Australian Government

Australian Centre for International Agricultural Research

Final report

project	**Scoping study to assess constraints and opportunities for future research into intensification of cropping systems in southern Bangladesh**
project number	LWR/2011/066
date published	January 2014
prepared by	Mohammed Mainuddin (CSIRO)
co-authors/ contributors/ collaborators	Howard M Rawson (consultant) Perry L Poulton, Riasat Ali, Christian Roth (CSIRO) K M Nabiul Islam, M Saifuzzaman (consultant) M Mizanur Rahman, M Enamul Quader, S M Shah-Newaz, (IWM) Motaleb Hossain Sarker, M Shahidul Islam (CEGIS)
approved by	Dr Evan Christen, Research Program Manager for Land and Water Resources, ACIAR
final report number	FR2014-02
ISBN	978 1 925133 01 1
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

This publication is published by ACIAR ABN 34 864 955 427. Care is taken to ensure the accuracy of the information contained in this publication. However ACIAR cannot accept responsibility for the accuracy or completeness of the information or opinions contained in the publication. You should make your own enquiries before making decisions concerning your interests.

Contents

List of Figures

List of Tables

1 Acknowledgments

The information provided in this study draws on data collected from various Government organizations of Bangladesh and on many discussions held with stakeholder and research collaborators. The authors wish to express their thanks to all for the generous sharing of their data and time.

This study used a great deal of the data, along with tools that were developed, from the Bangladesh Integrated Water Resources Assessment (BIWRA) Project funded by AusAID - CSIRO Alliance. Without these it would not have been possible to conduct this study at this depth with very limited time and budget constraints. So we are indebted to the BIWRA project, particularly to the Project Leader Mac Kirby, and Geoff Hodgson.

The field trials of wheat at four disparate sites across the country could not have been achieved without significant initial input from Bangladesh Agricultural Research Institute (BARI) to select, prepare and plant the plots for us in December prior to the official start of the ACIAR project. They also made continuing contributions by providing office and laboratory space and occasional travel for Dr Saifuzzaman, who ran all the trials and data collection, and occasional manpower both in Joydebpur and at each experimental site. Thanks for this generous unsupported personal commitment go particularly to Dr Naresh Chandra Deb Barma, Officer-in-Charge, and Principal Scientific Officer, Regional Wheat Research Centre, Gazipur, but also to the active network of BARI scientists in the coastal region built up during previous ACIAR projects.

This scoping study has its root in the full proposal submitted to ACIAR for funding, the idea of which was initially floated by the Late Dr Mirko Stauffacher (ACIAR Program Manager of Land and Water Resources) at the final review workshops of ACIAR projects in Bangladesh in 2009. The authors gratefully acknowledge the contribution of the Late Dr Mirko Stauffacher.

Discussions held with the ACIAR research program managers – Dr Andrew Noble, Dr Evan Christen, Dr John Dixon and Dr Gamini Keerthisinghe – that led to constructive feedback is also gratefully acknowledged.

Finally, special thanks to Dr Peter Carberry, Deputy Director and Theme Leader of the Sustainable Agriculture Flagship of CSIRO for his continuous help, interest and encouragement throughout the course of this study.

2 Executive summary

This report is the main output of a small project to identify gaps in current understanding and opportunities for future research investment by ACIAR to underpin sustainable intensification of cropping systems in the southern coastal zone of Bangladesh. It presents a synthesis of data on surface water, groundwater, irrigation, salinity, land use, and cropping systems, synthesizing both past and present activities and some new measurements made in a field study during the Rabi season of 2012 of previously unavailable dynamic crop-salinity data.

The coastal zone (CZ) occupies 31% (46,271 km^2) of Bangladesh, is home to about 40 million people of whom 65% live below the poverty line compared with 40% for the whole country. The zone is largely rural with 35% of the labour force depending on agriculture for their livelihood and producing 28% of its GDP. The government has declared the CZ as the zone most in need of poverty alleviation and improved food security. One approach is to increase cropping intensity, defined as the number of crops grown in a year multiplied by 100, from the current well below par 174% to something approaching 200%. This is challenging, much of the CZ land is saline to various degrees and salinity is spreading and intensifying. Moreover, in the dry season, agriculture of the coastal zone is primarily constrained by shortage of water to irrigate crops. Consequently, crop yields are well below attainable and large areas of land remain uncropped. Many agricultural workers are unemployed during the dry season.

The CZ has an extensive network of rivers, streams and natural and man-made canals. There are 123 embanked polders protecting 12,805-km^2 of land. During the monsoon (Jul-Oct), vast quantities of fresh surface water drain through the zone from upstream parts of Bangladesh and from neighbouring countries. Total annual runoff is 1200 to 1500 billion m^3. But the flow in the dry season (Nov-Mar) is very low. Since most of the land is less than 5 m above sea level, low outward flows allow seawater to enter the channels and streams resulting in unavailability of fresh surface water for irrigation. The saline water front is gradually moving inland due to increasing use of water upstream. Salinity in the soil is also increasing. About 1.02 million ha (about 70%) of the cultivated lands in the coastal zone are affected to varying degrees by soil salinity. Despite this, there is a general perception that surface water is not being used to its full potential. So a thorough understanding of the surface water resources is necessary.

There are 3 groundwater aquifers: shallow aquifer, lower shallow aquifer and deep aquifer within 50 m, 100 m and 300-400 m of the ground surface respectively. Shallow aquifers are affected by various degree of salinity at various places. There is no information on salinity for the deeper aquifer. The water table is very shallow, often less than 2 m deep. It underlies much of the underutilised agricultural land and drops only marginally during Rabi, recharging again during the monsoon. There is little sign of the groundwater table declining except in a few wells, and the water table is generally either steady or slightly increasing. In the coastal zone only 41% of the net cultivable area (NCA) is irrigated against about 63% at the country level, while in 10 out of 19 coastal districts NCA irrigation is less than 20%. There may be potential to use more groundwater in some areas, however, due to risk of salinity intrusion and other consequences to the aquifer system, groundwater development has been limited. So far, there are no studies on sustainable groundwater use in the CZ.

The current cropping system is dominated by Aman rice in the wet season and Boro rice, shrimp farming, and other Rabi crops in the dry season. The extent of dry season cropping is very limited mainly due to lack of irrigation water and soil salinity. Current analysis shows that there are over 700,000 ha of under-utilized medium highland that can potentially be brought under cultivation during the Rabi season. To understand the impact of soil salinity on yield, and to indentify wheat varieties with greater salinity tolerance, a field trial was conducted at 4 saline locations across the CZ. The results show that yield of wheat is correlated best with salinity averaged over the whole 90 cm soil depth and best with salinity measured in the first month after planting. Salt is the main driver of yield and alone accounted for 76% of yield variation at sites.

As described above, salinity and associated scarcity of irrigation water are the prime cause of current low cropping intensity in the CZ but farmer conservatism, narrow perceptions, limited knowledge of cropping and management options, and low initiative for change are also to blame. Despite all these constraints, the zone has much potential and opportunities to broaden farmers' cropping options without increasing their risks:

1. Currently most of the large quantity of surface water available during the monsoon is wasted through drainage. There is an opportunity to harvest and store useful volumes in the canals, ponds, and small streams in the CZ for irrigation uses in the dry season. This will require an assessment of the surface water resources and its interaction with groundwater and salinity.
2. There may be opportunities for sustainable use of groundwater in conjunction with stored surface water for strategic irrigation, possibly opening up some of the currently fallow areas for cropping in Rabi. The extent of these options will become clear only after further research.
3. Careful planning of the crop calendar may enable better use of untapped residual soil moisture at the end of monsoon season; make more fresh surface water available for irrigation from the streams and channels as salinity rises gradually and reaches maximum towards the end of the Rabi season. Successful use of these 'windows of opportunity' will hinge on knowledge of prospective crops, knowledge of the salinity dynamics of the location, matching crops to locations, and passing that knowledge to local farmers.
4. Breeding and field screening of salt tolerant species and genotypes rapidly and reliably, actually in the CZ. Material from this program feeds into that under (3). Farmers are eager to try purported 'salt-tolerant' materials.

By harnessing and exploiting these opportunities in a systematic, integrated way, the coastal zone can not only prevent further degradation of the resources but also can make a substantial contribution to economic growth, poverty reduction and improve livelihoods. However, the past and present activities in the coastal zone are far from systematic and integrated. So general research questions for sustainable intensification of the cropping systems are:

1. Where and how much surface water is available that can be sustainably used for irrigation? How can we maximize the collection and use of surface water?
2. Is there fresh groundwater available that can be used for irrigation? Is the extraction of groundwater in the area where it is used sustainable? How extraction affecting salinity and what are the long-term consequences?
3. How do surface water and groundwater interact? If there is an interaction, does it impact on salinity of the soil and groundwater in a negative or positive way?
4. Do different crops have different impacts on soil salinity in the coastal zone? What are the mechanisms? What are the most efficient agronomic and water management practices in terms of minimising salinity and maximising yield and do they differ between crops?
5. Can more rapid and reliable methodologies be developed for screening and benchmarking a wide range of species and genotypes for relative salinity tolerance in the field?

Accordingly, the following topics are recommended for further study. They are listed by scale.

Recommendation 1: *Develop regional (for the whole south-western coastal) scale understanding of the surface water and groundwater resources, recharge/discharge mechanisms and trends using hydrological and hydrogeological data, information and regional scale models.*

Regional scale (for the whole south-western coastal) understanding of surface water and groundwater systems is critical for assessing their significance and availability, and to find out how recharge and discharge processes are affected by rain and cyclone events, how they behave and interact during extraction, how their quality is impacted by rainfall, storm surge and tidal flooding, and what are the historical trends in resource availability, use and resource condition. This understanding will help in better planning, use and management of the resources at a sustainable level.

Recommendation 2: *Understand in detail the salt and water dynamics at the polder/sub-regional (cluster of polders) scale.*

This will help identify and evaluate best groundwater abstraction regimes in various areas or polders that will avoid deterioration of groundwater quality by encouraging diffuse rainfall recharge and discouraging leakage from saline surface water bodies.

Recommendation 3: *Develop suitable livelihood enhancing options through a participatory approach using field evaluation and modelling of interactions between crop types, soil types, irrigation methods, soil root zone salinity and groundwater salinity.*

This requires the evaluation of all components of a production system and should be integrated with the trials described in Recommendation 4, though with an additional layer of agronomic and water management treatments. This will help us to evaluate the whole cropping system and understand the salt and water dynamics imposed by cropping.

Recommendation 4: *Adaptive trials for screening of salt tolerant species and genotypes for the coastal zone.*

The adaptive trials should be done at multiple (up to 8) agro-ecological sites within the coastal zone chosen for different levels of salinity, different soil and water table variables, and sources of irrigation water with varying quality, and comparing genotypes of several species that might include species with different water use efficiencies.

In essence, the aim and objective of the follow-on project will be to increase cropping intensity in the coastal zone of Bangladesh through better understanding of crop, water and salinity processes and promotion of sustainable management practices.

A socioeconomic study presented here concluded that raising cropping intensity in the CZ to 200% within a decade would generate net economic benefits worth AU$260 million, which is equivalent to 0.3 percent of (2010-11) national GDP and 2.1 percent of (2010-11) coastal GDP. Employment benefits worth 273 million person-days would be generated over a decade. Obviously, this is likely to contribute to reducing the severity of poverty, if not its incidence, in terms of increased income and improved quality of life.

3 Background

Agriculture plays a pivotal role in Bangladesh's economy and in the lives of the vast majority of its population. Rural households in Bangladesh are highly dependent on agriculture for their livelihoods (Sultana, 2011). About 76 percent (BBS, 2010a) of the total population live in rural areas and are directly or indirectly engaged in a wide range of agricultural activities. Agriculture (crops, forests, fisheries and livestock) accounts for 21 percent (2008-09, BBS, 2010a) of the national GDP and directly supports the non-farm sector at 33 percent (World Bank, 2011). Urbanization continues to encroach on agricultural land at a rate of 1 percent per year (Quasem, 2011; World Bank, 2011) and drives a decline in land availability per capita (Barkat et al., 2007). A field study covering 24 villages during 2001-08 (Quasem, 2011) estimated the conversion of farmland to non-agricultural use at 0.56 percent per year resulting in a loss of 0.86 to 1.16 percent in rice production. Productive agricultural land is acknowledged as a critical future resource with arable land decreasing from 9.18 million ha in 1993 to 8.37 million ha in 1997 (Barkat et al., 2007) and reported at ~7.56 million ha in 2009. Thus, providing food security has been a crucial socioeconomic and political priority of the government of Bangladesh (Faisal and Parveen, 2004).

The current (2010) population of Bangladesh is 150 million and is projected to increase to 194 million by 2050 (UN Population Division, 2010). To feed this extra population, Bangladesh must increase food production substantially and this will require sustainable intensification of production from a land base that is in rapid decline, as mentioned above, due to urbanization and industrial development in the central part of the country (The Daily Star, 2012). There is a growing concern that, in the future, availability of food from the northern area known as the 'food basket' of the country will also be limited. The region that offers the potential for agricultural intensification is the southern coastal region of Bangladesh (Figure 3.1). Intensifying crop production to improve livelihoods and increase national food security in what is traditionally considered the rice-fallow areas of the coastal region of Bangladesh is a high priority for the Government of Bangladesh, (MoEF, 2008). This will not be easy, the area is exposed to regular, devastating cyclones and is subject to the related challenges of salinization through inundation and a lack of freshwater for irrigation and flushing during the dry season.

3.1 Aim and scope of the study

The aim of this scoping study is to identify the opportunities and constraints to the sustainable intensification of cropping systems in the coastal regions of Southern Bangladesh. The study is more focused on the physical constraints to intensification with some attention to the socio-economic constraints. There may have institutional constraints as well but they are not discussed in this study. A primary focus is to discern how smallholder farmers can intensify their cropping systems and how such outcomes can be supported. However, for farm level interventions to be sustainable against the backdrop of increasing salinity and limited water resources, these need to be scoped in the context of polder scale water and salinity management. The key outcome is targeted R and D Investment to achieve sustainable intensification of cropping in the southern coastal region of Bangladesh that capitalises on earlier work and builds on the momentum achieved in LWR/2005/146. This study will address the following key questions:

- What are the bio-physical and socio-economic constraints to farming system intensification and what are the potential solutions? What would facilitate greater farmer uptake of new and emergent cropping practices and technology that benefit rural livelihoods?

- Where in this coastal region are the fallow areas? Have the areas identified in previous studies with potentially fallow land increased their level of adoption of dry season (Rabi) crops? Where is there opportunity to intensify the existing production systems?
- How much water is available during the dry season? What are the implications of future climate change on water availability? What are the temporal dynamics of supply and how will they change in the future?
- What are the spatial and temporal trends in soil and groundwater salinity? How much production is lost due to soil and groundwater salinity? What will be the consequences of limited groundwater irrigation on aquifer salinity and sustainability and soil salinity and structure?
- How will these indicators of sustainability be affected by intensification of existing cropping and fallow regions?

Figure 3.1 Map of Bangladesh indicating the southern coastal region with salinity belt of interest from Khulna in the west to Noakhali in the east

3.2 Context and data sources

This is a direct follow-on project from ACIAR LWR/2005/146 - *Expanding the area for Rabi-season cropping in southern Bangladesh*, which focused on increasing Rabi season production through the introduction of wheat and mungbean into traditional rice-fallow systems in southern regions of Bangladesh less affected by salinity than the Southwest (i.e. on Barisal, Bhola, Jhalokati, Barguna, Patuakhali and Noakhali). The scoping study will draw upon a preliminary proposal submitted to ACIAR in 2010 (LWR/2010/094 - *Salinity and water management for intensifying cropping in coastal areas of Southern Bangladesh in a climate change environment*), arising from the final review of LWR/2005/146 and submitted as a result of a request from the former Research Program Manager of Land and Water Resources, the late-Dr Mirko Stauffacher. It will also draw upon a concept note submitted by team members of the LWR/2005/146 project - *Expansion of Rabi season cropping into fallow lands of southern Bangladesh*. In addition, the scoping study will explore the links with several others major research initiatives currently underway in Southern Bangladesh funded by ACIAR and other donors.

Key hydrologic and salinity data is sourced through collaboration with the Institute of Water Modelling (IWM) and the Centre for Environmental and Geographic Information Services (CEGIS). The data are jointly analysed and used to determine and document spatial trends in water availability and salinity. Both are CSIRO's partners in the Bangladesh Integrated Water Resources Assessment project funded by AusAID-CSIRO Alliance.

Socio-economic data is compiled drawing on available secondary data, again through linkages with partners in the Alliance project. A local consultant is commissioned to assist with this task.

In order to maintain momentum in the on-farm demonstration work previously carried out by LWR/2005/146, we retained the services of Dr M. Saifuzzaman, formerly the lead Bangladesh partner in LWR/2005/146. He is assisted by Dr Howard Rawson, a consultant who led the agronomic and physiologic research in LWR/2005/146. The intent is to carry out comparative field investigations of some Rabi crops (primarily wheat and dual-purpose triticale) across a salinity gradient in Southern Bangladesh. These trials compare and contrast spatial and temporal changes in salinity and water tables at field sites that represent points across the salinity-affected belt of Figure 3.1. Field sites are in Satkhira (west), Barguna, Patuakhali and Noakhali (east). The trials examine the impacts of the measured salinity and water patterns on crop growth and yield. By comparing a wide range of wheat breeding lines within the four closely described saline environments the studies attempt to develop a reliable field screening methodology for crop salinity tolerance. The intention is to carry that methodology into a forthcoming large ACIAR project for further development and use it to benchmark concurrently a range of species and genotypes for realistic salinity tolerance. Currently this benchmarking in Bangladesh is *ad hoc*.

Key stakeholders and prospective research partners in a follow-on project will be engaged through a series of bilateral consultations.

3.3 Objectives of the study

1. Review and synthesise published and unpublished literature and relevant projects/activities currently underway in the area including
   - Published and unpublished literature and reports.
   - Proceedings available within the local government and non-government organizations.

- Information on active and planned Government and donor agency funded projects and development activities for the region.

2. Assess the current farming systems of the region and identify opportunities for the sustainable introduction and expansion of Rabi season cropping on fallow lands in coastal zones of Southern Bangladesh. This includes:

- Assessment of the extent, spatial and temporal (over last 5-10 years) trend of land remaining fallow during the Rabi season using remote sensing (subject to the availability of the images and budget) and more recent (post 2006) localised statistical data (if available).
- Assessment of the spatial and temporal trends in production systems including variety and types of crops grown.
- Delineation of agro-ecological boundaries and zoning of the region based on soil maps, cropping systems, salinity, climate and other factors.
- Consultations with key stakeholders, research organizations and NGOs on the constraints and opportunities for the regions.
- A field trip to the region and discussions with local communities, farmers, and other stakeholders.
- Identification of potential constraints and opportunities for intensification of current crop or production related farming systems in the future.
- Identification of pathways to encourage farmer uptake of new and emergent cropping practices and technology.

3. Assess soil and water salinity (both surface water and groundwater) and water availability in the project area using:

- Analysis of spatial and temporal trends in soil, surface water and groundwater salinity based on available historical data. Estimation of areas of lost production due to soil and groundwater salinity.
- Assessment of groundwater condition (such as seasonal and long-term variation, temporal and spatial trend, aquifer conditions) using historical water level data.
- Assessment of water availability and sustainability condition using simple water balance approach at the farm and polder level.
- Identification of constraints and opportunities for Rabi season cropping from improved utilisation and management of available water resources.
- Comparing and contrasting spatial and temporal soil EC and water table depth at four points along the salinity affected belt of Figure 1, namely at Satkhira (west), Barguna, Patuakhali and Noakhali (east) throughout Rabi 2011-12.
- Relate the spatial and temporal patterns and absolute levels of salinity at these trial sites with yield of wheat and triticale crops in the trials.
- Using the trials, commence development of a reliable field methodology for screening species/genotypes for salinity tolerance and for benchmarking them.

4. Analyse the current socio-economic and livelihood conditions in the region of study. This includes:

- Assessment of current socio-economic conditions of the population and its dependencies on agriculture.
- Assessment of expected economic, social, environmental and livelihood benefits of intensification of farming systems.

5. Develop (through close consultation with the ACIAR Land and Water Resources Research Program Manager) a full proposal to ACIAR for a long-term R&D program on '"Intensification of the cropping systems through improved crop, water and salinity management in the coastal regions of Southern Bangladesh " including:
   - Documentation and synthesis of the information obtained in TOR 1, 2, 3, 4 and 5 in a final report to ACIAR in a format suitable for publication.
   - Preparation of a full ACIAR proposal

4 A brief description of the coastal zone

4.1 Location

The coastal zone of Bangladesh is located between 20°34' and 23°30' North latitude and between 88°50' and 92°29' East longitude (Figure 4.1). The zone forms the lowest landmass and is part of the delta of the extended ‘Himalayan Drainage Ecosystem’ (Islam et al. 2006). Rainfall associated with monsoon climate and snowmelt in the Himalayan ranges constitutes the main sources of water, flowing down through a myriad of rivers that also transport huge amounts of sediments. The landward distance of the delineated coastal zone from the shore is between 30 and 195 km whereas the exposed coast is between 37 and 57 km.

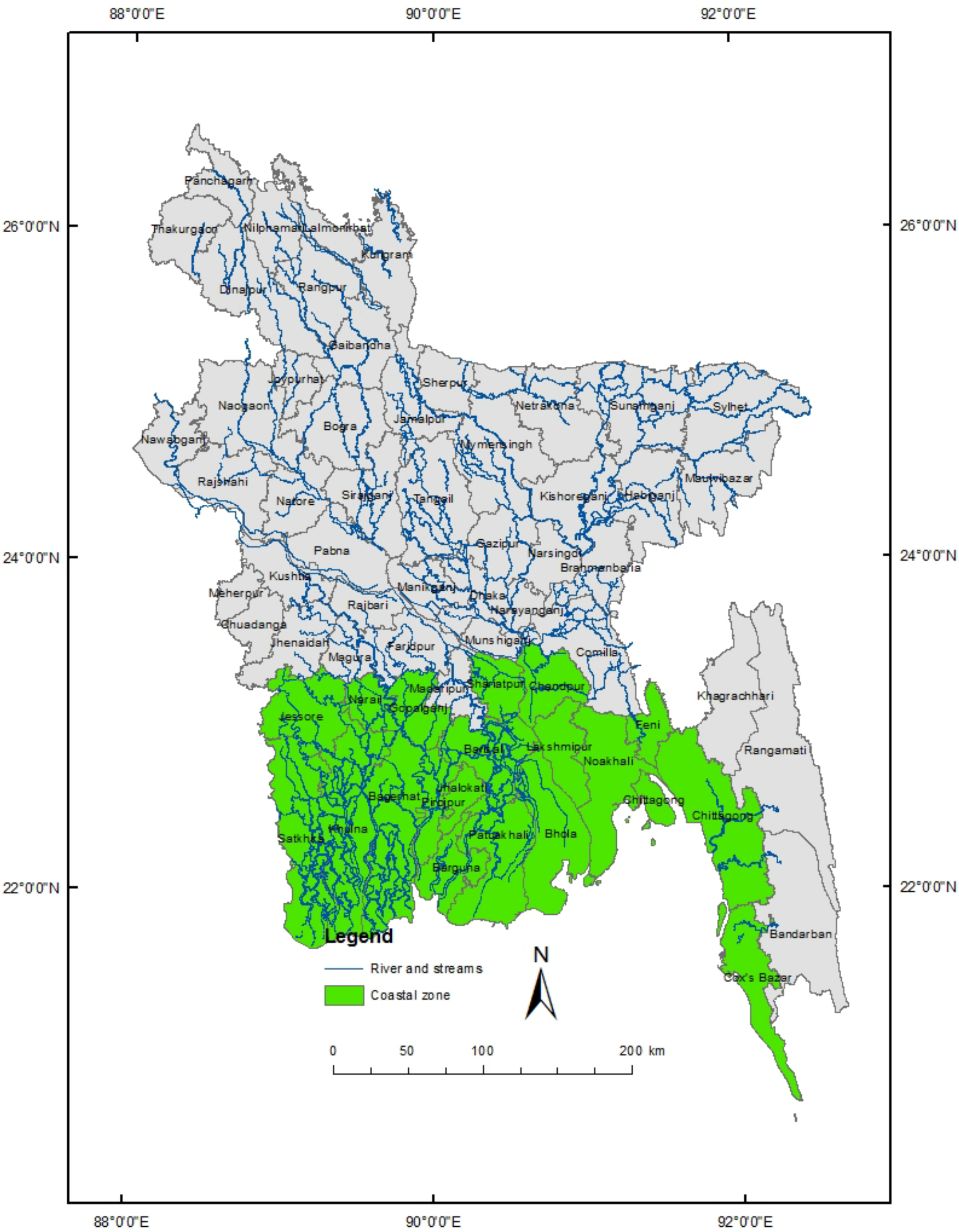


Figure 4.1 Location of the coastal zone

4.2 Physical characteristics

The coastal zone covers 19 districts facing or having proximity to the Bay of Bengal encompassing 153 upazilas (sub-district). These districts are listed in Table 4.1 and shown on the map of Figure 4.2. The total area is 46,271 km^2 and the population as of 2010 is 39.4 million. Together they account for 32 percent of the area and 28% of the population of Bangladesh (Table 4.1). Fifty one upazilas (sub-districts) of 12 districts are exposed to the coast and the remaining 102 upazilas are in the interior (Islam et al. 2006). The coastal zone is low-lying with 62% of the land have an elevation less than 3 metres and 86% less than 5 metres (IWM & CEGIS, 2007). The following features characterize the coastal morphology of Bangladesh (ESCAP, 1987).

- A vast network of rivers and channels (Figure 4.1).
- An enormous discharge of river water, heavily laden with sediments, mainly suspended.
- A large number of islands within the rivers and channels and seaward of the coast line.
- The “Swatch of No Ground” a submarine canyon running NE-SW about 24 km south of the Bangladesh coast, particularly across the continent shelf.
- A shallow northern Bay of Bengal funneling to the coast area of Bangladesh in the north.
- Strong tidal and wind actions
- Tropical cyclones and their associated storm surges.

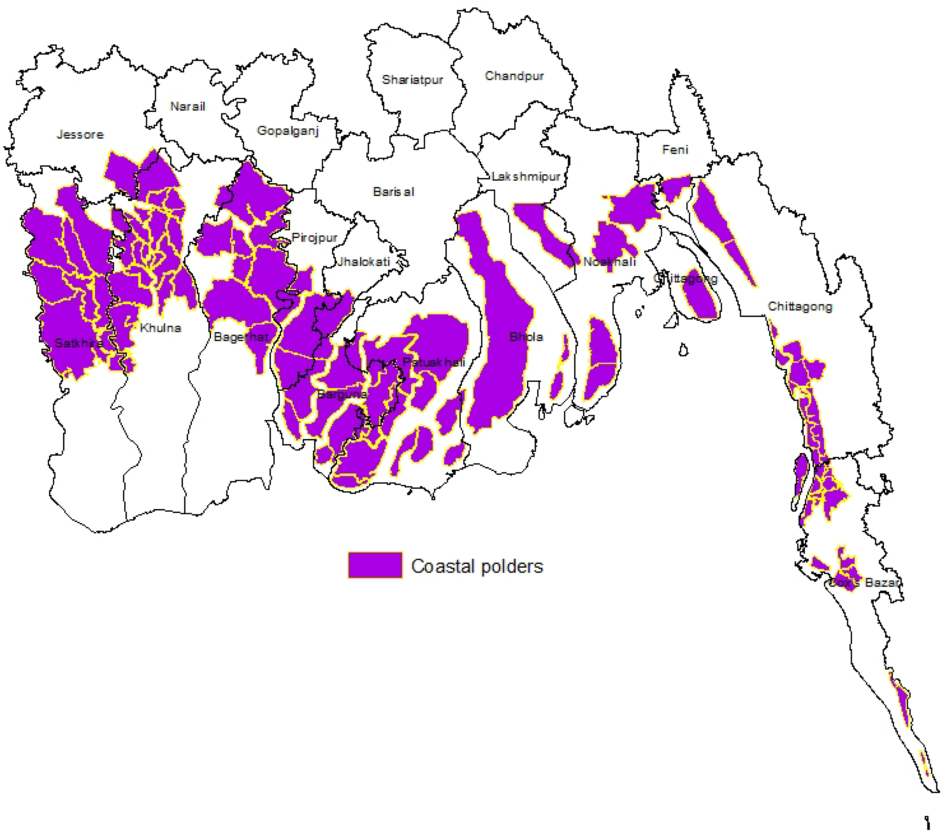


Figure 4.2 Polders in the coastal zone

Table 4.1 Area, population, and population density of districts in the coastal zone of Bangladesh

District	Area km^2	Population (000)	Population density, person/km^2
Bagerhat	3,959	1,527	386
Barguna	1,831	922	504
Barisal	2,785	2,394	860
Bhola	3,403	1,837	540
Chandpur	1,704	2,501	1,468
Chittagong	5,283	7,616	1,442
Cox's Bazar	1,492	2,290	1,535
Feni	928	1,484	1,599
Gopalganj	1,490	1,201	806
Jessore	2,567	2,866	1,116
Jhalokati	749	623	832
Khulna	4,394	2,397	546
Lakshmipur	1,456	1,788	1,228
Narail	990	747	755
Noakhali	3,601	3,211	892
Patuakhali	3,221	1,585	492
Pirojpur	1,308	1,153	881
Satkhira	3,858	2,062	534
Shariatpur	1,182	1,198	1,014
Total	**46,271**	**39,402**	**852**

There are 123 embanked polders (Figure 4.2). They were constructed in late 1960s to protect the land from tidal and monsoon flooding, saline water and to increase crop production. Together they protect about 12,805 km^2 of land in the coastal region (IWM & CEGIS 2007). Size of the polders varies from 604 ha to 227,000 ha; most of them are less than 15,000 ha. The Lower Meghna River conveys the combined flows of the Jamuna, the Ganges and the Upper Meghna to the Lower Meghna estuary. That estuary has many small and some large islands like Bhola, Sandwip, Hatia, and Manpura. Most of the large islands are protected from erosion by coastal embankments. Unprotected landmasses are the mud flats that are flooded during high tides (IWM & CEGIS, 2007).

The coastal zone has several ecosystems that have important conservation value: mangrove, marine, estuary, islands, coral and sandy beaches that provide habitat for an abundance of plant species as well as an array of fish and wildlife. The world's largest uninterrupted stretch of mangrove ecosystem, the Sundarbans, is situated in the southwestern part having an area of 577,100 ha (5,771 km^2). Land elevation there ranges from 1 m to 2 m and is flooded during high tides. The Sundarbans was declared a Ramsar Site in 1997, a World Heritage that should be conserved.

The coastal zone is prone to devastating cyclones and storm surge. They occur mainly in the pre-monsoon (April-May) and post-monsoon (October-November) period when the weather systems become unstable and develop into tropical cyclones. Records since 1877 show that at least 70 major cyclones have hit the coastal belt (Islam and Peterson, 2009). A cyclone in 1970 resulted in at least 300,000 deaths and another in 1991 led to the loss of 138,000 lives (IWM & CEGIS, 2007). Recent major cyclones were 'Sidr' and 'Aila' which struck the coast on 15 November 2007 and 25 May 2009, respectively. Both caused widespread damage and destruction to infrastructure, caused numerous deaths, disrupted economic activities, and affected social conditions, especially in the poorer areas of the south.

Bangladesh is recognised as one of the most climate-vulnerable countries in the world while its coastal zone is most vulnerable to climate change. The IPCC forecasts that global warming will result in sea level rises of between 0.18 and 0.79 metres, which would increase coastal flooding and saline intrusion into aquifers and rivers across a wide belt in the south of the country, although most of the area is protected by polders (MoEF, 2008). The Sundarbans are likely to disappear within 50 years. Coastal Bangladesh is also at great risk from tsunami because of its very low elevation and exposure to various water related hazards (IWM & CEGIS, 2007).

4.3 Climate

Bangladesh has a sub-tropical monsoonal climate. There are three main seasons in the year, namely winter (December – February), summer (March – May) and monsoon or rainy season (June – September). The variation in general climate among the different regions of the country is low. The coastal zone is generally considered hotter than the north with, for example, Patuakhali (Table 4.1) averaging 2.45 °C hotter than Dinajpur in the north during Rabi (Poulton and Rawson, 2011).

Bangladesh Meteorological Department (BMD) has about 16 stations located in the 12 districts in the coastal region. In addition, there is a vast network of rainfall monitoring stations maintained by the Bangladesh Water Development Board (BWDB). These are mapped in Dalgliesh and Poulton (2011, Fig. 14).

Figure 4.3 compares the annual rainfall of the coastal zone (all 19 districts) with the remaining parts of the country for the period 1985-2010. Rainfall data used here are the daily rainfall data for the BMD stations (for 12 districts) and BWDB data for the remaining 7 districts). In general, total annual rainfall in the coastal zone is slightly higher than the remaining part of the country.

Table 4.2 shows the monthly average (1985-2010) rainfall (not spatial average; average of the stations located within the district) for all the coastal districts. Rainfall is significantly higher in the southeastern districts (Lakshmipur, Feni, Noakhali, Chittagong, and Cox's Bazar) compared to the rainfall in the southwestern districts. The table highlights the relative dryness of the Rabi season, particularly in December and January. In some years there is no rain in these months.

Tables 4.3 to 4.5 show monthly average maximum and minimum temperatures and sunshine hours respectively for the coastal districts where there are BMD climate stations. Variation of these climate parameters within the districts is not significant.

Crimp and Laing (2011) analyzed rainfall and temperature data recorded at 13 meteorological stations (9 of these stations are in the coastal zone) over the time period 1948–2009 to assess recent changes in the climate of Bangladesh. The results show increasing mean, mean maximum and mean minimum temperatures at a rate of 0.103, 0.091 and 0.097°C per decade, respectively, with greater warming observed in winter compared to other seasons. Increases in annual and pre-monsoon rainfall were also observed at a rate of 5.5 and 2.5 mm yr^{-1}, respectively. The spatial pattern shows that monsoonal rains have increased in the north and west but declined in the east.

We have estimated daily reference crop evapotranspiration (ET_o) using daily climatic data for all the stations using the FAO Penman-Monteith method (Allan et al. 1998). Table 4.6 shows the monthly average ET_o of the 12 stations within the coastal region. Figure 4.4 compares the annual ET_o of the coastal region with the remaining part of the country. Estimated ET_o in the coastal zone is general lower than that of the northern region except during 1985-90 and 2005-2010. A lower ET_o can be associated with more efficient use of water by crops, so less water used per unit of yield produced. In the absence of other constraints to growth such as salinity, higher rainfall linked with higher water use efficiency could mean higher potential crop production in the coastal regions. In general, monthly rainfall is much higher than monthly ET_o during the monsoon (May to October) and lower between November and April (Figure 4.5).

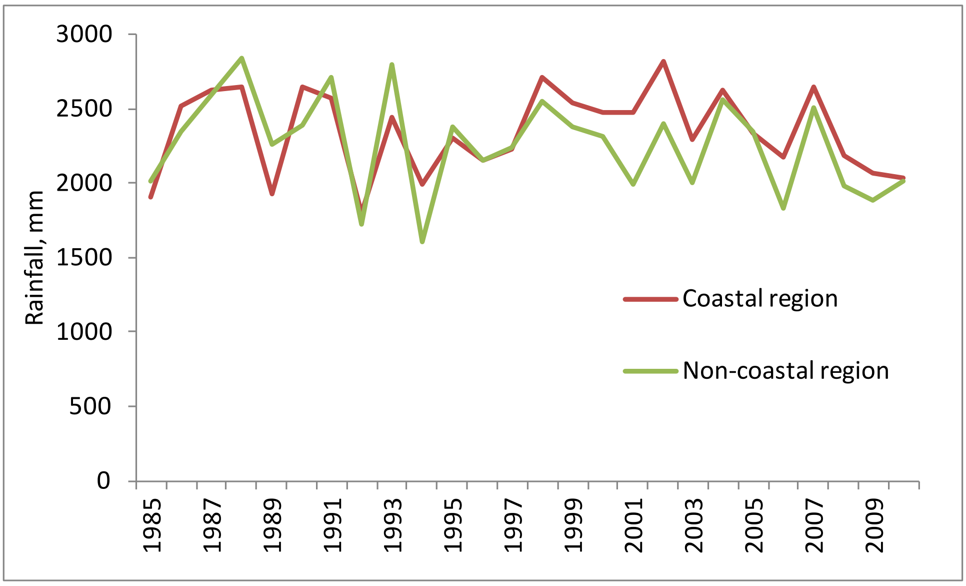


Figure 4.3 Annual rainfall

Table 4.2 Monthly average rainfall mm (1985 to 2010)

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Bagerhat	5	24	48	79	197	331	461	385	284	179	43	8	2044
Barguna	6	15	41	83	244	500	692	449	411	264	47	5	2755
Barisal	10	23	57	89	201	377	428	339	292	206	53	5	2079
Bhola	7	25	51	95	239	431	459	358	310	199	46	6	2226
Chandpur	5	23	66	104	238	314	421	317	287	175	39	5	1993
Chittagong	6	21	69	142	354	561	718	547	403	271	58	8	3158
Cox's Bazar	4	21	35	91	351	855	1010	675	412	248	88	20	3811
Feni	5	26	77	150	351	531	695	524	365	222	52	9	3008
Gopalganj	7	22	39	83	186	316	333	296	277	196	44	4	1804
Jessore	14	19	46	60	180	309	350	267	286	152	35	7	1726
Jhalokati	6	20	45	74	189	389	438	315	290	181	59	5	2013
Khulna	11	34	49	61	179	318	339	291	301	166	42	4	1796
Lakshmipur	3	23	56	81	297	525	576	422	338	177	40	7	2546
Narail	9	21	40	68	179	283	352	275	291	153	48	6	1726
Noakhali	5	20	54	116	282	579	774	552	422	262	63	12	3139
Patuakhali	6	26	43	95	216	497	588	428	380	242	53	3	2579
Pirojpur	11	29	37	79	214	452	441	359	354	196	54	8	2235
Satkhira	12	30	41	75	161	291	348	290	309	153	36	4	1752
Shariatpur	6	23	51	104	235	362	393	319	279	169	37	4	1981

Table 4.3 Monthly average maximum temperature °C (1985 to 2010)

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bagerhat	25.4	28.9	32.8	34.8	34.5	32.9	31.8	31.9	32.0	31.6	29.6	26.6
Barisal	25.5	28.7	32.5	33.7	33.5	32.2	31.2	31.5	31.7	31.7	29.9	26.9
Bhola	25.6	28.6	31.9	33.1	33.0	31.7	30.9	31.3	31.4	31.7	29.9	27.0
Chandpur	24.6	28.1	31.8	33.2	33.3	32.3	31.5	31.9	31.8	31.6	29.5	26.2
Chittagong	26.4	28.9	31.3	32.3	32.6	31.7	31.0	31.5	31.9	32.0	30.4	27.7
Cox's Bazar	27.1	29.3	31.7	32.9	32.9	31.4	30.6	31.0	31.6	32.1	30.7	28.3
Feni	25.7	28.4	31.3	32.4	32.4	31.3	30.7	31.2	31.5	31.5	29.8	27.1
Jessore	25.5	29.1	33.5	36.0	35.5	33.9	32.6	32.8	32.9	32.5	30.4	27.0
Khulna	25.4	29.0	33.1	34.9	34.8	33.3	32.1	32.3	32.5	32.1	30.0	26.8
Noakhali	25.1	28.2	31.6	33.2	33.0	31.7	30.8	31.3	31.5	31.5	29.5	26.3
Patuakhali	25.7	28.9	32.4	33.6	33.5	31.9	31.0	31.4	31.7	31.6	29.6	26.9
Satkhira	25.6	29.1	33.1	35.3	35.3	33.7	32.3	32.4	32.4	32.2	30.2	27.0

Table 4.4 Monthly average minimum temperature °C (1985 to 2010)

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bagerhat	13.9	17.5	22.0	25.0	25.9	26.5	26.3	26.4	26.0	24.5	20.6	15.8
Barisal	11.9	15.5	20.6	23.9	24.9	25.8	25.7	25.8	25.4	23.7	19.0	13.8
Bhola	12.5	16.0	21.0	24.2	25.2	26.1	25.9	26.1	25.7	24.0	19.6	14.5
Chandpur	13.5	16.3	20.9	23.9	24.9	26.0	26.0	26.1	25.9	24.4	20.2	15.6
Chittagong	14.1	16.8	21.0	24.0	25.0	25.6	25.4	25.4	25.3	24.2	20.3	16.0
Cox's Bazar	15.5	17.7	21.4	24.4	25.3	25.5	25.3	25.4	25.2	24.5	21.2	17.1
Feni	12.7	15.9	20.5	23.5	24.5	25.4	25.3	25.3	25.1	23.6	19.2	14.5
Jessore	11.2	14.8	19.6	23.8	25.1	26.0	26.0	26.1	25.5	23.1	17.9	12.7
Khulna	12.2	15.7	20.6	24.3	25.3	26.2	26.2	26.3	25.9	24.1	19.6	14.2
Noakhali	13.9	16.5	20.8	23.8	25.0	25.9	25.8	25.9	25.8	24.6	20.8	16.1
Patuakhali	13.4	16.7	21.2	24.2	25.4	26.2	26.0	26.1	25.8	24.2	20.2	15.2
Satkhira	12.0	16.0	20.8	24.5	25.6	26.4	26.2	26.3	25.7	23.5	18.6	13.5

Table 4.5 Monthly average sunshine hours (1985 to 2010)

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bagerhat	7.3	8.3	8.4	8.8	8.0	4.1	3.5	4.5	4.8	6.1	7.7	7.3
Barisal	7.3	7.9	7.9	8.0	6.8	3.8	3.5	4.2	4.5	6.8	7.5	7.3
Bhola	6.0	6.8	6.7	7.0	5.6	3.3	2.7	3.6	3.6	5.5	6.6	5.9
Chandpur	5.7	6.6	6.7	7.0	5.9	3.6	3.4	3.7	4.0	5.9	6.5	5.8
Chittagong	8.0	8.3	8.3	8.2	6.8	4.4	3.8	4.9	5.9	7.0	7.9	7.7
Cox's Bazar	8.6	8.9	8.6	8.7	7.3	4.4	3.6	4.6	5.7	7.3	8.2	8.7
Feni	7.0	7.6	7.6	7.5	6.5	4.2	4.1	4.9	5.3	6.8	7.7	7.4
Jessore	6.6	7.4	7.5	7.8	7.0	4.6	3.8	4.4	4.5	6.3	6.8	6.4
Khulna	7.4	8.0	8.2	8.6	7.7	4.6	3.8	4.5	4.8	6.9	7.7	7.6
Noakhali	7.2	7.9	7.9	7.8	6.7	3.9	3.6	4.7	5.0	6.8	7.6	7.5
Patuakhali	6.9	7.4	7.6	7.3	6.1	3.1	2.8	3.7	4.0	5.8	6.6	6.9
Satkhira	7.2	8.0	8.3	8.7	7.9	4.6	3.8	4.4	4.9	6.6	7.2	7.2

Table 4.6 Monthly average ETo in mm (1985 to 2010)

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Bagerhat	79	95	139	158	157	121	112	116	105	106	86	75	1348
Barguna	85	100	136	148	144	111	109	111	103	102	87	80	1315
Barisal	76	94	135	148	145	111	106	110	101	103	81	69	1280
Bhola	72	87	120	134	129	103	99	104	94	96	78	67	1182
Chandpur	66	82	118	134	134	109	106	109	98	98	78	65	1197
Chittagong	78	93	128	136	134	111	107	111	105	101	78	71	1253
Cox's Bazar	107	120	152	158	152	115	107	114	116	120	105	99	1465
Feni	76	90	126	136	137	113	111	116	106	103	84	71	1271
Gopalganj	69	85	125	139	137	111	110	111	101	98	78	65	1228
Jessore	82	104	156	180	175	132	120	122	111	108	86	73	1449
Jhalokati	76	94	135	148	145	111	106	110	101	103	81	69	1280
Khulna	79	95	139	158	157	121	112	116	105	106	86	75	1348
Lakshmipur	75	91	127	141	142	110	108	115	106	106	87	73	1282
Narail	82	104	156	180	175	132	120	122	111	108	86	73	1449
Noakhali	85	97	127	138	134	108	106	109	102	101	86	78	1274
Patuakhali	81	94	131	139	137	104	101	106	98	102	85	76	1253
Pirojpur	79	94	133	144	141	107	103	108	100	103	83	73	1267
Satkhira	84	100	144	166	165	123	114	116	106	108	89	78	1390
Shariatpur	69	85	125	139	137	111	110	111	101	98	78	65	1228

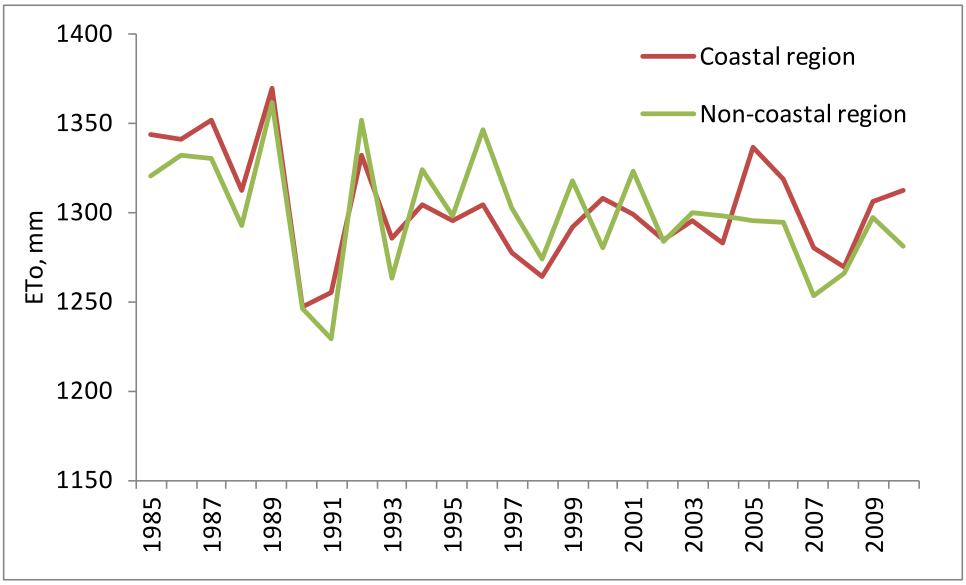


Figure 4.4 Annual reference evapotranspiration (ET_o)

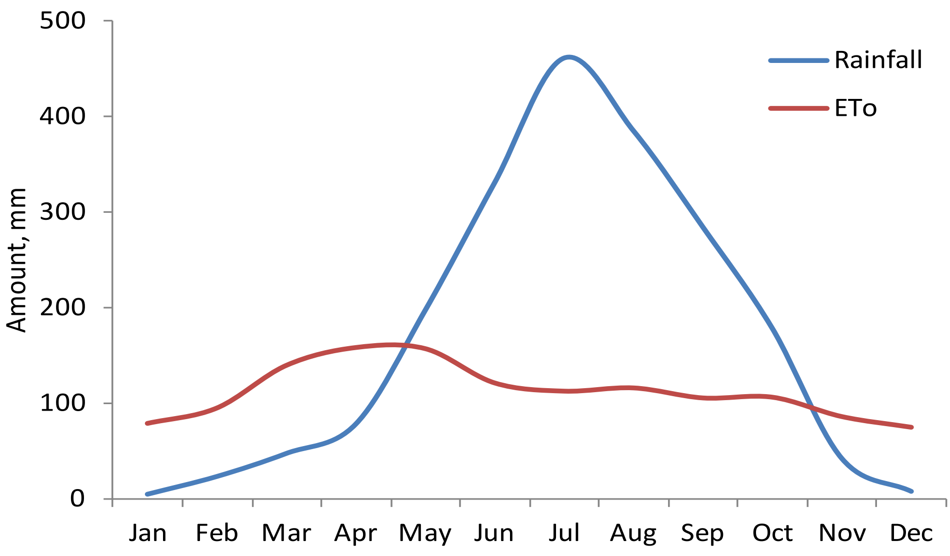


Figure 4.5 Comparison of average monthly rainfall and ETo for Bagerhat district

4.4 Salinity and agriculture

Much of the coastal zone of southern Bangladesh is affected by soil and groundwater salinity. The affected area extends from Noakhali in the east to an area just to the south of Khulna in the west (Figures 3.1 and 4.1), progressively extending further inland in a transect from east to west. Polders on the low lying land are protected from riverine flooding during the annual monsoon, and salt water intrusion (tidal surge) during the severe cyclonic activity of pre-monsoon (May) and post-monsoon (Oct-Nov) periods by dykes that follow the coastline and major waterways. Groundwater in the area is affected by salinity creating a shortage of safe drinking water and limited scope for traditional irrigation. Due to recent shifts in dry season river flows, increased upstream abstraction, and rise in sea level, the spatial and temporal dynamics and severity and extent of salinity is likely to shift, affecting traditional cropping systems and livelihoods both within the current salinity-affected belt, as well as areas outside this belt.

Traditionally, farmers in the coastal region of Bangladesh cultivate low-yielding local rice varieties under rainfed conditions during the wet season (Karim, 2006). Large areas of land remain fallow during the Rabi (dry season) due to soil salinity, lack of rainfall (Dalgliesh and Poulton, 2011) and a lack, or perceived lack, of good quality water for irrigation (Mondal et al., 2008). Recent ACIAR work (LWR/2005/146; Rawson, 2011) at over 200 farms in coastal parts of southern Bangladesh with no or only moderate levels of salinity, clearly showed that actual production was well below the regional potential. In that project, farmer wheat yields of more than 2.5 tonnes per ha were consistently possible without any supplementary irrigation when crops were planted into residual soil moisture that the plants could use until they reached the groundwater. A single well timed irrigation could raise yield to 3.5 – 4.0 tonnes per ha in many areas.

While there is intensive pumping of groundwater for dry season irrigation in many parts of Bangladesh, it is not the case in the coastal zone (discussed later in Chapter 5). Work led by IRRI (International Rice Research Institute) (Tuong et al., 2009) in the south-western saline belt of Bangladesh, as part of a Challenge Program Water for Food (CPWF) project, has shown that there is a potential to support cropping through judicious use of a combination of marginal-quality shallow groundwater, self-supplied water (from water harvesting, on-farm storage) and canal water. However, the study did not investigate the risk of salt accumulation in the soil profile and interaction of saline surface water with groundwater. Similarly, LWR/2005/146, despite having identified as one of its aims a better understanding of the interacting mechanisms of salinity and water on wheat yields on-farm, made little progress in this difficult area. Nor did it assess the effects of broad scale direct shallow-groundwater extraction by crops in the coastal zone, the consequence of wide uptake of its cropping proposals, on soil and groundwater salinity.

Levels of salinity in the coastal zones of Bangladesh have historically constrained agricultural production and according to recent reports (SRDI, 2010) they continue to rise (discussed later in Chapter 5). Such salinization of land has disastrous consequences to agriculture and impacts the livelihoods of its many thousands of small farmers. On the positive side, Bangladesh has the benefit of the annual monsoon rains that help leach deposited salts down below the soil crop-rooting profile. The monsoon rains falling upstream from Bangladesh also bring flooding fresh water into Bangladesh down the Brahmaputra and to a lesser degree the Ganges systems; this assists the leaching process and helps flush and top up water tables for Rabi dry-season crops. Without this annual leaching, salinity in the southern regions would severely curtail crop yields particularly during Rabi when salt in the soil profile can rise vertically through the root zone to the surface through capillarity (Dalgliesh and Poulton, 2011). This less-leached scenario could be the future since India has long-standing plans to link its section of the Brahmaputra to the Ganges to redirect Brahmaputra water to farmers in the western districts of India for crop irrigation. The water gain to Indian farmers would mean an equivalent water loss to Bangladesh farmers. India already has barrages on the Ganges controlling the flow of water south into Bangladesh.

As stated above, coastal Bangladesh is not entirely at the mercy of encroaching salinity and uncontrolled water flows as it has its network of polders. Polders in effect have gates that can to a degree manage the efflux and influx of water throughout the croplands. These are currently used to help drain waterlogged areas as well as reduce saltwater intrusion. Though the polders are a great resource, their effective use requires a good understanding of the effect of salt and water on land and crops. This knowledge must be tailored to the unique physical and environmental characteristics of each polder. This understanding is growing but remains limited to regional larger of coarse scale application. This scoping study will provide an overview of this knowledge gleaned from local gray literature and from experts in Bangladesh. This will be used by ACIAR as the basis for future research and development to more fully and sustainably utilise the natural and human resources of the saline coastal zone to optimise cropping output, for sustainable intensification of cropping in the region.

5 Surface water, groundwater, and salinity

5.1 Introduction

The conditions of the water resources systems in the coastal zone are a decisive factor for social and economic development (MoWR, 2006). Lack of availability and access to safe drinking and irrigation water is a major issue, reaching to a crisis level in the south-west. The reasons are reduced inflow of fresh water causing saline water intrusion, over-extraction of groundwater, and prolonged drainage congestion (MoWR, 2006). So a better understanding and management of the surface water and groundwater resources is of crucial importance.

5.2 Availability of surface water

Bangladesh lies within the broad alluvial delta formed by the confluence of the Ganges, Brahmaputra and Meghna (GBM) rivers. Bangladesh has a complex river network of about 230 rivers, including 57 cross-boundary rivers. About 92.5% of the 1.75 million km^2 of the combined basin area of the GBM Rivers is beyond the boundaries of Bangladesh and is located in China, Nepal, India and Bhutan (Figure 5.1). As such, Bangladesh acts as a drainage outlet for cross-border runoff (Mirza et al., 2003). The combined annual discharge of these rivers is about 40,000 m^3/s and the combined peak discharge in the order of 200,000 m^3/s (Hoque, 1997). The total annual runoff of the surface water passing through Bangladesh is in the range of 1,200 to 1,500 billion m^3. The sediment discharge is in the range of 1.2 to 1.7 billion tonnes which originates outside the country (Ali, 2002).

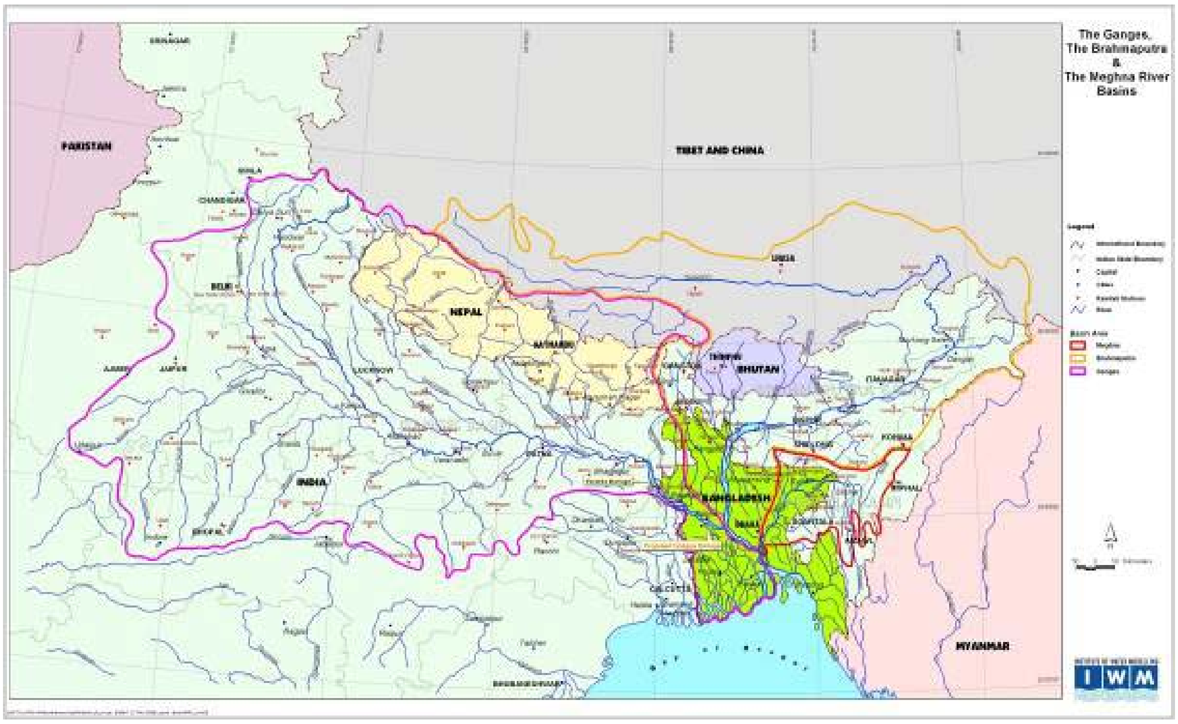


Figure 5.1 The Ganges, the Brahmaputra and the Meghna River Basin

The resulting huge volume of cross-border monsoon runoff, together with locally generated runoff and some physical factors, either singly or in combination, causes floods in Bangladesh. On average, about 20%, or about 3 million ha, of the country is flooded annually. In extreme cases, floods may inundate up to 70% of the country as was the case during the floods of 1988 and 1998 (Mirza et al., 2003). Despite this huge availability of water in the monsoon season, due to high seasonal variation (Figures 5.2 and 5.3) not much water is available in the dry season. So the dry season irrigation is mostly based on groundwater which will be discussed later.

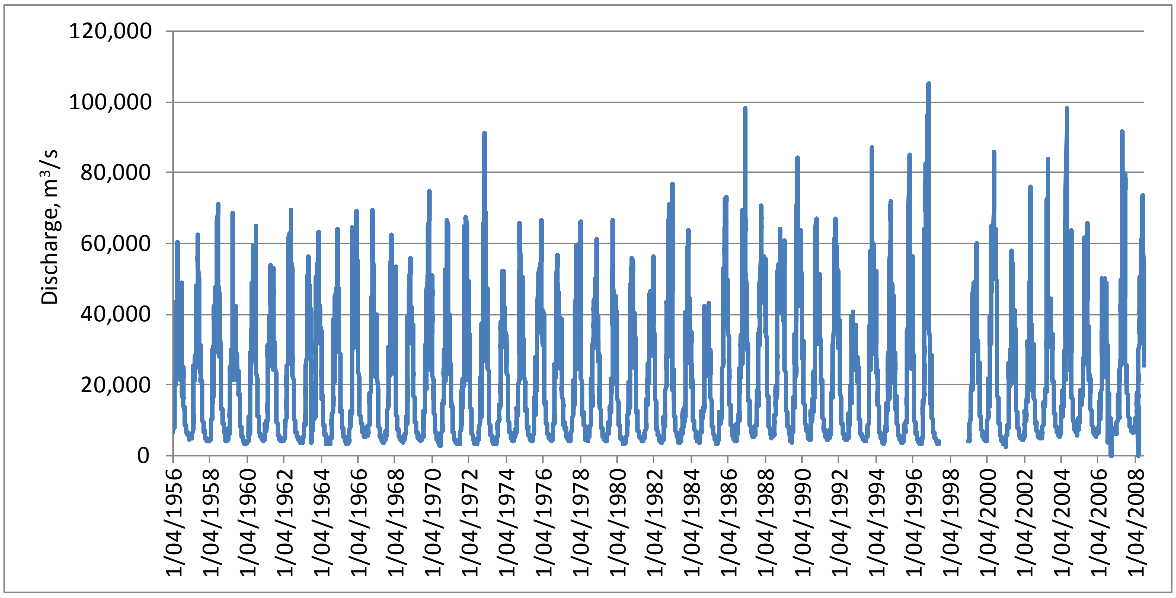


Figure 5.2 Daily discharge of water at Bahadurabad station (see Figure 5.4) on the Jamuna (Brahmaputra) River

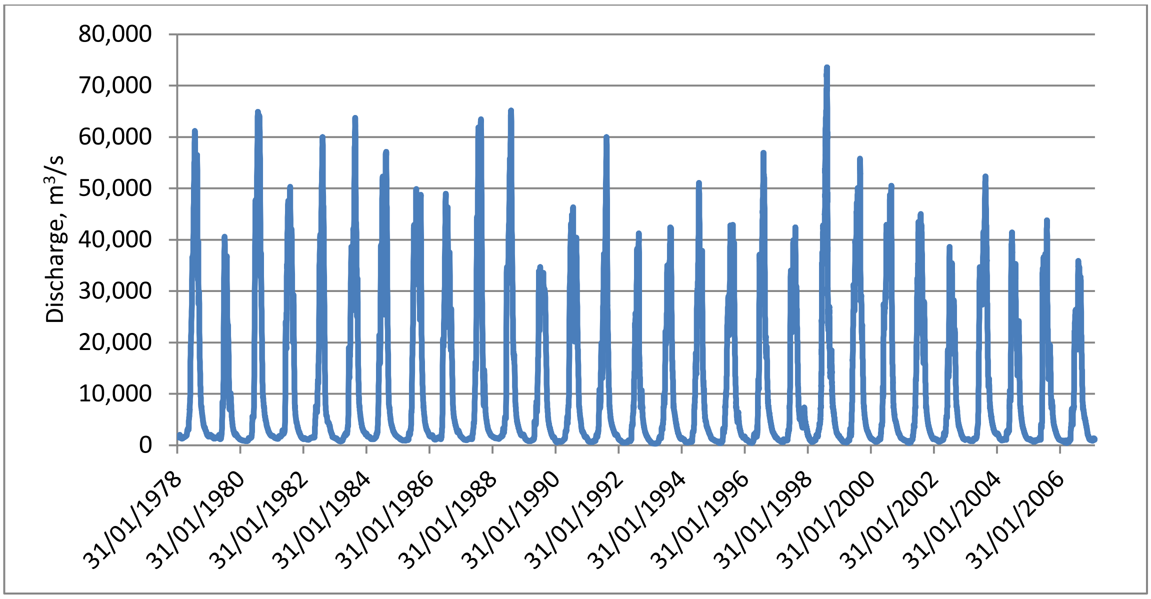


Figure 5.3 Daily discharge of water at Hardinge Bridge (see Figure 5.4) on the Ganges River

The low availability of water in the dry season is further exacerbated by withdrawal of water upstream in India. This is a major political issue between Bangladesh and India. Of the 54 common rivers between Bangladesh and India, there is a dry season water sharing treaty only for the Ganges River. The treaty is based on water available at the Farakka Barrage (a Barrage constructed over the river Ganges in the West Bengal state of India during 1961-1975 which is 17 km upstream of the Bangladesh border). There is an increase in water use upstream of Farakka Barrage; as a result, the Bangladesh share of water in the dry season is also getting reduced day by day. This situation may worsen further if the Indian River Linking Project is executed by India. The case is similar for other rivers.

The coastal zone is marked by an ever dynamic network of river and estuary system (Figure 5.4), interaction of huge quantities of fresh water that are discharged by the river systems in the monsoon, and a saline waterfront – penetrating inland from the sea in the dry season. The major rivers in the coastal zone are: Gorai, Arialkhan, Bhairab, Bhadra, Dakatia, Kobadak, Sibsa, Karnafully, Passur, Tentulia, Sangu and Lower Meghna. These rivers are mainly the distributaries of the Ganges and Brahmaputra Rivers as shown in Figure 5.4. So the availability of water in the dry season and salinity is highly dependent on the availability of freshwater flows from these rivers (Ganges and Brahmaputra).

The Gorai River is one of the main distributaries of the Ganges River. It originates from the Ganges near Talbaria, 15 km downstream of Hardinge Bridge and flows about 90 km towards the south and falls at Modhumati River near Bardia (Figure 5.4). It is the main source of fresh water supply to the South-West (SW) coastal zone of Bangladesh. It covers approximately 27 percent of the total area of the country. The environment and bio-diversity in the area is affected by the seasonal water coming through the Gorai River (Figure 5.5). As shown in Figure 5.5 there is no water flow at the offtake of the river (the discharge near offtake is zero) in the dry season. The upward pressure of the salinity front in this region fluctuates with the quantity of seasonal fresh water discharge of the Gorai (Figure 5.6) and affects the people's livelihood along with biodiversity. As shown in the right hand side of the chart in Figure 5.6, there is a negative discharge during January to May due to the upstream movement of the saline water in the river. Considering this, it is very important to ensure the flow augmentation of the Gorai River to meet the minimum environmental flow requirement during the dry season.

The main reason for no flow to the Gorai River from the Ganges in the dry season is the low flow of water in the Ganges. In addition to that, the river offtake has silted thereby obstructing flow into the river. To augment the flow into the Gorai River to prevent the saline surface water moving inland, the Government recently dredged the river offtake under the "Gorai River Restoration Project". Figure 5.7 (left) shows the discharge at the offtake of the Gorai River and surface water salinity at Khulna for the last five years (right chart). As shown in the Figure (blue dots in right chart), salinity has significantly reduced after the dredging in 2012.

Due to mean sea level rise (SLR), low-lying topography, drainage congestion, a funnel shaped coast exposing the land to cyclones and tidal surges, saline water intrusion has occurred into fresh water zones in the coastal zone of Bangladesh. In addition, excessive surface water diversion and groundwater abstraction upstream reduces fresh water flows to the estuary during the dry season. During the monsoon season a large volume of freshwater discharges into the Bay of Bengal through the Meghna estuary which impacts on salinity. The effect is reduced with the distance upstream from the Meghna mouth; the western parts experience much higher salinity levels than the eastern parts (IWM, 2012). The freshwater flow decreases during the dry season and increases salinity along the coast. Salinity increases steadily from December reaching a maximum during late March and early April in response to the Ganges flow trends (minimum flow occurs from late April to May). Rabi season cropping starts in December. So during a major part of the Rabi season, varying quality of surface water (from fresh to brackish) is available for irrigation. There is surface water irrigation (discussed later) in some areas using 'low lift pumps' (LLPs). There may be potential for further increase in irrigation area using surface water. During stakeholder consultations in Bangladesh (see report Appendix A), many organizations expressed the opinion that there is scope for increase in surface water irrigation in the central coastal zone. The main constraint is there is no irrigation infrastructure to transfer water from the rivers and streams to the field.

Rainfall during the monsoon season in the coastal zone is high (Fig. 4.3 and Table 4.2). Though there are no major water storage facilities in Bangladesh, in the coastal zone there is potential to store fresh water in canals, ponds, and other small streams. A story published in the English daily newspaper 'The Daily Star' (Hossain, 2012) states that farmers produced bumper yields of Boro and other crops during the Rabi season of 2012 on their saline affected land in Kalapara upazila of Satkhira district because they irrigated using fresh water stored in the canals. There is also potential for water harvesting in large ponds at the corner of rice fields and the stored water can then be used for strategic irrigation during the dry season and fish farming during the rainy season (e.g. Panigrahi et al., 2001). There is a general belief, raised during the stakeholder consultation, that surface water is not utilized to its potential and this has contributed to the disappearance of small channels, streams and natural canals. There is no initiative to re-excavate the canals and streams.

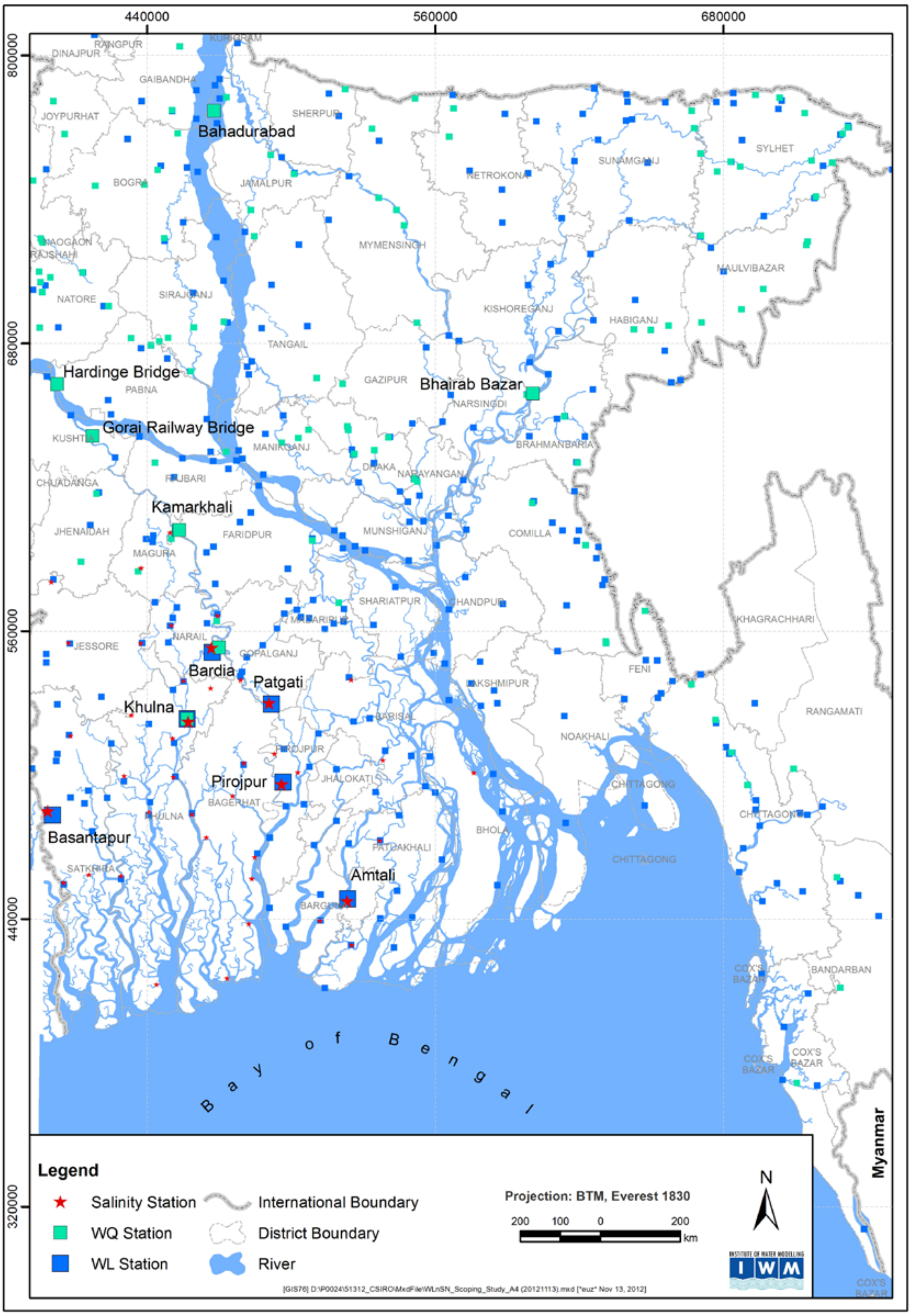


Figure 5.4 River network of the southwest coastal zone

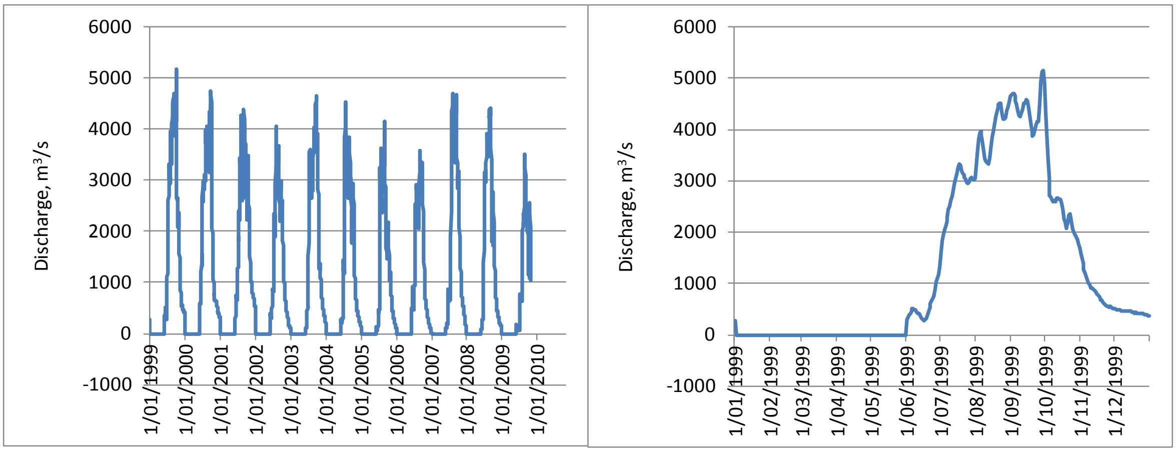


Figure 5.5 Daily discharge of water at Gorai Railway Bridge station (just below the Hardinge Bridge station on the Ganges in Figure 5.4) on the Gorai River

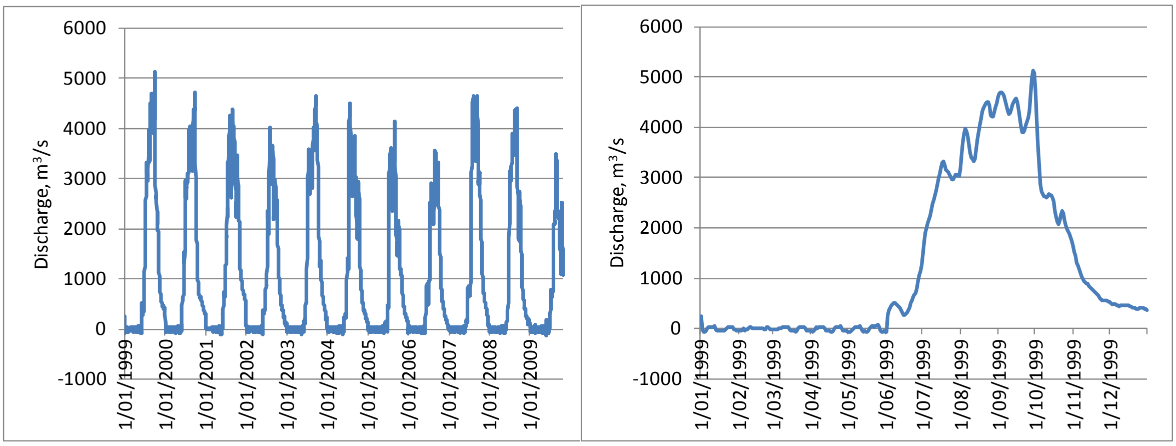


Figure 5.6 Daily discharge of water at Kamarkhali station (see in Figure 5.4) on the Gorai River (the high flows are almost same as in Figure 5.5, but the low flows are different)

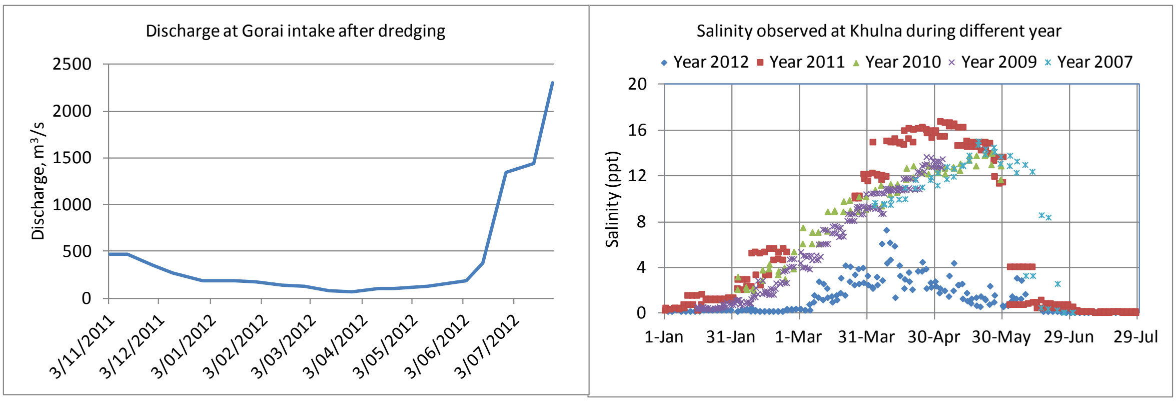


Figure 5.7 Discharge at Gorai offtake after dredging and salinity at different year at Khulna

5.3 Factors affecting surface water

Factors that affect surface water hydrology in the coastal zone are discussed below.

5.3.1 Sea level rise

One potential impact of global warming is rise in sea levels. According to IPCC, rise in sea level due to climate change is projected to be 14 cm, 32 cm and 88 cm respectively for 2030, 2050 and 2100. IWM has tested the potential impacts of sea level rise (SLR) using a hydrological model. The projected 88 cm rise in sea level is likely to submerge an additional 11 percent of low-lying (depth 0-30 cm MSL) coastal areas (4,107 km^2) with saline water by 2100. About 16 coastal districts are likely to face increased salinity due to increased inundation, storm surges and drainage congestion in polders. The tidal height is projected to increase by 30 cm and 80 cm from 32 cm and 88 SLR, respectively in the Shahabazpur channel at Daulatkhan (Figure 5.8).

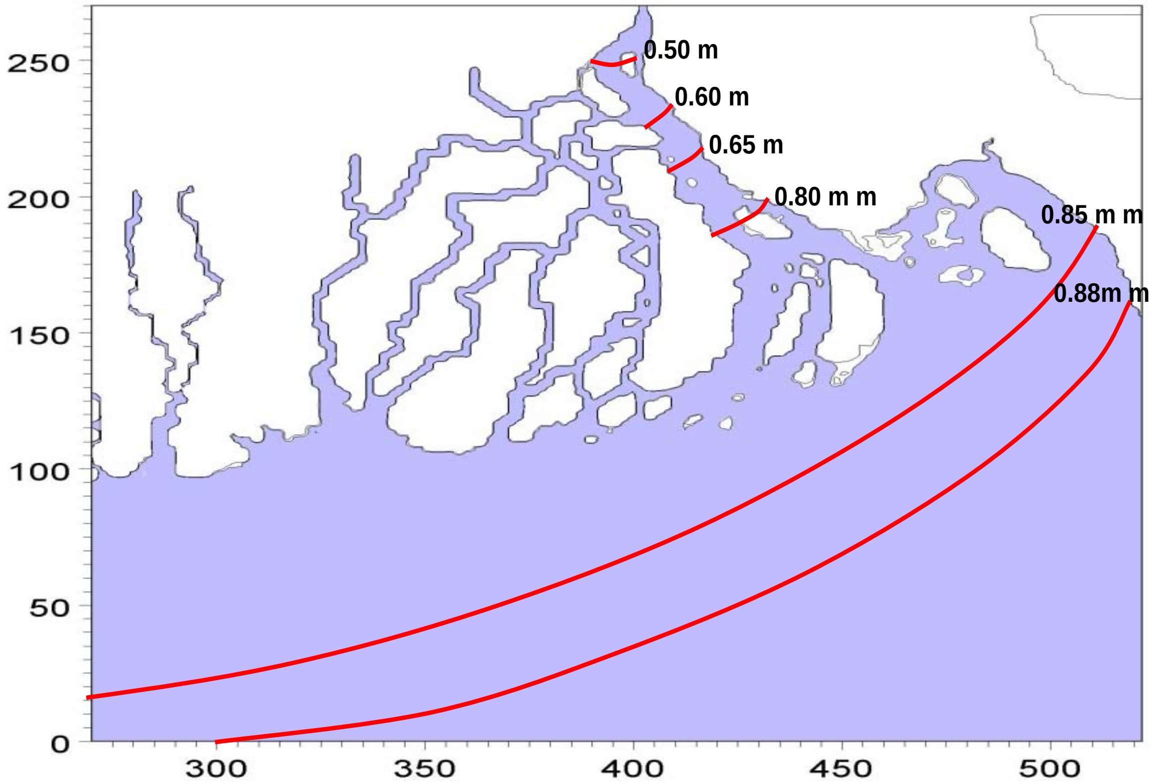


Figure 5.8 Projected water level rise in the Meghna Estuary by 2100 due to 88 cm SLR (source: IWM)

5.3.2 Cyclone induced storm surge

The Bay of Bengal and the coastal areas of Bangladesh are located at the tip of the Northern Indian Ocean forming the shape of an inverted funnel. The Bay is quite shallow. The area is frequently hit by severe cyclonic storms, generating long wave tidal surges. These surges amplify as they travel through shallow waters and result in disastrous effects on the coastal areas of Bangladesh. Most severe cyclones occur near the Chittagong-Cox's Bazar coast. Two to four severe cyclones occurred every 10 years in Bangladesh during the period between 1881 and 2001. Storm surge during a cyclone causes flooding in coastal areas and offshore islands resulting in saline surface water in the bay. The observational data indicate 1.5 to 9 m high storm surges occur during severe cyclones. The 1991 cyclone had the lowest pressure fall (of 74 mb) and the strongest wind speed (of 225 km/hr).

Simulation of the 1991 cyclone with a 32 cm SLR shows that the inundation depth and area increased substantially during 1991 cyclone. The storm surge broke over the coastal embankment at Hatia and submerged about 80 percent of the area (Figure 5.9). The surge height increased by 5 to 15 percent in the bay area (Figure 5.10). A 10 percent increase in wind speed (from 225 to 248 km/hr) during the 1991 cyclone resulted in a storm surge height of 7.8 to 9.5 m near the Kutubdia-Cox's Bazar coast.

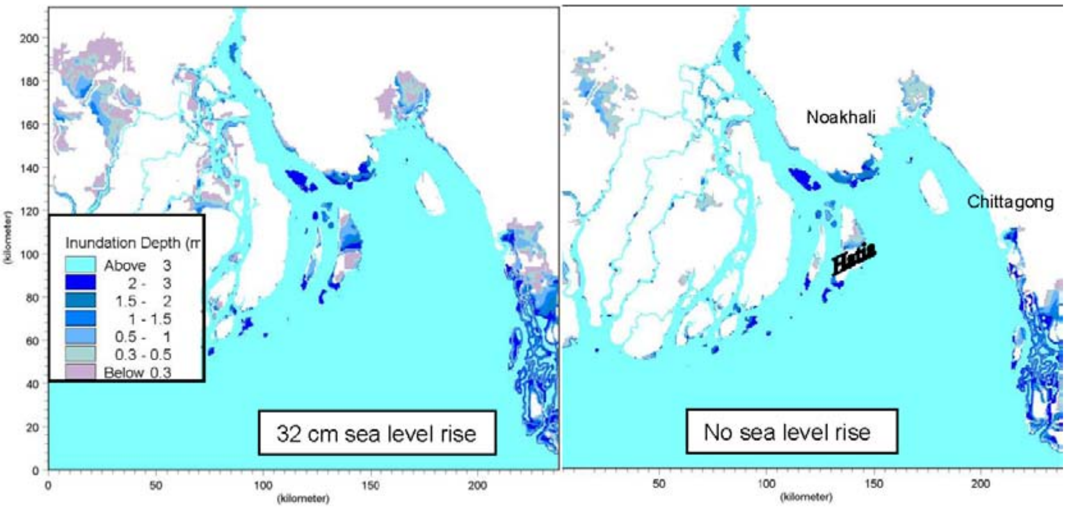


Figure 5.9 Increase in inundated area due to 1991 cyclone and sea level rise (32 cm SLR & Cyclone 1991, source: IWM)

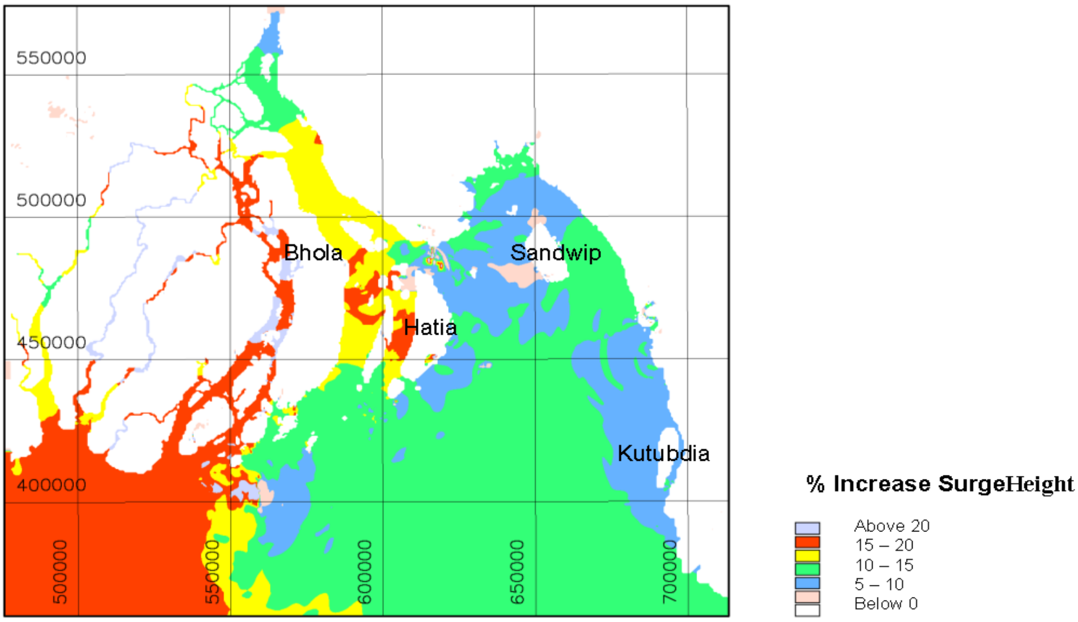


Figure 5.10 Percent increase in storm surge height due to 1991 cyclone and 32 cm SLR level rise (source: IWM)

5.3.3 Tidal current

Tidal waves carry salt water up stream into the watercourses where it mixes with fresh water and increases surface water salinity (Figures 5.11 and 5.12). The tidal wave of the Indian Ocean travels through the deep Bay of Bengal and approaches the coast of Bangladesh approximately from the south. It arrives at Hiron Point and Cox's Bazar about the same time. The extensive shallow area in front of the large delta causes some refraction and distortion. Some reflection of the tidal wave also occurs and contributes to significant amplification of the tidal wave in the Hatia and Sandwip Channels. The occurrence of tidal bores has been observed north of the Sandwip Island and Urir Char. Co-tidal chart (tide of equal range) of the coastal area is shown in Figure 5.13.

The water level variation is dominated by a semi-diurnal tide with a considerable variation in amplitude (neap to spring) of 0.6 to 1.4 times the average amplitude in the entire coastal area. The average tidal range is about 1.5 m in western part of the coastal area of

Bangladesh. In the area around Sandwip near Chittagong, the tidal range is significantly higher with an average range of over 4 m. The highest high-tide water level reaches about 6.5 m above PWD (Public Works Department). It is much higher during the cyclone surges.

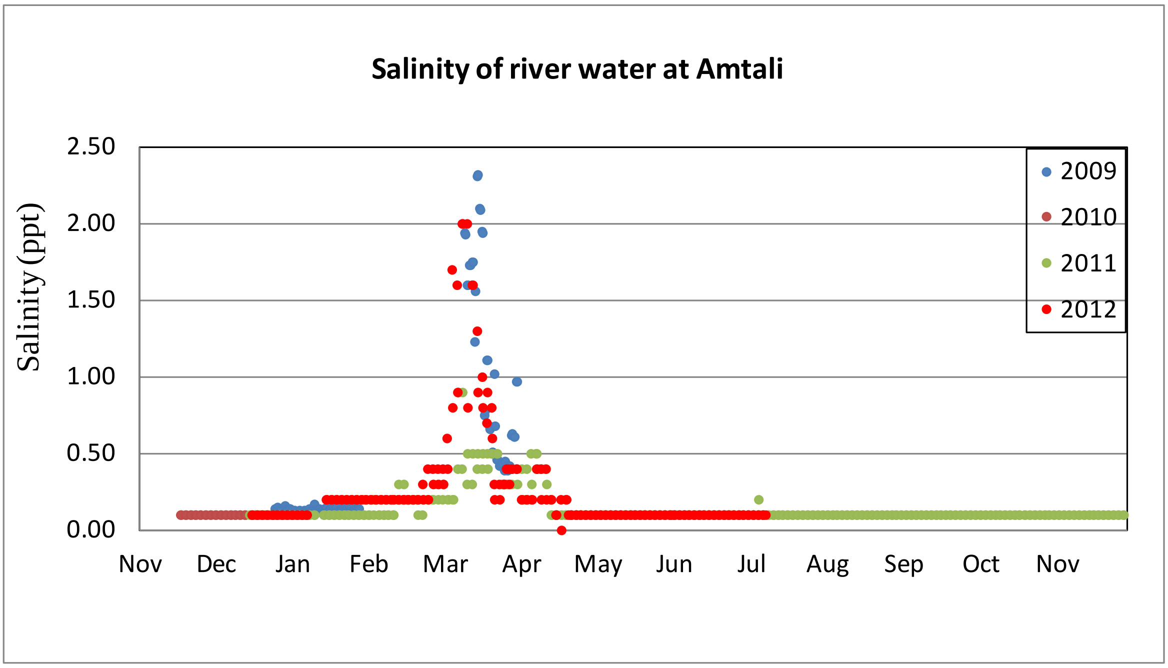


Figure 5.11 Salinity of river water at Amtali (location shown in Figure 5.4, a site used for 2011-12 agronomy studies in Chapter 7)

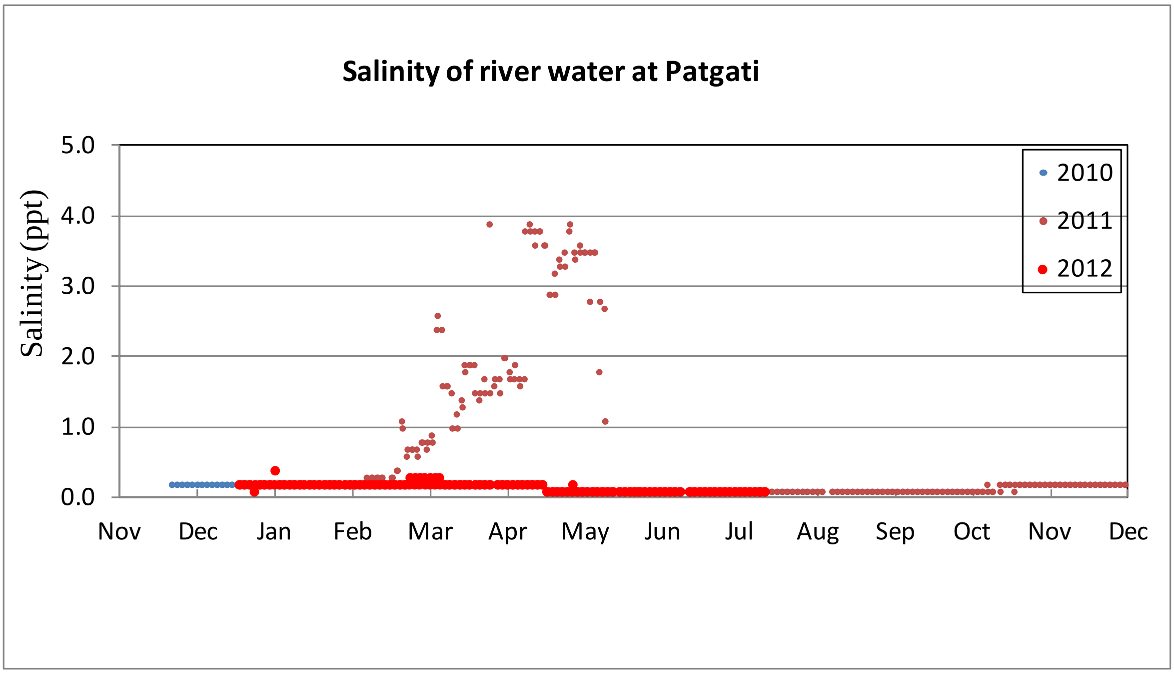


Figure 5.12 Salinity of river water at Patgati (location shown in Figure 5.4)

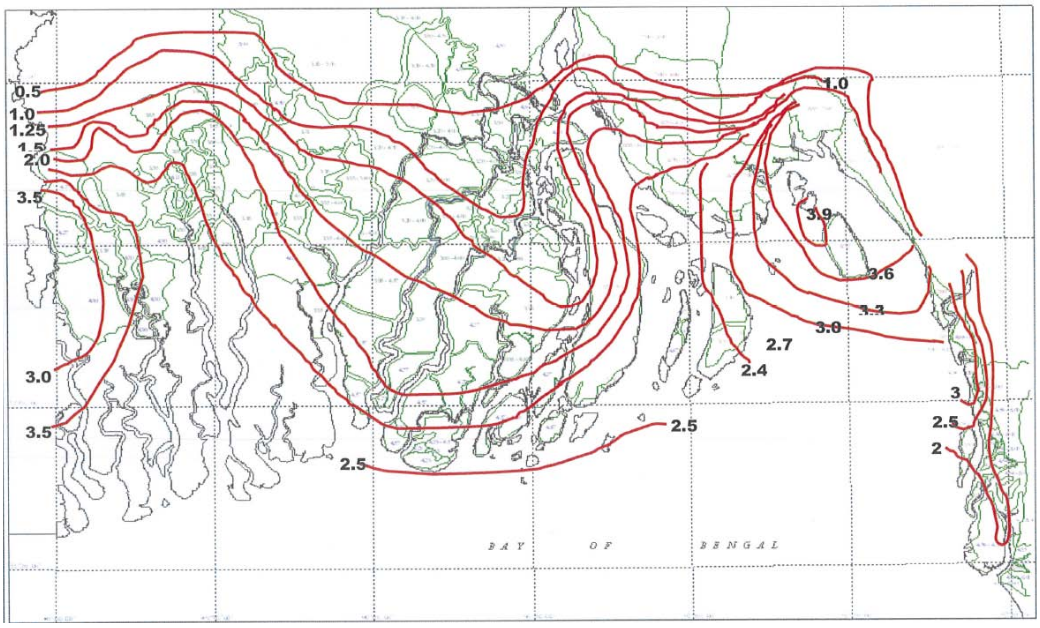


Figure 5.13 Co-tidal chart for the coastal area of Bangladesh (source: IWM)

5.3.4 Drainage congestions in the coastal polders

Drainage congestion in the coastal polders (polders are shown in Figure 4.2) obstructs the discharge of fresh water to the sea, which increases surface water salinity, and the risk of saline water intrusion. The drainage of coastal polders mainly depends on tidal characteristics of rivers surrounding the polders (Figure 5.14) and the degree of siltation in these rivers. In the rainy season, water levels in the surrounding rivers and streams are usually high preventing drainage of water from the polder. Unfortunately, the peak discharge of the main rivers occurs in the period of July to September, at the same time as local rainfall. The resulting drainage congestion may last over a month or longer. Drainage congestions and water logging is especially marked in the western coastal zone (Khulna and Jessore districts) and in the southern part of Noakhali and Lakshmipur districts (Islam et al., 2006).

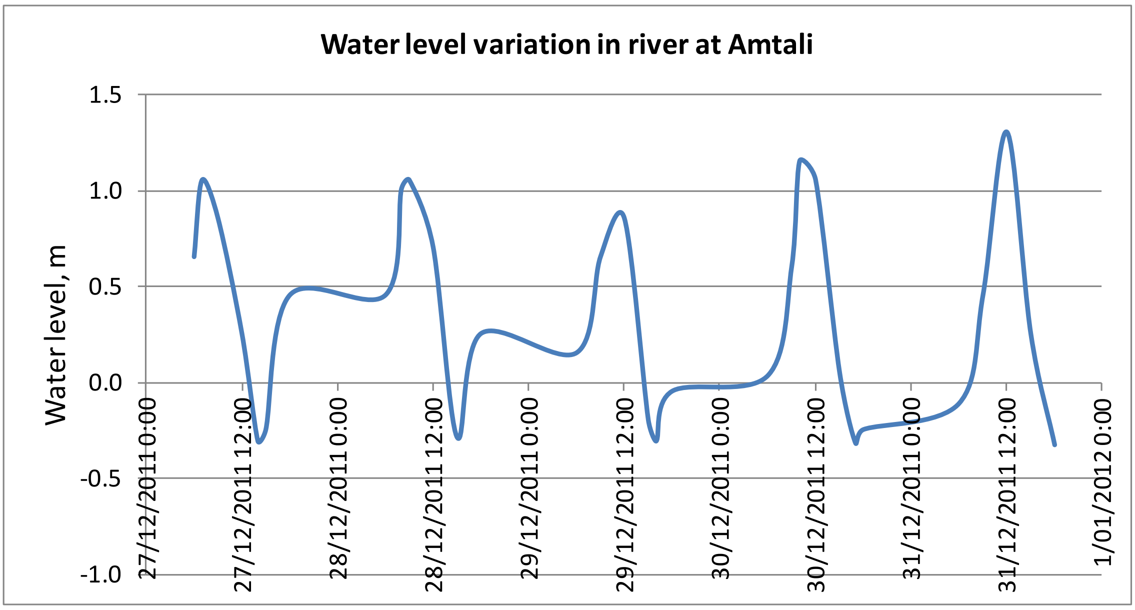


Figure 5.14 Tidal impacts on water level variation in the river surrounding the polder

Water management inside the polders is not helped by inadequate maintenance of structures, improper operation of sluice gates and channel siltation leading to drainage congestion. Polders were constructed with the initial objectives of tidal flood protection, prevention of salinity intrusion and to manage drainage during the monsoon, allowing paddy fields to be submerged for 72 hours. High yielding varieties of rice (HYVs) have been introduced to the polders and require irrigation and quick drainage. During the implementation of polder projects, embankments were constructed by closing a number of natural channels assuming that the area could be drained through a particular sluice using the channel network, but with time and as internal road networks expanded and new settlements were built, efficient drainage became more difficult. With the growing population, more area was brought under cultivation and more water was needed. This imposed additional pressure on the water management structures originally designed to provide supplemental irrigation during drought (for polders that have non-saline water in the surrounding rivers) and to drain out excess water for traditional rice cultivation. Now with progressive siltation and encroachment, internal channel flow capacity has been significantly reduced, causing drainage congestion, pollution and scarcity of water. Moreover, influential people have been commandeering sections of canals for fish farming. This involves blocking water flows to keep their fish enclosed leading to water stagnation and conflicts with crop farmers. Shrimp cultivation inside the polders, a more recent activity, requires flooding brackish water onto large areas of land. This hampers crop cultivation by neighbouring farmers, growth of natural vegetation for animal feed and availability of fresh drinking water. The solution of ad hoc opening up of embankments to drain out polluted water or flushing fresh water makes the polders vulnerable to tidal or storm surge flooding and in turn leads to losses of crops and properties.

5.4 Salinity trend in surface water

Salinity data indicate an enormous seasonal effect of the discharge of fresh water from the Lower Meghna River on the horizontal distribution of salinity in the estuary. Figure 5.15 and Figure 5.16 show the movement of 1 ppt salinity line during the monsoon season and the dry season, respectively. High salinities both in the monsoon and the dry season, in the southwest corner and along the Pussur-Sibsa system, are due to reduction in upstream freshwater flow and drainage congestion from siltation of major channels.

Saline water intrusion is highly seasonal in Bangladesh (Figures 5.11 and 5.12). During the dry season deep inland intrusion occurs through various inlets in the western part of the delta and through the lower Meghna estuary. A considerable further inland movement of the salinity front occurred during 2002, 2005 and 2009 as shown in Figures 5.17 to 5.19; this is likely to change the distribution and pattern of salinity in this area. The highest salinity occurs during droughts in the estuary because of low fresh flows from upstream.

Sea level rise may push the saline waterfront further inland. Figure 5.20 shows the impact of sea level rise on salinity intrusion (5 ppt isohaline) along the coastal zone during the dry season. The inland intrusion of 5 ppt isohaline is quite substantial in Bhola, Patuakhali and Barisal districts if the SLR is 32 cm or 88 cm (Figure 5.20). The only freshwater pocket in the Tentulia River is substantially affected by the saline water intrusion (5ppt) if SLR is 88 cm.

A considerable movement of the salinity front further inland is expected during the dry season that is likely to change the present salinity pattern in this area. This change may create problems for agriculture and fisheries sectors and for the flora and fauna of the southwest region.

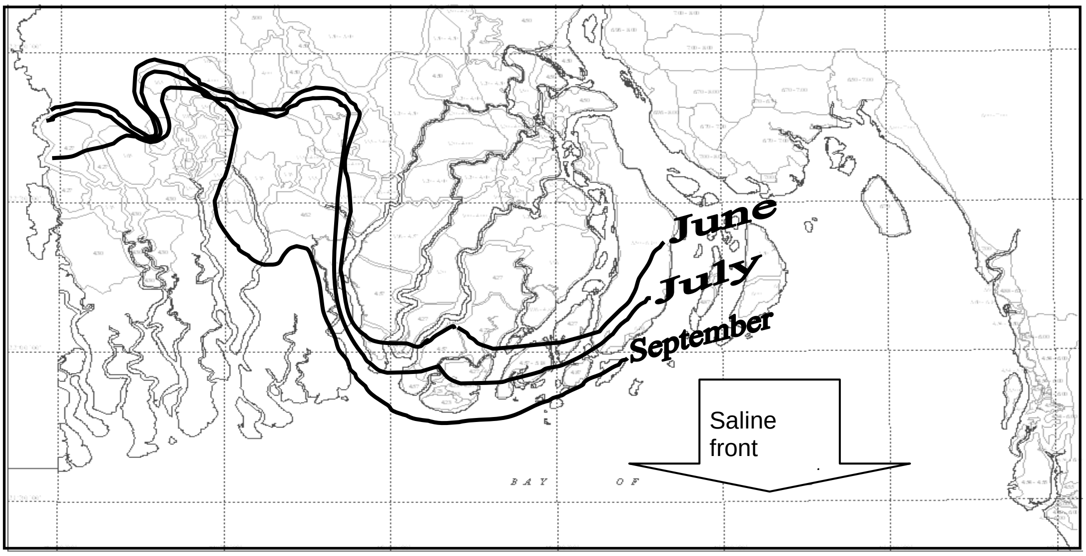


Figure 5.15 Salinity trend (1ppt) towards the ocean during the monsoon season (June to September, source: IWM)

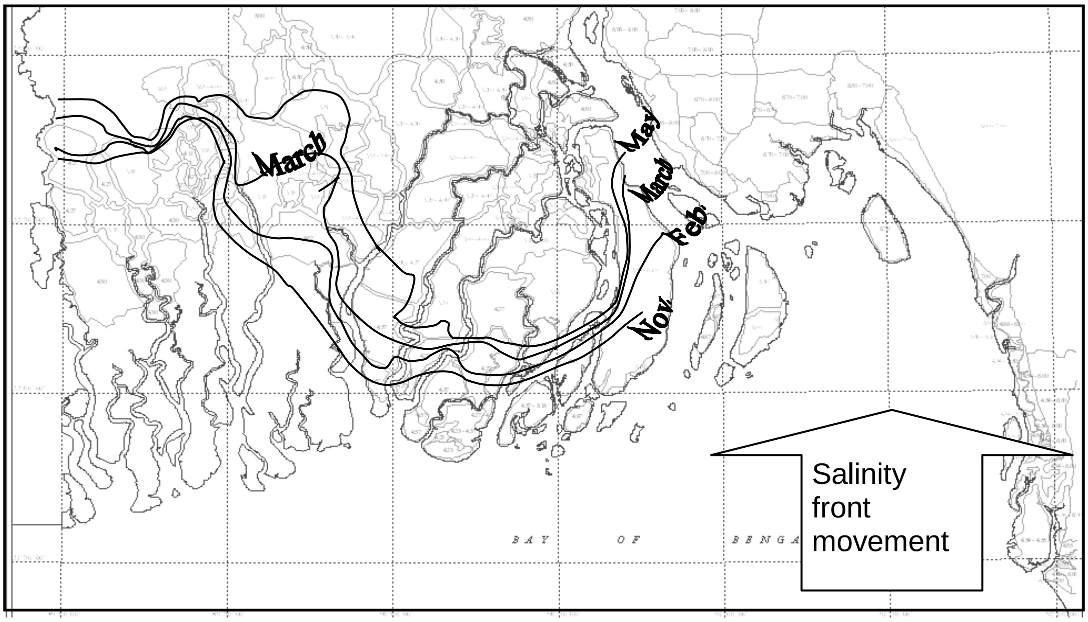


Figure 5.16 Salinity trend (1ppt) towards inland during the dry season (November to May, source: IWM)

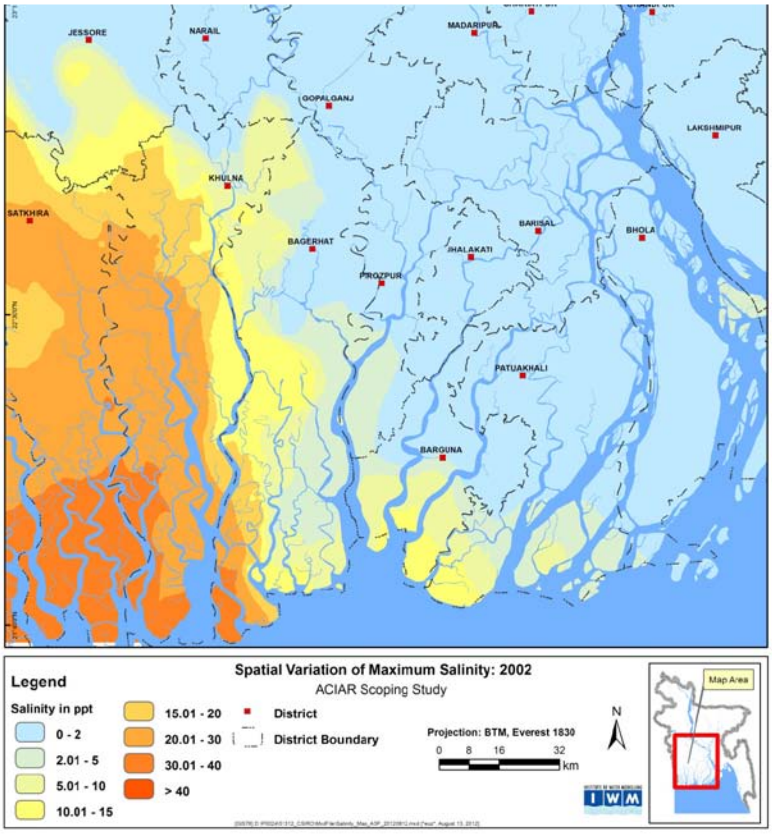


Figure 5.17 Spatial variation of maximum surface water salinity during the dry period in 2002

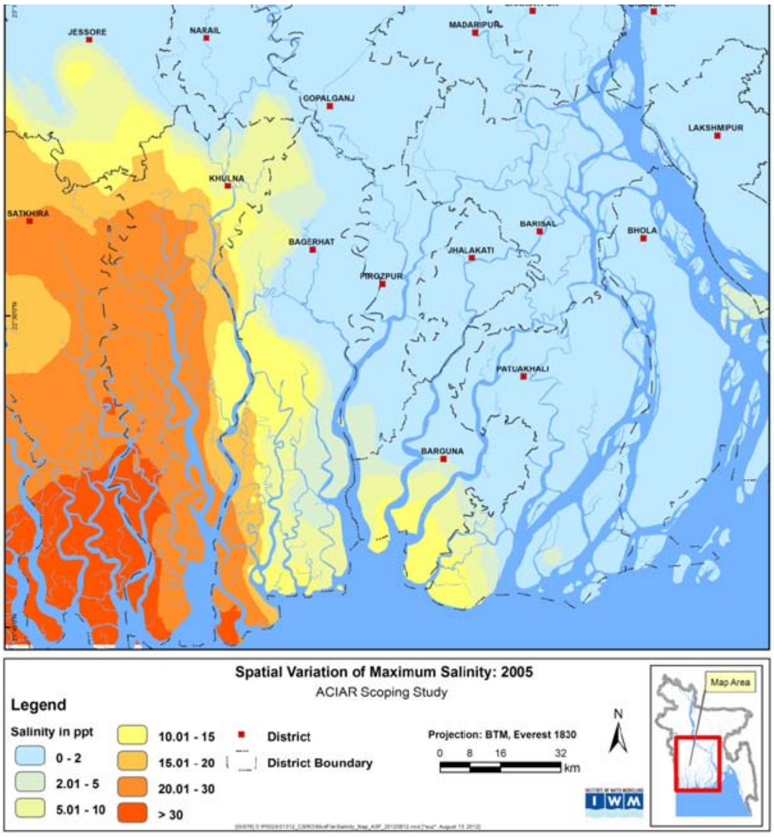


Figure 5.18 Spatial variation of maximum surface water salinity during the dry period in 2005

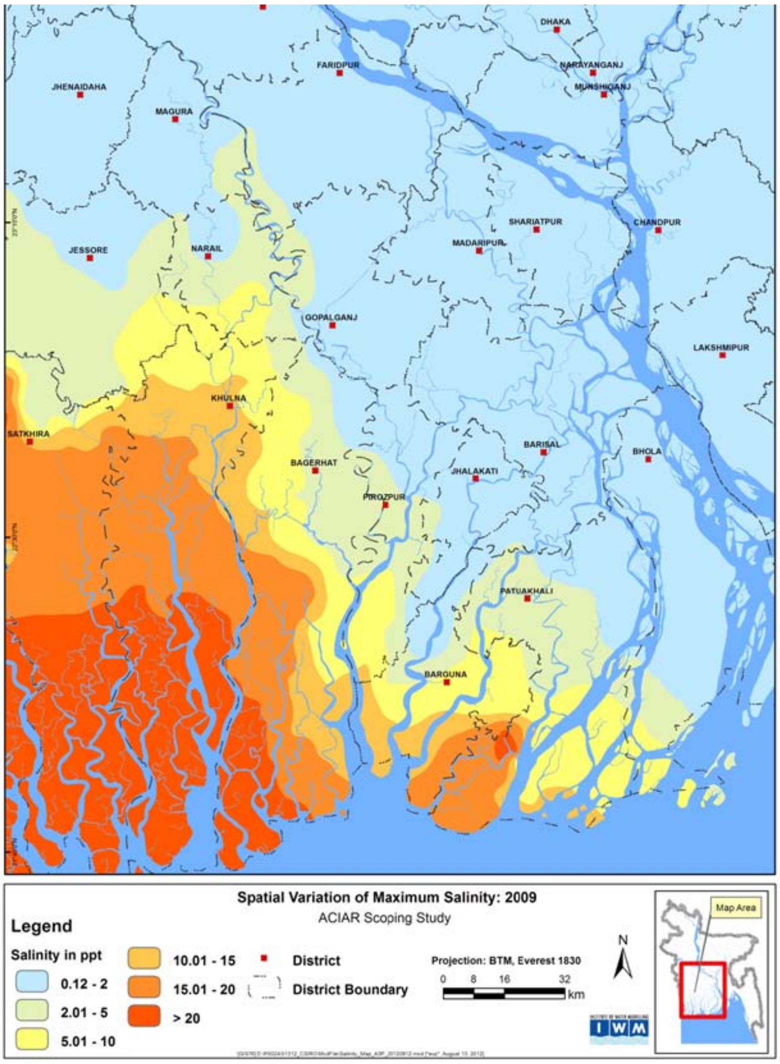


Figure 5.19 Spatial variation of maximum surface water salinity during the dry period in 2009

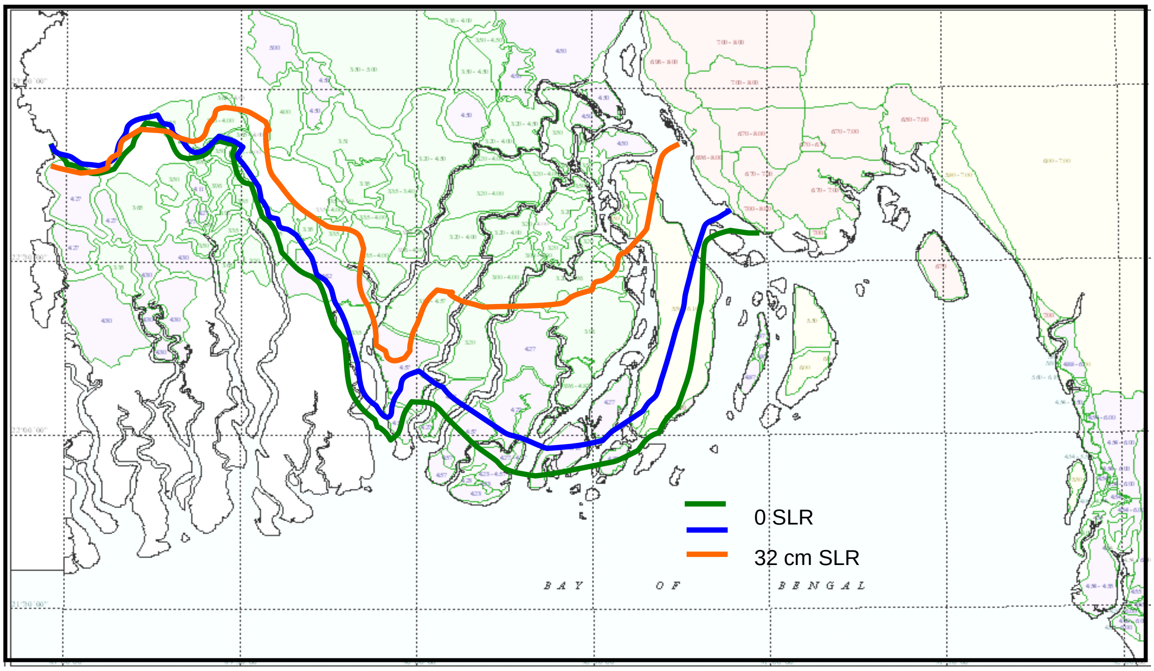


Figure 5.20 Line of equal salinity (5 ppt) due to various sea level rises during the dry season (MoEF, 2008)

5.5 Aquifer system in the coastal zone

Based on groundwater investigation and hydro-geological studies undertaken so far by different agencies, the aquifer system of coastal zone may be categorized into four different major aquifer systems. The depth and thickness of these aquifer systems are variable depending on sediment deposits and general topography. A brief description of each of these four aquifer systems is given below.

a) Upper shallow aquifer system:

This generally exists within 50 m of ground surface. It has a heterogeneous assemblage of sand, silt and clay. Its thickness varies from 2 to 6 m.

b) Lower shallow aquifer system:

This system of unconfined to semi-confined aquifers generally exist between 50 and 150 m below the ground surface and consists of medium to coarse sand with occasional fine sand and silt. The aquifer thickness varies from 20 to 80 m with some exceptions.

c) Deeper aquifer system:

In general the deeper aquifer system exists at about 200 m below the ground surface. At some locations it may exist at shallow depths due to local topography and geological conditions. This mostly-confined to semi-confined aquifer system generally consists of fine to medium sands.

d) Deep aquifer system:

This aquifer system exists below deeper aquifer system and is presumed to have a confined nature and sufficient hydrostatic pressure. According to Khan (1991), the deep aquifers in the country exist between 200 and 1000 m in the Dinajpur Platform area and between 300 and 1500 m in the basin area, which includes the coastal region of the country. The deep aquifer systems of Bangladesh have not been characterized in the past and require detailed investigative studies.

5.5.1 South-western region aquifer system

About 353 borehole logs were collated from different agencies for lithological characterization, hydrostratigraphic classification and aquifer system delineation of the study area. The depth ranges between 300 m and 400 m for 188 boreholes, between 200 m and 300 m for 143 holes and between 160 m and 200 m for 22 wells. Three columnar sections have been drawn along A-A/, B-B/, C-C/, covering western, middle and eastern part of the study area and traversing in north-south direction (Figure 5.21).

Section A-A/

Section A-A/ (Figure 5.22) covers the western part of the study area from Koyra, Khulna to Chaugacha, Jessore. Mainly three aquifer layers exist throughout the area. These are namely Fine sand aquifer, a combination of Fine and Medium (fine to medium sand) sand aquifer, and a combination of Medium and Coarse sand aquifer. The aquifer systems are extended and connected from Khulna to Jessore. Depth, thickness and composition of aquifer layers vary in different areas due possibly to variation in the depositional environment, change in river system, and change in flow condition. It is important to note that a combination of medium and coarse sand aquifer in Jessore area becomes a combination of fine and medium sand aquifer in the Khulna area. Clay layer (aquitard) is thicker in the Satkhira and Khulna area than in the Jessore area. An unconfined to semi-confined aquifer in the Jessore area becomes semi confined to confined in the Khulna area.

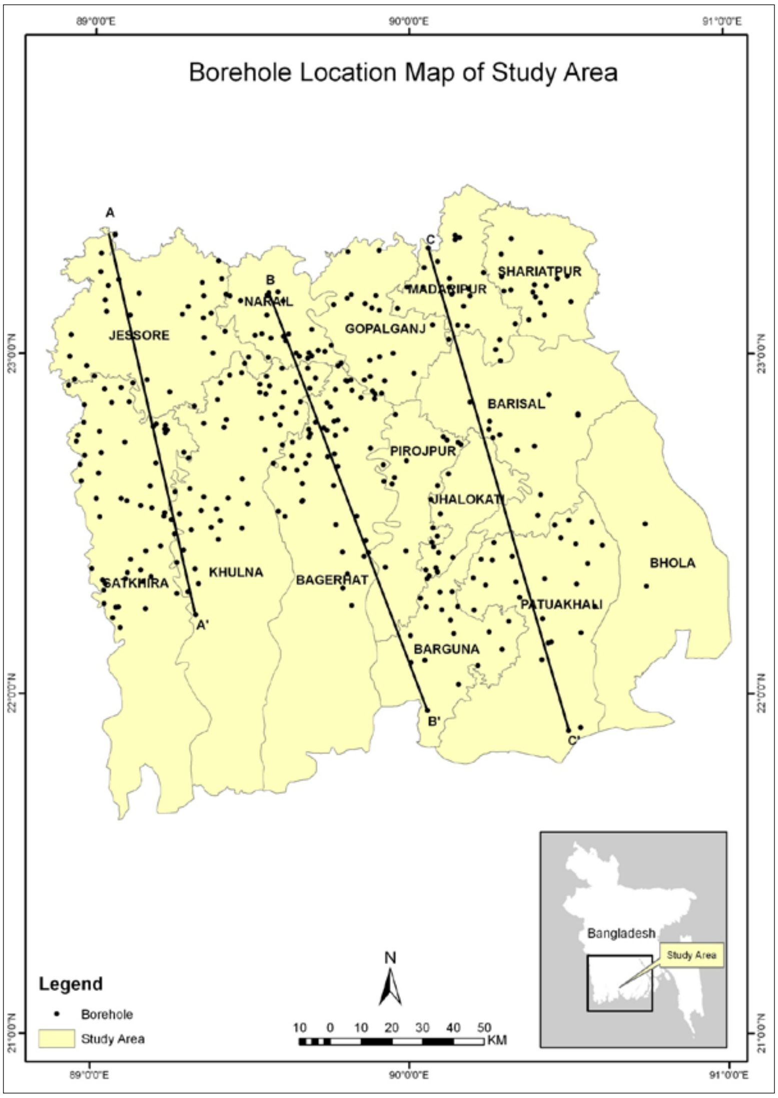


Figure 5.21 Columnar section line and borehole location of study area

Section: B-B/:

Section B-B/ (Figure 5.22) covers the middle part of the study area from Narail to Barguna. The area represents three types of aquifers namely fine sand aquifer, fine to medium sand aquifer, medium to coarse sand aquifer. The fine sand aquifer is the most dominant throughout the area. The medium sand aquifer also exists throughout the area at varying depths. This variation in depth and thickness may be attributed to shifting of the river channel and subsequent deposition. The clay layer thickens towards the Barguna area.

Section: C-C/

Section C-C' (Figure 5.22) covers eastern part of the study area. It represents the area from Madaripur to Patuakhali ranges. There are three aquifer types in the Gopalganj area and two in the Patuakhali area. The medium to coarse sand aquifer is dominant in the Gopalganj to Barisal area and fine sand aquifer is dominant in the Patuakhali area. In southern parts of the study area, a relatively thick clay layer overlies the sand aquifers.

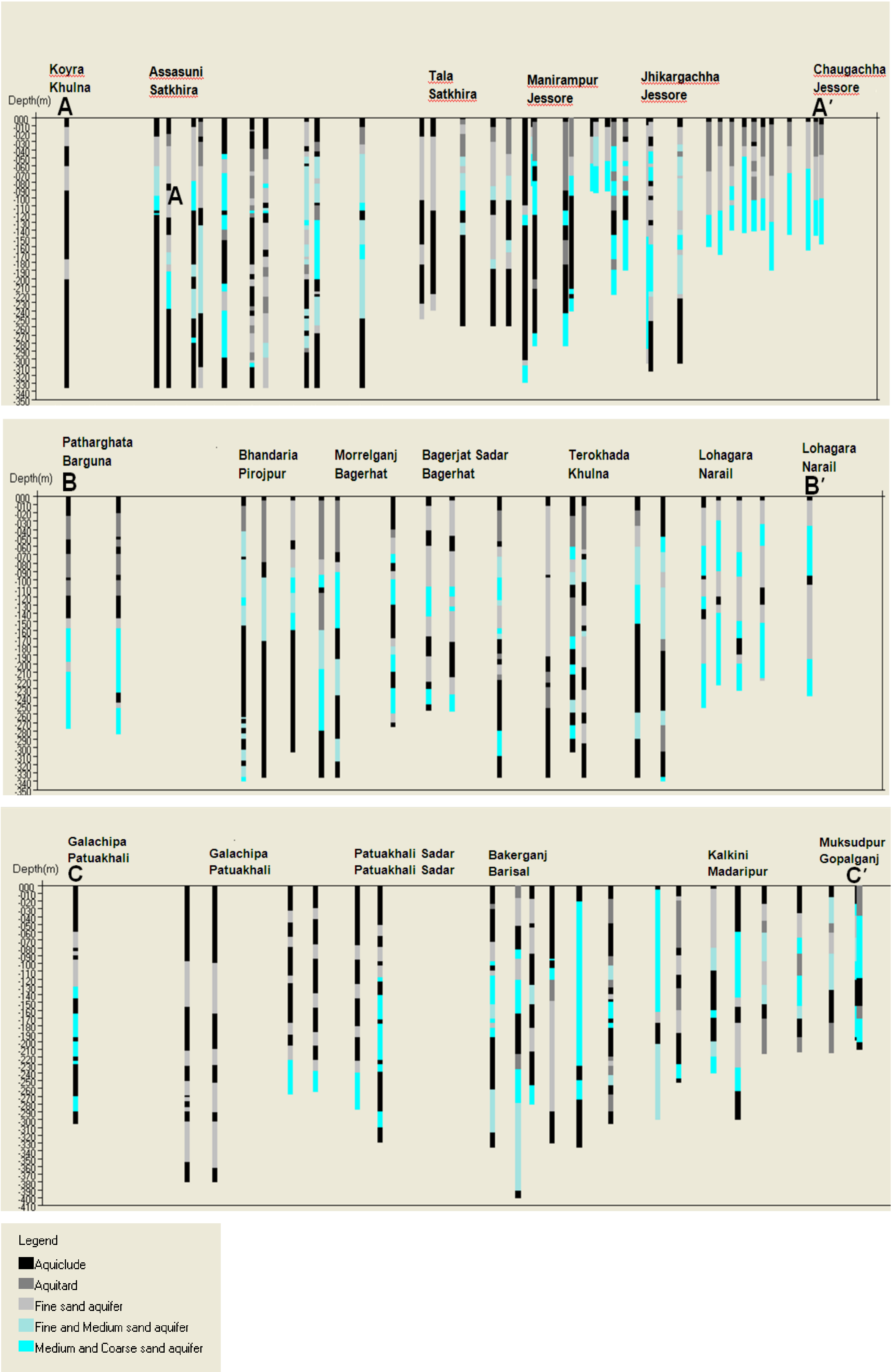


Figure 5.22 Columnar Sections along the south-western region

5.5.2 Khulna aquifer system

The Khulna aquifer system has been studied in detail as a representative area of SW region. To understand the Khulna aquifer systems, lithological characterization and hydrostratigraphic classification has been undertaken to identify the boundary of each individual unit.

Hydrostratigraphic cross sections have been used to determine the lateral and vertical extent as well as the depth of subsurface sediment formations particularly the aquifers in the study area. All together four cross-sections have been produced two of which are in the west - east direction, one along the northwest-southeast direction and one along the southwest - northeast direction (Figure 5.23). These subsurface cross sections reveal that aquifer and aquitard layer gradients are dissimilar to surface topography but overlying aquitard units separate all three aquifer units from each other.

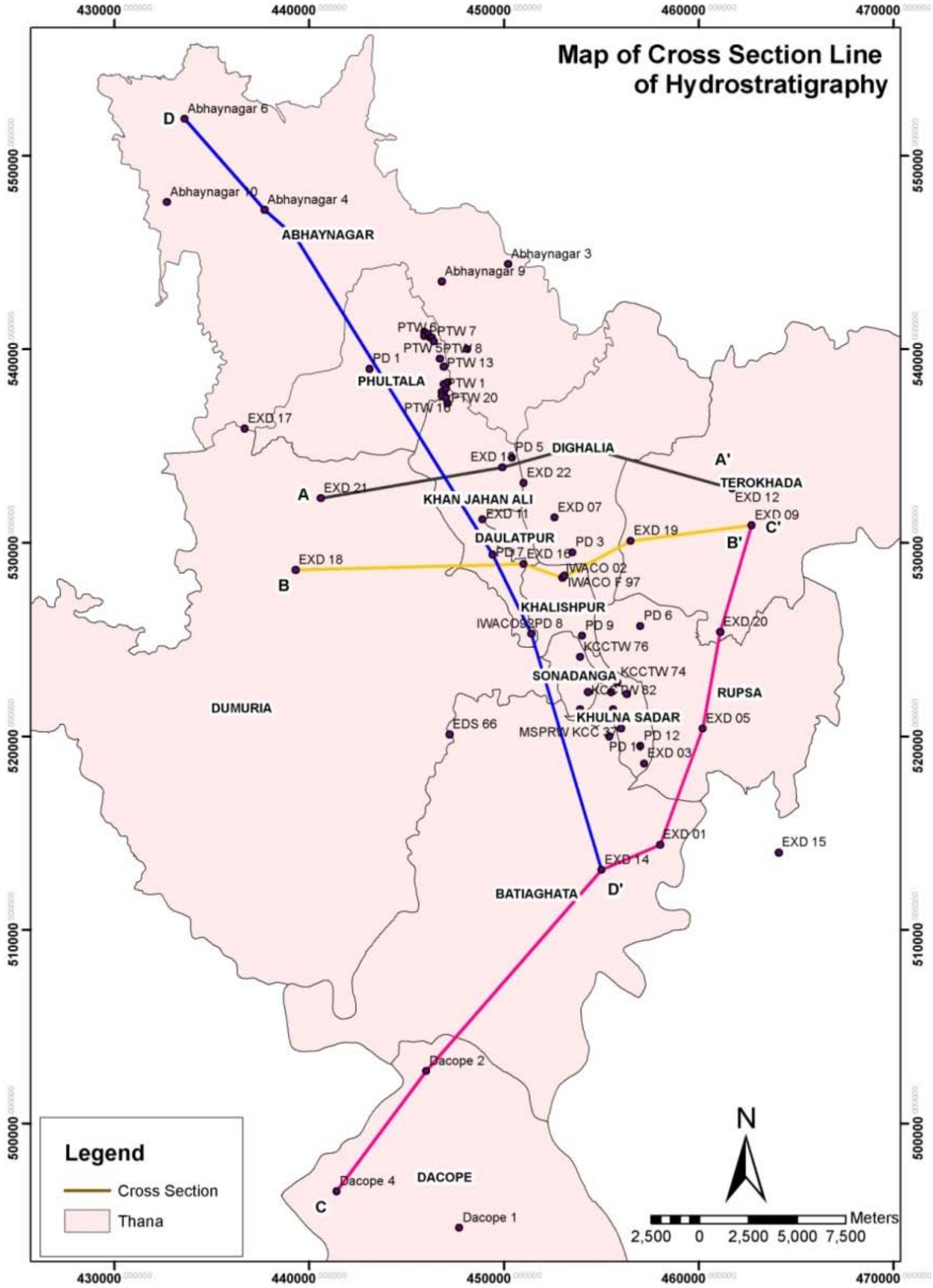


Figure 5.23 Cross section lines along the lithologs

A review of available hydro-geological reports revealed that the subsurface hydrostratigraphy of the study area has been studied in detail only up to a depth of about 360 m. Three different major aquifer layers have been identified which are separated by intermittent clay layers. The clay layers are thin in the south but become thicker towards the north and in some cases they exceed 200 m. A brief description of each of the three identified aquifer layers is presented below.

Upper shallow aquifer 1 usually exists within 50 m of the ground surface. The lower shallow aquifer layer 2 exists at around 100 m depth with relatively constant thickness, but has a southwards dipping direction. The deeper aquifer layer exists at about 250 m from the ground surface. This deeper aquifer is very thick in the south but reduces towards the north. It is about 100 m thick in Rupsha area. The deeper aquifer layers are more granular than the shallow aquifer layers. The sandy layers are also discontinuous and non-consolidated. The deeper aquifer is of confined type and is generally the only fresh groundwater resource in the study area. It is believed that this deeper aquifer is regularly recharged with through flow from distant areas.

West-East trending cross sections (AA' and BB'):

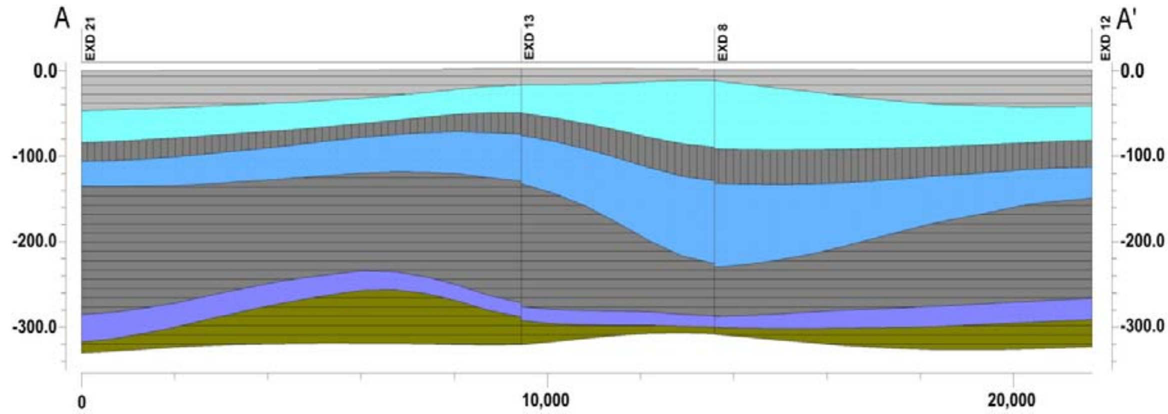
Cross sections AA' and BB' in Figure 5.24 are along the west-east direction. Both cross sections reveal that the aquifer units 1 and 2 exist throughout the cross section lengths from west to east (Figure 5.24). The units are thicker in the middle and relatively thinner towards the east and west. Aquifer unit 3 is also continuous but is much thinner than the upper two units. The depth of three units is variable throughout the cross section length.

South West-north east trending cross section (CC'):

Hydrostratigraphic cross section CC' (Figure 5.24) is along the southwest - northeast direction and covers middle to lower parts of the study area. The thickness of the aquifer unit 1 varies from southwest to northeast. Unit 2 is much thicker than unit 1 in the middle parts. Unit 1 thins where unit 2 becomes thicker. Unit 3 is much thicker in the northeast than in the southwest. Similar to cross sections AA' and BB', the depth of all three units is variable.

Northwest - southeast trending cross section (DD'):

Northwest - southeast cross section DD', reveals variable thickness of the three hydrostratigraphic units. Unit 1 is thicker in the northwest than in the southeast. All three units exhibit undulation with sharp dips and rises.



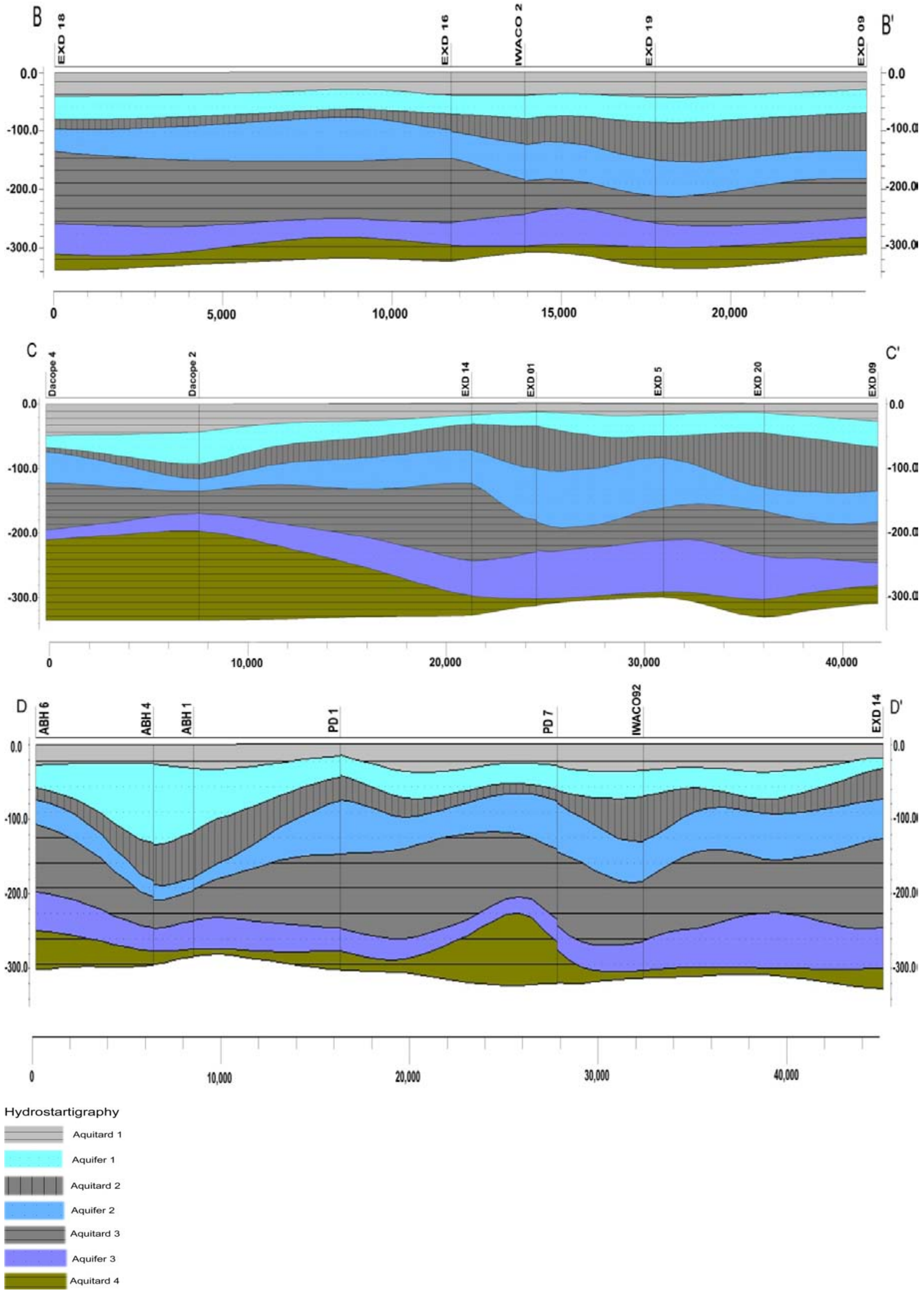


Figure 5.24 Hydrostratigraphic cross section according to Figure 5.23

5.5.3 Barisal-Patuakhali aquifer system

A review of available reports, data, and geological logs up to 400 m depth revealed a relatively complex system of aquifers which are separated by intermittent aquitards (Figure 5.25 and Figure 5.26). Where present the thickness of three aquifers varies both in horizontal and vertical direction. The aquifer-1 exists between 140 and 250 m in the northern parts and between 20 and 140 m in the middle parts and between 100 and 160 m in the southern parts. The aquitard 2 becomes thin in the middle parts. A cross section in west - east direction shows a varying thickness and depth of aquifers in southern parts of the area. In middle parts, both (1 and 2) aquifers are relatively thick which are separated by relatively a thin aquitard.

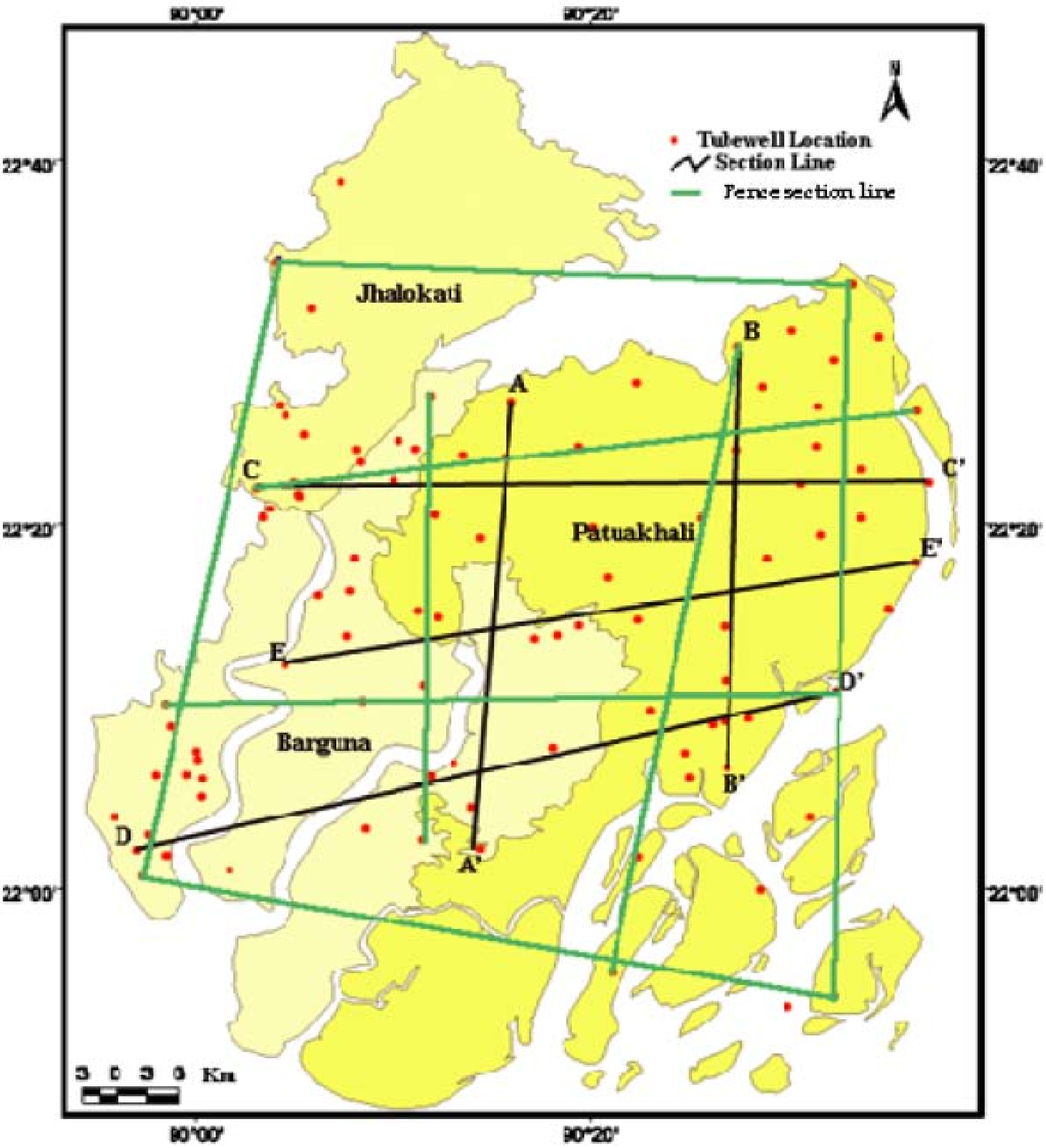
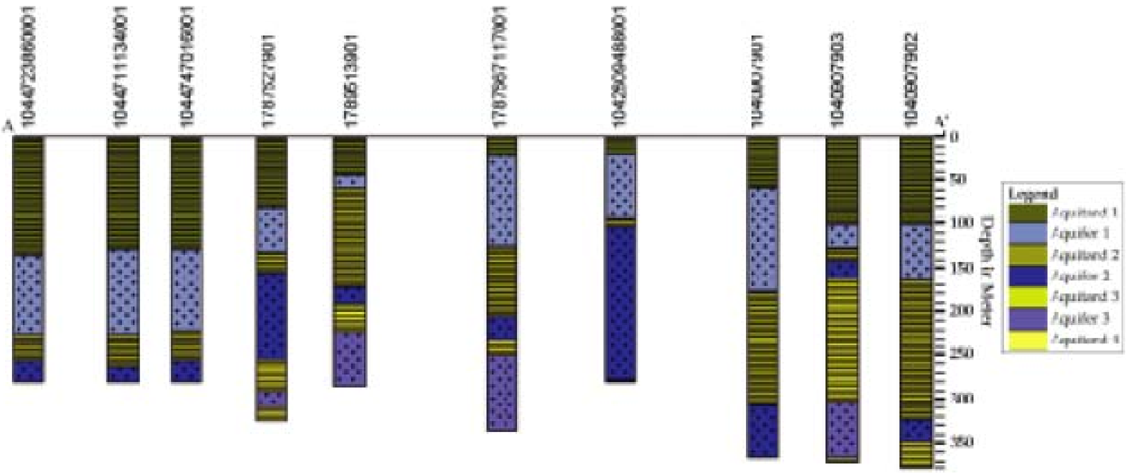
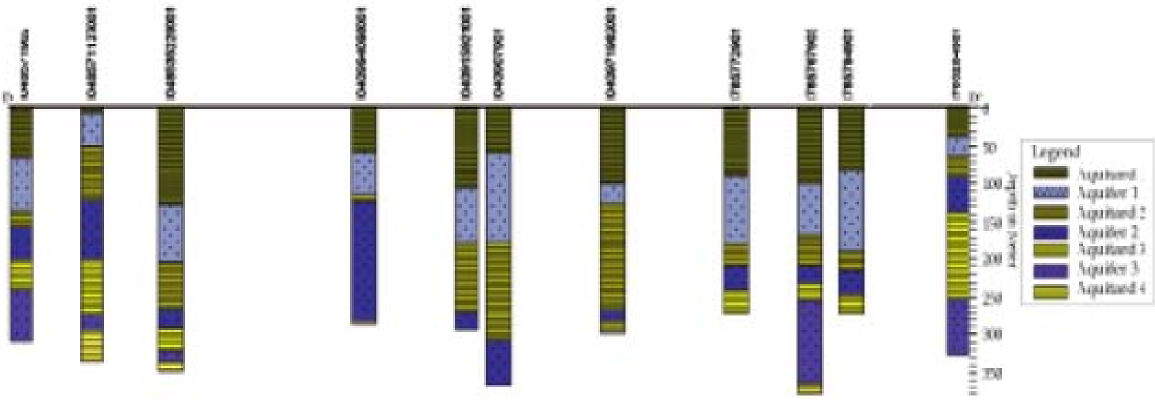


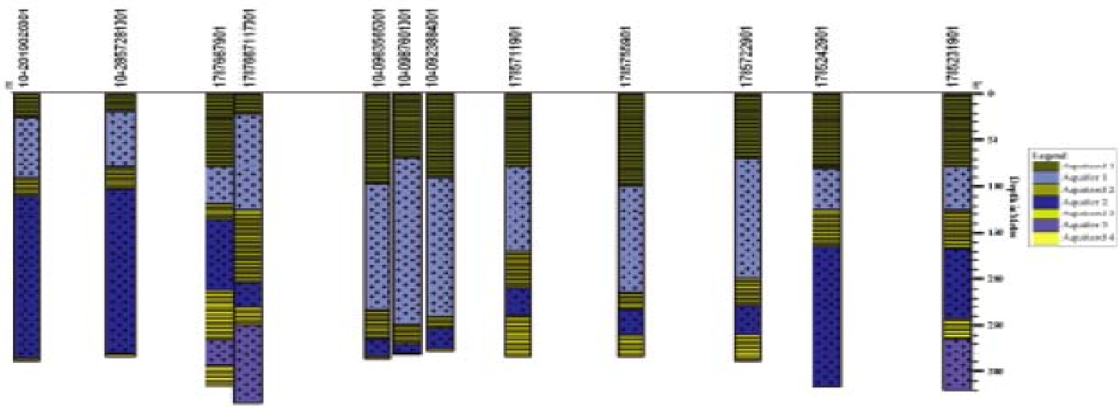
Figure 5.25 Location map of borelogs and hydrostratigraphic cross sections for the Barisal-Patuakhali



Section A-A/



Section D-D/



Section E-E/

Figure 5.26 Hydrostratigraphic cross sections for the Barisal- Patuakhali area

5.6 Trends in groundwater level

Figure 5.27 shows the trend analysis of groundwater level data available from the Bangladesh Water Development Board. The map does not include data from Jessore, Narail, Shariatpur, Chandpur, and Barguna districts of the southern coastal zone as the data were not available during the time of analysis. Chittagong and Cox's Bazar were not considered in the analysis. There are a few locations where groundwater levels are declining because they do not fully recover during the monsoon season. There is evidence of dry season groundwater level decline in a few locations in Satkhira and Gopalganj districts where groundwater irrigated areas are largest but they mostly recover during the monsoon season. At some locations groundwater levels also have a rising trend (Figure 5.27).

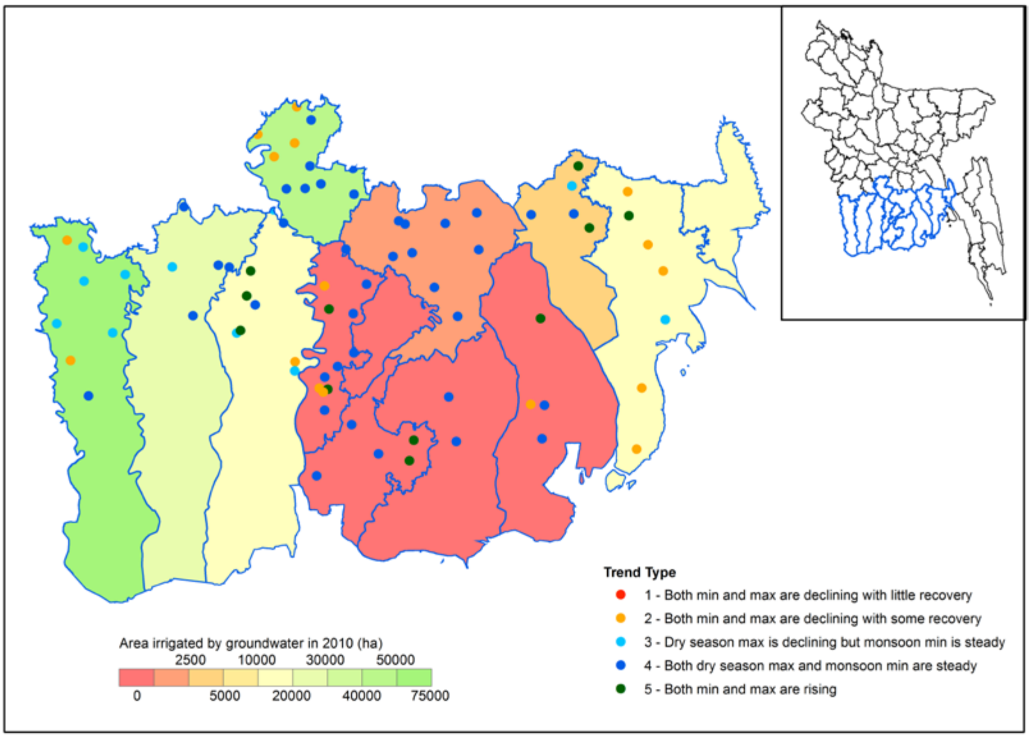
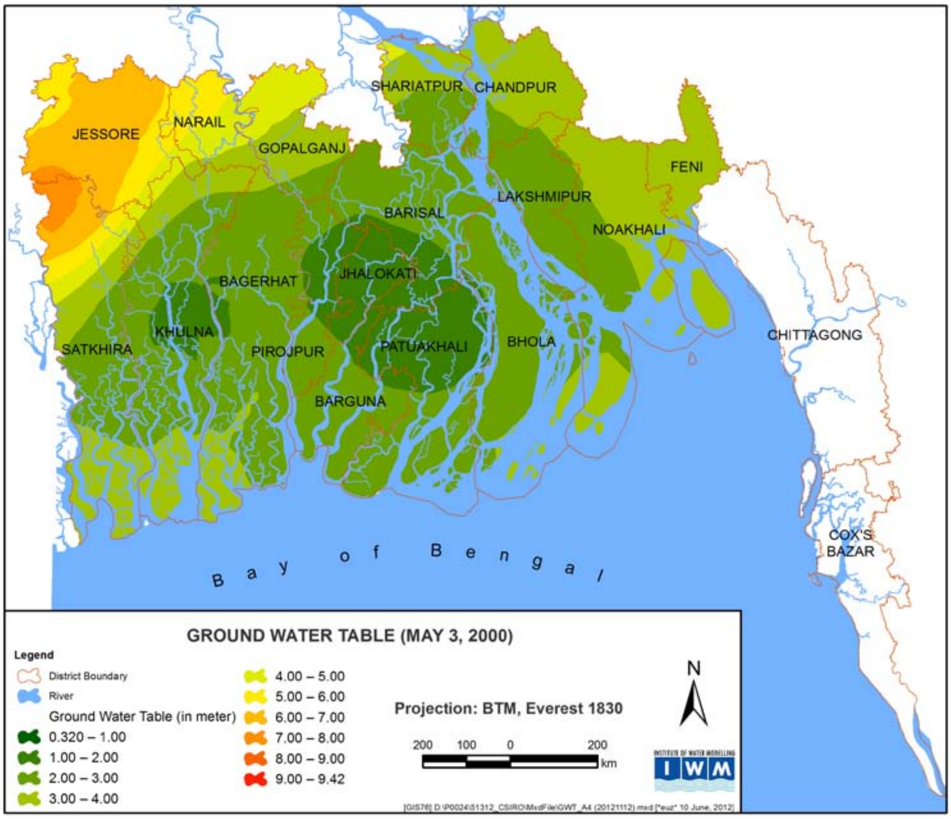


Figure 5.27 Groundwater trends in the south-western coastal districts of Bangladesh

Figure 5.28 and 5.29 shows the pre and post monsoon groundwater level surface maps for the whole southern coastal region. Pre-monsoon depth to groundwater level varies from 0.32 to 9.42 m in 2000 and 1.01 to 9.82 m in 2010. In general, the groundwater table is closer to the surface in the area adjacent to the coast and deepest in the area further from the coast. The deepest groundwater is in the Jessore districts, where there is intensive groundwater irrigation (discussed later in Section 5.9). The groundwater level hydrograph of a well in Jessore Sadar (district headquarters) is shown in Figure 5.30. The groundwater level at Jessore Sadar mainly varies between 3 m and 9 m. It rises in response to monsoon rains and declines in response to groundwater abstraction and evapotranspiration during the dry season. It shows stable temporal trends despite recent increases in groundwater abstraction.

Due to recharge during the monsoon season, groundwater level rise much closer to the surface as shown in Figure 5.29. In 2010, groundwater in the southern 2/3 of the coastal zone was between 0.37 and 1.00 m deep. In 2000, this was between 0.74 to 1.00 m. This indicates groundwater level is rising in some parts of the zone. As the groundwater table is within 1 m of the surface, clearly capillary rise can be expected to be a widespread phenomenon in most of the south, with implications for rabi cropping. The maximum depth to groundwater level has increased in some parts from a maximum of 4.26 m to 6.75 m. While some of this decline in groundwater table may be due to increased pumping it may also be due to variation in rainfall between these two years. Barguna is one of the districts where groundwater is within a meter of the surface at the end of the monsoon season. Barguna Sadar groundwater levels mainly fluctuate between 0.5 and 1.8 m from the soil surface (Figure 5.31). The hydrograph show slightly rising temporal trends in groundwater levels. Barguna has minimal abstraction (Figure 5.27).



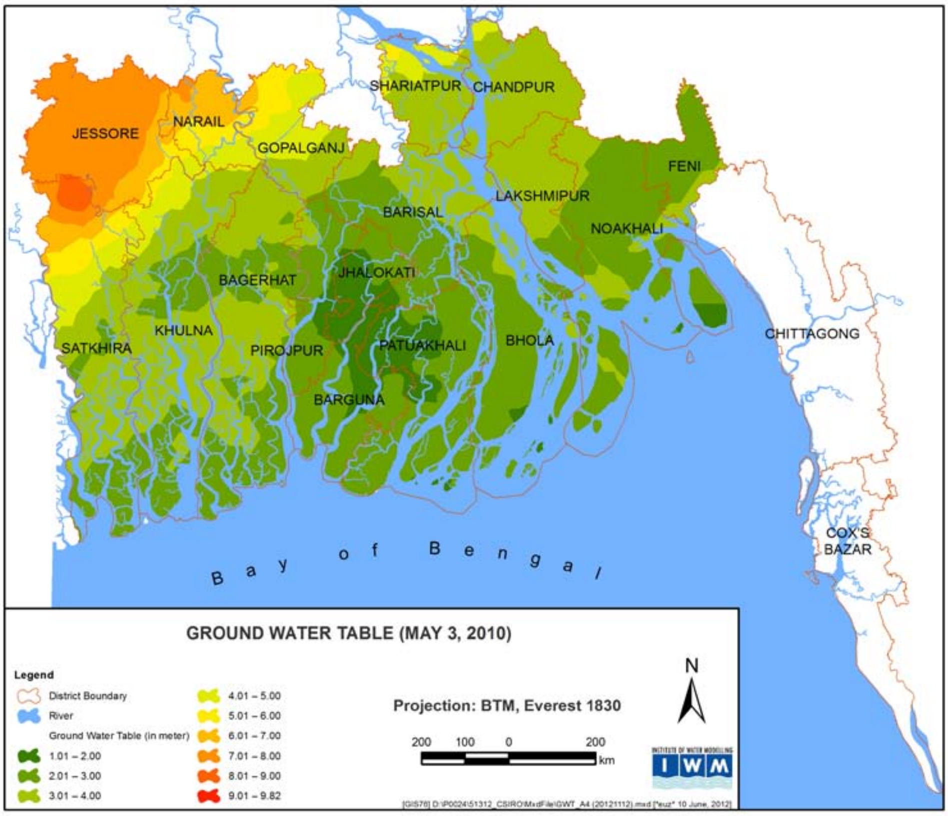
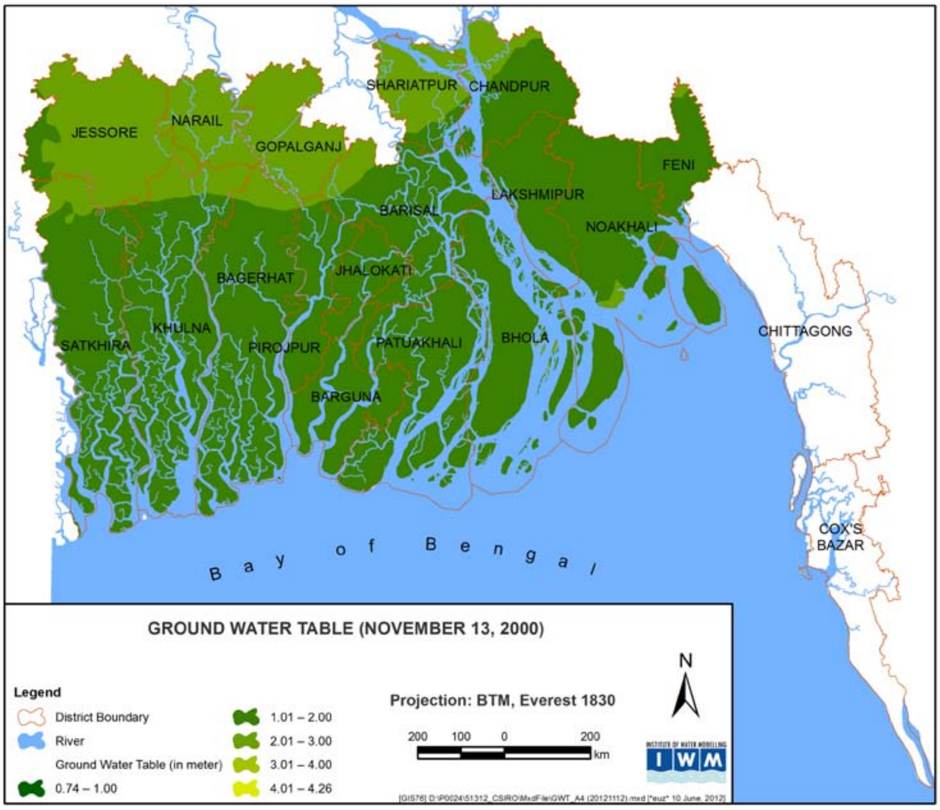


Figure 5.28 Pre-monsoon groundwater table surface map in the southern coastal zone for the year 2000 (above) and 2010 (below)



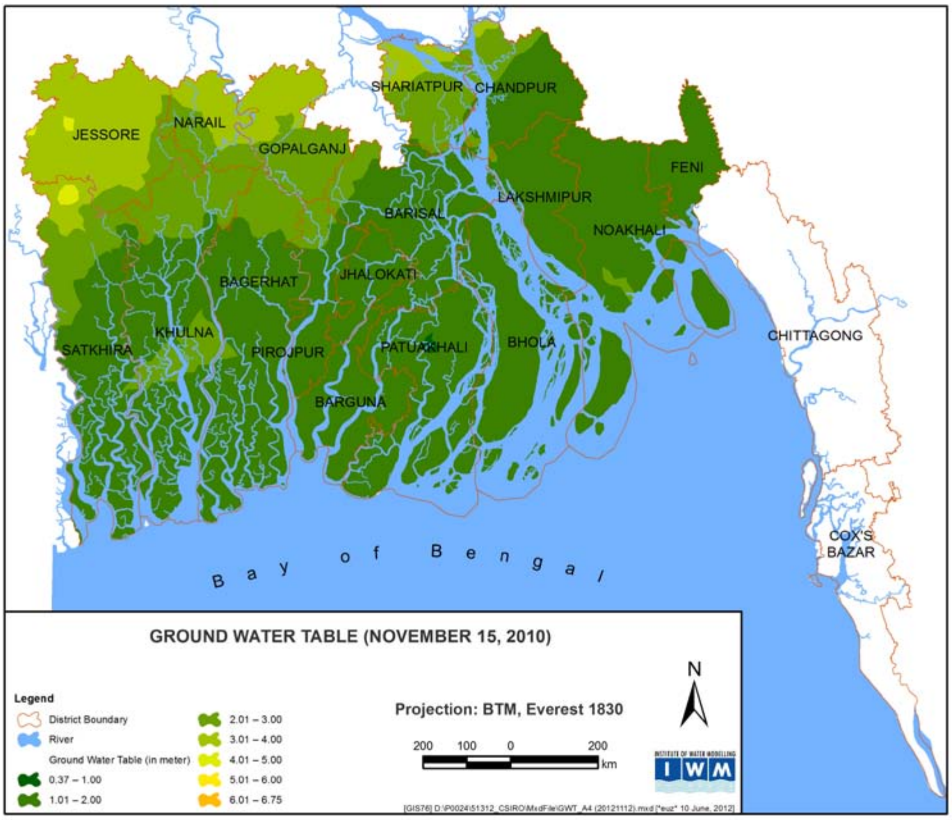


Figure 5.29 Post-monsoon groundwater table surface map in the southern coastal zone for the year 2000 (above) and 2010 (below)

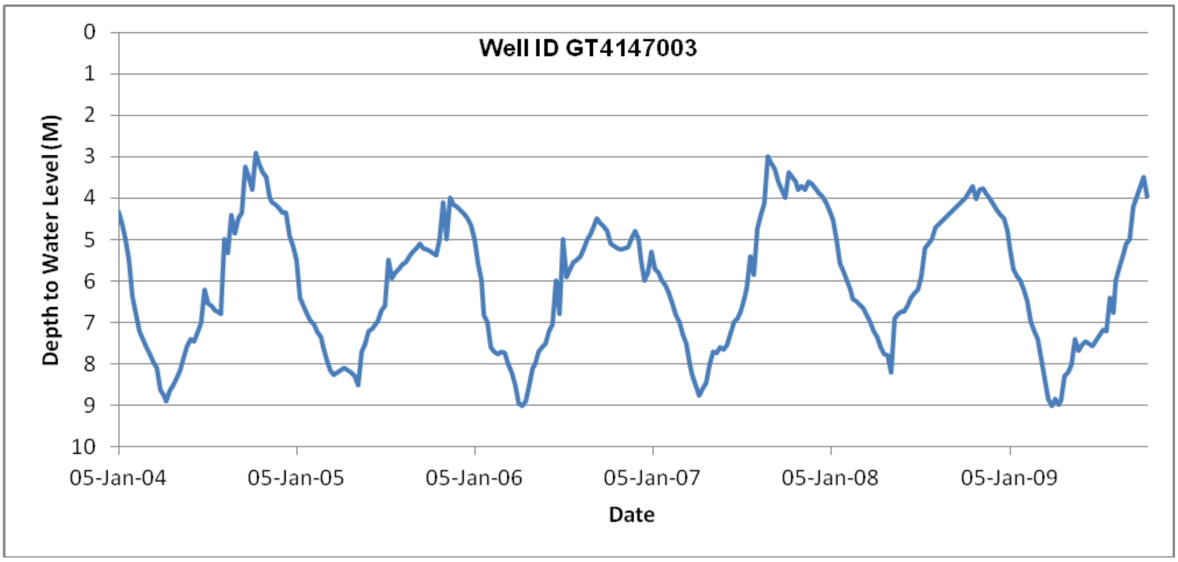


Figure 5.30 Temporal variation in groundwater level between 2004 and 2009 at Jessore Sadar

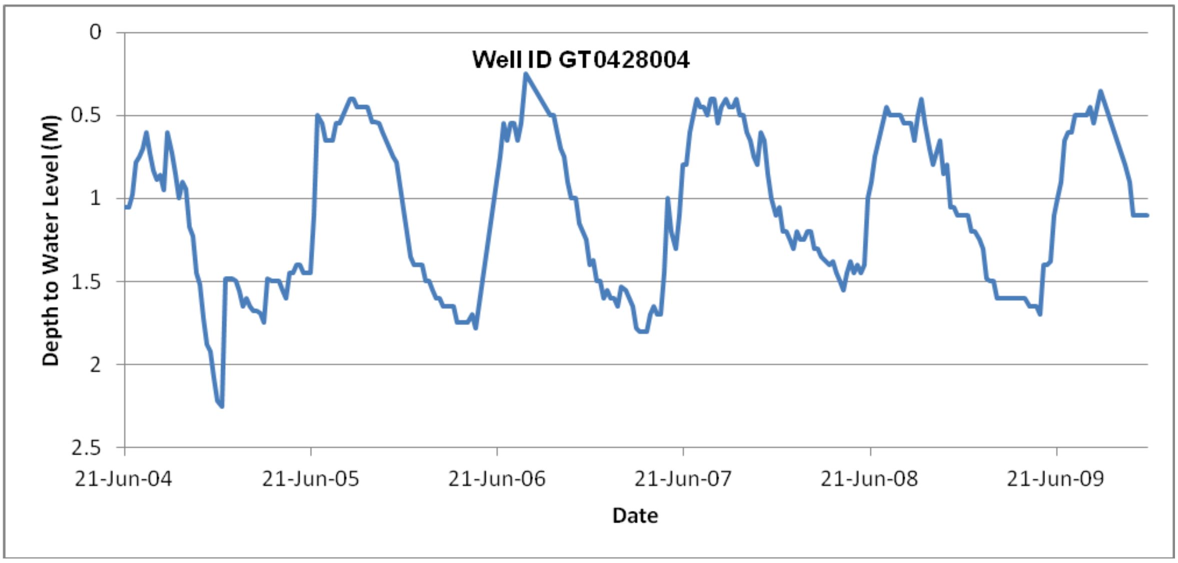


Figure 5.31 Temporal variation in groundwater level between 2004 and 2009 at Barguna Sadar

Since groundwater levels are either stable or rising in many coastal districts it means that additional groundwater abstraction is potentially possible in the coastal districts for irrigation or other supplies provided its quality is suitable for intended use.

A groundwater contour map is constructed using the year 2008 maximum depth to groundwater data from the study area (Figure 5.32). The maximum depth to groundwater varies within between 1.0 m and 6.5 m in the study area. Groundwater levels are shallow in the south and deep in the north of the study area. The gradients are relatively flat in the southern and eastern areas and steep in the northern and upper western parts of the study area. Groundwater movement should be relatively slow in areas where the gradients are flat and faster in areas where gradients are steep. A small cone of depression has developed to the south-west of the Gopalgonj district. Groundwater flow direction is local (Figure 5.33). It is not possible to ascertain any regional groundwater flow direction from this contour map.

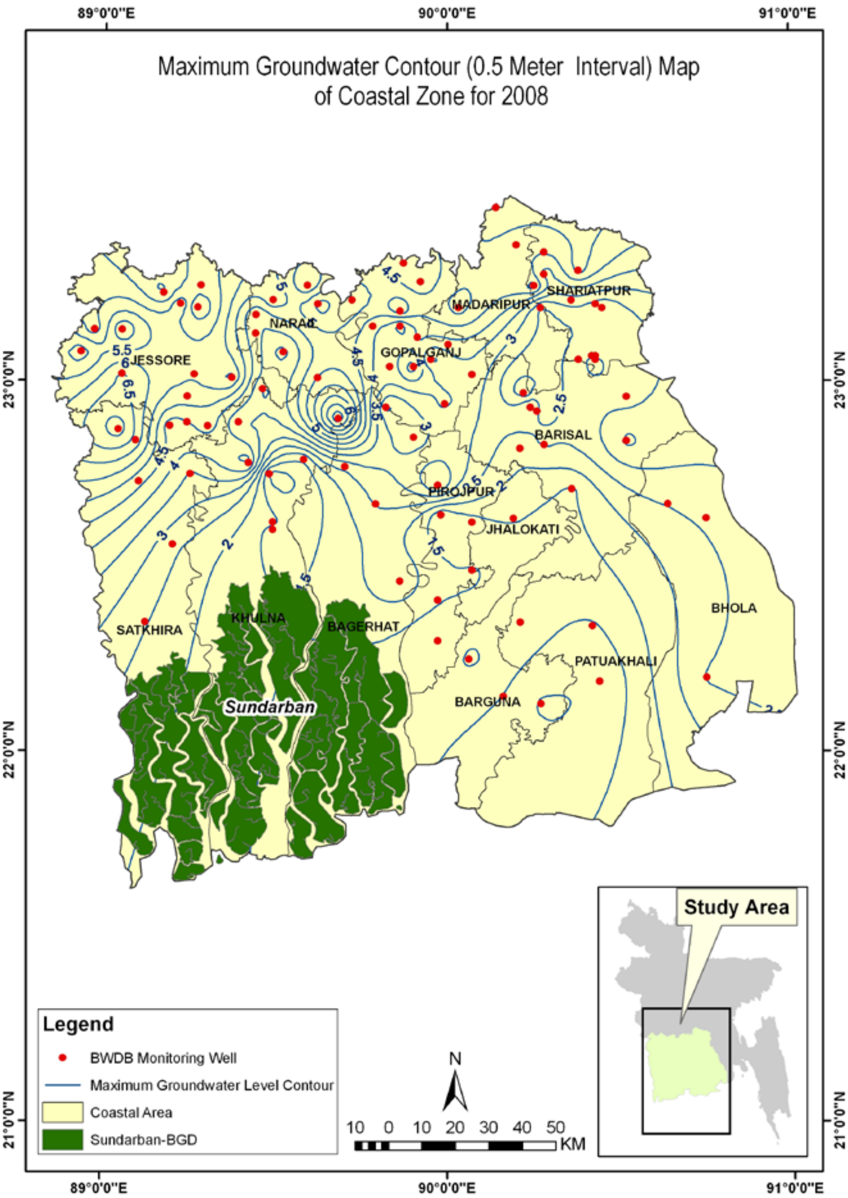


Figure 5.32 Maximum depth to groundwater contour map of the study area for 2008 (the name of the district does not indicate the location of the district head quarter)

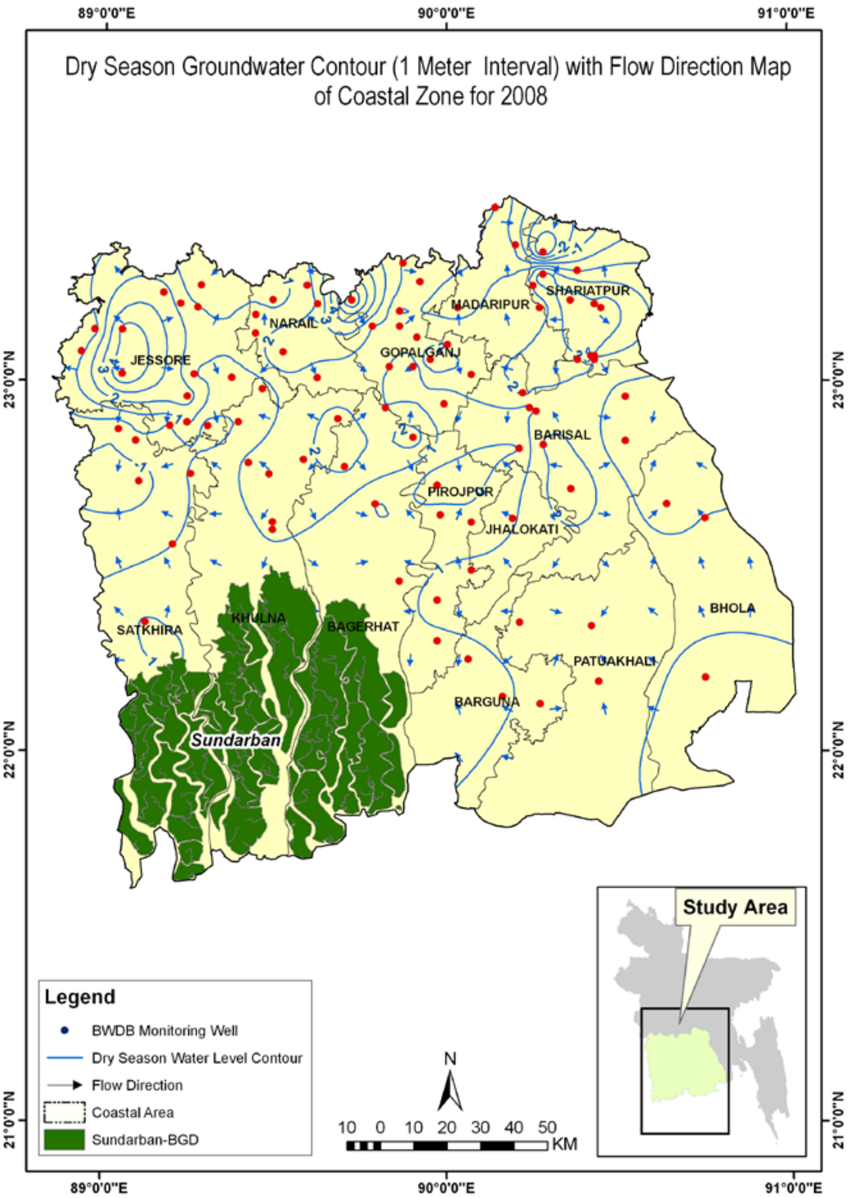


Figure 5.33 Groundwater flow direction in the south-western coastal Bangladesh during the dry season of 2008

5.7 Groundwater quality

Arsenic contamination and groundwater salinity are the major quality constraints in the coastal aquifers. The arsenic contamination in groundwater is above the permissible limit of 50 ppb in 16 of 19 coastal districts of the country (Figure 5.34). Generally the contaminated aquifers are between 7 and 120 m deep. The younger alluvial aquifers of the Holocene containing finer sediments lying at shallow depths have higher concentrations of arsenic. Arsenic bearing aquifers vary in depth and thickness at various locations. The contamination is complicated by the high variability of occurrence and distribution at both local and regional scales.

Groundwater salinity is another common problem in the coastal belt and islands of Bangladesh. Groundwater salinity data for the southwest region for April 1997 and April 2000 were collected from SRDI, processed and is compared in Tables 5.1 and 5.2. The area of saline groundwater has increased by about 4.7% over the three-year period. There is a significant increase in the very high saline groundwater areas (> 5 dS/m) over this period. The largest increase in the saline groundwater area is observed in the

Madaripur and Shariatpur districts (Table 5.2). About 104,000 ha of new land has been affected by various degrees of groundwater salinity over the three year period from 1997 to 2000.

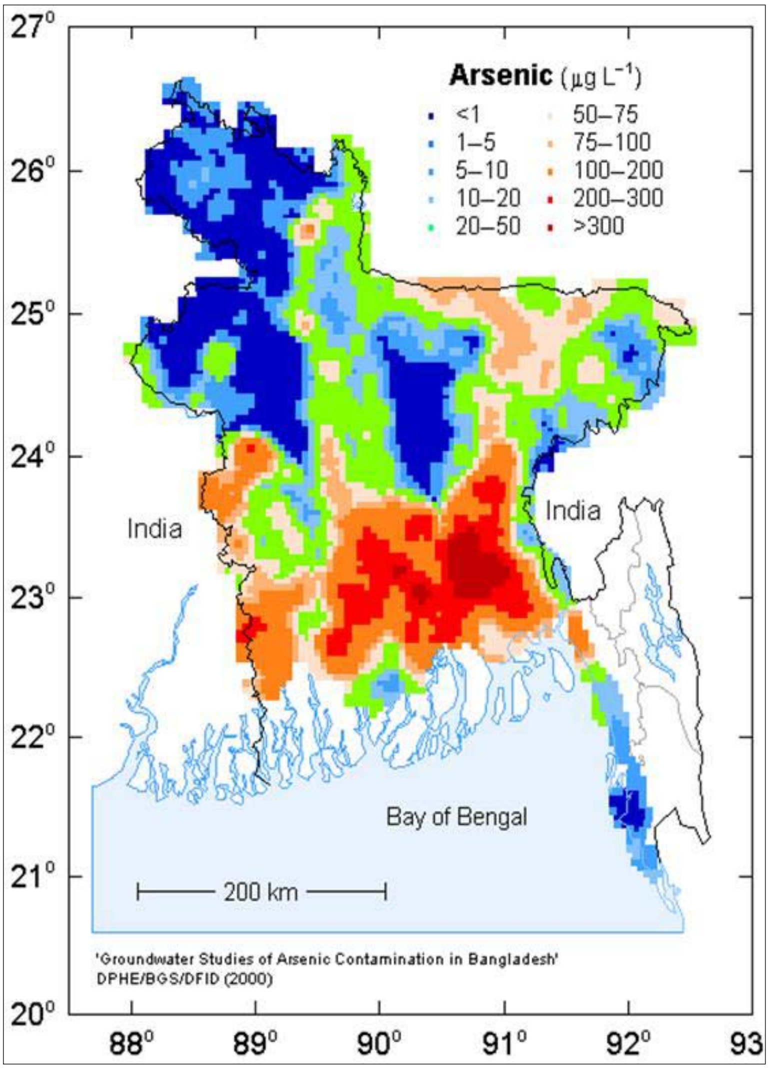


Figure 5.34 Groundwater arsenic contamination in the study area (BGS, 1999)

Table 5.1 Comparison of the saline groundwater areas in the south-western region of Bangladesh between April 1997 and April 2000 (SRDI data)

Salinity class (dS/m)	Saline groundwater area (ha) April 1997	Saline groundwater area (ha) April 2000	Increase in saline groundwater area (ha) 1997-2000
(< 0.75)	12,519	87,391	74,872
(0.75–3.0)	1,320,046	911,680	-408,366
(3.0–5.0)	593,828	905,210	311,382
(5.0–10.0)	287,987	368,012	80,025
(> 10.0)	10,343	56,551	46,208
Total Area	2,224,723	2,328,844	104,121
% Total			4.68%

Table 5.2 District-wise distribution of saline groundwater areas for the years 1997 (April) and 2000 (April) in the southwest region of Bangladesh

District name	Saline groundwater area (ha) 1997	Saline groundwater area (ha) 2000	Increase in saline groundwater area (ha) 1997-2000
Bagerhat	202,391	202,451	60
Barguna	132,523	132,523	0
Barisal	227,713	228,400	687
Bhola	182,330	182,330	0
Gopalganj	154,411	154,411	0
Jessore	253,977	253,977	0
Jhalokati	71,506	71,506	0
Khulna	206,090	206,090	0
Madaripur	109,049	112,369	3320
Narail	96,421	96,421	0
Patuakhali	245,846	245,846	0
Pirojpur	110,988	110,988	0
Satkhira	231,478	231,478	0
Shariatpur	0	100054	100054
Total	**2,224,723**	**2,328,844**	**104,121**

Bangladesh Agricultural Development Corporation (BADC) collected groundwater salinity data (EC) from various aquifer depths (6 m to 60 m from the ground surface) in the coastal zone during 2010, 2011 and 2012. Groundwater salinities maps were prepared using data from each sampling depth. Spatial groundwater salinity from three depths (6, 30 and 52 m or 20, 100 and 170 ft) is shown in Figures 5.35 to 5.37 respectively for 2010, 2011 and 2012. Groundwater salinity is relatively high near the coast and low away from the coast. Higher groundwater salinity near coastal areas is most probably due to interactions with sea water. It is generally lower at shallow depths and higher at greater depths. Groundwater salinity is generally higher during 2011 than 2010 but lower during 2012 which may be due to the time of water sampling for groundwater salinity. Local scale higher salinity at some locations may be due to excessive groundwater abstraction and subsequent movement of higher saline groundwater from outer areas into the cone of the depression, excessive leaching of salts from the soil surface due to extra storage space created by excessive pumping and shrimp cultivation due to infiltration of concentrated solution from shrimp ponds to aquifers. Groundwater irrigation may be limited in areas of high groundwater salinity unless it is used for irrigation of salt tolerant varieties of crop and horticultural species.

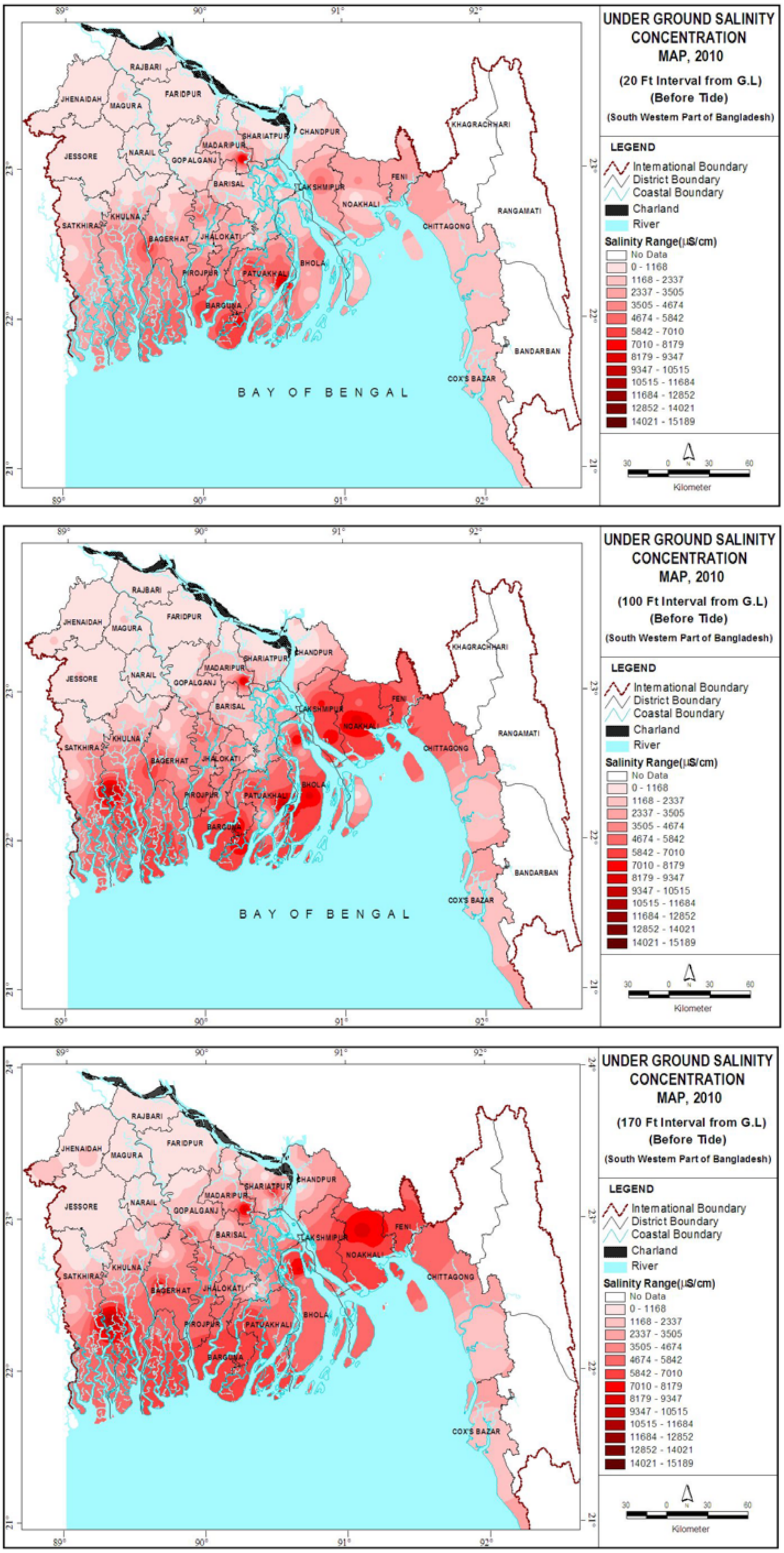


Figure 5.35 Spatial variations in groundwater salinity at three depths during 2010 in the coastal zone (1 $dSm^{-1} = 10^3\ \mu Scm^{-1}$, source: BADC)

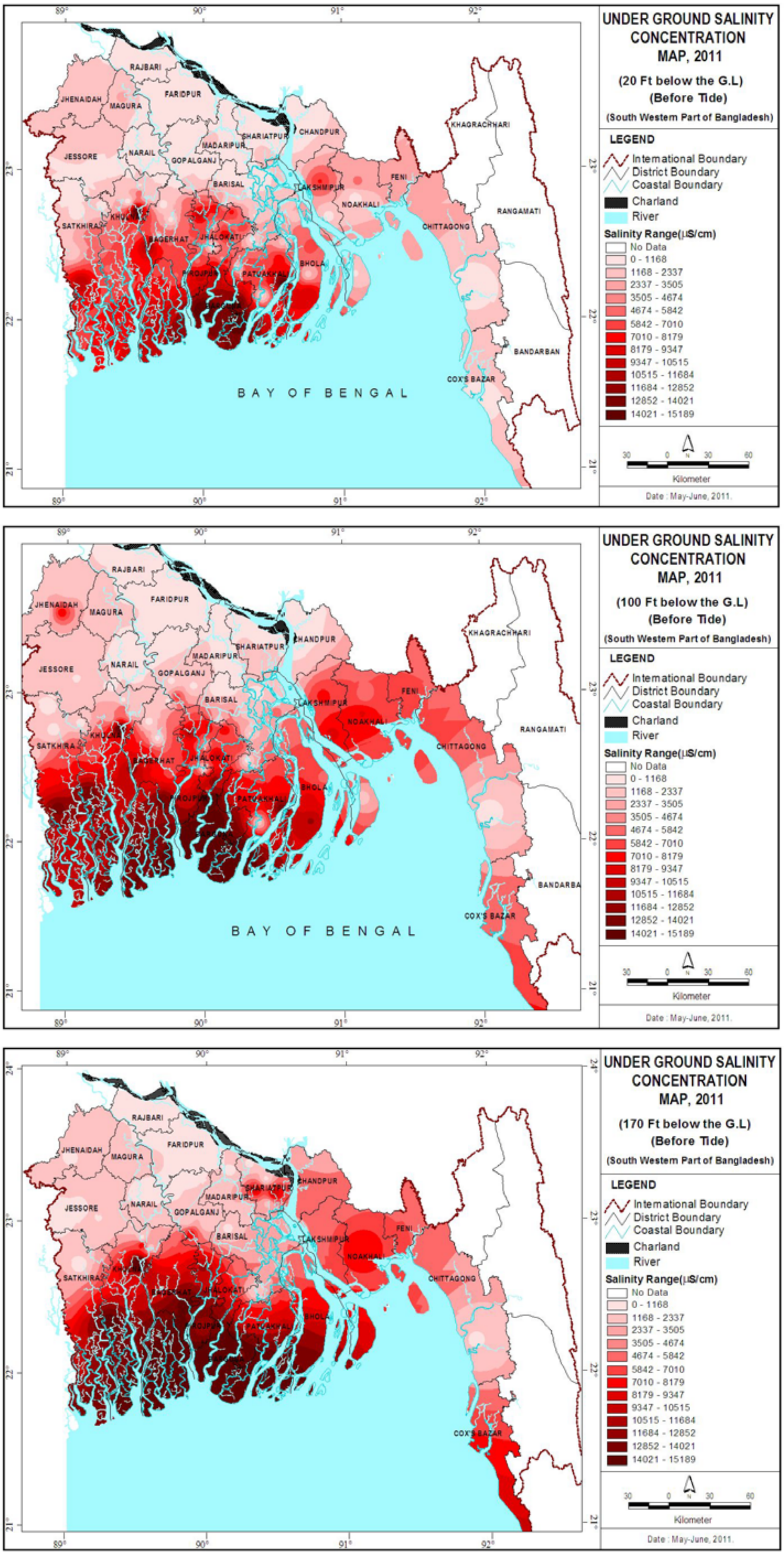


Figure 5.36 Spatial variations in groundwater salinity at three depths during 2011 in the coastal zone (1 $dSm^{-1} = 10^3$ μScm^{-1}, source: BADC)

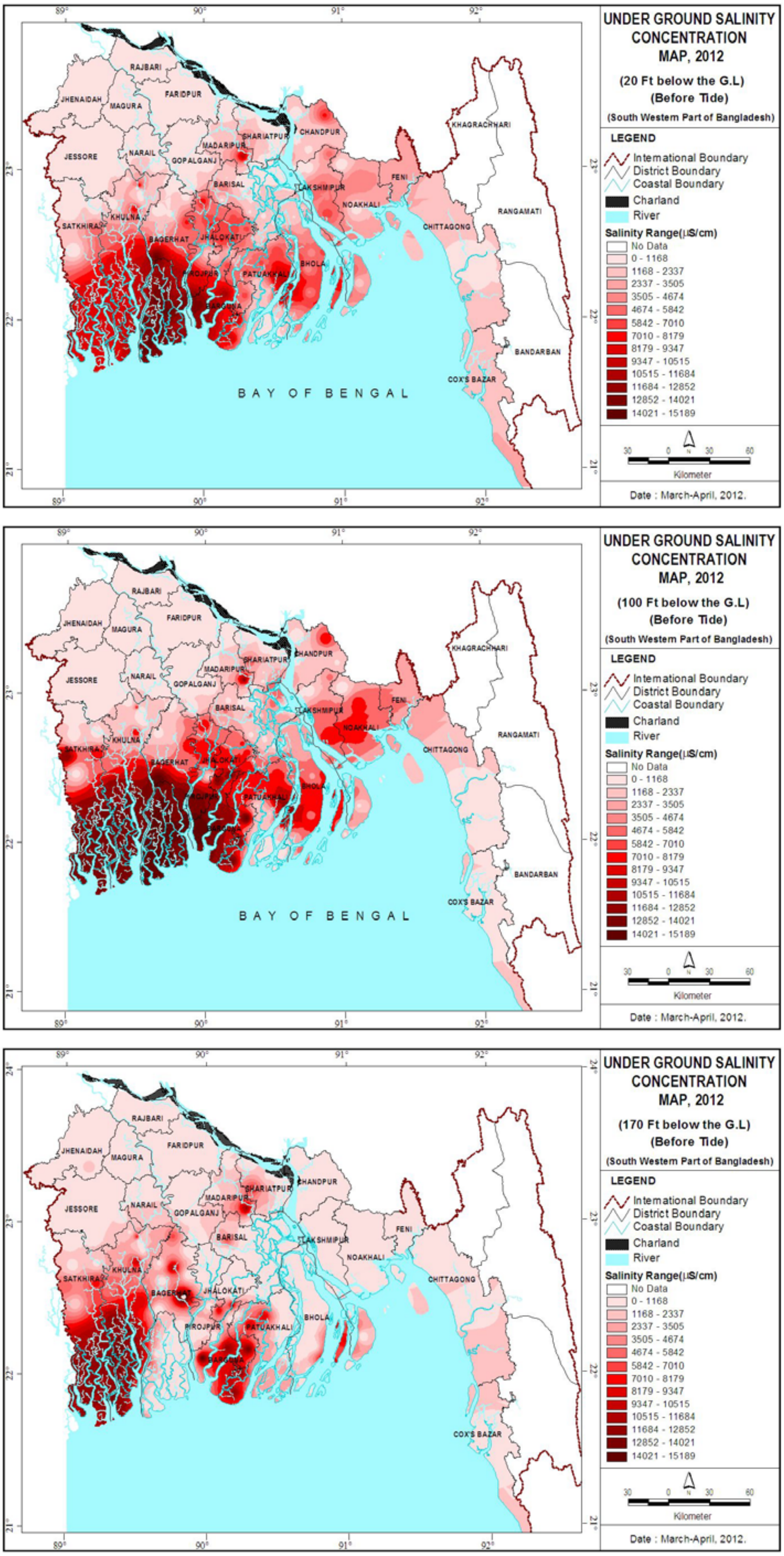


Figure 5.37 Spatial variations in groundwater salinity at three depths during 2012 in the coastal zone (1 $dSm^{-1} = 10^3\ \mu Scm^{-1}$, source: BADC)

5.8 Soil salinity

Salinity is a critical issue for the people of coastal Bangladesh. A rise of soil salinity has been noticed since 1975. About 1.02 million ha (about 70%) of the cultivated lands of the south and south-west are affected to various degrees by soil salinity (SRDI, 2000). About 0.282, 0.297, 0.191, 0.450 and 0.087 million hectares are affected with very slight (EC <2.0-4.0 dSm^{-1}), slight (EC 4.1-8.0 dSm^{-1}), moderate (EC 8.1-12.0 dSm^{-1}), strong (EC 12.1-16.0 dSm^{-1}) and very strong (>16.1 dSm^{-1}) salinity, respectively. The soil salinity data for 1973, 1997, 2000 and 2009 were collected from SRDI (SRDI, 1998, 2001, 2009, 2010, 2012) and processed to produce salinity maps (Figure 5.38). The salt affected areas and salinity increase over four decades in the greater districts are listed in Table 5.3. Table 5.4 lists areas of the greater districts (now called regions) under various degrees of salinity. Soil salinity has increased significantly over the 36-year period (Table 5.3). The affected areas under S1 (2.0 to 4.0 dSm^{-1}) and S4 (> 16 dSm^{-1}) classes increased sharply in 2009 in the south-western zone (Table 5.4). In the south central region, the salinity increase has been observed in the S3 and S4 classes. Southeast region shows large changes in the S3 class. At present, areas under the highest salinity class (> 16 dSm^{-1}) are identified in the southwest and some in the southeast zone. However no such areas exist in the south central zone. Soil salinity intrusion in the southeast region is negligible but changes in soil salinity from S1 class to higher classes are observed.

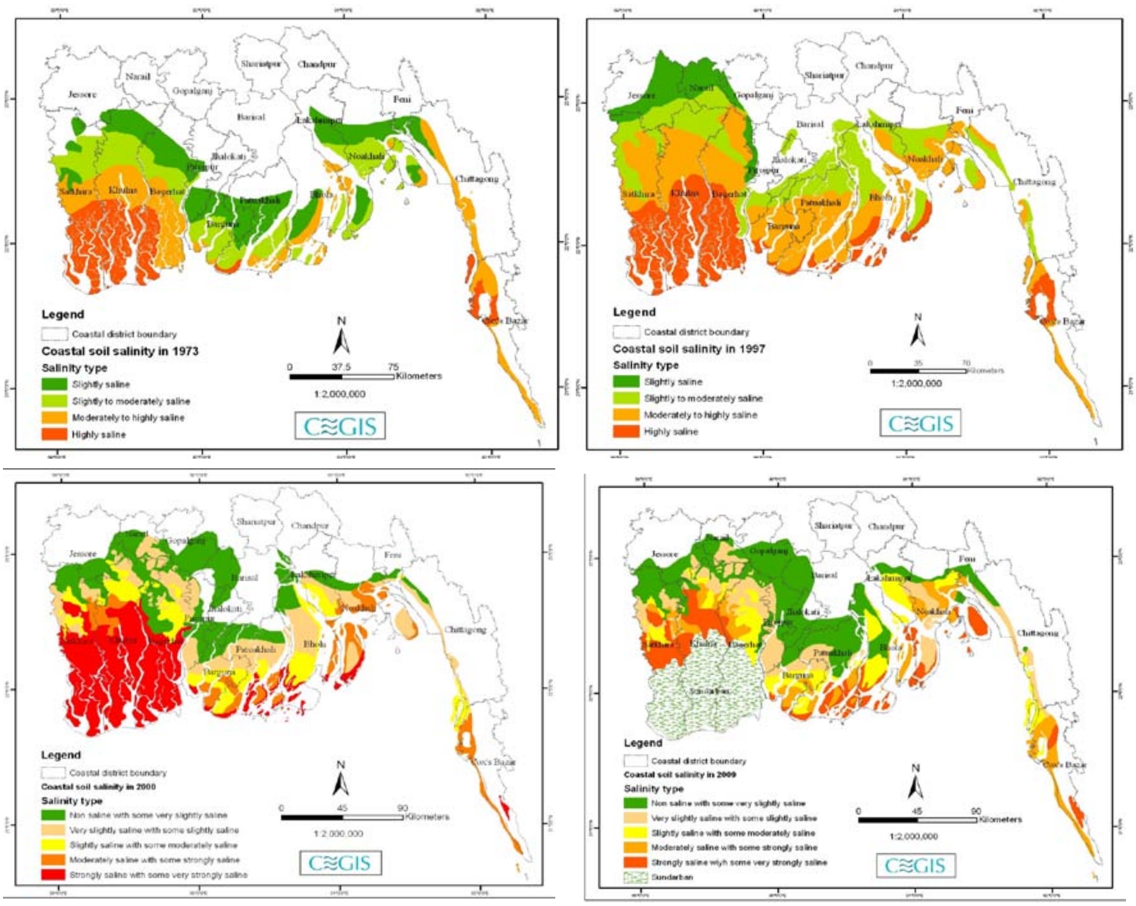


Figure 5.38 Soil salinity maps of coastal districts for 1973, 1997, 2000 and 2009 (SRDI Data)

Figures 5.39 and 5.40 show temporal trends in soil salinity in the greater districts of the coastal zone. The salt affected area is largest in Khulna and smallest in the Faridpur district (Figure 5.39). The salt affected areas remain relatively unchanged in Chittagong, Noakhali and Faridpur and increase over time in the other greater districts. The soil salinity class S4 areas restricted to only two districts during 1973 have expanded to some other districts over time (Figure 5.40).

Table 5.3 Changes in salt affected area in greater districts (1973-2009), SRDI data

Greater District	Salt Affected Area (000 ha)			Salinity increase over 4 Decades	
	1973	2000	2009	Area (000 ha)	Percent (%)
Khulna	374.4	417.5	432.2	57.8	16.5
Jessore	0.0	26.9	33.7	33.7	100.0
Barisal	61.6	136.6	149.1	88.7	102.8
Patuakhali	219.0	243.6	251.1	32.2	34.8
Faridpur	0.0	11.4	7.0	7.0	200.0
Noakhali	78.4	78.3	76.7	-1.7	5.9
Chittagong	100.1	106.5	106.8	6.4	13.8

Table 5.4 Soil salinity under different classes in the coastal zone

Greater District	Area under salinity classes (000 ha.)											
	S_1 (2.0-4.0 dSm^{-1}			S_2 (4.1-8.0 dSm^{-1})			S_3* (8.1-16.0 dSm^{-1})			S_4 (>16.0 dSm^{-1}		
	1973	2000	2009	1973	2000	2009	1973	2000	2009	1973	2000	2009
Khulna	48.7	93.7	88.0	255.2	119.9	102.3	52.1	161.3	170.5	20.7	48.4	68.4
Jessore	0.0	7.2	22.4	0.0	5.3	8.9	0.0	1.1	2.4	0.0	0	0.0
Barisal	29.6	60.1	77.0	32.7	43.6	42.2	0.0	28.6	24.1	0.0	5.3	3.0
Patuakhali	164.9	78.3	89.8	53.9	74.4	70.8	0.0	79.6	78.7	0.0	13.3	21.1
Faridpur	0.0	6.6	4.1	0.0	3.5	1.1	0.0	1.3	0.0	0.0	0.0	0.0
Noakhali	18.8	24.2	25.9	53.4	27.3	19.4	3.4	19.2	27.6	0.0	7.8	1.8
Chittagong	25.4	16.2	21.2	31.3	33.2	29.4	23.0	45.6	50.6	19.2	12.5	7.7

*S3= S3+S4, (S 3= 8.1-12.0 dSm^{-1}, S4= 12.1-16.0 dSm^{-1}); Source: SRDI, 2010

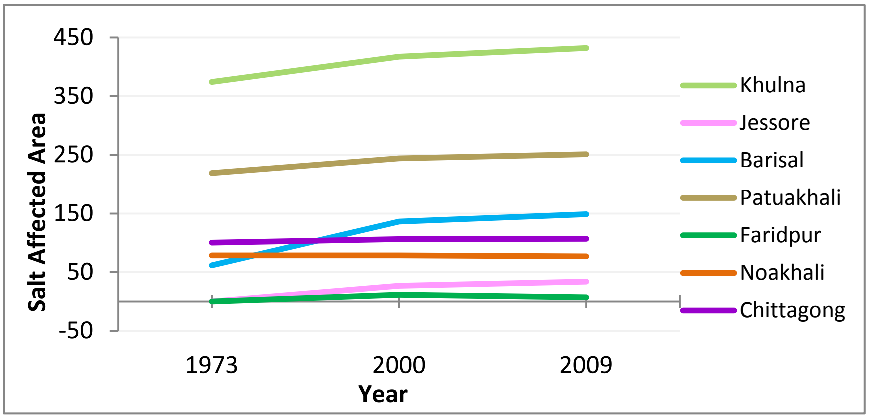


Figure 5.39 Temporal changes in salt affected areas of the greater districts

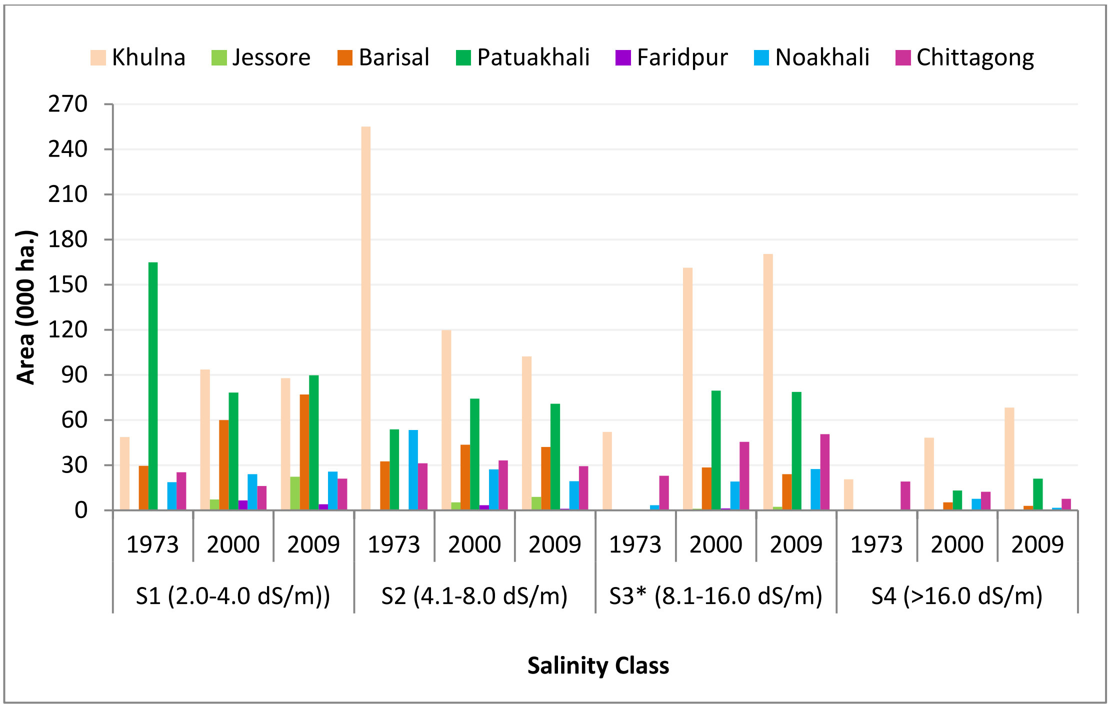


Figure 5.40 Changes in affected areas under various soil salinity classes in the greater districts

Agriculture is a major sector of the Bangladesh economy and southwest region of the country is suitable for growing rice. The soils of the coastal districts become saline in the dry season. However in the wet season, the northern part of the coastal districts is generally non-saline while the southern part of these regions remains non-saline to very slightly saline. Much land remains fallow during the dry season because crops cannot be grown due to salinity and lack of freshwater for irrigation. Ali (2005) investigated the loss of rice production in a village of the Satkhira district and found that rice production in 2003 was 1,151 metric tons lower than the year 1985, corresponding to a loss of 69 percent. Of the total production loss, 77 percent was due to conversion of rice fields into shrimp ponds and 23 percent was due to reduction in yield because of soil salinity (Sarwar, 2005).

Mondal (2001) studied the impacts of soil salinity on yield of various crops (Table 5.5) at Benerpota Farm of Bangladesh Water Development Board (BWDB) during 1986-87. The yield of wheat, barley millet, cheena, maize and chickpea was good when the salinity of irrigation water was between 1.55 and 1.8 dSm^{-1} but was reduced significantly when soil salinity was between 3.75 and 6.2 dSm^{-1}. A reduction in yield of at least 50 percent occurred in rice if irrigation water salinity was above 7.2 dSm^{-1}. This is a 12% reduction in yield per 1 dSm^{-1} increase in EC_e beyond the EC_e threshold of 3.0 dSm^{-1} (Allen et al., 1998). Most lands in the coastal zone are traditionally used for mono cropping with moderate to poor rain-fed rice yields during the monsoon. The land remains fallow due to high salt content (ECe > 8.0 dSm^{-1}) of the soil associated with the problem of quality of irrigation water (EC > 5.0 dSm^{-1}) during the rest of the year. A study by the World Bank (2000) suggested that increased salinity alone from a 0.3 meter sea level rise is likely to result in a reduction of 0.5 million metric tons of rice production. Sea level rise affects coastal agriculture, especially rice production in two ways. Salinity intrusion degrades soil quality that decreases or inhibits rice production. When the rice fields are converted into shrimp ponds, total rice production reduces due to a smaller area under rice production.

Farmers in this saline environment are inclined to convert from cropping to shrimp culture, as it is more profitable. But shrimp culture has long-term negative environmental impacts often unknown to farmers. In a relatively recent development, about 138,600 ha have been converted to Bagdha shrimp farming in the ecologically sensitive regions of southwest Bangladesh (EGIS, 2001) which border the Sundarbans, with 42,550 ha, 36,500 ha, and 49,550 ha being in the Satkhira, Khulna and Bagerhat districts, respectively. It's not just the increasing sea water intrusion; shrimp farming are a major cause of increasing salinisation as well. Shrimp farmers are usually well off and powerful who allow wilful flooding of polders with brackish/saline water overriding the needs of croppers. This is a major source of social conflict, and is a key impediment to intensification in South Bangladesh.

Table 5.5 Yield of various crops grown over saline soils of the coastal area

Name of crops	Maximum yield (t/ha)	Electrical conductivity (dSm^{-1})		Yield loss, %
		Irrigation water	Soil	
Wheat	2.45	1.55-1.80	4.00-4.85	25
Barley	2.17	1.55-1.80	4.00-4.85	29
Millet (Kaon)	1.07	1.50-1.80	4.00-4.75	12
Cheena (Bogai Kanchi)	1.46	1.50-2.00	4.85-4.90	22
Maize (Shavra)	3.95	1.50-2.00	5.80-6.20	45
Chick pea	0.78	1.50-2.00	3.75-4.95	-

Source: Mondal, 2001

Both groundwater salinity and soil salinity have substantial environmental impacts in the coastal zone. The farmers cannot grow crops during the winter or Rabi season if groundwater salinity is more than 3.0 dSm^{-1}. Soil salinization is closely related to the depth of saline groundwater. Soil salinity is high if groundwater is highly saline and shallow. Saline groundwater use over many years can develop soil salinity. Surface water irrigation is minimal in the south-western coastal zone due to surface water salinity. Brackish and saline groundwater is mainly used for irrigation. Soil salinity developed due to saline groundwater irrigation is flushed out during the monsoon season to some extent. The prolonged use of saline groundwater for irrigation has produced soil salinity in some areas of the south-western region. The degree of this salinity varies widely with area and season, depending on availability of freshwater, intensity of tidal flooding and nature of saline groundwater movement.

5.9 Irrigation in the coastal zone

Bangladesh's agriculture has made considerable strides in the last decades. Both production and mean yields of rice have risen (Figures 5.41 and 5.42). The total production and average yield of rice in 1976 financial year was about 11.5 million tonnes and 1.17 tonne/ha, respectively. In 2009-10 the total production was about 32 million tonne and the average yield was 2.82 tonne/ha (BBS, 2011a). The production and yield of wheat in 1976-77 were about 264,000 tonnes and 1.65 tonnes/ha, respectively. In 2009-10 these were approaching 1 million tonnes and 2.39 tonnes/ha (BBS, 2011a). The growth has resulted in rice-grain self-sufficiency being nearly reached– an objective few had thought achievable.

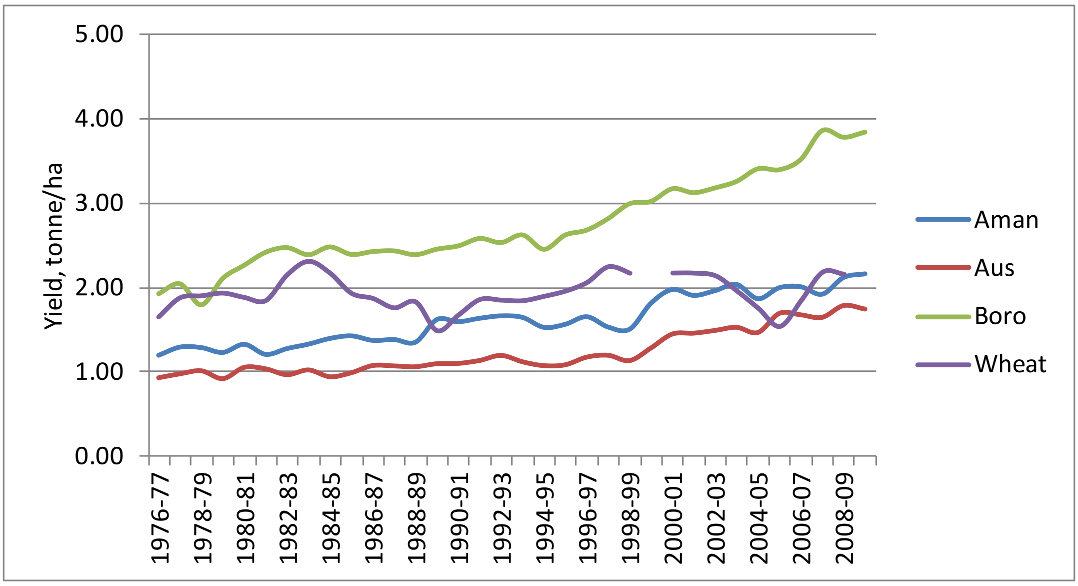


Figure 5.41 Average yield of rice and wheat in Bangladesh (data source: BBS)

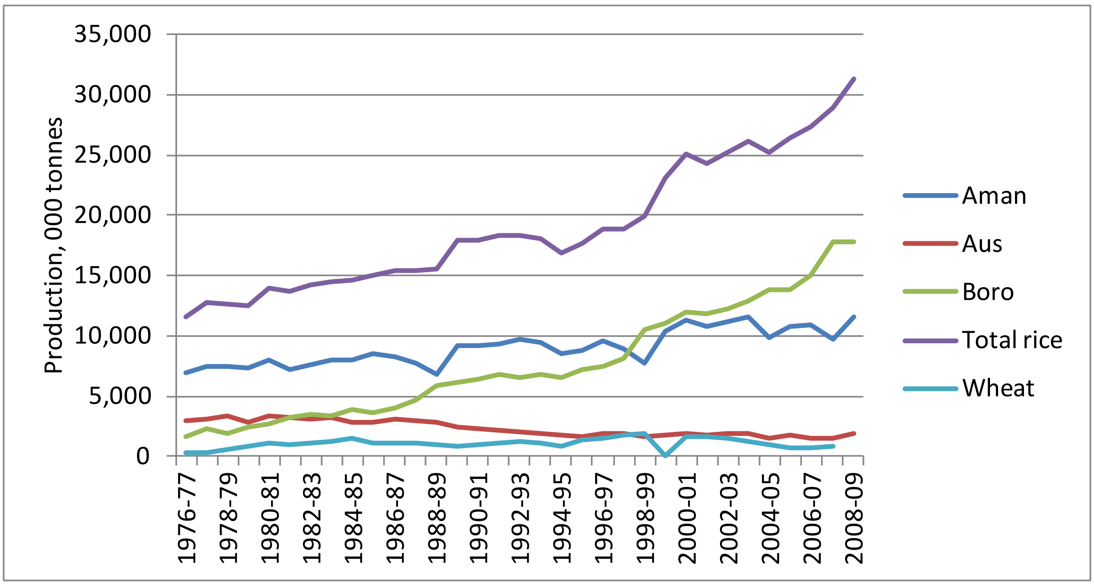


Figure 5.42 Production of rice and wheat in Bangladesh (data source: BBS)

Production increases have resulted from a substantial intensification of agriculture rather than from increases in cultivated area; indeed, the area available for cultivation is reducing (Figure 5.43). Overall cropping intensity for the whole country has grown substantially to 179 percent in 2007 from 145 percent in 1975, with an increasing proportion of land being double- or triple- cropped (discussed in detail in the next chapter). This growth in intensity was driven by increased cultivation during the dry season, particularly Boro rice (Figure 5.44), made possible by the growing availability of irrigation by groundwater through rapid increase in the adoption of STWs (Figure 5.45). In 2009-10, 63% of the net command area (NCA, 5.2 million ha) was irrigated, over 40% (3.34 million ha) of this by STW. Area irrigated by groundwater was 4.11 million ha (50% of the NCA). There is almost no growth in surface water irrigation: the increase in irrigation is due to pumping of groundwater by STW. Despite this overall phenomenal growth of irrigation by groundwater, there is significant variation among the regions and districts.

Figure 5.46 shows the percentage of land irrigated over the last 5 years (2005-2010). The maps clearly show that irrigation development in the coastal zone is significantly less than the rest of the country. In 2009-10, only 41% of the coastal zone was irrigated compared to 71% for the rest of the country. The variation among districts is also very high (Figure

5.47). While almost 100% of land is irrigated in Jessore, in Patuakhali and Barguna this is below 5%. The reason for this is less development of groundwater irrigation in the coastal zone (Figure 5.48 and Figure 5.49). Complex hydrology and hydro-geology of the coastal zone, salts in groundwater, vulnerability of freshwater aquifers to saline water intrusion and socio-economic considerations have slowed development of groundwater for irrigation in the coastal zone. Similarly, surface water irrigation has not developed due to lack of irrigation infrastructure, relative unavailability of water during the dry period, salinity, and socio-economic factors (Figure 5.50). Surface water irrigation is higher in the central coastal zone in the districts of Barisal, Bhola, Chandpur and Noakhali but the area irrigated varies from year to year (Figure 5.50).

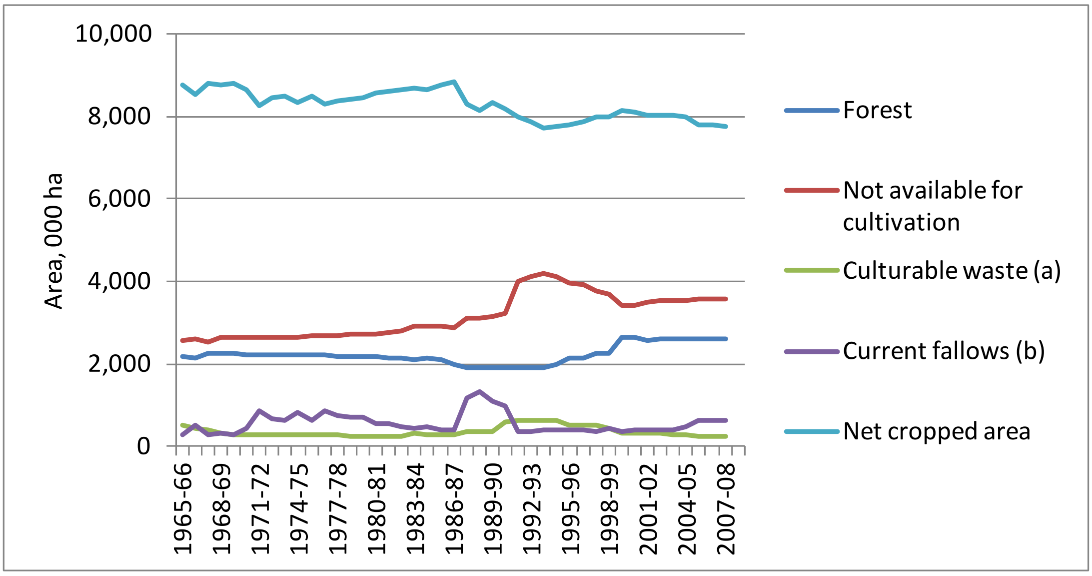


Figure 5.43 Land utilization by different land use type (data source: BBS)

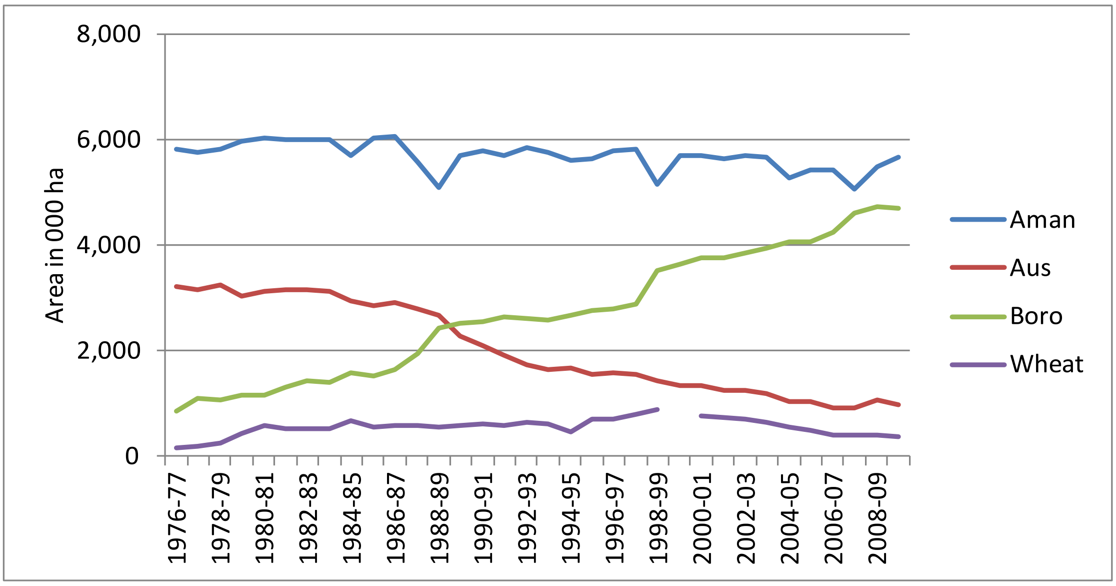


Figure 5.44 Total cultivated areas of rice and wheat (data source: BBS)

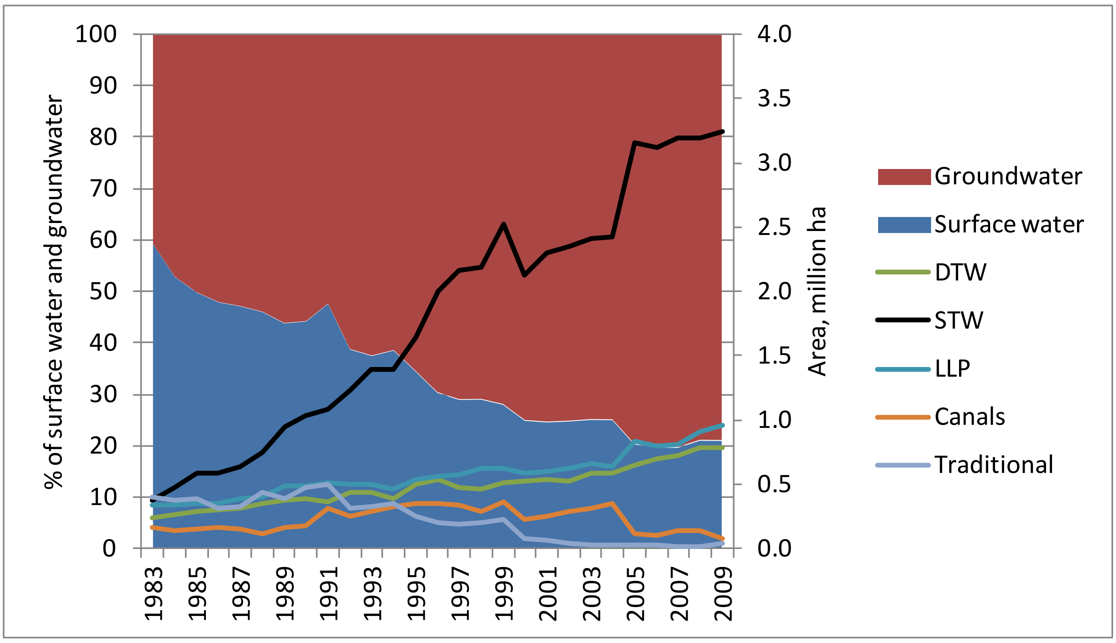


Figure 5.45 Area irrigated by different technology and source of water (data source: BADC)

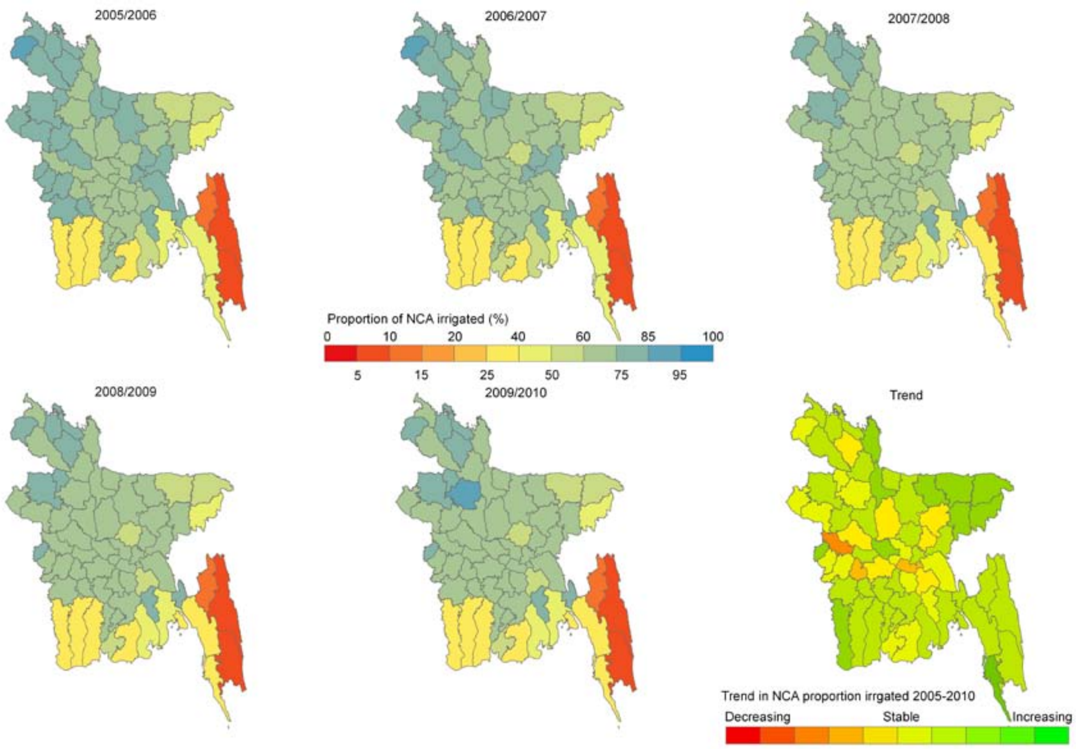


Figure 5.46 Percentage of NCA irrigated during 2005-6 to 2009-10 (data source: BADC)

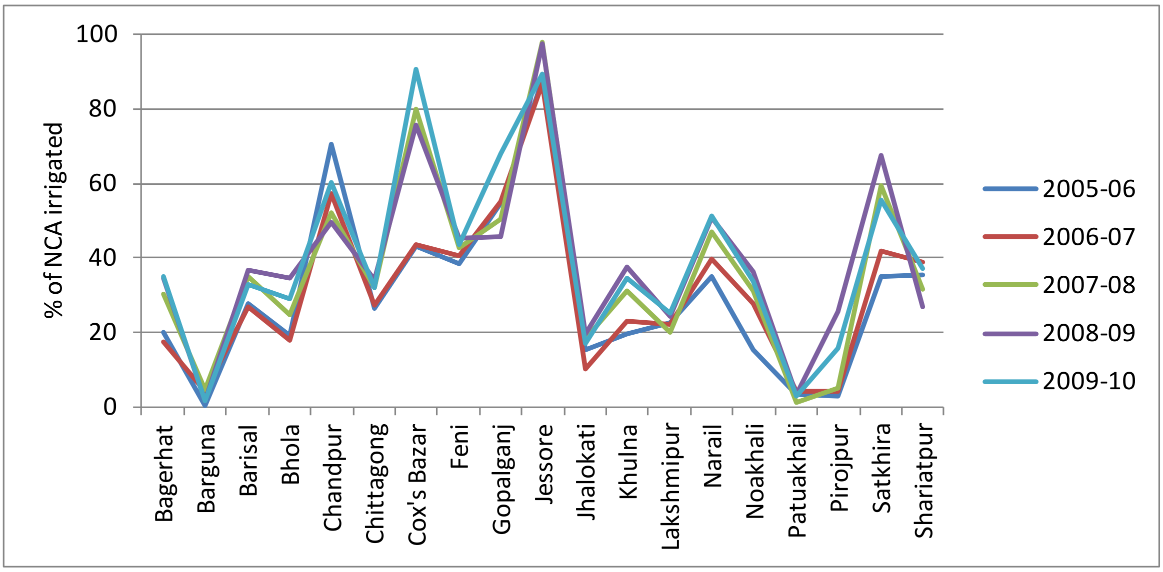


Figure 5.47 Percentage of NCA irrigated during 2005-6 to 2009-10 in the coastal zone (data source: BADC)

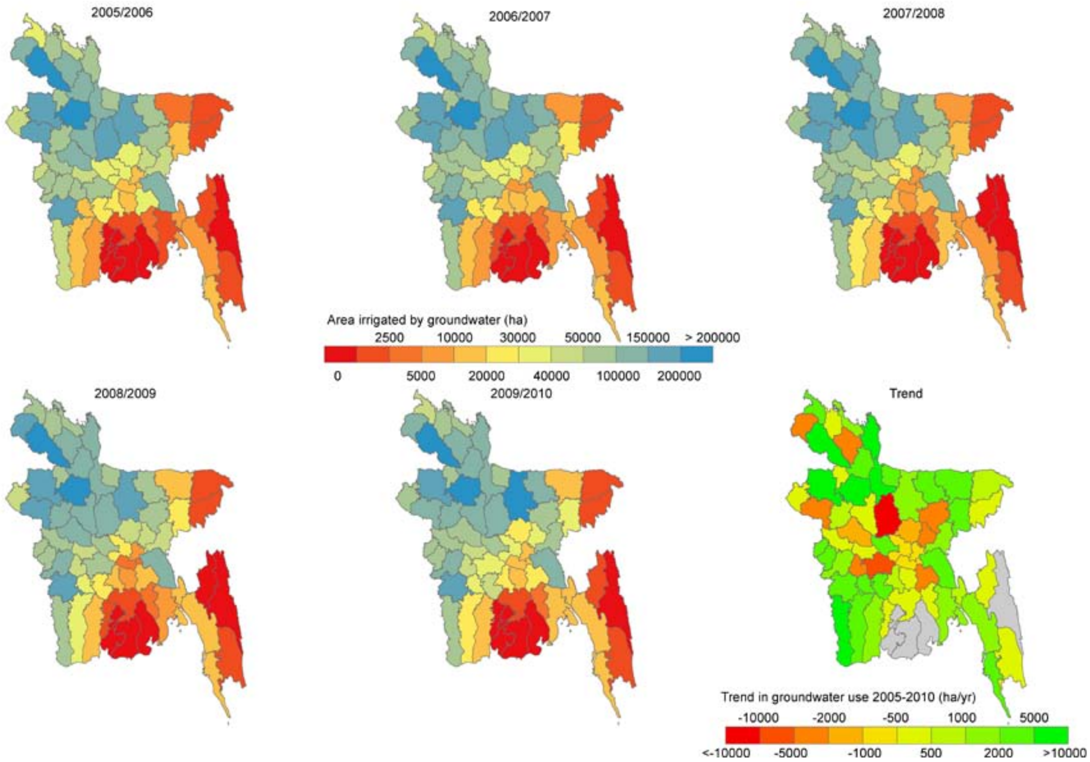


Figure 5.48 Area irrigated by groundwater by districts (data source: BADC)

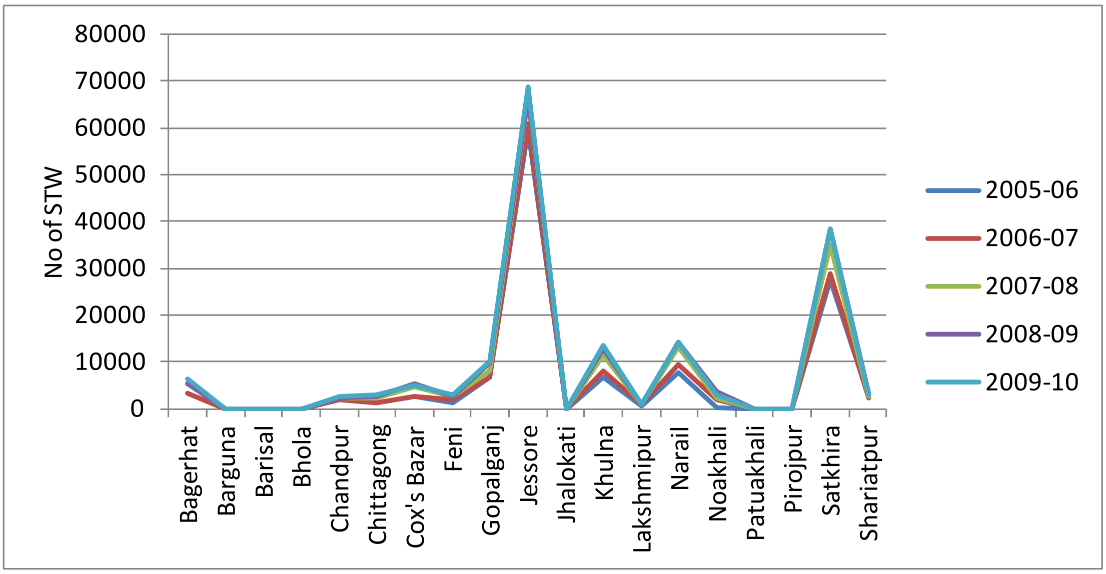


Figure 5.49 Number of shallow tube wells (STW) in the coastal districts (data source: BADC)

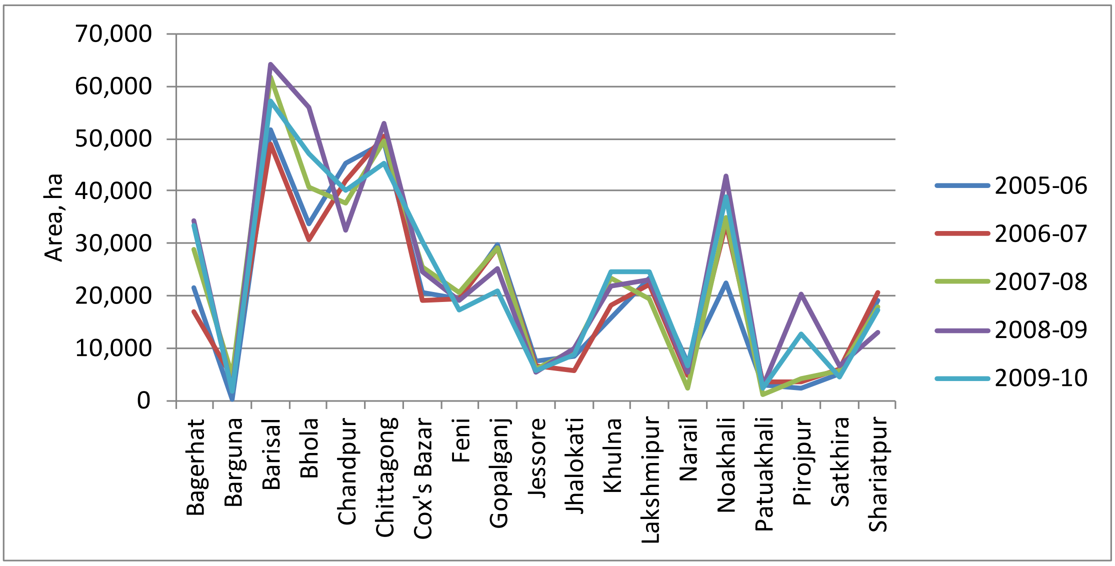


Figure 5.50 Area irrigated by surface water in the coastal zone (data source: BADC)

5.10 Net irrigation requirements of major crops

We have estimated 'net irrigation requirements' (difference between the potential crop evapotranspiration and effective rainfall, i.e. no water stress) of major crops currently grown in the coastal zone using a soil water balance simulation model developed by us. The model is similar to the CROPWAT model developed by Food and Agricultural Organization (FAO) of the United Nations (Allen et al. 1998), and gives identical results under the same conditions. The model simulates soil water for the upland (non-rice) crops and ponding water depth and soil water for rice, all on a daily time step. The inputs of the model are daily rainfall and reference crop evapotranspiration (ETo), crop coefficients at different growth stages, rooting depth, crop planting time and growing period, length of growth stages, yield response factor, soil properties such as field capacity, wilting point, saturated moisture content, depletion factor, ponding water depth and percolation rate for rice. The model can simulate both irrigated and rainfed crops. The model can consider a wide range of irrigation rules for the irrigated crops. The outputs of the model are actual crop evapotranspiration (ETa), potential crop evapotranpiration under well-watered conditions, irrigation requirement (for irrigated crops), and effective rainfall, drainage, runoff, and yield potential during the cropping period. Yield potential was estimated using an FAO crop-water production function given by Doorenbos and Kassam (1979).

We have considered 8 crops that are either currently being grown or recommended to be grown in the region by BARC (BARC, 2011) in the southern coastal zone. These are Aman rice, Boro rice, wheat, maize, sunflower, mustard, mungbean and tomato. Aman rice is the main rainfed crop which suffers from in-seasonal water stress due to prolonged periods without rain. This is the main reason for its low yield (compared to Boro as shown in Figure 5.41); it is transplanted during July and August. Supplementary irrigation during the no-rainfall period can significantly increase the yield of Aman rice in Bangladesh. Here we have estimated supplementary irrigation requirements for Aman rice. All other crops including Boro rice are cultivated during Rabi season.

The model has been used considering the daily climatic data for each district (as described in Section 4.3) for the period of 1985-2010. ETo values in the model are estimated by the FAO Penman-Monteith method (Allen et al., 1998) using daily maximum and minimum temperature, sunshine hours, wind speed, and maximum and minimum humidity. Crop coefficients, length of growth stages, and yield response factors are taken from the FAO Irrigation and Drainage Paper 56 (Allen et al., 1998). Crop duration and crop sowing or transplanting time are taken from the 2010 Yearbook of Agricultural Statistics of Bangladesh (BBS, 2011a) and BARI website (www.bari.gov.bd). The model does not consider capillary rise for non-rice crops so the net irrigation requirement is not sensitive to soil parameters. For rice, soil type determines the percolation rate. We have considered 4 different types of soil in the coastal zone: heavy clay, clay, clay loam and loam. The percolation rate from the rice field for these 4 types of soil is considered as 0.5, 1.0, 1.5 and 2.0 mm/day.

Sowing or planting time varies from field to field and location to location due to many factors and spans around two months for most of the crops considered (BBS, 2011a). Planting or sowing date affects net irrigation requirements due to the variation in rainfall and ETo. Rabi season starts at the end of monsoon season and as Rabi progresses rainfall decreases and ETo increases (Figure 4.5 and Tables 4.2 and 4.6). To see the likely variation in irrigation requirements covering the span of planting dates, we have used 5 different planting date, two weeks apart, for all crops.

Figure 5.51 shows the supplementary irrigation requirements for Aman rice transplanted on 15^{th} July for 4 different types of soil. The filled area shows the variation (maximum – minimum) and the line shows the average for the period 1985-2010. As expected, supplementary irrigation requirements vary from year to year, district to district and from soil to soil. Average (arithmetic average for the districts) requirement in heavy clay soil is around 105 mm compared to around 178 mm in loam soil. There is significant year to year variation (as shown by the change) in all districts due to the variation mainly in rainfall. However, average requirement does not vary significantly from district to district. In some years there is no need for irrigation particularly in the heavier soils (the filled area is at a minimum of zero), but in lighter soils irrigation is required every year in locations such as Satkhira, nearby Khulna, Gopalganj and Jessore.

The overall pattern of irrigation requirement for Boro rice is similar to that of Aman rice but varies significantly in terms of total amount (Figure 5.52). Year to year variation is also lower than that of Aman as the rainfall during the growing period is almost negligible with no significant variation (Figure 5.52). The average net irrigation requirement varies from about 500 mm in the heavy clay soil to about 700 mm in loam soil (Figure 5.53).

Figure 5.54 compares the net irrigation requirements of Aman and Boro rice for different planting dates in heavy clay soil. The variation is significant in Aman rice, with the lowest amount (average about 70 mm over the districts) required for 1st July planting to highest (average about 240 mm) for late planting. This variation is due to the variation in rainfall. May to October is the monsoon season with highest rainfall during July and August (Figure 4.5). Due to late planting, the part of the cropping season falls outside the monsoon season when rainfall is not sufficient to meet requirements. For Boro rice, the variation in net irrigation requirements is insignificant varying from 481 mm (average for the districts) for 30 January transplanting to 531 mm for 30 December planting. Irrigation requirement is lower for early (Nov-Dec) or late (Jan-Feb) planting. This is because of some rain falling during the immediate post-monsoon (Nov-Dec) and pre-monsoon (Apr – May) period (Figure 4.5), which respectively coincides with the early and late stages of the Boro crop.

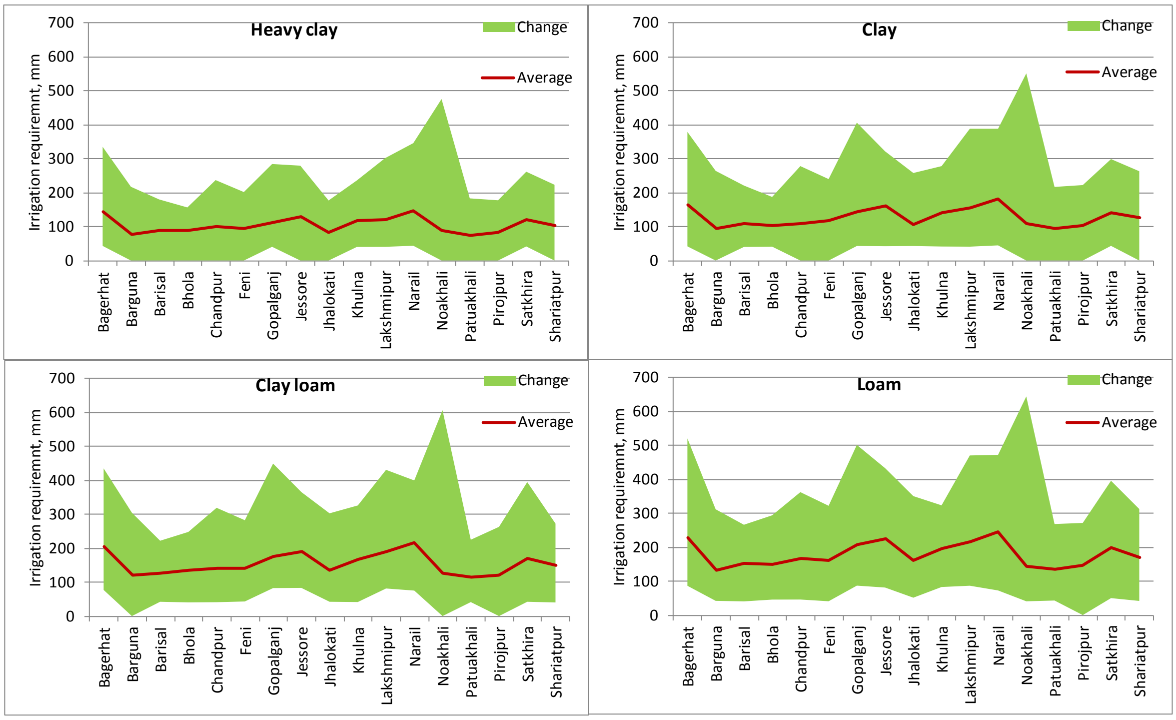


Figure 5.51 Supplementary irrigation requirements for Aman rice transplanted on 15 July

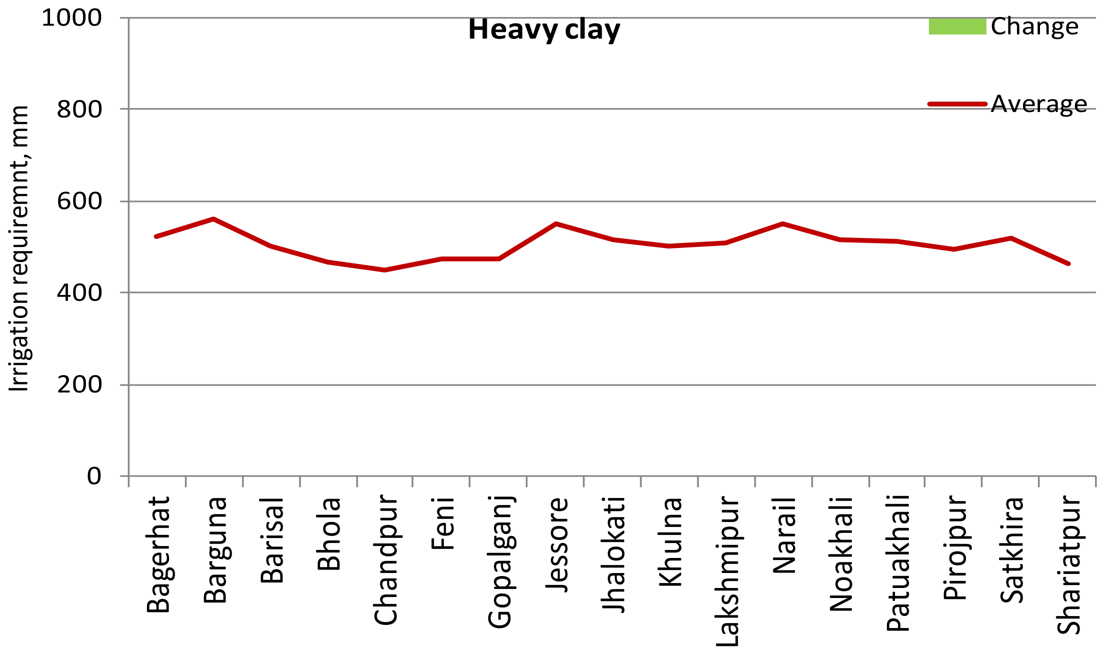


Figure 5.52 Net irrigation requirement of Boro rice transplanted in heavy clay soil on 1st December

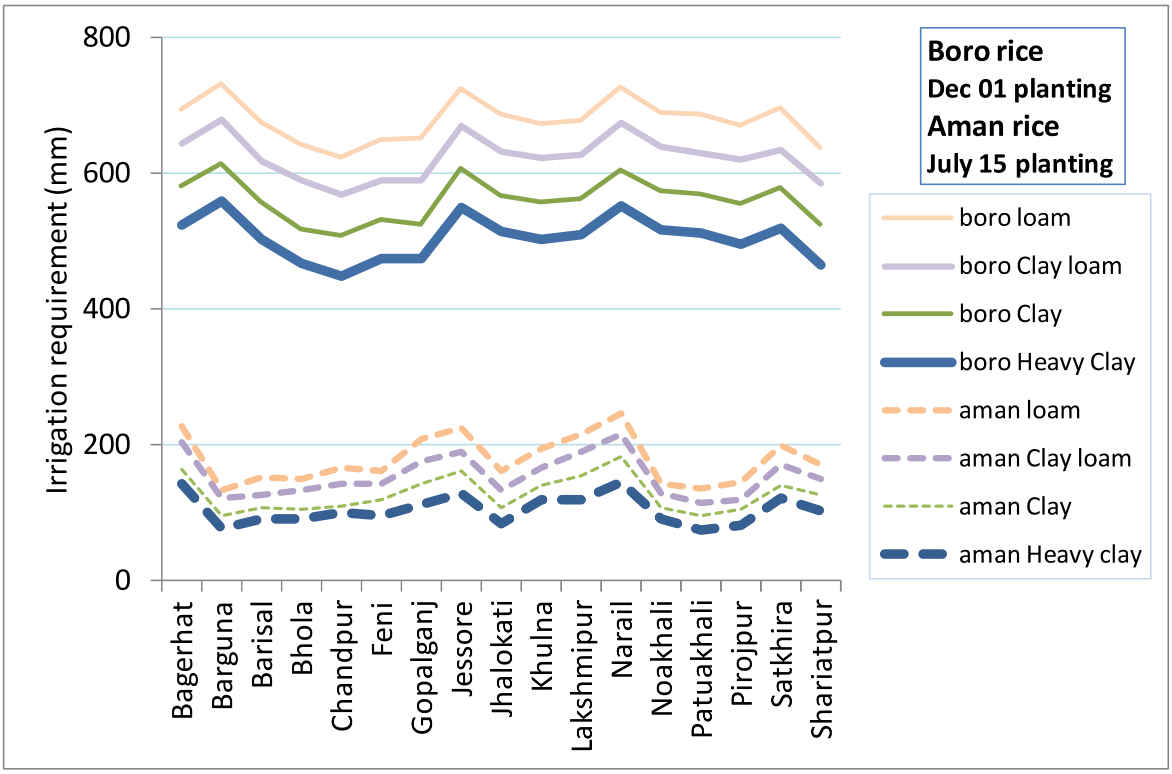


Figure 5.53 Comparison of the net irrigation requirements of Aman and Boro rice for different soils

Net irrigation requirements for wheat, maize, sunflower, tomato, mungbean and mustard are presented in Figure 5.55 (all the Figures are presented at the same scale to allow for visual comparison of the net requirements). Estimated average (average of all districts) net irrigation requirement for these crops sown on the same day (30 November) is 246, 284, 281, 339, 179, and 93 mm respective for wheat, maize, sunflower, tomato, mungbean and mustard. The model does not consider capillary rise though there is literature suggesting that plants roots are tapping into the shallow groundwater table in the coastal zone (Dalgliesh and Poulton 2011, comparing amounts from capillary-rise with those from the overall profile contributing to yield in wheat). So the actual requirements could be less than this amount. Similar to rice, irrigation requirement varies based on time of sowing (Figure 5.56). The variation is higher in wheat, maize, sunflower and tomato compared to mungbean and mustard.

Net irrigation requirements of these crops are much lower compared to that of Boro rice (Figure 5.56). In general, Boro rice required twice the amount required by wheat, maize, tomato and sunflower, and 3 times of the amount of pulses and 5-6 times of the amount required by mustard.

As there are limited water resources in the coastal zone, for intensification it is necessary to select the crops which require less water and also less sensitive to water stress. Rice is the most sensitive to water stress among the crops considered here; pulses and oilseeds are least sensitive (Doorenbos and Kassam, 1979).

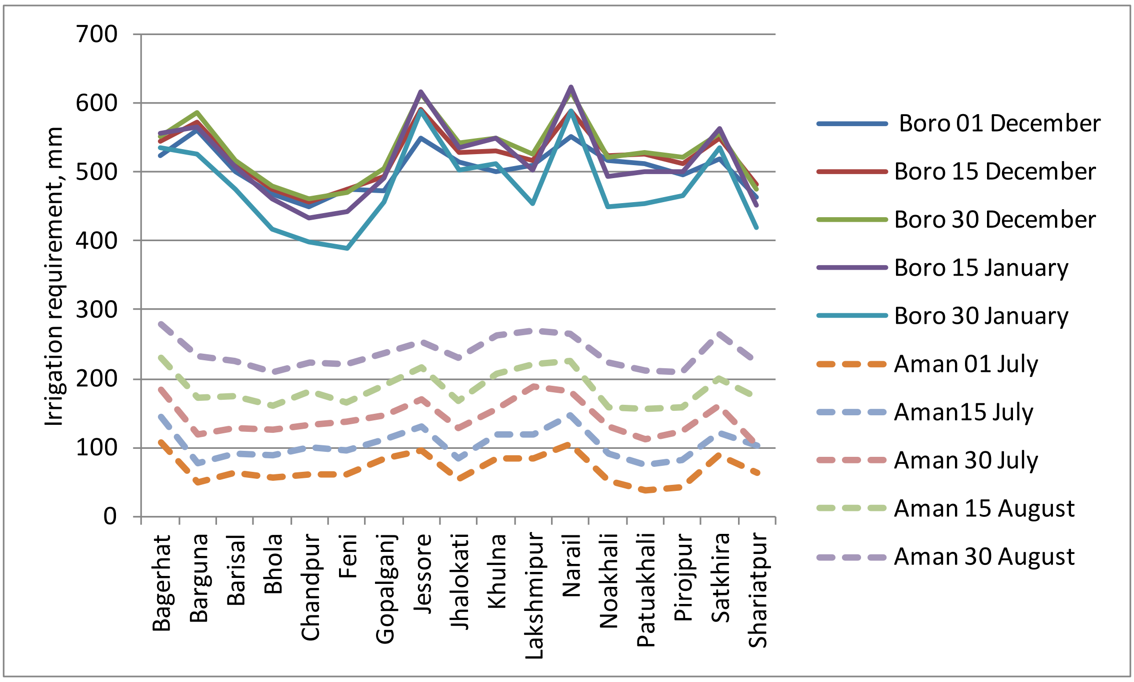


Figure 5.54 Comparison of the net irrigation requirements of Aman and Boro rice for different planting dates on heavy clay soil

Figure 5.55 Net irrigation requirements of several species in a clay loam soil sown on 30 November

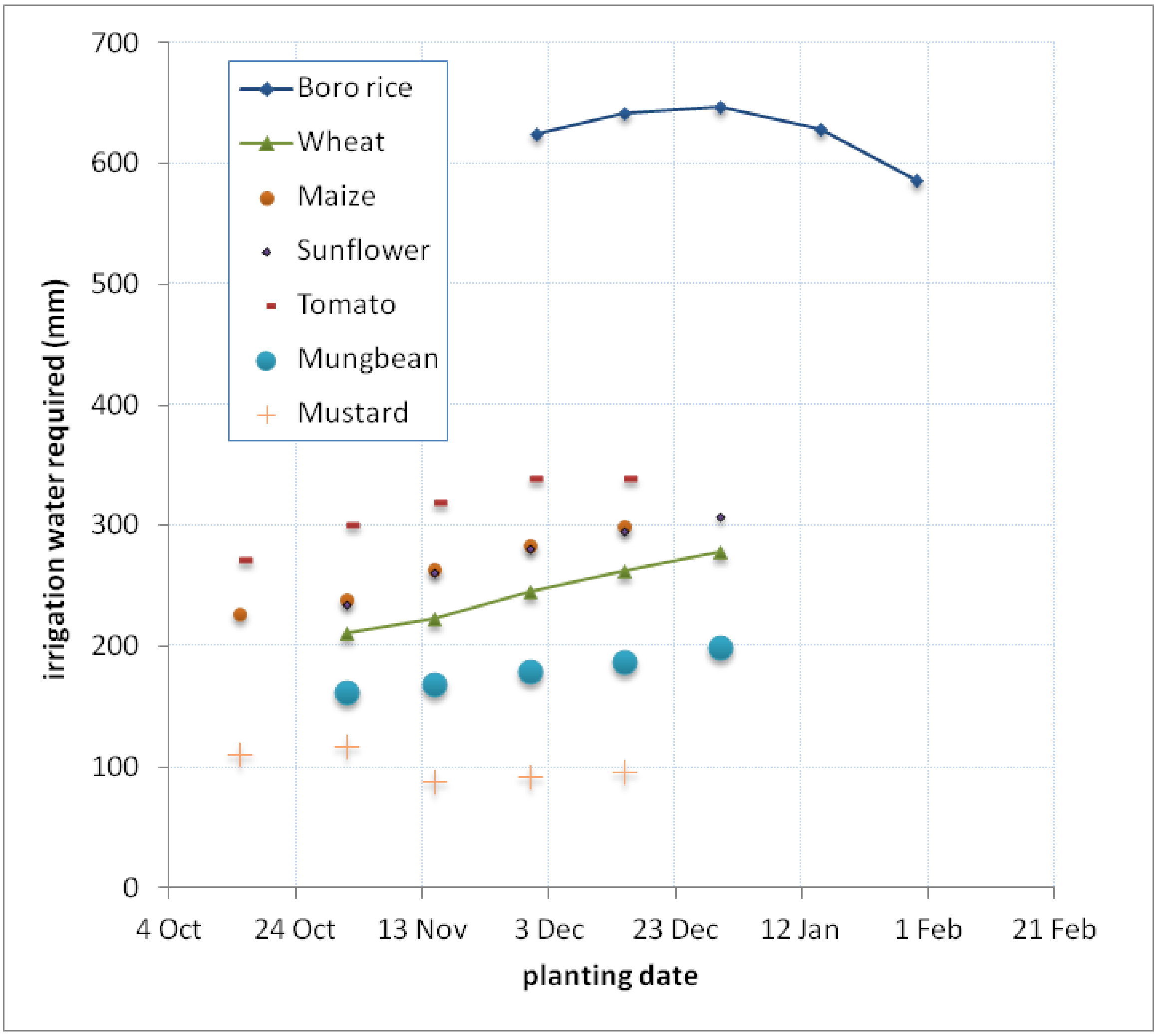


Figure 5.56 Irrigation water required by several species grown in a clay loam soil during Rabi season and planted at several dates averaging data for the districts shown in Figure 5.54 and 5.55

5.11 Conclusion

Life in riverine Bangladesh is based on water. It sustains an extremely fragile natural environment and provides livelihoods for millions of people. Agricultural production is the mainstay of the rural population's livelihoods system, and therefore its people's livelihoods are inextricably linked to the nation's water cycle. Surface water and groundwater are precious resources for the nation and are under great stress, with floods in the monsoon season, a shortage of surface water in the dry season, natural arsenic contamination of shallow groundwater, salinisation of both surface and groundwater in the coastal zone, the ingress of pollution in surface water, and increasing difficulties in meeting demand in many urban centres. The increasing population and economic development in Bangladesh will increase demand and competition for water resources, exacerbating an already difficult position. To add to the difficulties, changes in water quality and quantity are also expected as a consequence of projected climate change. As a consequence, there is real risk of supply shortages of safe drinking and irrigation water as well as in meeting growing industrial demand. Hence, water resources management in Bangladesh faces immense challenge for resolving many diverse problems and issues. In this chapter, we have discussed physical factors relating to surface water, groundwater and soil salinity. In summary, following are the major issues.

Scarcity of fresh irrigation water

Availability of fresh surface water in the dry season is highly dependent on the flow of water in the Ganges and Brahmaputra rivers, particularly the Ganges River. The flow in the Ganges River is declining gradually due to increased use of water upstream outside Bangladesh. The upstream withdrawal of Ganges water has increased salinity in the tidal rivers, decreased surface water availability in the rivers and canals, lowered the groundwater table and reduced soil moisture content. The reduced flow has also silted up the rivers, impeding flow to the coastal distributaries (e.g. The Gorai) even if there is more water in the Ganges. The availability of fresh water in the upstream rivers plays an important role in controlling salinity intrusion.

Surface water is mostly saline in the south-western coastal zone during the dry season thus limiting its suitability for irrigation at that time. There is a considerable movement of the salinity front further inland during dry season, which would eventually change the present salinity pattern in this area. Scarcity of suitable quality irrigation water during the dry season limits cultivation of Boro rice and other Rabi (winter) crops, and Aus cultivation during kharif-1 (April-July) season. Surface water in the coastal rivers is generally saline. Its salinity generally starts increasing from November, reaches above critical level (ECe 4 dSm^{-1}) post mid February and peaks during April and May. The surface water salinity decreases from June due to monsoon rainfall.

Groundwater availability and quality

The complex physical and chemical processes of groundwater and salinity are poorly understood in this area. However, from the limited data available, the present groundwater condition of the coastal aquifer can be briefly described. Upper shallow aquifer system in the coastal area yields relatively small volumes of water to shallow wells. The quality of the abstracted groundwater varies from fresh to saline. The shallow aquifer is mainly recharged from infiltration during the monsoon season. The sand and clay layers containing brackish/ saline water lie beneath the upper shallow aquifer in sequence. In most of the coastal area, a deeper aquifer occurs beneath the lower clay zone. Recent studies reveal that this aquifer is free from arsenic contamination in most of the coastal area. There is no evidence of groundwater over-exploitation in the coastal area because groundwater abstraction is limited at present. Seawater and arsenic contamination are common in the upper aquifer of the coastal area.

Groundwater resources of the south-western coastal region have not been fully explored or developed. The present management of groundwater resources is ineffective and inefficient due to lack of critical knowledge about the hydrogeology and hydrochemistry of the area. Inadequate monitoring of impact parameters, lack of planned and coordinated development activities, lack of regulation for groundwater use and protection and lack of appropriate authority for overall management of the groundwater resources are the main elements of ineffective and inefficient groundwater management.

There is only limited information available about the properties of various unconfined and confined aquifers. Exploratory drilling is limited to shallow and intermediate aquifers only. No regional groundwater models have been developed to evaluate groundwater resources, inter-aquifer leakage and interactions, surface water – groundwater interactions, groundwater recharge and sustainable yield. From shallow groundwater systems it appears that substantial volumes of groundwater could be available for abstraction from shallow groundwater systems. There is no information about current total annual groundwater abstraction and how much more can be abstracted sustainably. Similarly no information exists about the sustainable abstraction from deeper semi-confined and confined aquifer systems.

Groundwater is mostly brackish or saline in the shallow unconfined aquifers of south-western coastal Bangladesh. Groundwater levels in the southern delta regions are within 1 - 4 m of the ground surface during most of the year. Brackish groundwater irrigation of salt tolerant crops and horticulture is possible but to date only limited salt tolerant varieties have been developed. Leaching and flushing of salts accumulated during the dry season due to brackish and saline groundwater irrigation should occur during the monsoon season which makes it even more attractive.

Soil Salinity

Soil salinity has been continuously increasing in the south-western coastal zone since 1973. It is the most dominant limiting factor in the southern region of Bangladesh, especially during the dry season. It affects crops at various growth stages resulting in partial or total reduction of yield. A substantial portion of the south-western coastal zone of Bangladesh is affected by tidal saline water. A major portion of this region remains fallow during the Rabi and Kharif-I seasons. Effective management strategies for salinity control and mitigation to ensure sustainable current and intensified crop production have not been evaluated.

Unplanned brackish water shrimp culture

Introduction of brackish water shrimp cultivation continues to deteriorate soil quality and crop production. It affects both land fertility and crop production (BARC, 1990). Yield of low salt tolerant vegetable and other crops has reduced in areas affected by shrimp ponds. It is generally understood and widely believed that shrimp production, which uses saline or brackish water in ponds, has increased soil salinity in agricultural fields to a point where it becomes unfeasible to grow rice any longer, thus creating major problems of food security (Haque, 2006). However, no modelling studies have been conducted to assess the impacts of shrimp cultivation on the hydrology of the area and south-western coastal zone. Long term sustainability and viability of agriculture in south-western coastal zone requires proper assessment of impacts of long term shrimp cultivation on groundwater quality, ecology and the environment.

Poor drainage system

The soil permeability is very low which restricts downward movement of soluble salts present in the topsoil layers. Irrigation with saline water (EC 2.5-3.5 dSm^{-1}) during Rabi (dry season) results in the accumulation of salt in the surface soil layers. Fresh water for leaching application is often not available during the dry season. Most polders suffer drainage congestion during the rainy season. Due to malfunction of sluice gates resulting from siltation, the removal of excess water from the polder area is restricted. Perennial water logging due to ineffective drainage because of siltation and faulty sluice gate operation restricts the use of low lands within the poldered areas. It causes late transplanting of T. Aman crops which in turn delays harvesting and impacts sowing of the Rabi crops. Late transplanting also results in poor crop yields in the region.

Influential individuals use drainage channels for fishing. They close sluice gates and use other operations for fish culture and fish catching which restricts the free movement of excess rainwater. Due to restricted excess water movement the low lying areas remain fallow due to standing water. Soil and drainage management strategies should be evaluated to improve drainage and reduce siltation to aid timely discharge of water from polders. Impartial application of law and policies should minimize unauthorized use of drainage channels

6 Land use and current cropping system

6.1 Introduction

Since 2003 the southern coastal zone has attracted attention with reported estimates of 800,000 ha of potentially cultivatable land remaining fallow during the dry (Rabi) season. A Food and Agriculture Organization of the United Nations (FAO) funded study in 2003-05 suggested the possibility of increasing wheat production on fallow lands in the south (Rawson et al., 2007). This raised the question of "*Where and how much fallow land is available in the southern regions of Bangladesh*?". In 2005-10 the Australian Centre for International Agricultural Research (ACIAR) funded a study concluding that potentially 0.86 million ha of economically underutilized land rather than unproductive fallow was available in southern Bangladesh (Poulton, 2011). Of the 20 districts evaluated in that study, over 50 percent or 487,671 ha were available in the coastal districts of Bhola, Barisal, Jhalokati, Barguna, Patuakhali, Pirojpur and Noakhali. Statistical data used in that study were only available for years to 2005-06. The analysis presented here builds on previous studies to; evaluate spatial and temporal trends in land use and production using recently released statistical data; and focuses on changes in land utilization and cropping patterns in the selected southern *Regions Of Interest* (ROI) of Chittagong, Comilla, Noakhali, Faridpur, Barisal, Jessore, Khulna and Patuakhali[1]. Comparisons with changes in the northern regions during similar periods are also considered.

The main sources of data used in this analysis are attributed to the Bangladesh Bureau of Statistics (BBS) and the Department of Agricultural Extension (DAE) responsible for regional data collection. Statistical data for greater district wise (now called 'region') land utilization from 2003-04 to 2008-09; region wide estimates of production areas and yields for rice and wheat from 2006 to 2010; and Rabi crop production area and grain yields for the selected ROI from 2005-06 to 2009-10 have been analysed and results reported.

6.2 Spatial and temporal trends in land use

Bangladesh is a country of 14.8 million ha (BBS, 2010a) of which approximately 50% or 7.93 million ha (BBS, 2010a) is reported as being available for cultivation. Southern Bangladesh (Chittagong, Comilla, Noakhali, Faridpur, Barisal, Jessore, Khulna, Patuakhali) covers approximately 6.03 million ha of which 3.3 million ha (BBS, 2010a) are reported as available for cultivation. The southern coastal zone (19 districts as described in Table 4.1) covers 4.72 million ha with a net cultivatable area of 1.95 million ha (Islam et al., 2006). In Bangladesh, about 40 million people (Table 4.1) are coastal inhabitants, relying on agriculture, fisheries, forestry and salt panning for their livelihood and sustenance. The land of the southern delta area is affected by salinity, alkalinity or water logging with an estimated 2.4 million ha of coastal land (of which 1.02 million is cultivable land) currently affected to some degree by soil salinity. Tradition farming has depended on wet season rice (T. aman and T. aus) grown during the monsoon (June-Nov) with the addition of cereal, vegetable and fodder crops grown during the Rabi (Dec- Mar). Northern and southern regions differ in cropping options and frequency with rice-wheat rotations in

[1] These are old-districts which are now called 'region'. Each old district has been divided into several current 'districts'. All the current districts of Noakhali (Noakhali, Lakshmipur, Feni), Barisal (Barisal, Bhola, Pirojpur, Jhalokathi), Khulna (Khulna, Bagerhat, Satkhira), Patuakhali (Patuakhali, Barguna) and Chittagong (Chittagong, Cox's Bazar) are within the coastal zone. Only Chandpur of Comilla region (Comilla, Chandpur, Brahmanbaria), Shariatpur and Gopalganj of Faridpur region (Faridpur, Rajbari, Shariatpur, Madaripur, Gopalganj) and Jessore and Narail of Jessore region (Jessore, Narail, Magura, Jhenaidah) are within the coastal zone.

the north and local aman rice-fallow systems more prevalent in the saline affected southern coastal regions (Haque, 2006). Dependent on the current season and given adequate resourcing of land, labour and irrigation, farmers are able to sow rice in each of the 3 major growing seasons, Kharif-1 (April-July), Kharif-2 (August-November) and Rabi (December – March). The option for single, double and triple cropping is considered in estimating land utilization or cropping intensity and is calculated as a ratio between gross cropped area and the net sown area. Since the early 1970s a significant increase in the area planted during the Rabi to high yielding Boro rice varieties at the expense of lower yielding T. aus has increased the rice area by 2.07 million ha (Figure 6.1) and increased total rice production by over 300 percent (shown later in Figure 6.12). During the 2009-10 season approximately 71.3% and 60.0% of the net cultivatable land was planted to T. aman and Boro respectively. About 24.6% of the total rice production of Bangladesh comes from the coastal region. Aman is the dominant crop, covering about 57% of the total rice cropped area, aus covers 14% and Boro 29%.

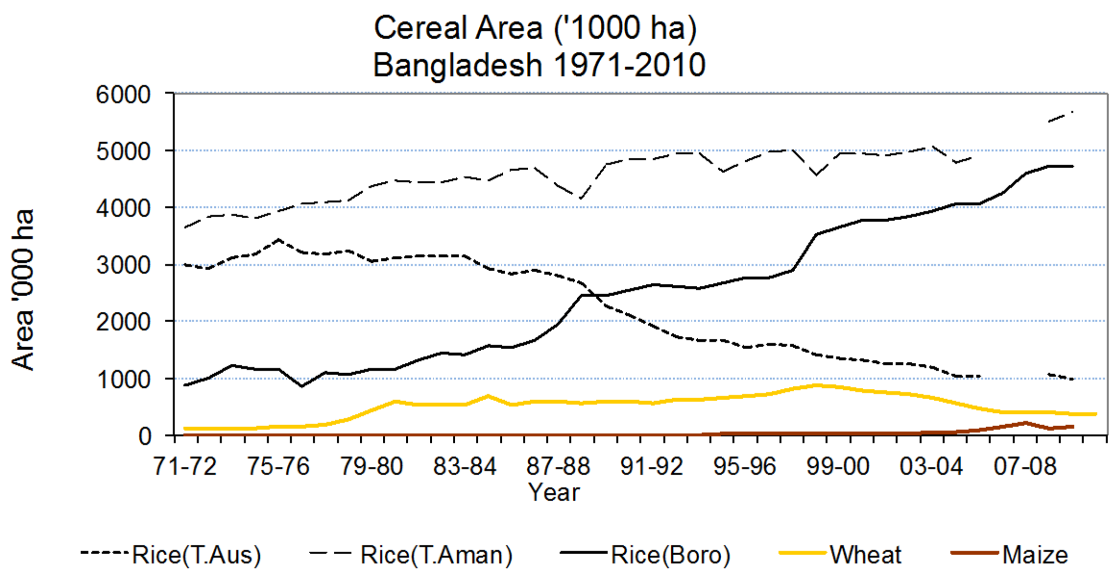


Figure 6.1 Area ('000 ha) planted to rice, wheat and maize between 1971 and 2010. Data supplied from the Bangladesh Bureau of Statistics (BBS)

6.3 Land utilization statistics

Since the early 1970s crop intensification has increased land utilisation in Bangladesh from 128 % in 1949 (Rahman, 2010) to 154 % in 1980-83, 177 % in 2000-03 (Quddus, 2009) and is currently around 181 % (2008-09). Cropping intensity is greater in the northern regions at 186 % (2008-09) compared to the southern coastal regions (excluding Chittagong and Cox's Bazar) at 174 % (2008-09). Land utilization estimates for southern ROI (Figure 6.2) and northern (Figure 6.3) districts from 2000 to 2009 are compared with national mean values. Figures are calculated from BBS greater district-wise (or region) land utilization data for 23 regions from 2003-04 with earlier values (2000-2003) estimated from countrywide land utilization data (BBS) and partitioned on a regional basis. Cropping intensity as reported by BBS exclude land defined as currently fallow and cultivatable wasteland. Values discussed in this report are calculated as that of the BBS, though an earlier assessment (Poulton, 2011) included these areas in the final calculations resulting in higher values for net sown area and lower estimates of land utilization. Analysis of these data estimate land utilization at around 175 percent for the southern ROI and 179 percent for the remaining northern regions for years 2001 to 2009.

A cropping intensity map (Figure 6.4) of the whole Bangladesh has been produced using BBS data of 2007-08. Detailed data by district is reproduced in Appendix B (Table B.1) for years 2000-2012 and for 2009 (Table B.2). Land utilization is calculated using estimates of single, double and triple cropped area for each district. Future capacity to increase intensification in Bangladesh has been questioned by a number of authors (Streatfield and Karar, 2008; World Bank, 2011). However, analyses of available statistical data indicate that there is capacity for intensification of existing cropping systems in a number of coastal regions, particularly the regions of Patuakhali, Barisal and Khulna. The challenge for farmers lies in identifying opportunities and implementation of good agronomic practice in overcoming local and regional constraints to agricultural production.

Land use as a percentage of total cultivatable land area including fallow and cultivatable wasteland for the coastal region is presented in Figure 6.5. These data show an increase in triple cropping with a corresponding reduction in reported fallow land (Figure 6.6) to around 0.2 million ha in 2008-09 as a result of a reduction in double cropping. Temporal differences between regions in area reported as fallow are highlighted in Figure 6.7.

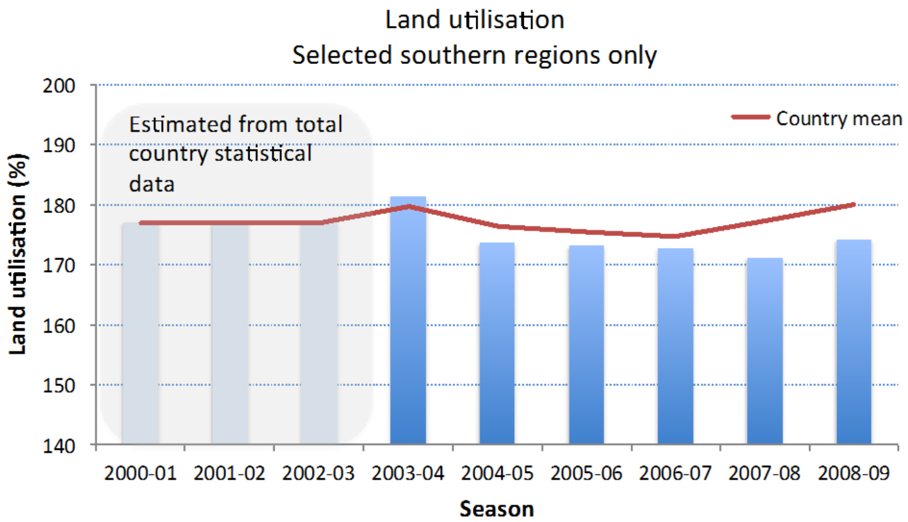


Figure 6.2 Land utilization estimates for the 8 selected southern regions of interest (Chittagong, Comilla, Noakhali, Faridpur, Barisal, Jessore, Khulna and Patuakhali) between 2000 and 2009. Red line signifies whole of country values. Data supplied from the Bangladesh Bureau of Statistics (BBS)

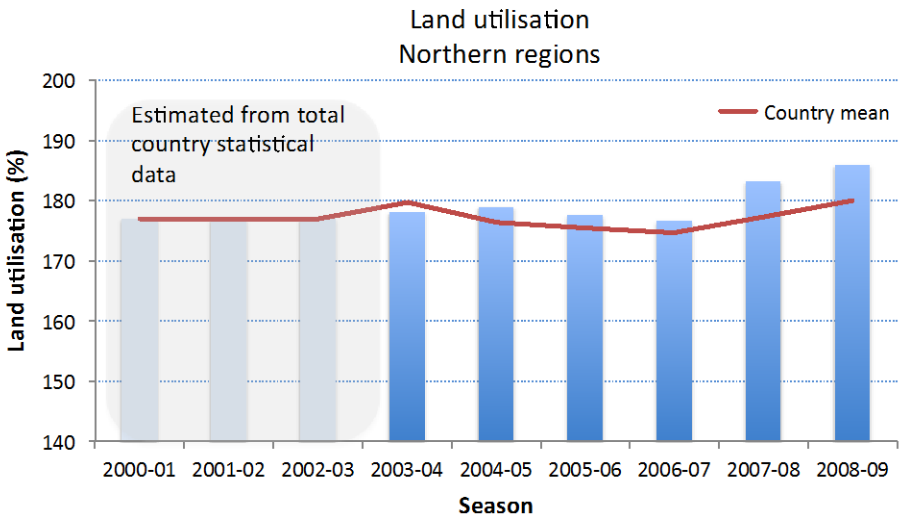


Figure 6.3 Land utilization estimates for remaining northern districts Bandarban, Khagrachari, Rangamati, Sylhet, Dhaka, Jamalpur, Kishoreganj, Mymensingh, Tangail, Kushtia, Bogra, Dinajpur, Pabna, Rajshahi, Rangpur (excludes the ROI in Figure 6.2) between 2000 and 2009. Red line signifies whole of country values. Data supplied from the Bangladesh Bureau of Statistics (BBS)

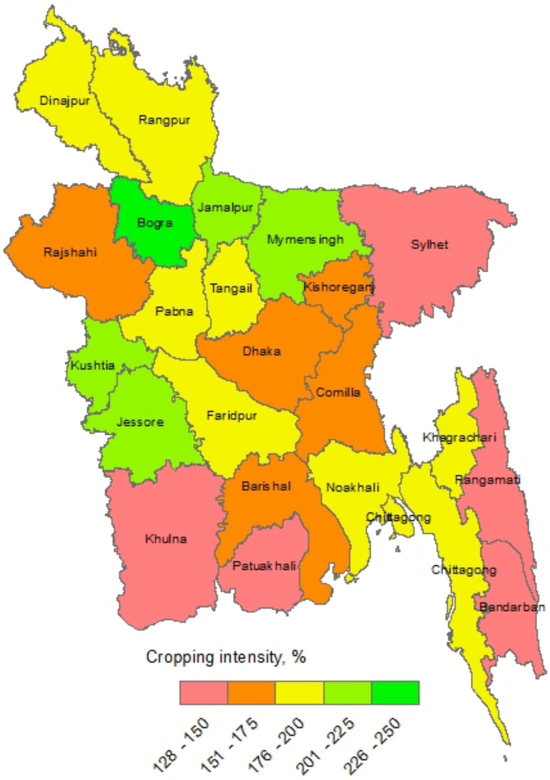


Figure 6.4 Region-wise cropping intensity as a percentage for 2007-08 (BBS)

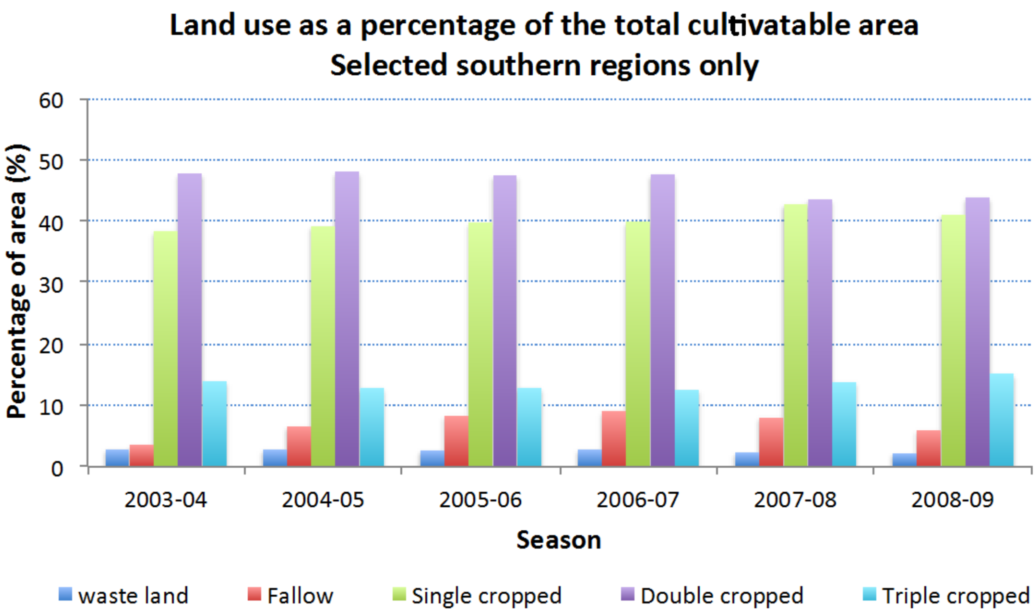


Figure 6.5 Land use as a percentage of cultivatable area between 2003 and 2009 for the 8 selected southern ROI. Data supplied from the Bangladesh Bureau of Statistics (BBS)

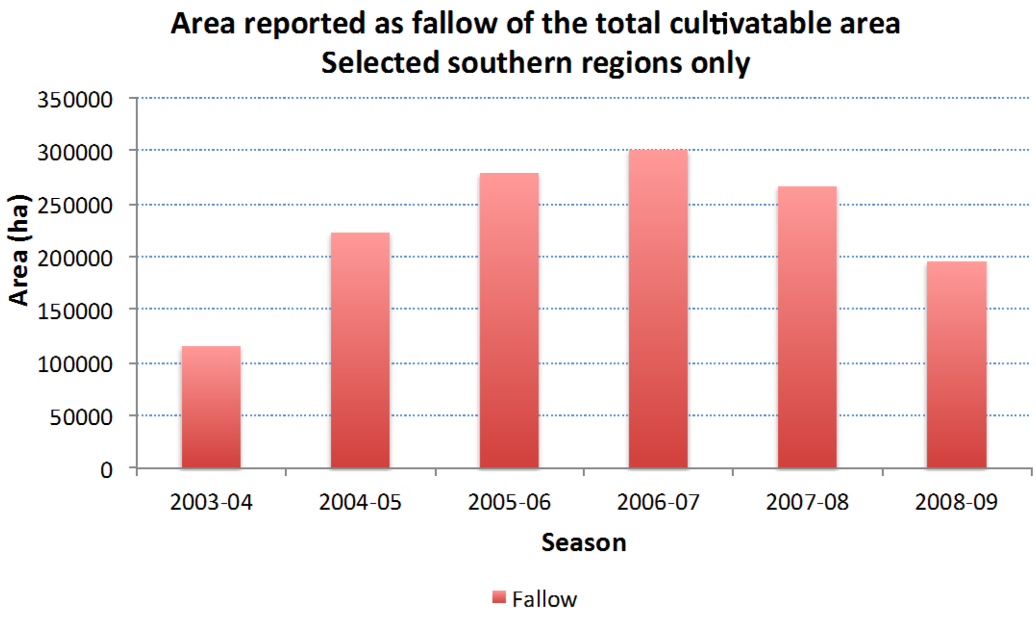


Figure 6.6 Area reported as fallow between 2003 and 2009 for the 8 selected southern ROI. Data supplied from the Bangladesh Bureau of Statistics (BBS)

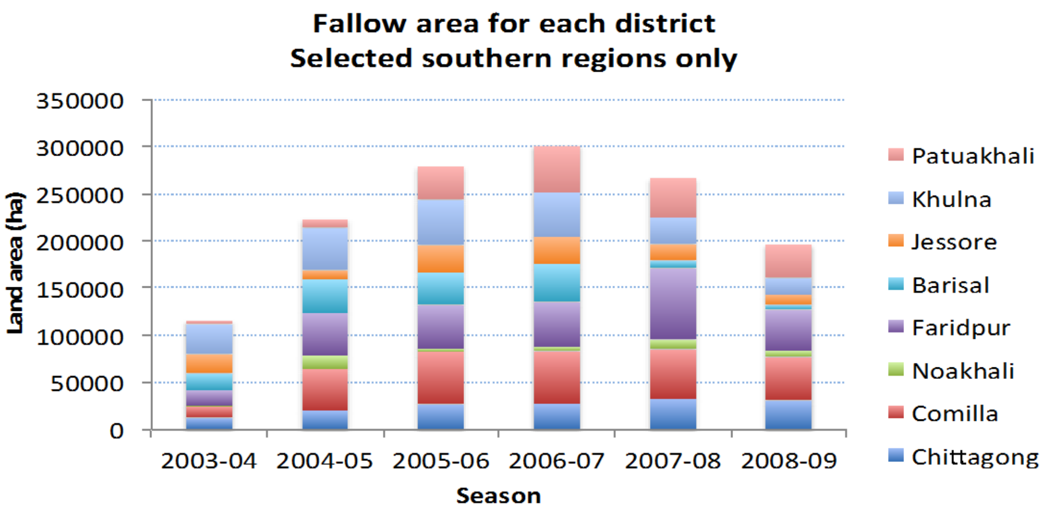


Figure 6.7 Area of reported fallow land for each of the 8 selected southern ROI between 2003 and 2009. Data supplied from the Bangladesh Bureau of Statistics (BBS)

These estimates raise the question of the definition of fallow land as documented by the FAO, 2007. Reported fallow area for the southern region is consistently lower than published estimates by Rawson et al., (2007) of “more than 400,000 ha” available during Rabi and estimates between 0.4 and 1.2 million ha from applying estimates of cropping frequency to land utilization data (Poulton, 2011). Analysis of satellite images by CEGIS described in section 6.8 supports earlier studies with estimates > 700,000 ha (2010) of potentially fallow land.

6.4 Cropping area and production statistics

An analytical approach, described by Poulton (2011) for estimating potential fallow area (during Rabi) from aggregated statistical data for Boro and alternative Rabi crops is applied with the inclusion of additional years from 2008 to 2010. Boro rice was calculated at nearly 50% of the country's cultivatable area during 2007-08 and is estimated at 54.4% of the total cultivatable area in 2009-10 with the southern ROI accounting for 17% (BBS data). Cultivation area for the majority of Rabi crops is combined for the southern region from 2001 to 2010 in Table 6.1. A previous study by Poulton (2011) based on earlier and less complete data used a constant figure of 23.8% of cultivatable area as a conservative estimate of the total Rabi cropping area other than Boro for each year. Evaluation of more recent data indicates a mean value for the past 9 years of ~25.9%. Combining these figures in relation to available cultivation area provides estimates of potentially available fallow land of 1.1 million ha of the total 3.32 million ha of cultivatable land in the southern ROI (Figure 6.8).

However, not all of this potential land is suitable for Rabi cropping. It is not realistic to assume that all of this land is available for planting at the most opportune time during the growing season. Southern Bangladesh is close to sea level and prone to inundation from monsoonal flooding. Five land classes are used to describe the extent and duration of inundation in Bangladesh (Table 6.2). Statistical data for the area of each land class by district is included in Table 6.3.

Table 6.1 Land area planted to Rabi crops (excluding Boro rice) for selected southern regions from 2001 to 2010. The percentage of cultivatable area sown to Rabi is shown in red. BBS values of total cultivatable area for the 2009-10 season are used as the baseline in calculation of Rabi area.

Region	2001-02 (ha)	2002-03 (ha)	2003-04 (ha)	2004-05 (ha)	2005-06 (ha)	2006-07 (ha)	2007-08 (ha)	2008-09 (ha)	2009-10 (ha)
Chittagong	53351	56628	58673	45400	37672	37017	38764	34365	34818
Comilla	144206	143109	140572	84799	78013	84231	79093	71029	72718
Noakhali	72052	71512	75094	58004	49920	44422	38571	38847	39867
Faridpur	263653	265072	271138	272177	283021	300615	296679	284917	334167
Barisal	120479	120781	114561	90483	87929	70382	60100	68362	73772
Jessore	184913	180393	191239	194430	194059	204305	183232	174833	221015
Khulna	61237	61672	64634	52178	47330	50796	43787	41447	44923
Patuakhali	63392	72532	77932	54578	48559	39161	20021	19208	18639
Total area	963284	971699	993842	852049	826503	830928	760247	733009	839920
	28.9%	29.2%	29.9%	25.6%	24.8%	25.0%	22.8%	22.0%	25.2%

Highland may be suitable for Kharif or perennial dry land crops if the soils are permeable. Medium Highland is suitable for crops that can tolerate shallow flooding, such as broadcast or T. aus paddy, jute and T. aman paddy, early Kharif dryland crops that mature before flooding starts can be grown on permeable soils, and late Kharif and early Rabi dry land crops on soils that drain in September-October. Medium Lowland is flooded too deeply for T. aus or T. aman paddy to be grown reliable. Deepwater aman is typically grown on such land. Mixed broadcast aus and deepwater aman is a common practice. Long aman seedlings may be transplanted as the floodwater recedes, if it does so early enough. Dry land Rabi crops can only be grown if floodwater recedes before December. A map of the coastal zone highlighting the area considered as water logged at the end of the monsoon in November for 2004 and 2009 is presented in Figure 6.9. In general the following broad land use patterns have been differentiated in the coastal area (Coastal Land Zoning Project-Inception Report, November 2007, Ministry of Land). In the high land area, aus/jute followed by dry land Rabi crops and vegetables or Boro (HYV) followed by T. aman. In the medium high land area, aus/jute followed by dry land Rabi crops and vegetables or boro (HYV) followed by T. aman or jute followed by T. aman or T. aman-fallow. In the medium low or low-lying area mixed aus and aman-fallow or boro (HYV/LV)-fallow.

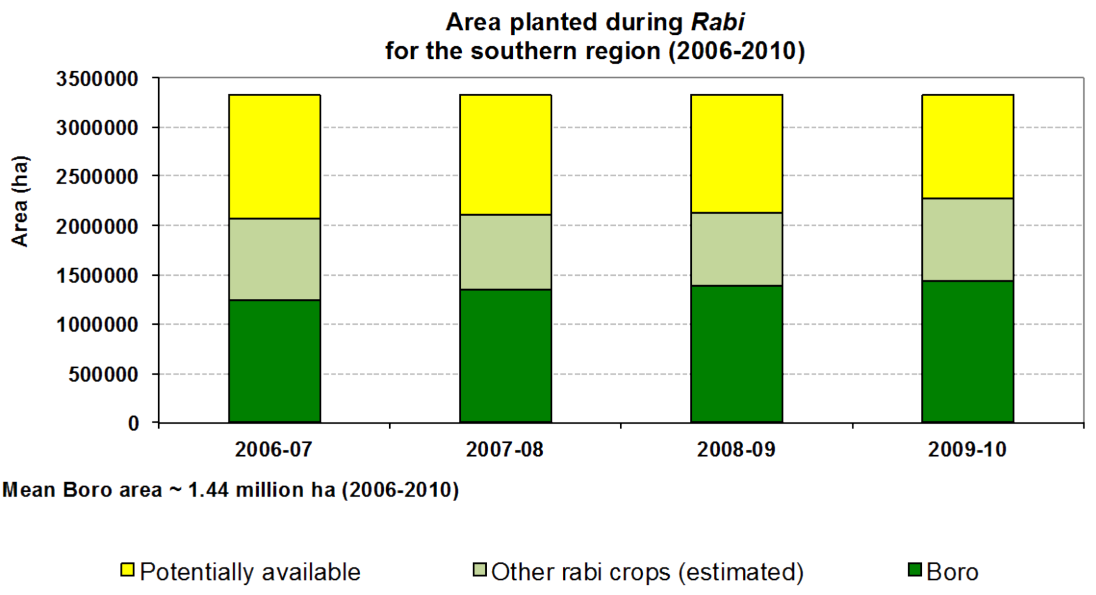


Figure 6.8 Area planted during the Rabi for Boro rice (BBS estimates) and alternative Rabi crops. The area of potentially available land is calculated from Boro statistical data and an estimate of alternative Rabi crops for the 4 years 2007-2010 use a mean value of 23.8 percent.

Table 6.2 Classification of land class (Land Resources Appraisal of Bangladesh for Agricultural Development, Part-II, UNDP, FAO, 1988)

Land class	Description
1 High land (H)	Land, which is above normal flood-level.
2 Medium Highland (MH)	Land, which normally is flooded up to about 90 cm deep during the flood season. This class has been subdivided into two classes: MH-1- normally flooded up to about 30 cm deep; and MH-2- normally flooded up to between 30-90 cm deep
3 Medium Low Land (ML)	Land which is normally flooded up to between 90 cm and 180 cm deep during the flood season
4 Low land (L)	Land, which is normally flooded to between 180 and 300 cm deep during the flood season.
5 Very Lowland (VL)	Land, which is normally flooded deeper than 300 cm during flood season.

Table 6.3 Area (hectare) of different land types within the study area

Land Type	District Name	Area (ha)	% total land
Highland	Bagerhat, Barisal, Bhola, Chandpur, Chittagong, Cox's Bazar, Feni, Gopalganj, Jessore, Jhalokati, Khulna, Lakshmipur, Narail, Patuakhali, Pirojpur, Satkhira, Shariatpur	471,804	16.5
Medium Highland	Bagerhat, Barguna, Barisal, Bhola, Chandpur, Chittagong, Cox's Bazar, Feni, Gopalganj, Jessore, Jhalokati, Khulna, Lakshmipur, Narail, Noakhali	1905,231	66.8
Medium Lowland	Bagerhat, Barguna, Barisal, Bhola, Chandpur, Chittagong, Cox's Bazar, Gopalganj, Jessore, Jhalokati, Khulna, Lakshmipur, Narail, Noakhali, Patuakhali, Pirojpur, Satkhira, Shariatpur	347,555	12.2
Lowland	Bagerhat, Barisal, Chandpur, Gopalganj, Jessore, Khulna, Lakshmipur, Narail, Patuakhali, Pirojpur, Satkhira, Shariatpur	97,268	3.4
Very Lowland	Chandpur, Gopalganj	31,360	1.1
Total		28,53,218	100

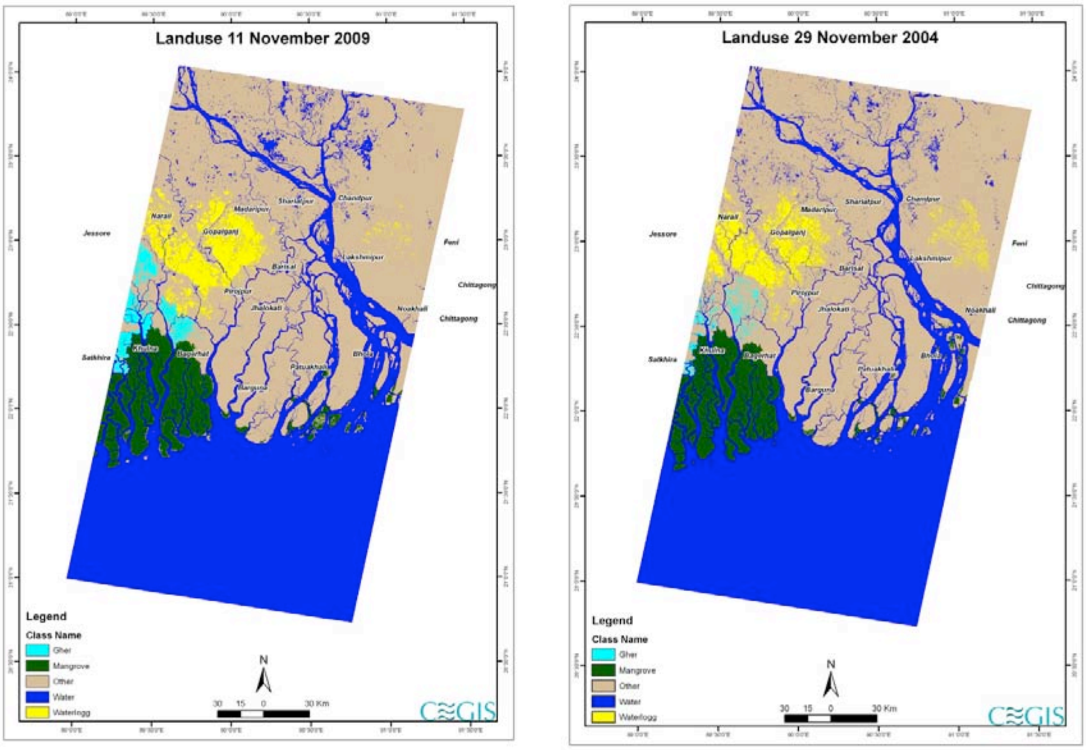


Figure 6.9 Area identified as being water logged (yellow) at the end of the monsoon in November for (a) 2009 and (b) 2004

Very-low land and low land remain wet longer after the end of the monsoon and are possibly affected by high levels of salinity and not suitable for timely sowing of Rabi crops.

For example, in wheat and mungbean cultivation, farmers prefer medium-high to medium-low land. By applying land classification class as a percentage of cultivatable area (Table 6.4), a more accurate estimate of potentially fallow land for the ROI can be calculated. Potentially 0.94 million ha of land classified as medium-high remain fallow in the southern coastal region of Bangladesh after accounting for the reported area sown to boro and alternative Rabi crops (Figure 6.8). Potentially available land classified as medium high for each of the 8 regions from 2006 to 2010 is presented in Figure 6.10.

Table 6.4 Percentage of cultivatable area for the ROI for each of the 5 land classification types as described Table 6.2.

Region	Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland	Total
Chittagong	50.2	35.5	7.6	0.0	0.0	93.3
Comilla	5.4	32.4	44.0	15.5	2.8	100.0
Noakhali	9.1	64.4	24.0	2.6	0.0	100.0
Faridpur	7.7	27.3	41.3	17.0	6.8	100.0
Barisal	3.5	88.3	6.6	1.5	0.0	100.0
Jessore	30.1	30.6	30.4	8.9	0.0	100.0
Khulna	14.7	68.9	13.0	3.4	0.0	100.0
Patuakhali	0.5	97.1	2.4	0.0	0.0	100.0

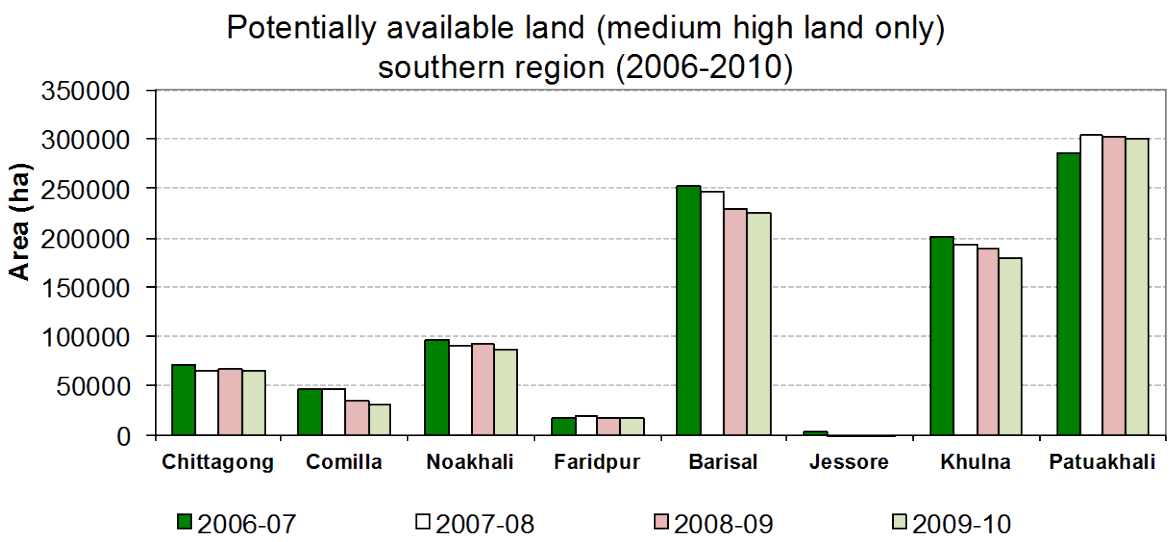


Figure 6.10 Potential fallow area (ha) for each of the 8 areas within the ROI from 2006 to 2010. Values represent the area classified as medium high land (class 2) and are calculated as the difference between total cultivation area and the sum of boro and all other Rabi crops.

6.5 Case study example

Variations in actual land utilization between regions can be attributed to a number of socio-economic and biophysical factors. A simple case study comparing two similar regions is discussed to emphasise this relationship. The Jessore and Khulna regions are located in the south west of Bangladesh with a similar cultivatable land area of 462,000 ha and 455,000 ha respectively (2008-09, BBS, 2010a). Jessore has a higher level of land utilization (216 %) compared with that of Khulna (128 %). Evident is the higher percentage of triple and double cropping reported in Jessore (~88 %) compared with the percentage of single cropping (~70 %) in Khulna (Figure 6.11). Based on these assumptions, Khulna has an estimated 0.17 million ha (2008-09) of potentially available land of medium-high land type compared to Jessore of near zero (Figure 6.11). This raises the question of, why this level of difference.

Inundation class type refers to the degree of inundation during monsoonal periods and does not consider coastal regions affected by varying degrees of soil salinity. Estimated potential area may be considerably less due to the level and extent of saline areas within a region (see Figure 6.16 under Section 6.7). Khulna in particular has 68 percent of cultivatable area classified as medium-high land compared to 30 percent for Jessore. Jessore covers three Agro-ecological Zones (Section 6.7) described as, High Ganges River Floodplain, Low Ganges River Floodplain and Gopalganj-Khulna Beels, soil salinity levels of which varies from < 2 dSm^{-1} to > 15 dSm^{-1} (Table 6.5). Khulna covers the above three AEZ and includes the Ganges Tidal Floodplain (Table 6.6). Relating the area of inundation class type with soil salinity status levels for each region identifies the percentage of cultivatable land potentially suitable for Rabi cropping. Khulna has a higher proportion of medium-high land but over 27 % of that area has a salinity level of higher than 2 dSm^{-1} compared with Jessore of less than 1 %. Table 6.7 supports the conclusion that large areas in the Khulna region are classified as being slightly saline to very strongly saline (see Figure 6.17 under Section 6.7) as evident by the dominant cropping system of T. aman-fallow. A more realistic assessment of potential fallow area (medium-high inundation class) is closer to 130,732 ha though land use by aquaculture is not considered in this evaluation.

Table 6.5 Soil salinity status (ha) for the Jessore region based on Agro-ecological zone and inundation class. Note: 1 MMHOS/cm = 1 dSm^{-1} (source: CEGIS)

Agro-echological zone (AEZ)	Soil salinity status	Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland
High Ganges River Floodplain	< 2 MMHOS/cm	108294	66154	21271	5910	0
High Ganges River Floodplain	4-8 MMHOS/cm	14	273	1	0	0
High Ganges River Floodplain	8-15 MMHOS/cm	0	9	0	0	0
Low Ganges River Floodplain	< 2 MMHOS/cm	478	969	487	194	0
Gopalganj-Khulna Bils	< 2 MMHOS/cm	2773	5128	14616	4277	0
Jessore region	< 2 MMHOS/cm	**111545**	**72251**	**36374**	**10381**	**0**
	4-8 MMHOS/cm	**14**	**273**	**1**	**0**	**0**
	8-15 MMHOS/cm	**0**	**9**	**0**	**0**	**0**

Table 6.6 Soil salinity status (ha) for the Khulna region based on Agro-ecological zone and inundation class. Note: 1 MMHOS/cm = 1 dSm^{-1} (source: CEGIS)

Agro-echological zone (AEZ)	Soil salinity status	Highland	Medium Highland	Medium Lowland	Lowland	Very Lowland
High Ganges River Floodplain	< 2 MMHOS/cm	9047	5515	1864	0	0
High Ganges River Floodplain	4-8 MMHOS/cm	1	23	0	0	0
High Ganges River Floodplain	8-15 MMHOS/cm	0	1	0	0	0
Low Ganges River Floodplain	< 2 MMHOS/cm	249	2522	4271	418	0
Gopalganj-Khulna Bils	< 2 MMHOS/cm	2490	12340	16306	7534	0
Ganges Tidal Floodplain	< 2 MMHOS/cm	1343	49842	828	0	0
Ganges Tidal Floodplain	2-4 MMHOS/cm	0	21764	0	0	0
Ganges Tidal Floodplain	4-8 MMHOS/cm	234	37333	1116	0	0
Ganges Tidal Floodplain	8-15 MMHOS/cm	0	3799	0	0	0
Khulna region	< 2 MMHOS/cm	**13129**	**70219**	**23269**	**7952**	**0**
	4-8 MMHOS/cm	**235**	**37355**	**1117**	**0**	**0**
	8-15 MMHOS/cm	**0**	**3799**	**0**	**0**	**0**

Table 6.7 Percentage (%) of cultivatable land in the Jessore and Khulna regions characterized by inundation class type. Note 1 MMHOS/cm = 1 dSm^{-1} (source: CEGIS)

Region	Soil salinity status	Cultivatable area (ha)	Highland (%)	Medium Highland (%)	Medium Lowland (%)	Lowland (%)	Very Lowland (%)	Total (%)
Jessore	< 2 MMHOS/cm	462000	48.3	31.3	15.8	4.5	0.0	99.9
Khulna	< 2 MMHOS/cm	455000	8.4	44.7	14.8	5.1	0.0	72.9
Jessore	4-8 MMHOS/cm	462000	0.0	0.1	0.0	0.0	0.0	0.1
Khulna	4-8 MMHOS/cm	455000	0.1	23.8	0.7	0.0	0.0	24.6
Jessore	8-15 MMHOS/cm	462000	0.0	0.0	0.0	0.0	0.0	0.0
Khulna	8-15 MMHOS/cm	455000	0.0	2.4	0.0	0.0	0.0	2.4

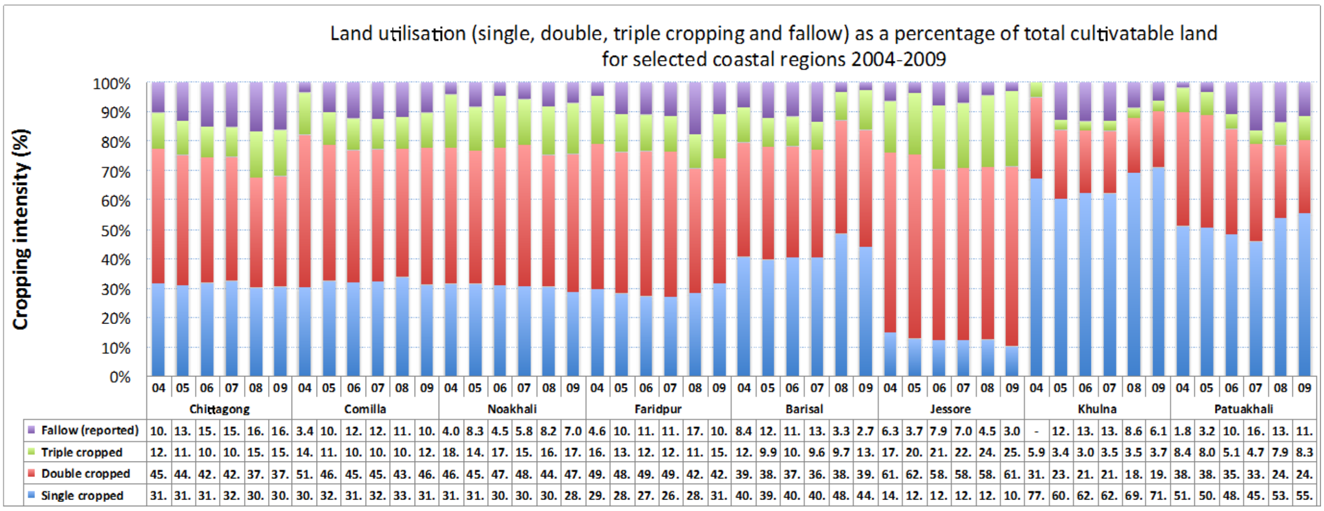


Figure 6.11 Land utilisation as a percentage of total cultivatable area classified as single, double or triple cropped and includes land reported as fallow. Data covers years 2004 to 2009 for each of the 8 Regions of Interest (ROI). Data supplied from the Bangladesh Bureau of Statistics (BBS).

6.6 Spatial and temporal trends in production

An increase in the area under cultivation and adoption of higher yielding varieties since the early 1970s (section 6.2) has contributed to an increase in crop production. Total rice production in Bangladesh has increased from 10 million tonne in the early 1970s to over 32 million tonne today (Figure 6.12). In contrast with northern Bangladesh, salinity is a major constraint on agricultural production in the southern coastal regions. The coastal area is vulnerable to cyclonic surge and saline water intrusion on agricultural land regularly occurs in coastal areas. It is considered that salinity constraints impact cultivation of HYV boro and other dry land crops in this region with rice-fallow cultivation the dominant farming system in the coastal areas. Wet season local T. aman rice is grown extensively in the coastal saline areas with normal yields between 2.5 and 3.0 t/ha. Outside of the monsoon the land would traditionally remain fallow due to high salt content (ECe > 8.0 dSm^{-1}) of the soil and with the poor quality of irrigation water (EC > 5.0 dSm^{-1}). These flat lands are generally classified as low or very low land and thereby frequently inundated with saline tidal water from nearly estuaries. Moreover, shallow groundwater tables contribute to soil salinity levels later in the Rabi from capillary rise. With the onset of the monsoon, soil salinity declines (ECe < 4.0 dSm^{-1}) enabling T. aman cultivation. During the monsoon season, most of the water of the coastal rivers is rain derived and of low salinity (EC < 2.0 dSm^{-1}). A detailed assessment of salinity effects on Rabi cropping at the farm and field level is given in Chapter 7.

Rice production data for the greater coastal districts for the 2001 to 2010 seasons is presented in Figure 6.13. These data reflect those constraints to cropping (previously described) particularly in the area of rice cultivation for districts of similar land area, Jessore and Khulna, used in Section 6.5 case study. Figure 6.13 demonstrates the dominance of boro cultivation in relation to other Rabi crops for the coastal regions from 2006 to 2010.

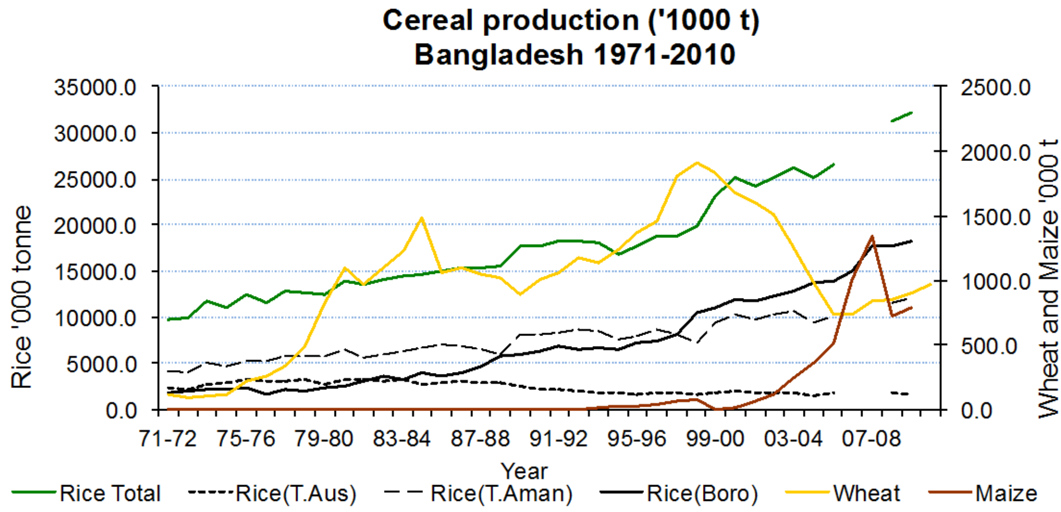


Figure 6.12 Grain production ('000 tonnes) for rice, wheat and maize between 1971 and 2010

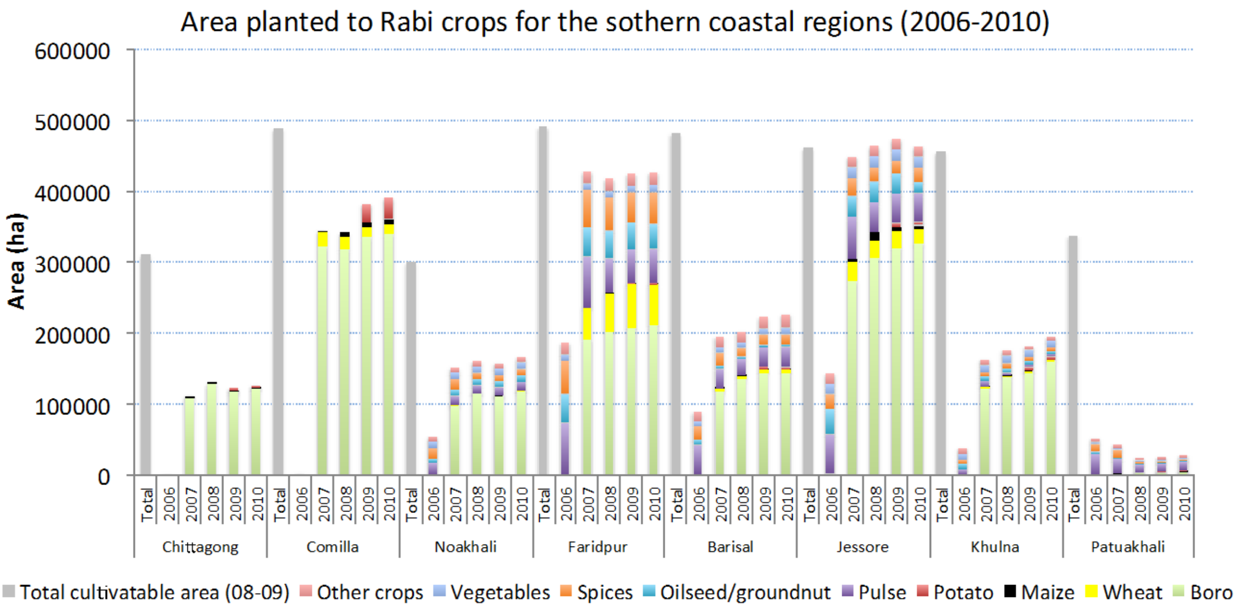


Figure 6.13 Rice crop production in the greater coastal districts (BBS data). Grey bars represent the total cultivatable area for each region

A detailed comparison of the area planted to crops other than rice from 2002 to 2010 is presented in Figure 6.14 with values tabulated for area (Appendix B, Table B.3) and production (Table B.4). These data show an increase in the area planted to boro with 4.0% decline in the area sown to other Rabi season crops since 2001-02. In addition, BBS data on wheat production for both northern and southern regions for 2006 to 2010 were evaluated. Area sown and final grain yield as a percentage change (±) of the 2006 values are presented in Figure 6.15 and highlight significant increases in area and yield for the southern region during the 2007-2009 period though a reduction in sown area (southern region) was measured in 2010. The area planted to wheat in the northern region declined by 6.0% for the same period. The increase in area and production during 2007 to 2009 may be attributed to a previous ACIAR study, LWR/2005/146 - *Expanding the area for Rabi-season cropping in southern Bangladesh*. A high number of farmers participated in or were exposed to SMT (Seed Multiplication Trial) evaluations and demonstrations during this period.

Figure 6.14 Area planted to Rabi crops other than rice for the coastal districts from 2002-2010 (BBS data). Data presented in Appendix B.

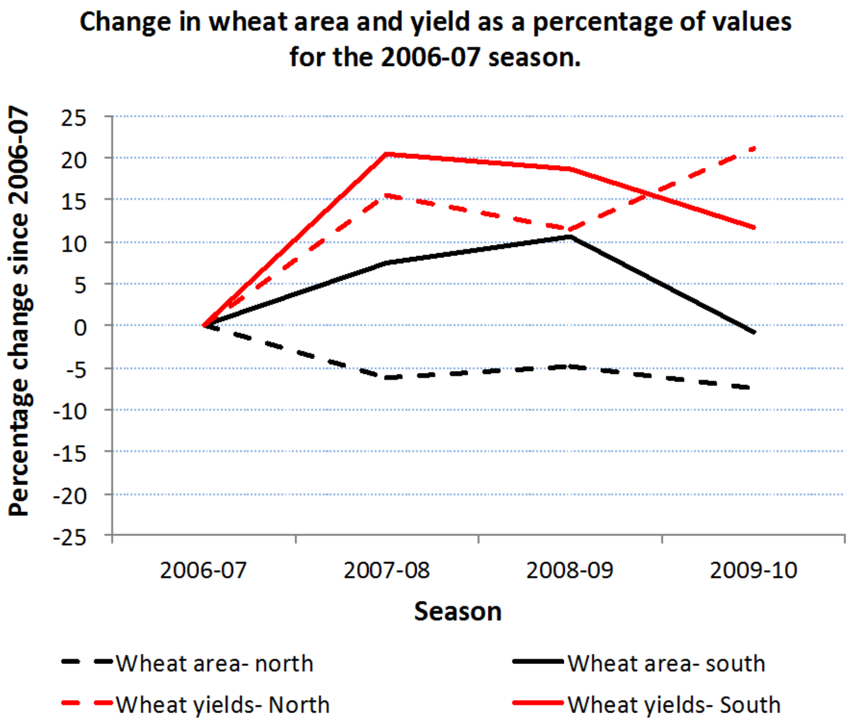


Figure 6.15 Comparison of change in sown area and mean yield of wheat as a percentage of the 2006-07 season for northern and southern regions

6.7 Agro-ecological zoning

An agro-ecological zone indicates an area characterized by homogeneous agricultural and ecological characteristics. This homogeneity is more prominent at the sub region and unit level. The agro-ecological zones of Bangladesh have been identified on the basis of four elements such as physiography, soils, land levels in relation to flooding and agro-climatology and ignore all political boundaries. Bangladesh has been tentatively divided into 30 agro-ecological zones. The Agro-ecological Zones (AEZ) database is unique and is being extensively used for agricultural planning, technology transfer and specific biophysical resource utilization program activities. The database on AEZ, however, needs updating, as over time there have been some changes in the land types due to the addition of roads and other infrastructural development, variability in precipitation and temperature as well as technical innovation in agriculture. The coastal region covers 15 agro-ecological zones, details of which are presented in Table 6.8 and Figure 6.16.

The AEZ database is a tool to assess land resources for better planning and management and monitoring of these resources. AEZ can be used in various assessment applications, including:

- inventory of land resource; inventory of land utilization types and production systems, including indigenous systems, and their requirements
- potential yield calculation; evaluation of land suitability and land productivity, including forestry and livestock productivity
- mapping agro-climatic zones, problem soil areas, land suitability, quantitative estimates on potential crop areas, yields and production
- assessment of land degradation, population supporting capacity assessment and land use optimization modelling

A regional AEZ map superimposed with soil salinity is presented in Figure 6.17 highlighting the extent of salinity and the relationship with the dominant land features of the Ganges tidal floodplain and young Meghna estuarine floodplain. The agro-ecological zone classification (AEZ) is a useful tool in identifying constraints within the existing cropping systems using biophysical land resource assessments.

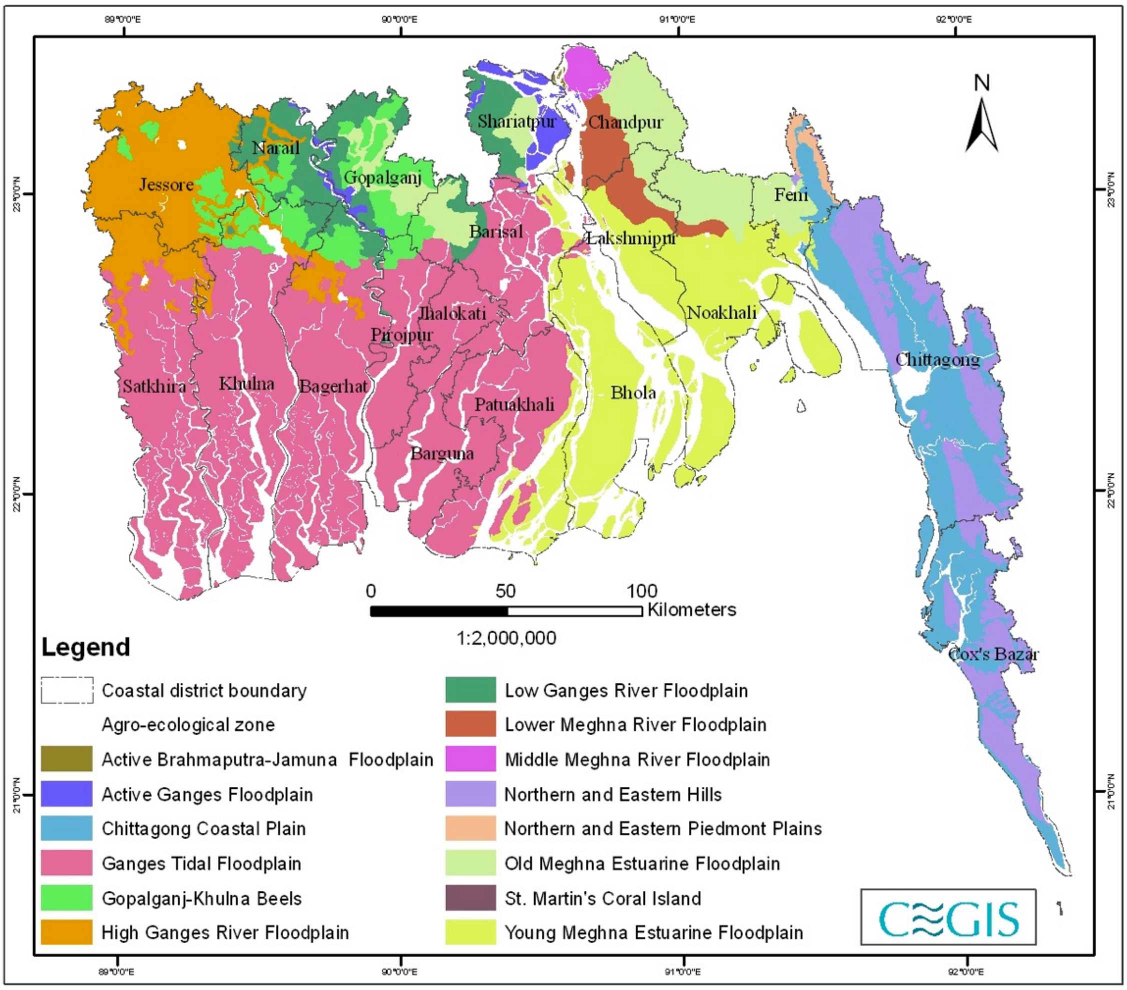


Figure 6.16 Agro-ecological Zones of the study area

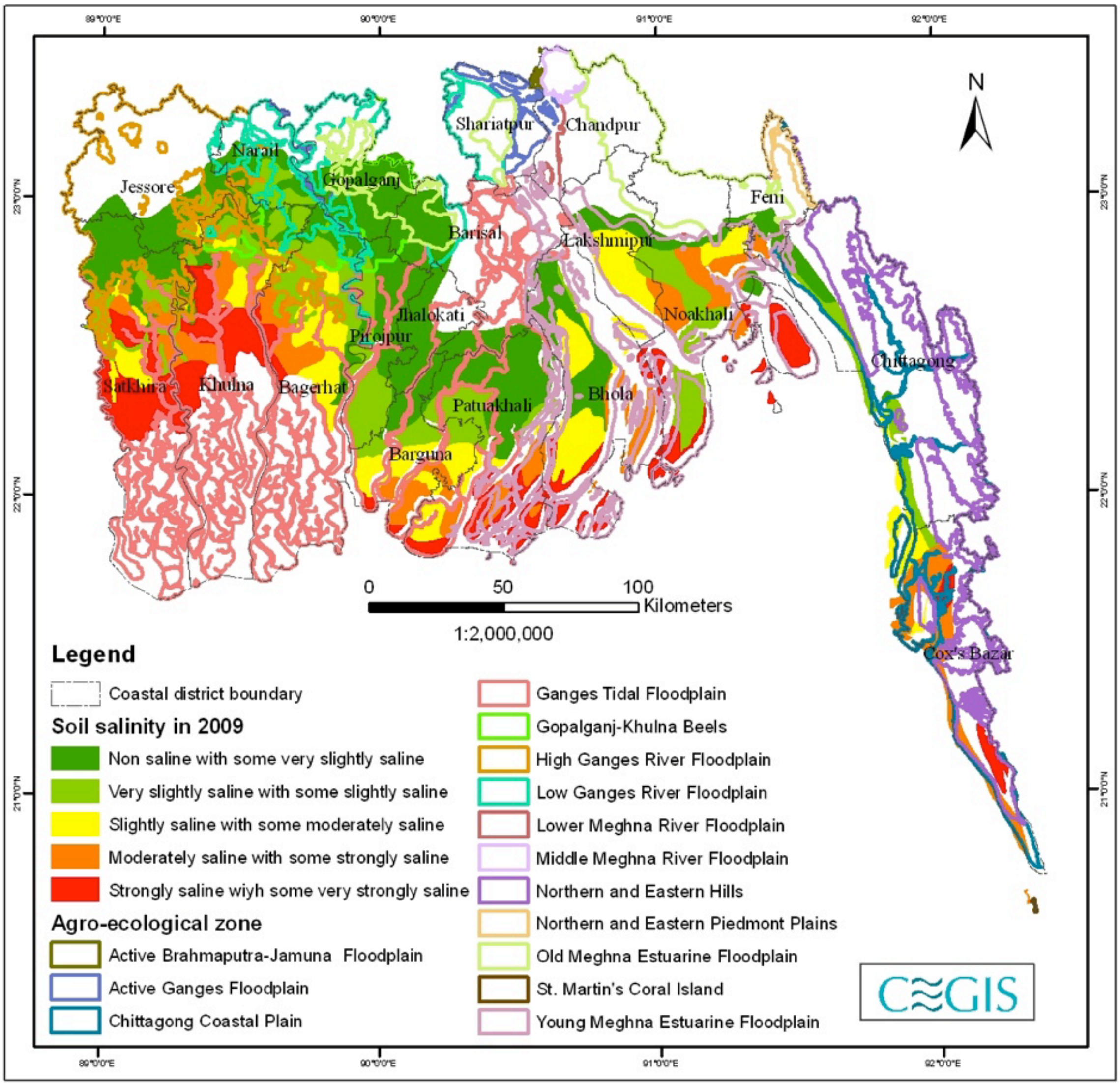


Figure 6.17 Soil salinity classes and Agro ecological zones for coastal regions of southern Bangladesh. [1] Very slightly saline (2.1-4.0 dS/m); [2] slightly saline (4.1-8.0 dS/m); [3] Moderately saline (8.1-12.0 dS/m); [4] strongly saline (12.1-15.0 dS/m); [5] very strongly saline (>15.0 dS/m) (Bangladesh Agricultural Research Council GIS project BGD/95/006).

Table 6.8 Distribution of agro-ecological zones in the study area

Agro-ecological Zone(AEZ) with AEZ Number	Districts	Area (ha) cover in study	% cover in study Area
Active Ganges Floodplain (AEZ 10)	Barisal	1,725	0.07
Chittagong Coastal Plain (AEZ 23)	Chittagong, Cox's Bazaar, Feni	325,547	12.78
Ganges Tidal Floodplain (AEZ 13)	Bagerhat, Barguna, Barisal, Bhola, Jhalokati, Khulna, Patuakhali, Pirojpur, Satkhira	1,209,185	47.47
Gopalganj-Khulna Beels (AEZ 14)	Bagerhat, Barisal, Khulna, Pirojpur	38,360	1.51
High Ganges River Floodplain (AEZ 11)	Bagerhat, Khulna, Satkhira	96,312	3.78
Low Ganges River Floodplain (AEZ12)	Bagerhat, Barisal, Khulna, Pirojpur	22,722	0.89
Lower Meghna River Floodplain (AEZ17)	Lakshmipur, Noakhali	28,566	1.12
Northern and Eastern Hills (AEZ 29)	Chittagong, Cox's Bazar, Feni	341,758	13.42
Northern and Eastern Piedmont (AEZ22)	Feni,	131	0.01
Old Meghna Estuarine Floodplain (AEZ19)	Barisal, Feni, Lakshmipur, Noakhali	83,970	3.30
St. Martin's Coral Island (AEZ 24)	Cox's Bazar	280	0.01
Young Meghna Estuarine Floodplain(AEZ 18)	Barisal, Bhola, Chittagong, Feni, Lakshmipur, Noakhali, Patuakhali	398,477	15.64
Total		**2,547,033**	**100.00**

6.8 Satellite imagery

Remote sensing and imagery analysis have been used extensively in monitoring temporal changes in land use in many countries. Multispectral Landsat 5 satellite images of the 2003 and 2010 Rabi were used to identify land use and in map preparation of the study area. The land use information such as “Bagda Shrimp Area”, “Crop”, “Fallow”, “Forest”, “Mangrove Forest”, “Settlements with Homestead Vegetation”, and “Inter Tidal Area” were delineated from analysis of the satellite images. The Landsat 5 TM image acquires images in seven spectral bands, covering the visible and near, middle and thermal infrared parts of the electromagnetic spectrum. It has a 30 m ground resolution for all bands except B and 6. The images were geo-referenced into the BTM coordinate system using DGPS corrected geo-referenced images. The ISODATA (Iterative Self-Organizing Data Analysis Technique) algorithm technique was used to perform unsupervised classification. Following this method each image was classified into 100 spectral classes. The similar spectral classes were grouped together into information classes based on available ancillary data and expert knowledge. Finally the information classes such as: “Bagda Shrimp Area”, “Crop”, “Fallow”, “Forest”, “Mangrove Forest”, “Settlements with Homestead Vegetation”, and “Inter Tidal Area” were derived from analysis of satellite images of both dates. Table 6.9 shows the acquisition dates and sensor of the satellite images of Landsat used in this analysis. Remote Sensing and GIS techniques were able to identify land remaining fallow (Table 6.11) during the 2003 and 2010 Rabi season. Rabi land use/cover maps for 2003 and 2010 are presented in Figures 6.18 and 6.19.

Uncultivated or potentially fallow land was estimated at 868,291 ha (2003) and 722,914 ha (2010) and consistent with estimates in this chapter based on statistical data. Figure 6.20 shows a map of the boro season rice crop prepared from available Landsat 5 images acquired on the 24th March 2003. Area coverage of Rabi crops was also extracted using the images. The area statistics of Boro season rice crop and Rabi season crops area are presented in the Table 6.10. Only districts that are fully covered by images were selected.

Table 6.9 Sensor and Acquisition Dates of Satellite Images

Sensor	Path/Row	Date
Landsat 5	Path-136, Row-44	08 February 2010
	Path-136, Row-45	06 December 2009
	Path-137, Row-44	30 January 2010
	Path-137, Row-45	30 January 2010
	Path-138, Row-44	06 February 2010
Landsat 7 ETM+	Path-136, Row-44	28 January 2003
	Path-136, Row-45	28 January 2003
	Path-137, Row-44	19 January 2003
	Path-137, Row-45	19 January 2003
	Path-138, Row-44	26 January 2003

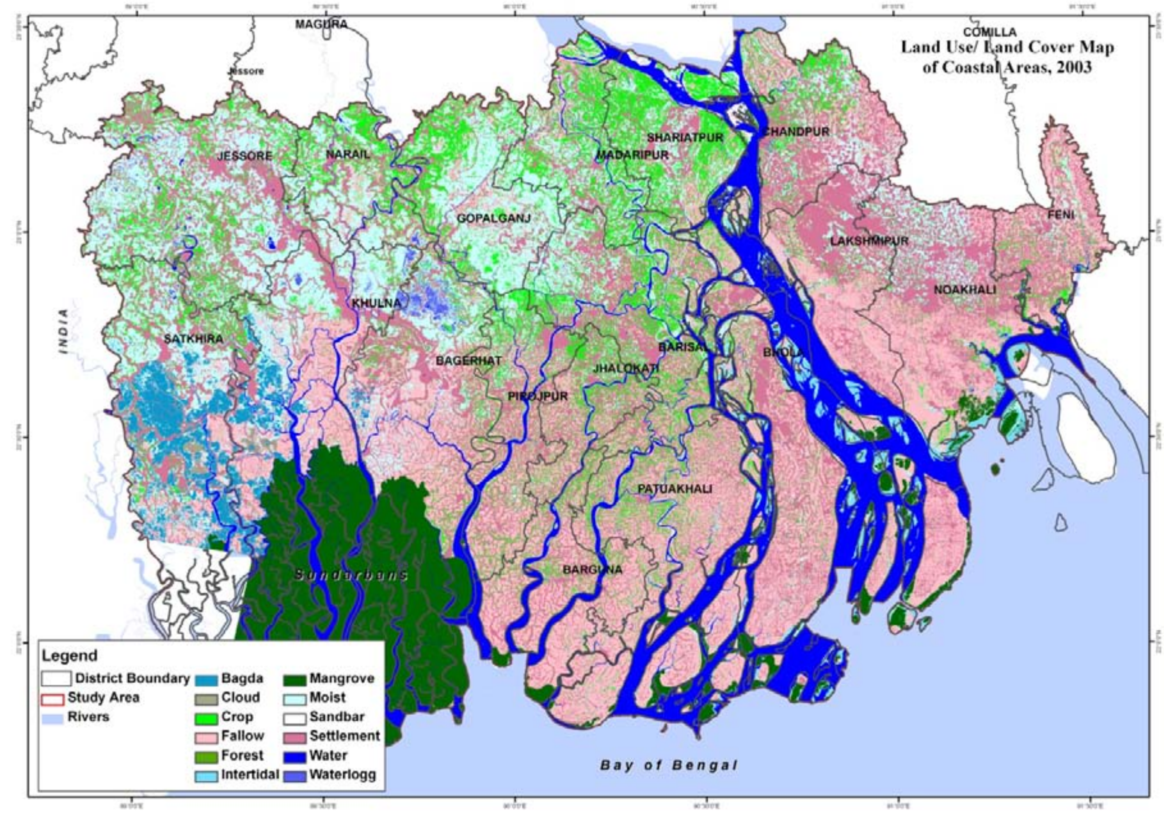


Figure 6.18 Rabi (dry) season land use/cover map of 2003

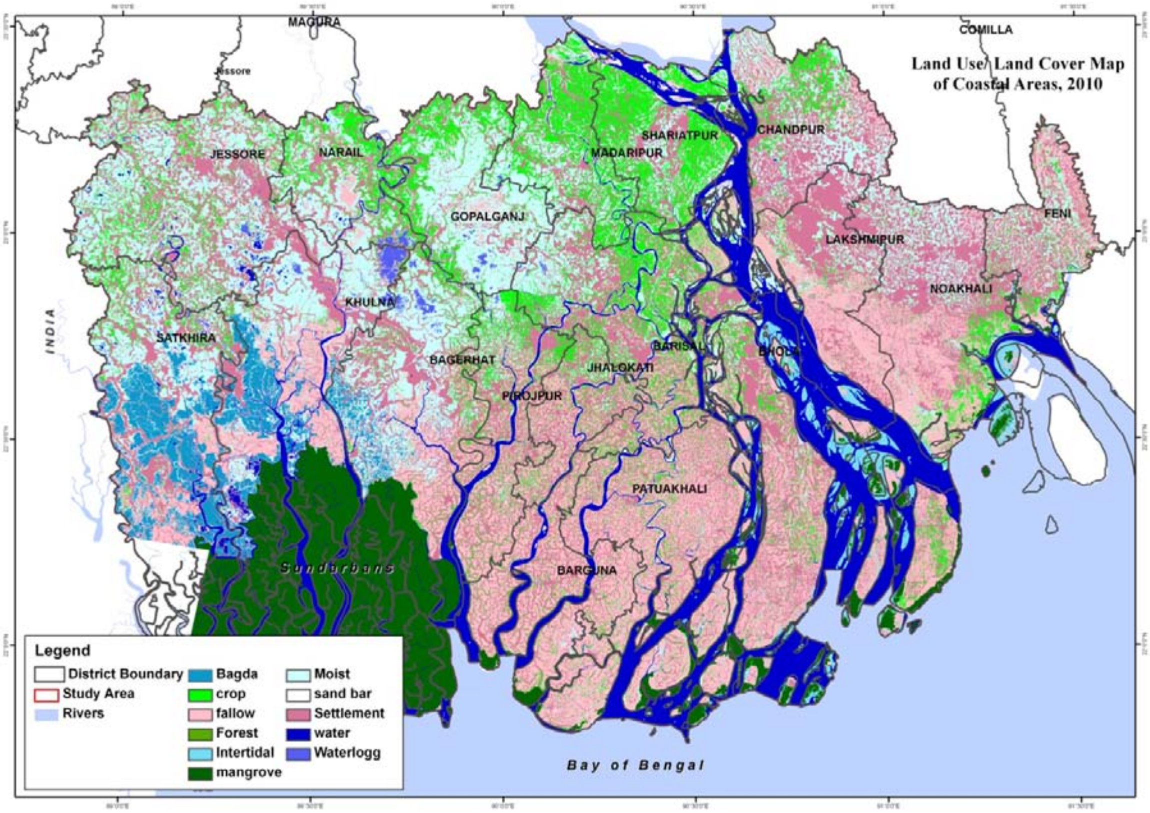


Figure 6.19 Rabi (dry) season Land use/cover map of 2010.

Table 6.10 Area Statistics of Boro season and Rabi season crops (2003)

District	Boro Rice Area (ha)	Rabi crops Area (ha)
Chandpur	42,753	8,756
Shariatpur	23,828	2,365
Gopalganj	59,810	5,400
Lakshmipur	17,153	6,180
Barisal	48,673	8,949
Bagerhat	22,494	4,675
Pirojpur	15,916	4,986
Bhola	19,923	8,159
Jhalokati	5,813	3,642
Patuakhali	1,524	24,856
Barguna	1,088	10,471

Table 6.11 District wise Fallow land in Rabi (dry) season of 2003 and 2010 for the 19 southern coastal districts

District	Fallow Land (Hectare)	
	Year 2003	Year 2010
Bagerhat	66603	33701
Barguna	71418	73427
*Barisal	48937	41615
Bhola	86661	76838
Chandpur	33359	18604
*Chittagong	33695	21450
Feni	37589	19189
Gopalganj	18756	8239
*Jessore	6640	13447
Jhalokati	22840	25277
*Khulna	54806	37427
Lakshmipur	50073	45665
Madaripur	14619	5711
Narail	12604	10529
*Noakhali	95838	82005
*Patuakhali	139738	143723
Pirojpur	40008	37450
Satkhira	19021	20877
Shariatpur	15088	7739
Total	**868,291**	**722,914**

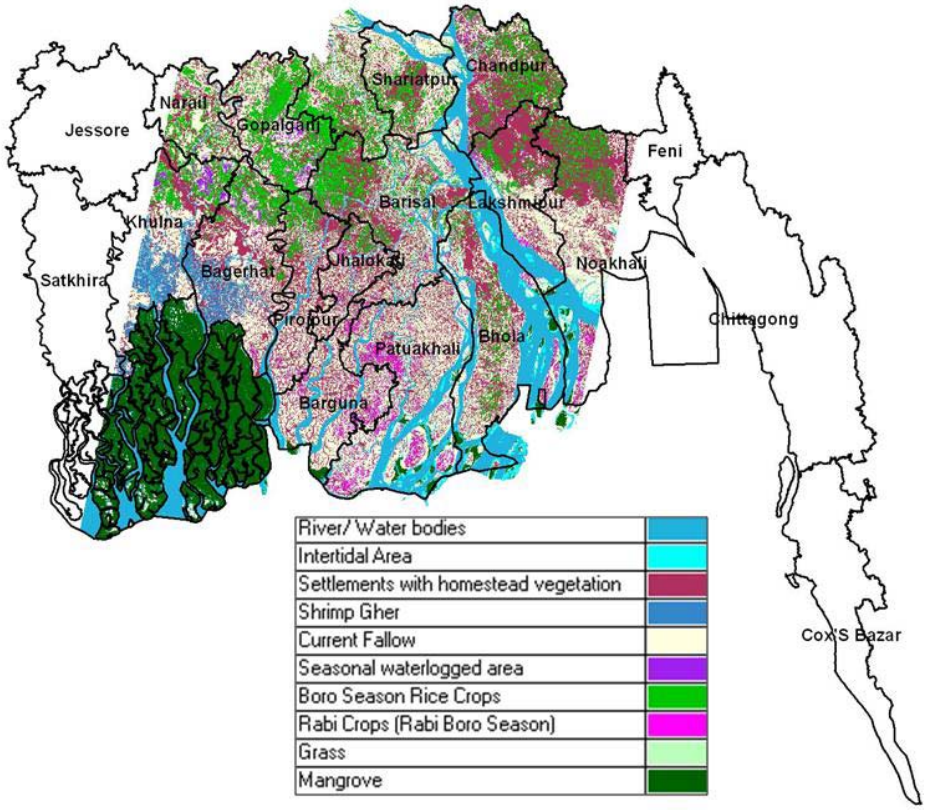


Figure 6.20 Boro season rice crop and Rabi crops map (2003)

6.9 Conclusion

Using current cropping and satellite data from the southern areas of interest to the project, namely Chittagong, Comilla, Noakhali, Faridpur, Barisal, Jessore, Khulna and Patuakhali, with subsidiary data from other southern zones, it is concluded that more than 700,000 ha of under-utilised land is potentially suitable for additional Rabi cropping in the coastal zone. This is in accord with estimates by Poulton (2011) using older data.

The calculations consider only medium high land for inclusion, as that becomes available for planting relatively early in Rabi, and exclude land that has salinity values higher than 2 dS/m by April; salt is at its highest values for the year in April as it has, by then, completed its capillary rise through the soil rooting profile (data in Chapter 7) and will later be leached back down the profile by monsoon rains.

Currently, Patuakhali has the largest under-utilised land area during Rabi followed by Barisal, then Khulna, which has up to 130,000 ha of land potentially suitable for additional cropping.

Triple cropping (i.e. where crops occupy the same land 3 times in the year, and cropping intensity is 300%) is practiced on only 15% of southern lands with double and single cropping each on around 40%; average cropping intensity in the south is 174%, ranging from more than 230% in Jessore to only 150% in Bagerhat. The north averages 180%.

Capacity exists for intensification of cropping systems in a number of coastal regions. The challenge for farmers lies in identifying opportunities and implementation of good agronomic practice in overcoming local and regional constraints to agricultural production.

Boro rice is the dominant Rabi crop ranging from more than 90% of all cropping in Chittagong and Comilla, through 70 to 80% at Jessore and Khulna, and falling to almost zero in Patuakhali where essential irrigation water is rarely available. In most southern regions the area planted to Boro rice has increased steadily since 2001 with other crops declining by 4%. Despite dominance of the preferred Boro, very many other species are cultivated. Details appear in Appendix B tables.

An increase in wheat yields and area sown during 2007 to 2009 in the southern coastal regions may be attributed to the on-farm activities undertaken during the ACIAR study, LWR/2005/146 - *Expanding the area for Rabi-season cropping in southern Bangladesh*. A significant number of farmers participated in or were exposed to on-farm evaluation and demonstration of newer varietal wheat and mungbean crops during this period.

7 Field and crop data collection and analysis

7.1 Introduction

7.1.1 Approaches to improve crop yields in saline soils

Solutions proposed to maintain or improve crop yields despite salinity have included large polder-scale and farm-scale engineering. These aim to prevent saline water incursions onto agricultural land during floods and to drain any flooded land. At the crop level, salt-tolerant varieties of crop species have been selected through conventional breeding and more recently through molecular engineering directly targeting cellular, organ and whole plant salt tolerance mechanisms. The potential beneficial outcomes from such plant engineering are large but the paths are several decades to having crops in the field. By contrast, conventional breeding and field selection results in adaptation over shorter timeframes but makes smaller steps. Farmers generally want improved varieties now.

7.1.2 Difficulties of screening more salt-tolerant crops in breeding trials

A problem in screening out the best materials from multi-cross breeding programs is that selection is normally done in saline fields and salt distribution is notoriously variable spatially and temporally (Richards, 1983). Even using 4 blocks of randomised replicate plots of each breeding line in such saline fields may not lead to the “correct” ranking of lines because salt differences between and within plots can be at the centimetre to meter scale (Barma et al., 2011). Barma et al. (2011) suggested a different way of analysing the data from screening trials. They measured EC of every plot along with biomass and yield and fitted a common curve for the site between biomass (and yield) and EC using all plot data. They then ranked each replicate of each selection by its deviation from the common curve. Higher biomass at a particular EC meant higher salt tolerance. The down side of this approach is that it requires very detailed measurement of salinity temporally and spatially across the screening site (horizontally and vertically to produce 3-D maps). It also assumes that selections that yield better at higher salinities also yield well at no salinity.

Some researchers have overcome spatial and temporal changes in salinity in selection procedures by planting into large-scale hydroponics tanks with carefully controlled added salt. Plant selection then has frequently been based on ability to germinate and survive, often under extreme NaCl concentrations (e.g. Epstein et al., 1980; McGuire and Dvorak, 1981). Unfortunately, though this methodology is relatively simple and can lead to reproducible results, the rankings of lines for salt tolerance at the seedling stage do not necessarily produce similar rankings for growth and final yield. This is because germination involves processes not found in established seedlings. For example, very young roots cannot exclude NaCl like mature roots. Plant survival can involves processes such as stomatal closure and osmotic adjustment that may be counter-productive to rapid growth. Really, the only reliable way to assess salinity tolerance of a range of species or genotypes is to measure plant growth throughout development in a similar soil and environmental condition and season to that intended for their ultimate use.

7.1.3 Effects of salt on yield

Plants species vary considerably in their tolerance of salt (for listings and references to sources refer to SRDI, 2010) and in their relative tolerance with stage of development. For example small-grain cereals are salt sensitive in the seedling stages and relatively tolerant during grain filling when there are no expanding green tissues. Relative tolerance may also be associated with whether roots are exposed to the salt in the soil profile or whether they can avoid it by tapping water from a low salinity water table or from irrigation. In experiments where the whole root zone was exposed to salt at one of 8 concentrations from 0 to 250 mol/m^3 after seedling establishment (using plants in gravel flushed every 20 minutes with nutrient solution and NaCl), barleys, wheats (T. aestivum and T. durum) and triticales all were reduced in biomass by approximately 0.27% per mol/m^3 by the time the seventh leaf had expanded (Rawson et al., 1988). So the rate of decline in production with increase in salinity was similar in all these species despite barleys being reputed to have the highest salt tolerance. However, the durum wheat varieties under high salt had produced only one third the biomass of the barleys at the seven leaf stage indicative of their relative production at zero salt. There was considerable varietal variation in salt tolerance within each of the species. SRDI (2010) indicate reductions in yield for vegetables occur at between 5 and 15% as salt rises above ECe (saturated soil extract) of 1 to 3 dS/m.

7.1.4 Measurement of salt in soils

Salinity is estimated by electrical conductivity (EC) of a water solution. Conductivity numbers increase with dissolved salt content, though they do vary slightly with which cations and anions are present (Richards, 1954). The conventional numerical description of salinity in soils is taken from a paste or saturated soil extract (ECe) where ECe is quantified in dS/m (deciSiemen/meter) where 1 dS/m = 1mS/cm = 1mmho/cm = 1000µS/cm. In the field, electrical conductivity is commonly estimated with an EC meter from an air-dry sample of soil mixed in 5 times its weight of rain or distilled water (EC 1:5). To convert EC (1:5) to ECe requires a multiplier that reflects the moisture holding potential of the soil. Approximate multipliers that reflect the water holding capacity of the soil are for sand 23, for sandy loam, silty loam and sandy clay loam 14, for light medium clay 8.6, for medium clay 7.5, for heavy clay 5.8 and for peat 4.9 (Slavich and Petterson, 1993). So the better the water holding capacity of the soil the smaller is the multiplier. For example, an EC 1:5 of 1.0 dS/m in Satkhira clay soil would convert to an ECe of around 8 dS/m while in the silty sand of Noakhali Hazirhat it would convert to an ECe of 10 to14 dS/m depending on its clay content. It is difficult to make comparisons between the effects on crop growth of saline soils if values are not expressed directly as ECe or as EC (1:5) associated with some description of soil type to allow the appropriate multiplier to be guessed and applied.

Because salt content changes with depth in the soil profile and changes through time at the same depth, the likely yield of a crop in any soil cannot be predicted from one or two measurements of EC (1:5), particularly if samples are taken outside the appropriate season for the crop. Equally, there must be some knowledge of where in the soil profile the crop's roots are extracting their water when EC measurements are made.

7.1.5 What we need to know to predict crop yields in saline soils and effectively screen species and breeding selections for salinity tolerance

To describe the soil: We need to know

1. EC (1:5) of the soil prior to planting, which will be a different date depending on the species, its distribution in the rooting profile, its change in distribution and amount throughout the season and its distribution spatially in the fields and locality where the crops are grown. It could be that there are minimal changes in these variables but they could also be large in soils that have a mobile water table and high vertical water vapour fluxes.
2. Depth and change in the water table height and salinity of the water table throughout the season; roots may be extracting much of their water from the water table
3. Soil water capacity and content through time. A crop unable to access water and growing through a salty soil will fail
4. Waterlogging; a waterlogged crop in warm locations rapidly becomes nitrogen deficient, yellows and dies in the presence or absence of salinity

To describe the environment: We need data on

1. Air temperature and humidity (vapour pressure deficit) as these drive water (and salt) fluxes through the soil profile and through the crop
2. Rainfall as this will affect crop water availability and growth, affect the evaporation of water from the soil surface and associated movement of salt through the profile, the concentration of salt and for significant rainfall events salt could be moved down the soil profile

To describe the crop: we should note

Crop emergence percentages which indicates the tolerance of the species to salt through germination and pre-emergence tissue extension

1. Crop establishment. This is very sensitive to salt at least in the small grain cereals where initial tillering may be prevented leading to few grain-bearing heads per ground area
2. Amount of dead leaf in the crop and whether it is old leaf, indicating salt is being compartmentalised into redundant tissues, or young leaf, indicating salt is moving freely into the plant and directly to expanding tissues because the roots have limited ability to exclude salt
3. Biomass and yield production at maturity. These measures are the amalgamation of the crop's resistance to salinity throughout its life

7.1.6 Aims of the field-based agronomic and breeding work in this Rabi season

1. To describe in centimeter to meter-scale the 3-dimensional distribution and movement of salinity (EC 1:5) throughout the soil rooting profile of contrasting cropped experimental sites through the 2011-12 Rabi season. The question to be answered is do all sites follow similar EC patterns and if not, what differences are there and why?
2. To measure the responses of crops to different concentrations of soil salinity and address the impact of salt distribution within the rooting profile on crop biomass and yield
3. To track the depth and EC of the water table under crops at saline sites and look for correlations with crop biomass and yield
4. To follow aims 1, 2 and 3 at four disparate but saline sites across the southern coastal zone, Hazirhat in Noakhali in the east, Benerpota (Satkhira) in the west, and Amtali (Barguna) and Kuakata (Patuakhali) in the central region.
5. To test and develop further a methodology for screening breeding selections for salinity tolerance in variably saline fields

The current studies were interlinked so that the 5 aims could be attempted for minimal expenditure. This could not have been achieved without significant initial unsupported input from BARI to select, prepare and plant the plots for us in December prior to the official start of the ACIAR project.

7.2 Results: Amounts of salts and distribution through soil profiles

7.2.1 Descriptions of the four sites used for cropping and EC descriptions

Benerpota in Satkhira (4-5 masl) is on a tidal river system that is prone to flooding with saline water whereas Hazirhat (8-9 masl Noakhali) has no such problem though lower areas can drain slowly after the monsoon. Amtali (Barguna) is also on a flooding river system while Kuakata is on a river system in Patuakhali a few kilometres from the most southerly coast (Figure 3.1). All can be found on Google Earth by entering their names plus Bangladesh or their latitude/longitude coordinates shown later in Table 7.1. Soil types (Figure 7.1) range from cracking clay (Satkhira) to sandy loam (Hazirhat). Crop growth and yield data were collected over several years from several sites in all these regions in a previous ACIAR study described in ACIAR Technical Report 78, 2011.

The cracking clay of Satkhira whitened with surface salt is shown in Figure 7.2 and an aerial view of the site from Google Earth appears in Figure 7.3. Marker signs in Block 4 of Figure 7.2 indicate the sizes of plots. Selected plots had 3 m long piezometer tubes inserted. These were used to measure water table depth and EC. All four sites were laid out in the same way as in Figure 7.2. The locality of the Noakhali (Hazirhat) site (Figure 7.4) has no significant surface rivers.

Figure 7.1 Soil of Satkhira (clay, setting like concrete) and Hazirhat, Noakhali loam, powdering easily

Figure 7.2 Satkhira site on 27 February 2012, 75 DAS. Block 1 plot 1 is in the far left corner of the picture. Block 4 is to the right. In each of the 4 blocks there were 28 plots, each of 4, 20 cm rows 2.5 m long, This layout was used at all sites. At the final harvest only the two centre rows of plots were cut

Figure 7.3 Satkhira trial site (yellow marker in centre) on Google Earth showing the adjacent saline water body 2-2.5m deep, also visible on Fig 7.2, and the curve of the river on left

Figure 7.4 Aerial view of the locality of the Hazirhat salinity site in Noakhali from Google Earth. There is no significant surface water body but a scattering of ponds mainly filled from monsoon rains

7.2.2 Methodologies used at the four sites

Soil profile cores to 90 cm deep were collected every 2 weeks during crop growth at Benerpota in Satkhira, Amtali in Barguna and Hazirhat in Noakhali, and once each month at Kuakata in Patuakhali. At each of the sites 28 wheat selections (including Triticale) were grown in randomized plots in four replicate blocks as in the photo of Figure 7.2. Each plot was cored at each date and soil samples were taken from 0-15, 15-30, 30-60 and 60-90 cm layers for salinity estimates (Figure 7.5). The samples were air-dried and subsamples mixed 1:5 with distilled water then EC 1:5 ratio was measured with an electrical conductivity meter. At each site and sampling date, 448 EC measurements were made.

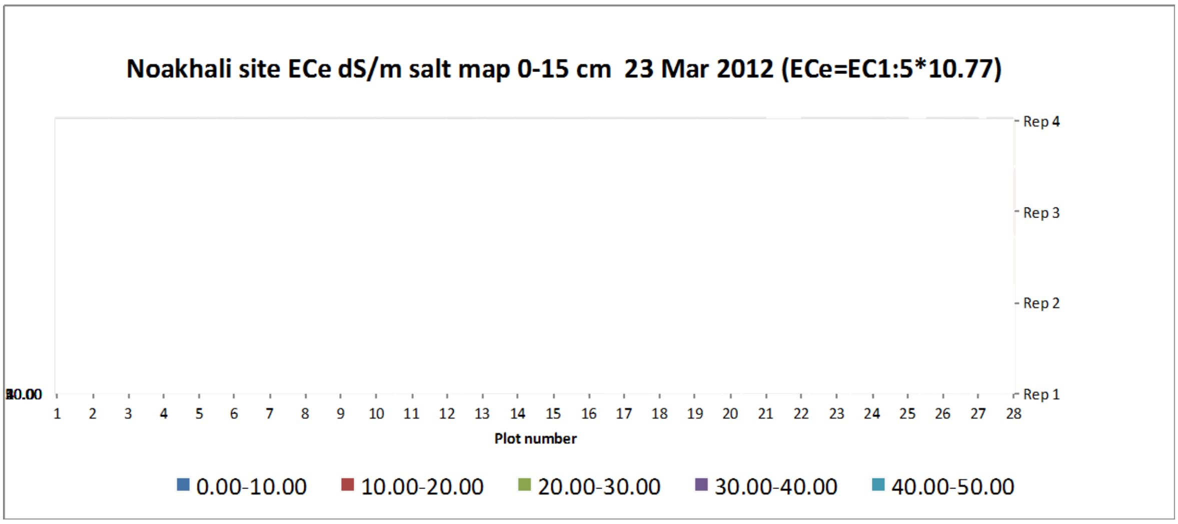


Figure 7.5 Plan view of the Hazirhat trial site in March 2012 showing the distribution of ECe (dS/m) in the surface 0-15 cm of the soil profile along the 28 plots and across Replicate blocks 1 to 4. The layout is exactly as in the photo of Fig 7.2. Data were collected as described in 7.2.2

Crops were sown on 14 December at Benerpota in Satkhira, 15 December at Kuakata in Patuakhali, on 19 December at Hazirhat in Noakhali and on 20 December 2011 in Amtali in Barguna. Irrigations were on 5 Jan, 2 Feb, 15 Mar at Benerpota from the nearby lake, on 4 Jan and 9 Feb at Kuakata, on 17 Jan at Hazirhat, and on 9 Jan and 11 Feb in Amtali. Only the centre two rows of all 112 plots were harvested at each site for measurements of fresh and dry weights to provide final biomass and yield estimates (2.5 m x 0.4 m = 1 m^2 cut). Subsidiary measurements were made of culms, heads, and grains to provide data of yield components. The names of the 28 breeding selections in plots will be provided in the last section of this chapter (Table 7.2).

The primary aim of the methodologies was to follow and describe in detail the three dimensional changes in EC 1:5 of soils and EC of the water table throughout the Rabi season at all sites to uncover any general patterns as well as site differences and the associated responses by the crops. Additional spot measurements were taken in farmers' fields using similar methodologies. No attempts were made to convert the EC 1:5 data to ECe (except in plan view and profile view salt maps), but this could be done by readers following the methodology described earlier under the header "Measurement of salt in soils". The only pertinent point to repeat is that EC 1:5 data from Satkhira clay soils will require a smaller multiplier than the other loamy sites to provide an estimate of ECe. All soil data presented are EC 1:5 expressed as mS/cm (same numerically as dS/m). Water table data are expressed as EC mS/cm.

7.2.3 Distribution of soil EC after planting

Questions to be answered were how is EC distributed by depth and within sites. Any crop roots during germination and early establishment would be directly exposed only to salinity in the upper 15 cm of the soil profile. Of interest though was to determine whether a high salt level at a point on the soil surface would reflect high salt deeper in the profile and vice versa. So would plants contending with high surface salt initially have to root through high salt throughout growth? Data from Hazirhat will be presented first and then other sites compared.

Hazirhat, Noakhali salts

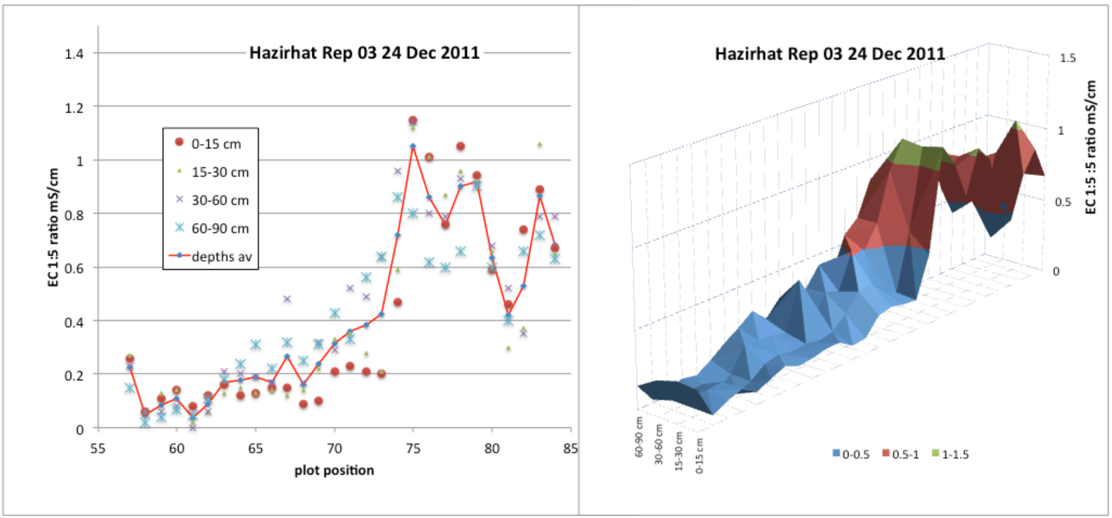


Figure 7.6 EC 1:5 profile along the length of Block 3 at Hazirhat Noakhali 24 December 2011 (5 days after planting) with depths plotted by symbol on left and as a 3-D map on right. The red line on left is the average EC of all depth categories to 90 cm. Colours on the 3-D map signify EC ranges differing by 0.5 mS/cm. For example, the blue section was EC 0 to 0.5 mS/cm applying to plots 56 to 73 while red is 0.5 to 1.0 mS/cm

EC 1:5 data of Hazirhat (Figure 7.6) collected shortly after planting show salts rising progressively along the length of Block 3 and doing so in all parts of the profile down to 90 cm. The 3-D graph with different colours representing 0.5 mS/cm bands amplifies the conclusion that where salt was high on the surface (back of graph) it was also high through the profile. Regressions between all depths of all EC data from the site confirmed this as a general conclusion for Hazirhat.

Data for all four blocks (reps) at Hazirhat (Figure 7.7) at this date show the site as being low in salt at one end and high at the other. Patterns shown here at 5 DAS (days after sowing) were little changed over the following month.

Benerpota, Satkhira salts

The first data set available for Satkhira was collected 35 days after planting (Figure 7.8). It showed some marked contrasts with the Hazirhat pattern.

Whereas at Hazirhat there were only small differences in EC with depth in the soil profile, and a marked trend in salinity across the site, at Satkhira the highest EC 1:5 values that exceeded 1.5 mS/cm were at depth and the lowest were in the surface layer. The 3-D map shows most EC values were in the red and green bands with few being blue, the dominant category at Hazirhat. Averaged by depth the Satkhira site was more uniform for EC than Hazirhat (Figure 7.9). However, there was a strong trend from Block 1 (uniform with depth) to Blocks 3-4 with their low surface EC and high deep-profile EC. Block 4 is closest to the saline water body (Figure 7.2).

Amtali, Barguna salts

Amtali in Barguna showed a further pattern for EC distribution with soil depth. Distribution for the full site (Figure 7.10) showed several patches of high EC that straddled the blocks. But most apparent were the extremely high 0-15 cm values approaching 4 mS/cm (ECe ~ 40 dS/m) that capped these saline patches.

The detailed pattern for Block 3 at Amtali is shown in Figure 7.11.

Figure 7.11 highlights the large difference in EC between the very saline surface layer and all other parts of the soil profile. Below 15 cm the pattern was one of decreasing EC with greater depth though, as at Noakhali, there was general correspondence between the level of EC at the surface and at depth in each plot. The 3D representation at Amtali has 8 bands of colour, each 0.5 mS/cm wide, and double the number at Satkhira.

Kuakata, Patuakhali salts

At Kuakata in Patuakhali, in those parts of the site where surface salinity was high it was much higher than in deeper layers, but where surface salinity was low it was less than in deeper layers (Figure 7.12). Possibly, in those patches where salt was high, surface evaporation had raised salt into the 0-15 cm layer.

7.2.4 Summary of site-specific EC patterns after planting

In summary, there appear to be four different patterns of salinity at the sites in the period after planting; that is (1), little variation in EC with depth to 90 cm (2), highest EC at depth and lowest at the surface (3), highest at the surface and lowest at depth and (4), a mixture of 2 and 3 depending on overall salinity levels. Plots varied in the degree to which they exhibited these characteristics.

1. At Hazirhat, Noakhali in the east there was *little to differentiate EC values* in different parts of the profile and in patches where EC was higher, that was reflected equally throughout the profile. Salinity rose from one end of the site to the other.
2. At Benerpota, Satkhira in the west, *EC was highest at depth* in the profile with progressively lower EC towards the surface soil. Within a plot there was no consistent tight relationship between soil EC and depth.
3. At Amtali, Barguna EC was very *high in the surface soil*. Absolute levels at the surface varied significantly spatially but high levels in any plot were reflected in high levels through the profile, and vice versa as at (1).
4. In patches where salinity was very high, Kuakata Patuakhali followed the pattern of Amtali, with surface EC being much higher than EC at depth. But where overall EC was low, surface EC was lower than EC at depth (Figure 7.13).

7.2.5 Salt effects on crop emergence and establishment

It is expected that the seedling and establishment phase of crop growth would have been negatively affected most by high EC 1:5 in the 0-15 cm soil layer where most roots would be. Thus, the ranking of sites for establishment should be Amtali<Kuakata<Satkhira=Hazirhat. This could only be tested at Amtali where surviving seedlings were counted. There, all seedlings died if the EC 1:5 of the surface soil was greater than 2.5 mS/cm (Figure 7.14). The few plots at Kuakata that exceeded 2.5 mS/cm at this crop stage achieved yields of less than 100 kg/ha. Figure 7.15 is a map of the Amtali site surface salinity expressed as approximate ECe.

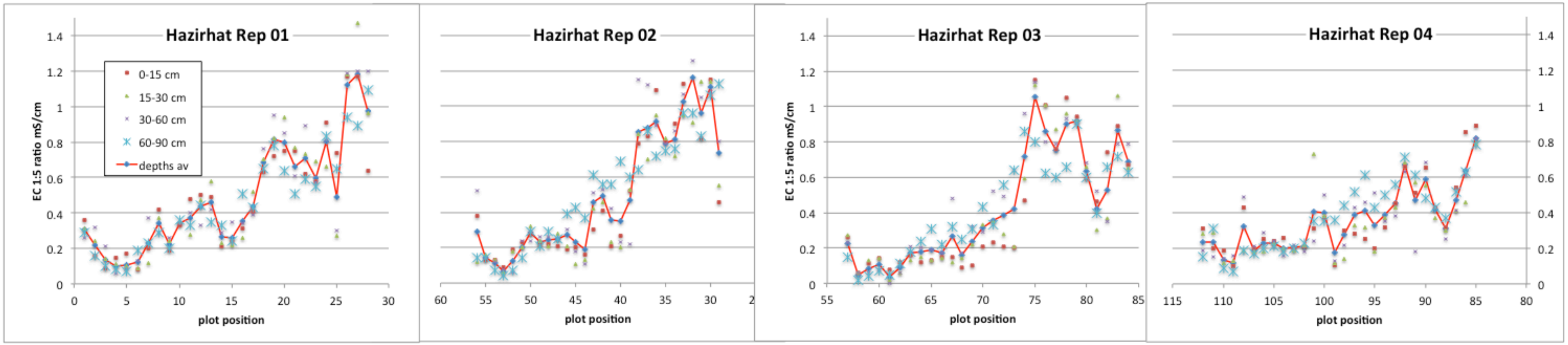


Figure 7.7 EC 1:5 profiles along the length of all 4 Blocks at Hazirhat, 5 days after planting. Rep 3 is also shown in Figure 7.6

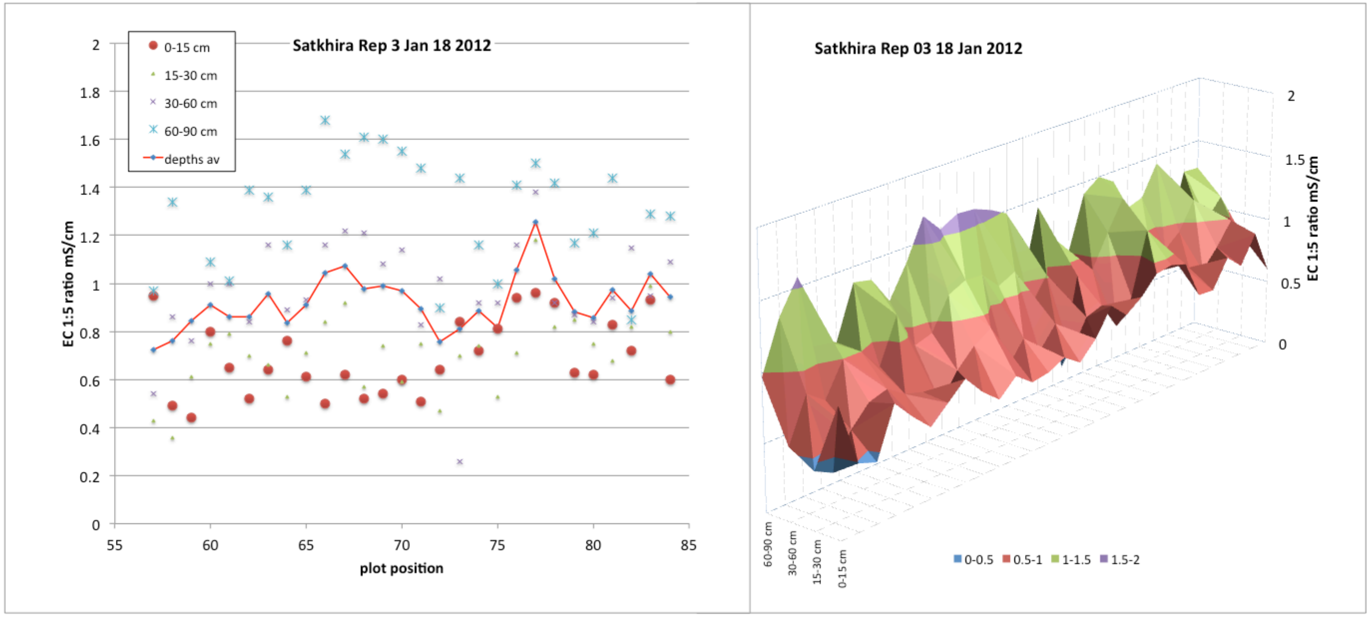


Figure 7.8 EC 1:5 profile along the length of Block 3 at Satkhira 18 January 2012 with depths plotted by symbol on left and as a 3-D map on right. The red line on left is average EC for all depths to 90 cm

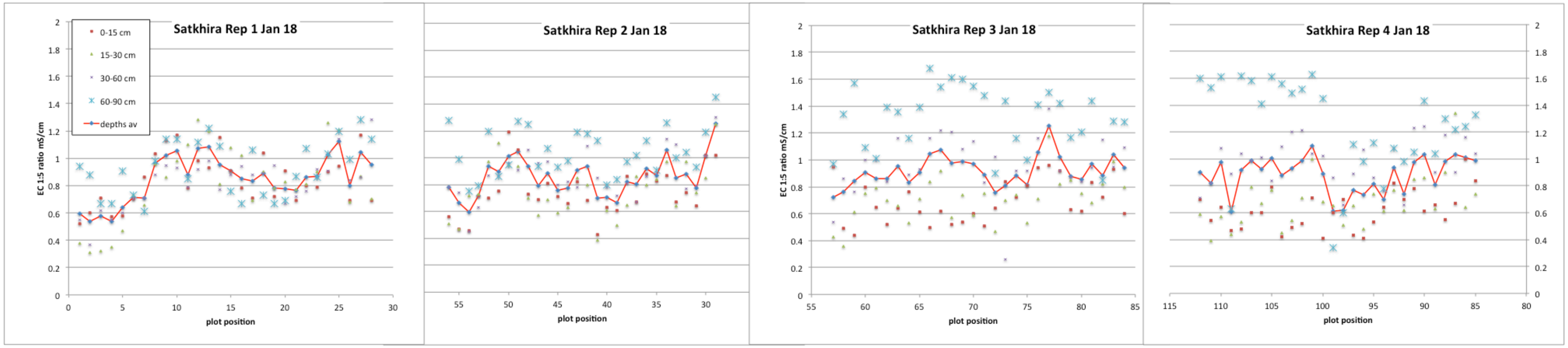


Figure 7.9 EC 1:5 profiles along the length of all 4 Blocks at Satkhira, 35 days after planting. Rep 3 is also shown in Figure 7.8

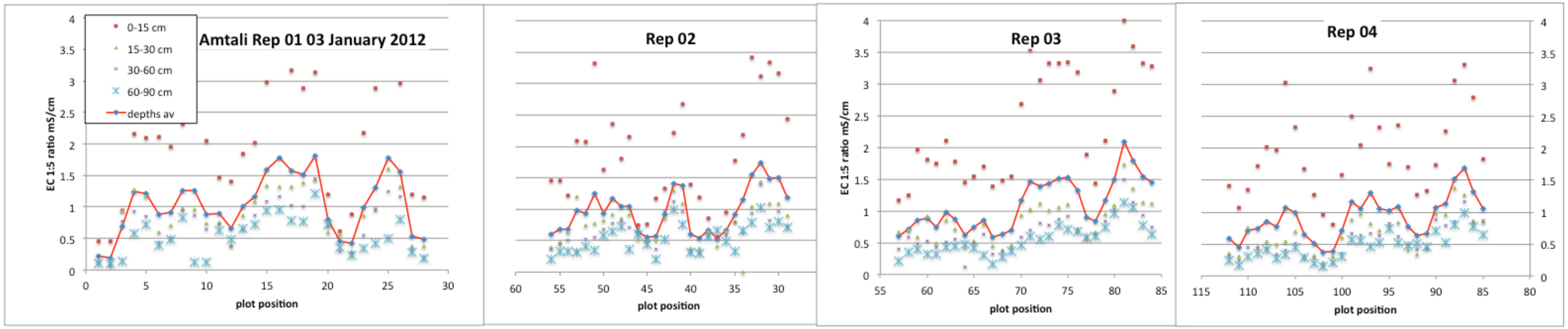


Figure 7.10 EC 1:5 profiles along the length of all 4 Blocks at Amtali, Barguna, 14 days after planting

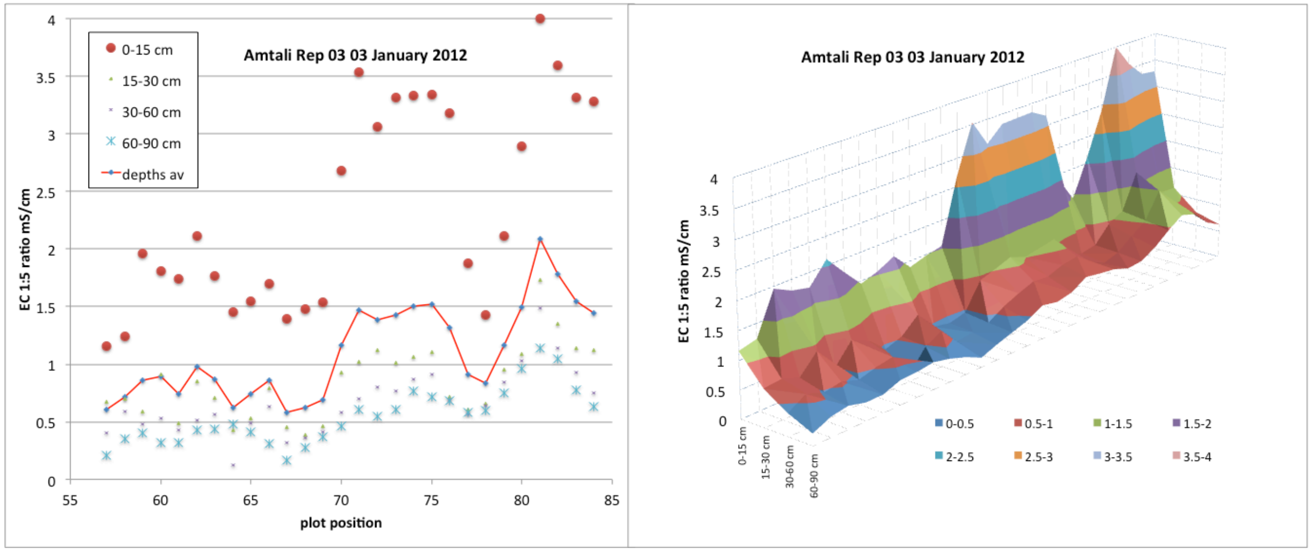


Figure 7.11 EC 1:5 profile along the length of Block 3 at Amtali, Barguna on 03 January 2012 with depths plotted by symbol on left and as a 3-D map on right. The red line on left is the average EC of all depth categories to 90 cm. Because surface soil EC values were much higher than those at depth the 3-D map has the 0-15 cm layer at the back for clarity unlike in earlier figures

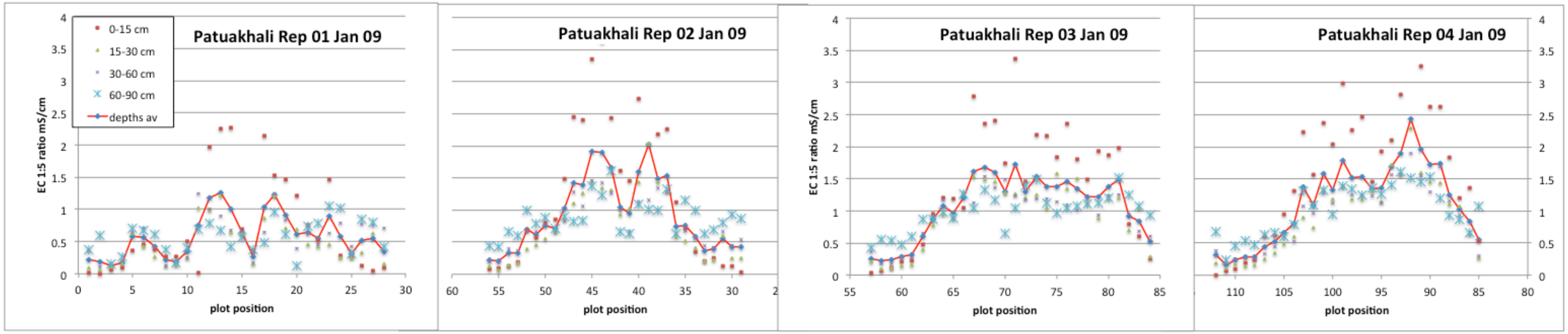


Figure 7.12 EC 1:5 profiles along the length of all 4 Blocks at Kuakata, Patuakhali, 21 days after planting

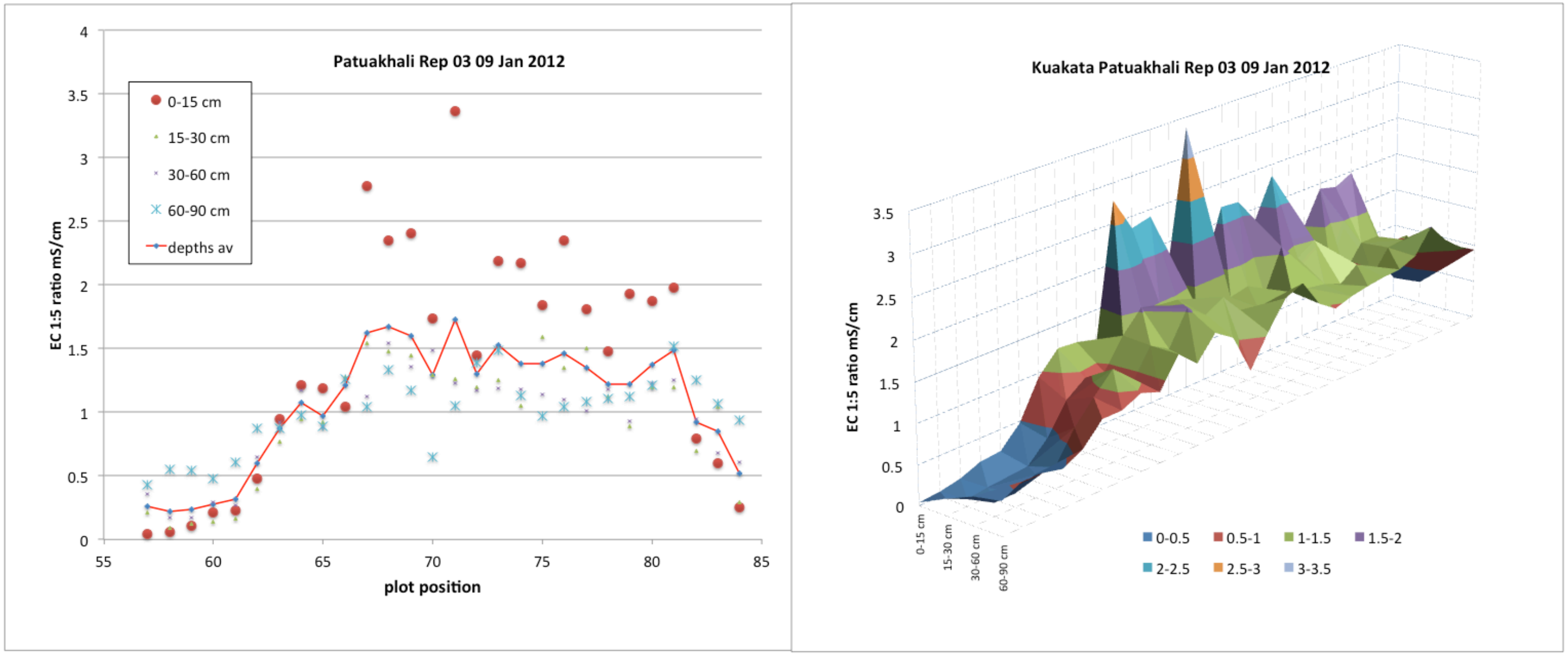


Figure 7.13 EC 1:5 profile along the length of Block 3 at Kuakata, Patuakhali on 09 January 2012 with depths plotted by symbol on left and as a 3-D map on right

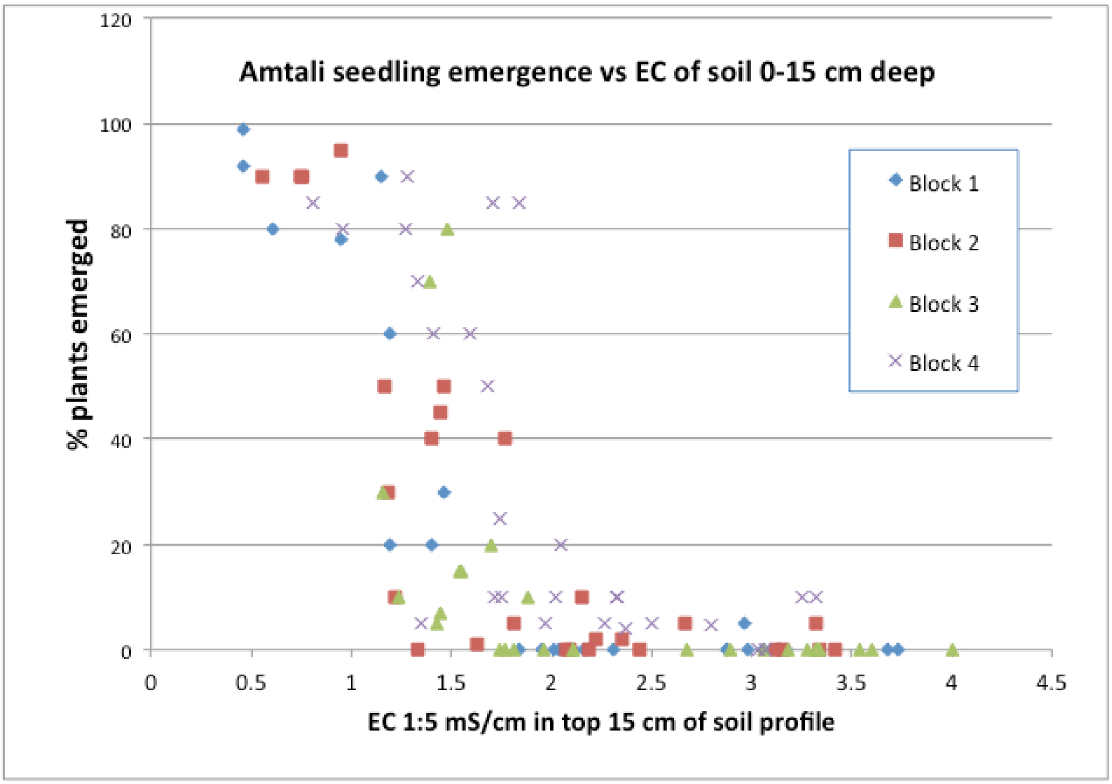


Figure 7.14 Percent seedlings emerged in Amtali plots vs EC 1:5 in the plot's surface 15 cm of soil

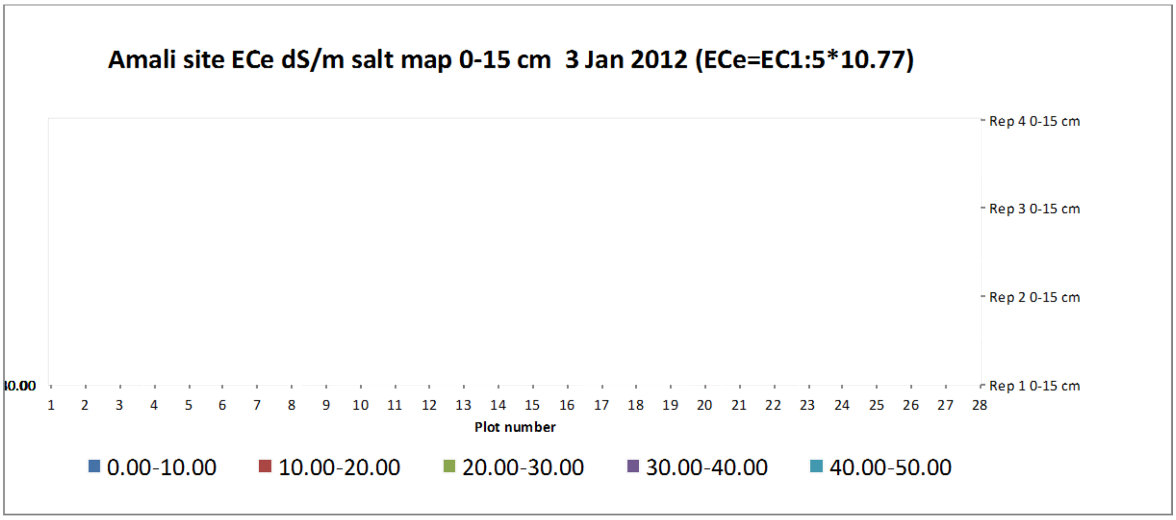


Figure 7.15 Plan view of the Amtali site showing distribution of surface soil salinity (ECe dS/m for 0-15 cm deep samples) during crop germination and establishment. Successful establishment occurred in the blue patches with some survival in the red sections. See Fig 7.26 for a photo taken from one end of the site later in the season.

7.2.6 Changes in soil profile EC through the Rabi cropping season

Soil data were collected throughout the Rabi season to determine whether the initial four patterns for EC distribution summarized above held. Detailed plot data are available on spreadsheets but only a summary is shown here. All sites had an increasing trend in EC with time (Figure 7.16). Hazirhat pattern changed the most with the 0-15 cm layer increasing dramatically in salts particularly at the end of the Rabi season while the lower part of the soil profile remained relatively unchanged. Amtali and Kuakata followed the same trend as Noakhali with large increases in salts in the 0-15 cm soil layer and minimal increases in the lower parts of the profile. Benerpota Satkhira continued to have most salts in the deepest parts of the profile at the likely lower limit of root penetration though there was upward movement. As will be shown later, the water table there was only 40-50 cm deep.

To what extent these different patterns are a consequence of cultivation and irrigation practices, surface flooding with saline water, profile flushing with rainwater during the monsoon and local impacts of saline water tables is not known without historic data.

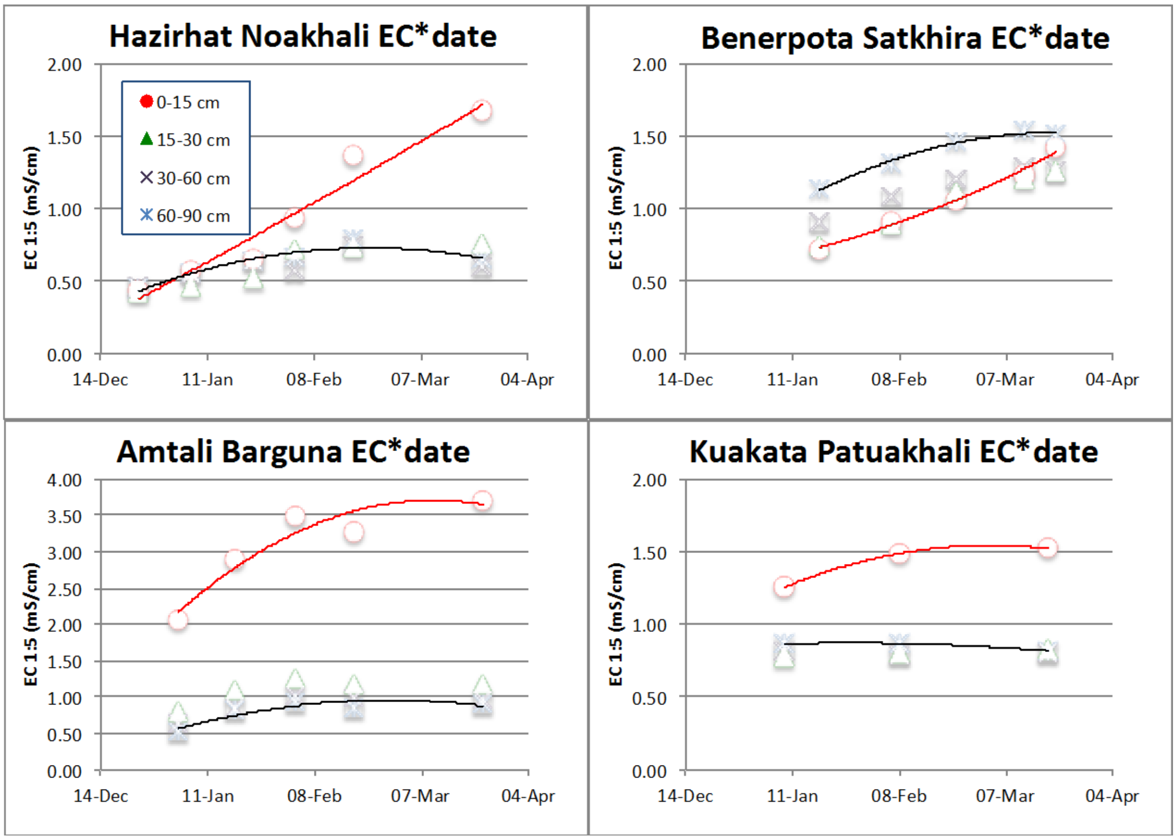


Figure 7.16 Soil EC 1:5 at different depths in the crop rooting profile for four sites through the Rabi season 2011-12. Each point is the average of all112 plots at the site. NB: Vertical axis for Amtali is 0-4 mS/cm and 0-2 mS/cm for other sites

7.2.7 EC and depth of the water table

Piezometer tubes 3 m long inserted in plots at each site were used to measure the depth and EC of free water in the soil profile. This was to look for any correlations with EC 1:5 of the soil itself and to give an idea of where free water might be in relation to likely rooting depth of the crop. Numbers for the whole season are available only from Satkhira and Amtali.

The water table at Satkhira was shallow throughout the season at 40-60 cm and was the least saline of any of the sites where comparisons were possible reaching only 5 mS/cm compared with closer to 10 mS/cm at other sites (Figure 7.17). Hazirhat water table was also shallow; in previous seasons free-water depth was 1 to 1.5 m at crop harvest in mid March.

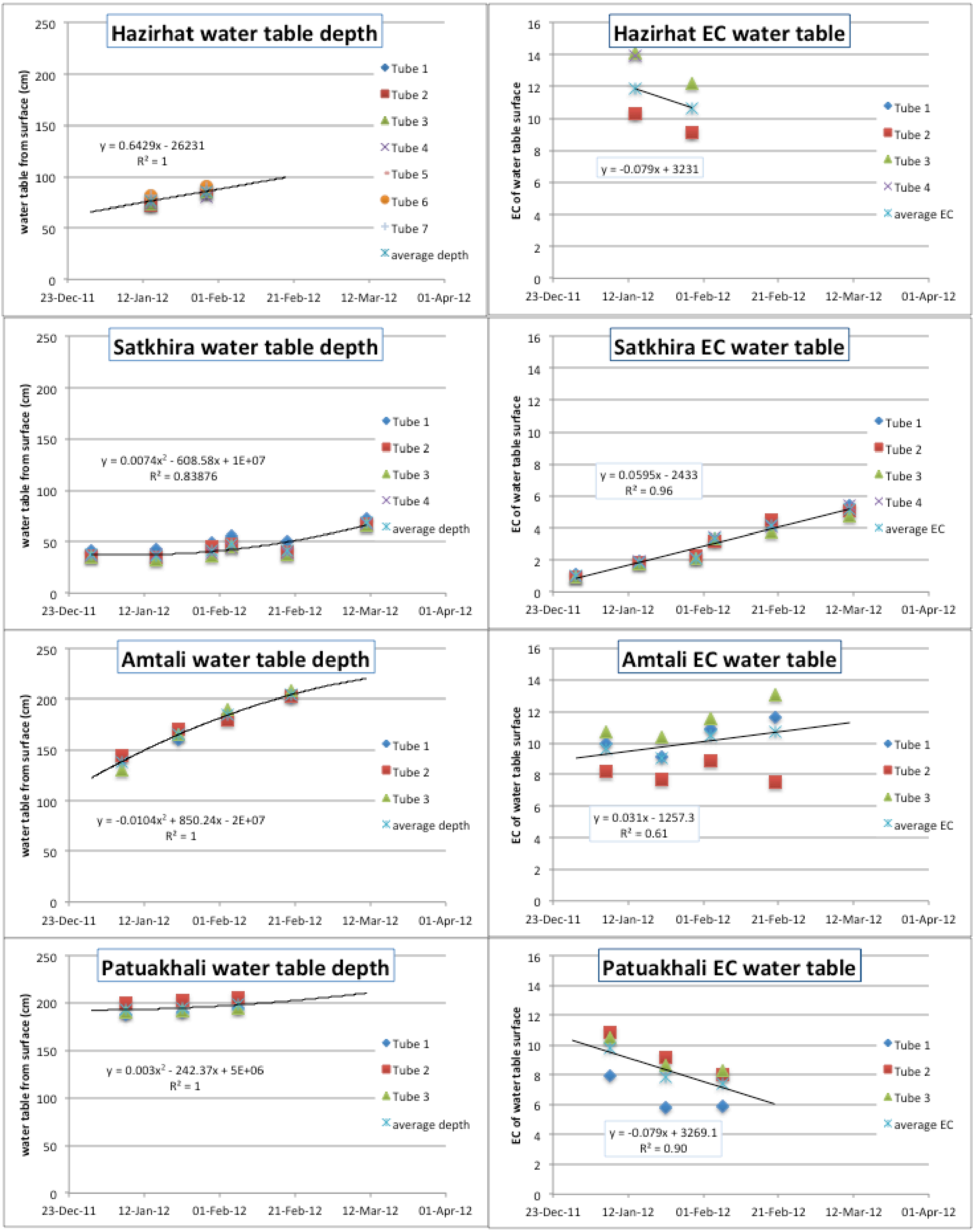


Figure 7.17 Depth and EC of the water table at the four sites measured by 3-m long piezometer tubes located in some plots throughout the Rabi season

Cereal roots commonly penetrate to 0.9-1 m so would have been able to access free water at both Satkhira and Hazirhat though not at Amtali or Patuakhali. At both Amtali and Patuakhali the water table was at 2 m throughout the crop heading to maturity stages.

7.2.8 Relationship between soil EC and EC of free water on the water table

As mentioned full-season data are available only for Satkhira and Amtali. To provide a fair comparison of the water table EC and soil EC, an un-weighted mean EC 1:5 was calculated for the full soil profile from 0 to 90 cm taking into account that the upper core samples were 15 cm long and the lower samples 30 cm long (Figure 7.18).

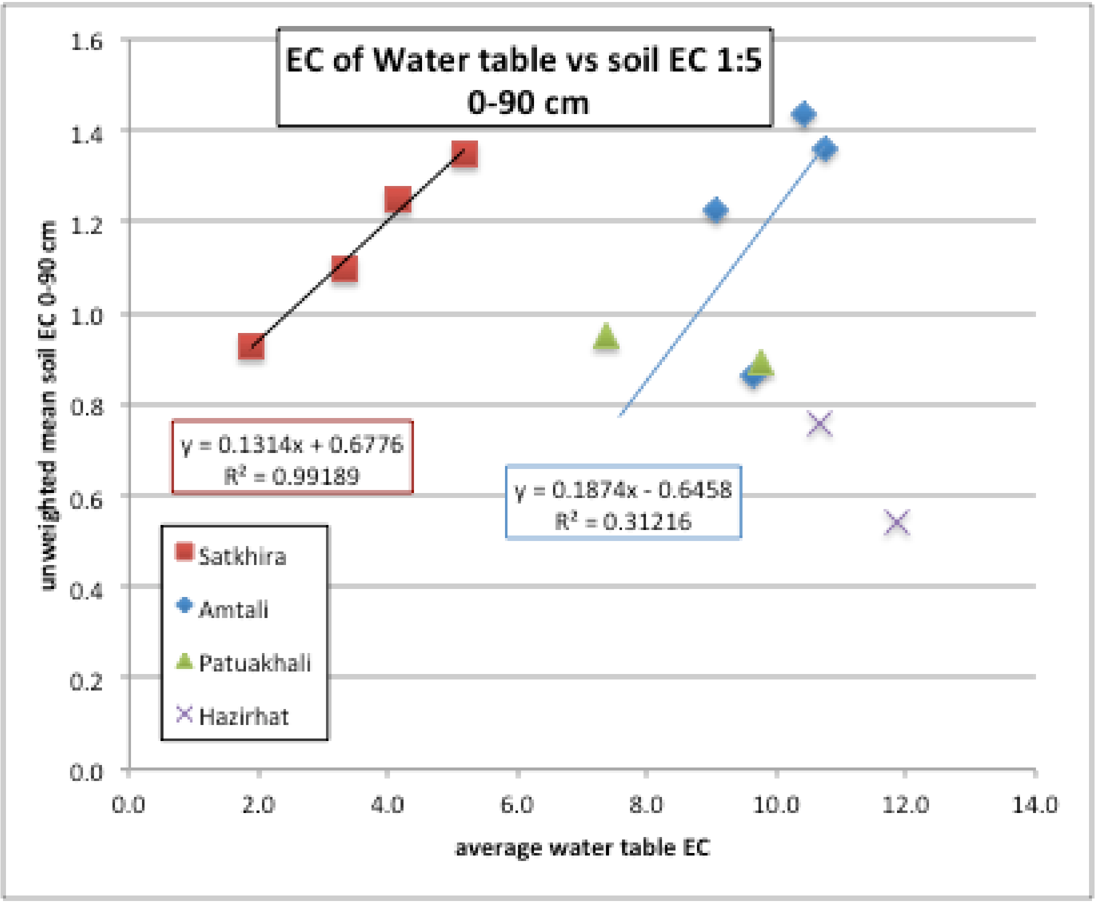


Figure 7.18 EC of water at the surface of the water table within piezometer tubes and EC 1:5 (mS/cm) for the average of 0-90 cm soil cores taken within a few days of the water samples. Lines are fitted through Satkhira and through Amtali data. Available points for the two other sites are shown

There was a strong relationship for Satkhira, probably good enough to predict soil EC from water table EC on a site scale, though not on a plot scale. The close overall correlation indicates that the salinity values in the Satkhira soil profile were dominated by the salinity of the shallow water table. The Amtali relationship was weak but had a similar slope to that from Satkhira while values from Hazirhat and Kuakata Patuakhali were too few to be useful.

7.3 Results: Effects of salts on crop production

7.3.1 Crop yields and soil EC at the plot level

Salinity varied plot to plot within each of the 4 sites as shown in Figure 7.7 for Hazirhat, Figure 7.9 for Satkhira, Figure 7.10 for Amtali and Figure 7.12 for Patuakhali. At Hazirhat for example, it commonly ranged from less than 0.1 to 1.2 mS/cm across the 28 plots within each of the four blocks shortly after planting. That is a 12-fold range. The plots were planted mainly to different selections of wheats that would not be expected to differ in growth response to salt by more than 10-15%. If wheat growth declines by between 5-15% for each mS/cm rise in ECe as indicated for more tolerant vegetables in SRDI (2010), we should be able to see big differences in yield from plot to plot, where plots are differentially saline, that would not be masked by the relatively small salt tolerance differences between varieties. In other words, we can assess all plots initially as though they were planted to the same variety of wheat.

Relationships between yield and salinity at Hazirhat, Noakhali and Satkhira

Figure 7.19 (left) shows yield (green) harvested in plots 57 to 84 of Block 3 at Hazirhat as well as the EC 1:5 values at each depth in the profile for those plots. Clearly yield is almost a mirror image of EC where low EC=high yield and high EC=low yield.

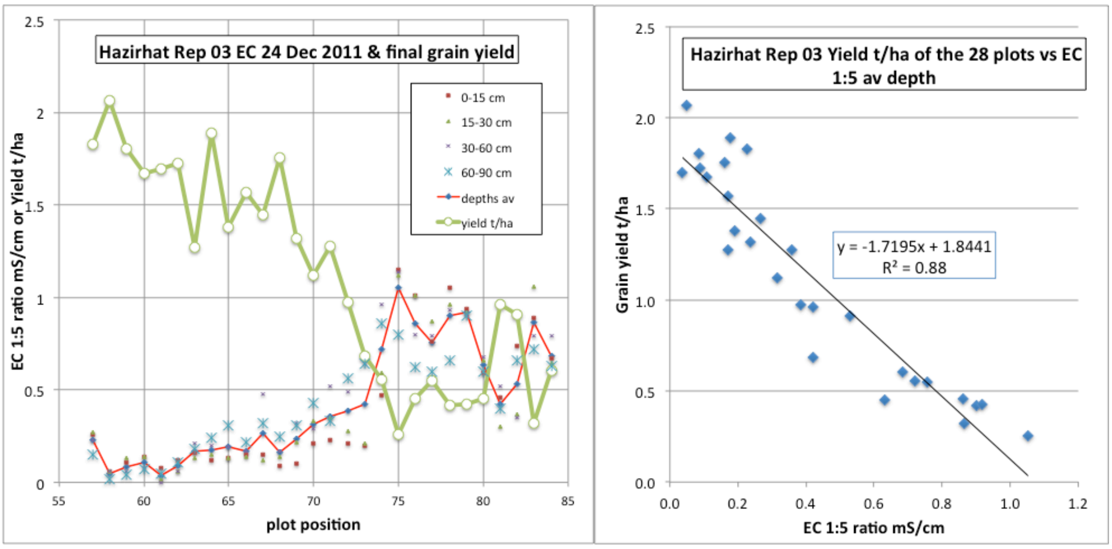


Figure 7.19 Response of yield (t/ha) to EC 1:5 (mS/cm) across the plots of Rep 3 at Hazirhat showing on left each plot in its relative position in the field and on right the same yield data plotted against the average EC (0-90 cm) shown as a red line on left

The closeness of the relationship between EC and yield is shown more clearly in Figure 7.19 (right) where the linear fit has a coefficient of determination of r^2=0.88, so explaining 88% of the variation for the 28 plots. This is remarkable because the EC values were collected 5 days after sowing and yield was harvested 90 days later indicating some tight linkages between EC and growth right through development. Fig 7.19 (right, inset equation) shows yield declined by 1720 kg/ha for every 1.0 mS/cm (1:5 ratio) rise in salts. If ECe for Hazirhat is around 14 times EC 1:5 (Introduction) that fall in yield is equivalent to around 7% for every dS/m (ECe). Block 3 data has been used as an example for Hazirhat, but other blocks showed a similar pattern with coefficients of determination for linear regressions being 0.64, 0.67 and 0.40.

If yield at maturity is linearly related to EC at shortly after sowing at Hazirhat as is indicated by the above data, is this also the case at other sites? Figure 7.20 shows an equivalent data set for Satkhira though using EC 1:5 values that were collected at 35 days after sowing.

Yield at Satkhira was double that at Hazirhat, reaching 4 t/ha, so the scales on Figures 7.19 and 7.20 differ. EC averaged over the 0-90 cm soil cores (red lines in the Figures) ranged between 0.6 and 1.1 mS/cm so over a slightly higher though narrower range than at Hazirhat. But there was no significant indication that yields were influenced by soil EC at Satkhira. Higher salinity plots did not have lower yields and vice versa (Figure 7.20). A linear regression between yield and EC had an r^2 of 0.002 confirming the lack of relationship (Figure 7.20 right). This was despite yield ranging over almost 2 t/ha amongst plots.

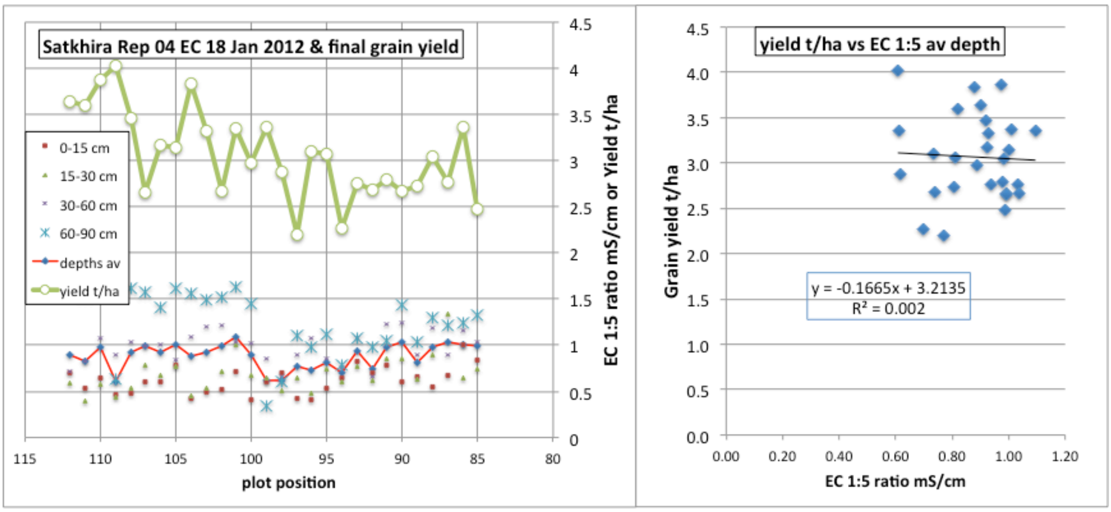


Figure 7.20 Response of yield (t/ha) to EC 1:5 (mS/cm) across the plots of Rep 4 at Satkhira showing on left each plot in its relative position in the field and on right the yield data plotted against the average EC (0-90 cm) shown as a red line on left

Block 4 was selected to test the yield by EC relationship because yield in that block varied more by plot than in other blocks, indeed by about the same amount as at Hazirhat Block 3. Other blocks showed a similar lack of significant linear relationship between yield and EC with r^2 values being 0.16, 0.12 and 0.17.

7.3.2 Apparent effects of EC 1:5 on yield at all sites, soil depths and coring dates

The following is an attempt to show, in a condensed form, the large amount of EC 1:5 data collected through the season, and how they relate to yield. It uses the linear relationships between EC and yield and their coefficients (i.e. the slopes and intercepts of the regressions), such as shown in Figures 7.19 and 7.20 (right side), to make comparisons. The linear relationships, where significant, provide an estimate of maximum yield in the block if EC were zero (the intercept of the regression, 1.844 t/ha in Fig. 7.19), the rate of decline in yield with increasing salinity (the slope of the regression, -1.719 t/ha per mS/cm in Figure 7.19), and the EC at which yield becomes zero (the intercept divided by the slope, 1.07 mS/cm in Figure 7.19).

Using the r^2, the intercept and the slope allows us to make first order comparisons between the sites and between the impacts on yield of salinity at different times and in different depths of the profile.

A higher r^2 value indicates that yield is more affected by the measure of salinity being tested. An r^2 of 1 can mean yield is 100% affected by salt while an r^2 of 0.5 means only 50% of the variation in yield might be due to salt. Figure 7.21 shows the significance of the relationships for Hazirhat throughout the season. It shows the r^2 values for yield vs the salinity at different depths (0-15 to 60-90 cm, and an average of all depths), for yield vs the soil salinity at different dates through the Rabi season (24 December to 23 March), and for yield vs salinity in the replicate blocks 1 to 4.

Hazirhat, Noakhali

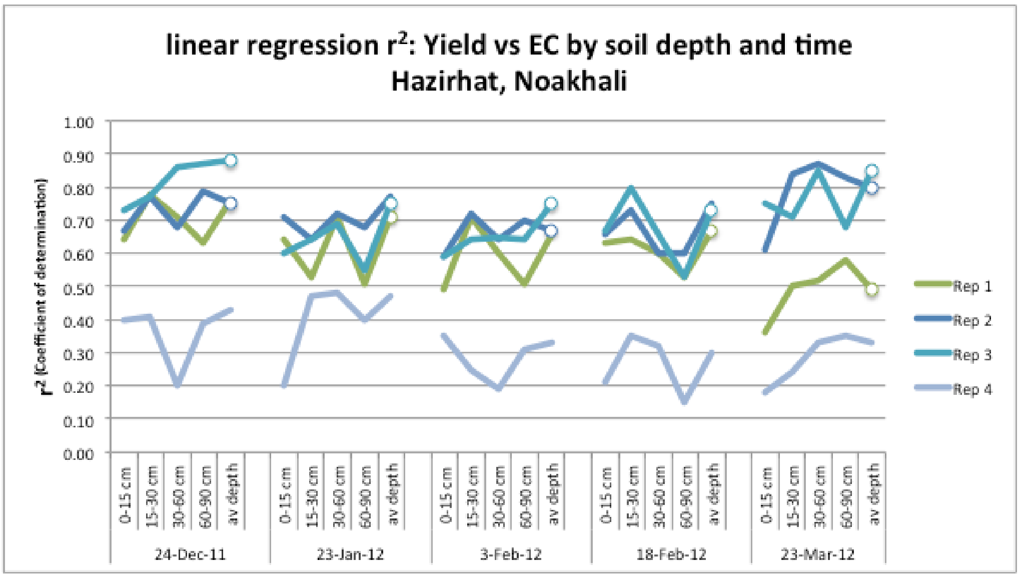


Figure 7.21 r^2 coefficients of linear regressions fitted between grain yield and EC 1:5 for different depths in the soil profile and for soil cores collected at different dates at Hazirhat, Noakhali. Data for the four replicate blocks (Rep 1 to Rep 4) are shown as separate colours to indicate variation across the site

The main points to be made from the r^2 coefficients of Figure 7.21 are:

- Linear regressions described the relationship between EC 1:5 and yield significantly in most cases at Hazirhat accounting for between 50 and 89% of all variation within most blocks (Reps). Block 4 (Rep 4) had the poorest relationship. In essence, salinity was a main constraint on yield.
- Though the relationship was marginally closest using EC data from 5 days after sowing (24 December), any date within the crop's growth provided a significant relationship, so any date was acceptable for doing soil coring in this season.
- On average, the best EC relationship with yield came from data that averaged all soil depths from the surface to 90 cm deep, though any depth, 0-15, 15-30, 30-60 or 60-90 cm, provided a significant relationship in most cases. The poorest fit could come from the 0-15 cm part of the profile. Note that EC varied relatively little with depth at Hazirhat until the February-March stages of crop growth (Figure 7.16).

Figure 7.22 uses the linear regressions between yield and salinity to estimate yield at the site if there were no salt (left) and the salt level at which yield becomes zero (right). The main conclusions follow:

- Estimated yield for Hazirhat in the absence of salts for this season and planting date was estimated at between 1.4 and 2.1 t/ha depending on the block tested.
- Highest yield estimates came from the EC 1:5 average value for all soil depths though for any block at any time the range for estimates was only 200 kg using EC at any depth.
- Estimates of the EC 1:5 at which yield would be zero were most conservative for cores considering the deepest soil or the average EC of the whole soil profile. For those soil layers they ranged from 1 to 1.5 mS/cm at planting to 1.2 to 3 mS/cm at the maturity harvest. Estimates using the surface soil late in the season were unreasonably high.

Full data are not shown for the rate at which yield declined with increasing EC 1:5 (i.e. the slope in Figure 7.19). They ranged for different blocks between 1.1 and 1.9 t/ha per mS/cm at soon after sowing to 0.5 to 1.2 t/ha per mS/cm at the end of the season.

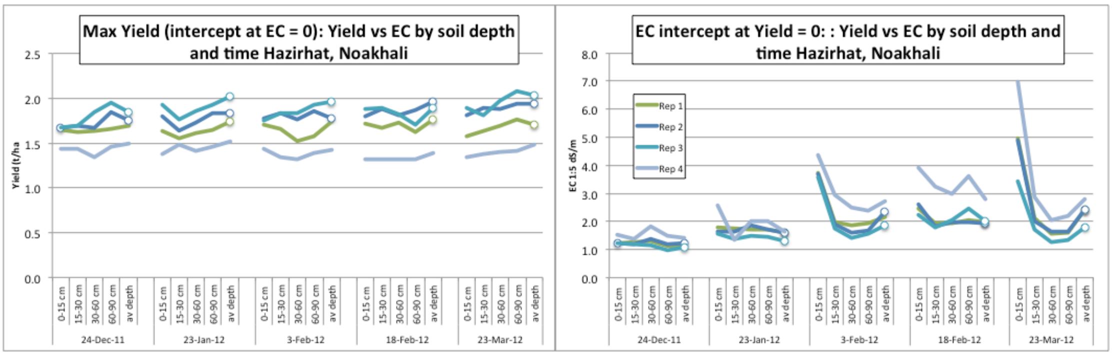


Figure 7.22 Estimates of yield where EC 1:5 = 0 mS/cm (left) and EC 1:5 where yield = 0 (right) for linear regressions fitted between grain yield and EC 1:5 for different depths in the soil profile and for soil cores collected at different dates at Hazirhat, Noakhali

Benerpota, Satkhira

At Benerpota, Satkhira the linear regressions between grain yield and EC barely reached significance in any comparison unlike at Hazirhat. However, for the sake of completeness the r^2 data are shown in Figure 7.23. Why yield was generally so poorly related to soil EC at Satkhira is not clear, though as already suggested, it may relate to the dominance of the very shallow water table EC.

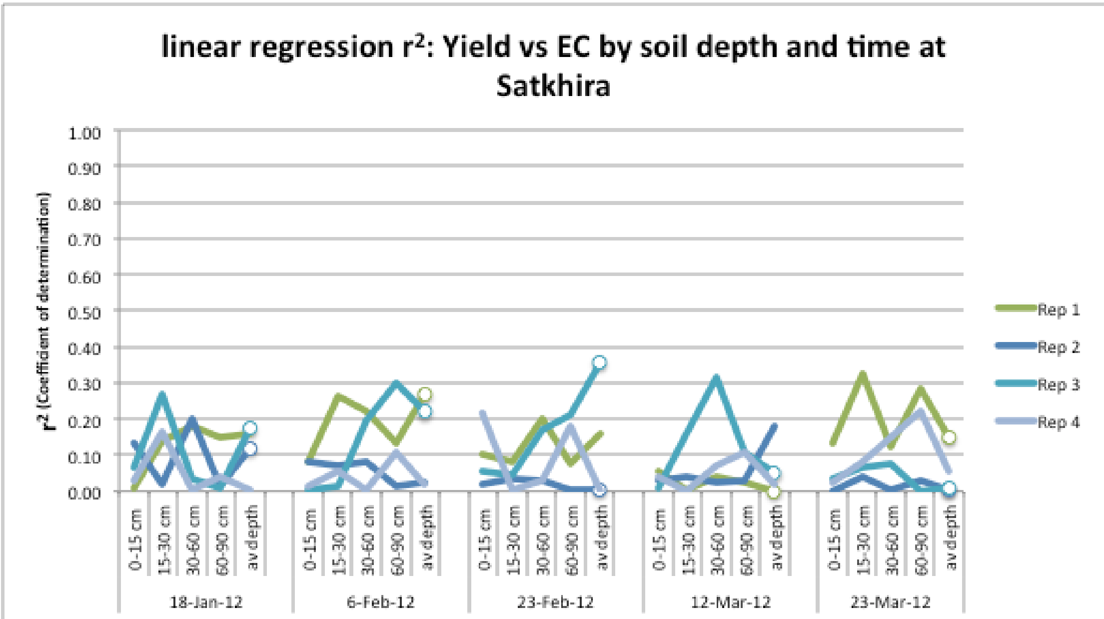


Figure 7.23 r2 coefficients of linear regressions fitted between grain yield and EC 1:5 for different depths in the soil profile and for soil cores collected at different dates at Benerpota Satkhira

Kuakata Patuakhali

At Kuakata Patuakhali the cooperating farmer harvested 15 plots from Blocks 1 and 2 before samples could be taken for yield analysis. Consequently, these blocks could not be compared as a whole against others primarily because of reduced data points and differences in variety composition. The regressions for the complete blocks 3 and 4 are shown in Figure 7.24.

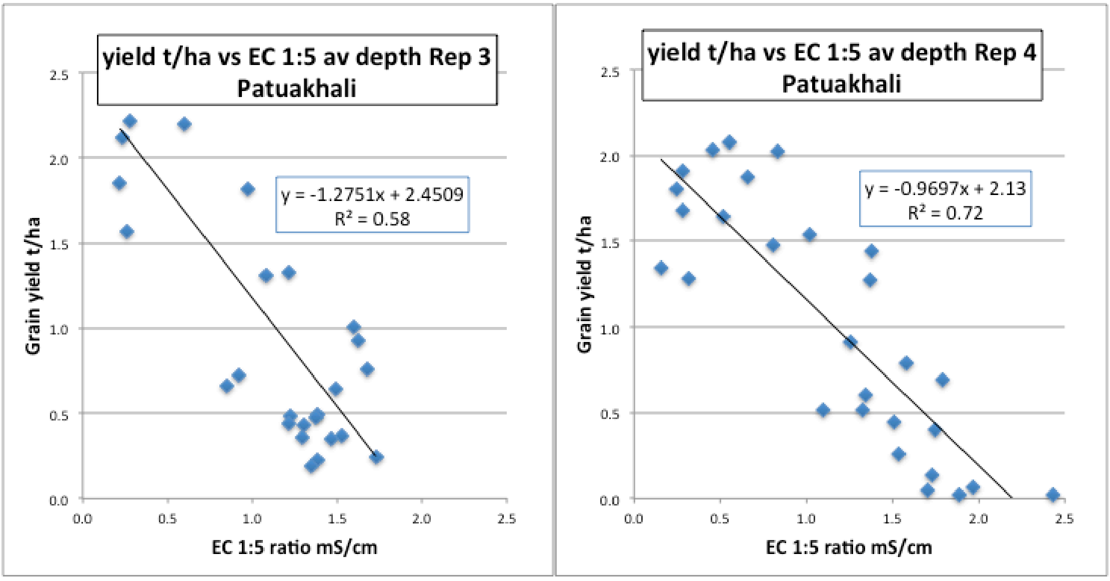


Figure 7.24 Response of grain yield (t/ha) to EC (mS/cm) for the plots of Reps 3 and 4 at Kuakata Patuakhali. EC shown is for the full 0-90 cm profile cored 21 days after planting

Yield was significantly correlated with EC 1:5 in these two blocks and the relationship became closer at the second date of analysis 51 days after sowing (Figure 7.25). Estimates of yield for the site when EC 1:5 was 0 ranged between 2.0 and 2.5 t/ha while the EC 1:5 when yield reached zero was around 2 mS/cm rather higher than at Hazirhat. It did not change between dates of soil coring. For the 4 data sets available, the rate at which yield declined with EC 1:5 was between 0.93 and 1.27 t/ha per mS/cm and within the range for Hazirhat for similar dates of soil analysis.

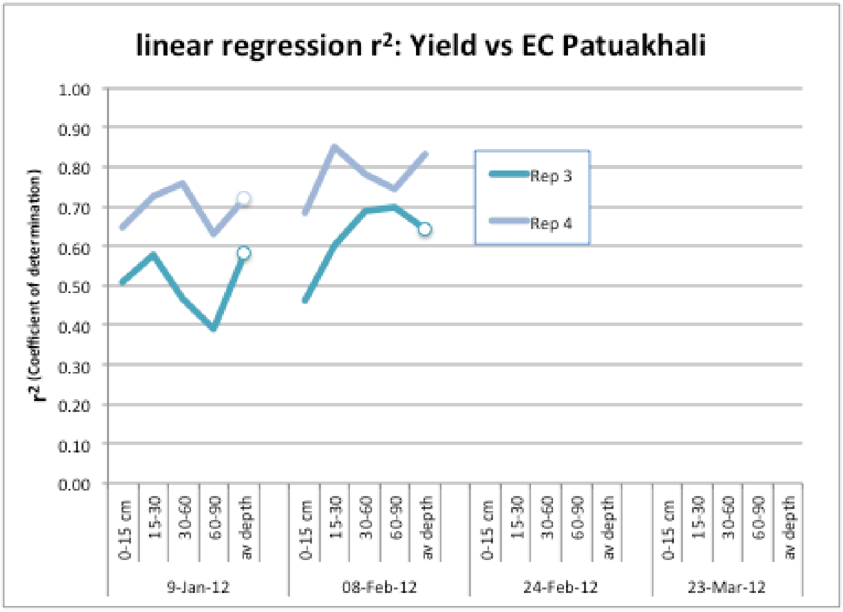


Figure 7.25 r2 coefficients of linear regressions fitted between grain yield and EC 1:5 for different depths in the soil profile and for soil cores collected at different dates at Kuakata, Patuakhali

Amtali, Barguna

At Amtali in Barguna many of the crops failed to germinate or establish due to extremely high surface soil salinity at planting (Figure 7.26 and Figure 7.14); a map of surface soil salinity (ECe) is in Figure 7.15. Figure 7.27 is an example of the distribution of yield on the site using Block 1. Plot by plot grain yields along the block are shown as a green line together with EC 1:5 values. Plots without plants are shown with zero yields. Yields are almost a mirror image of EC 1:5 of the surface soil (brown dotted line) or the 0-90 cm average. The close linear relationship between yield and EC is shown more clearly in the right hand graph (Figure 7.26); plots with zero crop establishment rates are not included.

Figure 7.26 Amtali salinity trial showing patchy emergence and growth across the site which is mainly barren. A triticale plot is in the foreground

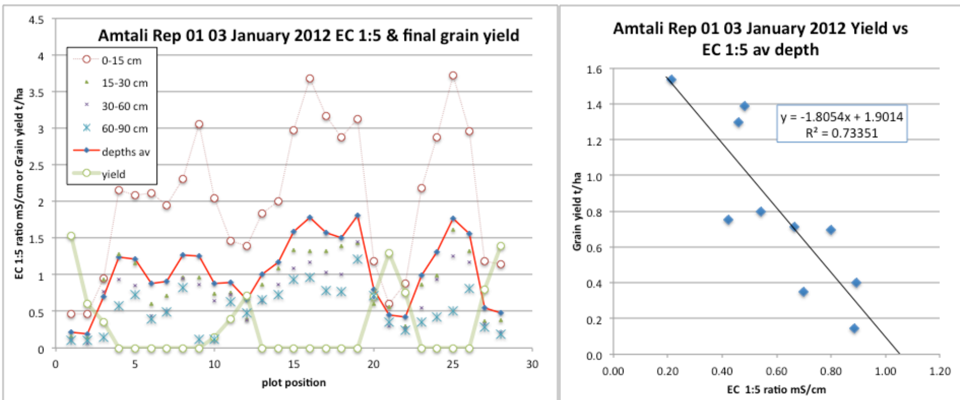


Figure 7.27 Response of Yield (t/ha) to EC 1:5 (mS/cm) across the plots of Rep 1 at Amtali, Barguna showing on left each plot in its relative position in the field and on right the few yield data graphed against the average EC (0-90 cm) shown as a red line on left. The 0-15 cm EC is the brown dotted line

The linear regression in Figure 7.27 predicts that yield at the site in the absence of salt was 1.9 t/ha, that yield declines with salt at the rate of 1.8 t/ha per 1 mS/cm (EC 1:5) and that zero yield would occur when salt levels in the 0-90 cm soil core reached 1.05 mS/cm (EC 1:5) in the 2 weeks following planting.

In order to get a better representation of salt:yield relationships for the site, all 45 plots that produced some yield are graphed in Figure 7.28 against EC averaged for 0-90 cm soil depths sampled at 2 weeks after planting. The data indicate the decline in yield per unit EC 1:5 was 1.2 t/ha per mS/cm. Because of the dramatic effects of surface EC on plant survival, these numbers can only be used as supporting evidence for performance at other sites. Plotting these yield data against soil sampled for EC at crop maturity produced non-significant r^2 values.

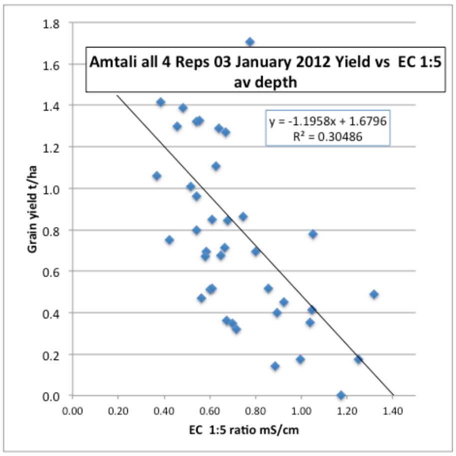


Figure 7.28 Relationship between yield and salt (EC 1:5 average all soil depths 2 weeks after planting) for the 45 plots that produced some yield on the Amtali site; all plants in 67 plots were destroyed by salt

7.3.3 General trends in salinity and yields across the four sites

The foregoing data reflect the variability and complexity of salts in soils and of yield production, but amongst this complexity there are some general relationships that simplify the findings. Table 7.1 summarises the data, but the summary must be considered in the light of missing plots at Kuakata, severe initial damage to plants at Amtali and all the variables associated with these rounded numbers. Satkhira is the best site for yield despite its high salinity reputation. Three seasons ago an ACIAR project harvested up to 5 t/ha wheat yields from this location. It has a very shallow water table by virtue of being surrounded by a lake that is used locally for irrigation. Consequently, the crops would never have been short of water. Unlike at the other three sites, there was no significant correlation between soil salinity and yield. The other sites indicated that yield of the cereals in the project would reach zero at 0-90 cm EC 1:5 values of between 1 and 2.4 mS/cm and that the loss in yield with increasing EC would occur at a little over 1 t/ha per mS/cm. Yield would be zero if surface soils exceeded an EC 1:5 of 2.5 mS/cm at planting. This only occurred at Amtali.

Table 7.1 Site averages for the four saline sites. Geo-references are in decimal degrees, soil EC is expressed as 1:5 ratio mS/cm for the surface 0-15 cm and for the lower profile early and late in the season, correlations between EC and yield used EC 1:5 for the averaged 0-90 cm soil profile. Details appear throughout the text. Data here are approximate

Salinity site	Latitude longitude degrees	Grain Yield t/ha	Water table depth	Water Table EC	Soil EC 1:5 early	Soil EC 1:5 late	r^2 EC vs yield	Soil EC when no yield	Yield loss per EC
Hazirhat Noakhali	22.7568 91.1247	1.06 ±0.03	1.0-1.2 m	11	0.5 - 0.4	1.7-0.7	0.7	1.3-1.8	1.2 t/ha per mS
Benerpota Satkhira	22.7495 89.1062	3.21 ±0.05	0.4-0.5 m	1-5	0.7-1.2	1.4-1.5	NS	NA	NA
Amtali Barguna	22.0846 90.2288	0.79 ±0.07	1.5-2.3 m	10	2.0-0.5	3.6-1.0	0.3	1-1.4	0.9-1.3
Kuakata Patuakhali	21.8335 90.1138	1.39 ±0.29	2.0 m	9	1.3-0.8	1.8-0.8	0.6	2.4	1.0-1.2

7.4 Results: Screening crop breeding lines for salinity tolerance

7.4.1 Crop materials used

There were 27 lines of wheat and one Triticale line (Table 7.2) planted at each site in four replicates. The first three selections have been used in previous ACIAR-associated trials and their yields and general performance are covered in ACIAR Technical Report 78 (Rawson, 2011). Shatabdi is high yielding general-purpose wheat that has been used widely after being released about a decade ago. The number in column 1 of Table 7.2 identifies all lines in the following presentation including on any graphs.

Table 7.2 Wheat varieties and selections included in all four trials

#	Selection	Pedigree
1	Shatabdi	
2	BARI gom 25	
3	BARI gom 26	
4	BAW 1142	(BCN//CEAT/AE.SQUA(895)/NL745 NC 00B3273-2B-020B-020B-5B-0B)
5	BAW 1143	(BAW 923/BAW 1004 BD(DI)1207S-0DI-4DI-010DI-010DI-0DI-DIRC7)
6	BAW 1146	(KAN//IAS 63/ALDAN BD(DI) 961S-0DI-62DI-010DI-010DI-0DI-03DI-DIRC6)
7	BAW 1147	(OASIS/3*ANGRA//708E BD01JA666S-3JA-010JA-010JA-010JO-HRJO-RC9JO)
8	BAW 1148	(OASIS/3*ANGRA//708E BD01JA666S-15JA-010JA-010JA-010JO-HRJO-RC5JO)
9	BAW 1150	(BL 1473/BL 1904 NC 001B3438-3B-020B-020M-1B-0B)
10	BAW 1151	(UP2338*2/4/SNI/TRAP#1/3/ KAUZ*2/TRAP//KAUZCGSS01Y00021T-099M-099Y-099M-099M-16Y-0B)
11	BAW 1153	(BAW 968/SHATABDI BD(JO)358-0DI-1DI-010DI-010DI-DIRC5)
12	BAW 1154	(KAN/GOURAB NCD99-01-0DI-1DI-0DI-0DI-0DI-0DI-18DI-0DI)
13	BAW 1140	(SOURAV/GOURAB BD(JE)959S-0DI-5DI-010DI-010DI-010DI-1DI-DIRC8)
14	BAW 1118	(BAW 969/SHATABDI BD(DI)1319S-0DI-6DI-1DI-DIRC7)
15	BAW 1122	(GARUDA//BAW 970/NL 297 BD (JE) 1228T-0DI-9DI-1DI-DIRC3)
16	BAW 1130	(GOURAB/PAVON 76 NCD99-04-0DI-1DI-0DI-0DI-0DI-0DI-22DI-DIRC4)
17	BAW 1051	(KLAT/SOREN//PSN/3/BOW/4/VEE#5.10/5/CNO67/MFD//MON/3/ SERI/6/NL297 NC2142- 7B-020B-025B-3B-0B)
18	BAW 1111	(AKR/3/URES/JUN//KAUZ BD(DI) 947S-0DI-5DI-010DI-010DI-1DI-HR2)
19	BAW 1135	(BAW 969/SHATABDI BD(DI)1319S-0DI-6DI-1DI-DIRC6)
20	BAW 1138	(CHEN/AE. SQ (TAUS)//BCN/3/2*PASTOR CMSS98Y00844S-040Y-0B-0MXI-3DI-010DI-010DI-1DI-DIRC6)
21	BAW 1156	(BL3306){ BL 3306 (SW89-3060/ACHYUT) NC 99B3173-3B-020B-020B-020M-3B-OB}
22	Francolin 1	(BABX/LR42/BABX*2/3/VIVITSI CGSS01B00046T-099M-099M-099Y-099M-30Y-0B)
23	BAW 1159	(KAN//IAS 63/ALDAN BD(DI) 961S-0DI-62DI-010DI-010DI-0DI-03DI-DIRC5)
24	BAW 1160	(BAW 1004/GARUDA BD(DI)1493-0DI-8DI-6DI-HR3R6DI)
25	BAW 1161	(BAW 677/BIJOY BD(JA)1365S-0DI-15DI-3DI-HR12R3DI)
26	BAW 1141	(V-01078)
27	BAW 1157	(BAW 923/BAW 1004 BD (DI) 1207S-0DI-4DI-010DI-010DI-0DI-DIRC6)
28	BARI Triticale 1	

7.4.2 Biomass and yield at the sites

Average yield at each site is in Table 7.1 showing Benerpota Satkhira producing around three times the yield at Kuakata Patuakhali and Hazirhat Noakhali with general ranking for site yield being the inverse of EC of the water table at the site. This is a rough relationship (r^2=0.99 for three values excluding Amtali) indicating a fall of 0.26 t/ha yield per unit of water table EC, an intercept at 3.8 t/ha and zero yield occurring at water table EC of 14.7 dS/m. In the following discussion, Amtali, with its poor emergence and establishment and few plots with final yields, will not be analysed except in passing.

7.4.3 Components of yield and salinity

At Hazirhat Noakhali, the responses of biomass and yield to salt were acceptably described by fitted curves and linear regressions for the 112 plots (Figure 7.29). Weight per grain declined in a linear fashion with salinity at 15 mg per mS/cm as did harvest index (HI, 10 units per mS/cm) though HI was very variable. Similar patterns, though less tight and with lower slopes, applied at Kuakata Patuakhali with weight per grain declining at 6.6 mg per mS/cm and HI at 4 units per mS/cm) while equivalent values at Amtali were 5 mg per mS/cm and 3 units per mS/cm (NS). On all these counts the Hazirhat site was the harshest growing environment.

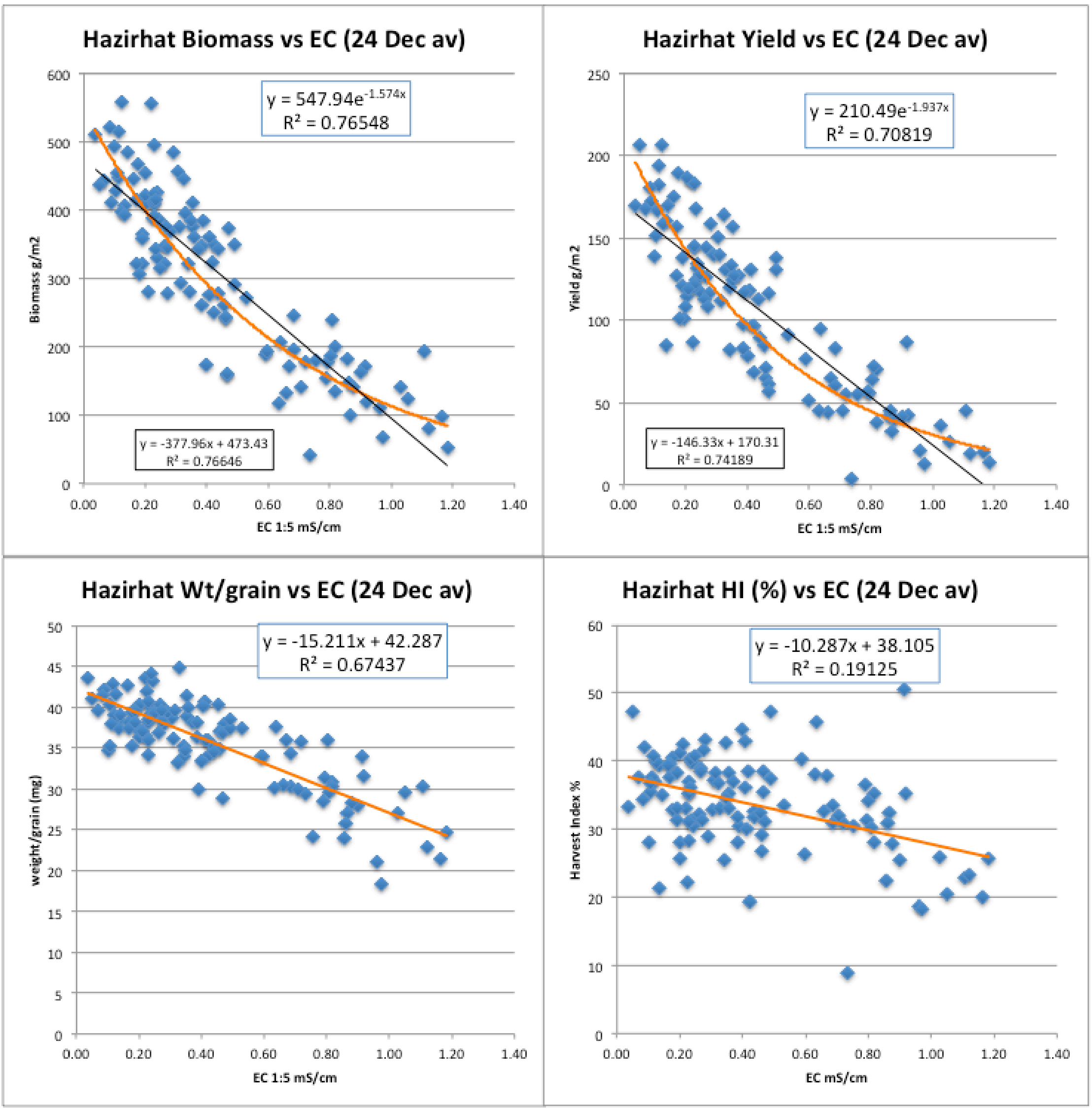


Figure 7.29 Yield components and soil average-depth-salinity at Hazirhat Noakhali using data from all 112 plots and breeding selections. Equations for the fitted linear and curvilinear trends are in boxes

Though biomass sets the potential for yield through numbers of culms established (declined at 143 /m^2 per mS/cm) the clear negative effect of salinity on weight per grain was a prime cause of HI declining with salinity. Grains per culm also declined (at 7 per mS/cm) with salinity but that effect was not significant.

At Satkhira there were no significant effects of salinity on yield components though most showed negative trends and the trends, excepting grains per culm and HI, were in the range for other sites (Table 7.3).

Table 7.3 Rate of decline in yield components per unit EC (1:5 ratio mS/cm) at the sites. No trends shown here for Benerpota Satkhira were statistically significant

	Biomass g/m^2/EC	Yield g/m^2/EC	Culms $/m^2$/EC	Wt/grain mg/EC	Grains/ culm/EC	HI %/EC
Hazirhat Noakhali	378	146	143	15	7	10
Kuakata Patuakhali	264	103	97	7	5	4
Benerpota Satkhira	436	143	100	6	0	1

7.4.4 Comparisons of the crop selections across sites

Assuming best performance at saline sites equals tolerance

The aim of the study is to identify salt-tolerant lines from amongst the selections. The idea behind Figure 7.30 was that as all three sites plotted are saline, best lines should be best at all sites. Consequently, the more tolerant lines should always clump together at the highest point of each regression, while the poorest lines should fall to the lowest locations. Comparing the Patuakhali-Hazirhat locations (green symbols) where there were significant responses to salinity, the best lines on this measure were 11, 15, and 6 at both sites while the poorest were 26 and 22. In the Satkhira-Hazirhat comparison 11, 15, and 6 were again high while 26 was again low. Sadly, this idea does not work because the ‘better’ lines here fortuitously were all grown in lower salinity plots at all locations and ‘poorer’ lines just happened to be randomized to high salt plots. Here randomized plots did not average out the more random distribution of salt across sites. In a traditional screening project with no knowledge of salinity levels in each plot, the above lines described as good would progress to the next level of screening. Interestingly, the ‘poor’ line 26 performed well in previous screening work.

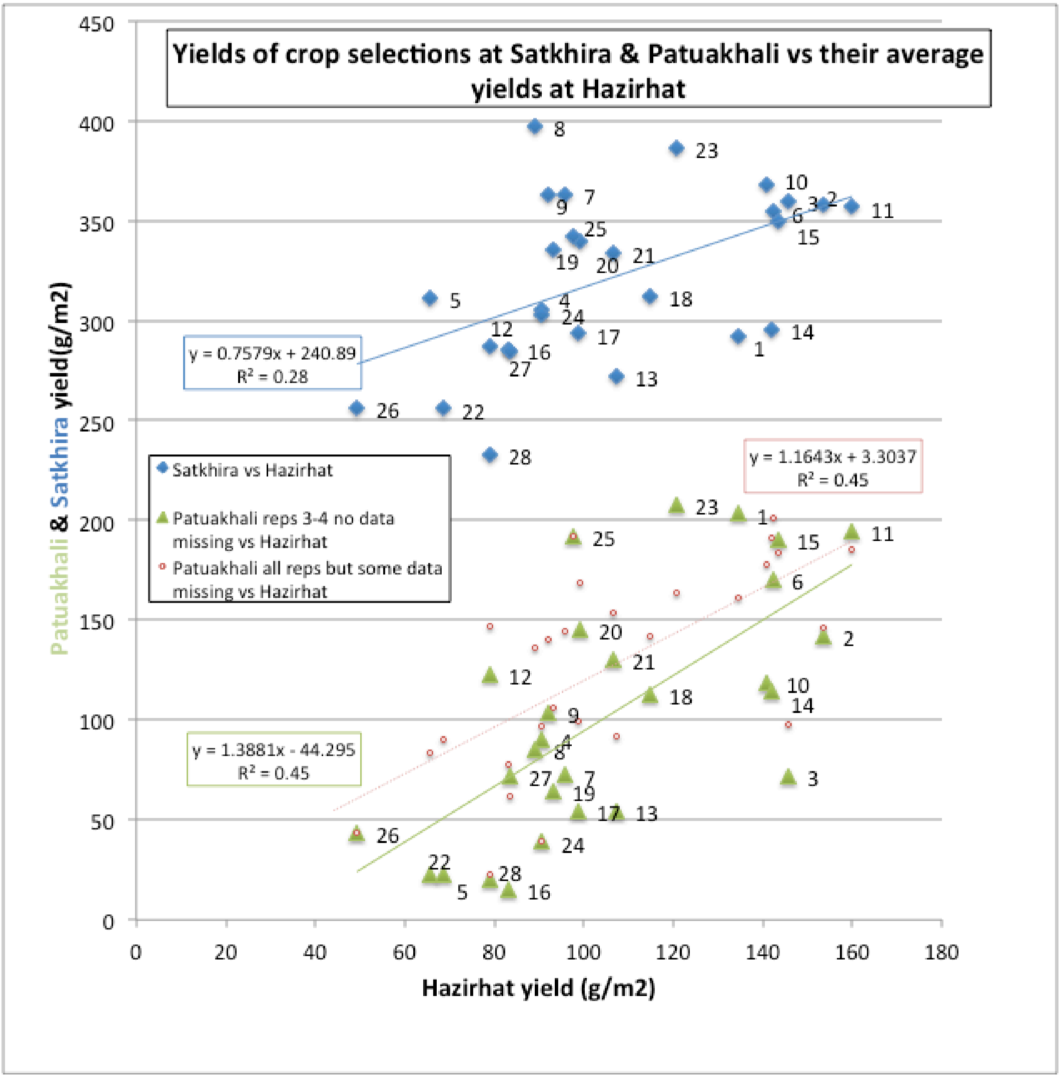


Figure 7.30 Yield at final harvest (g/m2) at Benerpota Satkhira (blue) and at Kuakata Patuakhali (green) plotted against Hazirhat Noakhali yield (x axis). The Patuakhali data (green) are from the complete blocks 3 and 4. Numbers on the points are the selection identifiers in Table 7.2, i.e. 1, 2, 3 are Shatabdi, BARI gom 25 and BARI gom 26 respectively

Weighting yield of crop selections against the salinity of their plots

Figure 7.31 shows the final yield harvested from each plot against plot salinity for all 112 plots of the 4 replicates at Noakhali. The curve is fitted through all points. Selection 26, identified by 4 red squares, that appeared to perform poorly for salinity tolerance on the previous analysis, falls close to the averaged fitted curve. Three of its plots were in high salt with none in low salt. Consequently, despite its average performance according to the curve, its site average yield was low and its standard deviation was small. On that score it would be incorrectly assessed as having poor salt tolerance. By contrast, accession 11 (mauve squares) fortuitously had all its plots in lower salt zones, hence had a high average site yield with low standard deviation and a misjudged high tolerance.

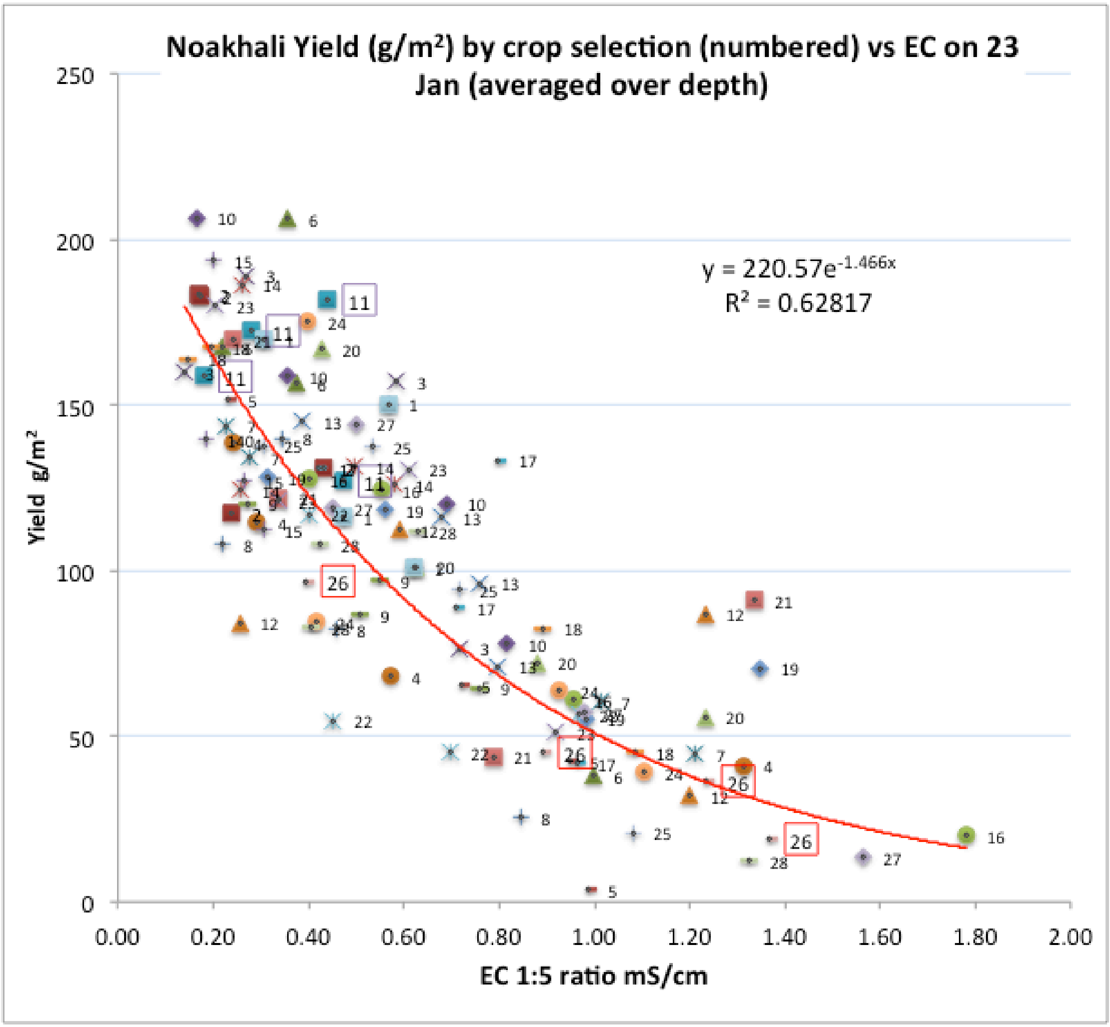


Figure 7.31 Grain yield of plots at Hazirhat Noakhali against plot EC 1:5 averaged over depth (0-90 cm at 23 Jan). Accession numbers as in Table 7.2 are shown. There are 4 reps of each accession

There are two ways to overcome this ‘poor’ plot selection problem leading to incorrect assessment of salt tolerance of lines.

1. After selecting the site and laying out the plots, check each plot for salinity to 90 cm and allocate each crop selection to a low, medium and high salt plot and then sow. Do not allocate selections to plots randomly. This new approach will lead to a complicated site layout but a better analysis that will potentially save years of misleading screening trials.
2. Alternatively fit the average curve through the data as in Figure 7.32, and then assess the deviation of each accession above (good) or below (poor) that curve but accept that the data are weighted to a limited salt regime.

Figure 7.32 follows this second approach. It shows the individual plot data and the associated fitted curve, both in blue, and the 4-plot averages for each accession in brown with an associated linear fitted regression; averaging the plots in this way removed the tails of the data and suppressed its curvilinearity. The two regressions are shown in boxes on the Figure.

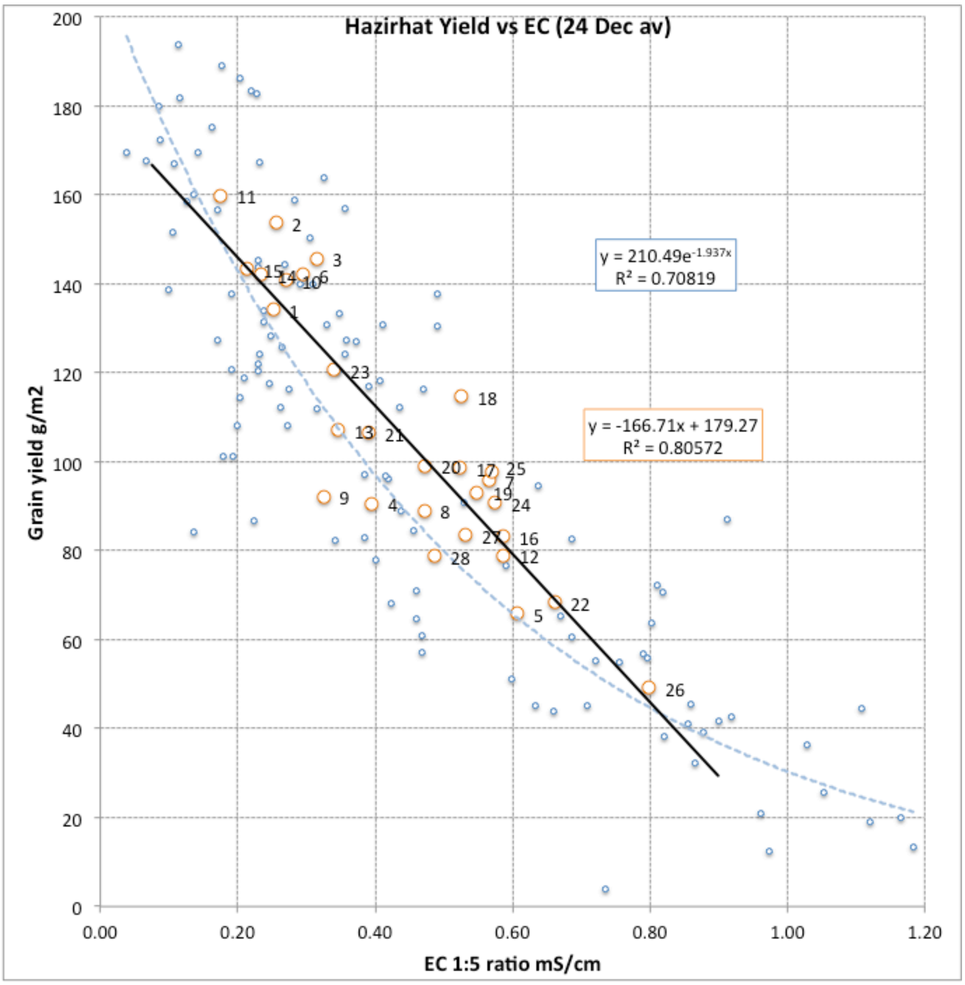


Figure 7.32 Accessions 4-reps-mean grain yield at Hazirhat Noakhali against 4-reps-mean soil EC (0-90 cm cores at 24 Dec 5 days after planting). Accession numbers are shown as in Table 7.2. See Fig. 7.29 for this same data set associated with other yield parameters. Linear regression fitted to means

In the low salinity bracket, accessions 11, 2, 3 perform well while 1 (Shatabdi) falls on the line. Under moderate salinity, 16, 18, 19, 24 and 25 show relative tolerance while 4, 8, 9 and 28 are poor; accession 28 is the Triticale material. In the high salinity grouping 26 is marginally above the line while 22 ranks better than 5, though both fall above the blue plot-based curve

If salinity tolerance is generic then similar rankings for accessions should appear at Kuakata Patuakhali though not necessarily at Benerpota Satkhira, because there a salinity response across the site was covert (Figure 7.23). Kuakata is shown in Figure 7.33 as a test of concept.

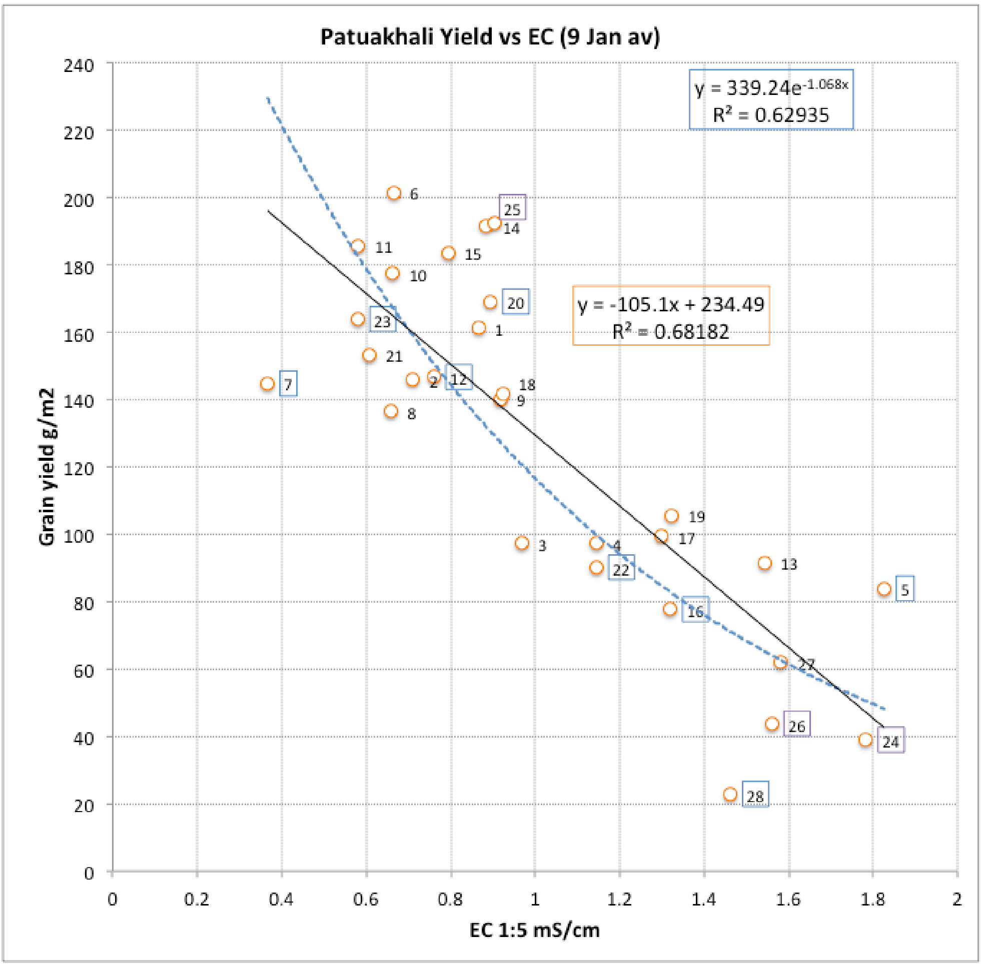


Figure 7.33 Accessions reps-mean grain yield at Kuakata Patuakhali against reps-mean soil EC (0-90 cm cores at 9 Jan). Accession numbers are as in Table 7.2. Linear regression fitted to means, curve to all plot data. Two reps and 3 reps means are in lilac and blue boxes respectively, 4 reps unboxed.

The salts were measured at the Kuakata site 2 weeks later than at Noakhali and some of the selections were represented by either 2 or 3 reps rather than the standard 4 (boxed numbers in Figure 7.33). Nevertheless, selections identified as ‘good’ at Noakhali fell above or on the regression line, being joined by Shatabdi, while those considered to have relatively ‘poor’ tolerance ranked similarly at Kuakata. Triticale again surprisingly was poor.

The situation at Satkhira is difficult to assess because of the relatively poor correlation between yield and EC and the limited spread of EC compared with other sites. However, using the above and below the regression line approach to rank accessions, the better performers listed previously at low salt 11, 2, 3 remain above, as do 19 and 25 (Figure 7.34). This listing may be meaningless in terms of salt, but rather indicates a ranking of selections for yield per se. To confirm or reject this, ranking for yield at Satkhira needs to be compared with rankings at other BARI trials where there is no salt. Nevertheless, for completeness, comparative listings appear in Table 7.4 for the sites. The salt categories are arbitrary as they differ between sites. *This table should be used with caution.*

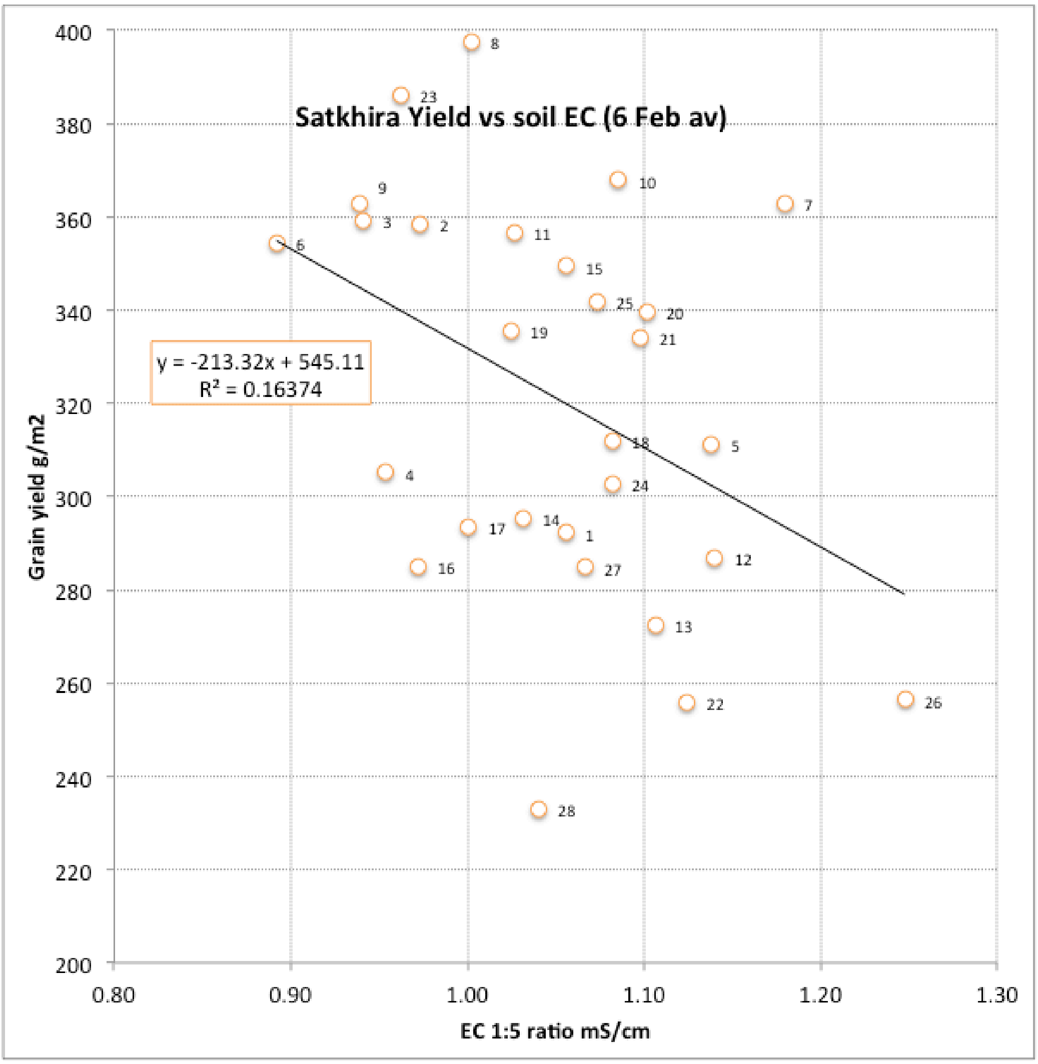


Figure 7.34 Accessions 4-reps-mean grain yield at Benerpota Satkhira against 4-reps-mean soil EC (0-90 cm cores at 6 Feb). Accession numbers are as in Table 7.2. Note the poor correlation of r2 = 0.16 and that the scales on x and y are compressed unlike on previous graphs

Table 7.4 Accession categories for yield in Figures 7.32, 7.33, 7.34 in the lower, medium and higher salt categories at each site. Salt categories are not equivalent across sites. Accession numbers are as in Table 7.1. Categories for good and bad are based on above or below the regression line on each figure

	Lower salt at site		Medium salt at site		Higher salt at site	
Better selection	Better selection	Poorer selection	Better selection	Poorer selection	Better selection	Poorer selection
Hazirhat Noakhali	2, 3, 11		16, 18, 19, 24, 25	4, 8, 9, 24	22, 26	28
Kuakata Patuakhali	6, 10, 11, 15	7	1, 14, 15, 20, 25	3, 4, 22	5, 13, 19	26, 28
Benerpota Satkhira	2, 3, 9, 23	4, 16, 17	8, 10, 11, 15, 19, 20, 21, 25	1, 14, 27, 28	5, 7	13, 22, 26

One question about Benerpota Satkhira relates to management at the site. It could be that the irrigation procedures were sufficient to buffer the crops from apparent soil salts and that EC measurements were not taken regularly enough to see any effects. To test this, soil cores were taken outside the irrigated area on 20 March and compared with those from the irrigated plots (Figure 7.35). There were no consistent differences indicating irrigation was not affecting soil EC distribution at this site.

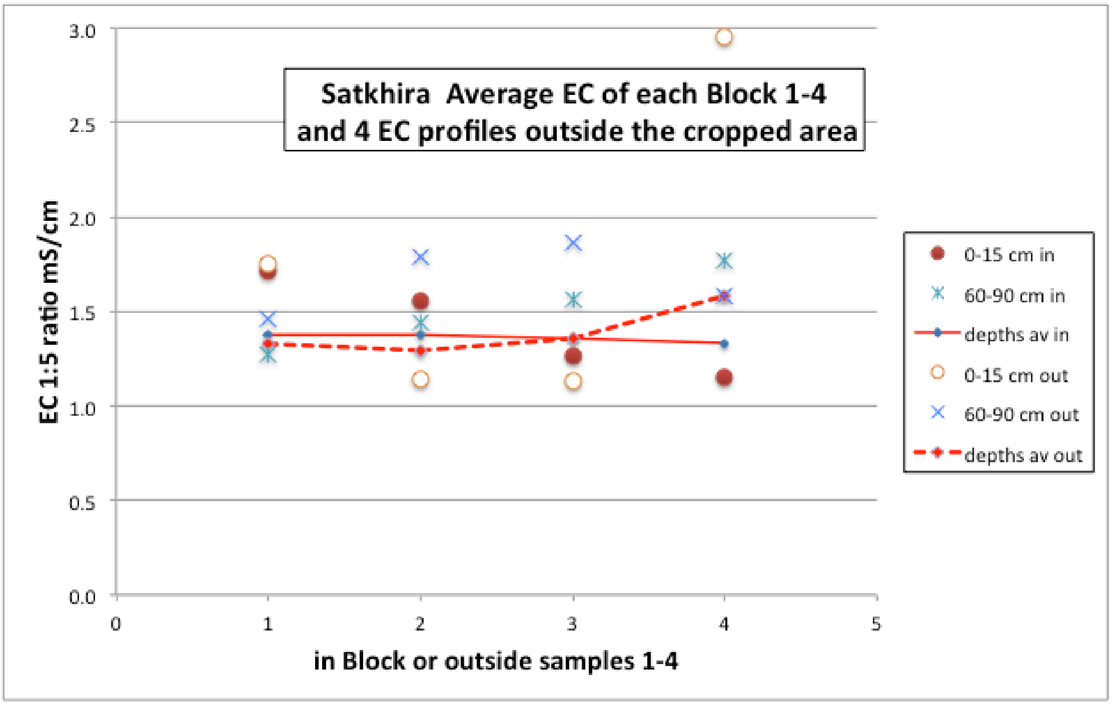


Figure 7.35 Soil EC (1:5 ratio) at Benerpota Satkhira from cores taken inside and outside the irrigated areas. The red lines indicate EC values averaged for all depths down to 90 cm

7.5 Take home messages

7.5.1 Describing salt in the landscape: what is useful?

This work plan began with the aim of putting more than a few snapshot numbers on the levels and distribution of salinity in four sites across Bangladesh, by following changes throughout the Rabi season. It was asking the question whether salinity of a site, from the viewpoint of growing a crop, can be acceptably assessed from one or two soil core measurements made at critical times. The answer is yes and no.

- It is yes at sites that have high surface salinity at planting time, where the soil may be covered in salt between the recently harvested stubble of a rice crop. As in the example of Amtali, Barguna, a cereal crop will fail if the surface soil salinity exceeds 2.5 mS/cm, though establish normally if it is at or below 1.2 mS/cm (EC 1:5 ratio); this problem could potentially be negated by pre-sowing cultivation and/or irrigation. At Amtali, soil salinity was moderate to low below the 15 cm horizon (Figure 7.36), so crops could grow once roots were established in lower parts of the profile. Indeed farmers at the site who delayed planting harvested better than 2 t/ha yields.

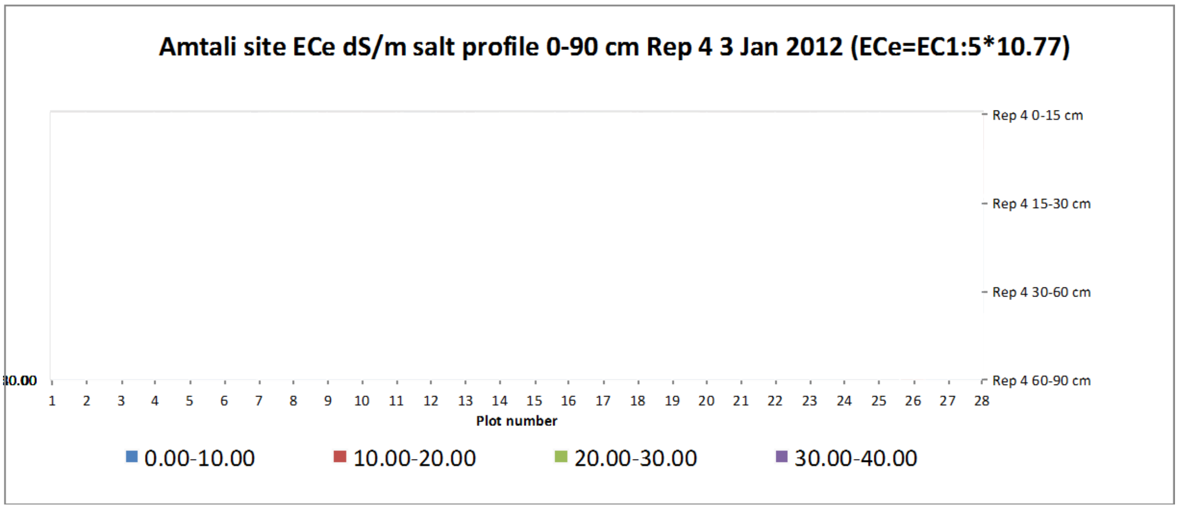


Figure 7.36 Vertical distribution of salinity (ECe dS/m) at Amtali site showing high salinity in the surface 15 cm of the profile (purple, green, red) but little below (blue) apart from occasional salt tongues dropping to 90 cm

- But more data are needed to determine the best agronomy to follow at such sites and also to determine the extent of such sites in the coastal zone.

- It is also yes at sites epitomized by Hazirhat in Noakhali. Here, at planting time in December, there was little variation in salt with soil depth though wide variation horizontally. So high salt at the surface meant high salt at depth and low surface salt meant low salt throughout. A few samples from the surface would define areas where crops of different tolerance would grow well. Changes in agronomy would possibly have no impact on yield in the more saline parts.
  - There would be a strong role for a ground conductivity meter such as the EM38-Mk2 in December to rapidly map and describe large areas for crop suitability.

- It is no at a site such as Benerpota, Satkhira where the surrounding water body maintained the water table close to the surface and uniform across the site and possibly dominated the potential productivity of the location. There the salinity of the water table at 2 mS/cm during crop establishment was not high enough to prevent production of substantial cereal crops. In this season biomass averaged 9 t/ha and yield 3.2 t/ha; in 2010 biomass and yield were 9.7 t/ha and 4.5 t/ha respectively and when planted late 7.9 and 3.3 t/ha. Yield variation across the site was similar to patterns in the current season.
  - Where the water table is close to the surface and does not fall below the rooting zone at any stage during crop growth it is likely to dominate production, over-riding soil EC profiles. EC measurements of groundwater in a piezometer or shallow tube well should be adequate to describe the cropping potential of the site. This may not work for very shallow-rooting species particularly as with capillarity rise of salt they will likely have to grow in EC 1:5 values of 1.5 mS/cm in March. Use of a ground conductivity meter at Satkhira may not help understanding of crop growth.

- Salt rise leading to crystals on the surface by March is common but this is not indicative of high salt levels throughout the rooting profile to 90 cm. At Hazirhat, Amtali and Kuakata EC at depth remained well below 1 mS/cm (1:5) throughout Rabi. The majority of crop roots were growing in these lower salt levels by February, and, in any case, cereals by this developmental stage have become less susceptible to salt.
  - Surface salt measurements at the end of Rabi do not bear much relationship to salt lower in the profile where roots predominate so alone are not a helpful measure of Rabi crop potential.

- The data presented here are from one season only, and as alluded to in the Introduction, salt profiles and seasonal patterns are dependent on rainfall, temperatures and vapour pressure deficits. Though it is uncommon to see such detailed salinity data particularly linked with crop growth and yield data as in this project, such data need to be repeated at least in part to understand the drivers of the patterns.
    - It is strongly recommended that this study be repeated next season with a key component being an instrument, such as an EM 38-Mk2 being used widely for cross calibration against any soil profile EC measurements, but also to expand the possible links between salinity and crop production across farmers' fields with a range of crops. After initial calibration of the EM 38 for EC and water, spot soil coring measurements would be minimal. Meteorological data would be required at central sites throughout the cropping seasons.
    - This approach would also be appropriate in pre-sowing EC mapping across breeders' trials screening for salt tolerance lines leading to more appropriate layout of trials and more rapid reliable screening.

7.5.2 Salt and yield: field data collection and modelling in tandem

As was pointed out in the Introduction and in this section, occasional spot measurements of salts in soils may not increase understanding of causes or lead to farming solutions if they are not associated with supporting crop and environment data. Spot data can lead to interesting but sometimes irrelevant hypotheses and considerable misplaced effort in research. Some early work assuming salt tolerance at germination may equal salt tolerance during growth is one case in point. Many trials in salt culture assuming salt in the profile is static through the season is another case. Small time-windows in the season when salinity might be low, but rising, offer opportunities for crop production that are not conceivable in such studies. The impacts of the many variables that affect crop production independently and in combination need to be better understood. This is the role of crop models but crop models need good field data on which to base their relationships. Salinity effects on production are often seen solely as effects on water relations of the crops, but what salinity, and where and when are critical questions.

- The data have shown good correlations between EC of the soil and yield, particularly at Hazirhat and particularly considering EC cores sampled around planting time. Similar conclusions apply to Kuakata and Amtali once the initial emergence effects are removed. But correlations at Satkhira were poor. Satkhira represents a large cropping zone in the west where crops are regarded as being seriously affected by salinity, though we have limited evidence of this.
    - Because the effects on crop production of interactions between environmental variables are very complex, advances in understanding, leading to better predictions of potential food production, can only come through computer modelling. Any future data collection work such as recommended in the final point under "Describing salt in the landscape", must be backed by a parallel modelling component.

7.5.3 Breeding & selection of salt tolerant species and genotypes: changed methods

This project has highlighted the difficulty of selecting for salt tolerance in the field because of the variability of sites and environments. But it has also indicated that field selection is the only reliable method for handling material that is close to being ready for on-farm use. Controlled environments are certainly appropriate for screening for physiological mechanisms in biotechnology programs and for selection of physical traits and phenological patterns within species, as practiced currently.

The data collected in the project suggested two approaches to screen for salinity tolerance, first to thoroughly describe the salinity profiles of the field site chosen for screening and only then allocate the plots to accessions, planting each accession across high, medium and a low salt plots, ignoring traditional blocking approaches.

The second, and less useful approach suggested was to use traditional replication with randomization and accept whatever salinity level individual accessions are allocated. Rank yield of accessions against plot salinity at the end of the season. The weakness of this approach is that few accessions will be distributed to plots crossing all salinity levels so ranking of accessions will be dominated by the number of plots at extreme salinity levels.

- If following the first approach of scanning a selection site for EC distribution prior to allocating plots to accessions, using a ground conductivity meter to map the site will significantly accelerate the process. Using this approach, different species could be compared for salinity tolerance and compared at a number of sites with different base levels and patterns of salt. This would lead to a more robust and usable analysis of salt tolerance than a simple ranking of “this species is more tolerant than that”.

8 Socio-economy and livelihood

8.1 Introduction

The salinity problems and the associated scarcity of water suitable for irrigation as discussed in Chapter 5 are generally considered the prime cause of the current situation of low cropping intensity in the coastal zone (SRDI, 2012), but farmer's ignorance, perceptions, conservatism and low initiative are also to blame (Khan et al., 2011). Consequently, a sizeable amount of cultivable land unnecessarily remains fallow in Rabi and Kharif-I seasons as discussed in Chapter 6.

This chapter uses recent statistics backed up by personal visits to Khulna (polders in Dumuria, Rupsa, Beel Pabla, and Alaipur) and Bagerhat (Morolganj and Shorankhola upazila, Rayenda) in September 2012 for interviews with farmers. The data are used to (1) identify constraints and opportunities to intensify agriculture in the southern coastal zone[2] (referred to as CZ), and (2) consider how intensification might impact on economic, social, environmental and livelihood parameters in the CZ. Throughout this chapter, data from the CZ are compared with those from the whole of Bangladesh.

8.2 Population and demography

Population and density

The southern CZ comprises 17 districts divided into 120 upazilas (sub-districts) of which 35 are coastally exposed. Its population is estimated at 29.5 million, about 20 percent of the national population, while populations of its districts range between 3,211,000 (Noakhali) and 623,000 (Jhalokathi, Table 8.1). Its area (39,426 km^2) is about 26.7 percent of the country's area. The density of population (716) is far below the national average (964), nearly 26 percent less, but the range is wide from 1530 down to 369 /km^2.

Urbanization

The CZ is much less urban than other parts of Bangladesh, 17 vs. 23 percent (Table 8.1) meaning around 80% is rural. However, significant variations exist among districts with Khulna having the highest proportion of urban population (33.5%) and Satkhira the lowest (10%). Naturally, the divisional districts, Khulna and Barisal, have relatively higher urbanization rates, 33.5 and 22.3 percent, respectively.

Islam (2004) predicted that by 2030 the population would be about 49 million for the total southern area. On this basis, the population for the current 17 districts is expected to be about 39 million in 2030.

Demographic characteristics

In terms of literacy, the CZ has a favourable rate (55.6%), with only three districts, Bhola, Shariatpur and Lakshmipur, falling below the national average of 51.8 percent. The districts of Jhalokathi, Pirojpur and Narail have high literacy rates, 66.7, 64.9 and 61.3 percent respectively.

---

[2] In fact, the coastal zone consists of 19 districts in three Divisions, Khulna, Barisal and Chittagong as described in Chapter 4. In this Chapter, coastal zone does not include the districts of Chittagong and Cox's Bazar. The focus of this study is to intensify cropping in the saline affected area in the coastal zone particularly in the southern coastal zone. As shown in Figure 5.42, only a small strip of area affected by salinity along the coast is in these two districts. There is not much agriculture in the saline affected area so it is unlikely that any follow-up research will include these two districts.

Table 8.1 Population and demographic characteristics

District	Area (sq. km)	Population (000)	Sex ratio M/F	Density (per sq km)	Literacy (%)	Urbanization (% of population)
Bagerhat	3959	1527	100	369	59.0	13.2
Barguna	1831	922	97	481	57.6	11.6
Barisal	2785	2394	96	823	61.2	22.3
Bhola	3403	1837	99	517	43.2	13.7
Chandpur	1704	2501	90	1404	56.8	18.0
Feni	928	1484	94	1530	59.6	20.4
Gopalganj	1490	1201	97	771	58.1	11.0
Jessore	2567	2866	101	1068	56.5	18.6
Jhalokathi	749	623	93	795	66.7	16.4
Khulna	4394	2397	103	522	60.1	33.5
Lakshmipur	1456	1788	92	1175	49.4	15.2
Narail	990	747	96	722	61.3	15.6
Noakhali	3601	3211	92	853	51.3	16.0
Patuakhali	3221	1585	96	471	54.1	13.1
Pirojpur	1308	1153	97	844	64.9	16.4
Satkhira	3858	2062	98	511	52.1	10.0
Shariatpur	1182	1198	93	970	47.3	11.3
CZ	**39426**	**29496**	**96**	**716**	**55.6**	**17.1**
Bangladesh	**147570**	**148737**	**100**	**964**	**51.8**	**23.3**

Note: Data refer to 2011. Source: Population census 2011

8.3 Selected socio-economic indicators

Basic facilities - Electricity, sanitation and drinking water

Access to electricity is crucial for economic and social development. About 53 percent of households in the CZ enjoy electricity connection, marginally lower than in the country as a whole (55%). The percentage of households with sanitation in CZ is 67.6%, better than the national average (63.5%, Table 8.2). Though 88% of CZ households depend on a tube well for their drinking water, as in the rest of Bangladesh, CZ has far less available per km^2 (158 vs. 201, Table 8.3).

Infant mortality rate

In terms of child mortality rates, overall the CZ enjoys a slightly better position than that of the nation, with deaths for every thousand being 46 as against 49 for Bangladesh as a whole; variation among districts is small (Appendix C, Table C.1).

Economically active population and participation rate

An average CZ district has around 651,000 economically active people aged above 15 years, rather less than the Bangladesh average of 885,000 (Appendix C, Table C.2) while comparative participation rates are 55.6% and 59.6% respectively. Districts such as Jessore, Barisal and Khulna have a much higher proportion of active people than Jhalokathi, Narail and Barguna.

Table 8.2 Selected socio-economic indicators by districts

District	% distribution of household with basic facility				
	Electricity	Sanitary toilet	Source of drinking water		
			Tap	Tube well	others
Bagerhat	49.71	61.79	26.83	64.43	8.74
Barguna	33.05	74.04	4.34	90.20	5.46
Barisal	58.11	76.54	.60	94.81	4.59
Bhola	42.83	72.38	.41	96.89	2.7
Chandpur	42.94	76.06	13.77	84.84	1.39
Feni	71.36	76.63	4.16	95.08	0.76
Gopalganj	54.02	73.01	23.44	76.42	0.14
Jessore	61.66	59.39	3.22	96.71	0.07
Jhalokathi	56.09	68.96	3.87	95.70	0.43
Khulna	67.05	61.34	4.57	90.57	4.86
Lakshmipur	38.66	64.92	9.32	89.50	1.18
Narail	57.07	73.42	.43	99.40	0.17
Noakhali	66.37	65.68	12.25	86.27	1.48
Patuakhali	36.52	67.55	6.23	91.54	2.23
Pirojpur	49.05	65.79	12.08	80.07	7.85
Satkhira	48.22	56.35	15.93	79.20	4.87
Shariatpur	47.02	74.54	.17	99.76	0.07
CZ	**52.95**	**67.61**	**8.59**	**88.53**	**2.88**
Bangladesh	**54.55**	**63.54**	**10.77**	**87.39**	**1.84**

Note: Data refer to 2010. Source: BBS (2011a)

Table 8.3 Level of infrastructure in CZ

	Infrastructure and urbanization		
District	*Density of Market (per km^2)	No. of tube wells (per km^2)	*Persons per one hospital bed
Bagerhat	102	55	4,465
Barguna	80	111	3,243
Barisal	65	204	2,065
Bhola	122	112	6,198
Chandpur	47	318	9,166
Feni	46	320	5,141
Gopalganj	75	172	578
Jessore	63	254	5,479
Jhalokathi	54	247	3,882
Khulna	116	118	2,131
Lakshmipur	66	279	10,936
Narail	66	178	6,322
Noakhali	116	162	6,094
Patuakhali	114	110	4,717
Pirojpur	57	179	5,223
Satkhira	49	113	4,875
Shariatpur	102	191	6,595
Coastal Zone (CZ)	**80**	**158**	**4,637**
Bangladesh	**70**	**201**	**4,276**

Note: Data refer to 2010-11, * Data refer to 2003. Source: BBS 2010a & 2011a

8.4 Economic sectors and sectoral contribution

In order to get a comprehensive idea about the contribution of the coastal region to the overall economy, one has to look at the major macroeconomic variables like Gross District Product and Per Capita Gross District Product. Additionally, one has to examine the sectoral contributions of agriculture, industry and the service sector.

Gross district product (GDP)

Gross district product expressed per km^2 is also a good indicator of the development level of any region. Average GDP per km^2 for a CZ district is estimated as TK 38.58 million, which compares quite unfavorably with the national estimate of TK 53.03 million (Figure 8.1, left). Most of the CZ districts have miserably low levels of GDP per unit area (Table 8.4). Jessore has the highest level of GDP per km^2 (TK 60.9 million), which is nearly 2.3 times higher than that of lowest GDP (TK 26.1 million) in Barguna.

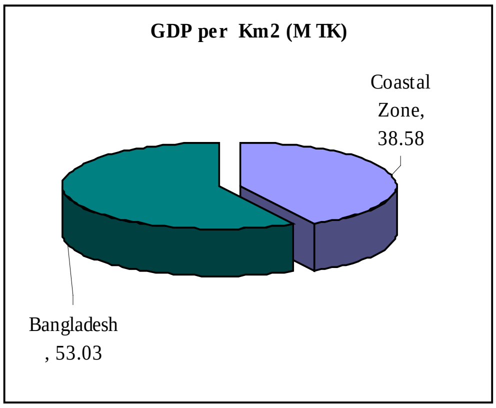
Considering for comparison a district as a unit, an average CZ district produces TK 89,470 million, which is only 73% of average national GDP of about TK 123,046 million (Table 8.4, Figure 8.1, right). Not all districts perform equally in terms of generating GDP. Jhalokathi has the lowest GDP (TK 29,896 million) while Khulna produces six times more (TK 194,552 million).

Nevertheless, the CZ as a whole contributes significantly to the economy of Bangladesh with its mainstay being agriculture. The data updated for 2010-11 shows that the share of agriculture to GDP in CZ was 27.6% against the national average of only 19.6% (Figure 8.2). This is a reversal of the situation for industries that contributed 19.4% in the CZ, as against that of the national average of 27.9% (Table 8.4). The service sector contributed 52 to 53% both in the CZ and nationally.

Table 8.4 GDP and sectoral contribution

District	GDP (million. TK)	GDP per km^2 (million.TK)	Per capita GDP (TK)	% of GDP by major sectors						
				All Agric	Crop	livestock	Fisheries	Forestry	Industry	Service
Bagerhat	103,455	26.13	67,751	34.9						
Barguna	51,692	28.23	56,066	36.9	16.7	4.6	12.3	3.0	14.8	48.4
Barisal	126,861	45.55	52,991	22.7	10.5	3.1	7.1	1.9	19.8	57.5
Bhola	94,670	27.83	51,534	33.8	14.7	4.4	12.8	2.0	15.5	50.5
Chandpur	111,400	65.38	44,543	24.8	12.5	3.0	7.8	1.7	20.1	55.1
Feni	54,340	58.56	36,618	23.1	10.7	3.3	7.2	1.6	22.1	54.8
Gopalganj	53,966	36.22	44,934	24.4	14.3	2.9	3.9	3.4	20.0	55.8
Jessore	156,324	60.90	54,544	24.7	16.1	3.0	3.8	1.9	25.6	49.6
Jhalokathi	29,896	39.92	47,986	25.1	12.2	3.9	6.7	2.4	17.3	57.6
Khulna	194,552	44.28	81,165	19.3	8.7	1.4	8.3	0.9	23.5	57.3
Lakshmipur	76,839	52.77	42,975	29.1	13.4	3.1	10.7	1.9	16.5	54.5
Narail	39,401	39.79	52,745	35.4	25.7	2.9	3.9	2.9	15.0	49.6
Noakhali	132,331	36.75	41,212	27.9	12.6	3.3	10.1	1.8	18.7	53.4
Patuakhali	85,291	26.48	53,811	36.9	17.8	4.2	12.1	2.8	13.7	49.4
Pirojpur	53,614	40.99	46,500	26.4	13.0	4.2	6.1	2.9	17.8	55.7
Satkhira	105,982	27.47	51,397	33.2	20.2	2.7	8.1	2.3	19.3	47.6
Shariatpur	50,378	42.62	42,053	26.8	15.3	3.8	4.7	2.9	20.4	52.8
CZ	**89,470**	**38.58**	**51,566**	**27.6**	**14.2**	**3.1**	**8.3**	**2.0**	**19.4**	**53.0**
Bangladesh	**123,046**	**53.03**	**53,236**	**19.6**	**11.5**	**2.4**	**3.7**	**1.6**	**27.9**	**52.5**

Note: GDP at current market price, 2010-11: Source: Own estimate, based on BBS data.



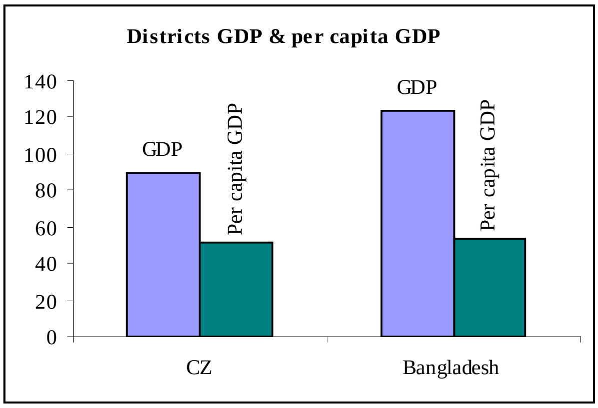
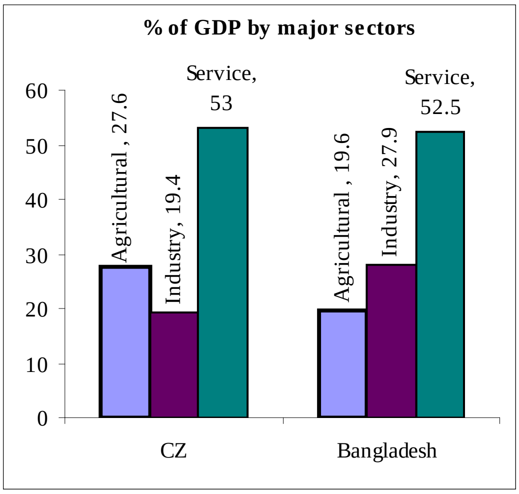


Figure 8.1 GDP per km^2 (million taka), GDP (million taka), and GDP per capita (thousand taka) for the southern coastal zone and Bangladesh



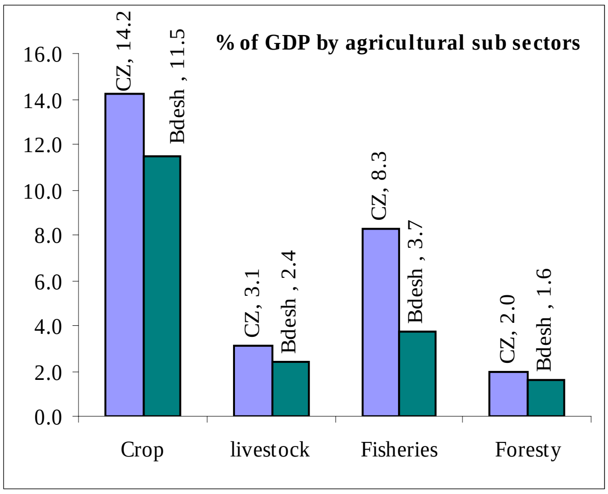


Figure 8.2 GDP by major sectors and agricultural subsectors

However, agricultural activities, being dependent on natural resources, frequently face physical challenges from recurrent natural hazards. In spite of that, Barguna, Patuakhali and Narail are the districts in which more than 35% of GDP comes from agriculture. Barisal, Khulna and Feni are the districts in which less than 25% of GDP comes from agriculture. They might suffer severe economic loss due to any catastrophic event. The divisional district, Khulna is the district that depends least on agriculture.

Some of the sub-sectors such as shrimp farming, whose economic (not social, however) importance has been growing day by day, are almost entirely located in the coastal region. Other such activities are marine foods, tourism, salt industry and forestry. Within the coastal districts, there are substantial variations in production, sectoral contributions and economic activities, which also impact on the level of economic development. It can be seen (Table 8.4) that Jessore and Khulna districts rank highest in industrial contribution while lowest in agriculture. Barguna, Patuakhali, Lakshmipur and Narail rank lowest in industrial performance but agriculture in those districts contributes nearly double that of the national average.

Per capita GDP

The value of the GDP is often deceptive, as it does not give any idea about the distribution of economic output. That is why per capita GDP is considered to be a better indicator. Per capita income in CZ districts is estimated as TK 51,566 as compared with the national figure of TK 53,236 at 2010-11 prices. However, considerable variations exist in per capita income among districts within the coastal zone. The divisional district of Khulna enjoys the highest per capita income (TK. 81,165). At TK. 36,618 Feni has the least (Table 8.4).

Trends in per capita income by district

As one can see from trend estimates between 1995/96 and 2005/06, the value of per capita GDP both for the CZ and the country as a whole are progressively increasing, but that for the coastal region is increasing at a slightly lower rate (31.6% vs. 33.1%) (Appendix C, Table C.3). Relatively higher per capita income growth during 1995-96 and 2005-06 were experienced in Bagerhat (45.3%), Satkhira (39.0%) and Barisal (36.1%). Lower per capita income growths during the period were shown in Narail (8.4%), Bhola (21.7%) and Gopalganj (21.8%).

Growth of GDP

An analysis of trends in GDP by sectors at the district level for 2005/06, compared to 1995/96, is shown in Table 8.5. Again, the overall growth in GDP appears to be lower in coastal districts, 3.6 percent compared to the national figure of 4.2 percent. Higher growth occurred in Noakhali (4.3%), Bagerhat (4.2%), Jessore (4.1%) and Khulna (4.0%) while Lakshmipur (1.9%), Narail (2.6%) and Gopalganj (2.9%) had lower growth rates. As regards agriculture, not all districts performed equally in terms of generating agricultural GDP; eight out of 17 districts had negative growth during the period. Worse still, the cropping sector experienced negative growth in all districts excepting Bagerhat, Chandpur, Khulna and Satkhira (Appendix C, Table C.4).

Table 8.5 District level growth in GDP by major sectors

District	Annual compound growth rate (%)			
	Agriculture	Industry	Service	Total GDP
Bagerhat	1.8	5.4	5.5	4.2
Barguna	-0.1	5.4	5.3	3.1
Barisal	0.6	5.3	4.9	3.8
Bhola	-0.1	5.4	5.1	3.1
Chandpur	-0.9	5.6	4.8	3.2
Feni	1.0	4.8	5.4	4.1
Gopalganj	-1.2	5.6	4.3	2.9
Jessore	0.9	5.3	5.4	4.1
Jhalokathi	0.8	5.3	4.9	3.8
Khulna	2.3	5.2	4.2	4.0
Narail	-0.9	5.4	4.8	2.6
Noakhali	1.5	5.5	5.6	4.3
Patuakhali	0.4	5.3	5.2	3.2
Pirojpur	-0.3	5.4	4.8	3.3
Satkhira	1.2	5.4	5.5	4.0
Shariatpur	-0.6	5.4	5.0	3.3
Lakshmipur	-2.7	5.5	4.3	1.9
CZ	**0.5**	**5.2**	**5.0**	**3.6**
Bangladesh	**1.1**	**5.2**	**5.0**	**4.2**

Note: Growth refer to 1995/96- 2005/06
Source: Own estimate, based on BBS data & Deb et al., 2008

8.5 Coastal livelihoods

Household by main source of income

The main characteristic of the CZ, which differentiates it from other areas, is its complexity. This complexity is manifested in the diversity and dynamic nature of the livelihoods of the people, especially the poor. Although agriculture is still the mainstay of the economy in the region, the CZ provides sources of livelihood that are not commonly available in other parts of Bangladesh. For example, more than 1.3 million people live on collecting fish, and honey, wax, leaves and wood from trees of the Sundarbans (Islam, 2011)[3]**.** In the CZ, 24.3% of people, more than three times the national figure, earn their living by fishing (Table 8.6).

In spite of that, the principal source of livelihood is still agriculture. The second major sources of livelihood are related to agro-based activities and SRF extraction activities. Per capita cultivable land is estimated as 0.14 acre, similar to the national average (0.13 acre) (Table 8.6). With respect to landlessness, however, CZ districts fare not too badly, the proportion of households owning no land being 8.2% compared to the national average of 9.6 %. In the urbanized districts of the CZ such as Khulna, Bagerhat and Satkhira, the scope of employment generation in industry and services is a little higher. In the offshore islands, a large number of people are dependent for their livelihood on natural resources. The distribution of households by main sources of income shows that nearly 21% of

[3] Islam (2011) estimated that more than one million (1.1 million) people are living on fish collection/ business alone, a fact that has some implication for agriculture intensification. However, they are currently on a very subsistence level of living and such activities are likely to experience a sharp decline because of fall in both catch and productivity in the future.

households in the CZ are currently dependent directly on agriculture apart from 14.7% engaged as agricultural day labourers (Table 8.7). The service sector provides employment to nearly 18.4% of households while non-agricultural work, including day labourers and other sectors, are the sources of employment for 46.4% of households (Appendix C, Table C.5).

Table 8.6 Coastal livelihoods: selected indicators

District	Landless (Owning no land) (% of HH)	Agricultural Labourer (%)	Per capita land (acres)	Per capita cultivable land (acres)	Fishermen (%)
Bagerhat	9.21	19.9	0.64	0.20	12
Barguna	7.63	2.0	0.49	0.22	38
Barisal	7.75	9.3	0.29	0.12	7
Bhola	8.45	19.0	0.46	0.15	14
Chandpur	5.18	18.2	0.17	0.07	7
Feni	4.16	3.9	0.15	0.07	19
Gopalganj	4.76	7.2	0.31	0.19	1
Jessore	9.56	25.5	0.22	0.15	10
Jhalokathi	3.83	8.1	0.30	0.16	26
Khulna	19.40	14.7	0.45	0.12	40
Lakshmipur	6.52	14.7	0.20	0.10	35
Narail	5.11	8.6	0.33	0.20	31
Noakhali	6.52	10.9	0.28	0.12	33
Patuakhali	7.35	4.2	0.50	0.21	31
Pirojpur	5.22	4.5	0.28	0.16	32
Satkhira	6.88	49.6	0.46	0.14	31
Shariatpur	11.34	5.1	0.24	0.12	46
Coastal Zone	**8.2**	**12.2**	**0.33**	**0.14**	**24.3**
Bangladesh	**9.6**	**11.6**	**0.25**	**0.13**	**8.0**

Note: Data refer to 2008-09: Source: BBS (2011b, 2011c) ; ECOMAC (2008)

Animal farming

Animal farming, or the value addition by the livestock and poultry sector, is an important occupation for the CZ population though this is less so than for the nation as a whole. In 1999-2000, for example, value adding by the livestock sector in the CZ on a district average was around TK 872 million (not shown in the Table) compared with TK 960 million in non-coastal regions (updated data are not readily available). An average CZ district is estimated to have 361,000 cattle, less than the national average district (410,000) (Appendix C, Table C.6).

Fisheries, shrimp/prawns

Fisheries are a very important sub-sector of the CZ as well as making a large contribution to the nation. For example, in 2008-09, the CZ produced 686,953 metric tonnes, almost one third of the output of the whole country estimated at 2,186,752 metric tonnes (Appendix C, Table C.7). Shrimp/prawn farming has also been a major activity in the coastal region. More than 217,700 hectares of land are used for shrimp/prawn cultivation in the CZ, producing almost the entire (99.95%) national production of nearly 145,600 metric tonnes, equivalent to 660 kg/ha (Appendix C, Table C.8). The extent of this activity can be seen in the satellite images of Chapter 6 (Figures 6.19, 6.20).

8.6 Poverty situation

Population below the poverty line

It is generally believed that CZ populations are suffering from marginalization and inequality in income (Islam, 2011). Poverty status can be considered as a proxy to the extent of marginalization. Poverty data are available for 2005 (Table 8.7). A comparative analysis of the CZ against the rest of Bangladesh shows poverty to be much higher in the CZ (Islam, 2011) with 65% of people below the poverty line compared to average district in Bangladesh (40%)[4]. Thus the poverty situation in the CZ is extremely severe, which has immense policy implications relating to the further intensification of agriculture. Of all the CZ districts, the poverty level for Shariatpur is estimated as the highest (85.2%) followed by Barguna (82.4%), Bhola and Chandpur (both 77.8%). Jhalokathi has the lowest poverty level (17.8%), followed by Gopalganj (36.5%) and Feni (39.1%) (Table 8.7).

Table 8.7 Poverty situation and structure of household heads

District	% Below poverty line 2005	Household headed (%) by	
		Male	Female
Bagerhat	61.30	95.8	4.2
Barguna	82.39	96.4	3.6
Barisal	77.82	96.8	3.2
Bhola	72.80	97.2	2.8
Chandpur	66.97	94.6	5.4
Feni	39.14	90.8	9.2
Gopalganj	36.54	97.0	3.0
Jessore	79.53	96.5	3.5
Jhalokathi	17.76	95.9	4.1
Khulna	47.68	96.2	3.8
Lakshmipur	59.96	92.2	7.8
Narail	68.51	96.0	4.0
Noakhali	61.30	94.0	6.0
Patuakhali	72.25	97.2	2.8
Pirojpur	74.27	96.4	3.6
Satkhira	64.82	96.0	4.0
Shariatpur	85.19	96.6	3.4
CZ	**64.5**	**95.6**	**4.4**
Bangladesh	**40.0**	**95.4**	**4.6**

Note: Population data refer to 2011; Poverty data refers to 2005. : The district population figures of 2001 taken as weights to estimate averages Source: BBS, 2011b

[4] Based on Cost of Basic Needs (CBN) method, the estimates are for lower poverty line, incorporating BBS-2005.

Food security and

Food security is the paramount issue for household well-being. People in permanent employment have the highest level of food security (ECOMAC, 2008) enjoying a secure food supply for 10 months each year on average (Table 8.8). By contrast, wage labourers and craftsmen have only 5 months of stable food supply while households depending on fishing and agriculture for income have food security for 8 months.

Table 8.8 Food Security across different livelihood groups

Livelihood	Average of secure months in a year
Agriculture Related Activities	8.01
Wage Earner/Day Labourer	5.45
Fisherman	8.00
Craftsman and Other	5.88
Permanent Employment and Business	10.21

Source: ECOMAC (2008)

Human poverty index

Surprisingly, the human poverty index (HPI)[5] in the coastal districts has been quite favourable compared to that of the country as a whole. For example, available data as of 2000 demonstrate that an average CZ district had HPI 30.3, as compared to national average of 35.5 (Table 8.9; Figure 8.3). However, average annual percentage improvement in HPI between 1995 and 2000 is much poorer in the CZ (-2.09%) than at the national level (-3.01%). On a different poverty measurement, that is, a distribution of households by level of insolvency or solvency (temporary/permanent or break-even) is not significantly different between the CZ and Bangladesh as a whole. (Appendix C, Table C.9).

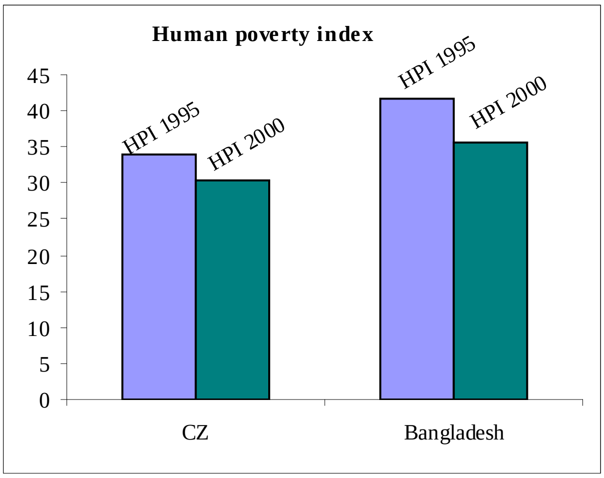


Figure 8.3 Human Poverty Index (HPI) - Coastal Zone and Bangladesh

[5] Human poverty index (HPI) is calculated as HPI = $[1/3 (P_1^3 + P_2^3 + P_3^3)]^{1/3,}$ whereas Deprivation in Longevity = P_1, Deprivation in Knowledge = P_2, and Deprivation in Economic Provisioning = P_3

Table 8.9 Human poverty index

District	HPI 1995	HPI 2000	Average annual % change in HPI during 1995-2000
Bagerhat	32.58	29.72	-1.76
Barguna	33.79	28.43	-3.17
Barisal	31.80	29.03	-1.74
Bhola	37.48	36.32	-0.62
Chandpur	33.28	29.76	-2.11
Feni	30.83	28.15	-1.74
Gopalganj	32.51	29.77	-1.69
Jessore	30.77	28.20	-1.67
Jhalokathi	31.54	25.40	-3.89
Khulna	32.51	27.95	-2.81
Narail	32.41	31.26	-0.71
Noakhali	36.33	33.05	-1.80
Patuakhali	35.76	30.56	-2.91
Pirojpur	31.16	25.82	-3.42
Satkhira	35.53	31.74	-2.13
Shariatpur	42.28	36.76	-2.61
Lakshmipur	34.80	32.39	-1.39
CZ	**33.86**	**30.32**	**-2.09**
Bangladesh	**41.8**	**35.5**	**-3.01**

Source: BBS data; Sen and Ali (2009), BIDS.

8.7 Major factors behind backwardness of the coastal zone

The above discussion demonstrates that in many respects the coastal zone is backward compared with other parts of the country, especially in terms of GDP, literacy rate, crop yields, cropping intensity, production levels, livelihoods and quality of life (as will be seen later). The CZ has a low level of agriculture technologies, lack of environment tolerant and modern varieties, and lack of improved fertilizer and water management, and limited pest and disease control measures. The coastal areas are subjected to flooding in the monsoon season[6] and water logging in parts of the zone during most of the dry season[7]**.** Tidal flooding simply adds to the severity of the problems.

While discussing the backwardness of the CZ, one has to mention salinity conditions relating to both soil and water in the area[8]. Due to salinity, farmers mostly cultivate low yielding, traditional rice varieties during the wet season. Most of the land remains fallow in the dry season (January-May) because of soil salinity, lack of irrigation water and proper drainage facilities as discussed in the previous Chapters. In recent years, along with increasing salinity, some areas have been subject to further intrusion of saline water (Figures 5.19 and 5.40). In those areas normal crop production becomes

[6] About 50% of the coastal lands face different degrees of inundation, thus limiting their effective use (SRDI, 2012).

[7] Introduction of brackish water for shrimp cultivation, lack of maintenance and faulty management of the sluice gates and polders are some of the contributing factors.

[8] While soil salinity is relatively less difficult to manage (Kabir et al. 2011), water salinity is not. Naturally, rainfall contributes to leach salt from soil surface but in dry season when rainfall is insufficient, the artificial process or irrigation is needed. Sometimes, deep-water irrigation is also required.

even more difficult[9]. As a result, most farmers can cultivate at best one crop within embankment and polder areas with only a few able to grow two or more crops. Irregular rainfalls, introduction of brackish water for shrimp cultivation, faulty management of the sluice gates and polders and tidal water flooding in unprotected areas are the main causes of increased soil salinity in the topsoils of the coastal region. The withdrawal of fresh river water from upstream simply adds to the problem. Even with all these restrictions, agriculture still remains the mainstay of the CZ economy contributing 27.6 percent to GDP and providing employment for more than 35% of the total labour force.

The main source of water for irrigation at present is surface water, although that is progressively shrinking in availability because of increasing withdrawal of fresh water from upstream, shortage of water in canals and ponds, expansion of shrimp cultivation and increasing water salinity especially in the dry season when available water can become unusable**.** Ground water for irrigation use, potentially extracted by shallow and deep tube wells (STW, DTW), is currently very limited in the coastal areas. A main reason is that the water extracted can be saline[10]. Additional to salinity, as field investigation reveals, STWs/DTWs are not workable in a few areas because of lower water table in the dry season. The primary reason that around 700,000 to 800,000 ha of agricultural land remains fallow in the Rabi (dry) season is because irrigation resources are very limited due to the general unsuitability of the area for deep and shallow tube wells (Khan and Afroz 2011b). Agricultural labourers largely become unemployed in lean seasons.

SERDI (2012a) observed existence of extremely inequitable distribution of land resources in some of the villages, where almost one-third of households do not own any agricultural land. The rich farmer households have twice as much or more land compared to other farm household types, but unfortunately the land is not productive due to climatic hazards and lack of fresh water for irrigation.

8.8 Current agricultural and livelihoods practices

8.8.1 Population exposed to salinity

More than five million people in the southern coastal districts are already exposed to high salinity (>5 ppt) (IWM & CEGIS, 2007) with people in Satkhira, Khulna and Bagerhat being at highest risk (Table 8.10). The population that will be at high risk following a predicted 26 cm sea level rise in 2050 is projected to be around 12 million (IWM& CEGIS, 2007).

8.8.2 Salinity Level with Implications for Agriculture

Since this project is related to agriculture it is worth examining soil salinity level critical to agriculture (Table 8.11). Soil salinity levels up to 4 dSm^{-1} are reported to have only small impacts on agriculture while 4 to 8 dSm^{-1} is generally unfavourable. Higher levels cause major problems (Table 8.11). However, this varies from crop to crop. Some crops are more tolerant to salt and some are less.

8.8.3 Seasonal calendar in coastal zone

As elsewhere in Bangladesh, there are three crop seasons in coastal areas (Table 8.12): Rabi season (dry season) nominally starts from mid-October and lasts up to mid March; *kharif I* (pre-monsoon) season starts from mid-March and lasts up to mid-July; *kharif* II season starts from mid-July and last up to mid October. Broadly, Rabi season crops are

---

9 In fact, people face risks in almost all their livelihood options, be it in agriculture, fisheries or livestock due to natural disasters, diseases and pests (Khan and Afroz 2011a).

10 At present, 17% of STW/tube wells water has EC > 2 dS/m; 50% of DTW/tube well water possess > 2.0 dS/m (SRDI, 2012).

Boro rice, wheat, potato, pulses, oil seeds and vegetables. The major crops grown approximately in *kharif I* season are jute and maize. In kharif II season, T Aman is the major crop.

Table 8.10 Population exposed to salinity (data not available for all districts)

District	Population exposed to salinity (000 and %)	
	High level (>5 ppt)	%
Bagerhat	390	7.2
Barguna	150	2.8
Barisal	2	-
Bhola	242	4.5
Feni	65	1.2
Khulna	1,507	27.9
Lakshmipur	64	1.2
Noakhali	406	7.5
Patuakhali	170	3.1
Satkhira	2,415	44.6
CZ	**5,411**	**100.0**

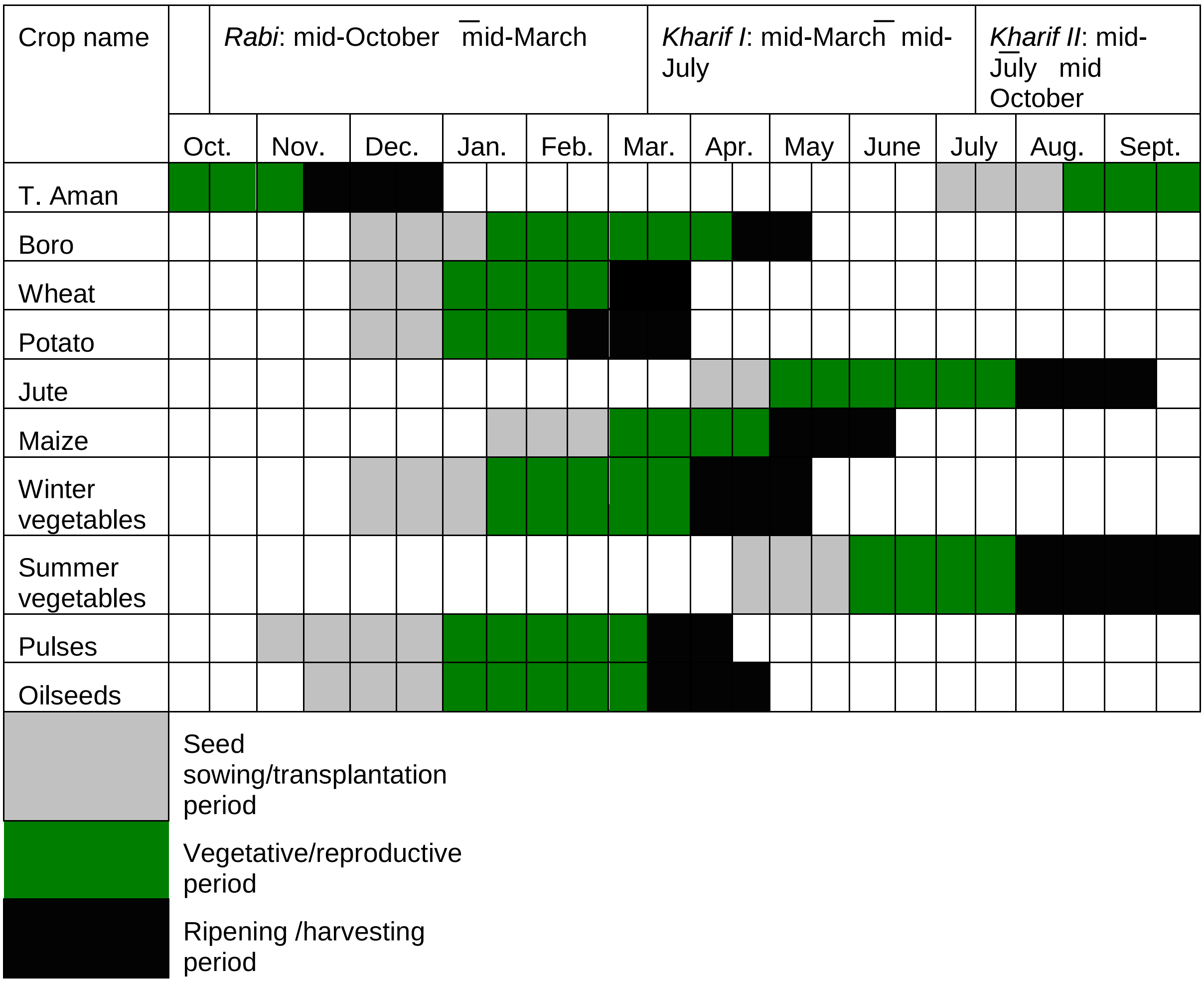
Note: Data refer to 2005. Source: IWM & CEGIS 2007

Table 8.11 Salinity level with implications for agriculture

Classification	Level of soil salinity (dS/m)	Implications for agriculture
Non Intrude	No soil salinity	Favourable for agriculture
Non saline	0-2	Favourable for agriculture
Slight salinity	2-4	Favourable for agriculture
Small salinity	4-8	Unfavourable for agriculture
High salinity	8-16	Very unfavourable for crop and livestock agriculture but favourable for brackish water fish culture
Very High salinity	>16	Not favourable at all for crop and livestock and agriculture but strongly favourable for brackish water fish culture

Source: BCAS (2011) and Soil Resources Development Institute (SRDI) (2012).

Table 8.12 Seasonal calendar in coastal Bangladesh



8.8.4 Current agricultural practices

Agricultural land by types

The height of agricultural lands has considerable implications for irrigated crop cultivation. Around 7.5 % of lands in CZ are highland compared to 35.5 % at the national level (Appendix C, Table C.10). Medium level lands constitute about 86.7 % in the CZ compared with 54% nation-wide while low-lands in the CZ make up 5.8 % (10.3% nationally). More data on this are presented and discussed in Chapter 6.

Distribution of farm and non-farm holdings

There are around 3.6 million farm holdings (23.9%) in the CZ as against 15.1 million in the country (Appendix C, Table C.11, 2008 data). Non-farm holdings number nearly 2.1 million as against 13.5 million nationally. In terms of total farm and non-farm holdings, farm holdings constitute 63.5% and the remaining 36.5% as non-farm holdings in the CZ. The corresponding percentages at national level are 52.9 % and 47.1 % respectively. The average area operated per holding is around 0.88 acre as against 0.82 acre nationally (Appendix C, Table C.12).

Land use pattern and irrigated areas

Land use patterns and current cropping systems have been discussed in detail in Chapter 6. Irrigated area in the coastal zone is also significantly less compared to the rest of the country as discussed in detail in Section 5.9 of Chapter 5.

Traditional practices and choice of crops

The choice of crops to grow largely follows tradition. Farmers are conservative preferring to follow familiar practices. They need no technical advice and use their own stored seeds thus saving money. They choose crops that first and foremost provide them with food security; only after that, they diversify into crops with considerations of profit (Khan and Afroz, 2011a). Crop choices also depend on natural capital. Where water is plentiful, Boro is an obvious choice; when it is limited, other crops are considered. As climate changes and natural capitals change with them, crop choices also change to ensure their livelihoods[11]. But the owner farmers with their greater capital flexibility are in a better situation. There are some indications that less wealthy farmers may be diversifying into other ways of collecting capital to supplement their basic farming activities (Khan and Afroz 2011a). There is a perception that some areas are risky for wheat because local kharif rice varieties can be of long duration thus delaying sowing of wheat beyond the date considered optimal (mid December, Saifuzzman et al., 2011). Additionally, late drainage of monsoon waters in some areas can delay the start of cultivation; and cultivation is slow particularly for farmers who still use bullock drawn ploughs (Khan and Afroz, 2011b)[12].

Crop yields

Table 8.13 compares the average yield of most crops grown in the coastal zone with the country average. Average yield of crops, in general, and rice crops, in particular, are at much lower levels compared to that of both non-coastal zone and the country as a whole. As can be seen from the Table 8.13, the yield rate of Aus in the CZ (1.59 tonne/ha) is lower than that of the overall national figure (1.74 tonne/ha). Similarly, the CZ yield rates of Aman (1.89 tonne/ha) and Boro (3.79 tonne/ha) compare unfavourably (13% and 2% less) with those of the national estimates, 2.16 tonne/ha and 3.84 tonne/ha respectively (Figure 8.4). Most other crops such as wheat, pulses, sugarcane and oilseeds have relatively lower yields.

Use of mechanised equipment

Currently, the number of tractors and power tillers (either owned or hired) per 10,000 farm holdings is 8 and 29 respectively as against 8 and 51 at the national level (Table 8.14)[13]. Interestingly and encouragingly, the proportion of use of threshing machines and mechanical seeders in the CZ is higher than in use nationally. Threshers particularly are seen as a critical part of farm efficiency. As machine use has risen in recent years, the reported use of draught animals per farm has declined across the country.

---

[11] Extreme soil salinity resulting from, among others, shrimp cultivation deters people from adopting crop diversification. It is encouraging, however, to note that in one of the two villages surveyed by (SERDI, 2012a) the level of adoption of agricultural techniques is considerable (SERDI, 2012a). Around 60 to 65% farmer households are now applying new fertilizers. They are also using modern agricultural technology like drum seeders to combat climatic hazards. In another village, many households build dwarf embankments around fields to protect them from saline water (SERDI, 2012a).

[12] The study also observed that the price of inputs like fertiliser is increasing and the seed cost of wheat is higher than that of any other crop because of scarcity. As such, many farmers cannot afford to grow wheat. This demand for providing subsidies on inputs. The study also suggested making farmers aware of the advantage of rotations including wheat (Khan and Afroz, 2011b).

[13] Business in tractors and power tillers has flourished in some areas as, for example, total recovery time of capital investment in a STW (shallow tube well) is now only around 3 years.

Table 8.13 Yield of major crops

Crops	Coastal zone (tonne/ha)	Coastal zone price (TK/tonne.)	Non-coastal zone (tonne/ha)	Country average (tonne/ha)
Local Aus	1.22	-	1.08	1.17
HYV Aus	1.99	-	2.06	2.03
Total Aus	**1.59**	-	**1.84**	**1.74**
B. Aman	1.17	-	1.20	1.19
T. Aman	1.59	-	1.58	1.58
HYV Aman	2.40	16990	2.51	2.49
Total Aman	**1.89**	-	**2.26**	**2.16**
Local Boro	1.58	14420	2.10	**2.00**
HYV Boro	3.67	NA	3.75	**3.74**
Hybrid Boro	4.60	12760	4.72	**4.70**
Total Boro	**3.79**	-	**3.85**	**3.84**
Total Rice	**2.46**	-	**2.94**	**2.82**
Wheat	2.22	17270	2.41	2.40
Pulses	0.86	48590	0.96	0.92
Oil seeds	2.07	33490	2.51	2.40
Sugarcane	32.87	-	38.75	38.22
Jute (bales)	12.71	26910	12.14	12.23
Summer vegetables	9.28	12780	5.09	5.70
Winter vegetables	7.37	11470	8.35	8.15

Note: All price data refer to 2009-10. Yields refer to 2009-10.
Source: Yearbook of Agricultural Statistics (BBS, 2011a).
Summer vegetables: Arum, Karalla, Lady's finger, Puisak, Culkumra, patal, chinchinga, chalkumra
Winter vegetables include cabbage, pumpkin, beans, brinjal, radish, water gourd, tomato, kumra and cauliflowers

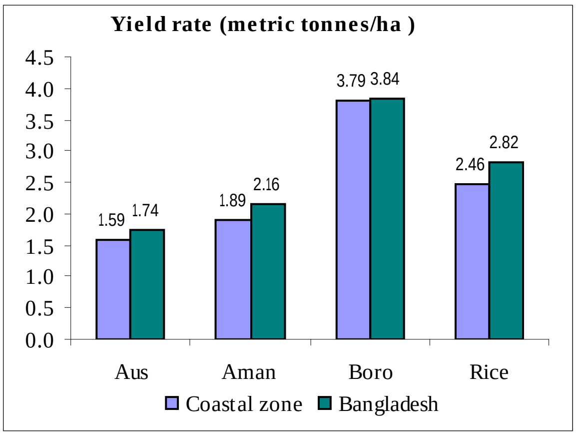


Figure 8.4 Comparison of yield of rice

Table 8.14 Number of agricultural machines used

Districts	No. of holding	No. of agriculture machines used				Use per 10,000 holdings			
		Tractor	Power tiller	Thresher	Seeder	Tractor	Power tiller	Thresher	Seeder
Bagerhat	339,217	391	853	1584	210	12	25	47	6
Barguna	201,929	145	1111	1144	40	7	55	57	2
Barisal	482,075	336	893	4648	893	7	19	96	19
Bhola	347,515	137	1014	1559	720	4	29	45	21
Chandpur	461,192	801	526	13591	1613	17	11	295	35
Feni	237,575	348	350	16184	796	15	15	681	34
Gopalganj	230,494	153	906	2488	45	7	39	108	2
Jessore	591,030	207	3804	38409	647	4	64	650	11
Jhalokathi	133,204	59	392	292	15	4	29	22	1
Khulna	502,835	227	1189	3594	61	5	24	71	1
Lakshmipur	332,818	254	363	5065	510	8	11	152	15
Narail	151,052	99	1279	15344	98	7	85	1016	6
Noakhali	544,943	693	1117	19092	2128	13	20	350	39
Patuakhali	323,502	230	343	569	614	7	11	18	19
Pirojpur	243,057	95	451	975	44	4	19	40	2
Satkhira	436,178	373	1874	7733	128	9	43	177	3
Shariatpur	225,523	143	395	1914	190	6	18	85	8
CZ	**5,784,139**	**4691**	**16860**	**134185**	**8752**	**8**	**29**	**232**	**15**
Bangladesh	**28,695,763**	**23694**	**146331**	**626658**	**30522**	**8**	**51**	**218**	**11**

Source: Own estimates based on BBS-Agricultural Census 2008 (BBS, 2011c)

Trends in agricultural crop area and production

Trend estimates for data available for 2008-09 and 2009-10 show that, in the CZ districts, Aus (local & HYV), HYV Aman and Local Boro have declined both in terms of acreage and production (Tables 8.15 and 8.16). For B. Aman and Boro (Hybrid & HYV), both acreage and production have increased indicating that farmers might be converting over from transplanting Aman, a very time consuming and labour intensive process, to broadcasting their seed. Regardless of the reason, rice production in the CZ increased by 3.6%, more than nationwide (2.1%). Wheat and jute declined in both acreage and production between 2008-10.

Table 8.15 Trend in agricultural crop area: coastal zone and Bangladesh 2008-2010

Crop	Rice cropped area (ha)					
	Coastal zone			Bangladesh		
	2008-09	2009-10	% change over previous year	2008-09	2009-10	% change over previous year
Local Aus	228,212	209,750	-8.09	375,934	336,785	-10.41
HYV Aus	225,972	216,426	-4.22	689,569	647,267	-6.13
Total Aus	**441,502**	**414,558**	**-6.10**	**1,065,503**	**984,052**	**-7.64**
B. Aman	102,342	129,883	26.91	403,132	475,529	17.96
T. Aman	787,665	331,437	-57.92	1,393,491	1,414,180	1.48
HYV Aman	732,290	710,608	-2.96	3,700,777	3,772,896	1.95
Total Aman	**1,531,297**	**1,558,271**	**1.76**	**5,497,400**	**5,662,605**	**3.01**
Local Boro	22,863	20,300	-11.21	122,168	107,329	-12.15
HYV Boro	586,329	639,067	8.99	3,780,323	3,913,750	3.53
Hybrid Boro	128,914	129,923	0.78	813,755	685,796	-15.72
Total Boro	**901,199**	**932,237**	**3.44**	**4,716,247**	**4,706,875**	**-0.20**
Total Rice	**2,873,998**	**2,905,066**	**1.08**	**11,279,150**	**11,353,532**	**0.66**
Other crops area (ha)						
Wheat	27,917	23,551	-15.64	394,612	376,256	-4.65
Pulses	94,947	96,058	1.17	226,393	240,139	6.07
Oil seeds	84,376	71,119	-15.71	485,647	297,856	-38.67
Sugarcane	10,452	10,627	1.67	126,266	117,505	-6.94
Jute (bales)	69,808	62,322	-10.72	420,473	416,346	-0.98
S. vegetables	36,582	36,573	-0.02	173,094	253,710	46.57
W. vegetables	38,734	39,184	1.16	183,825	190,794	3.79

Source: Own estimates based on BBS-Agricultural Census 2010 (BBS, 2011a)

Table 8.16 Trend in agricultural production: coastal zone and Bangladesh 2008-2010

Crops	Total production coastal zone (m. tonnes)		% changes over previous year	Total production Bangladesh (m. tonnes)		% changes over previous year
	2008-09	2009-10		2008-09	2009-10	
Local Aus	273,087	256,744	-5.98	446,576	393,434	-11.90
HYV Aus	462,987	430,217	-7.08	1,447,981	1,315,693	-9.14
Total Aus	**706,625**	**660,937**	**-6.47**	**1,894,557**	**1,709,127**	**-9.79**
B. Aman	112,437	152,182	35.35	**461,528**	566,792	22.81
T. Aman	1,140,448	528,372	-53.67	**2,077,071**	2,236,737	7.69
HYV Aman	1,752,661	1,706,026	-2.66	**9,074,570**	9,403,633	3.63
Total Aman	**2,792,931**	**2,939,827**	**5.26**	**11,613,169**	**12,207,162**	**5.11**
Local Boro	41,364	32,119	-22.35	217,544	214,550	-1.38
HYV Boro	2,155,673	2,347,194	8.88	13,866,302	14,622,485	5.45
Hybrid Boro	578,009	597,505	3.37	3,725,205	3,221,927	-13.51
Total Boro	**3,386,985**	**3,535,341**	**4.38**	**17,809,051**	**18,058,962**	**1.40**
Total Rice	**6,886,541**	**7,136,105**	**3.62**	**31,316,777**	**31,975,251**	**2.10**
Other crops						
Wheat	61,624	52,337	-15.07	849,046	901,490	6.18
Pulses	75,412	82,274	9.10	196,071	220,786	12.61
Oil seeds	136,522	147,199	7.82	661,312	716,171	8.30
Sugarcane	288,414	349,279	21.10	5,232,649	4,490,812	-14.18
Jute (bales)	812,330	792,058	-2.50	4,677,740	5,089,728	8.81
Summer vegetables	388,380	339,445	-12.60	1,440,069	1,445,162	0.35
Winter vegetables	280,703	288,951	2.94	1,468,418	1,555,271	5.91

Notes and source: Own estimates based on BBS-Agricultural census 2010 (BBS, 2011a)

Polder management and water management

Over the last four decades, 123 polders covering an area of about 13,000 km^2 have been constructed (Islam, 2011) with a view to increasing agricultural production through reducing flood damage and protecting the land from salinity intrusion. The polders currently consist of about 5,000 km of embankments, 6000 km of drainage channels and 2500 water control structures. The grand purpose of the polders has not been fully realised for many reasons. Shrimp and salt farming achieved through intentional saline water intrusion has undoubtedly caused great harm to agriculture and the environment, as well as creating social conflict in the coastal region[14]. Inaction of concerned national and local departments has generally added to these dreadful conditions and deprivations.

[14] It is, however, noted that shrimp cultivation has also some significant positive effects through generating huge linkage activities. This may be a good issue to be pursued in any future research.

Water logging is a major concern for the coastal farmers[15]. It is revealed that waterlogged areas have significantly increased from 62,000 ha in 1975-76 to 148,000 ha in 2008-09 due to seasonal submergence, tidal surges, increased roads and embankments, faulty sluice gates, and increased shrimp culture (BCAS, 2010). Most of the embankments, along with their sluice gates now need to be redesigned, matched to changed objectives and conditions, particularly in respect of global warming and climate change (O'Donnell et al., 2012)[16]. Careful water management is then essential to get optimal results from the huge investments in polders.

In short, the following are seen as bottlenecks to achieving the original purpose of fully functioning polders:

(1) Terrible physical conditions of particularly coastal polders

(2) Conflicts among land users (farmers, shrimps and salt production)

(3) Status of operation and maintenance (O & M) – lack of coordination and transparency

(4) Lack of funds for O & M

(5) Lack of attention on the part of policy makers

(6) Vulnerability to natural hazards

(7) Redesigning needs due to global warming and climate change

8.9 Potential benefit of cropping intensification

This section deals with potential benefit of cropping intensification to revitalise the agriculture of the polders through water management.

Potential benefit has been assessed along with the activities associated with potential economic benefit, social benefit, environmental benefit and livelihood benefit of agricultural (cropping) intensification. In assessing social and environmental benefits, one needs to consider agriculture, fisheries, employment, poverty reduction and gender development.

Agricultural outcome has been assessed through including aspects such as cropping pattern, cropping intensity and crop yield. The analysis that follows is largely based on some broad **assumption without proper adoption analysis** (due to lack of budget and time) and represents **direction of change rather than specific values for the potential changes** due to the proposed project. A more robust analysis will be done while preparing the project proposal.

The section also discusses some disadvantages that are likely due to the project.

8.9.1 Economic benefits

Benefits estimation - procedure and assumptions

At the very outset, a broad methodology along with important assumptions is in order. The analysis considers 2010-11 as the base year. The major dry-season crops considered are Boro rice (HYV and Hybrid), wheat, pulses, oilseed and vegetables. The cropping intensities for 2008-09 are 163.0 and 172.5 for the coastal zone and for Bangladesh as a

[15] In coastal area, most rainfall occurs in July and August when most of the land operations are done. During this period, there should be provision for adequate number of sluice gates in the embankment system to remove excess water and also to prevent ingress of saline water during high tide.

[16] The existing terrible conditions of the polders and embankments in SW Bangladesh, especially after Aila and Sidr, can be mentioned.

whole. However, available information from other sources (BBS Statistical Yearbook) suggests the national cropping intensity to be 182% in 2008-09. Based on historical information, one can assume an average annual 'autonomous' increase in cropping intensity by 1 percent for CZ zone and 1.5 percent for the national scenario. On this basis, one can estimate cropping intensity to be 166.3 for the CZ and 187.5 for the country for 2010-11. The national figure is projected to be 200.0 in four years time. Hence, the analysis assumes that a national level cropping intensity (200.0) will be reached in the CZ in 10 years time due to the proposed agriculture intensification project.

In order to get a ready and approximate figure, the increase in cropping intensity is assumed to have an impact on only rice (Boro), wheat and other dry-season crops. Boro rice (including Hybrid type), wheat and pulses/oilseeds/vegetables are considerably overlapping for some of the varieties and for some of the land types in one particular year. So, increased cropping intensity applies primarily to Boro, wheat and to some of the pulses/oilseeds/vegetables. Sugarcane is a perennial crop so that this is excluded from the analysis. And so is jute as it a wet-season crop. Substantial quantity of vegetables are also cultivated in summer so that they are also benefited if dry season agriculture intensification takes place through provision of irrigation and extension services, for example. The negative impact on Aus and Aman, if any, is considered insignificant in this brief analysis. The impacts on wet season crops (e.g. jute) and perennial crops (e.g. sugarcane), if any, are also not considered. There will be an increase in cropping intensity any way as an 'autonomous' growth and also due to various interventions that already exist in the benefited areas, which is, however, also not without costs. So, this is not considered in this analysis. Prices of crops are collected for 2009-10 (Table 8.13); hence they are converted to 2010-11 prices on the basis of a flat food-price inflation of 10 percent[17].

Potential impact on production

Following potential increase in cropping intensity and crop yield due to the proposed agriculture intensification project there will be a positive change in production. Average yield of crops, in general, and rice crops, in particular, may also increase[18]. So will output. As can be seen in Table 8.17, based on potential acreage increase and existing yield rates (Table 8.13) the proposed project is expected to create additional annual production in Boro rice to the extent of 259 and 61 thousand metric tonnes for hybrid and high yielding variety (HYV) respectively in a decade. The increased annual production of wheat will be in the range of 185 thousand tonnes, for pulses will be in the range of 8 thousand metric tonnes and that for oilseeds in the range of 15 thousand metric tonnes. The vegetables are expected to experience an additional annual production to the extent of nearly 31 thousand tonnes. Thus, the additional production by crops gives us the net returns (gross production net of costs) for each type. The net returns for Boro rice (both varieties) will be in the range of TK 807 million (about $10 million) per annum; for wheat this will be in the range of Tk 669 million ($8 million) . The oilseeds, pulses and vegetables are expected to generate annual net return of TK 345 million ($4 million), TK 294 million ($3.5 million) and TK 66 million ($0.8 million), respectively. In total, the proposed agriculture intensification project at the end is likely to generate annual economic benefits worth TK 2,180 million (over $26 million). In ten years, economic benefits worth TK 21,800 ($260 million) will be generated, which is equivalent to 0.3 percent of (2010-11) national GDP and 2.1 percent of (2010-11) coastal GDP[19].

[17] Food price inflation for the reference period was between actually 8 to 14 percent.

[18] To be on the safe side, the potential increase in crop yields has not been incorporated in this preliminary analysis (sort of a sensitivity analysis).

[19] The national and coastal GDPs were TK 7875 Billion and 1118 Billion respectively (2010-11 price)

The increased production level, if achieved, will contribute significantly to food security of the whole country. In order to attain this, however, there are several pre-requisites. One of them, among many, is quality irrigation water, which has to be made available[20]. Dissemination of the knowledge and opportunities for Rabi season cropping among farmers is essential. Apart from such knowledge extension, it is important that the systems to support the uptake of the new technologies are in place. Because, "local systems that supply seed for the new adapted varieties require development, as well as farmers' access to the required inputs and necessary finances are needed to complete the agronomic package" (Carberry, 2011)[21].

Table 8.17 Preliminary estimates of annual economic benefits generated by increased agricultural activities

Major dry-season crops	Estimated Area under dry-season crops (ha) 2010-11	Area under crops at the end of the Project (ha)	Potential increase in production (tonnes) per annum	Annual value addition (Million.TK at 2010-11 price)	Annual Net Return (Million TK at 2010-11 price)
Boro Rice					
HYV Boro	348,259	418,833	259,005	3,045.9	623.5
Hybrid Boro	65,468	78,745	61,074	779.3	183.1
Wheat	413,728	497,568	184,472	3,214.8	668.5
Pulses	97,182	107,029	8468	411.5	293.7
Oilseeds	70,002	84,188	14,683	490.0	344.5
Others (incl. winter vegetables)	36,575	43,987	30,852	342.9	66.4
All				8,894.9	2,179.7

Note: Currently 1 AU$ = 83.00 TK

In this context, a few field observations (from FGDs) can be mentioned here. It is revealed that currently, apart from salinity problem, DTWs and even the STWs are often not workable because of lower watertable. Rice cultivation is not profitable at all but is grown only for subsistence. In contrast, sunflower, potato (storage facilities needed), pulses, peanuts and wheat are proved to be much more profitable. The cultivation of maize is

[20] During FGDs, local farmers generally observed that presently one crop is cultivated in areas outside embankments and polders, and it is not difficult to cultivate three crops within embankments providing irrigation water, inputs and adequate extension services are available. It is also revealed that where there are farmers associations, improved support from agriculture extension workers and NGOs both within and outside embankments is feasible. But adequate number of sluice gates with their proper operations are needed. During monsoon salinity levels are tolerable but during the period between the month of January and June salinity level becomes acute.

[21] An observation during FGDs (Khulna and Bagerhat), however, indicates that the inputs costs (fertilizers, water etc) were so high and output price was so low this year that the farmers will give a second thought to whether or not they will grow paddy on their lands next year. Relevant studies (e.g.,SERDI, 2012b) maintain that there are two options open to the authority concerned : one, the input costs have to be reduced through some mechanism (e.g., subsidy); and the other, to ensure that they receive fair prices for their produce so that farmers do not have to incur losses from paddy cultivation.

increasing sharply to meet huge demand for poultry. Farmers categorically suggested that water logging within the polders is a major concern. Canals and ponds digging can be more effective for both irrigation, and domestic use. As chemical fertilizers are reportedly causing a decline in fertility farmers are increasingly using compost fertilizer. Currently, some NGOs are active in providing training on compost fertilizers; farmers have found this training very effective. Occasionally farmers have experienced problems with growing seeds from the market, without any endorsement and field tests from the proper authority. Recently, a large number of farmers in the costal districts incurred huge losses by using BADC-supplied adulterated Hybrid/HYV seeds (Islam, 2012). So the water logging problem has to be addressed and dissemination /demonstration regarding CC-tolerant crops and seeds have to be improved.

Employment and livelihood benefits

The proposed agriculture intensification is expected to generate substantial additional employment in the agriculture sector. As suggested earlier, the enhanced cropping intensity is expected to annually create increased cultivated area under crops – rice (Boro), pulses, oilseeds and vegetables. In total, more than 188 thousand hectares of additional lands are expected to be under extra cultivation per annum (Table 8.17). Annual employment generated by increased agricultural activities, by cropping and hired/family labour has been estimated and presented in Table 8.18. For hired and family labour, coefficients from a national input-output table prepared by BIDS (1998) are used[22]. Person days used in the cultivation of individual crops are taken from various studies conducted by BIDS (1998) and Islam et al. (2009)[23]. These indicate that the extra direct employment generated annually due to increased agricultural activities in the coastal zone is in the range of 27.3 million person-days.

Of the total incremental agricultural employment, 16.2 million (or 59.3%) person days will be as hired employees and 11.1 million (or 40.7%) person days as family labourers. Of this, 3.3 million (or 29.8%) person days will be used by family workers working on small farms, and the remaining 7.8 million (or 70.2%) person days will be used by family labourers working on large farms. It is estimated that approximately 9.8 million person days are likely to be taken up by women labourers[24].

Of the 27.3 million annual person-days generated by increased agricultural activities at the end of the project, more than 90 percent will be created from rice cultivation alone, followed by 4.1 percent by pulses, 3.0 percent by oilseeds and 2.6 percent by other crops (including vegetables). Assuming the project life to be ten years, employment benefits worth 273 million person-days will be generated during the project duration.

It may be argued, however, that not all the increment will be due to the proposed project, as some autonomous growth will always take place. In the case of cropping intensity, the increase in rice yield would be partly attributed to a switch to HYVs and increased use of inputs given higher extent of extension services to be provided[25]. However, extra employment due to intensive Rabi season crop production is likely to provide food and livelihood security to landless labourers, including women and children, with an alternative

---

22 See BIDS (1998): An Input-output Table for Bangladesh Economy, 1993-94

23 See Quasem (1999): Maize Production and Marketing in Bangladesh: An Indicative Exercise, BIDS-IFPRI, 1999 ; BIDS-ESGKF Survey, 1994; Islam et al. (2009). Benefit Monitoring and Evaluation (BME) Study, BIDS.

24 According to Labor Force Survey data (2010), the coefficient for women participation to total labor force is 0.36.

25 Risk of crop failure or higher losses due to flooding or natural hazards, however, is likely to dampen such efforts.

to seasonal migration and less preferred livelihood strategies, as also observed by Khan and Afroz (2011a).

Case of water not available and no Boro growth assumed

If the required irrigation water is not available for Boro expansion, the economic benefits in terms of employment generation are drastically reduced. This is mainly because of high labour requirements of Boro for transplanting, and harvesting. Considering "no Boro growth" but assuming equivalent higher growth of other Rabi crops[26]**,** it is estimated that the extra direct employment annually generated due to increased agricultural activities in the coastal zone is in the range of 5.3 million person-days.

Potential disadvantages

Finally, the project is likely to have disadvantages as well, in terms of employment to communities such as fishermen and perhaps boatmen. Many of these disadvantages, however, are likely to be offset by the generation of extra employment due to linkage effects through absorbing such displaced employment.

Table 8.18 Preliminary estimate of annual additional employment generation by increased agricultural intensification

Major crops	Annually increased area under crops at the end of the Project (ha)	Annual additional employment generation at the end of the Project (million Person days) (1)			Total employment generation at the end of the Project (million person days per annum) (2)
		Hired	Family		
			Small farm	Large farm	
Rice (Boro-Hybrid+ HYV)	167,701	14.78	2.95	6.92	24.65
Pulses	9,847	0.57	0.14	0.41	1.12
Oilseeds	7,093	0.43	0.11	0.27	0.82
Others (incl. vegetables)	3,706	0.42	0.11	0.19	0.72
All	188,347	16.2	3.31	7.79	27.31

(1) For hired and family labour (small and large farm), coefficients used from national Input-output Table prepared by BIDS (1998) (An Input-output Table from Bangladesh Economy, 1993-94)

(2) Person days used by various crops are taken from various studies conducted by BIDS (1998; 1999): (Quasem M A: Maize Production and Marketing in Bangladesh: An Indicative Exercise, Quasem, 1999; Rahman and Shaha, 1994; Islam et al (2009). Benefit Monitoring Study, LGED, BIDS

8.9.2 Livelihood enhancement, poverty reduction and linkage effects

Linkage effects

Increased employment generation through increased agricultural activities will enhance livelihoods. Besides, increased agricultural activities are expected to increase processing industries particularly food processing, small industries and other non-farm activities (which are more labour intensive) as employment output elasticity of such activities is quite high (e.g., 0.75) (Islam and Islam, 2012).

[26] Reportedly, in Bagerhat (Saranknola) Pulses like Khesari, Kalai, Mung do not need much water, only good moisture is good enough.

Benefits to livelihoods of non-poor and poor

A higher proportion of the non-poor beneficiaries belonging to higher landholding categories are likely to reap relatively higher output benefits. Considerable benefits are likely to be accrued by marginal and small farmers in the form of increased agricultural production. More importantly, a larger part of the employment is likely to go to the hired agricultural labourers, small and marginal farmers through increased cropping activities. Obviously, this is likely to contribute to reducing the severity of poverty, if not its incidence, in terms of increased income and improved quality of life.

Migration

SERDI (2012a) observed that particularly poor and landless people migrate to other places for work as there is very limited work opportunity for people within the surveyed CZ villages due to high soil and water salinity. The proposed project is likely to reduce the rate of migration, as they will have more opportunities to work as wage labourers in the fields due to increased cropping activities.

8.9.3 Gender and development

Women employment and empowerment

Women will be affected by the proposed project in several ways. They are likely to have direct additional employment as agricultural wage labour, and in jobs relating to seedbed preparation, due to increased cropping intensity or rise in output. Besides, they may have opportunities in income generating activities such as poultry raising, livestock keeping and non-farm activities

Having an income of their own may entail other changes such as their independence of action, through bringing about empowerment in terms of decision-making power and social mobility (Sultana, 2011). Their quality of life will eventually change positively.

If crop intensification is achieved through water conservation, and more use of surface water, this could help women by reducing the distance to fetch water for domestic use and for home gardening, as well as expanding opportunities for seedbed production.

Women and livestock

The proposed project is aimed at horizontal and vertical expansion of crop cultivation. This is likely to have some negative impacts on livestock production, which is largely carried out by women, and fisheries, through reduction of pasturelands and wetlands respectively. However, as farmers from Sarankhola in Bagerhat observe, the reduction of pasture lands is likely to be largely offset by increased availability of straw and other by-products for animal feed through increased cultivation of rice and other crops. This will provide animal manure for compost production.

In order to surmount the problem relating to reduction of grazing lands for livestock, newly accreted lands/char lands can be leased out to the poor community living on livestock and vegetables (instead of leasing to local elites and the richer section). The proposed project can also include activities to increase cultivation of cattle feeds such as improved Napier grass in the char lands.

Regarding fisheries, water bodies are an important natural resource for both farmers and fishermen. The crop intensification activities are likely to reduce fish stocks and capture. However, digging canals and ponds will not only increase availability of cheaper irrigation water but also will lead to more fish culture and domestic water use through PSF techniques.

As also observed by SERDI (2012a, 2012b), based on a survey of two villages in CZ, modern farming methods have decreased soil fertility leading to a decline in the number of livestock due to poor growth of grass for the animals to feed on.

8.10 Environmental impacts

Obviously, increased agricultural production requires increased irrigation water and this must be timely. Is it to be accessed as surface water or through groundwater extraction? The two have different implications.

The water bodies or wetlands will be under threat due to increased use of inputs such as chemical fertilizers, pesticides and other chemicals, which will harm the natural fishery. This is a likely concern for environmental impacts of the proposed project.

Fish cultivation in rice fields will be affected due to increased use of harmful fertilizers and pesticides. The proposed agriculture intensification may be followed by mechanical ploughing which may destroy beneficial soil fauna.

Over- extraction

Apart from the likely indirect impact of the project on increased pesticide use, over-extraction of ground water could lead to arsenic contamination that is already a problem. Over-extraction of groundwater would also reduce surface water flow, increase water salinity, and salinity intrusion into rivers and wetlands. Over extraction from DTWs may pose additional concerns. Further lowering of the water table due to over abstraction might result in aquifer contamination by both salinity and arsenic and this would be disastrous. However, increased collection and use of surface water are not expected to produce such adverse impacts.

8.11 Barriers for cultivators to undertake crop intensification

In rural Bangladesh, where agriculture is still the predominant activity, the impact of any land or water infrastructure improvements may immediately lead to greater adoption of modern high yielding variety (HYV) technology through the provision of increased irrigation and improved overall farm management methodologies led by farm extension services. However, as relevant studies (e.g., Islam et al., 2009) suggest, the increased adoption of modern technologies is likely to result in unequal income distribution among the poor and non-poor; modern technologies are relatively more capital intensive than traditional methodologies. The poor generally have little or no access to capital (Khan et al., 2011). This has to be addressed while designing the proposed project.

From what has been discussed, the following issues might pose barriers directly or indirectly to cultivators who might want to undertake agriculture intensification:

- Lack of capital
- Lack of irrigation facilities
- Inequality regarding irrigation access
- Inadequacy and availability of extension service
- Timely availability of irrigation water
- Lack of availability of quality seeds at the time needed
- Lack of availability of quality fertilizers at the time needed
- Inadequate marketing facilities [currently, marketable surplus for HYV Boro is 61% (Islam et al., 2009), which is likely to increase when the proposed project is implemented]
- Lack of fair price for crops produced
- Lack of electricity/fuel when needed
- High price of agricultural inputs (seed, fertiliser, water, machinery)
- Groundwater over-abstraction
- Decline of soil fertility and arable lands

8.12 Conclusions

The coastal zone of Bangladesh, widely recognized as a 'neglected area', is backward, fragile and vulnerable, but also full of opportunities. The first benefit is the huge structures of the polders that potentially can be used to manage and harvest fresh water and minimise salinity leading to much greater agricultural productivity. The northern parts of the country do not have these water and salinity management assets. Around one-third of the country and its population are in the coastal environment making the zone a high priority for policy and program development. The institutional environment, however, is not favourable to the people there. Narrow departmental and sectoral approaches to coastal development have adversely impacted coastal resources and communities. This is followed by policy overlaps, lack of coordination, problems with planning and management and resource allocation. Lack of power of local government institutions, gender disparity and lack of people's participation are common problems with the prevailing institutional environment. These are some of the institutional and environmental issues that have to be taken care of while designing the agriculture intensification project.

Following backwardness of the coastal zone, cropping intensification is expected to have considerable socio-economic impacts towards poverty reduction of its people.

9 Past and current activities, constraints and opportunities

9.1 Initiative for the development of the coastal zone

The first major plan to develop the coastal zone was initiated by the Government of Bangladesh (GoB) in collaboration with the United Kingdom and The Netherlands through a three year project 'Integrated Coastal Zone Management Plan (ICZMP)' which started in 2002 under the Ministry of Water Resources. The goal of the program was to create conditions in which the reduction of poverty, development of sustainable livelihoods and the integration of the coastal zone into national processes can take place (MoWR, 2004).

The main outputs of the project were the development of a Coastal Zone Policy (CZPo); a Coastal Development Strategy (CDS); and a Priority Investment Program (PIP). Under the PIP, the project identified and prioritized the possible investment in the coastal zone to develop and improve social, institutional and physical infrastructure.

Coastal Zone Policy

The Coastal Zone Policy (CZPo) was promulgated in 2005 (MoWR, 2005) with the aim that it would provide a general guidance to all concerned for the management and development of the coastal zone in a manner so that the coastal people are able to pursue their life and livelihoods within a secure and conducive environment. The policy explicitly emphasizes the integrated development of the region with policy framework and enabling institutional environment. Under the Section 'Sustainable management of natural resources' the policy identifies the medium and long-term sustainable management of water and agriculture as follows:

4.4.2 Water

- *Adequate upland flow shall be ensured in water channels to preserve the coastal estuary ecosystem threatened by the intrusion of soil salinity from the sea;*
- *Small water reservoirs shall be built to capture tidal water in order to enhance minor irrigation in coastal areas. Appropriate water management system within the polder utilizing existing infrastructures will be established for freshwater storage and other water utilization;*
- *Rainwater harvesting and conservation shall be promoted;*
- *Ponds and tanks will be excavated for conservation of water and local technology for water treatment (such as, pond sand filtering - P.S.F.) will be used for the supply of safe water;*
- *Steps will be taken to ensure sustainable use and management of groundwater.*

4.4.5 Agriculture

- *Programs for intensification of agriculture and crop diversification for improving the economic conditions of both male and female farmers and increasing food security at local and regional level shall be supported;*
- *Special development programs will be taken-up with a view to increasing the production of crops suitable for the coastal area with attention to maintenance of soil health;*
- *Use of chemical fertilizers and pesticides will be reduced, while organic manure and integrated pest management will be encouraged;*
- *Salt-tolerant crop varieties will be developed and extended along with possible measures to resist salinity;*
- *The scope of irrigation facilities will be explored and / or extended and a comprehensive water management for agriculture will be implemented.*

Coastal Development Strategy

The Coastal Development Strategy (CDS) focuses on the implementation of the CZPo (MoWR, 2006). The CDS is the *linking pin* between the CZPo and concrete interventions.

It prepares for coordinated priority actions and arrangements for their implementation through selecting strategic priorities and setting targets (MoWR, 2006). CDS identified 9 strategic priorities, evolved through a consultation process, which should guide interventions and investments in the coastal zone:

- *ensuring fresh and safe water availability*
- *safety from man-made and natural hazards*
- *optimizing use of coastal lands*
- *promoting economic growth emphasizing non-farm rural employment*
- *sustainable management of natural resources: exploiting untapped and less explored opportunities*
- *improving livelihood conditions of people; especially women*
- *environmental conservation*
- *empowerment through knowledge management*
- *creating an enabling institutional environment*

Implementation of these strategic priorities contributes to poverty reduction strategy nationally and achievement of Millennium Development Goals (MDGs) globally. Ensuring fresh and safe water availability (in the context of regional water resources management) and sustainable management of natural resources are two of the nine strategic priorities of the Coastal Development Strategy which is linked with 7 out of 8 of the Coastal Zone Policy objectives (MoWR, 2006).

The coastal belt is recognized in the **Sixth Five Year Plan** (FY2011 – FY2015) (GoB, 2011) as one of the pockets of poverty that are lagging far behind with respect to the national averages and where the benefits of Millennium Development Goals (MDGs) attainment need to be specifically reached. In recognition of the substantial development challenges, recently the Government has embarked on a perspective plan covering FY11 to FY21 (GoB, 2010). The Perspective Plan strategies include among others pursuing Integrated Water Resource Management (IWRM), encouraging research and better technology management and greater use of surface water and rain water. The Plan also emphasizes monitoring the quality and quantity of groundwater through continuous surveys and investigation.

The coastal region is prioritised in the **MDGs**, as an area of "high vulnerability to natural disasters and persistence in severe poverty and hardship"; and, as pocket where "livelihood options are limited". The MDG target for the proportion of rural population with access to safe drinking water by 2015 is 96.5% and that with access to sanitary latrines is 55.5% (GoB and GoN, 2012).

Bangladesh Agricultural Research Council (BARC) being an apex body of the National Agricultural Research System (NARS) has taken up a task to prepare a **Vision Document on Agriculture for 2030 and beyond** (Hussain and Iqbal, 2011; Jahiruddin, 2010; Ziauddin and Ahmmed, 2010; Rahman and Chowdhury, 2010; Nasiruddin and Hassan, 2009). Identification of researchable issues under different sub-sectors of agriculture and their priority ranking as high, medium and low is the first step in undertaking R & D projects in agriculture. Development of new varieties of crops resistant to salinity, drought, water logging, adaptation of crops with soil amendment, nutrient and water management in different agro-ecosystems, water management strategies for reduction of soil salinity and water logging, water management strategies for irrigated crops due to climate change are identified as high priority research areas.

Due to the vulnerability of these areas to cyclone, storm surge and tidal inundation, salinity intrusion and water logging, the agricultural, livestock and aquaculture activities are at serious risk and need additional support. Considering these challenges, climate change vulnerabilities and unexplored potentials of the region, the Government of Bangladesh in collaboration with FAO has undertaken a task to prepare a comprehensive ten-year master plan (http://typo3.fao.org/fileadmin/user_upload/faobd/docs/Delta_Project/brief_on_Southern_Master_Plan.pdf) to provide a road map for an integrated development in the southern region of Bangladesh aiming at i) increased agricultural productivity and sustainable food security; ii) poverty reduction and iii) alternate livelihood development for the poor. The Master Plan will focus on emerging new potentials in the region, mainly i) technological breakthrough for increasing productivity- new varieties and breeds, plant and animal health systems, farmer groups, etc; ii) harnessing seasonal and occasional quality surface water availability for irrigation and iii) enhancement of agricultural productivity through increased cropping intensity, reducing post-harvest losses, modelling of climate events and options of crop diversification.

9.2 Major development projects

ICZM considered an integrated and decentralized approach as an important mechanism for addressing the growing water resources problems in the coastal regions and sub-regions. Relevant issues are siltation of rivers and drainage channels, drainage congestion, salinity intrusion and tidal river management. In view of the above, several development projects have been developed. Some of them are either implemented or under implementation. These are:

Strengthening Sanitation and Safe Water Supply Programs in Arsenic and Salinity Affected Areas (in selected 10 upazilas of the coastal zone). The overall goal of this project is supplying convenient arsenic and salinity free water and sanitation facility for the people in the coastal zone.

Groundwater Management in the CZ of Bangladesh. The objective of this study is to develop an Interactive Information System (IIS) including user-friendly maps and guideline for groundwater use based on hydro-geological investigation.

Integrated water resource management of Greater Noakhali. This project aims at comprehensive development of the rural area through infrastructure development and rationalizing the existing projects. The major activities would include water management, removal of drainage congestion, control monsoon flooding and saline water intrusion, strengthen safe and equitable access to water for production, health and hygiene, facilitate capture and culture fishery, strengthen agricultural development, promote stakeholder participation and multipurpose use of the embankments/bunds; and develop a long-term inter-district sustainable mechanism (structure and procedures) for IWRM of the area.

Integrated drainage improvement of tidal influenced southwest region of Bangladesh. The project aims at applying the Tidal River Management (TRM) technique developed and implemented successfully in the Khulna-Jessore Drainage Rehabilitation Project.

Development of coastal agriculture in Bangladesh. The aim, as the name suggest, is the development of coastal agriculture to improve sustainable livelihood and congenial environment.

Ensuring fresh and safe water availability (in the context of regional water resources management). The conditions of the water resources systems (WRS) in the CZ are a decisive factor for social and economic development. Lack of availability and access to safe drinking water is a major issue, reaching to a crisis level in the south-west. The reasons are reduced inflow of fresh water causing saline water intrusion, over-extraction of groundwater, and prolonged drainage congestion. This strategic priority calls for a blending of local knowledge with technical expertise for a sustainable use of the regional water resources systems through a participatory and partnership approach at all management levels. A better understanding and management of the groundwater aquifers are of crucial importance (MoWR, 2006).

To manage the precious water resources in the coastal zone, GoB has implemented (or under implementation) several projects. These are:

Integrated Planning for Sustainable Water Management (IPSWAM), a Bangladesh-Netherlands joint venture, was started in 2003 with the aim to introduce an integrated and sustainable water resources management with the participation of local people (BWDB, undated). The overall objective of the program was capacity building of the stakeholders. The program was implemented in 9 polders in Khulna, Patuakhali and Barguna districts and was completed in June 2011.

Southwest Area Integrated Water Resources Planning and Management Project was started in 2005 in the Southwest region of Bangladesh covering the districts of Narail, Jessore, Magura, Faridpur and Rajbari and rehabilitation of damages caused by Aila Storm in selected polders in Khulna & Satkhira districts with the objective to rehabilitate a total area of about 100,000 ha (http://www.southwest-bwdb.info/objectives.php). The activities of the project includes providing water management infrastructure, training the WMAs in monitoring civil works and strengthening internal technical audit, and providing extension services including campaign for improved nutrient management, field demonstration and training and workshops and farmer tours. The project is scheduled to be complete in December 2013.

Water Management Improvement Project (WMIP): The objective of the Water Management Improvement Project (WMIP) for Bangladesh is to improve national water resources management by involving the local communities to play an expanded role in all stages of the participatory scheme cycle management (World Bank, 2004). The project started in 2007 and concludes in 2015 (http://www.worldbank.org/projects/P040712/water-management-improvement-project?lang=en).

Blue Gold Program: Recently the Government of Bangladesh and the Government of the Netherlands developed a program for Integrated Sustainable Economic Development by improving the Water and Productive Sectors in selected Polders (GoB and GoN, 2012). Its operations will concentrate on the polders of Patuakhali, Khulna and Satkhira covering 160,000 ha and provide direct benefits to approximately 150,000 households. Under Blue Gold, the BWDB will create effective protection in the polders against floods and an infrastructure for both irrigation and drainage water management inside the polders. This will increase productivity of crops, horticulture, fish, livestock and forest resources. 25,000 ha will be rehabilitated and on 135,000 ha water distribution and drainage systems will be fine-tuned. Blue Gold will facilitate “The Farmers Field Schools” to test inputs and husbandry practices particularly for land preparation and output processing. To ensure sustainability, and as part of community mobilization, the Program will place more emphasis on cooperatives as drivers of economic development.

The main components of the program include:

- an integrated method that is community based and aims at improving water management and insure water safety,
- improving agricultural and aquacultural productivity creating more income, and
- providing knowledge and strengthening business development.

Innovative solutions on water management, agriculture, aquaculture, WASH (Water, Sanitation and Hygine) and value chains will be introduced through the project.

9.3 Previous studies

9.3.1 Surface water and groundwater

Flooding due to tropical cyclones is one of the most devastating natural hazards in Bangladesh. The coastal zone of Bangladesh is particularly vulnerable to cyclonic storm surge floods and is likely to be affected by more intense cyclonic events in the foreseeable future due to climate change and sea level rise (Karim and Mimura, 2008). Various studies (e.g. Ali 2000; IWM, 2005; Azam et al., 2004; Madsen and Jakobsen, 2004) predicted storm surges and associated flooding along the coast due to direct overtopping of the surge wave over the coastline. However, impacts of climate change and sea-level rise (SLR) were not considered in those studies.

Estimates of the effects of climate change on coastal flooding are limited but dire. Karim and Mimura (2008) describe the impacts of a rise in sea surface temperature (SST) and sea level (SLR) on cyclonic storm surge flooding in western Bangladesh. They showed that for a storm surge under 2°C SST rise and 0.3m SLR, the flood risk area would be 15% greater than at present; the depth of flooding could increase by as much as 23% up to 20 km from the coastline. Mohal et al. (2006) estimated that about 11% more land could be permanently flooded during this century. The Sundarbans, the internationally recognized Ramsar site, will be lost by 2100 due to high salinity and permanent inundation from projected sea level rise. A 10% increase in wind speed over that registered during the severe 1991 cyclone will increase the storm surge level by 1.7 m along the eastern coast of Bangladesh. Huq (1999) predicted that 5.8 km^2 of agricultural land could be eroded by 2030 and over 11 km^2 by 2075.

Usable groundwater is critical to the future development of Bangladesh. Since Bangladesh declared independence on 26 March 1971, several large-scale studies have been conducted to assess countrywide groundwater resources (MPO, 1986; WARPO, 2000: GoB, 2002), though none focused on the coastal zone until 2010. Then, with concerns for a future of less available fresh water associated with climate change, a World Bank (2010) study evaluated the coastal aquifers of Bangladesh. In that study, three basic salinization mechanisms are considered: lateral (classical) seawater intrusion, vertical intrusion from surface or shallow saline sources, and the mixing of pre-existing fresh and saline water in the subsurface layers due to pumping. Analyses were based on two-dimensional profiles representing typical cross-sections of the aquifer perpendicular to the coastline, and salinization mechanisms were evaluated by numerical simulation using the SUTRA density-dependent groundwater flow and transport code.

The modeling analysis provided three general findings regarding salinization of fresh coastal groundwater resources in Bangladesh.

- Saltwater intrusion has already been occurring in some areas due to previous rise in sea level and storm surges. As a result of historical sea-level rise in the last thousands of years, the subsurface saltwater has been moving inland, especially in the low-topography regions of central Bangladesh.
- Pumping of fresh groundwater in the coastal aquifer accelerates saltwater intrusion and degradation of water quality along both horizontal and vertical salinization paths.
- Any future sea-level rise will increase the adverse impact of the already-occurring salinization processes to some extent.

These findings suggest that the direct impacts of sea-level rise on coastal inundation and extent of storm surges is of greater concern for groundwater conditions than classical lateral seawater intrusion. Moreover, pumping in the coastal zone, even without climate change, is an important determinant of salinization rate, and pumping-induced salinization rate is dependent on the pattern of the various sediment types that compose the aquifer fabric. Sea-level rise may shorten the lifetime of the fresh groundwater resource in the current coastal zone, although this impact may not appreciably increase salinization rates (World Bank, 2010).

Based on these major findings, World Bank (2010) described the overall vulnerability of the current deep freshwater portions of the coastal aquifers in Bangladesh as follows.

- Deep fresh coastal groundwater is vulnerable to vertical infiltration of saltwater due to periodic storm surge flooding, particularly where clay layers above pumping wells are absent and an unsaturated zone exists or where saline ponded water is allowed to remain following the surge.
- There is moderate vulnerability of the fresh coastal groundwater resource to lateral saltwater migration. The location of more vulnerable regions depends on the spatial distribution of aquifer hydraulic properties. More permeable and lower-porosity regions of the aquifer are more vulnerable than less permeable and higher-porosity regions.

- There is high vulnerability to salinization due to pumping-induced mixing of pre-existing fresh and saline groundwater, irrespective of the source of that saline water. Areas with pumps in aquifer material of low permeability or low porosity and areas where pumping occurs from freshwater pockets surrounded by saltwater are particularly vulnerable to mixing of saltwater into the water produced from wells.
- Groundwater in areas with lower topographic relief (central delta) is far more vulnerable to vertical and lateral intrusion pathways than groundwater in higher-relief (eastern delta) areas.

At the local level, very few studies on groundwater (GW) have been attempted. Mondal et al., under a CPWF project (Tuong et al., 2009), tested the hypothesis at Batiaghata and Tala upazilas, that GW is suitable for irrigation, and that its withdrawal for dry season rice cultivation would not result in salt-water intrusion into the aquifers . Their findings suggest that the suitability of GW for dry season irrigation in the area is rather site specific, and GW should only be used with caution in the area tested (a sub-district of the southwest region of Bangladesh). They warn that irrigation with marginal quality GW in Batiaghata may cause a build up of salts in the soil profile and propose more study is required.

Firoz (2010) used a model called FEFLOW to investigate key hydro-geological parameters governing GW flow and recharge both temporally and spatially over the Satkhira district, with a view to future GW management. The model does not consider salinity and interaction of surface water and groundwater. Bahar and Reza (2010) assessed shallow GW in Khulna city, measuring salinity, total hardness, and sodium percentage (Na%) and concluded that most of the groundwater samples were not suitable for irrigation or domestic purposes and far from drinking water standard. The study sampled only 26 boreholes within Khulna city so conclusions may not apply to the agricultural area of the region.

Haque et al. (2010) conducted a case study to see the impacts of shrimp culture on the surface (pond) and GW (tube-well) quality in three coastal sub-districts Sadar, Rampal and Morrelganj of Bagerhat. They found that salinity of both surface and groundwater increased after shrimp culture, and water became more turbid, odorous and less tasty. Alauddin and Hamid (1998) also inferred that shrimp culture had caused increasing salinity, destruction of mangroves and other vegetation, reduced biodiversity and land productivity and reduced of forest area in the south-western coastal region of Bangladesh.

9.3.2 Salinity and crop cultivation

Various government and non-government organizations have aimed to intensify cropping systems in the coastal zone by testing and developing alternative methods of soil cultivation and crop management, and by introducing improved genotypes of crops as well as screening for salt tolerant varieties. In 2003-5 FAO funded a BARI-led project that compared a range of machinery options in an attempt to accelerate presowing cultivation so that wheat could be planted at the optimum time immediately after T aman rice crops were harvested. The methods allowed Rabi crops to be sown into soils charged with a full profile of water from monsoon rains (non-saline). It also moved back the growing window so it would largely precede the capillary rise of salt through the profile in many coastal areas (Rawson et al., 2007, 2011). A scoping study by ACIAR immediately following the FAO thrust showed a full profile of plant available water in soils of the coastal zone ranged between 140 and 170 mm depending on soil type and location (Dalgliesh and Poulton, 2011 Table 8). This was enough to establish healthy crops without irrigation and take the roots into the effective zone of the water tables that are often very shallow in the region. This was an important lesson that farms in the historically T aman-fallow areas did not need to remain fallow through Rabi because water, though hidden, was available with appropriate agronomy, and salinity, though present late in the season, could be avoided. ACIAR continued its investment in the coastal zone in partnership with BARI through project LWR/2005/146 ‘Expanding the area of Rabi-season cropping in southern Bangladesh’ which began in 2006. The primary aim was intensifying crop production by introducing HYV wheat and mungbean in on-farm studies across the region and developing appropriate management approaches for the genotypes that minimised or avoided the need for irrigation and taught timeliness of all production processes guided by crop physiology. Combating salinity in marginally saline zones was approached through avoidance via timing but the ACIAR work did also support field-screening nurseries seeking salt tolerance in wheat introductions that led to the release of named varieties. The focus throughout however was exclusively on wheat, only one of the many crops that can be grown in the coastal zone, and exclusively on non-or marginally saline soils.

BARI has tested many other crops for the saline areas, for example evaluating tomato, chilli, watermelon, cucumber, barley and sunflower using different planting and irrigation techniques and comparing these approaches with those obtained from farmers' practice in the saline soils of Charmajid and Charmahiuddin (Noakhali district) (Islam et al., 2008). They concluded that drip irrigation sourced from rainwater harvested in ponds was efficient saving 45% of the water and 50% of urea and muriate of potash (MP) fertilisers used in farmer approaches. Yields were achieved by forward planning, enabling avoidance of the salt constraints imposed by traditional approaches. Water remaining in ponds was used for fish culture.

The vision of all stakeholders considering agricultural productivity in the saline zones is not salt avoidance by crops but salt tolerant genotypes that will yield well despite the salt. Towards this end, Aziz et al. (2009) at BARI, funded through BARC, aimed to identify the most salt tolerant genotypes of a range of species for growing in salty areas. Their cascading screening experiments were exhaustive. They used salt solutions in Petri dishes to assess germination in the laboratory, pot culture with saline solutions in a plastic house to assess early growth, seed bed culture with salt solutions to assess growth and yield and finally natural field conditions in the coastal saline area of Noakhali, Patuakhali, Satkhira and Khulna to assess crop performance of the pre-screened genotypes. Based on their results several genotypes of maize, mungbean, barley, wheat, soybean, mustard, sweet gourd and cowpea were selected as suitable for different salinity conditions in the coastal zone.

Though the Aziz et al. (2009) studies were exhaustive and their approaches noteworthy some of their conclusions may be questionable. For example, based on their data, their yield ranking for salinity tolerance of mungbean genotypes in Noakhali can be shown to be 88% due, not to genotype, but to initial differences in salinity of the plots allocated to each genotype. Put simply, the highest ranked genotypes were fortuitously grown in the least saline soil. Equivalent tests cannot be made on their yield rankings for genotypes of other crop species because the detailed salt data of individual plots are not shown. In most of their field studies a single salinity value for the whole trial is presented weekly or monthly assuming perhaps that salinity at trial sites will not vary spatially. This study highlights the potential difficulty of screening for salinity tolerance in the highly variable field environment especially if the environment is not described in detail and monitored throughout crop growth. A screening trial design aimed at minimising these difficulties and based on the experience of LWR/2005/146 is presented earlier in this report.

Ali et al. (2009) did studies on vegetables in the Khulna district. These considered the possible impacts of salinity, drought and waterlogging on production based on some general observations of the environmental variables that were not measured.

BRAC (2009) claims to be the first to introduce maize and sunflower into the coastal zone and farmers were advised that the sunflower genotype distributed is salt tolerant (reported by farmers during current ACIAR project field trips in Patuakhali and Barguna). This may be the case. However, tolerance could not be assessed since none of the BRAC studies monitored salinity, soil, water, or any crop parameters other than yield.

Since April 2011 BRAC has been conducting an action project 'Crop Intensification for Achieving Food Self-Sufficiency in the Coastal Regions of Bangladesh' in 26 upazilas of 7 cyclone-affected districts (Barguna, Jhalokathi, Patuakhali, Pirojpur, Bagerhat, Khulna and Satkhira) (BRAC, 2011). The activities of the project include distribution of cash grants to purchase different inputs for hybrid rice cultivation in the aus and aman seasons, provision of technical advice to farmers about crop cultivation, and collection of data relating to crop growth, production, and cost-benefits.

BRRI were interested to see the extent to which the water resources of the saline coastal areas could be used to increase boro rice production during Rabi using Satkhira as the test location (Rashid, 2010). They assessed the salinity of river water, shallow tube wells (52-75 m deep) used by local farmers, and salinity of deeper aquifers and concluded that only two sources i.e. pond water and groundwater from deeper aquifers, are suitable for irrigation to achieve best yields. They also concluded there is potential for increasing boro rice production using less saline groundwater. However, they did not assess long-term impacts of this action such as possible degrading of the soil due to secondary salinization.

Overall, much of the available research on salinity and crops for the coastal zone seems to be dominated by observation of the crop without measurement of the salinity environment and maybe some guesswork that a zone will be saline because it is nominated as such. Certainly, there seem to be no field data that track spatial and temporal changes in salinity and water in concert with observations on crop performance. Only with those data can a crop or genotype be benchmarked with its degree of salt tolerance and ranked against comparisons and the vision is checked against reality.

9.4 Current research activities

ACIAR and AusAID funded projects

Currently, in addition to LWR/2011/066, there are several ACIAR funded on-going projects in Bangladesh (http://aciar.gov.au/country/Bangladesh/currentprojects). These are:

- The Bangladesh component of ACIAR's climate adaptation project 'LWR/2008/019 – Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Laos, Bangladesh and India*'.*
- ASEM/2011/005 - Policy constraints in rice based farming systems in Bangladesh
- CIM/2007/121 - Sustainable intensification of maize-rice production systems in Bangladesh
- CIM/2009/038 - Introduction of short duration pulses into rice-based cropping systems in western Bangladesh
- LWR/2010/033 - Developing capacity in cropping systems modelling to promote food security and the sustainable use of water resources in South Asia
- LWR/2010/080 - Overcoming agronomic and mechanisation constraints to development and adoption of conservation agriculture in diversified rice-based cropping in Bangladesh

Climate Adaptation Project (LWR/2008/019): This project aims to develop multi-scale adaptation strategies and demonstrate processes that enable policy makers to deliver more effective climate adaptation programs relevant to farmer livelihoods and food security, while at the same time building capacity of farming households in selected regions of Cambodia, Laos, Bangladesh and India to adapt their rice-based cropping systems to climate variability and climate change. The primary focus in Bangladesh is the development and validation of the cropping systems model APSIM based on data from trials in ongoing and planned projects by the International Rice Research Institute (IRRI) and additional on-station trials in collaboration with Bangladesh research partners. The project's field sites are located in the coastal zone, one at Satkhira described and used in the present work.

Sustainable intensification of maize-rice production systems in Bangladesh: This project will identify, test and promote key interventions in four districts that will lead to sustainable cropping intensification - resulting in double- and/or triple-cropping rice-maize systems. Specific objectives to improve these systems are: (i) to assess and prioritise constraints to, and opportunities for, uptake of improved management options; (ii) to evaluate and identify elite maize germplasm tolerant of excess moisture; (iii) to develop locally adapted management solutions for high-yielding, profitable, resource-efficient, and sustainable rice-maize systems; and (iv) to build capacity and disseminate key technologies. The project does not include any coastal area.

Introduction of short duration pulses into rice-based cropping systems in western Bangladesh: This project will fit short-duration pulses (lentil, mungbean and field pea) into new cropping niches in western Bangladesh. This tailoring process involves introducing new super-short duration cultivars, the use of relay cropping (especially sowing pulses prior to the harvest of monsoonal 'aman' rice) and adoption of minimum tillage. The project team also aims to build the capacity of national growers and researchers to produce pulses. None of the coastal districts are included amongst trial sites.

Developing capacity in cropping systems modelling to promote food security and the sustainable use of water resources in South Asia: The overarching objective of this project is to improve water productivity in rain-fed and irrigated smallholder rice-based farming systems to enhance agricultural production and food security. It will establish a network of agricultural scientists in SAARC member states, identify a suit of improved crop and water management practices that increase water productivity, and strengthen institutional support for systems analysis and farming systems modelling. The research capacity developed by the project will translate into better defined and more appropriately targeted crop and water management practices, to be evaluated with more confidence and within shorter timeframes. In this way, recommended practices will reach farmers earlier, and have a greater impact for smallholders.

Overcoming agronomic and mechanisation constraints to development and adoption of conservation agriculture (CA) in diversified rice-based cropping in Bangladesh: This project aims to develop and accelerate the adoption of CA for selected soils, crops and cropping systems in Bangladesh, especially in rainfed areas and those with supplementary irrigation, so that farmers and households can benefit from cost saving crop production technologies and sustainable resource management. The project does not consider the coastal zone.

Bangladesh integrated water resources assessment project: This project, funded by AusAID-CSIRO Alliance, started in July 2011 and is scheduled to be completed in October 2013. The project is developing an integrated water resources / socio-economic study to provide a national overview of the resource, the impacts of development and climate change on both surface water and groundwater resources. It is assessing the way impacts will affect the poor and vulnerable, the amount of water that could be sustainably supplied to the different economic sectors such as agriculture, fisheries, industry and navigation, as well as to the population for drinking and sanitation purposes in order to promote economic growth and improve livelihoods of local people. The research will address current knowledge gaps in climate change impacts, groundwater resources at the national scale, and in the interaction between surface water and groundwater. The study is a country level overview study.

CPWF Ganges Basin Development Challenge

CPWF started 5 interrelated projects in July 2011 under the banner Ganges Basin Development Challenge (BDC) to increase the resilience of agriculture and aquaculture systems in the coastal areas of the Ganges Delta with the overarching aim of improving the livelihoods of Ganges coastal zone farmers (http://waterandfood.org/basins/ganges-2/). The specific objectives include:

- To establish a geo-referenced data base for the coastal zone of Bangladesh and to facilitate out-scaling of technologies through identification of their target domains and land use planning (Project G1).
- To develop and introduce resilient agriculture/aquaculture production systems in the coastal zone for the benefit of small farm households (Project G2).
- To improve water governance and management for resilient production systems (Project G3).
- To assess the impact of anticipated external hydrology changes on water resources in the coastal zone of the Ganges (Project G4).
- To enhance impacts through stakeholder participation, policy dialogue and effective coordination among other Government, NGO's, CGIAR and donors sponsored projects and programs in the Ganges BDC research Program (Project G5).

Each project addresses one specific objective. The objective of Project G1 is to develop a database for the coastal area and the objective of G5 is facilitating the policy dialogues as stated. The objectives of the other 3 projects are given below (http://waterandfood.org/basins/ganges-2/).

Project G2:

- Validate new germplasm suitable for various agricultural cropping systems and establish seed distribution networks in target zones
- Develop and disseminate more productive, profitable, resilient, and diversified rice-based cropping systems (including rice-aquaculture)
- Enhance the productivity of homestead production systems
- Develop novel brackish-water aquatic production systems for zones too saline for agricultural crops
- Produce technology and policy recommendations for up- and out-scaling

Project G3:

- The main objective of this research project is to understand the different modes and outcomes of water governance in selected polder sites and understand the role that communities play in such governance, conflict resolution and productive use of land and water resources.

Project G4:

The project aims to identify and prioritize the drivers that affect the water resources in the coastal zone of the Ganges basin and assess their effects on water resources towards building resilient water governance and management to cope with the projected future conditions.

The key outputs of the project include: list of key external drivers; climate change projections for the study region; projection of scenarios for land-use and climate change; flow availability; salinity zoning map of the coastal Ganges; flood depth-duration map; water storage volume inside polders; storm surge risk map; sedimentation rate in peripheral rivers; plan for improvement of canal system, sluices and embankments; operation rules for sluices.

Cereal System Initiative South Asia (CSISA)

This project seeks to decrease hunger and malnutrition and to increase food and income security of resource-poor farm families in South Asia through the accelerated development and inclusive deployment of new varieties, sustainable management technologies, and policies (https://sites.google.com/site/csisaportal/). The project is funded by Bill and Melinda gates Foundation and USAID.

The project has as its objectives:

- Widespread delivery and adaptation of production and post-harvest technologies to increase cereal production (rice, wheat and maize) and raise incomes in Bangladesh, India, Pakistan and Nepal.
- Crop and resource management practices for sustainable future cereal-based systems.
- High-yielding, abiotic stress-tolerant, and disease- and insect-resistant rice varieties and hybrids and similarly selected wheat and heat-tolerant and disease-resistant maize inbred lines and hybrids for current and future cereal and mixed crop-livestock systems
- Technology targeting and improved policies for inclusive agricultural growth.
- Creating a new generation of scientists and professional agronomists for cereal systems research and management.
- Project management, communication and impact assessment.

IRRI is leading a CSISA sub-project on ‘Sustainable Rice Seed Production and Delivery Systems for Southern Bangladesh’. IRRI is also leading the project ‘Stress-tolerant Rice for Africa and South Asia (STRASA)’ funded by Bill and Melinda gates Foundation which has a component in Bangladesh (http://www.irri.org/index.php?option=com_k2&view=itemlist&layout=category&task=category&id=184&Itemid=100030&lang=en).

Crop intensification Program of BRAC

BRAC has an on-going crop intensification project under the Agriculture and Food Security Program (http://www.brac.net/content/bangladesh-agriculture-food-security-crop-intensification). To rehabilitate the victims of Cyclone Sidr, BRAC introduced hybrid rice in winter (Boro/Rabi) season in the coastal area for the first time. The farmers cultivated this rice using tidal river water. Additionally, BRAC has implemented high yielding variety (HYV) and hybrid rice cultivation in pre-monsoon (Aus) and monsoon (Aman) seasons in traditional single-crop areas. BRAC has introduced maize, sunflower, and other vegetables as new crops in areas with limited non-saline water as part of the rehabilitation of Sidr victims. BRAC is continuing the adaptive research and demonstration to develop area specific cropping patterns, incorporating new knowledge for the coastal regions of Bangladesh.

Bangladesh Agricultural Research Institute (BARI) and Bangladesh Rice Research Institute (BRRI) are partners in most of the projects if not all described above. In addition to the overseas donor funded project, they also have regular research program in the coastal area. A majority of their work are mostly on the development of new varieties of crops suitable for particular locations or conditions and testing of new varieties in the farmers’ field (BARI, 2012; BRRI, 2012).

9.5 Constraints for cropping intensification

Agricultural development in the coastal saline belt is constrained by bio-physical, chemical and social factors that are common the world over. But additionally it has to deal with natural calamities that occur in the low-lying delta area. Every few years the whole southern coastal zone is exposed to the effects of cyclonic storms and tidal surges that force saline water up rivers and canals often leading to flooding and salinization of agricultural land. That is additional to the accompanying effects of hurricane-strength winds that can devastate communities, their property and their agriculture. Nothing in the southern zone is long-term.

Uneven monsoon rainfall that is highly variable in amount and timing (Poulton and Rawson, 2011) and higher temperatures than in the bread basket of the northern zones of Bangladesh also complicate utilization of land resources for agriculture development in the southern region. Variability of rainfall, uncertain dates of onset and recession of seasonal floods and risk of drought restrict cultivation of aus and aman rice by delaying sowing or transplanting and sometimes flash floods wash away the standing crop.

Bearing in mind this situation of extreme variability of weather in the coastal zone the major constraints for cropping intensification can be simplified to 2 main categories.

1. Water and salinity related constraints
2. Socio-economic and policy constraints

9.5.1 Water and salinity related constraints

Water and salinity related constraints are multi-faceted. These are:

Scarcity of fresh irrigation water: Scarcity of quality irrigation water during the dry season when rain is essentially absent for the two months of December and January limits cultivation of boro rice and other Rabi crops, and Aus rice cultivation during the Kharif-1 (March-July) season. The waters of the coastal rivers are usually saline. Salinity of most surface waters generally increases as the land drains and then dries during Rabi reaching maximum levels during April and May as discussed in detail in Chapter 5. Additionally, the often saline groundwater table is shallow, within 1-1.5 m of the surface throughout much of the year, thus minimising its use for irrigation.

Poor drainage system: In the study area very low soil permeability restricts downward movement of soluble salts. When Boro rice is grown during the dry Rabi season and irrigation is provided continuously with slightly saline water (EC 2.5-3.5 dS/m), salt from the water progressively accumulates in the surface soil. Due to the shallow groundwater table, the soluble salts cannot be leached down the soil profile. Together, poor permeability and poor infiltration rate limit the use of land for Boro rice during the dry season.

Water logging due to drainage congestion: In the rainy season, the poor functioning of sluice gates, often due to siltation of channels, restricts removal of excess water from the enclosed polders. Too deep water can delay transplantation of T Aman crops which in turn delays harvesting which then delays planting of Rabi crops. This cascade of delays, when due to the initial drainage congestion, depresses all yields in the region. The effects of poor drainage can reach further to soil salinity levels not decreasing within the polder areas thus constraining the adoption of high-yielding varieties of aman and aus rice.

Lack of water storage facilities and irrigation infrastructure: Plenty of fresh water is available in the coastal area during the wet season. But due to lack of big facilities water cannot be stored for use in the dry season. However, there are ponds, canals and small streams that could be used to store water. In some areas, fresh surface water is available at some distance from farmers' fields but due to transportation limitations they are not used. There is a general lack of policy and initiative.

Soil salinity: Soil salinity is a dominant factor limiting agriculture in the coastal zone, especially during the dry season as discussed in Chapter 5. It always reduces crop yield and in severe cases leads to total loss of yield. A substantial area of land is tidally affected by saline water.

Poor nutrient status of the soil: Fertility status of most saline soils ranges from low to very low in respect to organic matter content, nitrogen and phosphorus. Soil pH is high making micro-nutrients such as zinc, copper and boron less available. Even with fertiliser applications crop yields in these saline soils are low.

Heavy clayey texture / heavy soil consistency: The texture of many of the saline soils particularly in the west varies from silt clay to clay. Land preparation becomes very difficult as the soil dries out. Deep and wide cracks develop and surface soil becomes very hard. These also necessitate deep and rapid tillage operations.

9.5.2 Socio-economic and policy constraints

Unplanned brackish water shrimp culture: Land used for brackish water shrimp cultivation has been deteriorating due to progressive increases in salt and thereby reducing crop production (BARC, 1990). In particular, those vegetables with low salt tolerance now yield poorly.

Poor communication: Difficult communication and the remoteness of marketing facilities in the coastal zone also retard agricultural development in the region. Progressive siltation of waterways including canals and channels is also making travel by water difficult.

Poor marketing system: Farmers are dependent on adequate storage and marketing facilities for their crops. In the southern region, these are very poor and traditional. Lack of centralised storage compels farmers to sell most of their crops as soon as they are harvested and this is when prices are at their lowest. The poorest farmers have no option but to sell their crops immediately as they need the money to pay off their loans and finance their next crop.

Social conflicts: Influential persons commonly use Polder drainage channels for fishing. This involves building damming earth walls at regular intervals along the channels to hold the wild fish that have spread during monsoon flooding. It is well into the Rabi season before the fish are harvested and the walls demolished. Meanwhile, the polders remain flooded and the cascading delaying and yield-reducing consequences to affected T aman and aus crops escalate. Thus, conflicts arise between fishing persons and those in crop production in low-lying areas.

Lack of suitable salt- and submergence-tolerant crop cultivars: The use to which land is put in the southern region is determined by the height of the land in relation to the duration and depth of regular or seasonal tidal or rain water flooding, as well as to the degree of dry season salinity and availability of soil moisture. For example, high land drains first after the wet season so can be planted first to an early crop while, without drainage choices, low land can remain waterlogged. Crops and genotypes suited to all these environmental combinations and in particular with some salt tolerance are needed to fully utilize the coastal saline soils.

In flood prone areas, tolerance to submergence is an important trait for rice cultivation. Continuous rainfall and frequent surge of tidal water tend to submerge the seedlings in this region. Siltation further aggravates submergence through impeding drainage. Sometimes, standing crops of Aman are submerged completely for 2/3 weeks and replanting is necessary. Submergence-tolerant rice cultivars are required.

Lack of extension programs: Farmers need to be frequently updated as to what is new in technology and what new varieties of crops are available. Then, they need to be trained in how to best use these tools. Many learn from their relatives and neighbours and a high proportion just remain with the technologies proved to work reliably (but not necessarily optimally) by previous generations (Khan and Afroz, 2011b). Many parts of the coastal zone are considered remote so historically are not as well served by extension programs and extension personnel as more central regions. Personnel trained in managing saline farms are particularly required and an increased proportion of women officers is critical since many farmers are female (Khan and Afroz, 2011b).

Economic viability of crops: Just as farmers need extension workers to help them with new techniques they also need help with understanding the economic viability of the crops they could grow on their land, and their potential choices. This is often driven by the requirements of local markets but some farmers are closer to larger outlets so have more choice (Kabir et al., 2011).

Land tenure system: Big land ownership and unfavourable land tenure system and dominance of absentee farmers also discourage the adoption of modern technologies particularly by tenant farmers (Khan and Afroz, 2011a).

It is evident from the discussions throughout the report above that water related problems and soil salinity are common limitations in many parts of the coastal zone. Agricultural activities suffer greatly because of these and they are the primary constraints to the intensification of cropping systems. These limitations were also highlighted during our recent face-to-face discussions with key stakeholders, research organizations, and NGOs in Bangladesh. We (M. Mainuddin and Riasat Ali) met representatives from 15 organisations, covering a wide range of interests from research to implementation, from water and crops to social and economic. A report, including the list of organizations and persons we met, is given in the Appendix A.

9.6 Opportunities for cropping intensification

The coastal zone of Bangladesh is often perceived as a zone of multiple vulnerabilities. But it has much potential and opportunities. By harnessing and exploiting its opportunities in a systematic and coordinated way, the coastal zone can make a substantial contribution to achieve the national goals of accelerated poverty reduction and economic growth (MoWR, 2006).

In Bangladesh over thirty percent of the net cultivable area is in the coast (MoWR, 2006). Development of coastal agriculture has potential to improve sustainable livelihood and congenial environment. As argued originally by Poulton (2011) and updated in Chapter 5, there are plenty of fallow lands in the dry season that can be brought under cultivation which will lead to an increase in cropping intensity. Due to lack or perceived lack of fresh water for irrigation, salinity in the soil, lack of optimum management of the available resources, and the zone's vulnerability to natural disaster many farmers are still cultivating local varieties of crops. The average yield is therefore lower (Table 8.13) compared to the rest of the country. There is considerable potential to increase the yield and production of many crops. This was demonstrated in LWR/2005/146. A decade ago wheat was considered to be entirely unsuited to southern Bangladesh. But during the intervention of the ACIAR project it was grown throughout the region (Saifuzzaman et al., 2011) with, for one extreme example, a farmer within 30 km of the coast and mangrove swamps producing a 4.4 t/ha crop. His normal Rabi crop was grasspea while neighbour farmers left their land fallow. Wheat yield increases in the south averaged higher than in the northern breadbasket through farmers adopting new varieties and new agronomy taught by the project.

There is a lot of fresh surface water during the monsoon season. This water can be stored in the canals, ponds, and small streams inside the polders to be used for dry season strategic irrigation. However, these waterways need some rehabilitation works. The Blue Gold Program is aiming to do that in 26 polders in the region. Rainfall in the region is quite high so there is good potential for rainwater harvesting for irrigation. BARI has tested and analysed the benefit of this at the level of the experimental field (Islam et al., 2008). Storage ponds can be used for both irrigation and aquaculture to compensate for the cropping land lost to water storage. Once harvested, this water can be used efficiently using modern techniques (Akanda and Islam, 2008 using vegetables and fruits crops).

Despite the apparently negative prospect for use of the groundwater resources in the coastal zone (World Bank, 2010), as described in Section 9.3.1, World Bank also stated that careful management may enable use of the current coastal zone freshwater resources for a very long period of time, should sea level not rise appreciably. However, they emphasised that proper management of the coastal aquifer is an absolute prerequisite to mitigation of future salinization problems caused by possible sea-level rise.

Because of the many opportunities available to harvest and manage water, particularly in the polder system, the Government and other policy makers are giving high priority to coastal zone agricultural intensification as described in Section 9.1 and 9.2 (Coastal zone agricultural Master plan, Blue Gold Program, Coastal Zone Policy and Coastal Development Strategy).

9.7 Gaps in current research and opportunities

9.7.1 Gaps in surface water and groundwater research

As described in detail in Chapter 5, the hydro-geology, hydrology and salinity processes of the coastal areas are very complex being affected by tidal surge, cyclone, withdrawal of upstream surface water (particularly in the south-west region due to the construction of Farakka Barrage) and more recently, and certainly into the future, by climate change. Crop cultivation and shrimp farming are an integral part of the coastal food production system and they too have impacts on hydrology and salinity processes. Water is at the centre of this complex system being linked to all the processes and components. The availability of fresh and safe water is considered the most important issue in the Coastal Development Strategy (CDS: MoWR, 2006). This issue is currently far from a positive resolution. As discussed throughout previous chapters of this document fresh water flows are reduced, saline water intrusion is occurring and users are being profligate and unconcerned until they are directly affected. The challenge is to achieve water security by adopting integrated water resources management, frugal use of coastal groundwater linked to an understanding of the impacts of extraction, harvesting and storage of rainwater, conservation and optimised use of all available water. Integrated management of these coastal resources has been identified as the key for the development of the coastal zone in all recent policy documents from the government (e.g. MoWR, 2005; MoWR 2006).

Following the development of the CDS, several project concept notes have been developed as listed in Section 9.1. Some of these have been implemented. These projects are mainly development and management projects, not research projects. However, none of the projects have considered the system in an integrated way. The current project, related to groundwater, is a hydro-geological investigation concerned with the development of databases and Interactive Information System (IIS) including user-friendly maps and guidelines for groundwater use. The project does not consider groundwater salinity and its interaction with surface water. Projects on integrated water resources management such as IPSWAM and WMIP focused on infrastructure development and improvement and a structured approach to participatory water management. Their guidelines are adopted in the Bangladesh Water Development Board policy and used in the field by their staff. Water Management Groups (WMG) and their Associations (WMA), both cooperative structures, have proven to be effective partners in creating sustainable development (GoB and GoN, 2012). However, in none of these initiatives has there been components aimed at understanding the overall systems, how the components interact with each other, what are the causes and mechanics of salinity increase both in the soil and groundwater. However, all these projects have been and are contributing to the development of the coastal zone. The Blue Gold, which will be operational in 2013 for a 6 year period, is more or less the extension of the IPSWAM and WMIP project based on different polders.

Regional modelling of the surface water system in the coastal zone and its interaction with seawater intrusion in the rivers and streams are well studied, as described to some extent in Chapter 5. These studies also examine the impact of upstream water withdrawal and climate change. The coastal zone has rivers, channels and streams in a very dense network that is very likely to interact with the groundwater aquifers. No surface water studies consider this interaction. The CPWF G4 project is largely similar to earlier studies and also does not consider groundwater in its modelling.

So far, the most comprehensive study on groundwater in the coastal zone is that done by the World Bank (2010). As described in the report, the study only aimed to better understand the generic physics of the basin system representing general features and conditions along the coast of Bangladesh. The modelling analysis presented was limited to simplified cross-sectional aquifer systems and individual salinization mechanisms. These simple simulations were designed to capture the range of possible current conditions and future changes and to identify controlling factors and primary effects. They show that the process of lateral intrusion is very slow compared to the vertical infiltration of seawater, and that coastal pumping increases the rate of intrusion due to both mechanisms and increases fresh- and saline-water mixing. Land and water management decisions have major influences on vertical infiltration. So the study recommended that continued detailed modelling concomitant with data collection are vital for better understanding the spatial and temporal scales of salinization processes and for making optimal site-based management decisions. This is critical in supporting long-term planning and development efforts by the government in the coastal zone (World Bank, 2010).

As shown is Figure 4.2 (location of polders), and Figure 5.42 (Figures on salinity affected area), most of the salinity affected areas in the coastal zone are within the embanked polders. Polders were designed to prevent direct salt water intrusion to increase crop production. However, as shown in Figures 5.39 to 5.42 (Figures on groundwater salinity and soil salinity area) over the years, the salt-affected areas are gradually expanding (SRDI, 2010). Salinity of groundwater is also increasing (Figure 5.41), as embankment only prevents direct intrusion of water into the polders. The surface water of the streams surrounding the polders, which is often saline particularly during the dry period (Figures 5.17 to 5.19) fluctuates (Figure 5.14) several times in a day as the streams ebb and flow in concert with tides. The groundwater tables inside the polders are shallow (Figures 5.30 and 5.31) and these tables are likely to interact with tidal surge and the surrounding surface water. These possible interactions may make a major contribution to salinity mechanisms within the polders. To date these effects remain unexplored.

Land and water management for cropping inside the polders impacts on the groundwater table whether it is fresh, saline, or brackish. As described in the stakeholder consultation report in Appendix A, studies by SRDI show that there is capillary rise of groundwater from the water table and that crop roots are directly utilising it. The modelling done under the ACIAR project LWR/2005/146 indicated that for wheat crops in the southern zone (simulation for the meteorological data of 1971 to 2007) capillary rise contributes 60 to 100 mm to the water budget of the crop, the amount depending on the dryness of the season (details in Dalgliesh and Poulton, 2011). This is a significant proportion of the 250 mm water required to grow a 3.5 t/ha wheat crop; 146 mm is directly available from soil moisture at the start of Rabi season if planting is not delayed (see Fig.5.60 showing crop water requirements for a range of crops in the coastal zone). If the water table is not brackish, this is a very useful resource.

Some farmers in the coastal zone are sourcing brackish or saline groundwater and pumping it onto crops, presumably thereby impacting on soil salinity. Deep-rooted crops such as sunflower and maize are being introduced into the area. These, through tapping the water table and the soil profile of capillary rise, may also impact on soil salinity, though in the current absence of research this is not known. All these land and water management practices have consequences on vertical movement of salinity in the unsaturated zone and the linked saturated zone, though to what degree is not known.

Shrimp farming is widespread, particularly in the western part of the coastal zone in the districts of Bagerhat, Satkhira and Khulna. There are about 130,000 shrimp farms in these three districts. For shrimp farming saline/brackish water is brought inside the polders. This has major consequences on the groundwater systems and salinity mechanisms as well as on cropping intensification.

9.7.2 Gaps in crops-related research

Crops research by various organizations is targeted at the development of salt tolerant varieties, at testing and further screening of varieties possibly suitable for the coastal zone, and their demonstration in the field to encourage their uptake by farmers (e.g. G2 project of CPWF, CISSA, STRASA, regular program of BARI, BRRI and BRAC). In the short term, these steps are necessary and beneficial to farmers to improve their food security and livelihood. However, the sustainability of cropping with salt-tolerance crops is uncertain in the long run. In part it depends on whether the salt-tolerant crops are solely water harvesting and thereby further concentrating the salts in the root zone, making the soils even more saline, or whether some salt harvesting is occurring in parallel or indeed if salt moves up and down regardless, driven by the annual cycle of monsoon rainfall and dry season capillary rise. There are many unknowns, but what is clear is that soil salinity is increasing both spatially and temporally. To what degree this is due to cropping practices as above or to secondary salinization via bad irrigation methodologies is not known. At present no studies are looking at salinity and water dynamics in the root zone of any dry season crops and the effects of the crops on surface water and groundwater. The previous ACIAR funded project 'Sustainable Intensification of Rabi Cropping in southern Bangladesh using Wheat and Mungbean (LWR/2005/146)' recommended cropping intensification despite recognising that using their recommended agronomy, crops in the south will self-extract water direct from the water table, but in parallel it recommended assessing the sustainability of the approach in any future studies i.e. considering the whole integrated system. If only a few farmers practice direct crop-root extraction of water from the water table the effects will be minimal, but with polder scale crop-root extraction the effects are unknown.

9.7.3 Opportunities for research

While water related regional modelling mostly ignores the crop and land and water management practices at the local level, crop related research mostly ignores the hydrological processes. Soil, water (both surface water and groundwater) and crop are intricately linked and are the components of the complex integrated natural agro-ecosystem system. There is a delicate balance in this natural system which should be maintained for the long-term sustainability of the coastal zone. Any changes in any components alter the natural balance of the whole system and must be tuned considering the whole system.

So the research questions, the answers of which will lead to the sustainable intensification of the cropping system in the coastal zone, are as follows:

1. Where and how much surface water is available for irrigation? How can we maximize use of surface water? What is the prospect of local storage of surface water and rainwater harvesting for irrigation?
2. Is the use of groundwater (in the area where it is used) sustainable? Where and how we can use groundwater sustainably for irrigation? How groundwater pumping is affecting salinity and what are the long-term consequences?
3. How surface water and groundwater interacts? Is the surface water and groundwater interaction affecting salinity of the soil and groundwater?
4. What is the interaction between soil salinity (unsaturated zone) and groundwater salinity (saturated zone)? How does one affect the other? How do crop and water management practices affect that interaction? What are the impacts of different crops such as wheat, maize, sunflower, pulses and oilseeds and different irrigation practices such as flood, furrow or drip irrigation or alternative water saving techniques on soil salinity and groundwater?

5. What crops have the least impact on salinization in the coastal zone and through what mechanisms? Do salt tolerant crops have negative impacts through concentrating soil salinity or positive impacts through salt harvesting? In short, how do cropping and management affect the root zone salinity dynamics and how do they affect overall salinity?
6. What are the environmental consequences of using groundwater or brackish groundwater and brackish surface water for irrigation? Will the groundwater become more saline? Are there some stages in the crop's development when use of brackish water will have the greatest positive impact on yield?
7. Ultimately, how can we either stop the gradual advance or reduce the salt-affected area for the long-term environmental sustainability of the region and simultaneously intensify cropping for food security and livelihood of the population?
8. Can crops with the C_4 photosynthetic pathway such as tropical grasses (e.g. maize, sorghum) make a bigger contribution to sustainability of water resources? These species are far more efficient in their use of water to produce biomass (and yield) than C_3 species (e.g. soybean, wheat, rice, sunflower), potentially producing up to twice the amount of biomass per unit of water transpired especially in limiting situations where water is not available on demand (Rawson et al. 1977). However, as salt in the root zone appears to have its effects on growth directly through constraining leaf expansion and not through carbon fixation in a range of species (Rawson and Munns 1984, Munns et al. 1982) this water use efficiency benefit of C_4 species may not apply in saline zones. This is not researched.
9. Can more rapid and reliable methodologies be developed for screening and benchmarking a wide range of species and genotypes for relative salinity tolerance in the field? Current methodologies following the traditional approaches of plant breeding using randomised trials developed for ranking in soils that are spatially and temporally relatively uniform. An approach is suggested in Chapter 7.

9.7.4 Link with other studies

The proposed project is a direct follow-on from ACIAR project LWR/2005/146 - *Expanding the area for Rabi-season cropping in southern Bangladesh*, which initially focused on testing wheat as a potential Rabi season crop in Barisal, Bhola and Noakhali, though trials were conducted throughout all zones of southern Bangladesh. Modelling conducted and wheat management options tested in that project will provide a strong basis for the proposed project. Studies recently concluded by BARI on salt tolerance mechanisms and development of salt tolerant variety/technology of different crops/cultivars for coastal areas of Bangladesh would also help select suitable rabi crops for testing in the field experiment. In the southwest, the proposed project will build on the current CPWF G2 project for local level interventions to manage salt and water in both Aman and Boro rice. APSIM-ORYZA modelling (input used and output generated) done under ACIAR's climate adaptation project LWR/2008/019 – *Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Laos, Bangladesh and India* (ACCA) - can be linked for better design of the current study and further validation of the model. The project will also be benefitted from the climate change projections and social typological analysis done under the ACCA project. The proposed project will closely collaborate with the ACCA project for mutual benefits.

Bangladesh Integrated Water Resources Assessment Project funded by AusAID-CSIRO Alliance will provide general understanding of the groundwater research mechanism and impact of climate change on surface water salinity, impact of upstream withdrawal and climate change on sea water intrusion into the rivers and stream. The project is for the whole of Bangladesh including the coastal zone. The output of the coastal zone will help us understand the overall water situation of the zone and the external drivers and their impacts. CPWF-GBDC project G4 aims to identify and prioritize the drivers that affect the water resources in the coastal zone of the Ganges basin and assess their effects on water resources towards building resilient water governance and management to cope with the projected future conditions. We can complement these studies by investigating salinity dynamics and surface water and groundwater interaction as none of these studies are considering these. Institute of Water Modelling is the partner in this scoping study as well as with CSIRO-AusAID Alliance Project and CPWF-GBDC project. So the extra work will be additional work on top of many other things already done; not starting from scratch.

The proposed project will try to develop a strong link with the Blue Gold Program which could facilitate a viable pathway to impact. The polder scale modelling and field trials can be set in the polders under the program to see the impact of integrated participatory management.

The project if funded will explore and create link with other studies such as CISSA, STRASA (by using the varieties tested and recommended for the coastal zone), and projects of other government and non-government organizations.

10 Conclusions and recommendations

10.1 Conclusions

The key outcome expected from this study is a strengthened rationale and plan for ACIAR investment in a full project on crop intensification in the southern coastal zone of Bangladesh. We have tried to achieve this by:

1. Assessing, both spatially and temporally, water availability, soil and water salinity, extent of surface water and groundwater irrigation, and irrigation requirements of different Rabi crops for the coastal zone (Chapter 5).
2. Assessing the extent, spatial and temporal trend of the current production and farming systems including the land remaining fallow during the Rabi season (Chapter 6).
3. Assessing the impact of soil and water salinity on crop yield based on field trials of wheat in the salinity affected belt, namely at Satkhira (west), Barguna, Patuakhali and Noakhali (east) throughout Rabi 2011-12 (Chapter 7).
4. Assessing current socio-economic conditions of the population and its dependence on agriculture, and by estimating expected economic, social, environmental, and livelihood benefits of intensification of farming systems (Chapter 8).
5. Reviewing, collating, synthesising literature, current research and development activities, and by holding stakeholders' consultations and field visits (Chapter 9).

At the end of the main Chapters (Chapters 5-8), we have drawn relevant conclusions in detail. At the end of Chapter 9, we have discussed the constraints and opportunities of cropping intensifications, gaps in current research and opportunities based on the synthesis and explored the potential links with current activities with any potential follow-up project. Here we describe the main messages that can be drawn from this study.

1. The coastal zone is a complex agro-ecosystem affected by natural calamities such as cyclones, floods, water logging, tidal surge and sea water intrusion.
2. Availability of surface water flow from upstream is decreasing in the dry season so saline water is moving inland through the waterways. However there may be potential to use surface water for irrigation using local storage and rainwater harvesting.
3. Groundwater resources in the coastal zone have not been fully explored. Groundwater is mostly brackish or saline in the shallow unconfined aquifers and the water levels are mostly within 1 to 4 m of ground surface. In general, there is currently no sign of any decline in the water table.
4. Groundwater is being used in some areas, there may be potential for limited use in some other areas – but in both cases, environmental consequences are unknown.
5. About 1.02 million ha (about 70%) of the cultivated lands in the coastal zone are affected by various degrees of soil salinity. The salt affected area is increasing and moving inland.
6. Only 41% of the net cultivable area is irrigated in the coastal zone compared to 71% in the rest of the country. While there is gradual increase in irrigation in the north, there is almost no growth in irrigation over the last 5 years in the coastal zone.
7. Average cropping intensity in the coastal zone is 174% ranging from 230% in Jessore (furthest from the coast) to only 150% in Bagerhat (nearest to the coast). The average cropping intensity for the rest of the country is 180%.

8. More than 700,000 ha of under-utilised medium high land are potentially suitable for additional Rabi cropping in the coastal zone. Patuakhali region (greater district) has the largest under-utilised land area during Rabi followed by Barisal and Khulna.
9. Monitoring of salt distribution in the 4 field sites shows that distribution of salt varies widely across the soil surface and by depth across the soil profile. Distribution of salt in the soil changes through time particularly in the upper layer (0-15 cm).
10. Yield of wheat is correlated best with salinity averaged over the whole 90 cm soil depth and best with salinity measured in the first month after planting. Salt is the main driver of yield (76% of variation).
11. Field trials of wheat show its potential to grow in the coastal zone. Growing other crops such as maize, sunflower, pulses, oilseeds and vegetables using similar techniques should also be possible.
12. Socio-economic analysis indicates that in many respects the coastal zone is backward compared to the rest of the country, especially in terms of GDP, literacy rate, crop yields, cropping intensity, production levels, livelihoods and quality of life.
13. As of 2005, about 65% of the population in the coastal zone were below the poverty line compared to 40% at the country level. Current (2010-11) GDP from agriculture is about 28% compared to 20% at the country level.
14. The coastal zone is widely recognized as a 'neglected area', is backward, fragile and vulnerable, but also full of opportunities. The Government of Bangladesh is giving high priority for the integrated development of the coastal zone which is evident in various recent policy and planning documents, and development activities.
15. The main bio-physical constraints for cropping intensification are related to water and salinity. However, there is potential for intensification if the opportunities are harnessed and exploited in a systematic and coordinated way.
16. Synthesis of previous and current studies shows that there are gaps in our understanding of surface water and groundwater resources, salt and water dynamics, interaction of different components (soil, water, and crop) and long term environmental consequences.
17. Integrated agro-ecological studies considering crop, water and salinity at various spatial scales are necessary for the sustainable agricultural development of the zone.
18. Currently many complimentary activities are going on in the coastal zone, so this is the right time to gain maximum economic and social benefit with minimum investment.

10.2 Recommendations

Wheat production in the coastal zone appears both technically and economically feasible based on the results of on-farm trials undertaken in this scoping study. Similarly, other crops such as maize, pulses, oilseeds, vegetables can be grown in the under-utilized lands during the Rabi season to intensify the cropping system. However, due to the complexity of salt distribution horizontally, vertically and through time, this requires improved method of screening (developed under this study) of salt tolerant and suitable species and genotypes. In addition to that, Intensification of the cropping systems in the coastal zone will also require a thorough understanding and an optimal management of the land and water resources of the region to ensure their long term use and sustainability. Since surface water and groundwater resources are brackish a thorough evaluation of their likely impacts on soil and groundwater quality is required and strategies for avoiding or minimising such impacts are needed. There is a high risk of land and water resource degradation if these resources are used without their understanding and impact evaluation. So we need to develop strategies that are aimed at achieving maximum production with minimal resource degradation on a long term sustainable basis.

The evidence presented in this report appears sufficient to encourage further investment into exploring greater utilization of the available resources for the intensification of cropping system in the southern coastal zone of Bangladesh. Accordingly following strategies are recommended.

Recommendation 1: Regional scale (whole south-western coastal zone) understanding of the surface water and groundwater resources, recharge/discharge mechanisms and trends using hydrological and hydrogeological data, information and regional scale models.

Regional scale (whole south-western coastal zone) understanding of surface water and groundwater systems is critical for assessing their significance and availability, and to find out how these systems operate, respond to rainfall and cyclonic events, behave under stress, how recharge and discharge processes are affected by rain and cyclone events, how their quality is impacted by rainfall, storms surge and tidal flooding, and what are the historical trends in resource availability, use and resource condition. This understanding will help in better planning, use and management of the resources on a sustainable basis.

All hydrological and hydrogeological data and other relevant information should be collated and analysed to improve understanding of the surface and groundwater flow systems. Groundwater recharge and discharge processes should be studied to assess the fluxes into and out of groundwater systems. All relevant data and information should be used to evaluate the historical surface water and groundwater resource condition, temporal and spatial trends in surface water and groundwater availability, spatial and temporal trends in groundwater and surface water quality, historical surface water and groundwater use and spatial trends, and relationships between groundwater abstraction, groundwater levels and groundwater quality. Regional scale models such as WAVES could be used to assess the diffuse groundwater recharge rates and physical methods could be used to assess the localised recharge and discharge rates. This regional understanding of surface and groundwater systems should help establish a baseline against which the impact of various strategies such as increased groundwater abstraction to support intensified cropping on groundwater resource condition can be compared and reported.

Recommendation 2: Understanding the salt and water dynamics at the polder / sub-regional (cluster of polders) scale: Development of a sub-regional scale groundwater flow and transport model for detailed understanding and evaluation of groundwater resources, salt movement, surface water – groundwater interactions, and impacts.

Groundwater is being used for irrigation in some part of the coastal zone. There may also be potential to use fresh or brackish groundwater for limited irrigation in some other parts of the basin. Increased groundwater abstraction could lead to large drawdowns or hydraulic gradients which may cause leakage of bad quality water from surface water bodies such as shrimp ponds, rivers, creeks, polders and canals into groundwater and deteriorate the resource. It may also increase the risk of sea-water intrusion if gradients reverse due to larger drawdowns caused by heavy pumping. On the other hand, it may also encourage more diffuse rainfall recharge due to extra storage space created by heavy pumping. Groundwater may also flow laterally from adjacent saline groundwater areas into the cone of depression caused by pumping and thus deteriorate the resource. Sub-regional scale groundwater modelling should be undertaken to help assess the sustainable volumes of groundwater that can be abstracted on an annual basis for irrigation of dry season crops, and the impacts of various pumping regimes on diffuse and localised recharge and discharge rates and groundwater salinity. It may help identify and evaluate best groundwater abstraction regimes in various areas that will avoid deterioration of groundwater quality by encouraging diffuse rainfall recharge and discouraging leakage from saline surface water bodies. Because surface water – groundwater interactions may be significant in the south-western coastal region due to a large network of surface water bodies the development and use of coupled surface water and groundwater models such as FEFLOW coupled with MIKE 11, MODFLOW coupled with MIKE 11, SUTRA, or others will be required. Input and output of the model used in Recommendation 2 will be used as input to these models. They can also be linked.

Recommendation 3: Understanding salt and water dynamics at the field scale: evaluation and modelling of interactions between crop types, soil types, irrigation methods, soil root zone salinity and groundwater salinity.

This requires the evaluation of all components of a production system and may be (and should be) embedded with the trials described in Recommendation 4; i.e. there will be additional layer of agronomic and water management treatments on top of that. All parameters related to agronomic and water management (such as irrigation methods, sources and quality of irrigation water, local storage and rainwater harvesting for irrigation, depth to groundwater table etc.) will be monitored in addition to the parameters required for Recommendation 4. These parameters will be monitored throughout the year, which includes a rice crop in the wet season. This will help us to evaluate the whole cropping system. Since it is not feasible and cost effective to conduct experimental trials for all dry season crops, soil types, irrigation methods, irrigation application frequency and amounts the data collected through experimental field studies should be used to calibrate an unsaturated flow and root salinity model. This calibrated model could be used for assessing the relationships between crop productivity, soil type, irrigation method, irrigation water quality, soil root zone salinity, groundwater salinity, groundwater levels, and deep drainage. Various models such as LEACHC, HYDRUS 2D and others should be reviewed to select a model that suits hydrological, agronomic and climate conditions of the coastal zone of Bangladesh.

Recommendation 4: *Adaptive trials for screening of salt tolerant species and genotypes for the coastal zone.*

Though there are weaknesses of field trials and they are difficult to conduct properly and interpret, if done correctly they are the quickest route to benchmark and rank species and genotypes for salinity tolerance for specific locations and more widely. An approach using a high, medium and low salt plot for each species/genotype in trials for salinity–tolerance screening has been developed under this scoping study with detailed necessary conditions (timing, benchmarking species, relevant plot size, data collection, site and plot calibration, ranking plots for salinity category, allocating species or genotypes to plots, etc.). The adaptive trials should be done at 4 – 8 different agro-ecological locations within the coastal zone (such as different level of salinity, different soil and water table conditions, different sources of irrigation water with varying quality, etc.) and for several species and genotypes (should be based on the latest information available). Bangladesh Agricultural Research Institute (BARI) should be the main partners in this work in association with BRAC and through the BRAC on-farm outreach trials.

Understanding and evaluation of the whole system at all scale levels and assessment and management of the impacts of various ground water pumping regimes on crop productivity, land and water resources can lead to an effective and sustainable farming system in the coastal zone. The key to achieving this is a holistic understanding and management of all components of the farming systems.

11 References

11.1 References cited in report

Akanda, A.R., Islam, M.S. (Eds.), 2008. Marginal Water Resources Assessment and Use for Growing Horticultural Crops and Fodders in the Coastal Saline Areas of Bangladesh. Annual Report, Irrigation and Water Management Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh.

Alam, K., Hasan, A.K.M.S., Khan, M.R., . Whitney, J.W., 1990. Geological Map of Bangladesh: Dhaka, Geological Survey of Bangladesh Publication, scale 1:1,000,000

Alauddin, M., Hamid, M.A., 1998, Shrimp Culture in Bangladesh with Emphasis on Social and Economic Aspects. Department of Economics, University of Queensland, Australia 4072, p.53-62.

Ali, A., 2000. Climate change impacts and adaptation assessment in Bangladesh. Climate Research 12 (2), 109–116.

Ali, A.M.S., 2005. Rice to shrimp: Land use/ land cover changes and soil degradation in South-western Bangladesh, Land Use Policy.

Ali, L., 2002. An integrated approach for the improvement of flood control and drainage schemes in the coastal belt of Bangladesh. A.A. Balkem Publishers, The Netherlands.

Ali, M.Y., M. B Islam. Sk. M. Zaman, M. S. Islam, M. F. Hossain, M. S. Hossain, M.M. Hossain, P.K. Sarder.2009. Livelihood adaptation to climate change in coastal area of Khulna and drought prone High Barind Tract area of Bangladesh. On-Farm Research Division, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh.

Allen, R. G., Pereira, L. S., Raes, D., Smith, M.1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56, FAO, Rome.

Azam, M.H., Samad, M.A., Kabir, M., 2004. Effect of cyclone tract and landfall angle on the magnitude of storm surges along the coast of Bangladesh in the northern Bay of Bengal. Coastal Engineering Journal 46 (3), 269–290.

Aziz, M.A., Begum, F., Saha, R.R., 2009. Studies on salt tolerance mechanisms and development of salt tolerant variety/technology of different crops/cultivars for coastal area of Bangladesh. Agronomy Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur-1701.

Bahar, M.M., Reza, M.S., 2010. Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of Southwest Bangladesh. Environ Earth Science 61,1065–1073.

BARC (Bangladesh Agricultural Research Council), Soil and Irrigation Division, 1990. Salinity Problems and Crop Intensification in the Coastal Regions of Bangladesh. Soil Publication No. 33. BARC, Farmgate, Dhaka, Bangladesh, 63 pp.

BARC, 2011. Use of fallow land in the south region of the country and plan for crop cultivation (in Bangla). Bangladesh Agricultural Research Council, Farmgate, Dhaka.

BARI (Bangladesh Agricultural Research Institute), 2012. Annual report. Bangladesh Agricultural Research Institute, Gazipur, Bangladesh.

Barkat, A., Ara, R., Taheruddin, M., Hoque, S., Islam, N., 2007. Towards a feasible land use policy of Bangladesh. Human Development Research Centre, Dhaka.

Barma, N.C.D., Saifuzzaman, M., Hossain, A.B.S., Rahman, M.R., Saha, N.K., Rawson, H.M., 2011. Breeding wheat for heat and salt tolerance in southern Bangladesh *In*

Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

BBS & CPD, 2008. Growth, Income Inequality and Poverty Trends in Bangladesh: Implications for Development Strategy, Addressing Regional Inequalities: Policy Options and Strategies, CPD, Dhaka.

BBS (Bangladesh Bureau of Statistics), 2010a. Statistical Yearbook of Bangladesh 2009. Bangladesh Bureau of Statistics, Dhaka.

BBS, 1993. Population Census by Bangladesh Bureau of Statistics (BBS), 1993.

BBS, 2010b. Yearbook of Agricultural Statistics of Bangladesh, June 2010, Dhaka.

BBS, 2011. Report on Sample Vital Registration System-2010, October 2011, Dhaka.

BBS, 2011a. 2010 Yearbook of Agricultural Statistics of Bangladesh. Bangladesh Bureau of Statistics, Dhaka.

BBS, 2011b. Population and Housing Census 2011,Community Report, June 2012, Dhaka.

BBS, 2011c. Census of Agriculture 2008, National Series: Volume 1-4: Cropping Patterns, May 2011, Dhaka.

BCAS (Bangladesh Center for Advanced Studies), 2010. Assessing Long-term Impacts of Vulnerabilities on Crop Production Due to Climate Change in the Coastal Areas of Bangladesh, November, Dhaka

BCAS (Bangladesh Center for Advanced Studies), 2011. Planning and costing agriculture's adaptation to climate change in the salinity-prone cropping system of Bangladesh. International Institute for Environment and Development (IIED), London, UK.

BCAS, 1994. Vulnerability of Bangladesh to climate change and sea level rise: concepts and tools for calculating risk in integrated coastal zone management, Vols 1 & 2. Technical Report, Bangladesh Center for Advanced Studies, Dhaka.

BGS (British Geological Survey), 1999. Groundwater Studies for Arsenic Contamination in Bangladesh. Main Report and Supplementary Volumes 1-3. Dhaka, Bangladesh.

BIDS, 1998. An Input-output Table from Bangladesh Economy, 1993-94, Planning Commission, Dhaka

BRAC, 2009. Post-SIDR Livelihoods Rehabilitation: Final Report. BRAC, Mohakhali, Dhaka.

BRAC, 2011. Crop Intensification for Achieving Food Self-Sufficiency in the Coastal Regions of Bangladesh. Interim Narrative Report: 1st April-30th June 2011. BRAC, Mohakhali, Dhaka.

BRRI (Bangladesh Rice Research Institute), 2012. Annual report. Bangladesh Rice Research Institute, Gazipur, Bangladesh.

BWDB, undated. Integrated Planning for Sustainable Water Management, Bangladesh Water Development Board.

Carberry, P.S., 2011. Increased Rabi-season cropping in southern Bangladesh: an overview of this ACIAR project In Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp

CEGIS & IWM, 2007. Investigating the Impact of Relative Sea-Level Rise on Coastal Communities and their Livelihoods in Bangladesh, Final Report, June, Dhaka.

Crimp, S., Laing, A., 2011. Climate trend in Bangladesh. ACIAR Climate Change Adaptation Project Annual Report 2010/11, Vol. 2, Appendix 5.

Dalgliesh N.P., Poulton P.L., 2011. Physical constraints to cropping in southern Bangladesh: Soil and water. *In* Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

Davies, J., 1989. The pilot study into optimum well design: IDA 4000 Deep Tubewell 2 Project, v. 2, The geology of the alluvial aquifers of Central Bangladesh. British Geological Survey Technical Report WD/89/9.

Davies, J., 1994. The hydrogeologichemistry of alluvial aquifers in central Bangladesh.

Davies, J., Exley, C., 1992. Hydrochemical Character of the Main Aquifer Units of Central and North-eastern Bangladesh and possible toxicity of groundwater to fish and humans. BGS Technical Report WD/92/47R.

Deb, U., Hoque, Z., Nafisa, K., Bairagi, S.K., 2008. Growth, Income Inequality and Poverty Trends in Bangladesh: Implications for Development Strategy, Addressing Regional Inequalities: Policy Options and Strategies, CPD, Dhaka.

Doorenbos, J., Kassam, A.H., 1979.Yield response to water. FAO Irrigation and Drainage Paper No. 33. Rome.

ECOMAC, 2008. Economic Risk Assessment Report of the Coastal Livelihoods, Dhaka.

EGIS, 2001. Integrated environmental management, a case study on shrimp-paddy landuse strategies in the southwest region.

Epstein, E., Norlyn, J.D., Rush, D.W., Kingsbury, R., Kelley, D.B., Cunningham, G.A., Wrona, A.F., 1980. Saline culture of crops: a genetic approach. Science 210, 399-404.

ESCAP, 1987. Coastal Environmental Management Plan for Bangladesh. United Nations Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand.

Faisal, I.M., Parveen, S. 2004. Food security in the face of climate change, population growth, and resource constraints: Implications for Bangladesh. Environmental Management 34 (4):487-498.

FAO, 1988. Land resources appraisal of Bangladesh for agricultural development report 3(1), Rome, Italy

FAO, 2007. http://www.fao.org/fileadmin/templates/ess/documents/meetings_and_workshops/manilla06/final_country_reports/bangladesh/bangladesh_cr_full_document.doc

Firoz, A.B.M. 2010. Groundwater Management in the South-West Coastal Aquifer of Bangladesh. Master Thesis. University of Applied Sciences Cologne, Germany, Institute for Technology and Resource Management in the Tropics and Subtropics.

GoB (Government of Bangladesh) 2002. Report of the groundwater task force, Ministry of Local government, Rural Development & Co-operatives, Local Government Division, Government of the Peoples Republic of Bangladesh.

GoB (Government of Bangladesh) 2010. Outline Perspective Plan of Bangladesh 2010-201: Making Vision 2021 a Reality. Final Draft, General Economic Division, Planning Commission, Government of the People's Republic of Bangladesh.

GoB (Government of Bangladesh) 2011. 6th Five Year Plan: FY 2011 – FY 2015. General Economic Division, Planning Commission, Government of the People's Republic of Bangladesh.

GoB (Government of Bangladesh) and GoN (Government of the Netherlands), 2012. BLUE GOLD: Program for Integrated Sustainable Economic Development by improving the Water and Productive Sectors in selected Polders. Program Document available at http://bangladesh.nlembassy.org/binaries/content/assets/postenweb/b/bangladesh/netherlands-embassy-in-dhaka/import/wpp/tender-aug-2012/blue-gold---program-document-30aug12-final.pdf

Haque, A.K.M.M., Jahan, M.S., Azad, M.A.K. 2010. Shrimp culture impact on the surface and groundwater of Bangladesh. Iranian Journal of Earth Sciences, 2: 125-132.

Haque, S.A. 2006. Salinity problems and crop production in coastal regions of Bangladesh. Pak. J. Botany. 28 (5): 1359-1365

Hoque, S.A.K.M., 1997. Drainage and flood problems in Bangladesh: Environmental challenges and options. 7th ICID International Drainage Workshop. Malaysian National Committee on Irrigation and Drainage, Penang, Malaysia.

Hossain, S. 2012. Saline affected Kalapara green again with crops: farmers use sweet water stored in canals. The Daily Star, Monday April 30, 2012, Dhaka.

Huq, S., 1999. Vulnerability and adaptation to climate change for Bangladesh. Dordrecht ; Boston, Kluwer Academic Publishers.

Hussain, S.K., Iqbal, A. (Eds), 2011. Research Priorities in Bangladesh Agriculture. Bangladesh Agricultural Research Council, Farmgate, Dhaka.

Islam, K. M Nabiul & Islam, M. Nazrul 2012. *Employment in Bangladesh Manufacturing Sector: Pattern and Implications for Poverty Reduction,* Chapter 2, BIDS (Forthcoming).

Islam, K. M. N., 2011. Expenditure Tracking on Disaster Management Projects: The Role of Parliament Members, BIDS, PROGATI/USAID, Dhaka.

Islam, K. M.N. et al., 2009. Benefit Monitoring and Evaluation (BME), Main Report, BIDS, Dhaka.

Islam, M.R., 2004. Where land meets the sea: a profile of the coastal zone of Bangladesh, Published for Program Development Office for Integrated Coastal Zone Management Plan (PDO-ICZMP), Water Resources Planning Organization (WARPO), University Press, Dhaka

Islam, M.R., Ahmad, M., Huq, H., Osman, M.S., 2006. State of the Coast 2006. Integrated Coastal Zone management Program, Water Resources Planning Organization, Ministry of Water Resources, Dhaka, Bangladesh.

Islam, M.S., Akanda, A.R., Islam, M.N., Mondol, A.I., Akhand, N.A. (Eds.), 2008. Development of Integrated Salinity Management Techniques for the Coastal Ecosystem of Bangladesh. Final Report, Irrigation and Water Management Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh.

Islam, Q. R., 2012. Who will bear the responsibility of losses incurred by farmers?, The Daily Prothom Alo, 18 October 2012, Dhaka

Islam, T. Peterson, R.E., 2009. Climatology of tropical landfalling cyclones in Bangladesh 1877-2003. Journal of Natural Hazards 48, 115-135.

IWM and CEGIS, 2007. Investigating the Impact of Relative Sea Level Rise on Coastal Communities and their Livelihoods in Bangladesh. Dhaka, Institute of Water Modelling and Center for Environmental and Geographic Information Services.

IWM, 2005. Impact assessment of climate change on the coastal zone of Bangladesh. Final Report, Institute of Water Modelling, Dhaka, Bangladesh, 37p.

IWM, 2012. Bathymetric Survey for Pre-Work and Post-Work Measurement of dredging for Gorai River Restoration Project (Phase-II). Institute of Water Modelling, Dhaka, Bangladesh.

Jahiruddin, M., 2010. Agricultural Research Priority: Vision- 2030 and beyond, land and soil resources management. Bangladesh Agricultural Research Council, Farmgate, Dhaka.

Kabir, M.J., Rawson, H. M., 2011. Economics of Rabi crops and common rotations. In Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp

Karim, M.F. and Mimura, N. 2008. Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. Global Environmental Change 18, 490-500.

Karim, M.R. 2006. Brackish water shrimp cultivation threatens permanent damage to coastal agriculture in Bangladesh. In Environment and Livelihoods in Tropical Coastal Zones: Managing Agriculture-Fishery-Aquaculture Conflicts. C.T. Hoanh, T.P. Tuong, and J.W. Gowing (eds.) 61-71. UK: CABI Publishing.

Khan I.A, Afroz S., Bain, H., 2011. The challenge to increasing wheat production. Farmers' perceptions. *In* Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

Khan, I. A, Afroz, S., 2011a. Future of Rabi cropping in southern Bangladesh: Farmers' livelihoods: reality and options. *In* Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

Khan, I. A, Afroz, S., 2011b. Future of Rabi cropping in southern Bangladesh: Impact of intensified Rabi cropping on social dimensions of livelihood. *In* Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

LFS (Labour Force Survey), 2010. Report on Labour Force Survey, Bangladesh Bureau of Statistics, Statistics Division, Ministry of Planning, Dhaka.

Madsen, H., Jakobsen, F., 2004. Cyclone induced storm surge and flood forecasting in the northern Bay of Bengal. Coastal Engineering 51 (4), 277–296.

McGuire, P.E., Dvorak, J., 1981. High salt tolerance in wheat grasses. Crop Sci 21: 702-5.

Mirza, M.M.Q., Warrick, R.A., Eriksen, N. J. 2003. The implications of climate change on floods of the Ganges, Brahmaputra and Meghna rivers in Bangladesh. Climatic Change 57: 287–318, 2003.

MoEF, 2008. Bangladesh Climate Change Strategy and Action Plan 2008. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh. xvi + 68 pp.

Mohal, N., Khan, Z.H., Rahman, N., 2006. Impact of Sea level Rise on Coastal Rivers of Bangladesh. Proceedings of the International River Symposium, Brisbane, Australia.

Mondal, M.K., 2001. Development of sustainable salinity management techniques and their environmental impact assessment on the coastal ecosystem of Bangladesh.

Mondal, M.K., Tuong, T.P., Sattar, M.A. 2008. Quality and groundwater level dynamics at two coastal sites of Bangladesh: implications for irrigation development. Proceedings of the International Forum on Water and Food (IFWF2), Addis Ababa, Ethiopia, 9-14 November 2008.

Monsur, M.H.,1995. An introduction to the Quaternary Geology of Bangladesh; A guide for IGCP-347, Dhaka.

MoWR (Ministry of Water Resources), 2004. Contribution of Integrated Coastal Zone Management Plan Project towards formulation of the Poverty Reduction Strategy Paper (PRSP) for BANGLADESH. Available at http://www.warpo.gov.bd/rep/prsp/prsp&iczmp.PDF.

MoWR, 2005. Government of the People's Republic of Bangladesh. 2005. Coastal Zone Policy. http://www.warpo.gov.bd/pdf/czpo_eng.pdf

MoWR, 2006. Coastal Development Strategy. Approved at the 2ns meeting of the Inter-Ministerial Steering Committee on ICZMP held on February 13, 2006. Water Resources Planning Organization, Dhaka, Bangladesh). http://www.warpo.gov.bd/pdf/coastalDevPolicy.pdf

MPO.,1986. Groundwater Resources of Bangladesh. Technical Report No. 5. Master Plan Organization, Dhaka, Harza Engineering USA in association with Sir MacDonald and Partners, UK., Meta Consultant, USA and EPC Ltd. Dhaka.

Munns, R., Greenway, H., Delane, R., Gibbs, J., 1982. Ion concentration and carbohydrate status of the elongating leaf tissue of *Hordeum vulgare* growing at high external NaCl. II Cause of the growth reduction. Journal of Experimental Botany 33, 574-583.

Nasiruddin, M., Hassan, M.S., 2009. Agricultural Research Priority: Vision- 2030 and beyond, Rice. Bangladesh Agricultural Research Council, Farmgate, Dhaka.

NWMP, June 2001. National Water Management Plan (NWMP), WARPO. Annex-B: Development Strategy.

O'Donnell, M., Islam, N., Islam, T., Rahman, S., Khondkher, R. Hedger, M., Lee, J., 2012. Bangladesh Climate Public Expenditure and Institutional review (CPEIR), Planning Commission, Dhaka

Panigrahi, B., Panda, S.N., Mull, R., 2001. Simulation of water harvesting potential in rainfed ricelands using water balance model. Agricultural Systems 69: 165-182.

Poulton P.L. 2011 Physical constraints to cropping in southern Bangladesh: Land availability. *In* Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

Poulton P.L., Rawson H.M., 2011. Physical constraints to cropping in southern Bangladesh: Climate. *In* Rawson H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

Progotir Pathey, 2009. Volume 1: Technical Report, BBS and UNICEF, June 2010, Dhaka.

Quasem, A., 2011. Conversion of agricultural land to non-agricultural uses in Bangladesh: Extent and determinants. Bangladesh development Studies, Vol XXXIV. March 20011, 1.

Quasem, M. A., 1999. Maize Production and Marketing in Bangladesh: An Indicative Exercise, BIDS-IFPRI, Dhaka.

Quddus, M.A., 2009. Crop production growth in different agro-ecological zones of Bangladesh. J. Bangladesh Agril. Univ. 7(2): 351-360

Rahman, M.L., Chowdhury, M.A.Z., 2010. Agricultural Research Priority: Vision- 2030 and beyond, Pulses and Oil Crops. Bangladesh Agricultural Research Council, Farmgate, Dhaka.

Rahman, R. I. Shaha, B. K.,1999. *BIDS-ESGKF Survey*, Dhaka.

Rahman, S. 2010. Six decades of agricultural land use change in Bangladesh: Effects on crop diversity, productivity, food availability and the environment, 1948-2006. Singapore Journal of Tropical Geography. 31 (2): 254-269

Rashid, M.A. 2010. Groundwater potentiality for rice production in coastal saline areas of Bangladesh. Paper presented at the International Rice Congress in Hanoi, Vietnam. http://ricecongress.com/previous/pdflink/4282.pdf

Rawson, H.M. (ed), 2011. Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

Rawson, H.M. Begg, J.E. Woodward, R.G., 1977. Effect of atmospheric humidity on photosynthesis, transpiration and water use efficiency of leaves of several plant species. Planta 134, 5-10.

Rawson, H.M. Carberry, P.S. Hossain, A.B.S. Saifuzzaman, M., 2011. Background to wheat in southern Bangladesh: The challenge to increasing wheat production. In Rawson, H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

Rawson, H.M., Gomez-Macpherson, H., Hossain, A.B.S., Rashid, H., Saifuzzaman, M., Sufian, M.A., Samad, M.A., Sarker, A.Z., Ahmed, F., Talukder, Z.I., Rahman, M., Siddique, M.M.A.B., Hossain, I. and Amin, M., 2007. On-farm wheat trials in Bangladesh: a study to reduce perceived constraints to yield in traditional wheat areas and southern lands that remain fallow during the dry season. Experimental Agriculture 43, 21–40.

Rawson, H.M., Munns, R., 1984. Lef expansion in sunflower as influenced by salinity and short-term changes in carbon fixation. Plant Cell and Environment 7, 207-13.

Rawson, H.M., Richards, R.A., Munns, R. 1988. An examination of selection criteria for salt tolerance in wheat, barley and triticale genotypes. Australian Journal of Agricultural Research 39, 759–772.

Richards L.A. (ed), 1954. Diagnosis and improvement of saline and alkali soils. Washington D.C. 160 pp.

Richards, R.A., 1983. Should selection for yield in saline conditions be made on saline or non-saline soils? Euphytica 32 431-8.

Saifuzzaman, M., Rawson, H.M., Hossain, A.B.S., Barma, N.C.D., Huq, M. I., Islam, M. M., Farhad, M., Uddin, M. H., Rahman, M. S., Haque, M. E., 2011. Optimising wheat production through research: Best time window for southern farmers to grow wheat. In Rawson, H.M. (ed) Sustainable intensification of Rabi cropping in southern Bangladesh using wheat and mungbean. ACIAR Technical Reports No. 78. Australian Centre for International Agricultural Research: Canberra. 256 pp.

Sarwar, 2005. Impacts of Sea Level Rise on the Coastal Zone of Bangladesh, M.Sc. Thesis, by Md. Golam Mahabub Sarwar, Lund University, Sweden

Sen, B., Ali, Z., 2009. Spatial Inequality in Social Progress in Bangladesh, The Bangladesh Development Studies, Vol. XXXII, No. 2, June 2009, Dhaka.

SERDI (Socio Economic Research and Development Initiative), 2012a. Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Laos, Bangladesh and India, Living document No. 3, Report on a Household Survey

SERDI, 2012b. Developing multi-scale climate change adaptation strategies for farming communities in Cambodia, Laos, Bangladesh and India, Living document No. 3, Self Assessment Field Reports on Farmers' Adaptive Capacity to Climate Change.

Slavich P.G., Petterson, G.H., 1993. Estimating the electrical conductivity of saturated paste extracts from 1:5 soil, water suspensions and texture. Australian Journal of Soil Research 31, 73-81

SRDI (Soil Resource Development Institute), 2012. Saline Soils of Bangladesh, Ministry of Agriculture

SRDI, 1998). Soil salinity map of Bangladesh, Dhaka.

SRDI, 2001. Soil and Water Salinity Monitoring Report, Khulna-Barisal division , 1998-2000.

SRDI, 2009. Saline Soils of Bangladesh by Soil Resources Development Institute, Dhaka, Bangladesh

SRDI, 2010. Saline Soils of Bangladesh by Soil Resources Development Institute, Dhaka, Bangladesh

Streatfield, P. K., Karar, Z.A., 2008. Population challenges for Bangladesh in coming decades. J. Health Popul. Nutr. 26 (3): 261-272

Sultana, N., 2011. Women in rural agricultural livelihoods. In. Rawson, H (ed.) Sustainable Intensification of Rabi Cropping in Southern Bangladesh using Wheat and Mungbean. ACIAR Technical Reports 78, Australian Centre for International Agricultural Research, Canberra. 256 pp.

The Daily Star, 2012. No farmland to be left after 90 years. The Daily Star, Thursday July 12, 2012.

Tuong, T.P., Hoanh, C.T., PN10 Project Team. 2009. Managing Water and Land Resources for Sustainable Livelihoods at the Interface between Fresh and Saline Water Environments in Vietnam and Bangladesh. CPWF Project Report submitted to the Challenge Program on Water and Food (CPWF). Los Baños, Laguna, Philippines: International Rice Research Institute and Partner Organizations.

Umitsu, M., 1993. Late Quaternary sedimentary environments and landforms in the Ganges Delta. Sedimentary Geology, v.83, p.177-186.

UN Population Division, 2010. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2010 Revision, http://esa.un.org/unpd/wpp/index.htm

USAID, 2011. http://transition.usaid.gov/bd/programs/food_sec.html

WARPO, 2000. National Water Management Plan Project - Draft Development Strategy, Volume No. 4, Annex C: Land and Water Resources. Ministry of Water Resources, GOB.

World Bank, 2004. Bangladesh - Water Management Improvement Project. Washington D.C. - The World Bank. http://documents.worldbank.org/curated/en/2004/01/2948631/bangladesh-water-management-improvement-project

World Bank, 2010. Implications of Climate Change for Fresh Groundwater Resources in Coastal Aquifers in Bangladesh. The World Bank, Washington, USA.

World Bank, 2011. Bangladesh: Priorities for Agriculture and Rural Development. http://go.worldbank.org/770VR4DIU0

Ziauddin, A.T.M., Ahmmed, S., 2010. Agricultural Research Priority: Vision- 2030 and beyond, Farm Machinery, Irrigation & Water Management and Post-harvest Technology (Engineering aspects). Bangladesh Agricultural Research Council, Farmgate, Dhaka.

12 Appendixes

12.1 Appendix A: Stakeholders consultation report

Objectives

- Conduct a series of meetings with stakeholders from Bangladesh Government organisations, the private sector and NGOs to establish relationships and to obtain information on active and planned Government and donor agency funded projects and development activities for the region.
- Consultations with key stakeholders, research organizations, NGOs, on the constraints and opportunities for the region.
- Discussions with local partners (IWM and CEGIS) on the draft report and suggestions for improvement.

Report Summary

We met representatives from 15 organisations, covering a wide range of interests from research to implementation, from water and crops to social and economic.

The main findings are:

1. The hydro-geology and hydrology of the coastal areas are very complex and is affected by the tidal surge, cyclone, and surface water withdrawal in the upstream (particularly in the south-west region due to the construction of Farakka Barrage) by climate change during recent period.

2. Water and salinity are the main constraints to the intensification of the cropping systems. The problems are not similar everywhere. We need to divide the region into several zones and look for solution applicable to the respective zone.

3. Water related problems are multi-faceted. These are unavailability of freshwater for irrigation at the right time in some areas, transportation of fresh water to the field from areas where it is available, lack of water storing facilities, lack of information, policy and initiative to store water where storage facilities such as ponds, streams, channels, etc., lack are available or perceived lack of fresh groundwater for irrigation, water logging in the field due to drainage congestion and gradual movement of saline water front towards inland.

4. There is a widespread agreement that soil salinity is increasing and is making the land unsuitable for cultivation.

5. There are socio-economic constraints to intensification such as lack of marketing facilities and infrastructure particularly for the dry season non-rice rabi crops. Polder management, agriculture versus shrimp farming and land ownership are also important factors.

6. Crop intensification efforts are mostly limited to screening, field testing, demonstration and extension of salt tolerant varieties. A great deal of further research is still needed for proper long term field evaluation of salt tolerant crops and vegetables. However, there is a view that this is a never ending process as the salt tolerant varieties which are now suitable may no longer be suitable after few years in the same location due to increased soil salinity. So while the development of salt-tolerant varieties is essential, controlling or reducing salinity is also very important as well.

7. There are no studies to review which evaluated soil-salinity-water-plant relationship in an integrated manner. In many areas, crops tap into the saline groundwater table causing secondary salinisation. This may have long-term environmental consequences. Many

organizations emphasised lack of good studies on water availability and management for agriculture in the coastal region.

8. Intensification of agriculture and increasing production in the coastal area is a high priority agenda of the government and the policy makers to secure food for increasing population. A master plan “Master Plan for Agriculture for Coastal Region” is under way. This FAO funded master plan is led by Dr Z Karim (who was the former Executive Chairman of BARC and Secretary).

Mohammed Mainuddin and Riasat Ali visited Bangladesh during 25 August to 02 September, 2012. In Bangladesh, they were joined by Mac Kirby and Onil Banerjee who are engaged in a scoping study focusing on food security in the Eastern Gangetic Plains, particularly the northwest region of Bangladesh. Most of the meetings with Bangladeshi organisations involved discussion of both scoping studies. In this report we mostly deal with discussions about the scoping study for crop intensification in south-western coastal Bangladesh. The food security study visit is reported separately by Mac and Onil. Mac and Mainuddin also held some separate meetings for the Bangladesh Integrated Water Resources Assessment Study which is currently underway with Bangladeshi partners (the meetings for this study are also reported separately).

The format for each meeting was the same. Mac introduced the food security project and its aims in the meeting. This was followed by a discussion on issues in northwest Bangladesh. Mainuddin then introduced the southwest scoping study which was followed again by discussions.

We travelled from Australia to Dhaka on August 25, 2012 and arrived in Dhaka by midnight.

Sunday 26 August

Water Resources Planning Organization (WARPO)

1. Saiful Alam, Principal Scientific Officer, Water Resources

2. Dr Aminul Huq, Principal Scientific Officer, Agriculture

Following an introduction by Mainuddin, Saiful described his view on salinity issues in the coastal region of Bangladesh.

Due to Farraka Barage, constructed on the river Ganges in India, river flow during the dry season has decreased which has reduced flow into the Gorai Distributary. Gorai Distributary is a main feeder channel to keep salinity below a certain level in the stream. Due to low flow, salinity is gradually increasing and moving upstream in the dry season. Bangladesh Government’s planned Ganges (Padma) Barrage may increase flow in the river and keep saline front away.

Tidal surge is causing soil salinity. However, there are areas outside the tidal surge which are also saline and the reason is unknown. No detailed modelling has been conducted to identify the causes of salinity development. It is widely perceived that shrimp farming is one of the reasons for increasing soil salinity.

Saiful informed that a FAO funded master plan “Master Plan for Agriculture for Coastal Region” is currently being prepared under the leadership of Dr Z Karim (who was the former Executive Chairman of BARC and Secretary). A draft plan has been circulated to selected people for comments.

Bangladesh Centre for Advanced Studies (BCAS)

1. Prof Dr Syed Anwarul Haque (anwarul.haque@bcas.net), Senior Agricultural Specialist

2. Khandaker Mainuddin (khandaker.mainuddin@bcas.net), Senior Fellow

3. Dr Dwijen L Mallick (dwijen.mallick@bcas.net), Director and Senior Fellow

BCAS has a very climate-centric view. They think that coastal zone is badly affected by climate change. Climate change factors are tidal surge, sea level rise, erratic rainfall, etc. In their view, the main constraints to cropping intensification are:

- Adoption and extension of salt tolerant varieties of crops
- Lack of knowledge and education
- Varieties once worked are not working now because of high salinity
- Capillary rise of saline groundwater (which they term as a major problem) as the groundwater level is near the sea level
- Waterlogging of fields due to drainage congestion
- Lack of embankment protection or effective polder management
- Financial constraints
- Lack of economic development of the area

Due of poor knowledge of salinity management, many farmers are using more fertilizer in salt-affected land to achieve higher yield. Surprisingly some farmers have applied sugar assuming it neutralizes salinity and helps achieve a higher yield.

Soil salinity has also affected livestock production in the area; it has been declining gradually due to a lack of natural grass for livestock grazing.

Centre for Environmental and Geographic Information Services (CEGIS)

1. Shahidul Islam (sislam@cegisbd.com), Director, Remote Sensing Division

2. Motaleb Hossain Sarker (msarker@cegisbd.com), Director, Ecology Division

CEGIS is a collaborator in the scoping study and both Motaleb and Shahidul are the main individuals providing inputs into the study. They have already detailed the constraints and opportunities in their report for the scoping study. We discussed this draft report and suggested some additional work and modifications.

Shahidul and Motaleb also briefed us about their projects in the coastal region relevant to our scoping study. They are involved in a project entitled “climate change impact on rice in drought prone area and saline area of Bangladesh” funded by Norway. Another multinational (Bangladesh, Nepal and Pakistan) study about climate change impacts on food security is also relevant to our study to some extent. They are using the SWAT model plus DSSAT, together with climate change scenarios, to examine cropping adaptations and policy across the Ganges and throughout Bangladesh. In Bangladesh, 3 areas have been selected for the detailed work but will model the impacts across the whole country.

Monday 27 August

Bangladesh Institute of Development Studies (BIDS)

1. Dr K M Nabiul Islam (nabiul@bids.org.bd), Senior Fellow

Nabiul is involved in this scoping study and provides input about the socio-economic issues of the coastal region. He has submitted a report containing constraints and opportunities for cropping intensification, researchable issues and the potential economic, social and livelihood benefits for intensification. He highlighted the following issues during the meeting.

- A comparative analysis of coastal area and non-coastal area
- There is an ample scope to increase the irrigated area

- There are huge structural problems in the polders
- About 90 to 95% of the polders need an upgrade and redesign by increasing embankment heights, change of structures, etc.
- Severe storm surge destroy and increase salinity
- BADC study on salinity intrusion in the coastal aquifers
- Operation and maintenance of the polders is a problem. No donor funds O&M but there are funding opportunities available for new projects.
- Cropping intensification has potential disadvantages to livestock: no fallow land for grazing
- There are environmental adverse impacts as well such as pollutions due to fertilizer and pesticides use, green-house gas emission, etc.

According to Nabiul, the main constraints to intensification are:

- Lack of water, and
- Lack of marketing facilities.

Labour shortage is another problem due to which farmers are interested in shrimp farming than rice as only 1 labourer is required for 1 bigha (1/3 of an acre) of shrimp farming compared to 12 labourers for rice.

SAARC Agriculture Centre (SAC)

1. Dr Abul Kalam Azad (director@saarcagri.net), Director

2. Dr Ibrahim Md. Sayed, Coordinator of the SAARC-Australia project

3. Dr M Nurul Alam, Senior Program Specialist

4. Dr Niaz Uddin Pasha, Senior Technical Officer

5. Golam Mustafa

6. M. Nure Alam Siddique

7. Md. Abdullah

SAARC Agriculture Centre is a regional centre of SAARC (South Asian Association for Regional Cooperation). The member countries of SAARC are Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. They are mandated to work only on multi-country projects within SAARC. Our scoping study considers only the coastal area of Bangladesh so was not a part of the discussion. Discussion focused only on the food security scoping study.

Tuesday 28 August

Bangladesh Agricultural Research Council (BARC)

1. Dr Wais Kabir (ec-barc@barc.gov.bd), Executive Chairman

2. Dr Engr A A Hassan (md-nrm@barc.gov.bd), Irrigation and Water Management Specialist, Member Director, Natural Resources Management, , Bangladesh Agricultural Research Council (BARC)

3. Dr Engr Sultan Ahmmed (s.ahmmed@barc.gov.bd), Chief Scientific Officer, Natural Resources Management

BARC considers water as a main constraint to cropping intensification in the coastal area. The issues related to water are:

- Availability of water for irrigation
- Drainage congestion

- Increasing salinity of water.

BARC emphasised a lack of good studies on water availability and management for agriculture in the coastal region. Understanding hydrology of the coastal area is complex and need good studies. They referred to the study on salinity intrusion in the inland aquifers completed by the BADC and stressed the need of a buffer zone in the coastal region for the preservation of groundwater. For proper studies in the coastal region, project design is important and should consider the following:

- Shrimp farming versus crop cultivation
- Socio-economic conditions
- Market opportunities (due to less market opportunities, farmers are not interested to grow dry season crops).
- Water harvesting
- Climate change (has impacts on salinity build up).
- Erratic rainfall
- Tidal flood
- Drainage congestions due to polders
- Infrastructure development
- Land tenure issues
- Water harvesting for small farmers.

According to their land suitability mapping, some of the northwest is not suitable for boro rice production – yet it is the main area of boro rice. The government is now trying to reduce dry season cropping in the northwest and shifting production to the southwest coastal region. To facilitate this BARC has published a book titled “use of fallow land in the southern region and planning for crop production” in 2011. We were given a copy of this book.

Bangladesh Agricultural Development Corporation (BADC)

1. Dr Md Eftekharul Alam (eftekharalam@yahoo.com), Chief Engineer, Minor Irrigation Information Services Unit

2. Md Luftor Rahman (engrluftor@gmail.com), Assistant Chief Engineer, Minor Irrigation Information Services Unit

BADC is an implementing agency for agricultural development, with a former role in sourcing, storing and distributing inputs such as fertiliser. They also used to install and own tubewells. This role has been transferred to another agency that oversees spatial management and dissemination of technology.

BADC sees groundwater decline as a critical issue. BADC have monitored 3,000 wells, first fortnightly then automatically at higher frequency, for the last five to six years. This provides an alternative and possibly higher quality data resource than the BWDB monitoring. We have purchased the data. The monitoring shows the decline of groundwater, especially in the northwest. They also monitor groundwater salinity, and have shown that groundwater salinity has been increasingly near the coast.

The command area of DTW was 26 ha initially which has now reduced to 16 ha. Due to inefficient use of irrigation, 800,000 more irrigation equipments (shallow and deep tubewells) are in operation. Currently, there are about 1,600,000 equipments, though as of BADC estimates only 800,000 are required.

Bangladesh Water Development Board (BWDB)

1. Mollah Ruhul Alam, Additional Director General (Planning)

2. Md. Salim Bhuiyan (bhuiyan_salim@yahoo.com), Chief Planning

3. Amirul Hossain (Amirulbd63@yahoo.com), Executive Engineer, Flood Forecast and Warning Centre

BWDB is engaged in the Ganges Barrage Project which will have an impact on coastal salinity and agriculture. A MOU with a Chinese firm has been signed for the construction of the Ganges barrage to raise water level and enable surface water irrigation of 1.9 million hectares of land. The barrage will also be used to produce 160 megawatts of power. Barrage will increase the flow particularly in the dry season at the Gorai and other channels which will push the saline water further downstream. This will also increase freshwater availability for irrigation. The recent dredging of the Gorai mouth has increased the fresh water flow and has reduced salinity at Sundarban from 16 ppt to 2 ppt.

We also made a courtesy call to the Director General of BWDB Eng. K A M Shahiduzzaman.

Wednesday 29 August

Bangladesh Rural Advancement Committee (BRAC)

1. Professor W M H Jaim (jain.wmh@brac.net), Director, Research and Evaluation Division

2. Dr Md Sirajul Islam (sirajul.i@brac.net), Head, Agriculture and Food Security Programme

3. Dr Nepal Chandra Dey (Nepal.cd@brac.net), Research Fellow

4. Mr Alamgir

BRAC has a very active agriculture and aquaculture program in the coastal region. They introduced new crop varieties such as hybrid and HYV boro rice, HYV and hybrid aman and aus, and salt tolerant maize and sunflower. As there is no market for sunflower, BRAC has a refinery program to buy and produce sunflower oil. Sunflower is a deep-rooted crop so it has the potential to tap into the saline groundwater table and increase root zone salinity. There is no monitoring of salinity movement during the field trials. The focus is on the ‘short-term’ benefit of getting good yield of some crop without looking at the long-term environmental consequences on the land and sustainability.

Salinity and water availability is a major problem in the region according to BRAC. There is potential to store the river water in canals where it is fresh. Surface water was not utilized to its potential and this has contributed to the disappearance of small channels, streams and natural canals. There is no initiative to re-excavate the canals and streams. BRAC informed that Government is directing attention now to the southern area. This is the region where surface water for irrigation can be used though there is salinity in some areas.

Thursday 30 August

Bangladesh Agricultural Research Institute (BARI)

1. Dr. Md. Rafiqul Islam Mondal (dg.bari@bari.gov.bd), Director General

2. Dr. Md. Abdul Jalil Bhuiyan (dir.ss@bari.gov.bd), Director (Support and Service)

3. Dr Mukhlesur Rahman, Director (Training)

4. Dr Kamal Humayun Kabir, Director (research)

5. Shadat Hossain (sahadat.cso.bari@gmail.com), Chief Scientific Officer and Head, Agricultural Economics Division

6. Pijush Kanti Sarkar, Principal Scientific Officer (PSO) and Head, Irrigation and Water Management (IWM) Division

7. Dr Naresh Ch Dev Barma, PSO, Wheat Research Centre (WRC)

8. Dr Abdur Razzaque Akanda, PSO, IWM Division

9. Dr Md Saifuzzaman, retired PSO, WRC

10. Dr Abdur Rashid, SSO, Agricultural Economics Division

11. Dr Sujit Kumar Biswas, SSO, IWM Division

12. Amir Choudhury, SSO, On-Farm Research Division

Following are the points that came up during the discussion:

- In the coastal region, most farmers are share croppers and the decision for cropping depends on the land owner. There are also absentee land lords (who are not residing in the area) who are not available for a cropping discussion at the right time.
- There is a lack of marketing facilities for the dry season non-rice crops which is a potential constraint to intensification.
- Shrimp farming is extensive which is affecting the crop cultivation.
- There is a shortage of fodder for livestock. BARI is working on the introduction of salt tolerant cowpea and soybean in the fallow areas.
- There are a lot of ponds and ditches in the area that can be used for rain water harvesting and irrigation of low water requirement crops with some rehabilitation. However, there may be an issue of accessibility as ponds owner may not be the farmer. BARI had some water harvesting experiments.
- There are also a large number of natural channels, steams and canals that can be used as water storage for dry season irrigation. Currently there is a government program for rehabilitation of the canals.
- Apart from high salinity area, there is about 1 million ha of low saline area that can be used for crop cultivation.
- There are widespread waterlogging problems due to poor drainage system in the region. BARI is trying to find waterlogging tolerant crops and varieties. They have introduced waterlogging tolerant maize in some areas.
- Rabi crops cannot be sown before 15 December because of waterlogged soils. Soil is not ready for sowing until then.
- Most crops can be grown if the salinity is below 5 dS/m. There is a need for education and extension for the farmers. Involvement of extension worker should be from the beginning of the research project.
- There is a potential to introduce triticale as fodder. Maize may not be suitable. BARI studies the adoption of mungbean in the region.
- Long duration rice crop should be replaced with short duration crop to make the land available for rabi crops.

Bangladesh Rice Research Institute (BRRI)

1. Dr. Md. Shamsher Ali (dr@brri.gov.bd), Director (Research)

2. Dr Engr. Md. Abdur Rashid (arashidiwm@yahoo.com), Chief Scientific Officer and Head, Irrigation and Water Management Division

3. Mr Md Maniruzzaman, SSO, IWM Division

4. Dr Jatish Chandra Biswas, PSO, Agronomy Division

5. Dr Mahbubul Alam, SSO, IWM Division

6. Md. Hazrat Ali, Rice Farming System Division

7. Md Rafiqul Islam, Adaptive Research Division

8. Abdus Salam, Agricultural Economics Division

The following points were discussed during the meeting.

- The main problem in the coastal region is water. Water is an over-riding factor for coastal agricultural intensification. There is fresh water in the rivers and streams particularly in the south-central (Barisal and Patuakhali region) area but due to conveyance problem it is not used. The crop fields away from the streams cannot utilize water. There is also a shortage of low lift pumps (LLP) that are used to pump water from the rivers and streams to the field or channels. Excavation and rehabilitation of the canals is also needed.
- Waterlogging or drainage congestion is another water related problem. This creates problems of harvesting. Need mechanization for harvesting and seeding.
- It is necessary to understand salinity. Salinity and drainage are the major problems. Drainage is a man-made problem due to blockage of natural channels for shrimp farming.
- At 200-250 ft depth, there is groundwater having salinity 2-3 ds/m, which is suitable for irrigation. Freshwater is available from the aquifers at a depth of 500-600 ft. Fresh surface water is available until February. After that groundwater can be used or both surface water and groundwater can be used in conjunction.
- Reduce rice area in the north-west and increase production in the south is a priority of the government.
- Due to tidal fluctuation in some areas transplanting rice is delayed causing delayed harvest. Also traditional aman rice is of long duration and is harvested during January and February. Photo-sensitive variety of aman is transplanted so even early transplanting won't help. So there is not enough time to go for rabi crop.
- There is a lack of education and awareness. Farmers sometimes pump saline groundwater and irrigate field. There is no measurement of salinity by the farmers.
- Due to labor shortage the labor wages are high so farmers are not interested to grow labor intensive crops.
- The problems are not similar everywhere. We need to divide the region into several zones and look for solution applicable to the respective zone.
- Rabi crops are more profitable but too risky due to high price fluctuation. Price fluctuation in rice is lower so relatively safer to cultivate.

Sunday 2 September

Soil Resources Development Institute (SRDI)

1. Md Khurshed Alam, Director
2. Md. Delwar Hossain Mollah, PSO
3. Dr M A Bari, PSO
4. Bhidhan Kumar Bhander, PSO and In-Charge of Khulna Salinity Station
5. Gazi md Zainal Abedin, SSO
6. Nilima Akhter, SO

Following are the main points raised in the discussion.

- SRDI is a government organization and works only in the area of surface water and soil salinity. They don't monitor or work on groundwater salinity.
- Due to low flow from upstream the saline surface water front is moving inward in the southern part. Salinity intrusion is lower in the Noakhali area.
- Khulna Regional Station (located in Botiaghata sub-district) of SRDI is carrying out some works on salinity management for dry season crops. They have screened

spinach after planting on 20 February. Planting cannot be done earlier due to waterlogging in the field. Salinity of the top soil increased from 3.2 dS/m to 8.6 dS/m from January to May. The salinity of the irrigation water (water collected in the pond) was 1.8 dS/m. No salinity measurement was conducted for groundwater so the rise of salinity may be due to capillary rise of saline groundwater. They have also screened okra (planted on 27 Feb) and bitter gourd (planted on 6 March).

- They also carried out soil salinity management experiments using straw mulch, drip irrigation (using pitcher), raised bed, farm pond, and utilization of unused bunds for cropping. Using mulch both at the bottom and top of the soil reduced maximum soil salinity from 8.6 to 6.9 dS/m. This is mainly because of bottom mulch as it reduced the capillary rise of saline groundwater. Other technology has also reduced the salinity (2.7-6.9 dS/m for drip using pitcher, 1.7 to 6.9 dS/m for raised bed).
- The main constraints to intensification are waterlogging, share cropping and polder management. Where polder management is good, agriculture is good. So better polder management is critical for intensification. Market access is also a big problem though vegetables have a market and demand.
- Shrimp farming is widespread in the southwest region: there are 130,000 shrimp farms in the Khulna, Bagerhat and Satkhira districts. They are also a problem for agriculture.
- SRDI has also assessed the potential for surface water storage at the local sub-districts (Botiaghata) by surveying canals and streams. Similar survey is needed to assess the potential for surface water storage.

Institute of Water Modelling (IWM)

1. Dr AFM Afzal Hossain (afh@iwmbd.org), Deputy Executive Director (Planning and Development)

2. S M Shah-Newaz (sms@iwmbd.org), Director, Flood Management Division

3. S M Mahbubur Rahman (smr@iwmbd.org), Director, Water Resources Planning Division

4. Md Sohel Masud (msm@iwmbd.org), Director, Irrigation Management Division

5. Mr Mizanur Rahman, Senior Specialist (Hydro-geologist)

6. Dr Enamul Quader, Senior Specialist (Surface Water Hydrology)

IWM is a partner in the scoping study providing input on surface water availability and salinity, hydro-geological condition, groundwater and groundwater salinity. The report contains details on water availability and salinity condition of the region and constraints to production. The discussion was mostly on the draft report.

IWM have done some feasibility studies of potential barrages on the Ganges, Jamuna Teesta (barrage height extension). The barrages (or extensions) would allow greater surface water irrigation, in line with national policy to reduce groundwater use by increasing surface water irrigation. The Ganges Barrage will increase flow at the Gorai River which will have significant impact on salinity. IWM recently completed a study on salinity measurement in the Gorai River before and after dredging of the mouth. The results in the draft report show a significant decline in river water salinity after dredging.

Thursday, 06 September

International Rice Research Institute Country Office (IRRI, Bangladesh)

1. M A Bari, Country Manager, STRASA (Stress Tolerant Rice for Africa and South Asia) Project

During my first visit to Bangladesh during 28 April to 07 May, I visited IRRI country office and discussed the project with Dr Zainul Abedin (IRRI representative), Dr S M Abdus Sattar, and Dr Monoranjan Mondol.. IRRI has a number of on-going projects in the coastal areas which will be discussed in detail in the report.

This time, I met Dr Bari to collect a copy of the soon-to-be published report titled 'Site Suitability for Dissemination of Salt –tolerant Rice Varieties in Southern Bangladesh.

Institute of Water and Flood Management (IWFM)

Institute of Water and Flood Management (IWFM) of Bangladesh University of Engineering and Technology (BUET) pursues research and capacity development in the field of water and flood management which is vital for economic development and social prosperity of the country. Due to time constraint, we could not visit the institute. I talked to two faculty members of the Institute (Prof. Shah Alam Khan and Dr A K M Saiful Islam) earlier when I met them during a workshop on the Ganges Basin Development Challenge Projects (Ganges BDC) organized by CPWF. IWFM is a partner along with IWM on the Ganges BDC project entitled "Increasing the Resilience of Agricultural and Aquaculture Systems in the Coastal Areas of the Ganges Delta". This time S M Shah-Newaz of IWM (who is a partner in the study) had a telephonic conversation with Dr Saiful Islam on 08 September (Saturday), 2012; we have received a list of on-going and completed projects with summary and the list of master and PhD thesis titles.

IWFM has done a wide range of studies related to water management, climate change, IWRM etc. but none of them are specific to the coastal areas except the on-going BDC project.

12.2 Appendix B: Tables related to landuse and current cropping system

Table B.1 Cropping intensity in coastal districts (2000-2012)

Division name	District name	Year							% change
		2000_01	01_02	02_03	03_04	04_05	05_06	11_12	
Barisal	Pirojpur	170.94	170.99	170.51	168.87	166.26	165.82	169.00	102%
Barisal	Barisal	170.94	170.99	170.51	168.87	166.26	165.82	191.00	115%
Barisal	Jhalokati	170.94	170.99	170.51	168.87	166.26	165.82	195.00	118%
Barisal	Barguna	149.94	151.76	151.93	156.50	156.05	151.67	196.00	129%
Barisal	Patuakhali	149.94	151.76	151.93	156.50	156.05	151.67	208.00	137%
Barisal	Bhola	149.94	151.76	151.93	156.50	156.05	151.67	235.00	155%
Chittagong	Noakhali	187.40	187.39	188.07	186.39	182.03	186.29	185.00	99%
Chittagong	Chittagong	179.36	179.58	179.22	178.74	177.74	174.96	185.00	106%
Chittagong	Cox's Bazar	179.36	179.58	179.22	178.74	177.74	174.96	194.00	111%
Chittagong	Feni	187.40	187.39	188.07	186.39	182.03	186.29	212.00	114%
Chittagong	Chandpur	190.42	189.68	190.25	183.64	176.47	175.84	202.00	115%
Chittagong	Lakshmipur	187.40	187.39	188.07	186.39	182.03	186.29	224.00	120%
Dhaka	Gopalganj	181.81	182.31	182.06	186.16	183.14	183.65	190.00	103%
Dhaka	Shariatpur	181.81	182.31	182.06	186.16	183.14	183.65	196.00	107%
Khulna	Narail	195.45	198.22	199.90	202.91	208.50	210.36	212.00	101%
Khulna	Bagerhat	133.92	134.33	136.36	137.81	134.66	131.62	147.00	112%
Khulna	Jessore	195.45	198.22	199.90	202.91	208.50	210.36	244.00	116%
Khulna	Satkhira	133.92	134.33	136.36	137.81	134.66	131.62	191.00	145%
Khulna	Khulna	133.92	134.33	136.36	137.81	134.66	131.62	197.00	150%

Table B.2 District wise land utilization in the coastal region (DAE, 2009)

District Name	Total Cultivable Land (ha)	Single Cropped Land (ha)	Double Cropped Land (ha)	Triple Cropped Land (ha)	More than three cropped area (ha)	Net Cropped Land (ha)	Cultivable waste (ha)	Major Crops Grown in the area
Khulna	1,33,317	36,904	70,425	8,970	0	1,16,298	17,183	Boro, Aman, Aus, Vegetable, Jute, Pulses, Til, Spices, Sugarcane
Bagerhat	1,33,153	76,802	34,905	6,428	0	1,18,135	8,612	T.Amon, B.Amon, Boro, Aus, Jute, Wheat, Mustaed, Maize,Peanut, Potato, Sweet Potato, Sugarcane, Pulses, Spices, Bettle Leaf, Winter vegetables
Satkhira	1,49,129	5,57,984	49,700	19,269	701	1,25,467	7,711	Rice, Jute, Wheat, Potao,

								Sugarcane, Mustard, Pulses, Til, Spices, Vegetables
Barisal	1,81,659	49,395	85,862	23,515	31	1,58,803	2,667	Rice, Jute, Betel Leaf, Potato, Pulses, Vegetables, Water melon
Jhalakathi	54,507	11,397	30,623	6,524	0	48,545	879	Rice, Wheat, Potato, Vegetables
Pirojpur	93,632	34,814	32,228	11,387	0	78,429	10,318	Rice, Pulses, Oilcrops, Potato, Banana, Betel leaf, Amra, Guava, Betelnut, Coconut
Patuakhali	1,99,325	46,564	83,801	46,476	0	1,76,841	1,970	Aus, Amon, Potato, Sweet Potato, Khesari, Felon, Mung, Peanut,Tal, Chilli, Water melon, etc.
Bargona	1,04,081	33,121	33,492	25,729	0	92,341	862	Amon, Aus, Mung, Khesari, Potato Chilli, Water melon
Bhola	1,83,870	23,006	78,513	64,442	0	1,65,961	3,573	T.Amon,Aus, Boro, Wheat, Potato, Mung, Khesari, Lentil,Felon, Mustard, Chilli,Peanut, Watermelon, Onion, Garlic, Sweet Potato, Sugarcane, Vegetable
Noakhali	1,95,175	78,342	55,404	40,032	0	1,73,778	14,105	Aman, Aus, Boro, Groundnut, Soybean, Mung, Chilli, Felon, Khesari, Sweet Potato, Water melon, Vegetable
Laksmipur	1,09,673	16,087	42,559	33,958	0	92,604	3,590	Aman, Boro, Aus,Soybean, Chilli, Groundnut, Vegetable
Feni	75,922	8,106	48,130	10,056	0	66,292	1,202	Aman, Aus, Boro, Wheat, Potato, Sweet Potato, Summer and Winter Vegetable,

								Sugarcane, Chilli
Chittagong	2,34,986	59,236	1,19,490	31,908	25	2,10,659	15,213	Rice, Jute, Wheat, Potato, Maize, Mustard, Vegetable, Pulses, Sugarcane, Felon, Groundnut, Ginger, Spices, Watermelon, Onion, Coriender, Betel leaf
Cox's Bazar	82,467	18,160	44,272	10,744	1,626	74,802	4,045	Rice, Potato, Sweet Potato, Mustard, Vegetable. Sugarcane, Groundnut, Betel leaf
Bhola	1,83,870	23,006	78,513	64,442	0	1,65,961	3,573	T.Amon,Aus, Boro, Wheat, Potato, Mung, Khesari, Lentil,Felon, Mustard, Chilli,Peanut, Watermelon, Onion, Garlic, Sweet Potato, Sugarcane, Vegetable

Table B.3 Area (Ha) and Production (Tons) of Major Crops in the Coastal Region (19 Districts) in Year 2009-2010

	Aus Total		Aman Total		Boro		Wheat		Potato	
District	Area	Yield	Area	Yield	Area	Yield	Area	Yield	Area	Yield
Chittagong	42,278	102,440	189,973	489,940	68,588	233,954	7	6	3,662	45,270
Cox's Bazar	660	2,208	73,308	224,982	50,817	160,378	0	0	523	6,568
Chandpur	11,989	21,376	52,363	99,437	66,298	271,490	2,055	3,434	12,605	263,747
Noakhali	44,764	67,146	116,936	216,332	58,635	220,937	28	34	188	1,878
Lakshipur	28,504	44,466	88,537	160,341	28,581	101,834	51	100	100	2,041
Feni	12,130	24,879	57,075	147,196	31,604	102,302	76	124	223	3,338
Gopalganj	5,015	4,333	39,036	40,051	77,915	330,593	4,944	11,752	332	6,746
Shariatpur	10,250	7,913	16,220	18,280	31,087	115,364	5,323	11,460	527	11,413
Barisal	31,728	49,051	126,028	232,144	63,691	220,626	767	1,160	586	12,411
Jhalokhati	20,682	39,110	45,873	78,764	8,255	31,113	11	19	184	3,301
Pirojpur	23,502	40,940	80,303	137,800	18,967	65,626	22	44	777	10,601
Bhola	65,579	78,826	166,727	288,938	54,681	180,939	1,781	3,617	2,592	49,696
Jessore	32,756	71,736	138,087	313,596	156,559	627,645	4,373	10,994	3,016	75,189
Narail	6,879	8,606	50,422	88,793	39,670	171,176	2,486	6,043	144	1,749
Khulna	5,875	8,319	88,184	215,874	42,959	158,218	162	381	384	4,601
Bagerhat	6,728	11,054	97,158	184,795	45,459	165,425	204	386	246	3,613
Satkhira	3,426	7,424	84,031	193,271	72,784	263,114	1,263	2,779	3,736	58,838
Patuakhali	60,903	94,887	209,453	348,530	4,566	10,621	5	6	677	12,652
Barguna	43,848	80,856	101,838	175,772	425	1,000	0	0	1,120	21,066
Coastal	**457,496**	**765,569**	**1,821,552**	**3,654,836**	**921,541**	**3,432,355**	**23,558**	**52,339**	**31,622**	**594,718**
Bangladesh	**984,053**	**1,709,107**	**5,662,603**	**12,207,452**	**4,706,774**	**18,058,153**	**376,256**	**901,485**	**434,564**	**7,930,251**

Source: Yearbook of Agricultural Statistics, 2010. Bangladesh Bureau of Statistics (BBS, 2011a)

Table B.4 Area (Ha) of Major Crops in the Coastal Region for years 2001-2010

Area-hectare

Distname	Year	Oilseeds	Pulses	Potato	es & Condime	Tobacco	/egetables (W	Vegetables (S	getables (S &	Sugarcane	Fibres	Fruits
Chittagong	02	1655	7349	7999	10301	453	8132	10485	18618	1645	178	15638
	03	1335	7622	8466	10441	451	8363	10882	19245	1655	142	18153
	04	1342	6679	9099	10400	471	9399	11317	20716	1669	146	19467
	05	1447	5152	6533	10107	465	9306	12385	21691	1679	119	10591
	06	1437	2442	3992	9105	314	7964	11983	19947	1627	3	10787
	07	1593	2238	4101	8836	310	7788	11831	19619	1605	3	10543
	08	1562	2711	3974	10082	84	7829	11975	19805	2472	3	10046
	09	1539	3098	4379	5647	65	7832	12264	20096	1544	3	10257
	10	1997	3236	4185	5193	149	7900	11676	19576	1452	0	10707
Comilla	02	47708	20404	27780	16754	55	7292	11018	18310	1979	14635	7598
	03	47741	20311	27869	16709	55	7343	10825	18168	1983	13444	7655
	04	48405	19575	27942	16602	6	7513	10522	18035	1983	10706	7841
	05	13790	10208	23167	17246	0	7414	9775	17189	1908	8666	2401
	06	11353	7950	18670	16515	0	7539	10390	17930	1993	9621	4370
	07	11771	7019	29481	16778	0	6507	10585	17092	1414	9012	2247
	08	11719	5375	32593	10938	0	6971	11241	18212	1230	8393	1874
	09	9343	5632	26908	11670	0	7213	11871	19084	1187	7594	1483
	10	6522	5475	30615	11152	0	7356	11869	19225	1021	9418	1159
Noakhali	02	11946	22709	2614	15926	0	6463	8753	15216	781	346	11266
	03	11602	21829	2428	15981	0	6507	8998	15506	726	1127	11311
	04	11659	22235	2539	16038	0	6702	9405	16107	779	708	14433
	05	12256	17264	1603	15993	0	6776	10362	17138	704	521	2887
	06	5564	17369	765	14955	0	6267	8747	15014	654	219	4128
	07	7867	12472	850	14474	0	5481	9156	14638	658	89	2531
	08	8591	11512	781	8341	0	5368	9627	14995	664	146	3168
	09	8214	12105	504	8406	0	5490	9851	15341	696	111	3321
	10	9144	12101	510	8420	0	5562	10071	15633	640	251	3240
Faridpur	02	37075	84256	2885	23615	109	3535	6216	9751	16167	89458	6552
	03	36833	83218	2918	23512	111	3486	5981	9468	16198	92339	6457
	04	36768	83736	2922	30291	109	3553	6437	9990	16264	91093	6402
	05	38293	79857	3278	37233	91	3658	5429	9087	15607	90123	4037
	06	34299	72848	1817	45891	79	5945	9095	15040	13905	104786	3451
	07	40762	72060	2104	51298	34	5872	10154	16026	13541	111379	3564
	08	39013	48235	2444	45672	27	6012	11091	17103	13562	137329	4384
	09	37919	47403	1663	40827	24	6206	11427	17633	12508	134676	3690
	10	34833	48207	1983	43343	129	6815	11593	18408	12342	182070	4447
Barisal	02	9174	51952	4166	26853	14	4271	8636	12907	904	1752	21392
	03	9059	51458	3586	26768	10	4391	8424	12814	911	2436	22163
	04	8013	46221	3436	25764	4	4450	8371	12820	1174	2671	22828
	05	7960	43850	3282	20228	0	4087	8709	12796	1198	2060	7818
	06	7507	42304	4569	18051	0	4405	8450	12855	730	1906	8457
	07	4891	28140	4012	17760	0	4363	8496	12859	724	1738	8754
	08	3550	22783	4603	12216	0	4248	8664	12912	721	2452	9526
	09	3157	27281	3828	14305	0	4816	9397	14213	1265	2204	11506
	10	3311	28305	4140	13879	0	5862	9833	15695	1282	4104	12890
Jessore	02	45288	54022	5131	9816	465	8114	10141	18255	9965	39176	12936
	03	45141	54444	5192	9988	455	8314	10619	18933	7934	35900	13025
	04	42547	58508	4152	14429	500	9180	11467	20647	9555	36037	16331
	05	44220	54471	4961	18150	502	10024	15999	26023	9029	40412	12661
	06	35546	54784	5461	18814	486	10265	16015	26280	8078	48060	12566
	07	30666	59159	5560	23174	552	11621	15631	27252	7483	52388	13702
	08	29136	41133	6236	17397	549	12168	16921	29089	7169	62428	7016
	09	28258	40520	5850	16022	867	11717	16746	28463	6488	58110	7001
	10	14981	40386	4408	18045	3319	11773	16851	28624	6781	114045	7276
Khulna	02	11728	5876	10245	3624	22	6265	7072	13336	4520	5016	13941
	03	12050	5797	10619	3527	18	6121	6778	12899	4314	4929	14298
	04	12110	5613	10643	3729	16	6129	6785	12914	4338	5239	16817
	05	13199	7891	4157	4478	6	6457	7248	13705	3869	5632	6490
	06	7665	8252	3776	4492	0	6384	7938	14322	3329	6786	6648
	07	7733	8695	5504	4678	0	6791	8403	15194	3150	7403	6843
	08	6403	3766	5000	5215	0	6989	11294	18283	2600	7874	5940
	09	5681	3486	4737	4140	0	6804	9712	16516	1883	7751	6964
	10	4252	3400	4367	4036	0	6640	9628	16268	1802	15550	4876
Patuakhali	02	2501	41770	277	10520	0	1898	6368	8266	318	217	5892
	03	2234	50414	285	10597	0	2074	6303	8377	301	174	6453
	04	2266	54612	263	11398	0	2293	6774	9067	293	210	6596
	05	2574	45562	289	476	0	2246	6291	8537	247	193	2991
	06	3604	29263	0	11020	0	1512	4812	6323	212	20	2929
	07	2286	19998	2017	10985	0	1238	4617	5856	156	23	2457
	08	1117	10659	1475	2533	0	1188	3573	4761	114	70	2864
	09	1144	11553	1012	2131	0	1204	4114	5318	119	33	2013
	10	1130	11864	1797	398	0	1189	4111	5300	123	19	2120

Table B.5 Production (Tonnes) of major crops in the Coastal Region for years 2001-2010

Production-metric tons

Distname	Year	Oilseeds	Pulses	Potato	es & Condim	Tobacco	egetables (V	egetables (	etables (S &	Sugarcane	Fibres	Fruits
Barisal	2001-2002	5200	34035	46705	16740	20	16720	59045	75765	18100	13040	120400
Chittagong	2001-2002	2545.56	3810	95425	16715	685	67510	82540	150050	26310	245	94250
Comilla	2001-2002	35015	16905	451960	20595	55	49895	90880	140775	69415	160375	35335
Faridpur	2001-2002	34480	64480	25505	41820	90	22225	32605	54830	658015	892591	44840
Jessore	2001-2002	31320	46060	95140	24620	380	59520	70245	129765	438300	404835	91735
Khulna	2001-2002	5815	4485	155270	7035	20	50570	43125	93695	287795	58775	92300
Noakhali	2001-2002	10600	16420	27000	12675	0	34910	57080	91990	26985	1060	62205
Patuakhali	2001-2002	1915	34705	1660	7145	0	6375	43060	49435	7665	430	37485
Barisal	2002-2003	5060	34175	40685	18075	15	17475	58305	75780	18410	19355	130965
Chittagong	2002-2003	2570.55	3970	102820	17540	720	70010	77965	147975	22495	140	105630
Comilla	2002-2003	35385	16985	453415	21575	55	50145	89130	139275	69575	111995	38230
Faridpur	2002-2003	31680	65610	26485	42815	90	22275	30165	52440	680225	932721	45005
Jessore	2002-2003	32310	50710	104505	26110	435	61475	72620	134095	447505	393440	94315
Khulna	2002-2003	6020	4155	152620	6880	20	47620	41270	88890	262355	61180	93765
Noakhali	2002-2003	10450	15400	24860	12540	0	33615	64600	98215	23625	5290	65610
Patuakhali	2002-2003	1640.43	42600	1680	7250	0	6740	40790	47530	7130	340	40605
Barisal	2003-2004	4710	27595	38675	20580	5	18610	56950	75560	23065	19640	112800
Chittagong	2003-2004	2430.55	3490	110920	17975	840	78500	91965	170465	21335	180	109235
Comilla	2003-2004	36445	16395	456415	19750	10	52625	87240	139865	69530	89945	40565
Faridpur	2003-2004	31930	66245	25420	94490	90	22940	33780	56720	661650	1046151	44180
Jessore	2003-2004	29640	58335	84850	63550	420	69010	79170	148180	452390	415620	137410
Khulna	2003-2004	6500	4235	156215	8855	15	48505	39405	87910	132360	64470	110180
Noakhali	2003-2004	10925	16400	26455	12740	0	35445	67975	103420	24505	2845	77180
Patuakhali	2003-2004	1706.68	45965	1545	7435	0	7900	42810	50710	7030	505	42390
Barisal	2004-2005	5270	30490	39564	19530	0	16400	58535	74935	23545	11305	146685
Chittagong	2004-2005	2791.11	16240	78792	21680	845	78640	108355	186995	21470	170	217640
Comilla	2004-2005	13010	8510	384918	26850	0	51175	81740	132915	63990	68982	122085
Faridpur	2004-2005	35130	52925	33007	190935	80	23400	29105	52505	636440	1022035	122240
Jessore	2004-2005	38700	50370	97271	92285	415	78980	150235	229215	444815	451600	225375
Khulna	2004-2005	17605	8810	61091	14230	5	53265	45240	98505	149450	70873	130895
Noakhali	2004-2005	11805	11395	15605	25780	0	33950	73905	107855	22355	1707	141650
Patuakhali	2004-2005	2945	37405	1805	945	0	8010	33635	41645	6315	426	103725
Barisal	2005-2006	4460	28170	59432	14985	0	20520	58205	78725	8735	14644	184475
Chittagong	2005-2006	2810.83	1930	43364	21750	555	64570	96315	160885	19780	360	161315
Comilla	2005-2006	9645	6625	271576	27030	0	53605	85495	139100	76260	91655	126870
Faridpur	2005-2006	33610	63775	24979	209860	75	35805	52920	88725	262855	1318684	130890
Jessore	2005-2006	45800	57530	104251	96785	185	97255	149795	247050	368880	583031	226755
Khulna	2005-2006	5346.63	9050	54443	13430	0	62115	61150	123265	54160	89109	140365
Noakhali	2005-2006	10040	11290	7725	23125	0	32075	53220	85295	21085	2101	69960
Patuakhali	2005-2006	2305	20100	0	6945	0	5890	25780	31670	5525	330	76822
Barisal	2006-2007	43020	16605	60517	14825	0	20265	57275	77540	8390	13532	185190
Chittagong	2006-2007	13895	1670	45826	22065	435	64975	95305	160280	19395	410	156608
Comilla	2006-2007	27855	5970	427289	28385	0	45715	86055	131770	57125	91127	137940
Faridpur	2006-2007	70555	59680	28444	240170	40	33692	66396	100088	256740	1396892	156335
Jessore	2006-2007	54350	59320	103336	140270	445	111000	151495	262495	265625	643223	266700
Khulna	2006-2007	73900	9320	68355	20980	0	71585	60285	131870	52245	98287	171055
Noakhali	2006-2007	28710	8665	9377	21985	0	25750	52285	78035	18555	1052	69455
Patuakhali	2006-2007	27250	11935	35887	8705	0	4550	24240	28790	2135	340	81130
Barisal	2007-2008	4042	14977	79741	11018	0	19803	55997	75800	8175	22615	123248
Chittagong	2007-2008	2440	2678	46870	21464	247	64315	99219	163534	20558	557	163633
Comilla	2007-2008	11396	4884	558827	22172	0	54903	95299	150202	21550	79561	129712
Faridpur	2007-2008	30078	54976	42126	232049	31	34942	59673	94615	428070	1377588	173189
Jessore	2007-2008	23766	33541	119717	112099	461	107563	169601	277164	243084	726762	230419
Khulna	2007-2008	4638	3220	62268	33232	0	73614	96450	170064	44947	87431	144756
Noakhali	2007-2008	9766	8431	9589	13298	0	24264	58677	82941	17203	1528	79846
Patuakhali	2007-2008	999	6403	26939	2130	0	3849	19025	22874	1136	623	56057
Barisal	2008-2009	3357	20393	65165	13052	0	21579	60154	81733	6524	19242	150343
Chittagong	2008-2009	3304	2700	52241	14828	212	64636	101815	166451	28525	522	184859
Comilla	2008-2009	9854.75	4946	415529	21586	0	54455	104108	158563	36541	80853	130231
Faridpur	2008-2009	29707	42531	28465	223176	29	40042	65383	105425	343317	1507439	165554
Jessore	2008-2009	23613	35465	91739	109692	964	108063	170035	278098	240746	679893	212979
Khulna	2008-2009	4093	3332	45033	21897	0	68680	83505	152185	23636	90833	141214
Noakhali	2008-2009	9880	9740	5237	12661	0	24797	62496	87293	16723	1276	80939
Patuakhali	2008-2009	1072	6481	16258	1888	0	3897	20155	24052	785	287	67247
Barisal	2009-2010	4026	24015	76017	13510	0	29010	59362	88372	6207	34829	177681
Chittagong	2009-2010	4624	2922	51839	15203	323	65113	102140	167253	17851	459	241058
Comilla	2009-2010	6246.37	4763	614393	20857	0	57671	106452	164123	26901	89737	125625
Faridpur	2009-2010	30877	47278	39744	230973	164	48367	72240	120607	514802	2201039	175335
Jessore	2009-2010	14867	37534	103903	122676	3602	109974	170765	280739	304220	1513225	208534
Khulna	2009-2010	2229	3637	67064	14466	0	67864	82164	150028	23652	191727	180423
Noakhali	2009-2010	10900	11334	7239	13481	0	25596	65767	91363	14326	2337	92123
Patuakhali	2009-2010	7442	5754	33720	752	0	3756	18838	22594	874	235	62573

12.3 Appendix C: Tables related to socio-economy and livelihood

Table C.1 Infant mortality rate and under-five mortality rate

District	Infant mortality rate, Per 1,000 live births	Under-five mortality rate Per 1,000
Bagerhat	50	65
Barguna	50	66
Barisal	46	60
Bhola	40	50
Chandpur	50	65
Feni	40	51
Gopalganj	39	49
Jessore	48	62
Jhalokati	44	56
Khulna	39	49
Lakshmipur	55	73
Narail	37	46
Noakhali	44	56
Patuakhali	47	61
Pirojpur	54	72
Satkhira	57	76
Shariatpur	48	62
CZ	**46**	**60**
Bangladesh	**49**	**64**

Note: Note : Data refer to 2009-10

Source: BBS (2010a); Progotir pathey, 2009

Table C.2 Economically active person aged 15 years and over and labour force participation rate.

District	Economically active population (000)			Participation rate (%)		
	Total	Male	Female	Total	Male	Female
Barguna	376	259	117	57.2	80.1	35.1
Barisal	1004	720	285	56.2	79.1	32.5
Bhola	659	453	207	59.2	78.7	38.4
Jhalokati	281	219	62	52.1	79.3	23.6
Patuakhali	619	433	186	59.2	82.9	35.6
Pirojpur	408	316	92	49.5	76.2	22.6
Chandpur	808	642	166	47.3	75.2	19.4
Feni	498	343	155	53.3	78.4	31.2
Lakshmipur	615	467	148	51.0	79.6	23.9
Noakhali	861	651	210	50.4	76.7	24.5
Gopalganj	450	321	129	53.8	75.1	31.5
Shariatpur	451	330	121	57.2	83.5	30.8
Bagerhat	633	444	189	57.1	80.4	34.0
Jessore	1199	795	404	63.1	82.4	43.2
Khulna	976	714	262	54.1	79.8	28.7
Narail	288	198	90	60.8	84.7	37.6
Satkhira	947	657	290	59.0	82.3	35.9
CZ	**651**	**468**	**183**	**55.6**	**79.6**	**32.5**
Bangladesh	**885**	**617**	**268**	**59.3**	**82.5**	**36.0**

Note : Data refer to 2010.

Source: Own estimate, based on BBS data & LFS, 2010

Table C.3 Trends in per capita income by district

Districts	(US $)			% change in 2005/06, compared to 1995/96
	1995/96	1999/00	2005/06	
Bagerhat	302	353	439	45.3
Barguna	311	346	388	24.7
Barisal	263	299	358	36.1
Bhola	287	314	350	21.7
Chandpur	228	262	288	26.4
Feni	237	262	318	34.6
Gopalganj	246	272	300	21.8
Jessore	327	357	437	33.6
Jhalokati	253	275	330	30.5
Khulna	416	456	559	34.5
Lakshmipur	287	310	311	8.4
Narail	291	326	361	24.2
Noakhali	243	274	325	33.9
Patuakhali	323	347	393	21.5
Pirojpur	258	289	333	29.2
Satkhira	277	309	384	39.0
Shariatpur	225	252	281	24.7
CZ	**294**	**326**	**387**	**31.6**
BANGLADESH	**323**	**355**	**431**	**33.1**

Note: Growth refers to 1995/96- 2005/06.: Source: Own estimate, based on BBS data

Table C.4 Growth of agricultural GDP by sub-sectors

District	Annual compound rate of growth (%)			
	Crop	Livestock	Fisheries	Agriculture
Bagerhat	2.3	0.4	1.4	1.8
Barguna	-1.5	0.9	0.9	-0.1
Barisal	-0.5	0.7	1.8	0.6
Bhola	-0.3	4.9	-1.6	-0.1
Chandpur	1.4	0.8	-4.8	-0.9
Feni	0.0	0.9	2.2	1.0
Gopalganj	-1.8	-0.9	-2.0	-1.2
Jessore	0.5	-1.2	3.7	0.9
Jhalokati	-1.5	1.3	4.5	0.8
Khulna	2.1	1.6	2.4	2.3
Narail	-1.9	-1.3	4.0	-0.9
Noakhali	-0.9	2.5	4.8	1.5
Patuakhali	-0.9	0.7	1.6	0.4
Pirojpur	-0.6	1.1	-1.5	-0.3
Satkhira	2.8	-3.1	-0.5	1.2
Shariatpur	-2.1	0.7	1.8	-0.6
Lakshmipur	-0.9	1.3	-6.0	-2.7
CZ	**0.2**	**0.8**	**0.8**	**0.5**
Bangladesh	**1.2**	**0.5**	**1.0**	**1.1**

Note: Growth refers to 1995/96-2005/06.
Source: BBS data & CPD 2008

Table C.5 Household by main source of income

District	Total HH (000)	% of Household					
		Self-employment agri.	Self emplyment non-agri.	Service	Day labourer agri.	Day labourer non-agri.	Others
Bagerhat	398	17.3	22.6	11.1	18.1	23.4	7.5
Barguna	231	24.7	19.9	9.5	8.2	21.6	16.0
Barisal	571	26.6	16.5	15.6	10.0	19.6	11.7
Bhola	385	34.3	17.7	7.0	13.2	17.9	9.9
Chandpur	554	10.5	16.1	19.5	19.7	14.3	20.2
Feni	306	15.7	16.3	19.3	4.9	14.1	29.7
Gopalganj	259	34.0	12.0	15.1	20.8	11.2	6.6
Jessore	662	34.1	23.4	10.9	18.0	8.0	5.6
Jhalokati	190	16.8	15.3	13.7	24.2	20.0	10.0
Khulna	600	14.3	18.0	22.5	19.5	17.7	8.0
Lakshmipur	409	11.2	17.6	24.4	14.2	13.7	18.6
Narail	178	27.5	25.8	9.6	20.8	7.3	9.0
Noakhali	586	19.8	11.9	17.2	11.1	14.7	25.9
Patuakhali	356	29.8	16.0	12.4	14.0	17.1	11.0
Pirojpur	288	21.2	11.1	14.9	14.2	20.8	17.7
Satkhira	539	27.3	19.1	4.6	25.6	15.0	8.3
Shariatpur	262	18.3	21.8	14.9	17.9	14.5	12.6
CZ	**398**	**20.6**	**17.3**	**18.4**	**14.7**	**15.4**	**13.7**
Bangladesh	**521**	**23.2**	**17.3**	**15.2**	**18.8**	**14.3**	**11.1**

Note : Data refer to 2010. Source: LFS, 2010

Table C.6 Number of livestock in coastal zone

District	Number of Cattle & Buffaloes (000)	Number of Goats & Sheep (000)
Barguna	297	117
Barisal	421	170
Bhola	302	193
Jhalokati	127	46
Patuakhali	484	199
Pirojpur	221	87
Chandpur	276	126
Feni	143	35
Lakshmipur	181	92
Noakhali	376	215
Gopalganj	238	67
Shariatpur	171	134
Bagerhat	309	181
Jessore	719	716
Khulna	375	288
Narail	196	100
Satkhira	452	491
CZ	**361**	**212**
Bangladesh	**410**	**275**

Note : Data refer to 2008-09.

Source: Agri. Census 2008 (BBS, 2011c)

Table C.7 Annual production of fish

District	Annual production of fish (mt)	% of total national production
Bagerhat	69,858	3.19
Barguna	21,564	0.99
Barisal	60,456	2.76
Bhola	52,676	2.41
Chandpur	60,036	2.75
Feni	39,073	1.79
Gopalganj	14,148	0.65
Jessore	50,810	2.32
Jhalokati	9,593	0.44
Khulna	66,213	3.03
Lakshmipur	62,628	2.86
Narail	12,699	0.58
Noakhali	55,915	2.56
Patuakhali	33,191	1.52
Pirojpur	19,372	0.89
Satkhira	44,705	2.04
Shariatpur	14,016	0.64
CZ	**686,953**	**31.41**
Bangladesh	**2186,752**	**100.0**

Note : Data refer to 2008-09.

Source: Statistical Yearbook 2010

Table C.8 Annual production of shrimp/prawn farm

District	Area of shrimp/prawn (ha)	%	Production of shrimp/prawn (mt)	%
Barguna	409	0.19	240	0.16
Barisal	180	0.08	65	0.04
Bhola	3,215	1.48	1,468	1.01
Jhalokati	21	0.01	9	0.01
Patuakhali	3,116	1.43	1,386	0.95
Pirojpur	4,485	2.06	2,423	1.66
Chandpur	0	0.00	0	0.00
Feni	5	0.00	3	0.00
Lakshmipur	5	0.00	2	0.00
Noakhali	65	0.03	36	0.02
Gopalganj	142	0.07	105	0.07
Shariatpur	1	0.00	1	0.00
Bagerhat	59,424	27.27	41,504	28.51
Jessore	6,545	3.00	3,733	2.56
Khulna	51,921	23.83	34,452	23.66
Narail	1,215	0.56	517	0.36
Satkhira	52,357	24.03	28,549	19.61
CZ	**217,734**	**99.93**	**145,513**	**99.95**
Bangladesh	**217,877**	**100.0**	**145,585**	**100.0**

Data refer to 2008-09

Source: Agricultural statistics 2010

Table C.9 Percentage distribution of household by economic condition

District	% of household by economic condition			
	Permanent insolvency	Temporary insolvency	Break-even (Income = expenditure)	Solvent
Bagerhat	16.6	15.5	53.1	14.8
Barguna	19.1	19.7	43.3	17.9
Barisal	21.3	13.7	50.5	14.5
Bhola	14.3	10.9	63.0	11.8
Chandpur	16.2	9.7	60.1	14.0
Feni	10.7	18.5	53.9	16.9
Gopalganj	12.6	9.9	71.0	6.5
Jessore	20.3	6.6	53.7	19.4
Jhalokati	15.4	10.6	59.5	14.5
Khulna	21.5	18.5	49.5	10.5
Lakshmipur	23.7	19.2	47.9	9.2
Narail	12.9	5.2	63.9	18.0
Noakhali	15.5	9.9	64.3	10.3
Patuakhali	17.4	9.9	56.5	16.2
Pirojpur	8.5	7.0	64.8	19.7
Satkhira	11.2	16.6	55.6	16.6
Shariatpur	9.3	2.3	73.4	15.0
CZ	**16.4**	**12.2**	**57.3**	**14.1**
Bangladesh	**16.9**	**12.5**	**56.2**	**14.4**

Note : Data refer to 2010.

Source: BBS, 2011b

Table C.10 Percentage distribution of agriculture land by levels

District	% of land type		
	High	Medium	Low
Bagerhat	3.9	93.2	2.9
Barguna	0.0	100.0	0.0
Barisal	2.7	92.6	4.7
Bhola	2.4	97.6	0.0
Chandpur	2.2	88.1	9.7
Feni	5.0	95.0	0.0
Gopalganj	3.2	48.8	48.0
Jessore	37.7	59.0	3.3
Jhalokati	4.7	95.3	0.0
Khulna	3.8	94.2	2.1
Lakshmipur	2.7	95.5	1.8
Narail	15.2	70.3	14.5
Noakhali	0.3	98.4	1.3
Patuakhali	0.1	97.5	2.4
Pirojpur	1.8	93.7	4.5
Satkhira	19.3	80.6	0.1
Shariatpur	5.1	84.6	10.3
CZ	**7.5**	**86.7**	**5.8**
Bangladesh	**35.5**	**54.2**	**10.3**

Note : Data refer to 2008. Land levels are defined as per flood levels.

Source: BBS-Statistical Yearbook 2010

Table C.11 Distribution of farm and non-farm holdings

District	Holding (000)		%	
	Farm	Non-Farm	Farm	Non-Farm
Bagerhat	233	107	68.6	31.4
Barguna	145	57	71.9	28.1
Barisal	322	160	66.8	33.2
Bhola	222	125	64.0	36.0
Chandpur	270	188	59.0	41.0
Feni	129	191	40.3	59.7
Gopalganj	156	167	48.4	51.6
Jessore	375	184	67.0	33.0
Jhalokati	97	37	72.5	27.5
Khulna	208	216	49.0	51.0
Lakshmipur	215	109	66.5	33.5
Narail	110	40	73.3	26.7
Noakhali	356	117	75.2	24.8
Patuakhali	213	110	66.0	34.0
Pirojpur	177	66	72.9	27.1
Satkhira	252	42	85.9	14.1
Shariatpur	149	176	45.8	54.2
CZ	**3,629**	**2,090**	**63.5**	**36.5**
Bangladesh	**15,183**	**13,513**	**52.9**	**47.1**

Note : Data refer to 2008.

Source: Agriculture Census 2008

Table C.12 Farm holdings status by ownership and operation

District	Owned area		Operated area	
	Area (000 acres)	Average area per holding	Area (000 acres)	Average area per holding
Bagerhat	346	1.02	382	1.13
Barguna	231	1.15	243	1.20
Barisal	368	0.76	369	0.77
Bhola	276	0.79	328	0.94
Chandpur	232	0.50	237	0.51
Feni	149	0.63	152	0.64
Gopalganj	262	1.14	267	1.16
Jessore	497	0.84	522	0.88
Jhalokati	121	0.91	118	0.89
Khulna	380	0.76	370	0.74
Lakshmipur	198	0.59	219	0.66
Narail	175	1.16	177	1.17
Noakhali	419	0.77	491	0.90
Patuakhali	376	1.16	388	1.20
Pirojpur	215	0.89	218	0.90
Satkhira	402	0.92	425	0.97
Shariatpur	191	0.85	196	0.87
CZ	**4,838**	**0.84**	**5,101**	**0.88**
Bangladesh	**22,755**	**0.79**	**23,505**	**0.82**

Note : Data refer to 2008. Source: Agriculture Census 2008