Spatial and Temporal Variation of Groundwater Salinity in Barisal and Khulna Divsion of Bangladesh

Khan Faisal Ahmed

DEPARTMENT OF WATER RESOURCES ENGINEERING

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Reg. No. 100616007 P

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CERTIFICTION OF APPROVAL

We hereby recommend that the M. Engg. Research work presented by Khan Faisal Ahmed entitled **"Spatial and Temporal Variation of Groundwater Salinity in Barisal and Khulna division of Bangladesh"** be accepted as fulfilling this part of the requirement for the degree of Master of Engineering in Water Resources.

Dr. Umme Kulsum Navera — Chairman of the committee (Supervisor)
Professor
Dept. of Water Resources Engineering
BUET, Dhaka

Dr. M. Mirjahan Miah — Member
Professor
Dept. of Water Resources Engineering
BUET, Dhaka

Dr. Md. Sabbir Mostafa Khan — Member
Professor
Dept. of Water Resources Engineering
BUET, Dhaka

CANDIDATE'S DECLARATION

This is certify that this project work entitled **"Spatial and Temporal Variation of Groundwater Salinity in Barisal and Khulna divsion of Bangladesh"** has been done by me under the supervision of Dr. Umme Kulsum Navera, Professor of the Department of Water Resources Engineering (WRE), Bangladesh University of Engineering and Technology (BUET), Dhaka. I do declare that this project or any part of it has not been accepted elsewhere for the award of any degree or diploma from any other institution.

Khan Faisal Ahmed

Signature of the candidate

ABSTRACT

Bangladesh is an agricultural country. Food production of Bangladesh depends on water. Two coastal divisions Barisal and Khulna were surplus in food production. But due to natural hazards the production is decreasing day by day. Salinity causes unfavourable environment and hydrological situation that restrict normal crop production throughout the year. One of the most severe natural calamities is the saline water intrusion. The saline water intrusion is now a major concern for the food security of Bangladesh.

The variation of salinity concentration with depth is significant as shallow aquifer has low concentration and the deeper part of the coastal aquifer is highly affected by saline water intrusion. To find salinity concentration at different depth below surface level and to find the present status of ground water salinity are major objectives of the project.

In many places of the study area the salinity concentration at 30 meter depth is between 3227 μS/cm to 11830 μS/cm. In monsoon the salinity concentration decreases and increases in dry season. The saline affected area of south western part was more or less 3256836 hactares in last December of 2010. For spatial distribution in the upper shallow aquifer the salinity concentration was low in comparison with the lower shallow aquifer. The salinity aerial extent was also larger in comparison with the upper shallow aquifer. The ground water saline concentration was higher in the months March, April, and May as compared with other months. At 30 meter depth Jessore, Satkhira, Khulna, Bagerhat, Pirojpur, Jhalokati and Bhola are most affected area but at 55 meter depth the affected area mainly the coastal districts (Satkhira, Bagerhat, Pirojpur and Bhola). The worse situation of ground water is in Jhalokati and Satkhira where the all ground water at 30, 45 and 55 meter are harmful for crop cultivation. More research and time series data are required for finding out the effect of tide on the salinity concentration of ground water.

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Chapter 1

Introduction

1.1 Background

Bangladesh is perspiring with different types of natural disasters. There are a number of environmental issues and problems those are hindering development of Bangladesh. Salinity intrusion due to reduction of freshwater flow from upstream, salinization of ground water and fluctuation of soil salinity in coastal area are some of the major concern of Bangladesh (BADC, 2011).

The total area of Bangladesh is 147, 570 km^2. The coastal area covers about 20% of the country and over thirty percent of the net cultivable area. It extends inside up to 150 km from the coast. Out of 2.85 million hectares of the coastal and offshore areas about 0.83 million hectares are arable lands, which cover 30% of the total cultivable lands of Bangladesh. A part of the coastal area, the Sundarbans is a natural mangrove forest covering about 4, 500 km^2. The remaining part of the coastal area is used in agriculture. The cultivable areas in coastal districts are affected with varying degrees of soil salinity. The coastal and offshore area of Bangladesh includes tidal, estuaries and river floodplains in the south along the Bay of Bengal. Land use for agricultural purpose in these areas is very poor, which is roughly 50% of the country's average (Petersen and Shireen, 2001).

The southwest region of Bangladesh consists of a very intricate river system where strong tidal effects are observed. Groundwater salinity is occurred by seawater intrusion. The position of the saline water interface is dependent upon the through-flow from the upper basin and local seasonal recharge. If the withdrawal exceeds recharge or if the rate of through-flow is reduced, the non-equilibrium fallout would intrude saline water in the coastal aquifer. In the coastal belt saline groundwater is generally occur between 40 and 200 m below ground surface (EGIS, 2001a). Sometimes this depth limit for saline groundwater exceeds. The gradual encroachment of groundwater salinity is creating problem for agriculture, industry and domestic uses. Salinity is the measure of concentration of dissolved (soluble) salts in water. The two widely used methods for evaluating salinity are electrical conductivity (EC; unit: mmhos) and chloride concentration (unit: mg/L). Salinity can also be indirectly assessed by measuring TDS (total dissolved solids) content of water and its measurement unit is mg/L (Sarker, 2005).

Salinity in the coastal region is due to continuous accumulation of salts from tidal flooding. These accumulated salts are subsequently removed by means of leaching or washing of freshwater flushing, however, the removal in most of the cases are inadequate. On the other hand, shallow water table during dry season (November – May) delivers soil salinity through capillary rise (CEGIS, 2002).

There is an interrelation between groundwater and soil salinity in the coastal region. If groundwater gradients are reduced (it may happen in coastal aquifers where excess pumping has disrupted the hydraulic equilibrium), then the outflow of freshwater will be reduced and denser saline water would replace the freshwater space of the aquifer. Salt concentration increases as water is removed from the soils by crop evapotranspiration. When the salt concentration exceeds the threshold level, the crops suffer and eventually yield is reduced (Sarker, 2005).

The coastal saline area lies about 1.5 to 11.8 meters above the mean sea level. The Ganges River meander flood plain systems are standing higher than the adjoining tidal lands. The tidal flood plain has a distinctive, almost level landscape crossed by innumerable interconnecting tidal rivers and creeks. The estuarine islands are constantly changing shape and position as a result of river erosion and new alluvial deposition (Karim et al., 1982).

Salinity causes unfavourable environment and hydrological situation that restrict normal crop production throughout the year. The freshly deposited alluviums from upstream in the coastal areas of Bangladesh become saline as it comes in contact with the sea water and continues to be inundated during high tides and ingress of sea water through creeks. The factors which contribute significantly to the development of saline soils are:

- Tidal flooding during wet season (June- October)
- Direct inundation by saline or brackish water and upward movement
- Lateral movement of saline groundwater during dry season (November- May).

Observation in the recent past indicated that due to increasing degree of salinity of some areas and expansion of salt affected areas as a cause of further intrusion of saline water, normal crop production becomes more restricted. In general, soil salinity is believed to be mainly responsible for low land use as well as low cropping intensity in the area (Rahman and Ahsan, 2001).

During dry season salinity occurs in the coastal aquifers due to drop in hydraulic heads. During this critical season saline water reaches as far as north of Magura, approximately 240 km from the coast (Halcrow, 1993b).

Out of 1.14 million hectares of coastal and offshore lands, about 0.37 million hectares of arable land has been badly affected at greater Khulna region by various degrees of salinity in different cropping seasons (NWMP, 2001). Besides the above problem, it is found that about 138, 600 ha of land are under shrimp farming in the ecologically sensitive regions of southwest Bangladesh (EGIS, 2001b). Being proliferated by these types of exodus activities, the biodiversity of coastal region including the Sundarbans, are under greater threat (EGIS, 2001a).

It is also anticipated that the over abstraction of ground water for irrigation in upper reaches, especially in the unconfined aquifer of Kushtia-Jessore areas, may be causing movement of salinity front through the districts of Khulna division. In the coastal area the availability of freshwater restricted to relatively thin and deep aquifers (EGIS, 2001a).

1.2 Land use pattern

Land use in this coastal area is diverse and competitive. Agriculture, shrimp farming, salt production, forestry, ship-breaking yards, ports, industry, settlements and wetlands are some of the uses. With the continually increasing population and their demands, the following features emerges which are (i) Demand for expansion in all land uses (urban area, settlement, shrimp, etc.), (ii) Increasing demand for new uses (tourism, export-processing zones and others) and (iii) Encroachment and conversion of land from one use to another (Islam, 2009).

Land uses have gone through major changes over the last half century. Land use in the 1950s had been mainly for paddy cultivation, but salinity intrusion and tidal flooding prevented further intensification. Consequently during the years 1960 to 1980 a number of organizations such as World Bank helped with large-scale polderization in order to boost up the rice production. A decade later, drainage congestion inside and heavy siltation outside the polders made the southwestern area unsuitable both for agriculture and in extreme cases even for human habitation. Then many coastal polders were constructed to protect agricultural land from inundation of salt water which were turned then into large shrimp ghers (The man-made ponds used to shrimp cultivation). The priority was reversed and salt water was willingly being allowed in the ghers to raise shrimp. Land previously used for agriculture and mangroves were transformed often forcibly to shrimp farming (Islam et al., 2004).

Land use for agricultural purpose in coastal area is very poor. Salinity problem received very little attention in the past. Nevertheless, symptoms of such land degradation with salinization are becoming too prominent in recent years to be ignored. Increased pressure of growing population demand more food. Thus combating land salinization problem is vital for food security in the country through adoption of long term land management strategy (BADC, 2011).

Based on the above observations and discussions a study has been conducted to identify the present status of saline prone area in the southwest part of Bangladesh that is Barisal and Khulna division. This project work is based on the past research work which was done by Sarker, 2005 on saline water intrusion and saline affected area of southwest region of Bangladesh. In addition to that depth wise spatial distribution of ground water salinity concentration, tidal effect in ground water salinity concentration and safe/ harmful ground water situation was observed in the study area.

1.3 Objectives of the project

The aim of the study is to identify the extension of saline water intrusion in the coastal aquifer and to find out the saline prone area. The specific objectives are:

1. To find the level of concentration of salinity at different depths below surface level.

2. To locate the saline prone area by using GIS maps in southwestern (Khulna, Bagerhat, Satkhira, Jessore, Magura, Narail, Meherpur, Kushtia, Jhenaidah, Chuadanga, Barisal, Potuakhali, Pirojpur and Bhola) part of Bangladesh and compare the result with previous delineated area.

3. To observe the effect of tide on the concentration of salinity in coastal aquifers.

1.4 Structure of the report

The structure of the project report is briefly described below:

Chapter 1 describes the background, objectives and output of the study

Chapter 2 describes the literature review of relevant studies

Chapter 3 describes the theory and methodology of the study including data collection and analysis process

Chapter 4 describes the detail description of the study area

Chapter 5 describes the results and discussions of the study

Chapter 6 describes the conclusions and recommendations

Chapter 2

Literature Review

2.1 Introduction

A brief review of various earlier studies that took place during the last two or three decades related to salinity issues in the southwest region of Bangladesh has been described in this chapter. Furthermore, GIS based salinity studies that took place outside the country have also been briefly mentioned. In general, the groundwater quality, salinity processes and mechanisms in groundwater and soils, and its intrusion in the region have been discussed in brief.

2.2 Relevant studies on salinity

Very few studies have been carried out on salinity related issues specially the groundwater salinity in a larger scale and in a detailed level. The relevant studies that have been executed by different organizations are: FAP 4, BARC, BRRI, SRDI, etc. Brief descriptions of these studies are given in the following sub-sections of this chapter.

Abarca and Clement (2008), reported that the mixing zone between freshwater and seawater is of extreme importance for reactive transport processes and seawater recirculation. The amplitude of this mixing zone is proportional to the dispersion coefficients. Therefore, actual detailed measurements of the mixing zone would help to evaluate the dispersion coefficients. Experiments have been widely used to map the seawater intrusion wedge. However, none effort has been devoted to actually map the mixing zone. Here, we proposed a methodology based on the visualization of the mixing between an alkaline freshwater solution and acidic seawater by means of a pH indicator. Depending on the pH of the ending solutions, different portions of the mixing zone can be mapped. The experiments carried out in a 2D tank at a lab scale (50 x 20 x 2.2 cm) show a thin but measurable mixing zone. The experimental results have been used to calibrate a numerical model of the experiment and allowed us to quantify the dispersive values of the system. In particular, we evaluated the transverse dispersion coefficient since mixing occurs basically perpendicular to the flow direction.

Abd-Elhamid and Javadi (2008), stated that a large number of coastal aquifers are threatened by saltwater intrusion. Saltwater intrusion may occur due to human activities and by natural events such as climate change and sea level rise. In coastal aquifers, over abstraction due to high demands for domestic water supply is the main cause of saltwater intrusion. Also the rise in sea level due to the climate change accelerates the saltwater intrusion into the aquifers which reduce the fresh groundwater resources. With the impact of sea level rise and over pumping combined together the problem becomes even more serious and requires fast solutions. Coastal aquifers are affected by the rise in the sea level due to climate change and global warming. It is estimated that the mean sea level will rise in a range among 20 to 88 cm during the current century. The rise in sea level will shift the saltwater interface further inland. As a result, the extraction wells those were originally in fresh groundwater may then be located in brackish water or saline water and upconing may occur. Consequently, the abstraction rates of these wells may have to be reduced or the wells abandoned. This is considered one of the most serious impacts of sea level rise. Therefore, saltwater intrusion due to sea level rise should be predicted and prevented (or at least controlled) to protect groundwater resources. This paper presents a review of the mathematical models developed to study the impacts of climate change and sea level rise on saltwater intrusion in coastal aquifers and the measures that could be taken to reduce the impact. The impact of climate change and sea level rise on saltwater intrusion is discussed and analyzed. A new method is proposed to control saltwater intrusion considering the impact of climate change and sea level rise. The main benefits of the proposed methodology are discussed. It is shown that the proposed method is economical, has less environmental impact and could be used for sustainable development of water resources in coastal areas.

Kim et. al. (2008), stated that the study is intended to evaluate fresh-saline water interactions in coastal region influenced by external forces including tidal fluctuations and seasonal rainfall variations. Five different coastal zones were considered on Jeju Island, Korea, and electrical conductivity (EC) profiles at these monitoring wells were examined to identify the configurations of fresh-saline water interface. In order to analyze the dynamic behaviors of fresh-saline water interactions, we utilized multi-depth EC and temperature probes and obtained a time-series data. The monitored data showed that EC and temperature vary with both tidal fluctuations and heavy rainfall. Spectral filter was used to remove the effects of tidal forces and provide the influence of heavy rainfall events on EC and temperature. Time-series data of EC and temperature in the subsurface at various depths enabled us in understanding the interaction processes between fresh and saline water.

Noman and Chowdhury (2008), stated that Global Warming has already started to hit the Bangladesh coastal areas. The salty sea water intrusion and its disastrous effects in landscape, ecology and human health already created wide scale agony amongst the inhabitants of Bangladesh coastal belts.

Oki and Presley (2008), stated that Freshwater thickness in a coastal freshwater-lens system commonly is evaluated from vertical salinity profiles (measured by fluid-electrical-conductivity logs or water-quality samples at various depths) in deep observation boreholes. Flow within an observation borehole caused by withdrawals from pumped wells and ocean tides can significantly affect measured salinity profiles. Borehole flow can be recognized from diagnostic step-changes in a salinity profile, comparisons between salinity profiles from deep and shallow boreholes, or flow measurements. Knowledge of borehole flow is important for proper interpretation of salinity profiles by water managers and ground-water modelers.

Sarker (2005), studied the saline area of south western part of Bangladesh. He studied the groundwater salinity in southwest region of Bangladesh using GIS Technique. The comparative analysis of spatial data (from SRDI) shows that a total of 104121 ha new land has been affected in the southwest region by various degrees of groundwater salinity during its three years from 1997 to 2000, which is about 5% increment of the total groundwater salinity area compared to 1997 area.

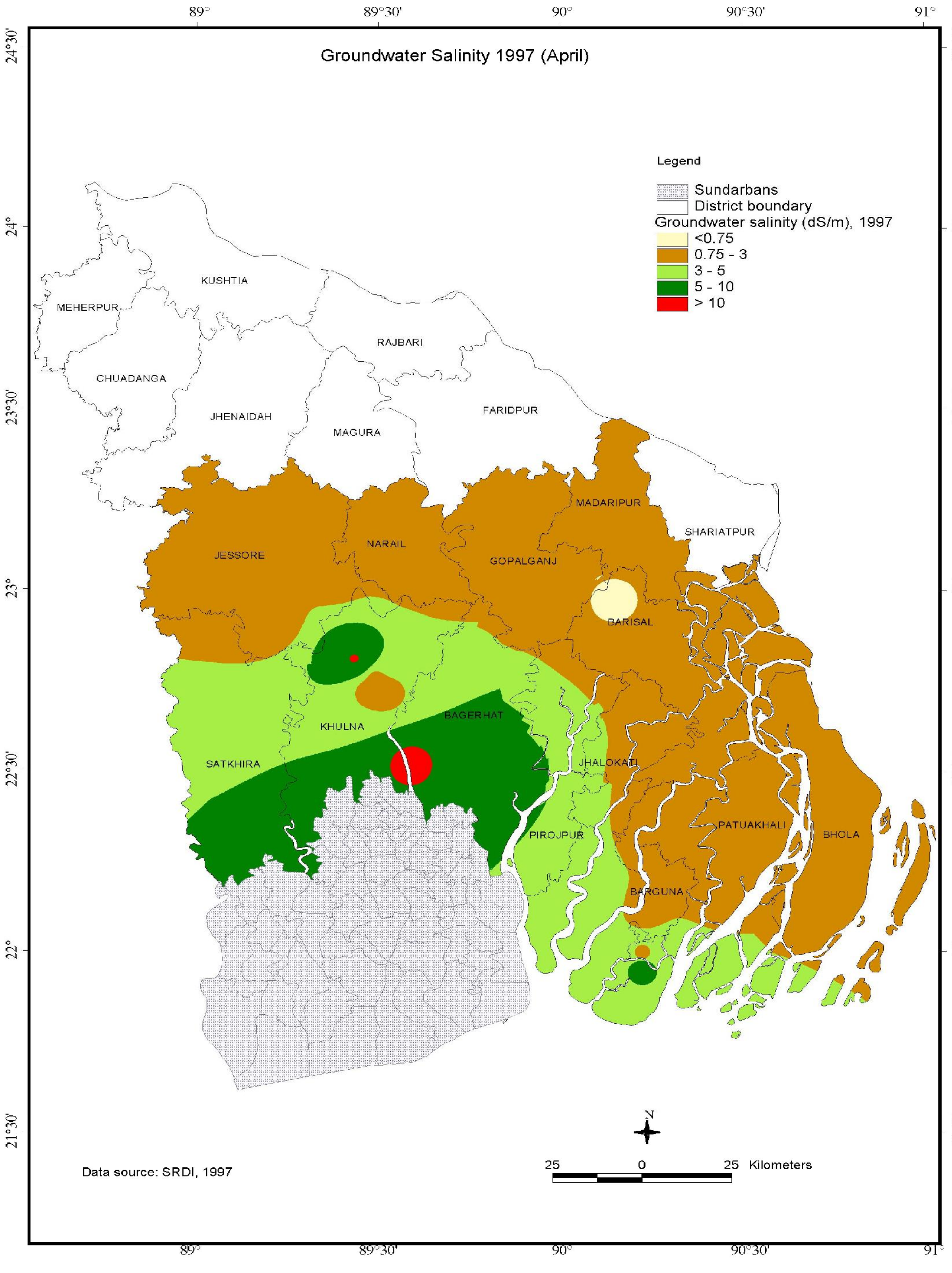

Figure 2.2.1: Spatial distribution of groundwater salinity, 1997 (Source: Sarker, 2005)

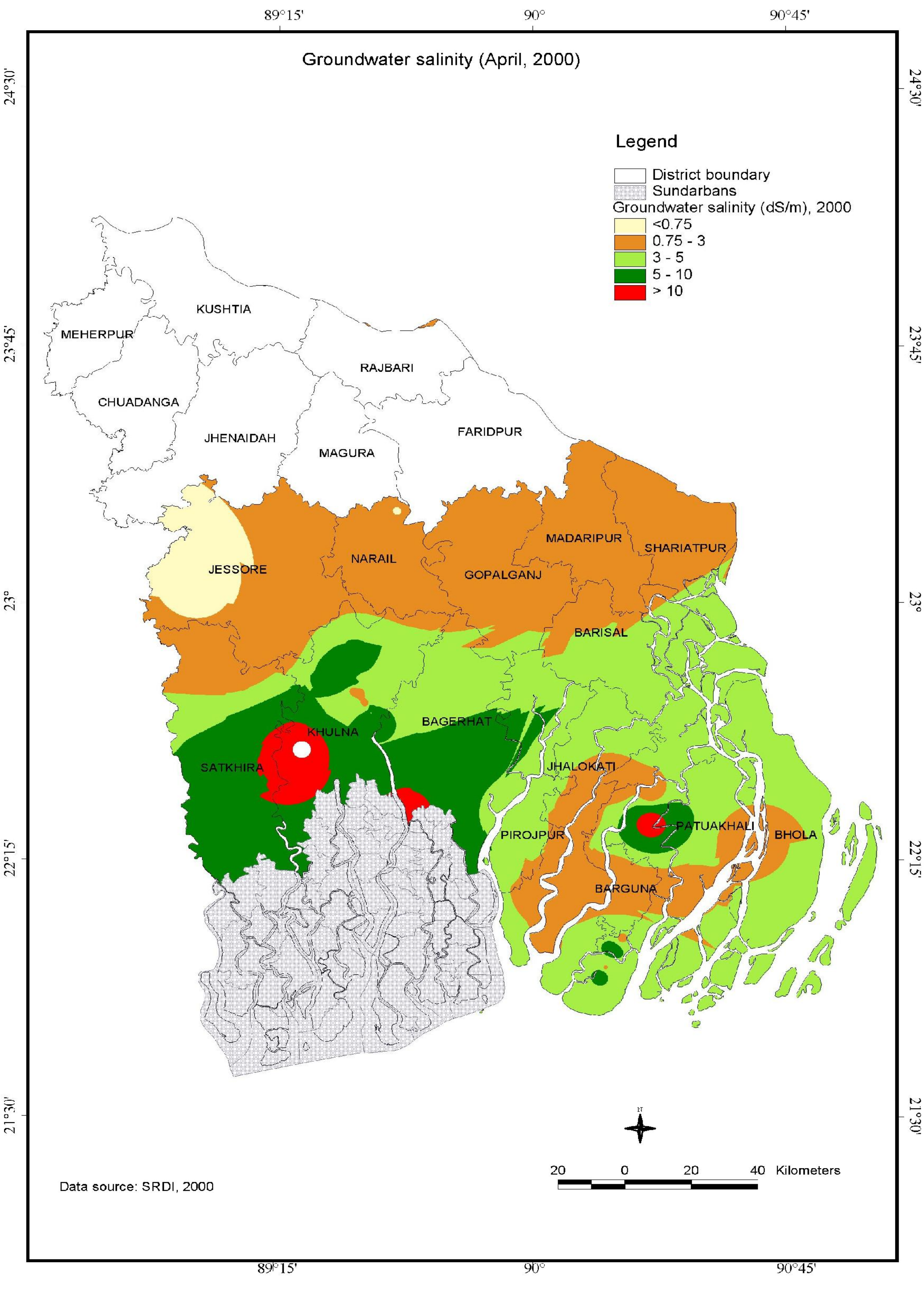

Figure 2.2.2: Spatial distribution of groundwater salinity, 2000 (Source: Sarker, 2005)

Table 2.2.1: Ground water affected area in 1997 and 2000

Salinity class (dS/m)	GW salinity area (ha) April 1997	GW salinity area (ha) April 2000	GW salinity area (ha) (increased)
(< 0.75)	12519	87391	74872
(0.75–3)	1320046	911680	-408366
(3–5)	593828	905210	311382
(5–10)	287987	368012	80025
(> 10)	10343	56551	46208
Total Area	2224723	2328844	104121
% Total			4.68%

(Source: Sarker, 2005)

Mondal (2001), conducted a research program on "Development of suitable salinity management techniques and their environmental impact assessment on the coastal ecosystem of Bangladesh" in association with the Bangladesh Agricultural Research Council (BARC). Mondal mentioned that the greater Khulna district alone contributes about 23% of the total coastal ecosystem. Out of 1.14 million hectares of coastal and offshore area, about 0.37 million hectares of arable land has been badly affected in greater Khulna district by various degrees of salinity in different cropping seasons. Generally four categories of salinity exist in the coastal areas ranging from S1 (2-4 dS/m) to S4 (>16 dS/m) (Karim and Hussain, 1990). The major part of this area (0.255 million hectares) is under S2 category (4-8 dS/m) followed by (0.049 million hectares) S1 (2-4 dS/m) and (0.048 million hectares) S3 (8-16 dS/m) categories. Only 0.02 million hectares area is under S4 (>16 dS/m) category. Most of the land remains fallow in the dry seasons. No crop can be grown because of salinity hazard and lack of freshwater. Farmers do shrimp farming to about 60% area in Satkhira and about 40% each in the Khulna and Bagerhat districts. The rest of the area remains fallow where different nonrice crops are grown if root zone soil salinity can be kept as minimum as possible by adapting different salinity management techniques like raised bed with drainage, improved sorjan system, trench cut, horizontal leaching, pond rice system, two way leaching, ditch with dike etc.

Moreover, sub-soil and sub-strata remain saline throughout the year and shallow groundwater also remains harmful to very harmful stage (SRDI, 1991).

SRDI (2000), studied on soil and groundwater salinity in coastal areas of Bangladesh. High salt content is limiting crop intensification in the coastal zones of Bangladesh. Salt enters inland through rivers and channels during the late part of the dry season when the downstream freshwater flow becomes low. Salt also enters the soils by flooding with saline river water to concentrate in the surface layers through evaporation. River water causes an increase in salinity of the groundwater and possibly, makes it unsuitable for irrigation. Salinity causes unfavorable environment over prevailing hydrological condition, to restrict intensive crop production throughout the year. Thus the soil and groundwater salinities are making rabi including boro cultivation difficult.

Mondal (1997), reported from the study it has been known that the salinization process of both surface 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 ecosystem. Mondal recommended that a careful aquifer management technique is required to make use of available fresh groundwater for irrigation, which will increase the irrigation potentiality in the coastal area especially in the dry season. In many places of the coastal area, groundwater salinity ranges from 1.5-2.0 dS/m during the dry season. By adapting proper techniques, many winter crops and vegetables can be grown by using s.hallow groundwater.

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 this plan is groundwater, which is a major source of potable water and irrigation supply within the project area. In recognition of the potential for groundwater development, hydrogeological component was incorporated in the study to provide assessment of groundwater resource where issues considered are abstraction and recharge, aquifer properties, and water qualities along with salinity. The study tried to relate freshwater and saline groundwater interactions at a conceptual state not in detail. The salinity distribution and processes studied by FAP 4 has been shown in Figure 2.2.3. The study shows the following points:

(i) presence of a saline front and lenses of freshwater in the upper aquifer;

(ii) presence of saline wedge in the main aquifer; and

(iii) existence of hydraulic continuity between groundwater and rivers.

In the upper aquifers the position of the saline fronts can be controlled by regional flow of groundwater towards the sea and the 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 groundwater has the potentiality to cause adverse changes. The over abstraction of the groundwater for irrigation at upstream, for example, the unconfined aquifers of the Kushtia-Jessore areas will tend to move the saline front inland, resulting in more wells beginning to pumping brackish and saline groundwater. 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 (FAP 4, 1993).

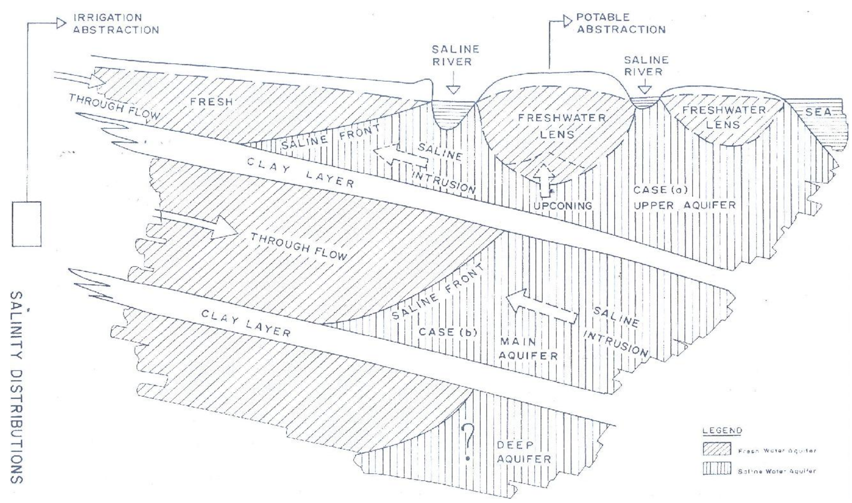

Figure 2.2.3: The salinity distribution and processes at southwest region (Source: FAP 4, 1993)

SRDI (1990), has initiated a monitoring program in 1990, to estimate the extent of the salinity problem in the coastal region. The program included frequent collection of soil, surface (river) water and groundwater samples. SRDI has a total 126 monitoring sites as shown in Table 2.2.2. In 1990 it has been known that out of 2.85 million hectares of the coastal and offshore lands, about 0.833 million hectares are saline affected (Karim and Hussain, 1990). The recent past observation by SRDI (2000) shows the increasing degrees of salinity at some new areas and thus expanded the salt affected areas. Further SRDI engaged in mapping the soil salinity with the help of modern tools like GIS. In this regard, SRDI conducted a special reconnaissance survey in the coastal areas of Bangladesh. A special field survey was carried out in February - May, 2000 in the eastern part of the coastal arable lands and south western part of the Sundarbans. The broad objectives of this survey were:

- updating the 1973 and 1997 soil salinity maps of the coastal areas;
- characterization of soluble salts in soils of coastal saline areas; and
- identification of agricultural constraints and existing land use pattern in the coastal areas of Bangladesh.

The extent of salinity in 2000 was assessed by interpreting the published Upazila Land and Soil Resource Utilization Guides (Upazila Nirdeshika) and data obtained from different locations under salinity monitoring program.

Table 2.2.2: Number of different salinity monitoring sites by SRDI

Type of monitoring site	Number
Groundwater	15
Surface water	42
Soil and groundwater	17
Soil and surface water	13
Soil, surface and groundwater	12
Soil	27
Total sites	126

A sample soil salinity map of the SRDI study of the year 1973 has been shown in Figure 2.2.4.

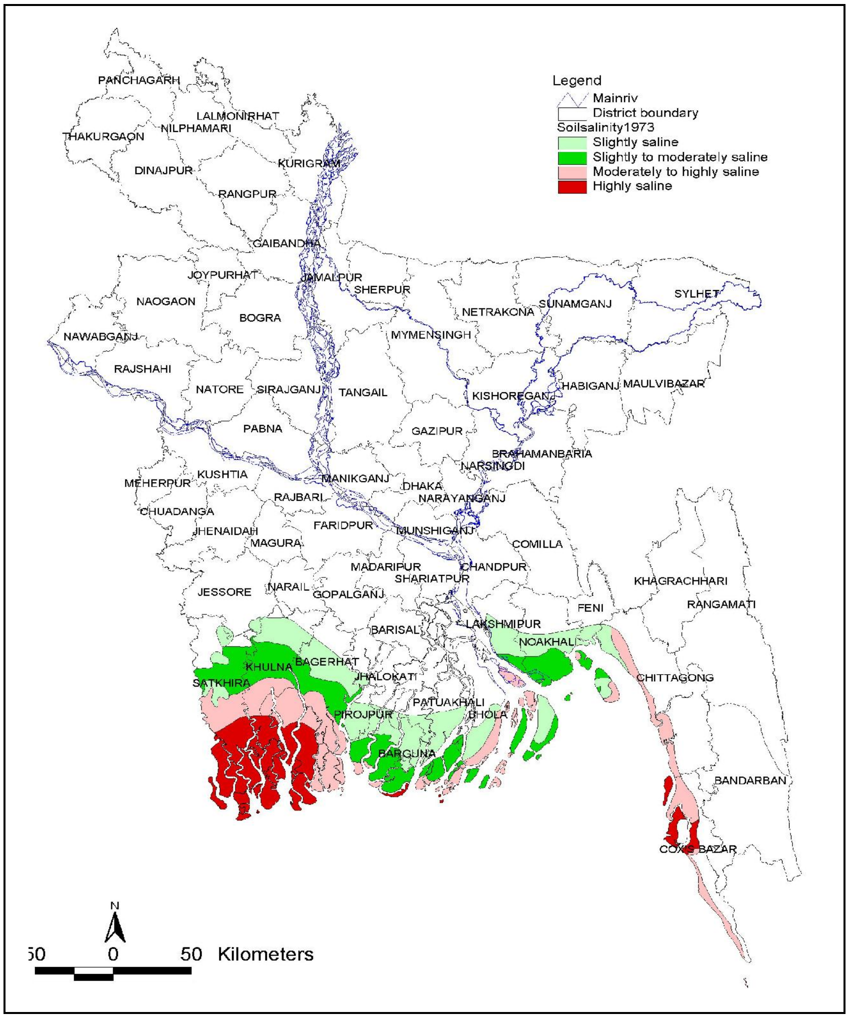

Figure 2.2.4**:** Soil salinity map of 1973 (Source: SRDI, 1991)

Karim and Husssain (1990), reports that in Bangladesh over 30% of the net cultivable area is in the coast region. Out of 2.85 million hectares of the coastal and offshore areas about 0.833 millions hectares of the arable land, which constitutes about 52.8% of the net cultivable areas in 64 upazilas of 13 districts are affected by varying degrees of soil salinity. Agricultural land-use in these areas are very poor, which is much lower than the country's average cropping intensity (159%), ranging from 62% in Chittagong coastal region to 114% in Patuakhali coastal region.

The freshly deposited alluvium from upstream in the coastal areas of Bangladesh becomes saline once it comes in contact with seawater and continuous to be inundated during the high tides and ingress saline water through creeks. The factors which contribute significantly to the development of saline soils are:

- tidal flooding during wet season (June - October);
- direct inundation by saline water; and
- upward or lateral movement of saline groundwater during the dry season (November - May)

2.3 Summary

Most of the researchers of Bangladesh tried to find out the categories of soil salinity and its impact on cropping system. FAP 4 relates freshwater and saline groundwater interactions at a conceptual state not in detail. Recently many researchers reports the effect of sea level rise on the saline water intrusion. Many studied on the mixing zone of fresh water, saline water interface of coastal aquifers. Sarker (2005) found out the spatial distribution of ground water salinity of the year 1997 and 2000. He also relates ground water salinity with soil salinity.

This project is targeted to find out the recent status of saline prone area, pre and post monsoon distribution of ground water salinity and also the depth wise spatial distribution of ground water salinity. This study also finds the present concentration of ground water salinity of different upazilas of the study area while it is safe or harmful for irrigated agriculture.

Chapter 3

Theory and Methodology

3.1 General

Meteorological, topographical and tidal water level data have been collected from different sources. Salinity data collected from Bangladesh Agricultural Development Corporation and Soil Resources Development Institute. The tidal water level data were collected from Bangladesh Inland Water Transport Authority. The data are then processed and analyzed for getting study outcomes.

3.2 Theory

Salinity is being estimated measuring the electrical conductivity (EC), chloride (Cl^-) concentration and total dissolved solids (TDS). EC has been measured using EC meter and TDS has been measured using TDS meter. The EC meter has the measurement unit either in milli Siemens/cm (mS/cm) or in micro Siemens/cm (μS/cm). The units of salinity for soil and water are converted into same unit using standard conversion factor of the literature.

Salinity measures include EC of a solution or soil and water mix, as weight of salts in a given amount of water, or the quantity of molecules of salts in a solution. Each of these measures has particular uses. A popular tool to measure the salinity is Electromagnetic Induction Meter or EC Meter, which estimates the electrical conductivity. It can be mention that prior to the 1960s, there was no international agreement in place as to which was the best unit to measure EC. Consequently, scientific literature adopted millimhos/cm (mmhos/cm) and micromhos/cm (μmhos/cm), where 1 mmhos/cm = 1000 μmhos/cm.

The metric equivalent for mho is Siemens (S), where 1 mmhos/cm = 1 mS/cm = 1000 μS/cm. Now a days the scientific literature uses the dS/m to measure EC, with mS/cm and μS/cm to measure EC for groundwater and soil culture, where 1 dS/m = 1 mS/cm = 1000 μS/cm as measured by an EC meter.

More recently the metric system has changed the unit into dS/m but fortunately, it turns out that numerically these units are the same and being expressed as 1 dS/m = 1 mmhos/cm. Further, there is relationship between Cl^- concentration and EC.

The exact relationship depend on the chemistry of water, the actual ions making up the salts in the water, but usually the relation is like as 1 dS/m = 600 - 800 mg/L (or ppm). For this study conversion unit is taken as 1 dS/m = 700 ppm.

Ministry of Environment and Forest published a circular in 1997 on water quality standards for drinking water and irrigation, where irrigation water quality was within salinity 600 ppm or 857 μS/cm and for drinking water the salinity within 150 to 600 ppm. The SRDI standard level for Bangladesh of salinity classes as harmfulness to crops and drinking purposes based on EC values are shown in Table 3.2.1.

Table 3.2.1: Classification of groundwater salinity suitability based on EC values for crops and drinking purposes

Groundwater salinity class	**EC (μS/cm) class for crops**	**EC (μS/cm) class limit for drinking purposes**	
		Bangladesh standard	WHO guideline values
Safe	< 750	500 – 1500	250 – 450
Harmful	750 – 3000	> 1500	> 450
Very harmful	> 3000		

Sources: SRDI Thana Nirdeshika on land and soil resources utilization and safe water option report of UNICEF

The movement of saline water into a freshwater aquifer or surface reservoir is known as salt water intrusion and if the source of this saline water is sea water then this process is known as sea water intrusion. Aquifers in hydraulic connection with saline or sea water may contain salt water in adjacent portions while other portions of the aquifer contain fresh water. Fresh water is slightly less dense (lighter) than salt water and it tends to float on top of the salt water when both fluids are present in an aquifer. The relationship based on the density difference between salt water and fresh water is used to estimate the depth to salt water based on the thickness of the fresh water zone above sea level. The relationship is known as the Ghyben-Herzberg relation. In the coastal area of Bangladesh, hydro geological conditions vary considerably even within short distances. Ground water, with a gradient of about 1:20000, flows from north to south having localized outflow into rivers and ponds in the dry season and inflow into the aquifer from surface water sources in the rainy season. Transmissivities of the main aquifer in the coastal area range from 250 m^2 /day to 10000 m^2 /day with an average value of 1000 m^2 /day. The storage capacity of the aquifer generally increases with depth with the increase in the grain size of aquifer materials. The entire area is underlain by thick water bearing formations of varying depths and the regional hydrogeology is very complex (Ahmed, 1996).

For deposition of silt and clay, the spatial distribution and concentration of salinity in the estuary are important in the formation of the delta. The intrusion of saline water inlands determines the suitability of estuary water for drinking, irrigation and other purposes. During the wet season, the vertical variation of salinity may play a role in the seasonal storage of sediment at the outside of the estuary (BWDB et al. 1998).

3.3 Methodology

The raw data were in complex format (some are in µS/cm and some are in ds/m) which are not suitable for analysis. At first the data were processed by using tools of Microsoft Office Excel 2003. Ground water level, depth and ground water salinity data are analyzed for this study. Brief descriptions of these analyses are given in subsequent subsections below:

3.3.1 Determination of the present aerial extent and concentration of salinity

Analyzing the data of November (2010), May (2011) and using the arc view 3.2a software the salinity extension map was prepared (figure 5.2.1, 5.2.2 and 5.3). This figure exhibits the present aerial extent and concentration of salinity in the study area. This map showed the area of salinity according to the salinity concentration range. The different colour of the map indicated the different salinity concentration of ground water of the study area. These two maps (figure 5.2.1 and 5.2.2) also showed the seasonal variation (dry and wet season) of ground water salinity.

3.3.2 Determination of the saline effected area

Data of 2010 was used to find the level of concentration of salinity intrusion in the aquifers of south-western part of Bangladesh. Using these data the area of saline effected ground water was identified. Using arc view 3.2a software the maps of the respective year was prepared. The results of this study was compared with the previous delineated area of the year 2000 which were identified by sarker (2005) where he identified the ground water saline effected area of the year 2000.

3.3.3 Formation of salinity concentration maps at upper and lower shallow aquifer

The data of 2010 were collected from BADC. This data were collected at different depths from the ground surface. So the salinity concentrations of ground water at different depth were found. The data of upper shallow aquifer and lower shallow aquifer were used to show the salinity concentration map at upper and lower shallow aquifer. Using these data and by the help of arc view 3.2a software the map of ground water salinity at 30 meter and 55 meter depth were prepared. Prepared maps ware used for the spatial variation of salinity concentration of ground water at upper and lower shallow aquifer of the study area.

3.3.4 Determination of temporal variation of ground water salinity concentration

The monthly variation of salinity concentration of the year 2005, 2006, 2007 and 2008 of Mothbaria of Pirojpur and Bhola sadar of Bhola district and salinity concentration of the year 2005, 2006, 2007 and 2008 of Keshobpur of Jessore and Kalia of Narail district were used for determining the temporal variation of salinity concentration.

3.3.5 Determination of the difference between the obtained results with Standard level

The water salinity standards for irrigation for Bangladesh circulated by the ministry of environment and forest were compared with the collected data. Thus the difference of salinity with standard level was found.

3.3.6 Observation of tidal effect on salinity concentration of ground water

The salinity monitoring well of Betagi, Bamna and Patharghata of Barguana district are situated near the Bishkhali River. Bishkhali is a tidal river. The tidal data (high tide and low tide) were collected from Bangladesh Water Development Board. The tidal data of Bishkhali River of the stations Bamna and Patharghata of the month November, 2010 and tidal data of the station Betagi of the month November, 2010 and June, 2011 were used for observing the effect of tide on the concentration of ground water salinity. The salinity concentrations of ground water of these three wells at depth 15 meter to 55 meter were collected for the observation. The changes were shown in tabular format.

3.4 Data Collection

Different types of data were used in this study. The sources are BADC, SRDI, BWDB and BMD. Recent available data were collected and used for this study to get the present situation of ground water salinity.

3.4.1 Summary of data collected from different sources

Data Type	BADC	SRDI	BWDB	BMD
Salinity	√ (2010, 2011)	√ (2001- 2009)		
Meteorological				√
Tidal water level			√ (2010, 2011)	
Groundwater level	√			

3.4.2 Bangladesh Agricultural Development Corporation (BADC)

BADC has observation wells for monitoring static ground water level and ground water salinity in all over the Bangladesh and in the coastal area of Bangladesh respectively. BADC has started monitoring ground water salinity in the year 2010. The salinity observation wells are installed at a depth of 60 meter. BADC collected data of salinity at different depth interval from ground surface. BADC also has automatic ground water level recorder in all over the Bangladesh for monitoring ground water level.

For showing spatial distribution of salinity at different depth the salinity data of BADC was used. The observation wells were installed in 2010. From the very first year the data collection was started.

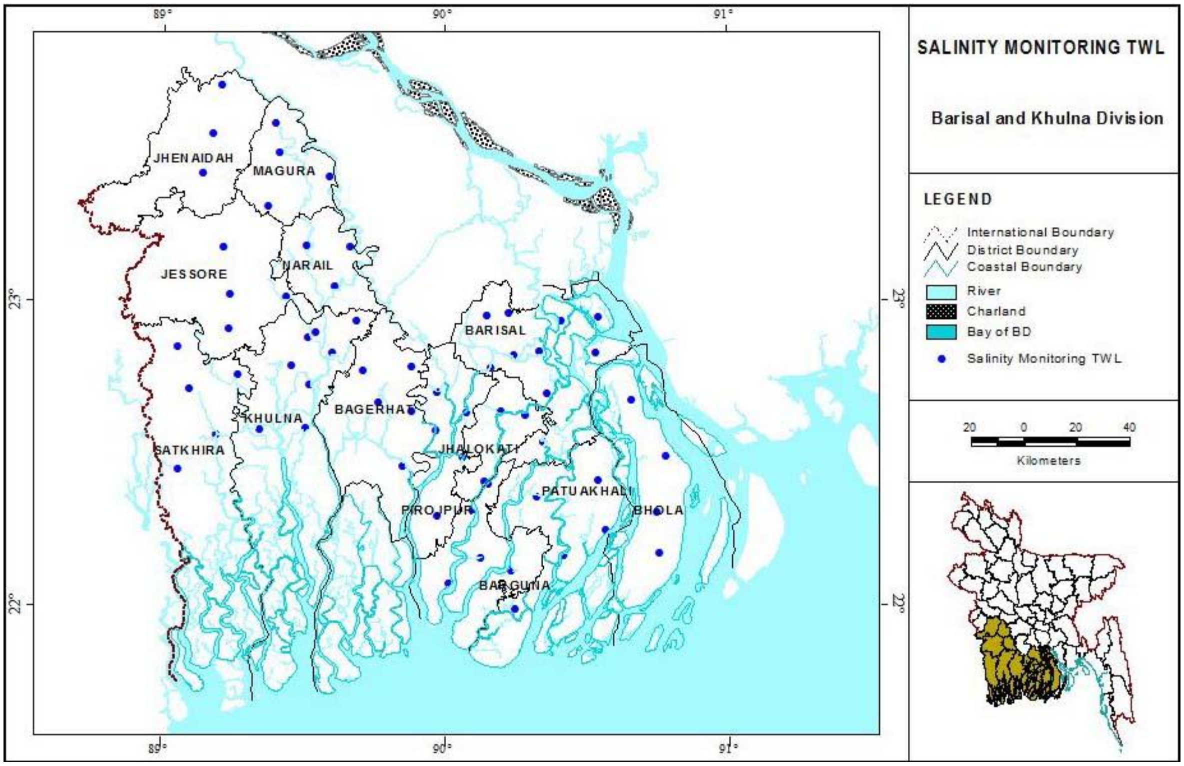

Figure 3.4.1: Salinity monitoring wells of BADC in the study area

3.4.3 Soil Resources Development Institute (SRDI)

Soil Resources Development Institute (SRDI) has the program to monitor soil and water (both groundwater and surface water) salinity. The program includes sample collection from the field, analysis of data in the regional or local laboratories, documentation of the study, and recommendation for necessary measures for remedy of salinity and cropping practices. The major objectives of their study are (i) identify the soil and water salinity, (ii) to identify the present land use and crop tolerances to salinity, and (iii) provide necessary database to develop appropriate technology for future cropping pattern and management practices. From the SRDI data it has been found that emphasis has been given on soil salinity data collection, however it shows that the sampling sites of soil and water salinities are not in the same location. They have even used different monitoring sites in different years. Salinity data from 2001 to 2008 were collected for the analysis of temporal distribution of ground water salinity.

3.4.4 Bangladesh Meteorological Department (BMD)

BMD has data of rainfall, temperature of 34 stations all over Bangladesh. The number of stations located in the study area is 7. So all related data were collected from the BMD website.

3.4.5 Bangladesh Water Development Board (BWDB)

BWDB has observation tubewells for groundwater quality monitoring throughout the country. BWDB has started groundwater quality monitoring activity since 1960. Currently water samples are collected in dry seasons through 117 tubewells and piezometric wells. Of these, approximately 40 designated water quality-monitoring wells are located in the southwest region, however many of the wells are found not sampled on a regular basis. The tidal data of the Bishkhali River of Bamna, Patharghata statioans of the year 2010 and Betagi station of the year 2010 and 2011 were collected from BWDB.

3.5 Summary

The objectives of this study identified the saline affected area and salinity concentration of upper shallow and lower shallow aquifer of Barisal and Khulna divisions. More or less simple and easy analysis was done to achieve the targets. The surface maps were prepared using the arc view 3.2a software.

Chapter 4

Study area

4.1 General Information

The study area is covering the southwest region of Bangladesh, comprises an area of approximately 35568.76 sq km or 24.7% of the total land area of Bangladesh, including the greater districts of Kushtia, Jessore, Khulna, Barisal, and Patuakhali. The western part of the study area is bounded by the Indian border, Ganges-Padma and Lower Meghna Rivers to the north and east, and the Bay of Bengal to the south. The study area is located in south west (SW) and south central (SC) part of Bangladesh according to the National Water Management Plan. The location of the study area is shown in Figure 4.1.1.

Barisal Division with an area of 13295.55 sq km is bounded by Dhaka division on the north, Bay of Bengal on the south and Chittagong division on the east. Main rivers are Arial Khan, Bishkhali, Burishwar, Tentulia, Paira, Haringhata, Baleshwar, Kirtankhola, Katcha, Agunmukha. Administration Barisal division was established in 1 January 1993. It consists of six districts, 38 upazilas, 353 union parishads, 3159 mouzas, 12 municipalities, 25 wards and 4163 villages. The districts are Barisal, Jhalokati, Pirojpur, Bhola, Patuakhali and Barguna. Khulna Division with an area of 22273.21 sq km is bounded by Rajshahi division on the north, Bay of Bengal on the south and Dhaka divisions on the east, West Bengal on the west. Main rivers: Ganges, Gorai, Ichamati, Kobadak, Shibsa, Kumar, Rupsa-Pasur, Bhairab, Chitra, Raymangal and Mathabhanga The Sundarbans is located in this division covering parts of Satkhira, Bagerhat and Khulna districts. Administration Khulna division consists of one city corporation, 10 districts, 28 municipalities, 5 thanas, 59 upazilas, 569 union parishads, 6093 mouzas, 256 wards, 709 mahallas and 9277 villages. The districts are Khulna, Satkhira, Bagerhat, Jessore, Jhenaidaha, Magura, Narail, Kushtia, Chuadanga and Meherpur.

According to the 2011 population census of the Bangladesh Bureau of Statistics (BBS), the total population of the study area was around 23.71 million, while the country's total population was 142.30 million. The population density of Barisal is 643 per sq km against the density of 964 per sq km for Bangladesh as a whole. This increased population will affect the farming community and the proportion of landless households (including fishermen). This population pressure will also affect the water resources, agriculture and the environment of the study area.

The topography in the northern part of the study area up to Jessore-Faridpur is comparatively high to medium land and the elevation drops from +15 m PWD to +6 m PWD at an average slope of 1 in 7500. Further south of Jessore-Faridpur, the topography starts to slope gently and soon becomes flat.

In the study area 467003 hactares land are high land, 1500644 hectares land are medium high land, 288187 hactares land are medium low land and 65006 hactares land are low land.

The Sundarbans, the largest mangrove forest in the world – is situated in the study area bounded by the Bay of Bengal in the south. It covers an area of over 0.6 million ha in the districts of Khulna, Bagerhat and southern part of Satkhira. Out of 0.6 million ha of forest about 0.2 million ha is occupied by rivers, channels and other water bodies. The entire area can be categorized into three major zones recognized on the basis of salinity as freshwater zone, moderately saline zone and high saline zone.

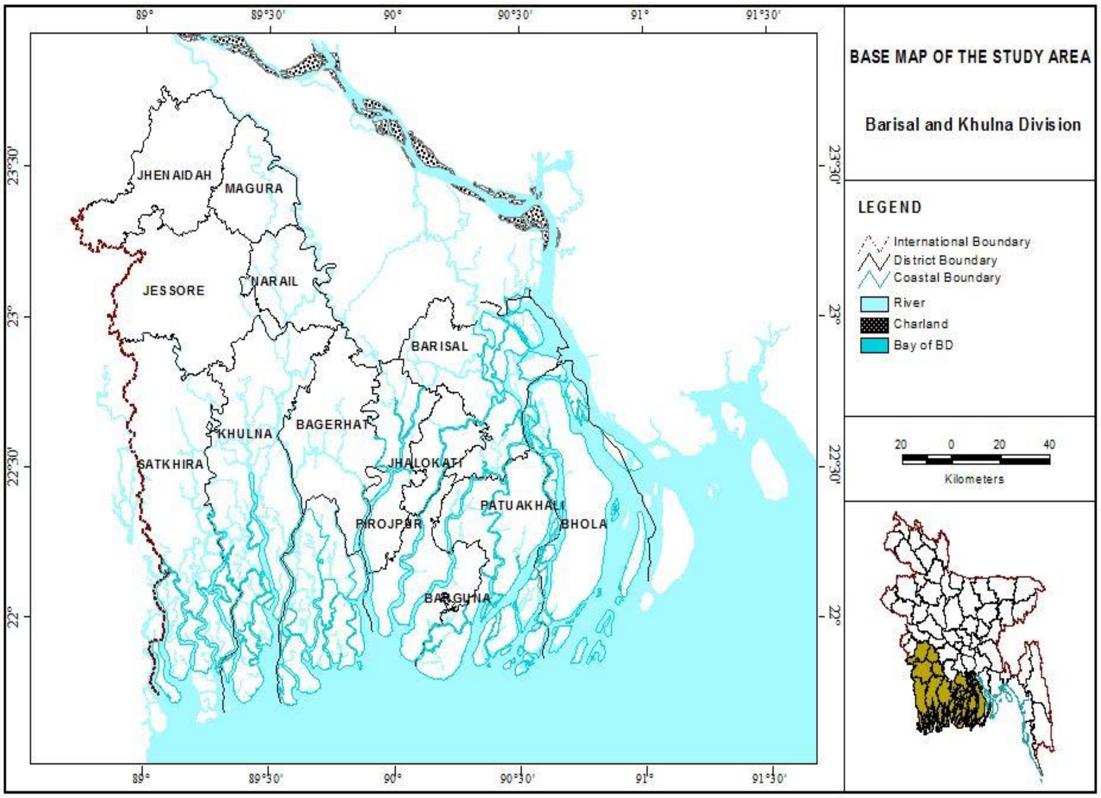

Figure 4.1.1: Study Area (Barisal and Khulna Division)

4.2 Climate

The climate of the study area is typically monsoon with a warm and dry season from March to May followed by a rainy season from June to October and a cool period from November to February. The mean annual rainfall in SW region is about 2000 mm of which about 70% occur during the monsoon season. The distribution of rainfall usually varies in a northwest (minimum 1500 mm) to southeast direction (maximum 2900 mm). Most of the rainfall occurs in the study area from the third decade of May to mid October.

The rate of evaporation of the area is about 900 mm to 1500 mm. The relative humidity of the area is high varying between 70% in March and 89% in July. The mean annual temperature varies between 21°C and 31°C. The lowest minimum temperature in winter does not fall below 10°C. The study area experiences a moderate to high duration sunshine hours, ranging from a mean annual 5.2 hours to a maximum 7.0 hours. General sunshine hours of the study area in the monsoon (June-September) are much lower than the rest of the period (October–May) of the year.

In early summer (March-May), violent thunderstorms called nor'westers produce wind speeds up to 60 km per hour (approx.) over the study area. In late monsoon (September-November), storms with very high intensity often occur which may produce wind speeds up to 160 km per hour causing waves to crest as high as 6 m in the Bay of Bengal leading to disastrous flooding (tidal flood) in the coastal parts of the study area.

The southern part of the study area, particularly the southeastern coastline is vulnerable to cyclones during the monsoon season when storm surges can cause water level to rise up to 4 m above tide and seasonal levels. Between 1960 and 2007, several severe cyclones hit the Barguna, Bhola, Patuakhali and Khulna coastal areas, causing enormous loss of life and property.

4.2.1 Agro Ecological Condition

Barisal and Khulna Division is located in seven AEZs namely AEZ 1P0: Active Ganges Flood Plain; AEZ 11: High Ganges River Flood Plain; AEZ 12: Low Ganges River Flood Plain; AEZ 13: Ganges Tidal Flood Plain; AEZ 14: Gopalganj Khulna Beels and AEZ18: Young Meghna Estuarine Flood Plain and AEZ 19: Old Meghna Estuarine Flood Plain. AEZ 13 covers all districts of Barisal division except Bhola and the Chars in the Meghna River (AEZ 18) and a very small portion of AEZ 14 in the districts of Perojpur and Barisal. The portion of AEZ 14 in Barisal Division lies adjacent to an area of the same zone in the district of Gopalganj.

4.2.2 Topography

The land of AEZ 13 is mostly medium high land with homesteads on high lands. There is a very small fraction of medium low land. The land of AEZ 18 is also mostly medium highland with homesteads on highland. There are few patches of medium lowland in the offshore islands.

The small part of AEZ 14 has fully different characteristics. 23% of it is very low land while 26% is low land. Homesteads cover a very small part on raised land. The water logged areas are parts of this low and very low land.

The land in the division is alluvial deposit of recent origin. The elevation varies from 0 M PWD - 4.5 M PWD. The topography of the problem area depict that the overall land elevation is less than 2 M PWD. The area elevation curve depicts that about 50% of the land is below average ground level. There is a significant area below 1 m PWD. This land all belong to the water logged area of Barisal Division. The lowest high water level is 1.4 m in the dry seasons where as the lowest low water is slightly less than 0 m PWD. The average Low water level remains around 0.5 m PWD in dry season. Thus for a significant area it would be very difficult to drain out the water in the period free from tidal lockage.

4.3 Climatic Baseline

4.3.1 Rainfall

The study area experiences the sub-tropical monsoon climate typical of Bangladesh. There are four major seasons in the study area relative to the annual hydrological cycle that is reflected by seasonal distribution of annual rainfall. Barisal is the most reliable rainfall station in the division. The data have been used in the preparation of various reports. So the data of Barisal has been used to depict the situation of the project area. The average annual rainfall in the area is about 2233 mm. The data fits well with the Isohyet of the country as shown in Figure 4.3.1. The mean monthly rainfall at different stations in the project area is shown in Table 4.3.1.

Table - 4.3.1: Mean Monthly Rainfall (mm)

Name of Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Barisal	8	26	47	109	223	456	433	401	311	160	45	14	2233

(Source: NWMP, 2001)

Average Annual Rainfall Isohyets

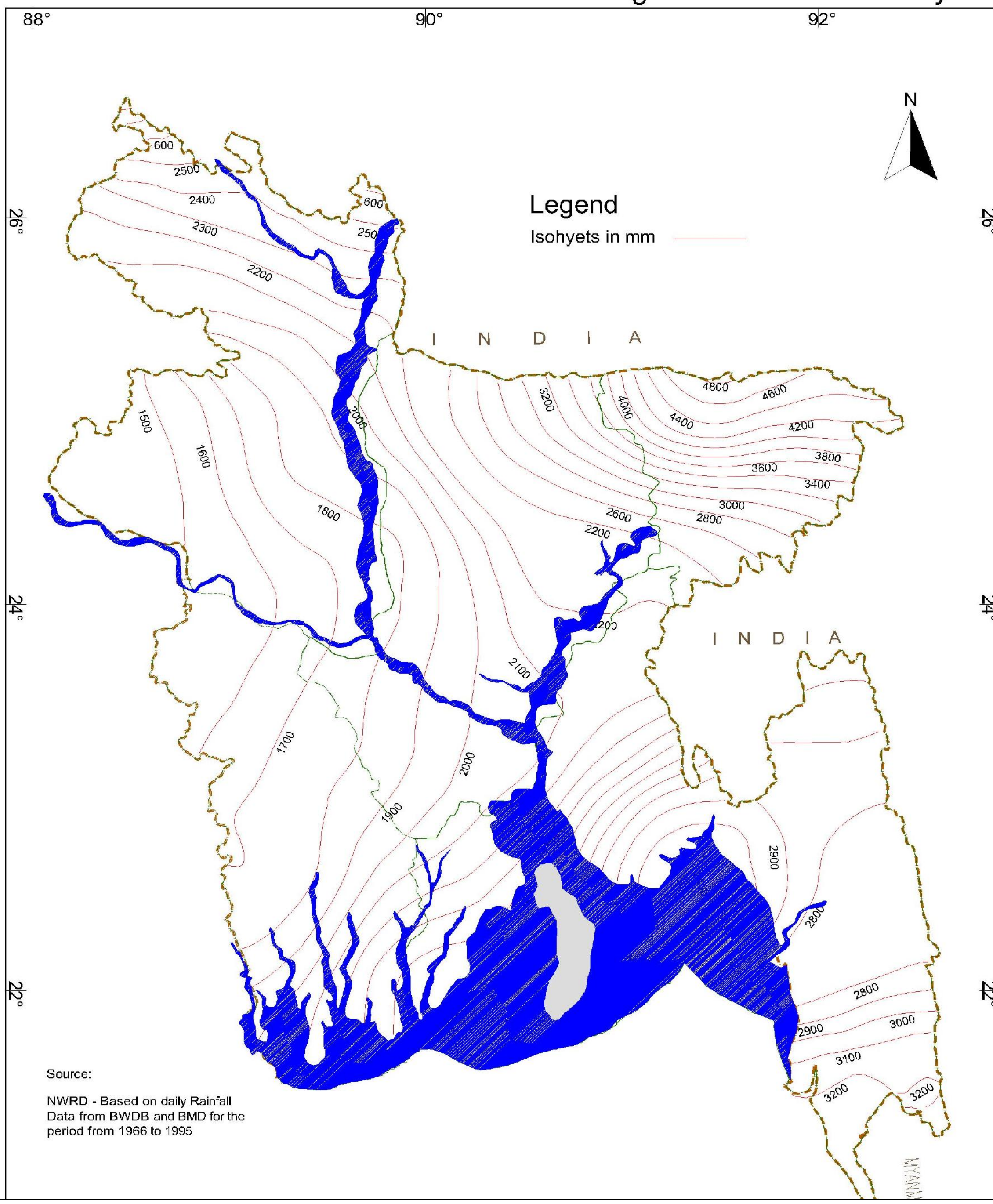

Figure 4.3.1: Average Annual Rainfall Isohyets (Source: NWRD)

4.3.2 Seasonal Distribution

The seasonal distribution of rainfall is very much skewed. Four rainy months from June to September register most (71.70%) of the rainfall. The post-monsoon, October to December (Fall/Autumn), is warm and humid with unstable atmospheric conditions that induce local thunderstorm and cyclones from the Bay of Bengal and gets (9%) of rainfall. The cool dry season January-March (winter), is sunny with infrequent rainfall (3.63%). The summer extends from April and May gets 14.87% of annual rainfall. This is hot and is characterized by thunderstorms called Nor'westers, with heavy local rainfall and hail. The seasonal distribution is given in Table 4.3.2 below.

Table-4.3.2: Seasonal Rainfall Distribution in mm and Percentage

Seasons	Rainfall (mm)	Percentage (%)
Autumn(October –December)	219	9.87
Winter(January - March)	81	3.63
Summer (April – May)	332	14.87
Monsoon (June - September)	1601	71.70
Total	2,183	100.00

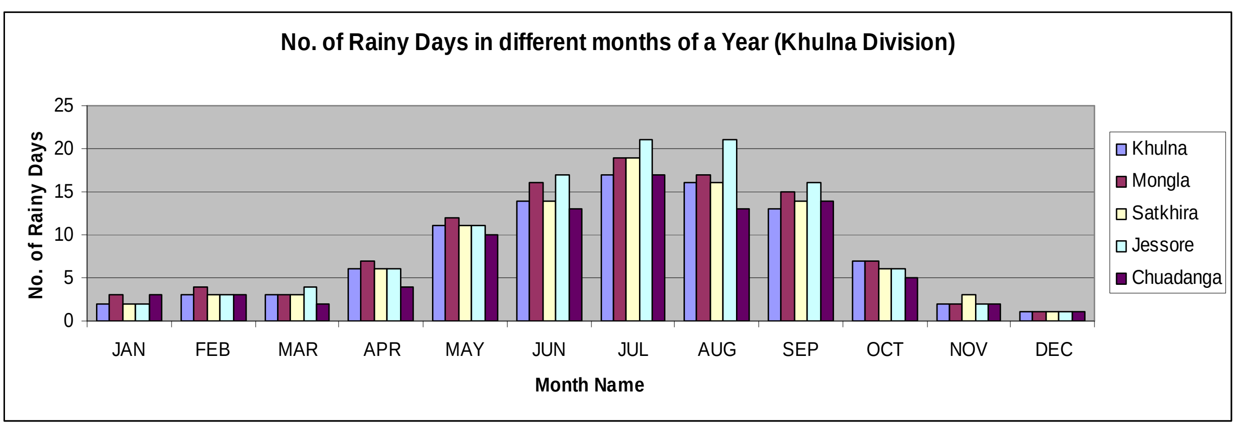

Figure 4.3.2: Rainy days of different months in Khulna division

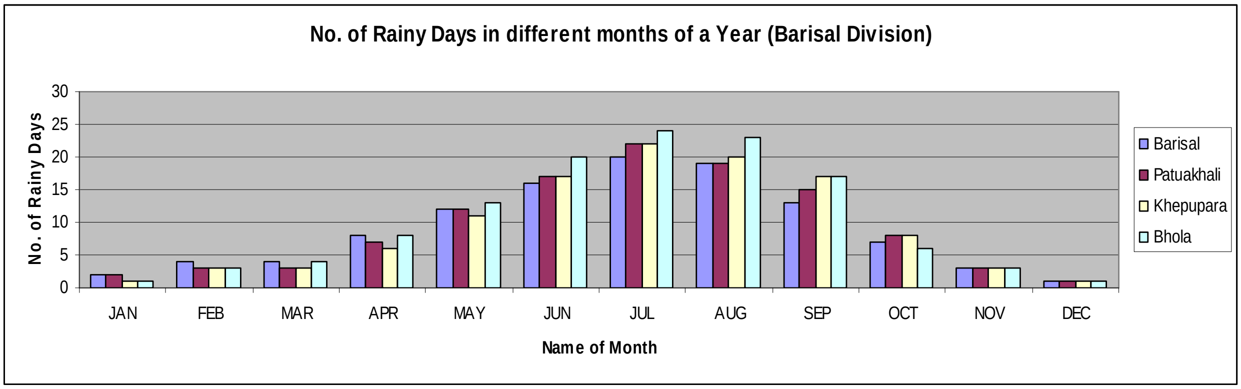

Figure 4.3.3: Rainy days of different months in Barisal division

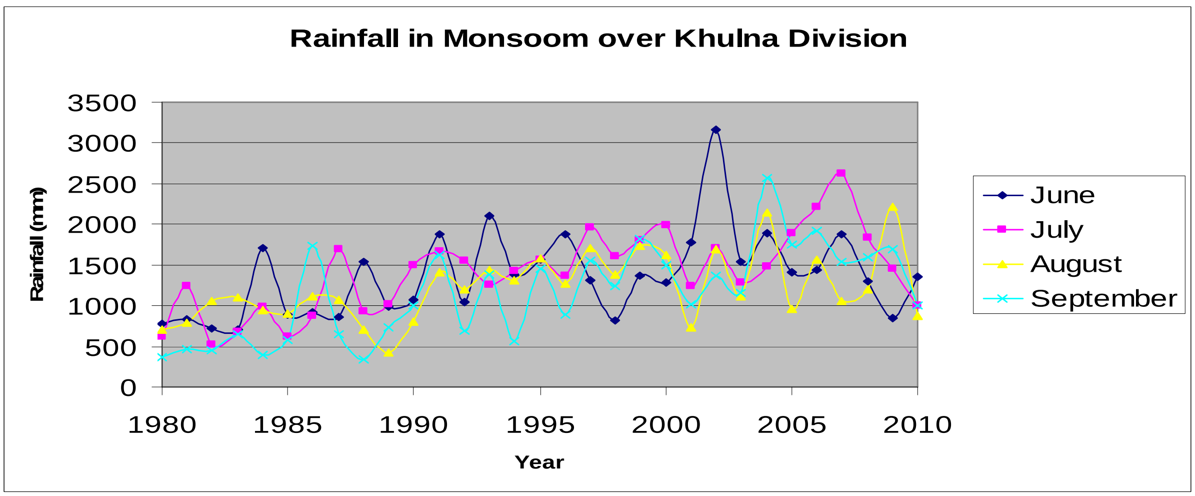

Figure 4.3.4: Rainfall in Monsoon in Khulna division

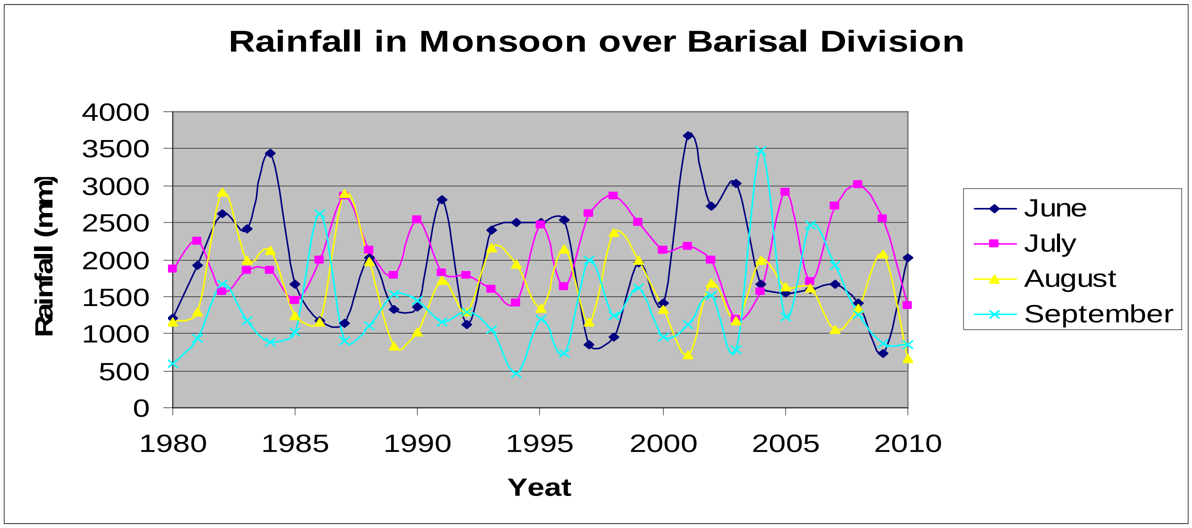

Figure 4.3.5: Rainfall in Monsoon in Barisal division

Most of the rainfall occurs in the monsoon time. June, July, August and September are the time of monsoon. Most of rainfall which is around 71% occurred in monsoon and most of the rainy days are also in the months of monsoon. July is the month where maximum rainy days occurred in both Khulna and Barisal divisions. Rainfall has more or less an effect on the ground water salinity. In monsoon it pushes back the saline water to the south coast of Bangladesh. The salinity concentration decreases during monsoon and increases in dry season.

4.3.3 Temperature

Average maximum, average minimum temperatures of study area are shown by bar diagram in figure-4.3.6, 4.3.7, 4.3.8 and 4.3.9. The average low temperature occurring in January is 13.4^0 Celsius, while the average high temperature is 33.8^0 Celsius occurring in April. The extreme low temperature may be 6.5^0 Celsius in February and the extreme high temperature may be 41.1^0 Celsius occurring in May.

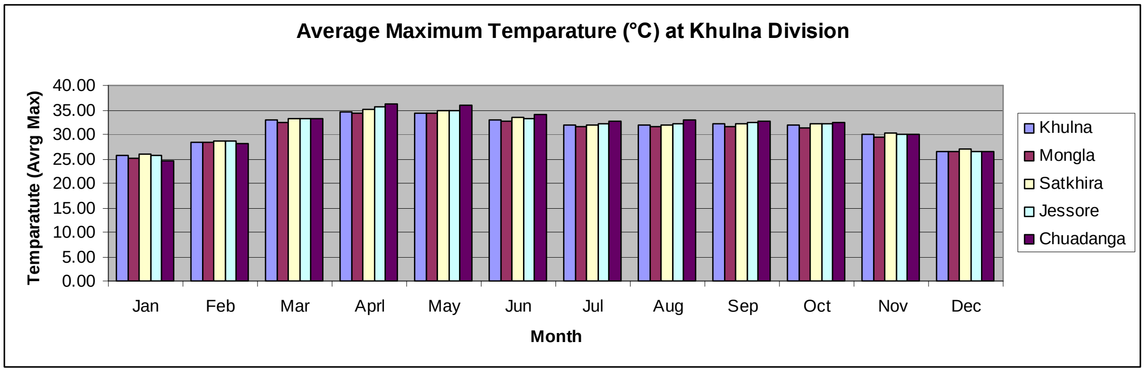

Figure 4.3.6: Average maximum temperature at Khulna division

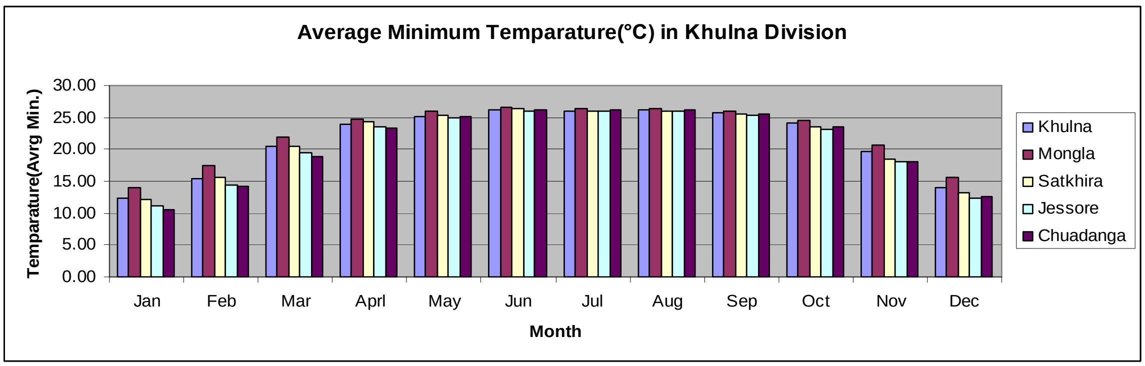

Figure 4.3.7: Average minimum temperature at Khulna division

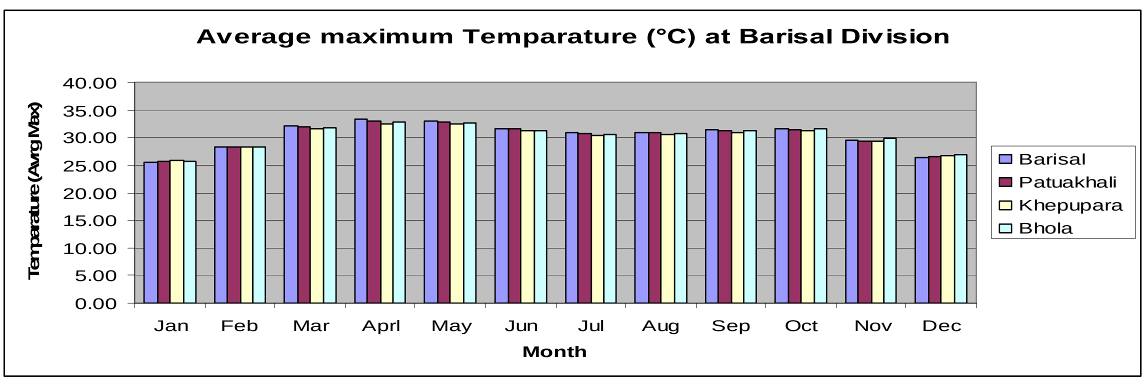

Figure 4.3.8: Average maximum temperature at Barisal division

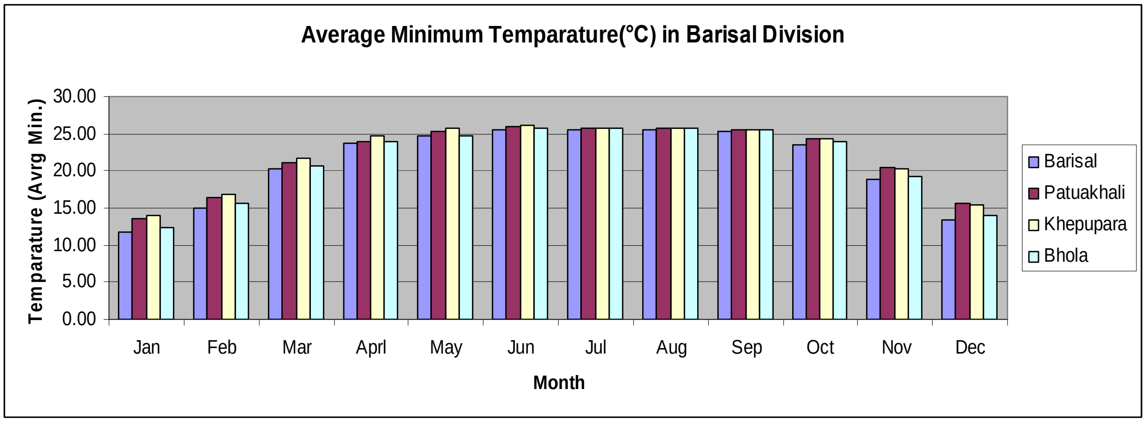

Figure 4.3.9: Average minimum temperature at Barisal division

Considering the average maximum temperature April and May are the hottest months of the year. So evaporation also increases in these months which result in the increase in soil salinity. Temperature is a climatic factor which has an effect on humidity and evaporation. So it has no direct effect on ground water salinity but it has an effect on soil salinity.

4.4 Ground water

The ground water zoning map of the study area is in figure 4.4.1 showed that in most of the area the static water level is within 0 to 5.3 meters below the ground level. The Jessore, Magura and Jhenaidah district are in the critical position for ground water. The static water levels of these areas are within 5.3 to 7.6 meters below ground level. The most critical area for ground water is in Satkhira and Jhenaidah district where the water level went below 7.6 meters from ground surface. The deep tube well and shallow tube well use bar diagram figure 4.4.2 and 4.4.3 also support the ground water situation of the study area. In Barisal division there is nearly no use of deep tube well and shallow tube well for irrigation purpose (BADC Irrigation equipment survey report 2009-10).

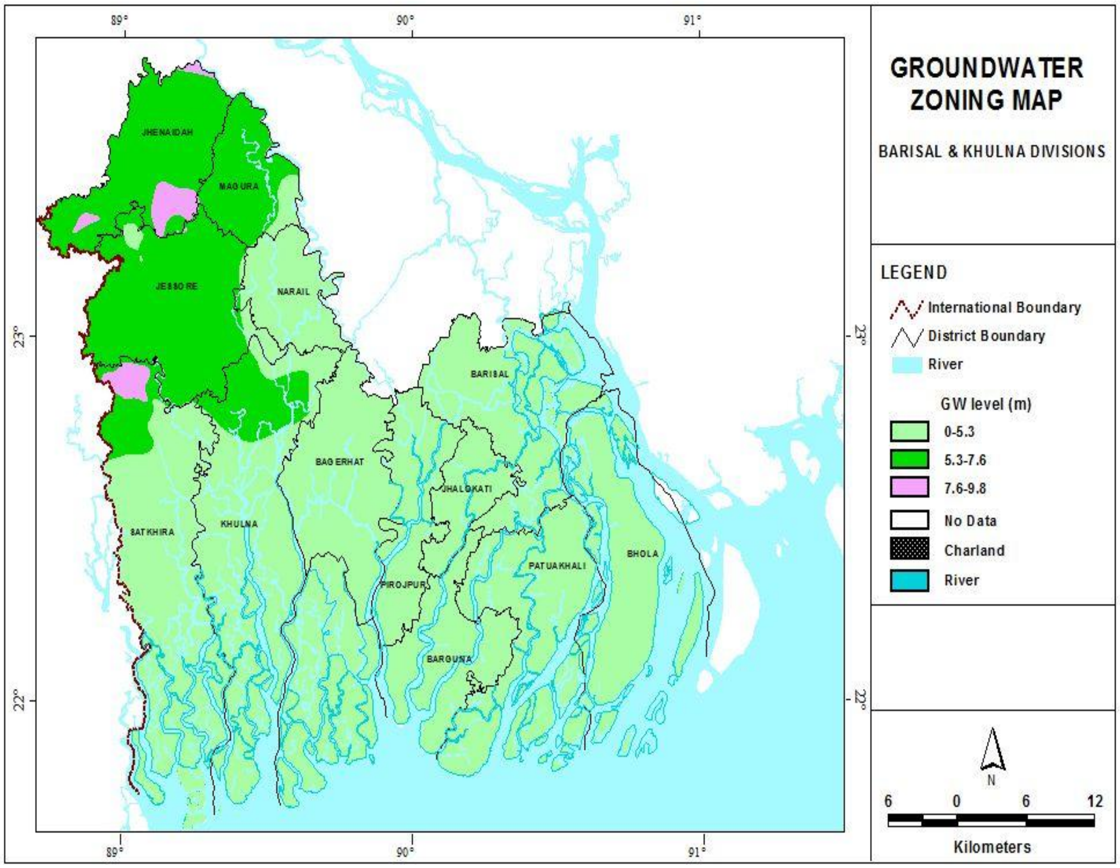

Figure 4.4.1: Groundwater zoning map of the study area (Source: BADC, 2010)

The ground water zoning map of the study area showed us that the static ground water level of Jessore, Magua, Jhenaidah districts and some part of Satkhira and Khulna are with 5.3 to 7.6 meters below surface. The static water level of some part of Satkhira and Jhenaidah are below 7.6 meters. It means that fresh water pressure is decreasing in these areas. Most of the deep tubewells and shallow tubewells are also in these areas of the division. So the depletion of ground water level in upstream results in the increasing pressure of the saline water.

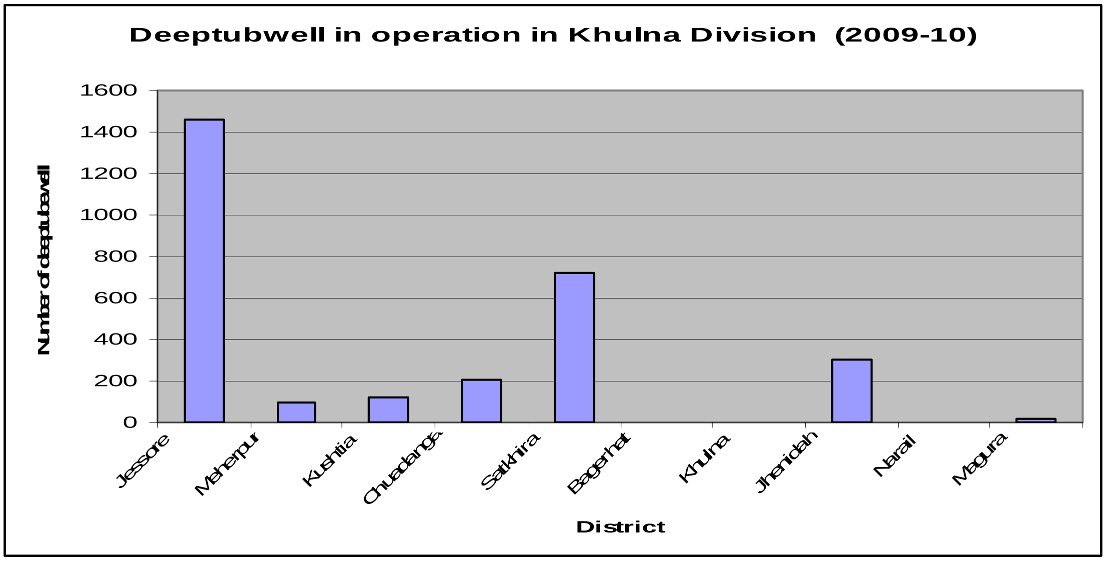

Figure 4.4.2: Number of Deep tube well for the year 2009-10

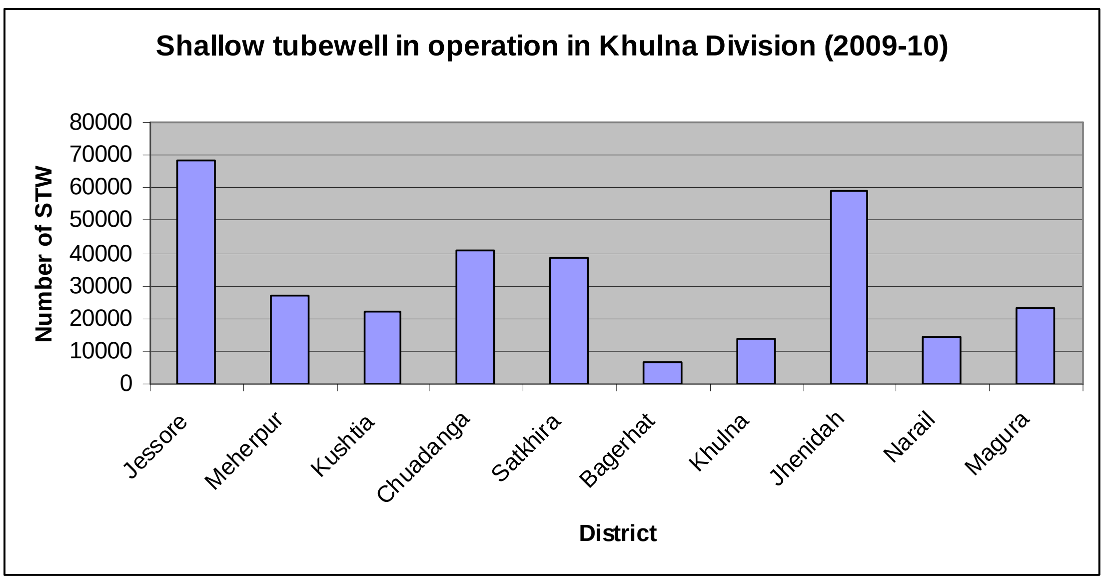

Figure 4.4.3: Number of Shallow tube well for the year 2009-10

4.5 River system of the region

Geographically, the rivers Ganges-Padma to the north, the Meghna estuary to the east and the Bay of Bengal to the south surround the study area. The rivers of the southwest region are dominated by tides. Many rivers, especially those in the southwestern part, carry very little freshwater but act as tidal channels for tides originating from the Bay of Bengal. Many distributaries receive excessive drainage flows during the monsoon from inland rivers, which mostly follow the course of former regional rivers. The river network systems of the study area (Figure 4.5.1) are the Ganges-Gorai, Madhumati and Chandana–Barasia, Arialkhan-Kumar, Bhairab-Mathabanga, Passur-Sibsa, Arialkhan-Baleswar, Barisal-Buriswar and Bhairab-Mathabanga system.

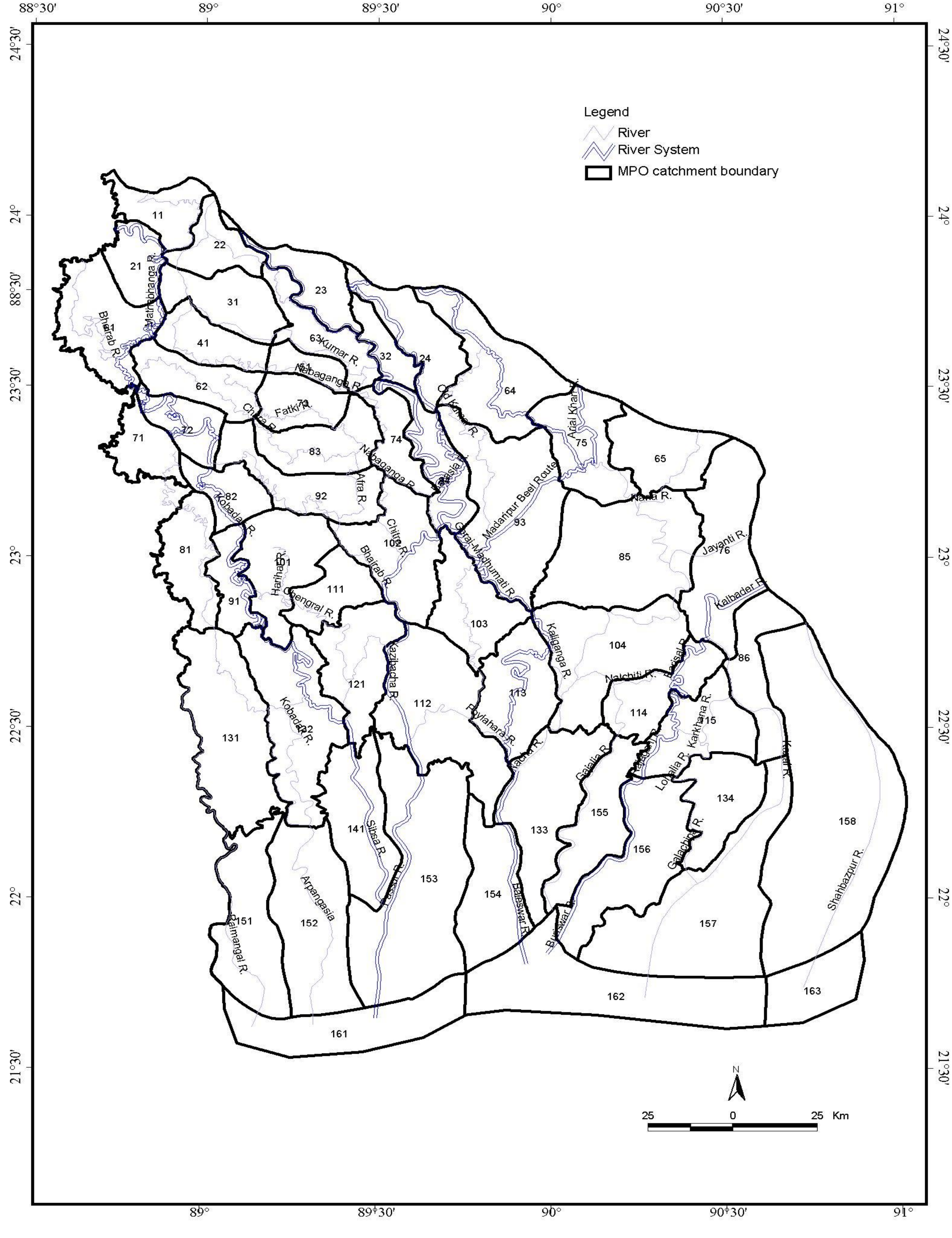

Figure 4.5.1: River system of the south west region of Bangladesh (Source: Sarker, 2005)

4.6 General geology of study area

The different geological units of the study area have been shown in Figure 4.6.1. Those units that belong to Pleistocene-Holocene (recent) ages are hydro-geologically important for the study area. While older units are deep (i.e., below 200-300 m), warrant serious consideration be given regarding groundwater resource available to otherwise younger sediments, though deep aquifers are exploited elsewhere in Bangladesh. However, the general geology of the study area can be described through several important parameters like stratigraphy, lithology and regional structure.

The study area is covered entirely by Holocene alluvium comprising deltaic, terrace, meander, inter-stream and swamp deposits. These sediments continue to accumulate from detritus deposited by the main rivers, particularly on the floodplain of the Meghna. Although the sediments become progressively older with depth there is no specific evidence of wells in the study area encountering Pleistocene sediments because of their general similarity in lithology to Holocene sediments and lack of fossil evidence. Elsewhere in Bangladesh, Pleistocene to early Holocene sediments, which were laid down by an ancestral river system, have been uplifted and are exposed at the surface. These older sediments are slightly compacted and oxidized as compared to Holocene sediments. However, again, there is no record of such deposits occurring within the study area.

The lithology of the various sediments referred to above varies from clay, through silt, to fine, medium and occasionally coarse sand. The geometry of individual sedimentary units is inevitably complex and there is a general lack of horizontal continuity on a local scale. Also, there is an upward fining of the sequence, while the degree of sorting decreases with depth.

A fairly broad correlation between lithology and depth has been established for the youngest sediments in Bangladesh and its principal characteristics are thought to apply to the project area. The three uppermost units, each of which is important hydro-geologically, are as follows:

- an upper, surface layer, of mainly clay and silt, which in parts of Barisal, Khulna and Faridpur contains peat layers;
- an intermediate layer of mainly fine sand and clay referred to as the Composite Aquifer; and
- a deeper layer, containing mainly fine to coarse sand and known as Deep Aquifer, which is separated from the Composite Aquifer sequence by a clay layer.

In general in the southwest and south central areas the upper clay layer is comparatively thick, and this is particularly true in southern Barisal district where it may be up to 150 m thick. In such areas the composite and deep aquifer sequences are probably found in the 150-300 m depth range.

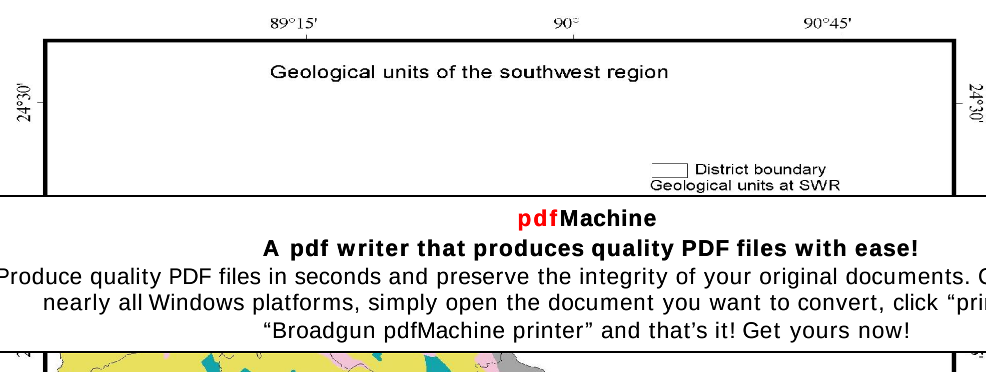

Figure 4.6.1: Geological units of south western area (source: Sarker, 2005)

4.7 Hydrogeology of the Study Area

4.7.1 Aquifer system

Considering the groundwater investigation and hydro-geological studies so far done by different agencies, the aquifer system of coastal area may be categorized into four different major aquifer systems. The depths of these aquifer systems are variable to sediment deposits and general topography. For example in the Mongla Port area the aquifer is within the range of 24-150 m (EPC, 1998). The lithology of the coastal aquifer has been shown in Figure 4.7.1. Brief descriptions of these four aquifer systems are given below:

Upper shallow aquifer system: This system generally exists within 50 m below ground level consisting mostly very fine sand. This system has heterogeneous assemblage of sand, silt and clay. Thickness of such unconfined aquifer varies from 2 to 6 m.

Lower shallow aquifer system: This consists of unconfined to semi-confined aquifer, which generally exists between 50 and 150 m below ground level; consists of medium to coarse sand with occasional find sand and silt. The aquifer thickness varies from 20 to 80 m with some exception.

Deeper aquifer system: In general the deeper aquifer system exists about 200 m below ground level. But in some places geologically similar deeper aquifer system may exist in higher elevation due to local topography and geological situations. The aquifer generally consists of fine to medium sands and mostly confined to semi-confined in nature.

Deep aquifer system: This aquifer exists below deeper aquifer system in reasonable depth and presumed to have confined nature and sufficient hydrostatic pressure. According to Khan (1991), the deep aquifer system in the country exists between 200 and 1000 m and some places more than this limit.

Further the main hydro-geological characteristics of the aquifers of southwest region, as described by different units, are as follows:

Upper clay and silt: This unit is characterized by high porosity but low permeability. Due to its extensive thickness in parts of the study area it effectively precludes major groundwater development because it is unable to support tubewells itself and makes the lower aquifers too deep to be economically exploited on a large scale for irrigation. In most parts of the study area its main importance is the extent to which it controls downward percolation to the deeper units below.

Composite Aquifer: This unit is characterized by high porosity and moderate permeability. Where it is shallow enough to be exploited is capable of providing water to HTW and Manually Operated Shallow tubewell for irrigation (MOSTI).

Main Aquifer: This main aquifer is characterized by high porosity and moderate to high permeability. Where it is accessible, it is an important aquifer, which provides large quantities of water to DTW and STW/DSSTW. The distribution of these units is such that the most favorable hydro-geological conditions exist in the northern part of the study area.

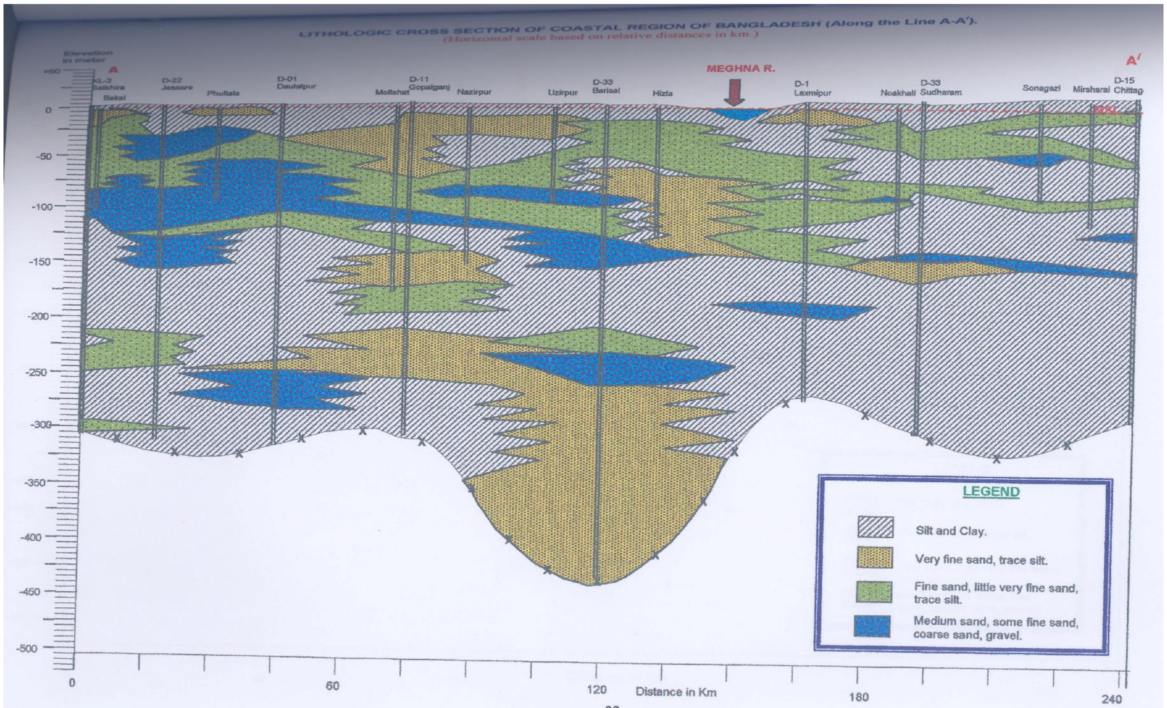

Figure 4.7.1: Lithology of the coastal aquifer

4.8 Summary

The study area Barisal and Khulna divisions are coastal area. Many rivers run through these two divisions to the Bay of Bengal. River flow decreases in dry season and most of rainfall occurs in monsoon. A huge number of shallow and deep tube well lift ground water in dry season. The aquifer system of the study area can be classified as shallow aquifer, deeper aquifer and deep aquifer. The deep aquifer system exists between 200 and 1000 meters and some places more than this limit.

Chapter 5

Results and Discussions

5.1 General

To determine the spatial variation of ground water salinity at different depth below surface level the data of 2010 were used. For finding out the saline prone are in south western Bangladesh the data (delineated data) of the year 2010 were used.

For observing the effect of tide on the concentration of ground water salinity the water level data (high and low tide) of the Bishkhali River were used. The salinity observation wells of Betagi, Bamna and Patharghata are near the Bishkhali River. The tidal data of Bishkhali River were compared with the salinity concentration data in tabular format.

To determine the temporal variations of groundwater salinity for the southwest region of Bangladesh, five different years (2005, 2006, 2007 and 2008 data for Khulna division and 2005, 2006, 2007 and 2008 data for Barisal division) have been considered as the base years for further data analysis. These base years are selected based on the years of data available for soil salinity. The different data analyzed under this study are (i) groundwater depth wise (upper and lower shallow aquifer) salinity concentration; (ii) extend of groundwater salinity and (iii) observing the effect of tide on the concentration of ground water salinity.

5.2 Present status of ground water salinity in the study area

The present situation (2010) of the study area for ground water salinity at 30 meter depth below ground surface is shown in the figure 5.2.1. At this depth the saline water intrusion in the coastal belt is clear as the ground water salinity of the coastal area are very high. The salinity concentration of part of Khulna, Bagerhat, Jhalokati, Bhola and Satkhira are within the range of 665μS/cm to 8540μS/cm. These concentrations of ground water salinity are very much harmful for the crop and human. Most of these areas are out of crop cultivation for high saline ground water. The rainfall of Bhola in June, July and August respectively 466 mm, 445 mm and 396 mm while the normal rainfall of these months are 760 mm, 850 mm and 550 mm respectively. So rainfall in Bhola in 2010 was less than the normal rainfall. The rainfall of 2010 in Satkhira was less than the normal rainfall which is described in last paragraph and a total of 38445 nos. of shallow tube wells (STW's) and 720 nos. of deep tube wells were used for irrigation in 2009-10 irrigation season in Satkhira district. These STW's lift ground water from a maximum depth of 25 feet below surface. For deep set STW's the lifting depth increases a little more. Most DTW's lift ground water from the depth of 50 to 105 meters below surface level. There was nearly no water flow from upstream through the Kobadak River. The natural and man made circumstances have some effect on ground water salinity.

In monsoon (June, July, August and September) there are more rainfall occurred in the study area compared to rest of the year. The rainfall also increased the river discharge of the study area. So the rainfall and the increased river discharge push the ground water salinity to the south. So the salinity concentration of ground water of dry season in May, 2011 is relatively high compared to after rainy season in November, 2010 ground water salinity. The figure 5.2.1 showed the dry season ground water salinity distribution (May, 2011) and figure 5.2.2 showed the after rainy season ground water salinity distribution (November, 2010).

The ground water salinity concentration of Barisal and Khulna division are largely affected by the monsoon. The figure 5.2.1 showed that the salinity concentration (which is indicated by deep red colour) of ground water were higher than the salinity concentration of figure 5.2.2. It was stated before that figure 5.2.1 indicated the dry season ground water salinity and figure 5.2.2 indicated the after rainy season ground water salinity.

For indicating different salinity concentration, the red colours of different density were used. The higher the salinity concentration the deeper the red colour.

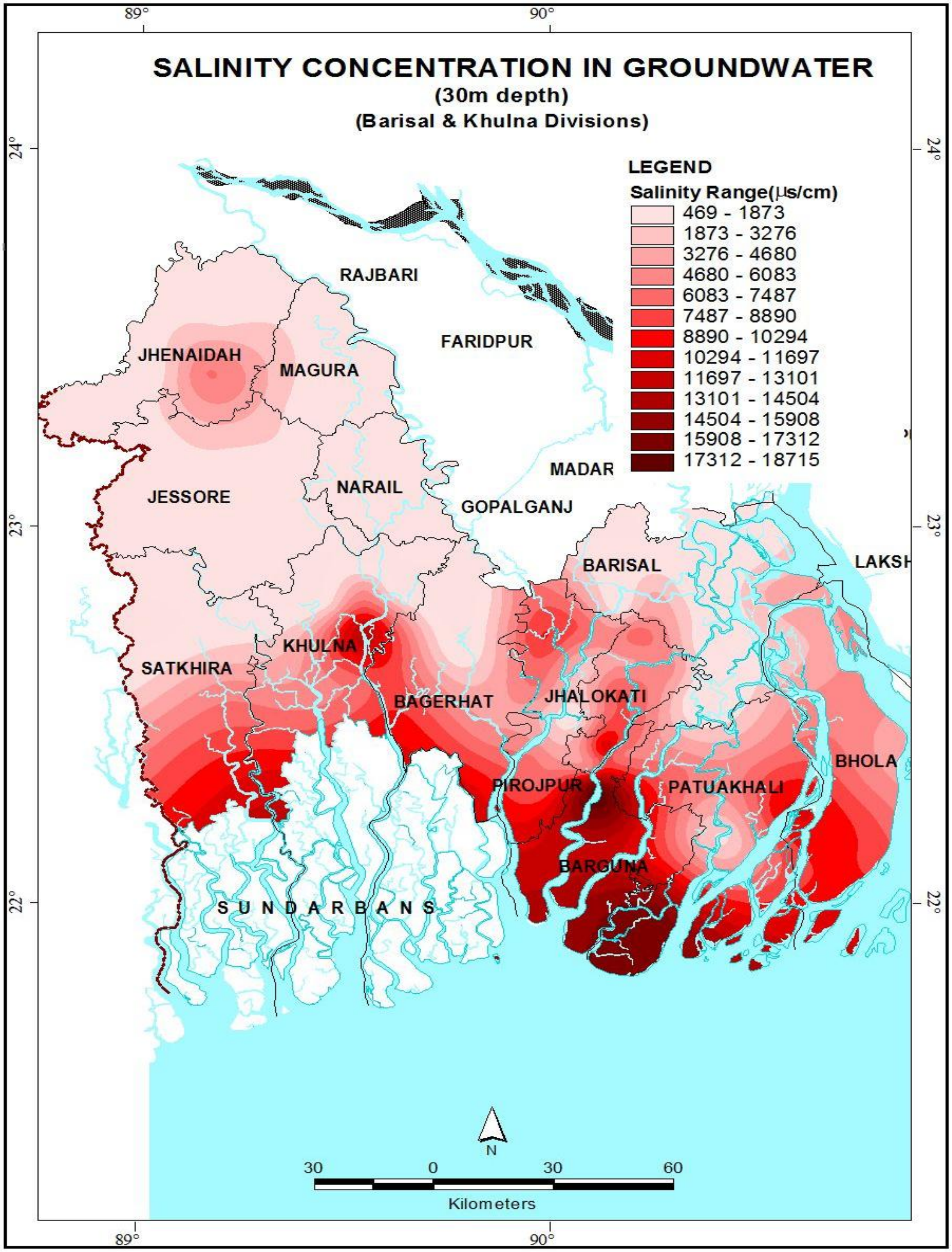

Figure 5.2.1: Dry season ground water salinity (May, 2011)

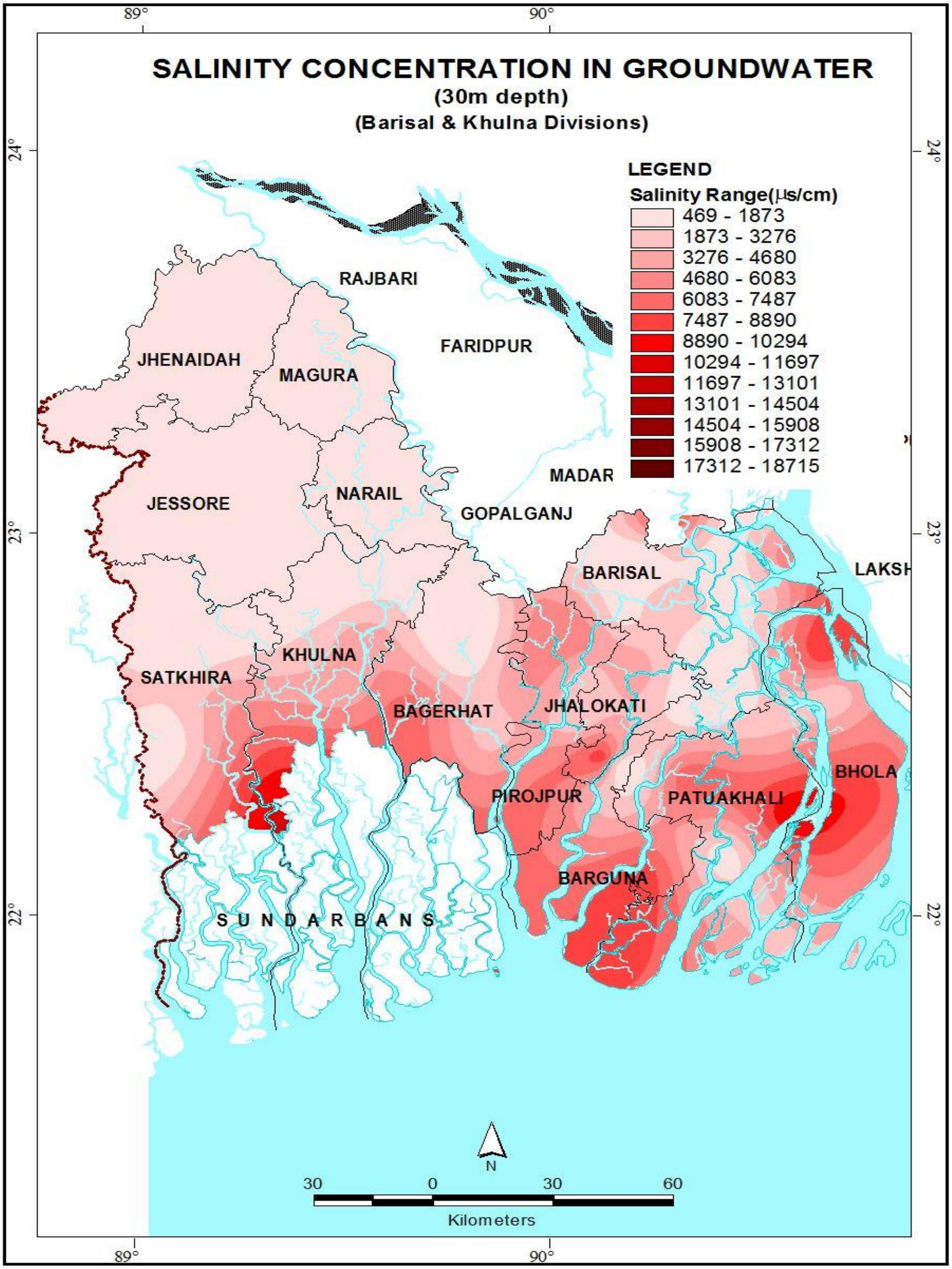

Figure 5.2.2: After wet season ground water salinity (November, 2010)

5.3 Ground water salinity area (Hectares) of different concentration

The south west part of Bangladesh is suffering from various degrees of salinity. Ground water of 313415 hectares of were found below 750 µS/cm, 1398218 hectares were within 750 to 3000 µS/cm, 422495 hectares were within the range 3000 to 5000 µS/cm, 1106495 hectares were found within 5000 to 10000 µS/cm and 16213 hectares were found more than 10000 µS/cm. A total of 3256836 hectares' ground water (depth 15 meter) was found saline in December, 2010. This area was 2224723 hectares' in 1997 and 2328844 hectares' in 2000 (Sarker, 2005).

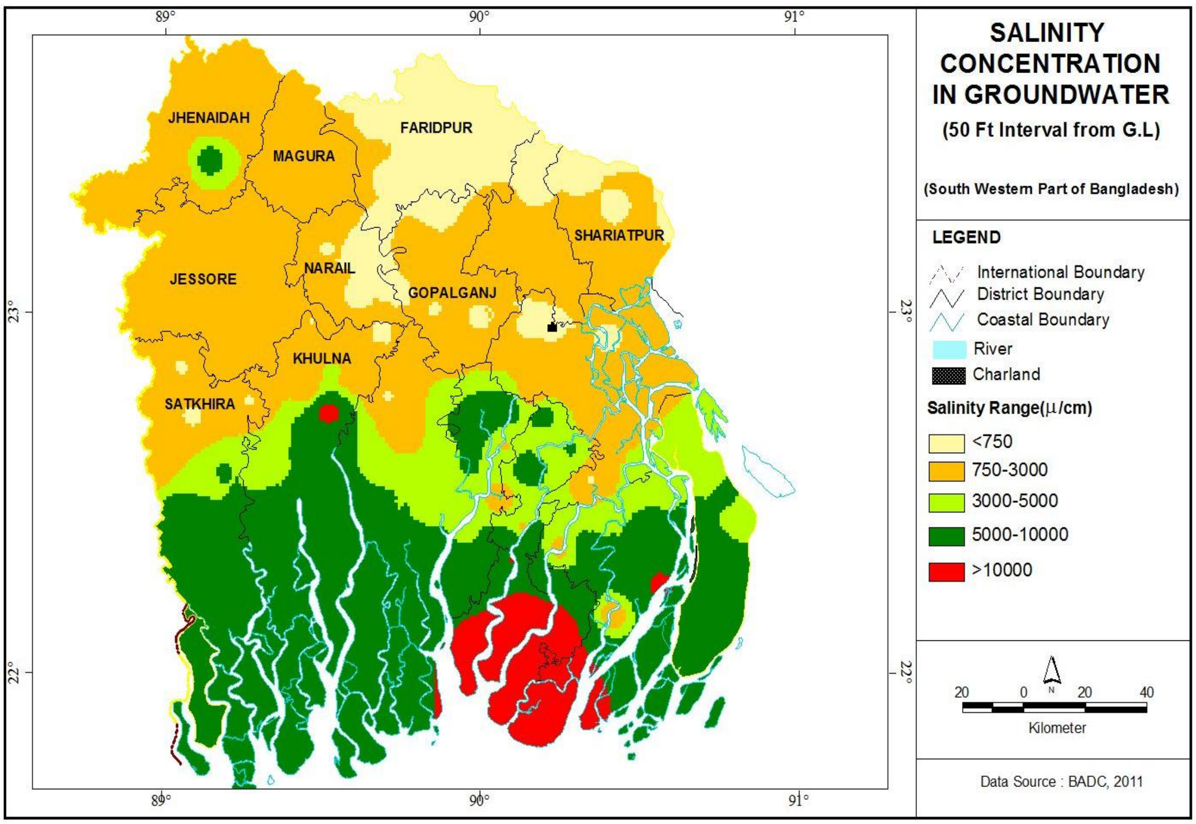

Figure 5.3.1: Saline affected area of south western area

5.4 Spatial distribution of ground water salinity in upper and lower shallow aquifer

The saline concentration of Satkhira (Assasuni, Debhata, Kalaroa, Kaliganj and Tala), Bagerhat (Morrelganj), Pirojpur and Bhola (Sadar and Burhanuddin) districts are acute at lower shallow aquifer which is about 55 meter below ground surface. The salinity concentrations of these districts were within 403µS/cm to 8540µS/cm. This range of salinity concentration is harmful for both drinking and crop production.

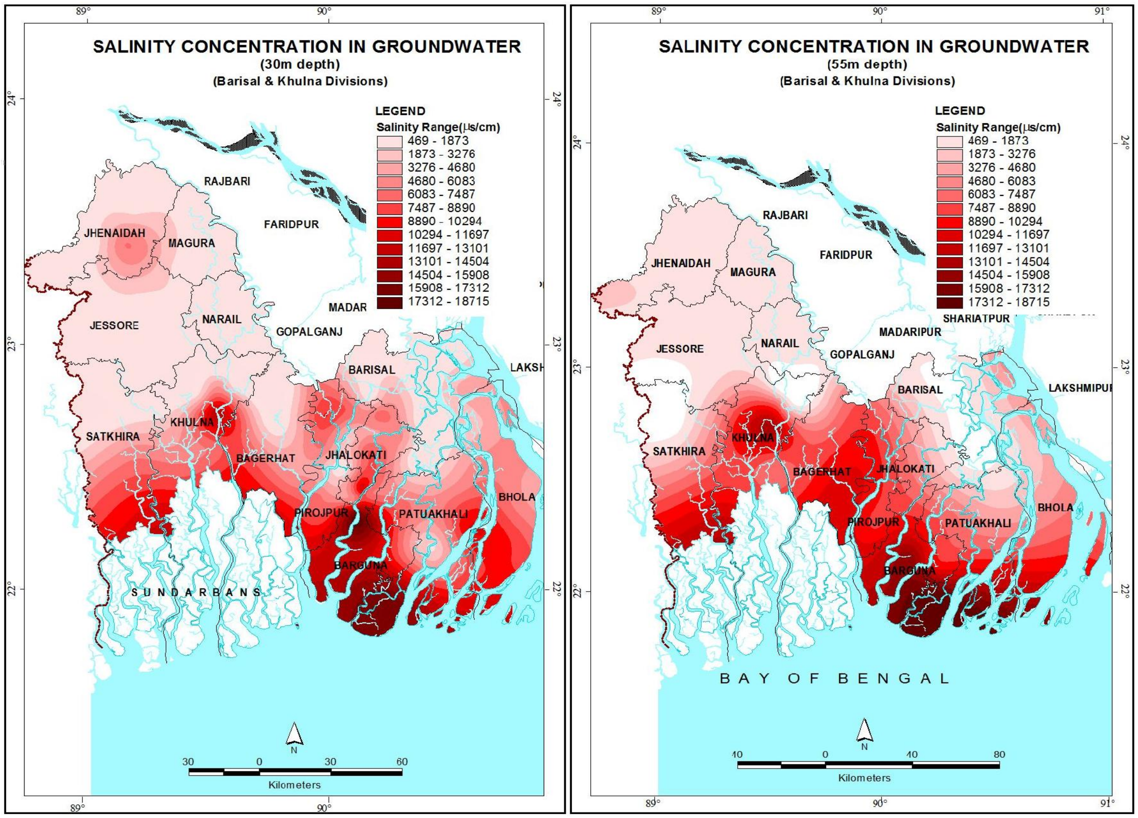

Figure 5.4.1 Spatial distribution of ground water salinity at upper shallow aquifer (30 meter) and lower shallow aquifer (55 meter)

In upper shallow aquifer (which is nearly 30 meter below ground surface) the saline water intrusion in the coastal belt is clear as the ground water salinity of the coastal area were also very high as like lower shallow aquifer. The salinity concentration of part of Khulna, Bagerhat, Jhalokati, Bhola and Satkhira at upper shallow aquifer were within the range of 395µS/cm to 8002µS/cm.

For spatial distribution in the upper shallow aquifer the salinity concentration was low in comparison with the lower shallow aquifer. The salinity aerial extent was also larger in comparison with the upper shallow aquifer.

5.5 Temporal variation of groundwater salinity

The temporal variation of groundwater salinity in the study area has been analyzed using available time series data from SRDI. A trend of salinity change for the period 2005-2008 of Pirojpur and Bhola districts of Barisal division and for the period 2005-2008 of Jessore and Narail dirstricts of Khulna division has been analyzed for the study area. Bar chart representation of monthly groundwater salinity data as shown in Figures 5.5.1 to 5.5.4 for different places indicate that March-May are the critical months in terms of salinity concentration. With the onset of rainfall, salinity decreases as a whole in the subsequent months to its tolerable limit. However in few places salinity concentration remains above safe drinking limit.

The causes of high salinity in March-May are (i) very little rainfall in the winter period, (ii) saline river water intrusion, and (iii) accumulation of salts in the surface due to evapotranspiration.

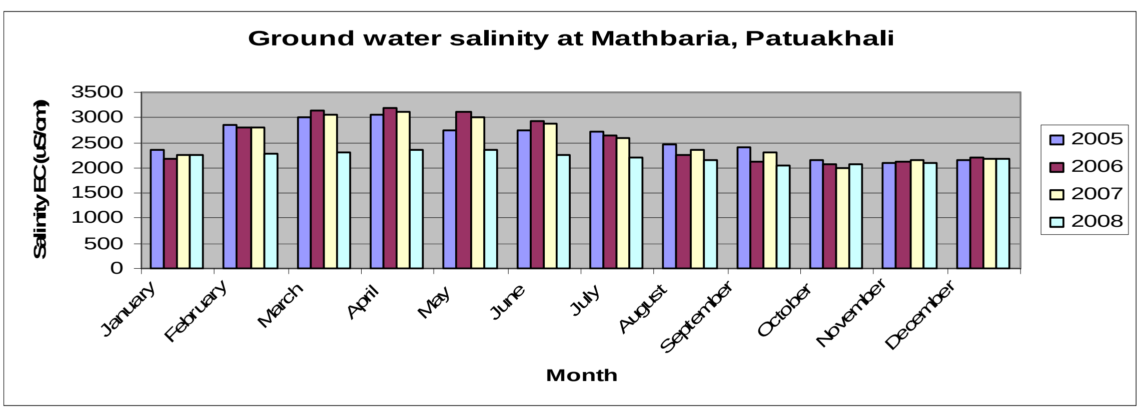

Figure 5.5.1: Monthly variation of ground water salinity at Mothbaria, Pirojpur

The ground water salinity at Mothbaria of Pirojpur is within the limit of 2.50 dS/m every month of the year 2005-2009 except the month February, March and April. The highest salinity is observed March, April and May of the year 2006, 2007 and 2009 which was more than 3.00 dS/m.

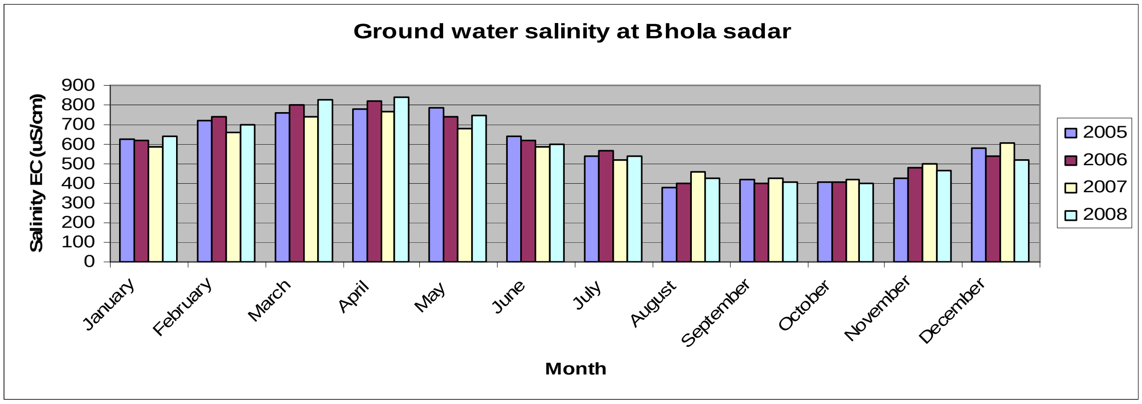

Figure 5.5.2: Monthly variation of ground water salinity at Bhola sadar

The ground water salinity at Bhola sadar is within the limit of 0.70 dS/m every month of the year 2005-2009 except the month February, March, April and May. The highest salinity is observed in March and April of the year 2006 and 2008 which was more than 0.80 dS/m.

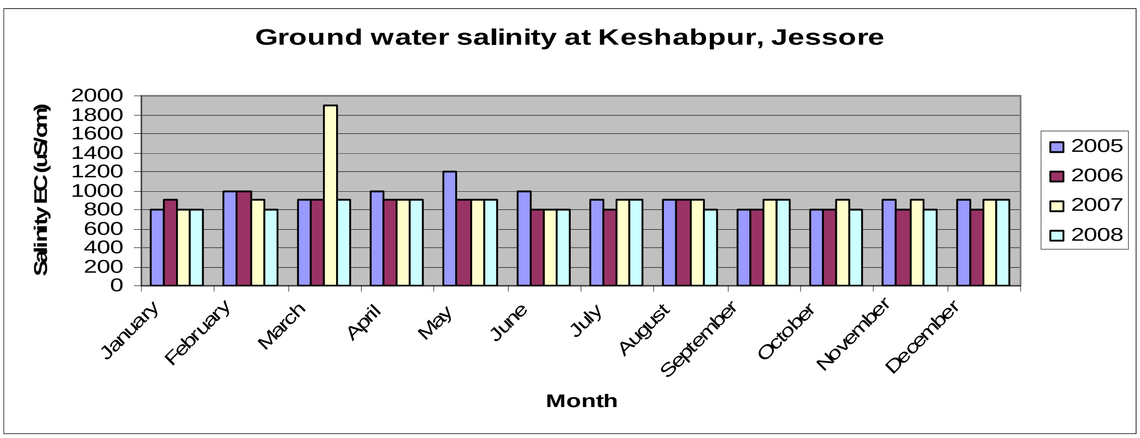

Figure 5.5.3: Monthly variation of ground water salinity at Keshobpur, Jessore

The ground water salinity at Keshobpur of Jessore district is within the limit of 1.00 dS/m every month of the year 2005-2009 except the month January, February and March. The highest salinity is observed in January and February of the year 2004 which was more than 2.00 dS/m.

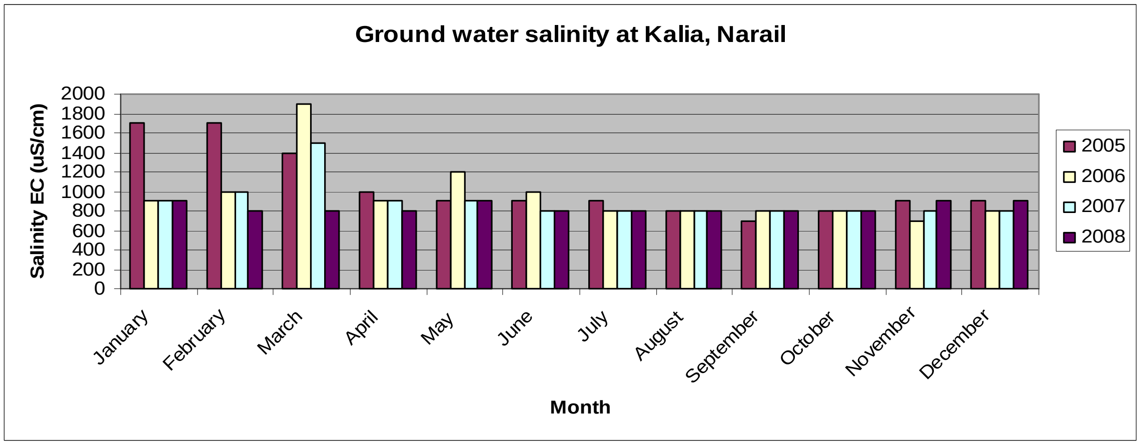

Figure 5.5.4: Monthly variation of ground water salinity at Kalia, Narail

The ground water salinity at Kalia of Narail is within the limit of 1.00 dS/m every month of the year 2005-2009 except the month January, February, March, April and May. The highest salinity is observed February and May of the year 2004 which was more than 2.50 dS/m.

5.6 Comparison between the obtained results with Standard level:

Groundwater salinity is one of the important water quality parameters. For agriculture and drinking purposes the ranges of water quality values including salinity should be known for safe uses. So, the community for its effective uses should know the safe and harmful distributions of groundwater salinity of the region. The standard level of salinity for irrigation will be compared with the collected data. Thus the safe and harmful condition of salinity with standard level will be found. The standard level for irrigation is 600 ppm or 857 µS/cm.

Table 5.6.1: Safe and Harmful situation of ground water salinity at 30, 45 and 55 meter depth for irrigation

		30 M	**45 M**	**55 M**
District	**Upazila**	**Situation**	**Situation**	**Situation**
Bagerhat	Fakirhat	Safe	Safe	Safe
Bagerhat	Morrelganj	Harmful	Harmful	Harmful

District	Upazila	30 M Situation	45 M Situation	55 M Situation
Jessore	Abhaynagar	Harmful	Harmful	Harmful
Jessore	Keshabpur	Harmful	Harmful	Harmful
Jhenaidah	Jhenaidaha sadar	Harmful	Harmful	Safe
Jhenaidah	Kaliganj	Harmful	Harmful	Harmful
Khulna	Khulna sadar	Harmful	Harmful	Harmful
Khulna	Batiaghata	Harmful	Harmful	Harmful
Khulna	Dacope	Harmful	Harmful	Harmful
Khulna	Terokhada	Harmful	Harmful	Harmful
Magura	Shalikha	Safe	Safe	Safe
Magura	Sreepur	Harmful	Harmful	Harmful
Narail	Narail sadar	Harmful	Harmful	Harmful
Narail	Lohagara	Harmful	Harmful	Safe
Satkhira	Assasuni	Harmful	Harmful	Harmful
Satkhira	Debhata	Harmful	Harmful	Harmful
Barguna	Amtali	Harmful	Harmful	Harmful
Barguna	Patharghata	Harmful	Harmful	Harmful
Barisal	Agailjhara	Harmful	Harmful	Harmful
Barisal	Bakerganj	Safe	Harmful	Harmful
Bhola	Bhola sadar	Harmful	Harmful	Harmful
Bhola	Burhanuddin	Harmful	Harmful	Harmful

5.7 Observing the effect of tide on the concentration of ground water salinity

Using the available data the observation was done to find the effect of saline water intrusion into the ground water. The Bishkhali is a tidal river which flows through Bamna, Betagi and Patharghata upazila of Barguna district. The salinity observation wells were situated near the tidal river Bishkhali. The tidal data (high tide and low tide) of November, 2010 and May, 2011 were collected from the Bangladesh Water Development Board. Always a sharp difference of salinity concentration was found between the time high tide and low tide. These differences were shown in tabular format below. As for example, at Betagi station on 28th November 2010 during the high tide and low tide the water levels of Bishkhali River were recorded respectively 1.35 m PWD and 0.65 m PWD while the salinity concentrations of observation well were at 30 meter depth 3046 μS/cm, 3075 μS/cm respectively and at 45 meter depth 3026 μS/cm, 3760 μS/cm respectively. For observing the data of other stations and respective observation wells the same results were found for every case. Figure 5.7.1 illustrates the location of the salinity monitoring wells in Betagi, Bamna and Patharghata in Barguna district.

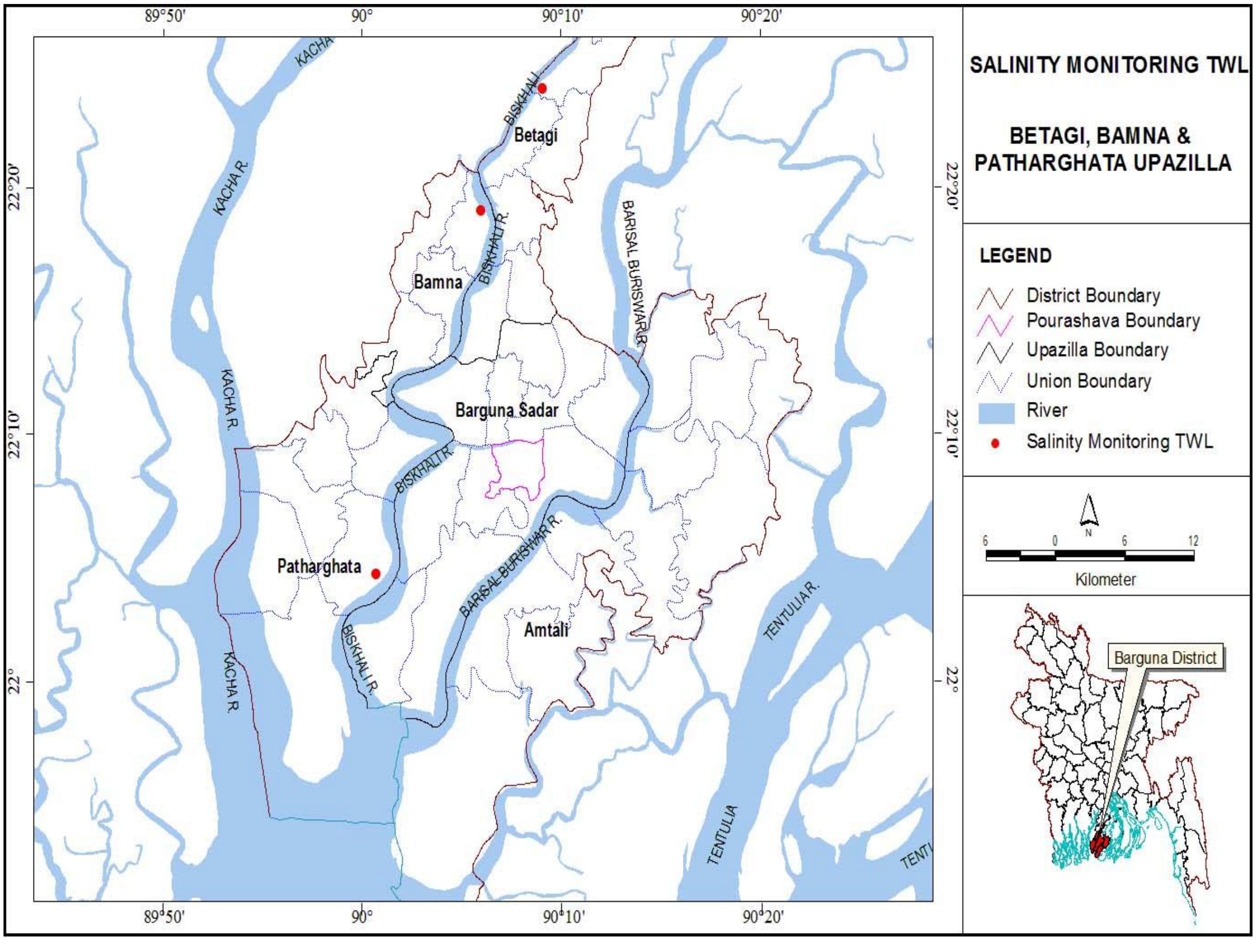

Figure 5.7.1: Salinity monitoring wells at Betagi, Bamna and Patharghata in Barguna

Table 5.7.1: Effect of tide of Bishkhali River on groundwater salinity at Patharghata

Patharghata, Borguna (11-28-2010) **Bishkhali River**

Tidal Situation	Water level (mPWD)	Salinity Concentration (µS/cm) at 30 meter depth	Salinity Concentration (µS/cm) at 45 meter depth	Salinity Concentration (µS/cm) at 55 meter depth
High Tide	2.05	6353	4661	6058
Low tide	0.35	6454	6112	6858

Table 5.7.2: Effect of tide of Bishkhali River on groundwater salinity at Bamna

Bamna, Borguna (11-28-2010) **Bishkhali River**

Tidal Situation	Water level (mPWD)	Salinity Concentration (µS/cm) at 30 meter depth	Salinity Concentration (µS/cm) at 45 meter depth
High Tide	1.55	3394	3994
Low tide	0.85	3434	4475

Table 5.7.3: Effect of tide of Bishkhali River on groundwater salinity at Betagi in November, 2010

Betagi, Borguna (11-28-2010) **Bishkhali River**

Tidal Situation	Water level (mPWD)	Salinity Concentration (µS/cm) at 30 meter depth	Salinity Concentration (µS/cm) at 45 meter depth
High Tide	1.35	3046	3026
Low tide	0.65	3075	3760

Table 5.7.4: Effect of tide of Bishkhali River on groundwater salinity at Betagi in June 2011

Betagi, Borguna (06-06-2011) **Bishkhali River**

Tidal Situation	Water level (mPWD)	Salinity Concentration (µS/cm) at 30 meter depth	Salinity Concentration (µS/cm) at 45 meter depth
High Tide	1.97	7480	8040
Low tide	0.38	7570	8310

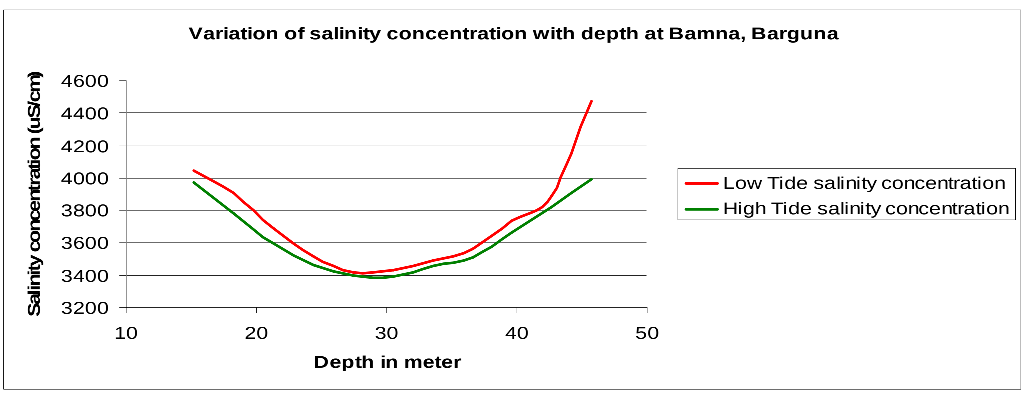

Figure 5.7.2: The variation of ground water salinity concentration during low and high tide at different depths

Chapter 6
Conclusions and Recommendations

6.1 General

The study area is severely affected by various degree of ground water salinity. A limited data were found for this study though an attempt has been made to collect all the relevant data related to ground water salinity of Barsal and Khulna division of Bangladesh from different organizations. Based on the collected data the analysis was done for the study area.

6.2 Conclusions

The analysis showed the saline prone area, saline affected area with time and depth wise salinity concentration of ground water. An attempt was also made to observe the effect of tide on ground water salinity. The major findings of this study are as follows:

1. The ground water of the study area has been affected by salinity considering the salinity concentration at 30 meter and 55 meter below the existing ground surface. The deeper part below 55 meter of the near coast aquifer is highly affected by salinity and in this part the salinity concentration is around 3227 μS/cm to 11830 μS/cm (Standard level for irrigation 857 μS/cm).
2. According to the spatial distribution of ground water the salinity concentration of the upper shallow aquifer (30 m below GL) was low in comparison with the lower shallow aquifer (55 m below GL). The aerial extend of the salinity of the lower shallow aquifer was also larger in comparison with the upper shallow aquifer.
3. In this study, the saline prone area which is harmful for the agricultural production (EC<857 μS/cm) is found to be 2943421 hectares. This saline prone area which is harmful for agricultural production was 2241453 hactares in the year 2000 (Sarker, 2005). This indicate that the ground water salinity has been extended around 31.31% over the last 10 years ;

4. The concentration of salinity of ground water increases in dry season during February to May of each year which is applicable for Barisal division. In Khulna division the salinity concentration also increases in dry season but the seasonal variation is not so acute.
5. The results show that the salinity concentration of the study area is in a bad state when it was compared with the standard values suggested by SRDI. The worst situation of ground water quality prevails in Jhalokati, Barguna and Bhola area where all the ground water up to 15 meter from GL is harmful for crop cultivation.
6. There are effects of tide on the concentration of salinity of ground water in an observation well. According to Oki and Presley "Flow within an observation borehole caused by withdrawals from pumped wells and ocean tides can significantly affect measured salinity profiles"**.** So the salinity of an observation well can be affected by tides as well as withdrawal of ground water from the aquifer. This statement supports the effect of tide on the concentration of ground water salinity of an observation well. So this statement supports the effect of tide on the concentration of ground water salinity and also matches with the result of this analysis.

6.3 Recommendations

The project work is targeted to find the saline affected area of Barisal and Khulna divisions. The recommendations of this project work are stated below

1. In this study limited amount of data has been studied within the study area. For better understanding a wide range of data can be used for the analysis.
2. Extensive ground water salinity data collection by automatic EC meter including data logger should be introduced in the south west region;
3. The change in seasonal variation of concentration of salinity can be thoroughly investigated as it produces an impact on the seasonal crop and economic condition of the local people.

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Appendix-A

Ground water salinity of different months in 2005, 2006, 2007 and 2008

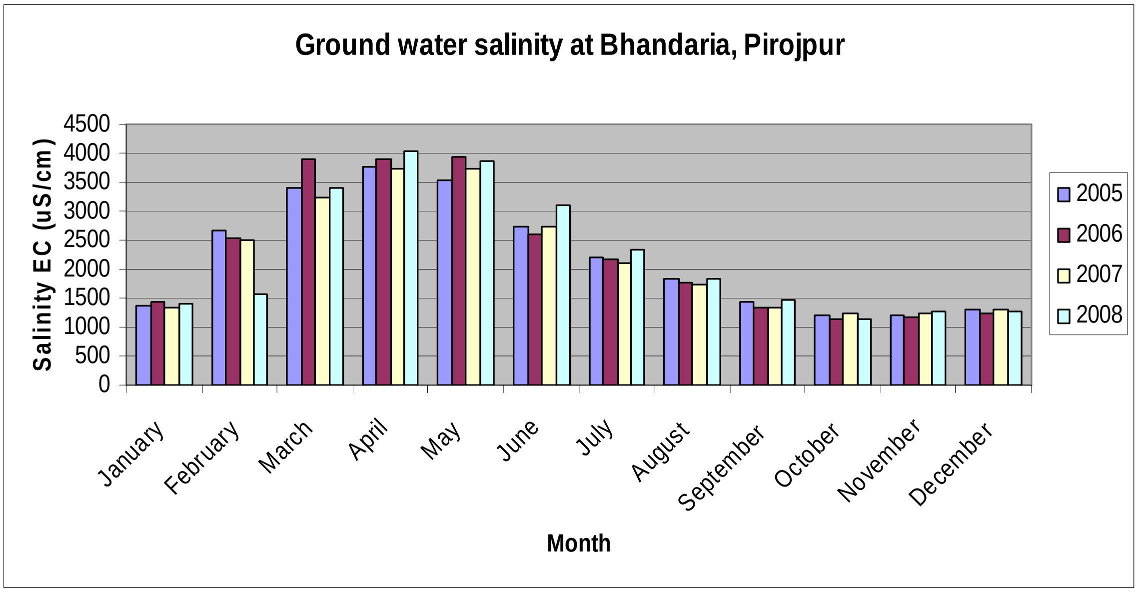

Figure A1: Ground water salinity at Bhandaria, Pirojpur

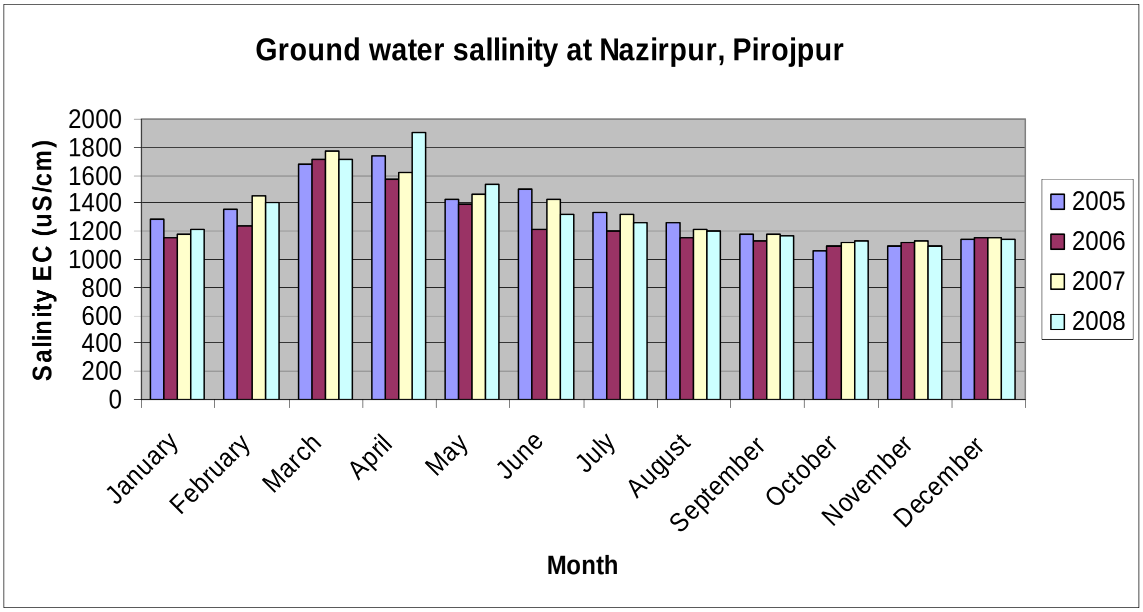

Figure A2: Ground water salinity at Nazirpur, Pirojpur

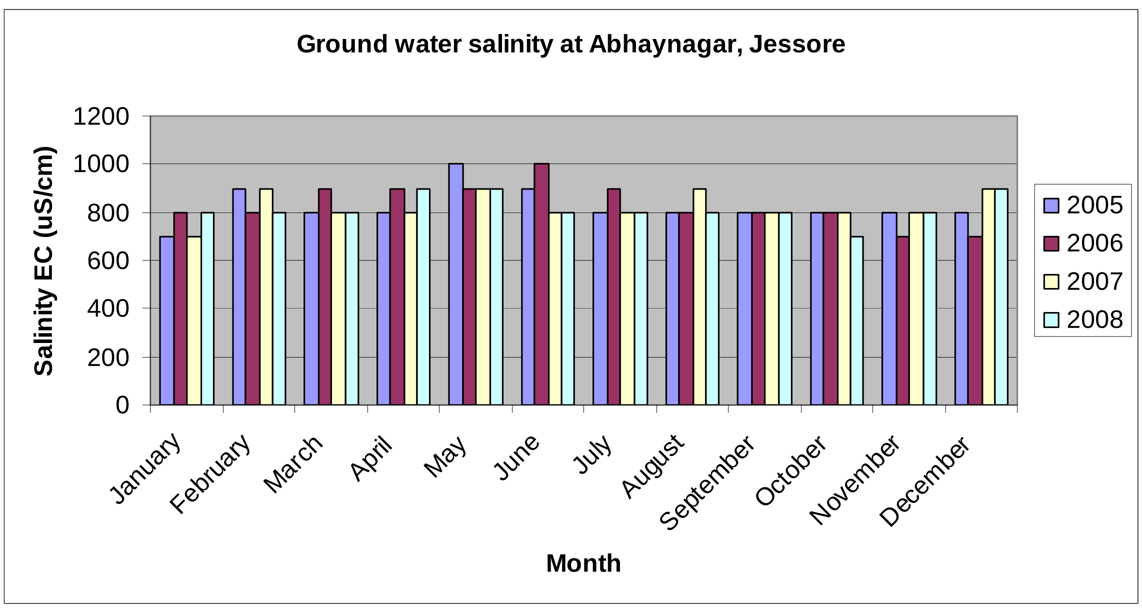

Figure A3: Ground water salinity at Abhaynagar, Jessore

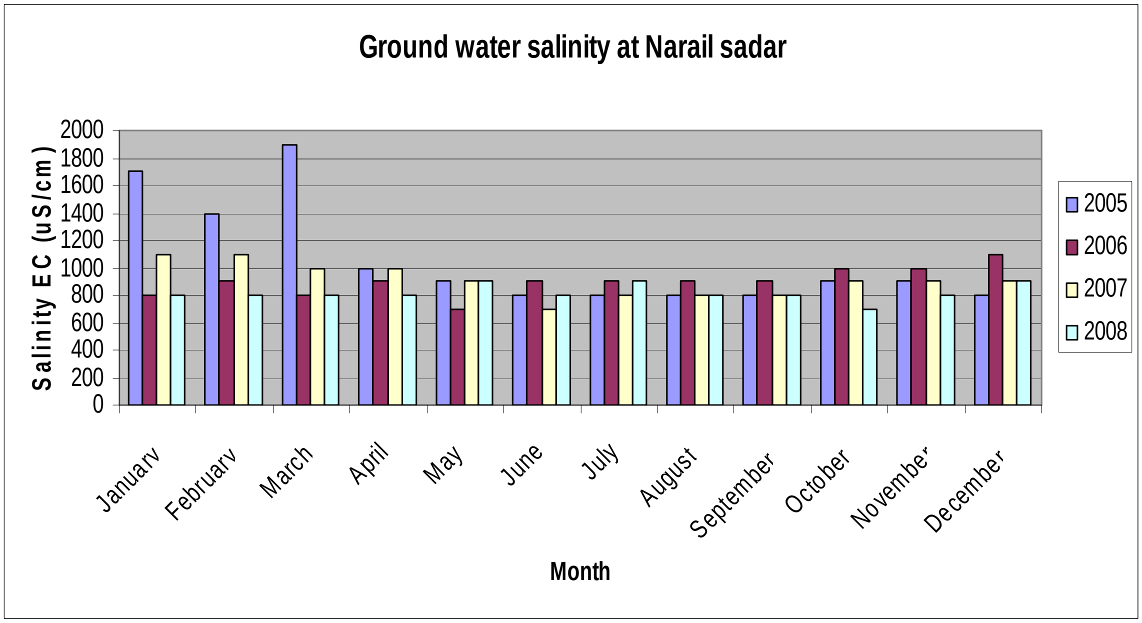

Figure A4: Ground water salinity at Narail sadar

Appendix-B

Normal rainfall distribution in monsoon

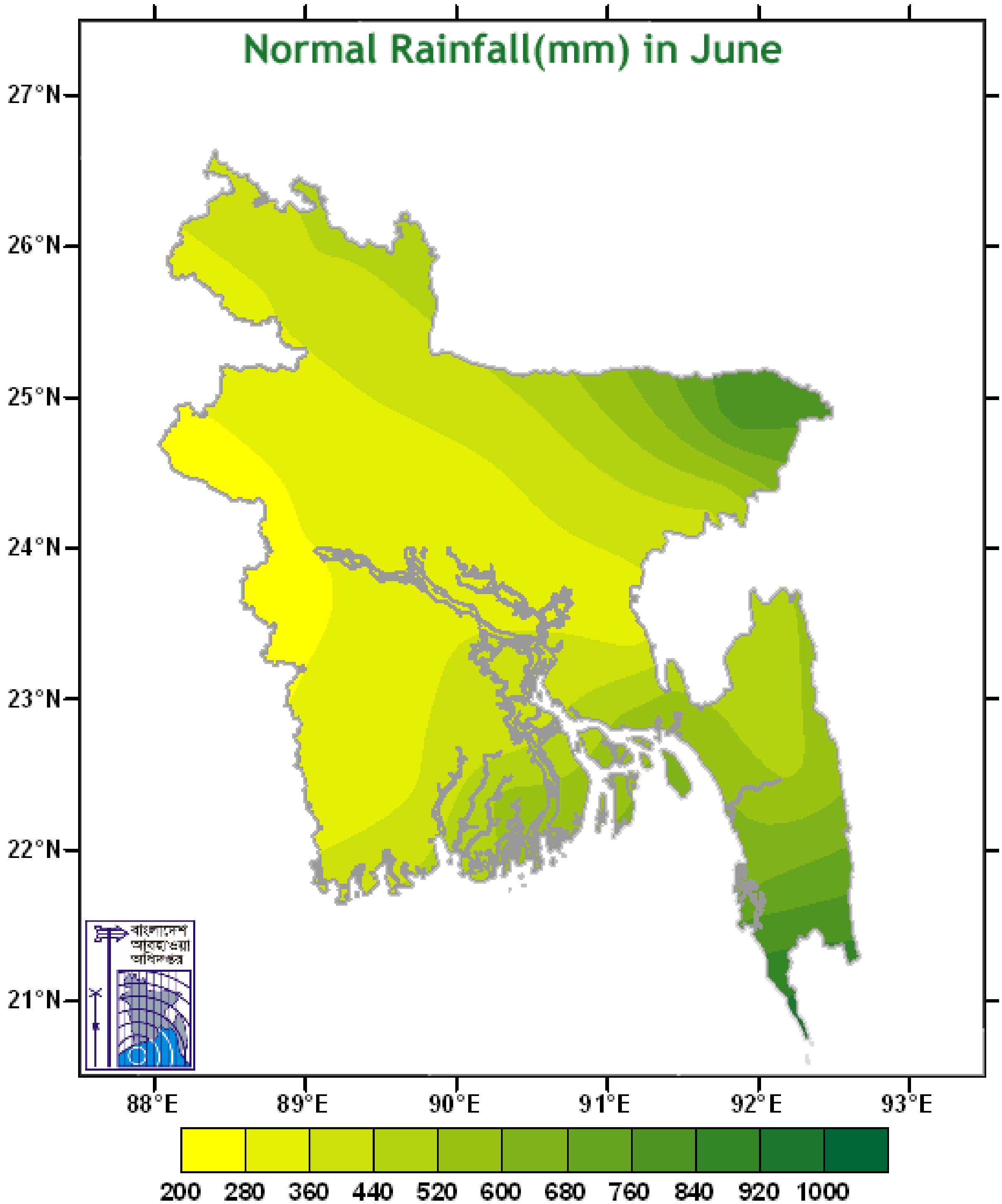

Figure B1: Normal rainfall distribution in June

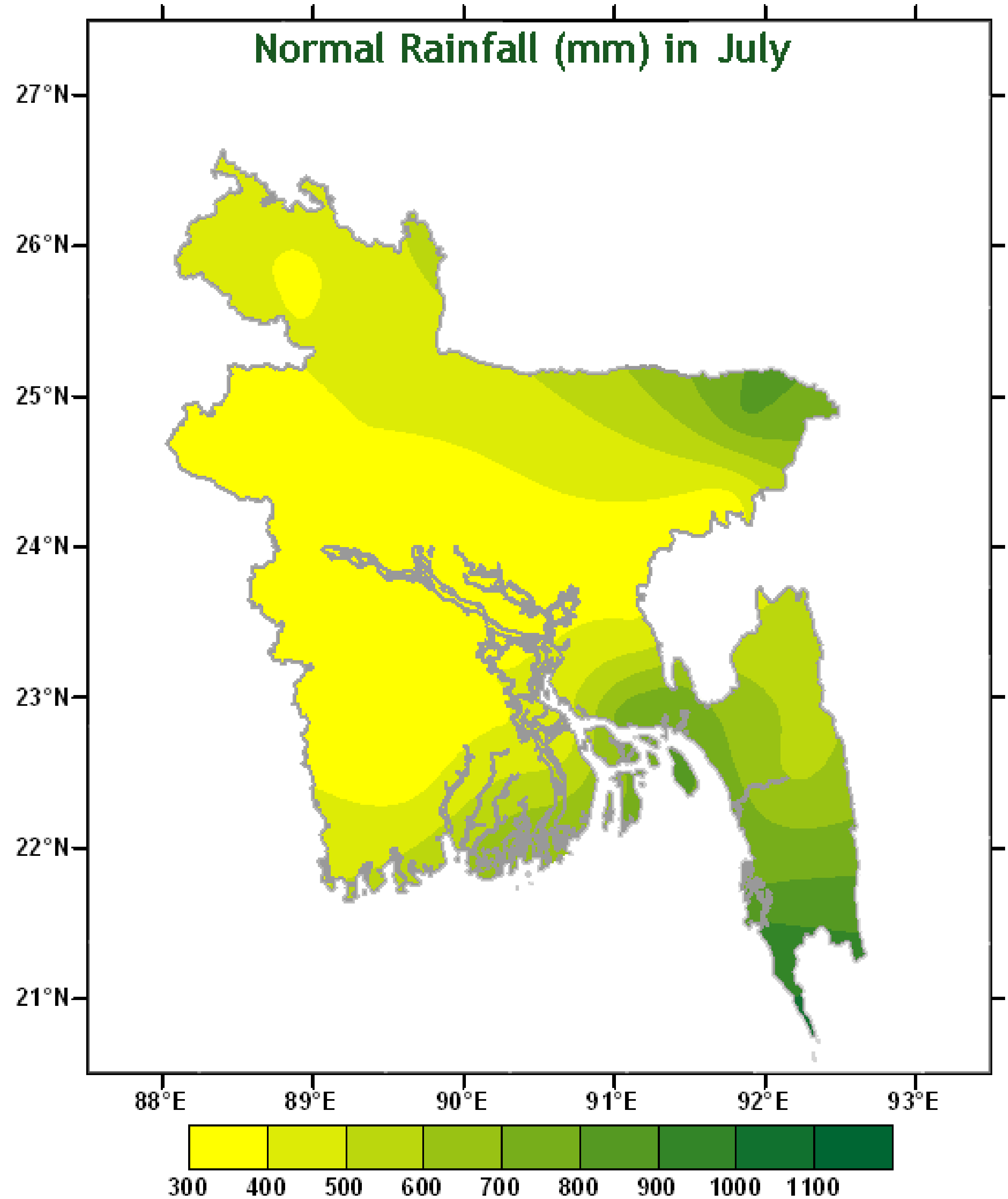

Figure B2: Normal rainfall distribution in July

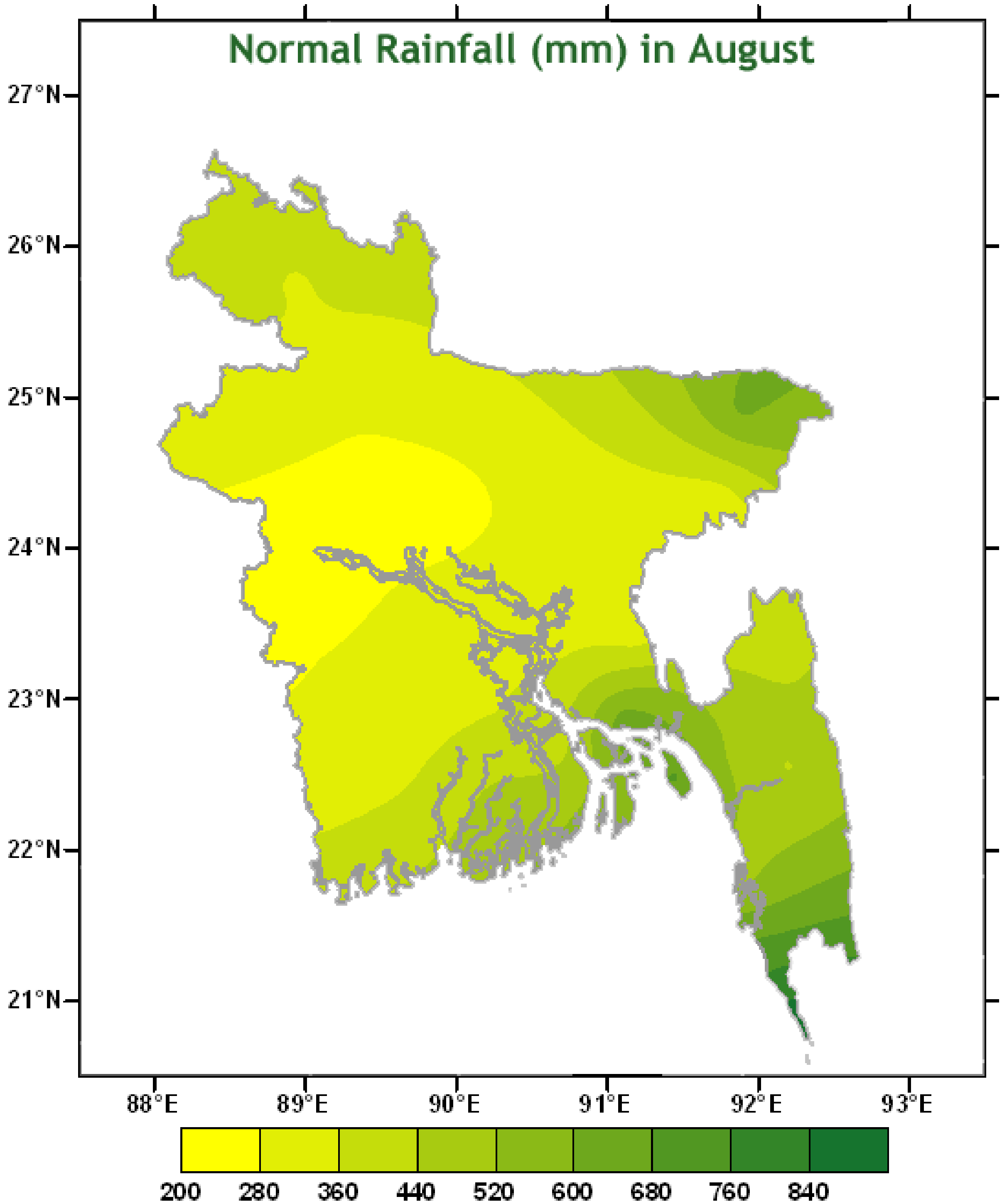

Figure B3: Normal rainfall distribution in August

Appendix-C

Safe and harmful position of ground water at different depth for irrigation

District	Upazila	30 M	45 M	55 M
		Situation	Situation	Situation
Bagerhat	Bagerhat sadar	Safe	Harmful	
Bagerhat	Chitalmari	Harmful	Harmful	
Bagerhat	Fakirhat	Safe	Safe	Safe
Bagerhat	Mollahat	Safe	Harmful	
Bagerhat	Morrelganj	Harmful	Harmful	Harmful
Jessore	Kotwali	Safe	Safe	Safe
Jessore	Manirampur	Safe	Safe	Safe
Jessore	Abhaynagar	Harmful	Harmful	Harmful
Jessore	Keshabpur	Harmful	Harmful	Harmful
Jhenaidah	Jhenaidaha sadar	Harmful	Harmful	Safe
Jhenaidah	Shailkupa	Harmful	Harmful	Harmful
Jhenaidah	Kaliganj	Harmful	Harmful	Harmful
Khulna	Khulna sadar	Harmful	Harmful	Harmful
Khulna	Batiaghata	Harmful	Harmful	Harmful
Khulna	Dacope	Harmful	Harmful	Harmful
Khulna	Terokhada	Harmful	Harmful	Harmful
Khulna	Paikgachha	Harmful	Harmful	

District	Upazila	30 M Situation	45 M Situation	55 M Situation
Khulna	Dumuria	Harmful	Harmful	Harmful
Khulna	Rupsa	Harmful	Harmful	Harmful
Khulna	Dighalia	Safe	Safe	Safe
Magura	Magura sadar	Harmful	Safe	
Magura	Shalikha	Safe	Safe	Safe
Magura	Mohammadpur	Harmful	Harmful	Harmful
Magura	Sreepur	Harmful	Harmful	Harmful
Narail	Narail sadar	Harmful	Harmful	Harmful
Narail	Kalia	Harmful	Harmful	Harmful
Narail	Lohagara	Harmful	Harmful	Safe
Satkhira	Satkhira sadar	Safe	Safe	Safe
Satkhira	Assasuni	Harmful	Harmful	Harmful
Satkhira	Debhata	Harmful	Harmful	Harmful
Satkhira	Kalaroa	Harmful	Harmful	Harmful
Satkhira	Kaliganj	Harmful	Harmful	Harmful
Satkhira	Tala	Harmful	Harmful	Safe
Barguna	Barguna sadar	Harmful	Harmful	
Barguna	Amtali	Harmful	Harmful	Harmful
Barguna	Bamna	Harmful	Harmful	
Barguna	Patharghata	Harmful	Harmful	Harmful
Barguna	Betagi	Harmful	Harmful	

District	Upazila	30 M Situation	45 M Situation	55 M Situation
Barisal	Barisal sadar (Kotwali)	Harmful	Harmful	
Barisal	Hizla	Harmful	Harmful	
Barisal	Muladi	Safe	Safe	
Barisal	Mehendiganj	Harmful	Safe	
Barisal	Gaurnadi	Harmful	Safe	
Barisal	Wazirpur	Harmful	Harmful	
Barisal	Banari para	Harmful	Safe	
Barisal	Agailjhara	Harmful	Harmful	Harmful
Barisal	Bakerganj	Safe	Harmful	Harmful
Barisal	Babuganj	Harmful	Safe	
Jhalokathi	Jhalokathi sadar	Harmful	Harmful	
Jhalokathi	Nalchity	Harmful	Harmful	
Jhalokathi	Kanthalia	Harmful	Harmful	
Patuakhali	Patuakhali sadar	Harmful	Harmful	
Patuakhali	Dashmina	Harmful	Harmful	
Patuakhali	Bauphal	Harmful	Safe	
Patuakhali	Galachipa	Harmful	Harmful	
Patuakhali	Kala para	Harmful	Safe	
Bhola	Bhola sadar	Harmful	Harmful	Harmful
Bhola	Daulatkhan	Harmful	Harmful	
Bhola	Burhanuddin	Harmful	Harmful	Harmful

District	Upazila	30 M Situation	45 M Situation	55 M Situation
Bhola	Char Fasson	Harmful	Safe	
Bhola	Lalmohan	Harmful	Safe	
Bhola	Tazumuddin	Harmful	Safe	
Bhola	Manpura	Harmful	Harmful	

Appendix-D

Safe and harmful condition of ground water at different depth for drinking water

District	Upazila	30 M Situation	45 M Situation	55 M Situation
Bagerhat	Bagerhat sadar	Safe	Harmful	
Bagerhat	Chitalmari	Harmful	Harmful	
Bagerhat	Fakirhat	Safe	Safe	Safe
Bagerhat	Mollahat	Safe	Safe	
Bagerhat	Morrelganj	Harmful	Harmful	Harmful
Jessore	Kotwali	Safe	Safe	Safe
Jessore	Manirampur	Safe	Safe	Safe
Jessore	Abhaynagar	Safe	Safe	Safe
Jessore	Keshabpur	Safe	Safe	Safe
Jhenaidah	Jhenaidaha sadar	Safe	Safe	Safe
Jhenaidah	Shailkupa	Safe	Safe	Safe
Jhenaidah	Kaliganj	Safe	Harmful	Harmful
Khulna	Khulna sadar	Safe	Safe	Safe
Khulna	Batiaghata	Harmful	Harmful	Harmful
Khulna	Dacope	Harmful	Harmful	Harmful
Khulna	Terokhada	Safe	Harmful	Harmful
Khulna	Paikgachha	Harmful	Harmful	
Khulna	Dumuria	Harmful	Harmful	Harmful

District	Upazila	30 M Situation	45 M Situation	55 M Situation
Khulna	Rupsa	Harmful	Harmful	Harmful
Khulna	Dighalia	Safe	Safe	Safe
Magura	Magura sadar	Safe		
Magura	Shalikha	Safe	Safe	Safe
Magura	Mohammadpur	Safe	Safe	Safe
Magura	Sreepur	Safe	Safe	Safe
Narail	Narail sadar	Safe	Safe	Safe
Narail	Kalia	Safe	Safe	Safe
Narail	Lohagara	Safe	Safe	Safe
Satkhira	Satkhira sadar	Safe	Safe	Safe
Satkhira	Assasuni	Harmful	Harmful	Harmful
Satkhira	Debhata	Harmful	Harmful	Harmful
Satkhira	Kalaroa	Safe	Safe	Safe
Satkhira	Kaliganj	Harmful	Harmful	Harmful
Satkhira	Tala	Safe	Safe	Safe
Barguna	Barguna sadar	Harmful	Harmful	
Barguna	Amtali	Harmful	Harmful	Harmful
Barguna	Bamna	Harmful	Harmful	
Barguna	Patharghata	Harmful	Harmful	Harmful
Barguna	Betagi	Harmful	Harmful	
Barisal	Barisal sadar (Kotwali)	Safe	Safe	

District	Upazila	30 M Situation	45 M Situation	55 M Situation
Barisal	Hizla	Harmful	Harmful	
Barisal	Muladi	Safe		
Barisal	Mehendiganj	Harmful		
Barisal	Gaurnadi	Safe		
Barisal	Wazirpur	Harmful	Harmful	
Barisal	Banari para	Harmful		
Barisal	Agailjhara	Safe	Safe	Harmful
Barisal	Bakerganj	Safe	Safe	Safe
Barisal	Babuganj	Harmful		
Jhalokathi	Jhalokathi sadar	Harmful	Harmful	
Jhalokathi	Nalchity	Harmful	Harmful	
Jhalokathi	Kanthalia	Harmful	Harmful	
Patuakhali	Patuakhali sadar	Harmful	Harmful	
Patuakhali	Dashmina	Harmful	Harmful	
Patuakhali	Bauphal	Harmful	Safe	
Patuakhali	Galachipa	Safe	Safe	
Patuakhali	Kala para	Harmful		
Bhola	Bhola sadar	Harmful	Harmful	Harmful
Bhola	Daulatkhan	Harmful	Harmful	
Bhola	Burhanuddin	Harmful	Harmful	Harmful
Bhola	Char Fasson	Harmful		

District	Upazila	30 M	45 M	55 M
		Situation	Situation	Situation
Bhola	Lalmohan	Harmful		
Bhola	Tazumuddin	Harmful		
Bhola	Manpura	Harmful	Harmful	