainfall and temperature under climate change condition, those are required for option simulation, option formulation etc.

9.1 Generation of Rainfall and Temperature under Climate Change

9.1.1 Climate Change Projections

The extent, intensity and magnitude of climate change impacts are not known exactly. The present study focuses on salinity intrusion due to three types of cases, these are both and separate cases for the impact of climate change, sea level rise. For incorporating the climate change impacts into the models the rainfall and evaporation changes are to be projected for 2050.

IPCC Special Report on Emissions Scenarios (SRES) recommended several scenario families. A Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC. Four pathways were used for climate modeling and research for the IPCC fifth Assessment Report (AR5) in 2014. The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come. The RCPs – originally RCP2.6, RCP4.5, RCP6, and RCP8.5 – are labelled after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m2, respectively). Since AR5 the original pathways are being considered together with Shared Socioeconomic Pathways: as are new RCPs such as RCP1.9, RCP3.4 and RCP7.

The RCPs are consistent with a wide range of possible changes in future anthropogenic (i.e., human) GHG emissions, and aim to represent their atmospheric concentrations. Despite characterizing RCPs in terms of inputs, a key change from the 2007 to the 2014 IPCC report is that the RCPs ignore the carbon cycle by focusing on concentrations of greenhouse gases, not greenhouse gas inputs. The IPCC studies the carbon cycle separately, predicting higher ocean uptake of carbon corresponding to higher concentration pathways, but land carbon uptake is much more uncertain due to the combined effect of climate change and land use changes.

In RCP 8.5 emissions continue to rise throughout the 21st century. Since AR5 this has been thought to be very unlikely, but still possible as feedbacks are not well understood. RCP8.5, generally taken as the basis for worst-case climate change scenarios, was based on what proved to be overestimation of projected coal outputs. It is still used for predicting mid-century (and earlier) emissions based on current and stated policies.

9.1.2 Rainfall & Evapotranspiration

Those input data that are sensitive to climate change such as meteorological data (rainfall, evaporation) and hydrological data (river water level and discharge at the boundary locations) are used in the model setup incorporating the effect of climate change scenarios. Under the present study downscaled Global Climate Model (GCM) have been used. In this circumstances climate change factor generally referred as 'Delta Factor' is used from the several ensembled GCM for the scenario RCP 8.5. So, 'Delta Factor' is calculated for Rainfall and Evaporation for the year 2050 considering scenario RCP 8.5. Rainfall data for future 2050 are given at the station Khulna, Satkhira & Jessore for the scenario RCP 8.5. It is also same for evapotranspiration.

9.1.3 Sea Level Rise

To take into account the effect of SLR, which is one of the influential factors of this study as the study area is in the coastal region, the IPCC recommendations based on synthesis report in respect of SLR has been considered. It states that the anticipated SLR by 2050 would be of the order of 0.52 meter. This sea level changes have been taken into account in establishing the boundary condition in model setup where needed as per the changes of hydrometeorological data as rainfall & evapotranspiration. As well as salinity data are also given for 2050 at the scenario RCP8.5 for upstream boundary to downstream boundary.

9.1.4 Formulation of Scenarios

The calibrated and verified models have been simulated for several scenarios and the results have been analyzed to evaluate the performance and to achieve the study objectives for the study area. The model has been simulated for the following scenarios:

Scenario-0: Base Condition

Hydrological & hydro-meteorological condition has been considered as of base year 2020

Surface water salinity has been considered as of base year 2020

Hydro-geological parameters are considered as of base year 2020

Land use and water demand for domestic, irrigation and industrial etc. has been considered for base year

Scenario-I: Impact of Climate Change and Sea Level Rise on Groundwater Salinity in Future

Hydrological & hydro-meteorological condition has been used for the year 2050, predicted considering RCP 8.5.

Surface water salinity & sea level rise (SLR) for the year 2050 has been used

Groundwater abstractions for domestic, irrigation and industrial purposes has been used for the year 2050.

All other conditions have been kept as of base condition

Scenario-II: Impact of only Climate Change on Groundwater Salinity in Future

Hydro-meteorological condition has been used for the year 2050, considering RCP 8.5.

Groundwater abstractions for domestic, irrigation and industrial purposes has been used for the year 2050

All other conditions have been kept as of base condition

Scenario-III: Impact of only Sea Level Rise on Groundwater Salinity in Future

Surface water salinity & sea level rise (SLR) for the year 2050 has been used

Groundwater abstractions for domestic, irrigation and industrial purposes has been used for the year 2050

All other conditions have been kept as of base condition

9.2 Model Setup for Different Scenarios

In model setup for different scenarios, the parameters that are not sensitive or less sensitive to climate change have been kept unchanged. Significant parameters under this category are hydraulic conductivity, transmissivity, specific yield, storage coefficient, conductance etc. of the aquifer obtained through calibration are kept unchanged for different scenarios. Number of geological and computational layers with their top and bottom elevations, soil properties and soil moisture retention curves, DEM of the study area, crop data base (leaf area index, root zone depth, crop growth stages and growing season) of individual crops etc. are also kept unchanged.

The input data that are sensitive to climate change such as meteorological data (rainfall, evaporation etc) and hydrological data (river water level and discharge at the boundary locations) are used in the model setup incorporating the effect of climate change scenarios RCP 8.5 for 2050s.

To consider the effect of SLR, which is one of the influential factors of this study as the study area is in the coastal region, the IPCC recommendations based on synthesis report in respect of SLR has been considered. It states that the anticipated SLR by 2050 would be in the order of 0.52 meter. This sea level changes have been considered in establishing the boundary condition in model setup where needed. The initial conditions in terms of mass concentrations have also been specified, and for October 2020's conditions are taken as initial condition. Here groundwater salinity is also changed as per the change of sea level rise.

Boundary conditions of the SW model for future climate change scenarios have been extracted from GBM basin model and BoB model. GBM basin model has been used to have the upstream boundary condition and BoB model has been used for determining the downstream boundary condition of the SW models. Both GBM basin model and BoB models took into consideration the effects of climate change. Findings and recommendations of IPCC has been used in the GBM and BoB model.

9.3 Analysis and Evaluation of Simulated Scenarios

Model simulated results for different scenarios have been analyzed, presented and compared with the base condition by reviewing the spatial distribution map of groundwater salinity for shallow aquifer. From the analysis of field data as well as model simulated result, it is observed that the salinity in groundwater reaches its highest level during the month of May. That's why the spatial distribution of groundwater salinity for the month of May for different scenarios, have been compared with base condition for better understanding. A brief description of the model simulated results for different scenarios are described below:

Scenario-0: Base Condition

From the model simulated result for scenario-0, the spatial distribution map of GW salinity of the shallow aquifer has been prepared for the dry season and shown in the Figure 9.1.

In this scenario, around 312 square-km area is in <600 mg/l salinity zone. Keshabpur, Manirampur, Abhaynagar and Tala are in this zone. The highest salinity zone consists of only 401 square-km area and the prople of Paikgacha, Batiaghat, Sonadanga, Khan Jahan Ali, Daulatpur face this salinity. About 291 square-km area has the salinity ranging from 600-1000 mg/l and it cover the eastern part of Keshabpur, Manirampur, Abhaynagar etc. People of Phultali, Dumuria has face the salinity in the range of 1000-2000 mg/l. Table 9.1, shows the percentage saline area for Scenario-0.

Table 9-1: Groundwater Salinity in Shallow Aquifer for Scenario-0

Salinity (mg/l) **S1**	**Area (sq. km)**	**Percentage (%) of total area**	**Upazila**
<600	312	21	West-middle Keshabpur, west Manirampur, Tala, Abahaynagar (upper)
600-1000	291	20	East Manirampur, Abhaynagar, East Keshabpur, some part of Dumuria & Tala
1000-1500	196	14	Dumuria, little part of Abhaynagar
1500-2000	254	17	Dumuria, Phultala , Paikgacha
>2000	401	28	Paikgacha, Batiaghata, Dumuria, Daulatpur

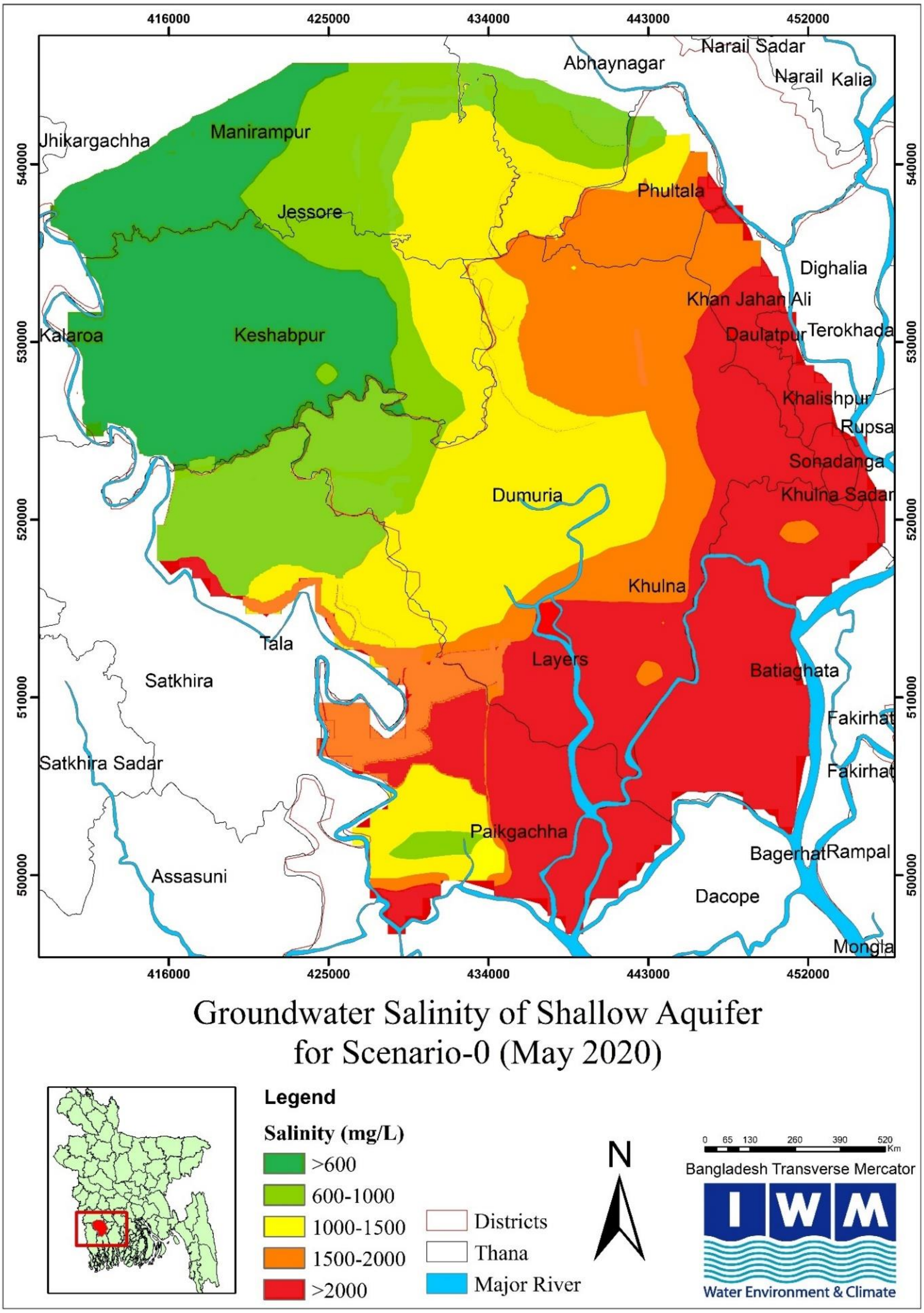


Figure 9-1: Groundwater Salinity for Scenario-0

9.3.1 Scenario I

For understanding the impact of climate change and sea level rise on groundwater salinity in future (in the year 2050), surface water level along with surface water salinity for the year 2050 and rainfall & evaporation for RCP 8.5 have been considered during model simulation. The other parameters have been kept unchanged.

From the model simulated result for this scenario, a spatial distribution map of groundwater salinity has been prepared and shown in Figure 9-2. The figure shows that around 500 square km which is about 34% of the total area will suffer due to salinity intrusion more than 2000 mg/l. A part of Tala, Paikgacha, Batiaghata, Daulatpur & Dumuria etc. Comparatively, people of Keshabpur, Manirampur will be in safe zone (lower the 600 mg/l salinity intrusion). Table 9.2, shows the percentage of the area of salinity intrusion for Scenario-I.

Table 9-2: Groundwater Salinity in Shallow Aquifer for Scenario-I (May 2050)

Salinity (mg/l) **S1**	**Area (sq. km)**	**Percentage (%) of total area**	**Thana Name**
<600	293	20	West-middle Keshabpur, west Manirampur
600-1000	135	9	Middle Manirampur, Upper Abhaynagar, some part of Keshabpur, Dumuria
1000-1500	275	19	Dumuria, Eastern Keshabpur, Manuriampur, Abhaynagar, Phultala, Paikgacha west)
1500-2000	258	18	Dumuria, Phultala , Paikgacha
>2000	493	34	Tala, Paikgacha, Batiaghata, Dumuria, Daulatpur

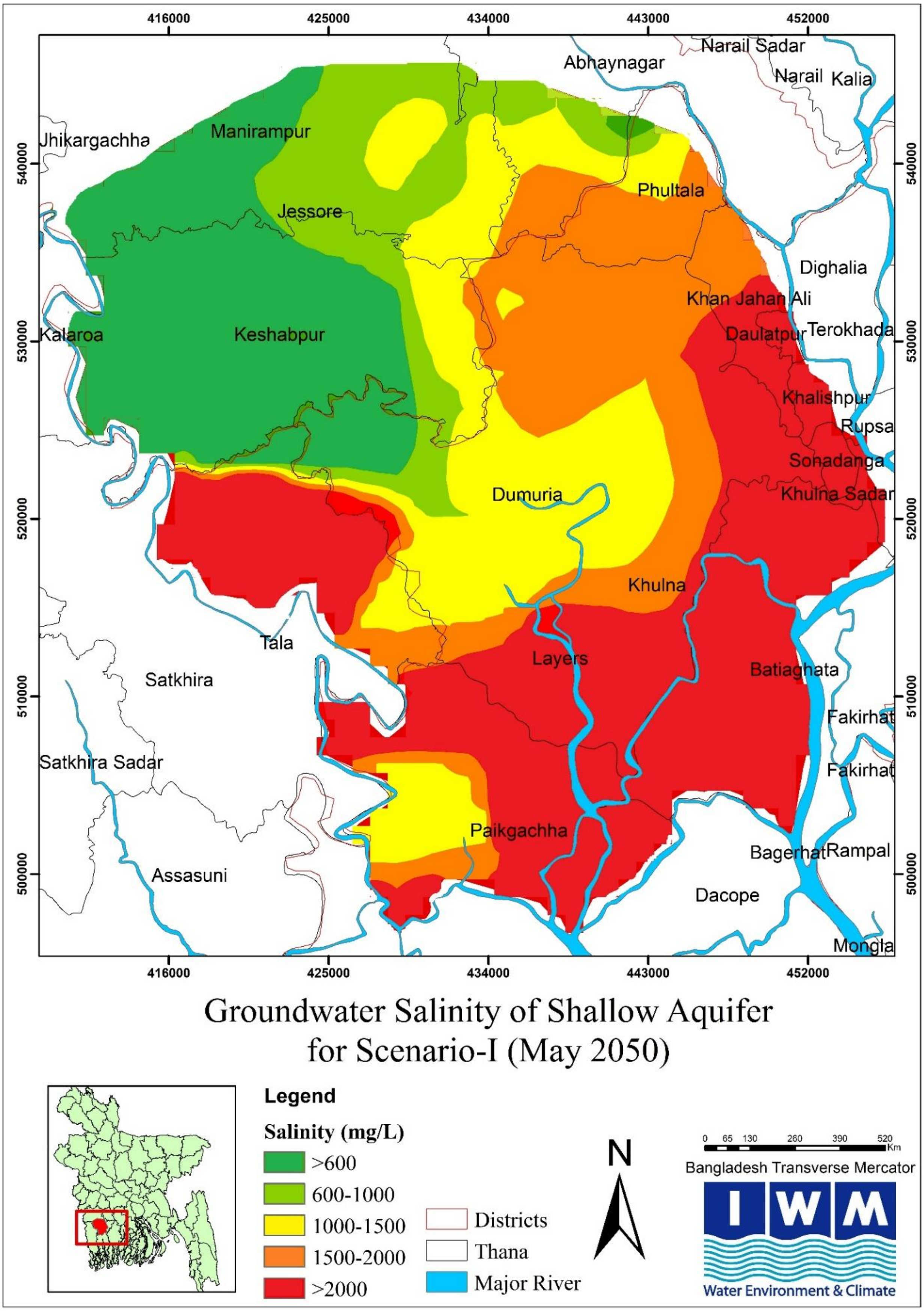


Figure 9-2: Groundwater Salinity in Shallow Aquifer for Scenario-I (May 2050)

9.3.2 Scenario II

For understanding the impact of only climate change on groundwater salinity in future (in the year 2050), only the Rainfall & Evaporation for RCP 8.5 have been considered for the year 2050. The other parameters along with surface water level have been kept unchanged.

From the model simulated result for this scenario, a spatial distribution map of groundwater salinity has been prepared and shown in Figure 9-3. The figure shows that around 29% of the total area will suffer because of more than 2000 mg/l salinity intrusion which is about 415 square km area. A part of Paikgacha, Batiaghata, Daulatpur and Dumuria are in this zone. The people of Keshabpur, Manirampur will be comparatively in safe zone (lower the 600 mg/l salinity intrusion) and the volume of this area is about 294 square km. Table 9.3, shows the percentage of the area of salinity intrusion for Scenario-II.

Table 9-3: Groundwater Salinity in Shallow Aquifer for Scenario-II (May 2050)

Salinity (mg/l) **S2**	**Area (sq. km)**	**Percentage (%) of total area**	**Thana Name**
<600	294	20	West-middle Keshabpur, west Manirampur
600-1000	143	10	Middle Manirampur, Upper Abhaynagar, some part of Keshabpur, Dumuria
1000-1500	304	21	Dumuria, Eastern Keshabpur, Manuriampur, Abhaynagar, Phultala, Paikgacha west), Tala
1500-2000	298	20	Dumuria, Phultala , Paikgacha, Tala
>2000	415	29	Paikgacha, Batiaghata, Dumuria, Daulatpur

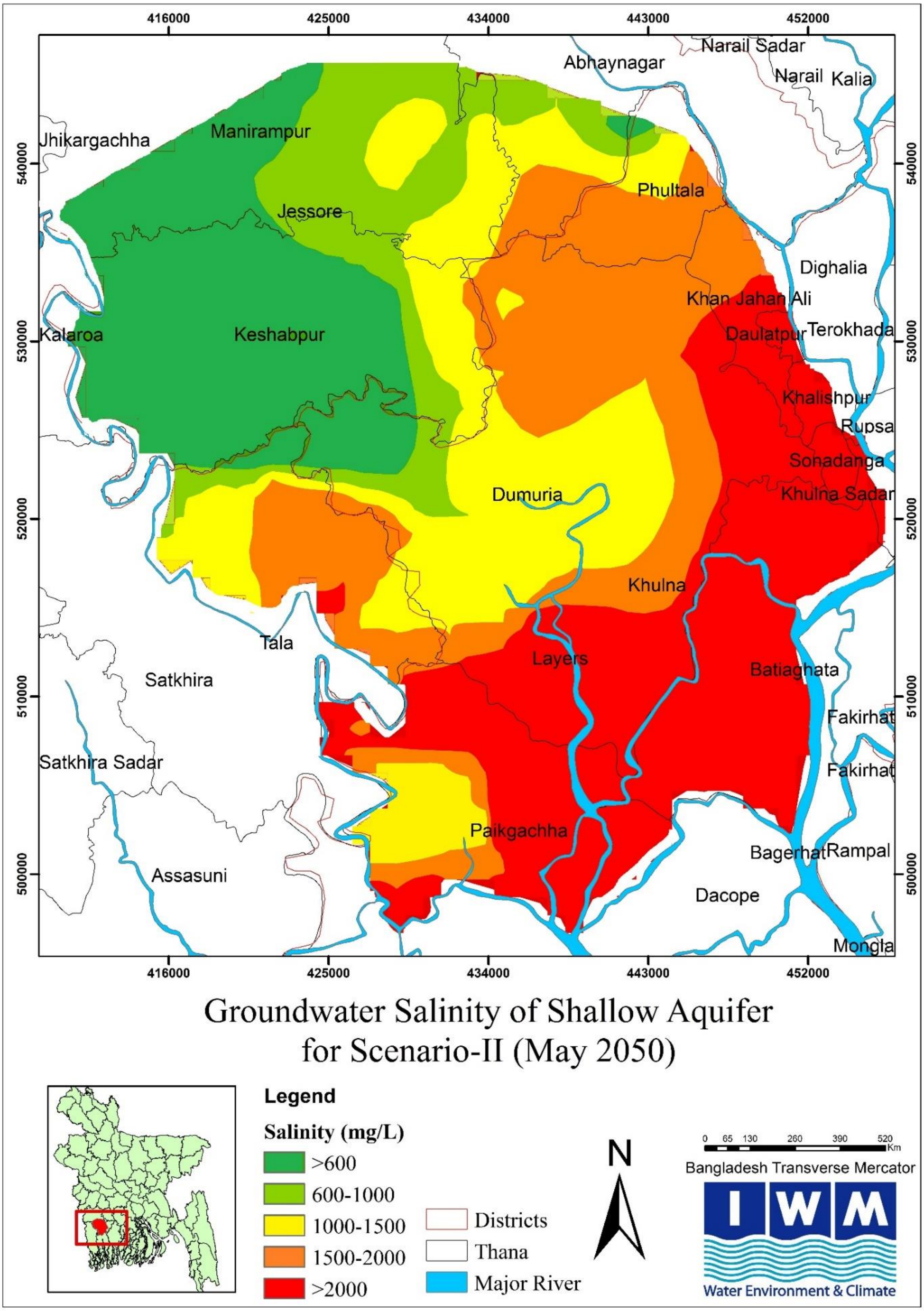


Figure 9-3: Salinity of Groundwater in shallow aquifer for model scenario 2 (May 2050)

9.3.3 Scenario III

For understanding the impact of sea level rise on groundwater salinity in Future (for 2050), the surface water level along with surface water salinity for the year 2050 have been considered. The other parameters have been kept unchanged.

From the model simulated result for this scenario, a spatial distribution map of groundwater salinity has been prepared and shown in Figure 9-4. The figure shows that around 33% of the total area will suffer because of more than 2000 mg/l salinity intrusion which is about 472 square km. A part of Paikgacha, Batiaghata, Daulatpur, Dumuria are in this zone. The people of Keshabpur, Manirampur and Abhaynagar will comparatively be in safe zone (lower the 600 mg/l salinity intrusion) and the volume of this area will be about 301 square km. Table 9.4, shows the percentage of the area of salinity intrusion for Scenario-III.

Table 9-4: Groundwater Salinity in Shallow Aquifer for Scenario-III (May 2050)

Salinity (mg/l) S3	**Area (sq. km)**	**Percentage (%) of total area**	**Thana Name**
<600	301	21	West-middle Keshabpur, west Manirampur, Abhaynagar
600-1000	108	7	Middle Manirampur, Upper Abhaynagar, some part of Keshabpur, Dumuria
1000-1500	311	21	Dumuria, Eastern Keshabpur, Manuriampur, Abhaynagar, Phultala, Paikgacha west), Tala
1500-2000	262	18	Dumuria, Phultala , Paikgacha, Tala
>2000	472	33	Paikgacha, Batiaghata, Dumuria, Daulatpur

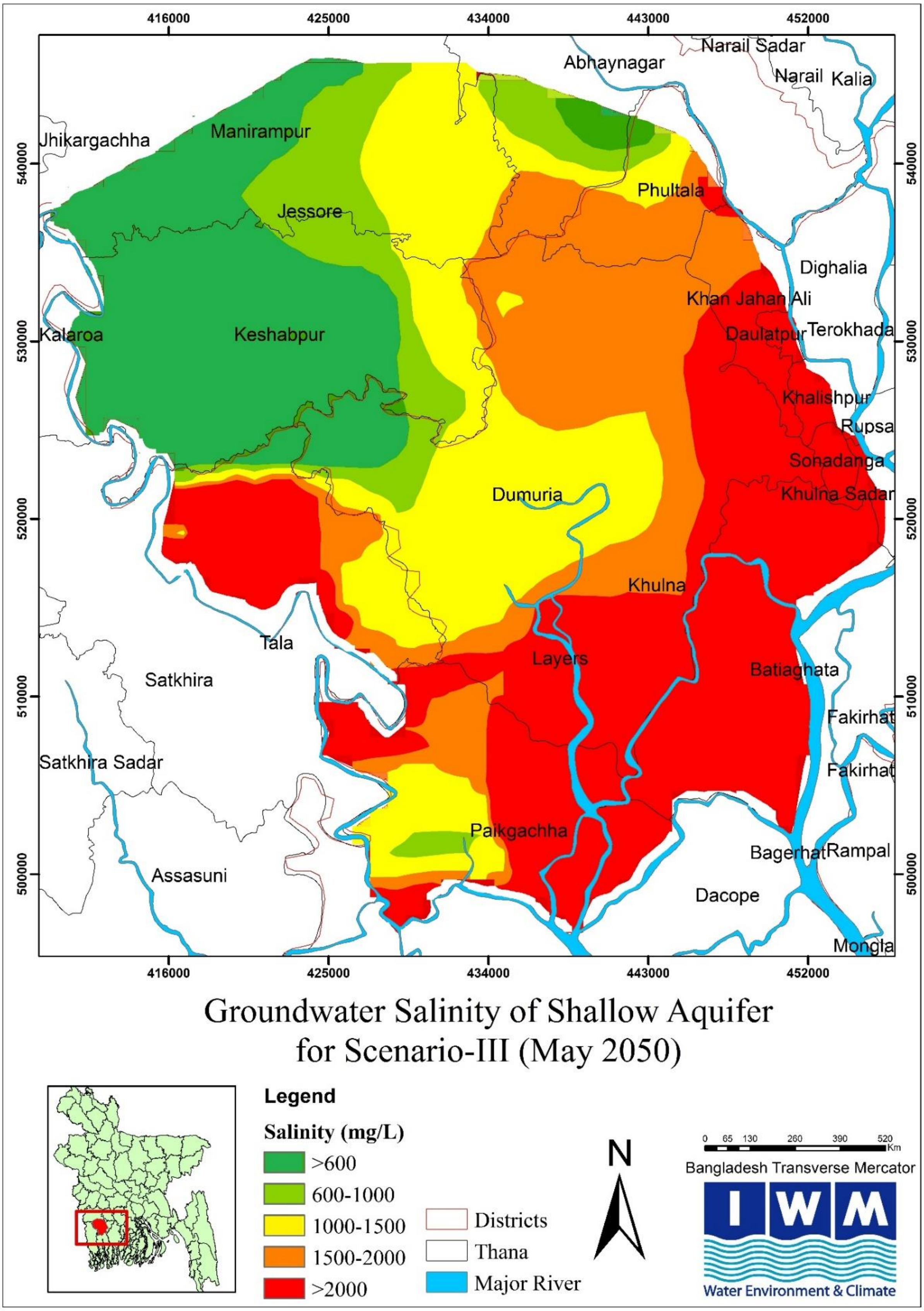


Figure 9-4: Salinity of Groundwater in shallow aquifer for model scenario III (May 2050)

9.4 Comparison of the scenarios

9.4.1 Comparison of the Scenarios with Base Condition

Table 9-5: Comparison among three Scenarios

Salinity (mg/l)	**Area (sq. Km)**				**Changes (%) in different scenarios compared to Scenario-0**		
	Scenario-0	**Scenario-I**	**Scenario -II**	**Scenario -III**	**Scenario -I**	**Scenario -II**	**Scenario-III**
<600	312	293	294	301	-6.1	-5.8	-3.5
600-1000	291	135	143	108	-53.6	-50.9	-62.9
1000-1500	198	275	304	311	38.9	53.5	57.1
1500-2000	254	258	298	262	1.6	17.3	3.4
>2000	401	493	415	472	23.0	3.5	17.7

Compared to scenario-0 (i.e. base condition), all three scenarios give worser situation. Among three scenarios, scenario-I shows the worst situation. For Scenario-I, the saline zone (salinity <600 mg/l) will decrease by 6.1%, on the other hand, the area having salinity greater than 2000 mg/l will increase by around 23.01%. About 53.6% area will be shifted from salinity 600-1000 mg/l, in scenario-I compared to base model and in the scenario-II it will be 50.9%. But in the scenario-II the area of the highest salinity zone (>2000 mg/l) will increase 3.5% compared to the base model. Among all the three scenarios compared to the base model, scenario-II comparatively gives better situation. Again, in scenario-III, 62. 9% area will change (decrease) from the area having salinity 600-1000 mg/l and will increase by 57.1% of area having salinity 1000-1500 mg/l.

10 Refences

1. Aggarwal, P.K., A R Basu, R J Poreda, K M Khulkarni, K Forehlich, S A Tarafdar, M Ali, N Ahmed, A Hossain, M Rahman, S R Ahmed, 2000, A Report on Isotope Hydrology of Groundwater in Bangladesh: Implications for Characterization and Mitigation of arsenic in Groundwater. IAEATC Project BGD/8/016.
2. BADC, June 2011, Forecasting Saline Water Intrusion, Irrigation Water Quality and Water Logging Program In Southern Area, Ministry of Agriculture, Government of Bangladesh.
3. BGS and DPHE, 2001, Arsenic contamination in groundwater in Bangladesh, Kinnibrugh, D.G. and Semdley, P.L. (Editors), vol 2, Final Report, BGS Technical Report WC/00/19, British Geological Survey, Keyworth, United Kingdom.
4. BWDB,Mathematical Modelling Study (Groundwater and Surface water) to Assess Upazila wise Surface Water and Groundwater Resources and Changes in Groundwater Level Distribution due to Withdrawal of Groundwater in the Study Area (Package-1)
5. BWDB,Mathematical Modelling Study (Groundwater and Surface water) to Assess Upazila wise Surface Water and Groundwater Resources and Changes in Groundwater Level Distribution due to Withdrawal of Groundwater in the Study Area (Package-1)
6. DANIDA/DPHE, 2001, Hydrogeology summary report, DPHE-DANIDA Water Supply and Sanitation Components.
7. Davies.J., November 17, 1994, The Hydro-chemistry of Alluvial Aquifers in Central Bangladesh. In: Nash, H. & McCall. J. (eds), November 17, 1994, Groundwater Quality, AGID Special Publication, Chapman and Hall, London, pp 9-18.
8. Davis.J., November 17, 1994, The Hydro-chemistry of Alluvial Aquifers in Central Bangladesh. In: Nash, H. & McCall. J. (eds), November 17, 1994, Groundwater Quality, AGID Special Publication, Chapman and Hall, London, pp 9-18.
9. Davis. J. Exley. C., 1992, Final Report, Short Term BGS Pilot Project to Access the Hydro-Chemical Character of the Main Aquifer Units of Central and North-eastern Bangladesh and Possible Toxicity of Groundwater to Fish and Human, British Geological Survey Technical Report WD/92/43R.
10. HASKONING & IWACO B.V, February 1981, Volume 3, Final Report, Khulna Water Supply Project - Feasibility Study, Department of Public Health Engineering, Ministry of Local Government Rural Development and Cooperatives, Government of the People's Republic of Bangladesh.
11. IBRD (1972). Bangladesh Land and Water Resources Sector Study, Vol-VII (The International Bank for Reconstruction and Development (IBRD))
12. IWACO B.V, 1985, Final Report, Geohydrological Investigation in Khulna Water Supply and Sanitation Projects, Department of Public Health Engineering, Ministry of Local Government Rural Development and Cooperatives, Government of the People's Republic of Bangladesh.
13. IWM, 2002, Volume-I, Final Report, Khulna-Jessore Drainage Rehabilitation Project, Special Monitoring of Rivers and Tidal Basins for Tidal River Management, BangladeshWater Development Board, Ministry of Water Resources, Government of the People's Republic of Bangladesh.
14. IWM, 2004, Manual on Data Processing.
15. IWM, July 2010, Volume I, Final Report, Feasibility Study for Sustainable Drainage and Flood Management of Kobadak River Basin under Jessor and Satkhira Districts, Bangladesh Water Development Board, Ministry of Water Resources, Government of the People's Republic of Bangladesh.
16. IWM-DPHE, May 2015, Joint Action Research on Salt Water Intrusion in Groundwater in the Coastal Area, Final Report.

17. Mondal, M.K., 2001, Development of Suitable Management Techniques and their Environmental Impact Assessment on the Coastal Ecosystem of Bangladesh. Published by Bangladesh Rice Research Institute (BRRI) in association with Bangladesh Agricultural Research Council (BARC).
18. Monsur, M.H., 1995, An Introduction to the Quaternary Geology of Bangladesh.
19. MPO, 1986, Technical Report No. 5 on Groundwater Resources.
20. SDRI, 2010, Coastal Saline Soils of Bangladesh, SRMAF Project, Ministry of Agriculture, Government of the People's Republic of Bangladesh.
21. Sir William Halcrow & Partners Ltd et al., August 1993, Volume -6, Final Report, Southwest Area Water Resources Management Project TA No. 1498-BAN, Land Resources, Agriculture and Fisheries (FAP-4), Flood Plan Coordination Organization, Ministry of Water Resources, Government of the People's Republic of Bangladesh.
22. SRDI, 2009, Saline Water Quality Assessment, Present Status and Scope of Using Present Data Base, Paper presented in Training Programme on "Land Resources Database & Its Use in Agricultural Development Activities, February 2009, Soil Research Development Institute, Dhaka.
23. Umitsu, M., 1993, Late Quaternary Sedimentary Environments and Landforms in the Ganges Delta. Sedimentary Geology, v.83, p. 177-186.
24. UNDP, 1982, Ground-Water Survey - The Hydrologic Conditions of Bangladesh, New York, United Nations, United Nations Development Programme.
25. World Bank, February 2010, Implications of Climate Change for Fresh Groundwater Resources in Coastal Aquifers in Bangladesh.