

BASELINE STUDY: 04

Groundwater

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Executive Summary: Study 04

Since few decades, groundwater is the main source of irrigation and one of the key factors making Bangladesh self sufficient in food production. Before 1970s, surface water (e.g., pond, river), rainwater and dug wells were the main source of drinking and domestic water supplies in Bangladesh. During the late 1970s and early 1980s groundwater was introduced in order to avoid contaminated surface water with pathogenic micro-organisms. Thousands of hand-operated tubewells were installed in rural areas of Bangladesh to provide pathogen-free groundwater-fed drinking water supply. The exact number of hand tubewells is not known but an estimated 10 million tubewells exist in the country. Importance of groundwater irrigation increased with the introduction of HYV seeds in late 1960s' to meet the food demand for growing population. Bangladesh receives huge water during monsoon causing regular seasonal flood in the low elevated areas, and during the dry irrigation season, scarcity of water threatens time-bound irrigation in many areas that leads to extensive use of groundwater. The country started emphasizing groundwater irrigation in the mid-1970s' with Deep Tube Wells (DTW), but soon after, shifted its priority to Shallow Tube Wells (STW).

Bangladesh is located at the mouth of the Bay of Bengal and occupies much of the Bengal Delta, formed by the deposition of the Ganges-Brahmaputra-Meghna (GBM) river system. During the Pleistocene and Holocene time large volume of sediments were laid down in the GBM Delta Complex by the mighty rivers that built up the delta and aquifer systems. The unconsolidated near surface Pleistocene to Recent fluvial and estuarine sediments underlying most of Bangladesh generally form prolific aquifers. Thick semi-consolidated to unconsolidated fluvio-deltaic sediments of Miocene age to the Recent form many aquifers. But except the Holocene and the Dupi Tila Sand Formation of the Plio-Pleistocene age, others are too deep to consider for groundwater abstraction. From the present available subsurface geological information it appears that most of the aquifers occur between 30 to 130 m depth. These sediments are cyclic deposits of mostly medium to fine sand, silt and clay (Figure 2.5). However, due to arsenic contamination in shallow groundwater and salinity intrusion in upper aquifers, importance of exploitation of deep groundwater (down to 350-400 m bgl) has been increased. The individual layers cannot be traced for long distances, horizontally or vertically i.e. distribution of aquifer sediments in the subsurface is very complex. Aquifer-aquitard alteration is highly variable even within a short distance.

The groundwater resource of Bangladesh is facing different problems including quality hazards in many areas where the exposure to pollution from agriculture and arsenic contamination in shallow groundwater makes the water unfit for human consumption. It has been reported that out of 64 districts, 61 are affected more or less. About three million tubewells, installed at shallow depths (10 to 50 m), discharge groundwater with arsenic concentrations more than the Bangladesh drinking water standard of 50 µg/l. About 28 to 35 million Bangladeshis have been exposed to drinking water containing arsenic that exceeded the Bangladesh arsenic standard, and 46 to 57 million people have been exposed to drinking water containing arsenic that exceeded World Health Organization (WHO 2008) arsenic standard of 10 µg/L (DPHE-BGS 2001). Deep tube wells, with the depth range between 100 and < 300m, were installed in the main aquifer in recent years as an attempt to find groundwater with insignificant or no arsenic concentration. But, these wells often contain high concentrations of iron, manganese and high salinity. In the coastal zone, salinity of the upper aquifers (down to 200-250 m depth bgl) is extremely variable and changes abruptly over short distances. In most areas, the water is too saline for domestic and irrigation use due to either to connate salts or estuarine flooding. Large-scale groundwater abstraction from deep aquifers could eventually result in contamination of the deeper fresh and safe groundwater resource by inducing relatively rapid downward flow from high-arsenic and saline regions.

With increasingly growing demands on the groundwater supplies, areas of urban as well as rural Bangladesh have started facing water problems, including the drying up of wells during peak irrigation period and continuous lowering of water table mainly in city areas. In Dhaka city, permanent declining trend of groundwater level is observed due to excessive withdrawal for city water supply and around Dhaka city for industrial withdrawal. The BMDA has been implementing large scale groundwater irrigation schemes since few decades that causes decline of groundwater table below the suction limit (7.5 m) of hand tubewells in many areas. Permanent declination is also noticed in many areas under Barind. In the High Barind area significant land gradients exist, which influence groundwater movement. Study showed that considering the maximum value the average water use by farmers was 35-50% more than the recommended limit that has no use to the growth of crops.

The demand of water use has significantly been increasing to meet the planned irrigation, domestic and industrial needs in Bangladesh, where the development of water resources is very high. In a small land area with about 140 million populations, where more than 75% are directly involved in agriculture, it is really difficult to govern water resources for sustainable use. The challenge is not solely one of groundwater management, but one of comprehensive water management. Effective means to optimize water resources are conjunctive use of groundwater and surface water and artificial recharge in overstressed aquifers.

Bangladesh has formulated good numbers of policies, plans and acts in the sectors related to water development and uses. Many of the important and essential related issues have been covered by and well written in these documents. The main weakness of most of these tools is inadequate implementation and application. Existing laws and regulations do not cover sufficiently in areas such as the rights, powers, and duties of individual users and the government. There is also lack of research-based education and advocacy campaigns. Scientific and institutional approach analyzing research outputs for sustainable water use is still far behind. Most of these policies and plans were never reviewed though many years have passed after implementation.

Practices, techniques and technologies can be improved for improved efficiency of water use to reduce wastage of water and ensure optimum economic and social benefits. Strong regulatory control mechanisms are urgently needed to enable proper management of the resource. Faced with the difficulties in enforcing water abstraction limits and in view of the negative impacts of over-pumping of this critically valuable resource, implementation of the water policy is needed to move towards the introduction of new water management approaches. Water sector institutions must have a legal and regulatory framework under Water Act 2013 which they will operate.

In Bangladesh, climate change impacts are expected to be very high. By affecting environment, livelihood activities, food security and important ecosystem, climate change imposes a real threat to the stability of Bangladesh. Climate change is one of many factors that would influence future water stress in most regions. In Bangladesh, water sector means a lot for its livelihood and socio-economic development as water has a very close link to dependent agriculture. Keen attention is needed to adopt appropriate and sustainable strategy to combat climate change impacts and ensure food security and safe water supply for all.

Groundwater is one of the most valuable natural resources and plays a vital role in the development process of the country. Its sustainable development and proper management can be done with a clear understanding of the groundwater system, its geology, hydrogeology, the subsurface flow and the response of the system considering seasonal, tidal and pumping stresses. Matching long term withdrawals of groundwater to recharge is the principal objective of sustainable groundwater resource planning. Maintaining the water balance of withdrawals and recharge is vital for managing human impact on water and ecological resources. As such, investigation of the aquifer systems, understanding of formation behaviour, regular monitoring of groundwater storage and quality are important for the development and integrated management of water resources of the country.

1. Introduction

In many parts of the world, groundwater resources are ubiquitously available in large volumes of good quality. Developing access to these resources is in such places rather simple and cheap, and often does not entail large governmental coordination or support. These intrinsic hydrological advantages of groundwater give rise to several scale-neutral socioeconomic benefits, making it a favoured grass-roots level source. Since few decades, groundwater is the main source of irrigation and one of the key factors making Bangladesh self sufficient in food production. Before 1970s, surface water (e.g., pond, river), rainwater and dug wells were the main source of drinking and domestic water supplies in Bangladesh. During the late 1970s and early 1980s groundwater was introduced in order to avoid contaminated surface water with pathogenic micro-organisms. Thousands of hand-operated tubewells were installed in rural areas of Bangladesh to provide pathogen-free groundwater-fed drinking water supply. The exact number of hand tubewells is not known but an estimated 10 million tubewells exist in the country. The vast majority of these tubewells are private, which penetrate the shallow parts of alluvial aquifers down to depths of 10–60 mbgl (meter below ground level) (DPHE-BGS 2001).

Importance of groundwater irrigation increased with the introduction of HYV seeds in late sixties to meet the food demand for growing population. Bangladesh receives huge water during monsoon causing regular seasonal flood in its low elevated areas and during dry irrigation season, scarcity of water threatens time-bound irrigation in many areas that leads to extensive use of groundwater (Figure 1.1). The country started emphasizing groundwater irrigation in the mid-seventies with Deep Tube wells (DTW), but soon shifted its priority to Shallow Tube Wells (STW) (Figure 1.2).

The first major irrigation project was started in the early sixties in the northwest of Bangladesh under Bangladesh Water Development Board (BWDB). DTW and STW irrigation was extended rapidly during the late 1970's and the 1980's. In 1972, Bangladesh Agricultural Development Corporation (BADC) initiated capital-intensive methods for DTW installation in Bangladesh and provided well components for rapid expansion of groundwater irrigation.

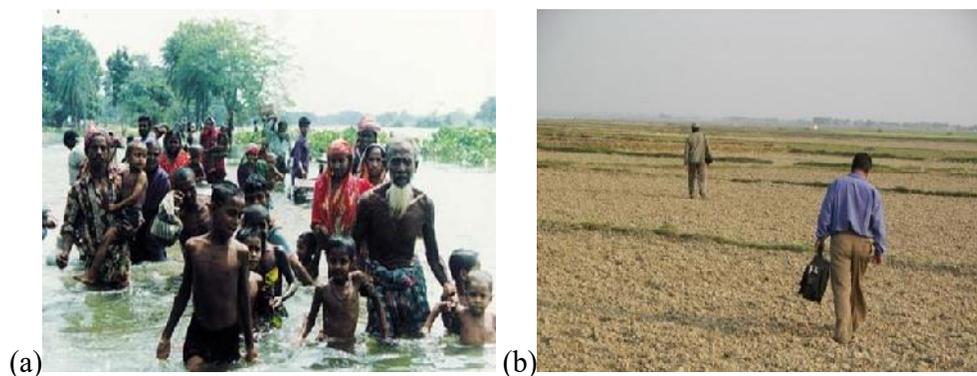


Figure 1.1: There is too much water in monsoon causing widespread flood (a) and shortage of water during dry irrigation period (b).

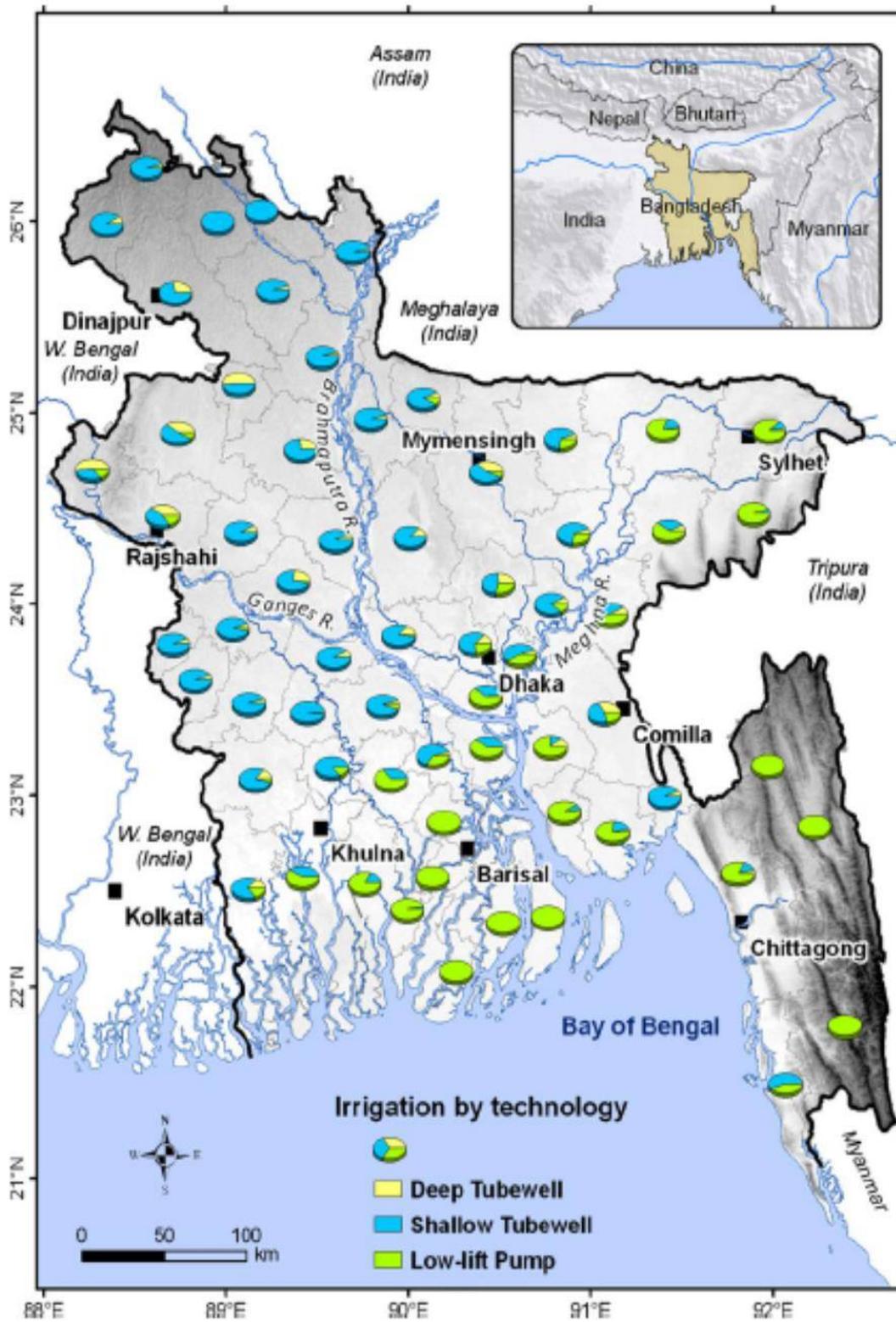


Figure 1.2: Relative proportion of dry season irrigation pumping technologies in Bangladesh (Shamsudduha et al. 2011).

In the prevailing water market, the pump owners installed their wells or pumps in their own plots or other peoples' plots to irrigate their own plots and sell excess water to other farmers under varied formal/informal contractual arrangements. The expansion of the groundwater market has also been created kinds of associated business establishing local workshop for manufacturing irrigation pumps, pipes, spare parts and development of mechanic skills in rural areas. The market is dominated by dynamic private sector involving about 1.7 million owners and managers of mechanized pumps, 0.76 million owners and operators of non-mechanized and traditional irrigation devices with about 7.6 million irrigator farmers (Figure 1.3) (Mandal 2000). Hence, groundwater-irrigated agriculture plays an important role not only in increased food production but also in poverty alleviation by providing jobs and small business opportunities in rural areas.



Figure 1.3: About 75% of country's population is involved directly or indirectly on agricultural activities. Sustainable water management is required to improve their livelihood.

1.1 Status of Surface Water Irrigation

More use of surface water, when and wherever available, is highlighted in the National Water Policy (NWP 1999) of Bangladesh. Water storage has a key role to play for both sustainable development and adaptation to climate change. A vast area of Bangladesh suffers from scarcity of water for irrigating its agricultural lands not only in dry months but also during monsoon. There is considerable scope for the collection of rainwater before huge losses due to evaporation, transpiration, and runoff and drainage. To reduce the harmful effect of floods and to use the surplus water of irrigation, BWDB has constructed a number of embankments, barrages and canals. BWDB has already implemented projects to cover about 1.7 Mha land area under surface water irrigation.

Ganges-Kobadak Irrigation Project, a large surface irrigation system of the country on the right bank of the river Ganges, better known as G-K Project, covers an area of 197,500 ha in south-west Bangladesh. The G-K Project represents an irrigation system in which water is lifted from the Ganges River by pumps and is distributed by gravity canals. The objectives were to increase food production, and cropping intensity, and improve cropping patterns and the socioeconomic conditions of the farmers. Implementation of the project started during the year 1954-55. In 1962-63, some local varieties of rice were cultivated under this irrigation project for the first time. At that time HYV rice was not available in the area. Afterwards, cultivation of HYV rice became popular among the farmers. However, the project has suffered from problems both at the implementation and operational stages. Water use has been considerably higher than anticipated and this has led to reluctance to develop the full irrigable area. Operations to extract water from the Ganges are made difficult because dry-season water levels are significantly below the level for which the pumps were designed and up to one million cubic meters of silt has to be dredged annually from the canal leading from the Ganges to the pump house.

A vast area of northern Bangladesh suffers from scarcity of water for irrigating its agricultural lands not only in dry months but also during monsoon when a prolonged spell of scarcity/no rainfall affect crops. Considering this, Teesta Barrage was constructed to increase agricultural production through supplementary irrigation and thereby creating employment opportunities (Figure 1.4a). Although the implementation of the project started in 1960, the actual construction of the Barrage was taken up in 1979 and that of canal system in 1984-85.

Chandpur Irrigation Project located in Chandpur and Lakshmipur district cover a gross area of 54,036 ha. It provides irrigation facilities to 24,291 ha and drainage facilities to 21,578 ha of land. The project started in 1963 and was completed in 1978. Meghna-Dhonagoda Project is located in Matlab upazila of Chandpur district (Figure 1.4b). The project provides irrigation water to an area of 14,400 ha. It includes 65 km of flood embankment, 220 km of irrigation canal, and 125 km of drainage channel.

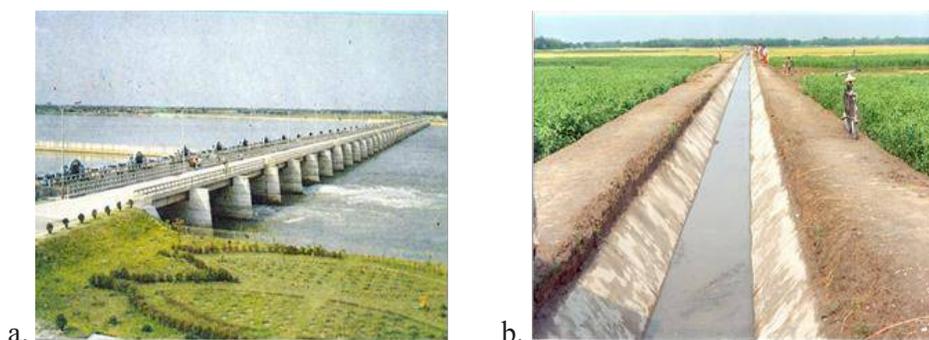


Figure 1.4: Surface water irrigation schemes of BWDB: (a) Teesta Barrage project in north-west; (b) Meghna-Dhonagoda irrigation project in south-east.

However, surface water provides less than 20% of dry season irrigation. Construction of more surface water irrigation projects can reduce stress on groundwater. The Government of Bangladesh has given emphasis for implementation of the Ganges Barrage Project for sustainable poverty alleviation and environmental conservation by providing storage water irrigation in the Southwest region of the country. Obstacles to manage conjunctive use include differences in abstraction costs between surface and groundwater. Farmers in the upstream receive abundant surface water through their irrigation canals are less interested to irrigate with groundwater, which would be far more expensive than the highly subsidized surface scheme.

2. Regional Hydrogeological Framework

2.1 Physiographic Setting

About 80% of the land area of Bangladesh is flat and low elevated, intersected by numerous rivers and their distributaries. Generally four major physiographic units exist at the surface of Bangladesh (Figure 2.1). These are a) Tertiary sediments in the northern and eastern hills; b) Pleistocene terraces in the Madhupur and Barind tracts in the center and west; c) Recent (Holocene) floodplains of the Ganges, the Brahmaputra and the Meghna rivers; and d) The Delta, covering the rest of the country. These major units can be classified into seven broad divisions i.e. a) Hilly Regions, b) Pleistocene Uplands, c) Tippera Surface, d) Tista Fan, e) Flood Plains, f) Delta Plain and g) Sylhet Depression and Inland Marshes (Figure 2.2). Each of these divisions can be subdivided with distinguished characteristics of its own.

Tertiary Hills occupy about 18% land of Bangladesh. North-south striking hill ranges occupy the eastern districts of Chittagong, Cox's Bazar and the three Hill Tract districts. The anticlines form the hills and synclines the valleys. The hills become higher towards east reaching a maximum height of 1003 m. The lowest ranges generally follow the eastern coast of the Bay of Bengal. The Pleistocene Uplifted Terraces cover an area of about 10% of Bangladesh. Determination of the concealed Pleistocene red clay that composes the rock type in the immediate vicinity of the Barind area and the Madhupur Tracts, should increase their areas considerably. The Barind Tract is located in the west of the Brahmaputra River. It falls in the central part of north Bangladesh and covers districts under Rajshahi division. The Barind Tract is the product of vertical movements of Pleistocene period and reaches a maximum height of 20 m above recent flood plains. The Madhupur Tract is situated in the east of the Brahmaputra River. It looks like a chain of isolated circular to elongated low hillocks standing at a higher level than the surrounding flat alluvial plain and is affected by a series of faults. The Madhupur Tract reaches a maximum height of 17 m from sea level and is elevated during the same period as that of the Barind Tract.

The area between the Meghna flood plain in the west and the Tripura Hills in the east was uplifted in Early Holocene times and termed as Tippera Surface (Bakr 1977). This physiographic unit is made up of estuarine sediments of Early to Middle Holocene age. The present day rectangular drainage pattern of this flat area was artificially developed for irrigation purposes. Parts of Comilla and Chandpur districts fall under this geophysical division. The Teesta Fan lies on the northwestern part of Bangladesh. It is the extension of the Himalayan piedmont plain that slope southward from a height of 96 m to 33 m with a gradient of about 55 cm/km. The region is covered by the piedmont sand and gravel, which were deposited as alluvial fan of the Teesta, Mahananda and Karatoya rivers and their distributaries.

The flood plains of the Ganges, the Atrai, the Brahmaputra-Jamuna, the Old Brahmaputra, and the Meghna rivers cover approximately 40% of Bangladesh's landform. The elevation of the major part of the flood plain ranges from 3 to 5 m above the mean sea-level. The flood plain covers the central, north and northeastern part of the country. The Brahmaputra-Jamuna Flood Plain is located between the Barind and Madhupur Tracts. Elevation of this surface is 29 m in the north and about 6 m in the south. The Ganges Flood Plain extends from the western border of the country, south of the Barind Tract, to further east, where it merges with the Jamuna Flood Plain. The Meghna Flood Plain merges with the southern part of the Old Brahmaputra Flood Plain in the northwest and with the Sylhet Depression in the north. Landform of the flood plain is characterized by natural levees distributed in a mottled pattern which forms shallow depressions and small ridges. The maximum height of the levees is 30 m above the sea level.

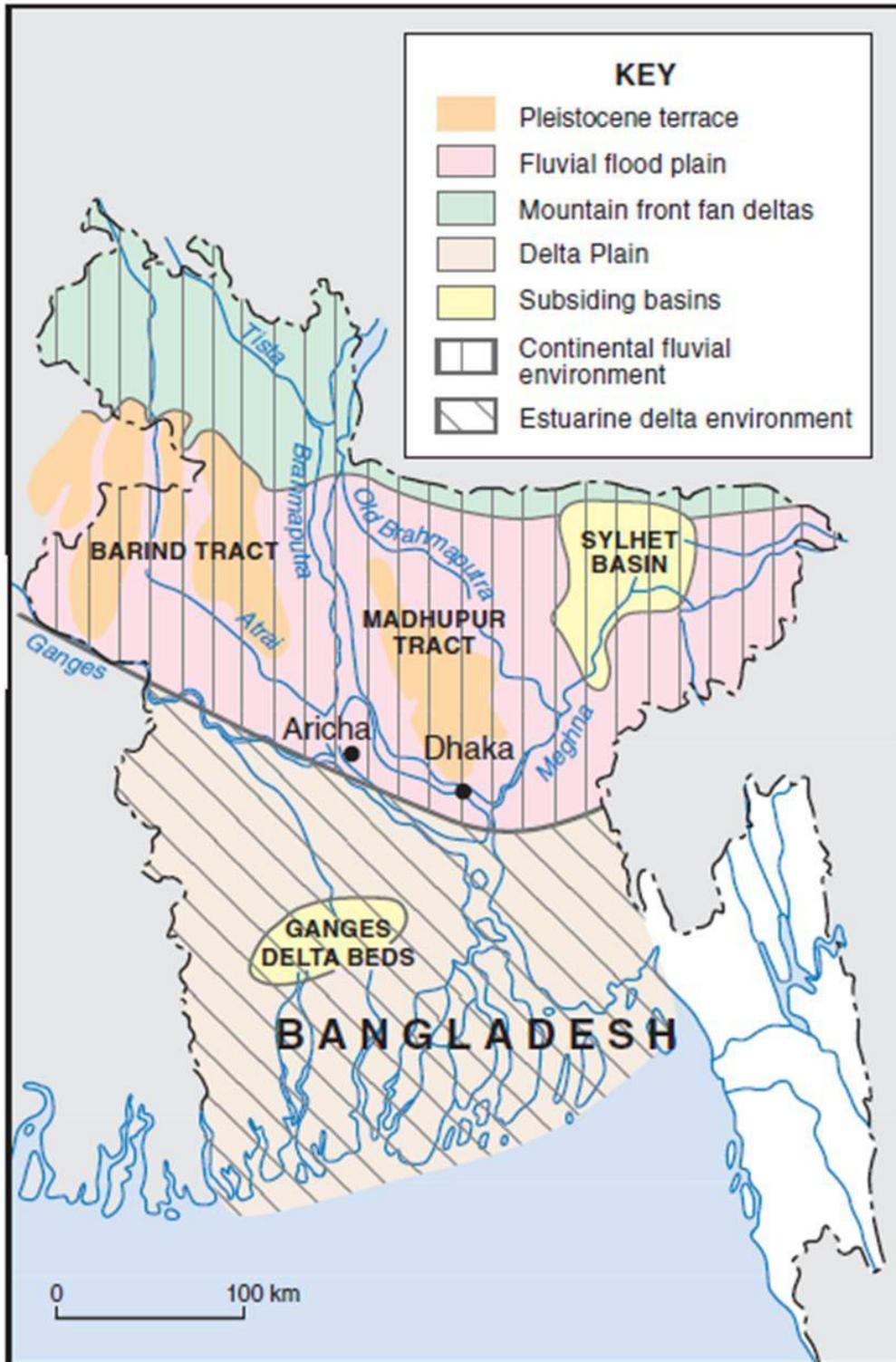


Figure 2.1: Major physiographic units of Bangladesh (BGS-DPHE 2001).

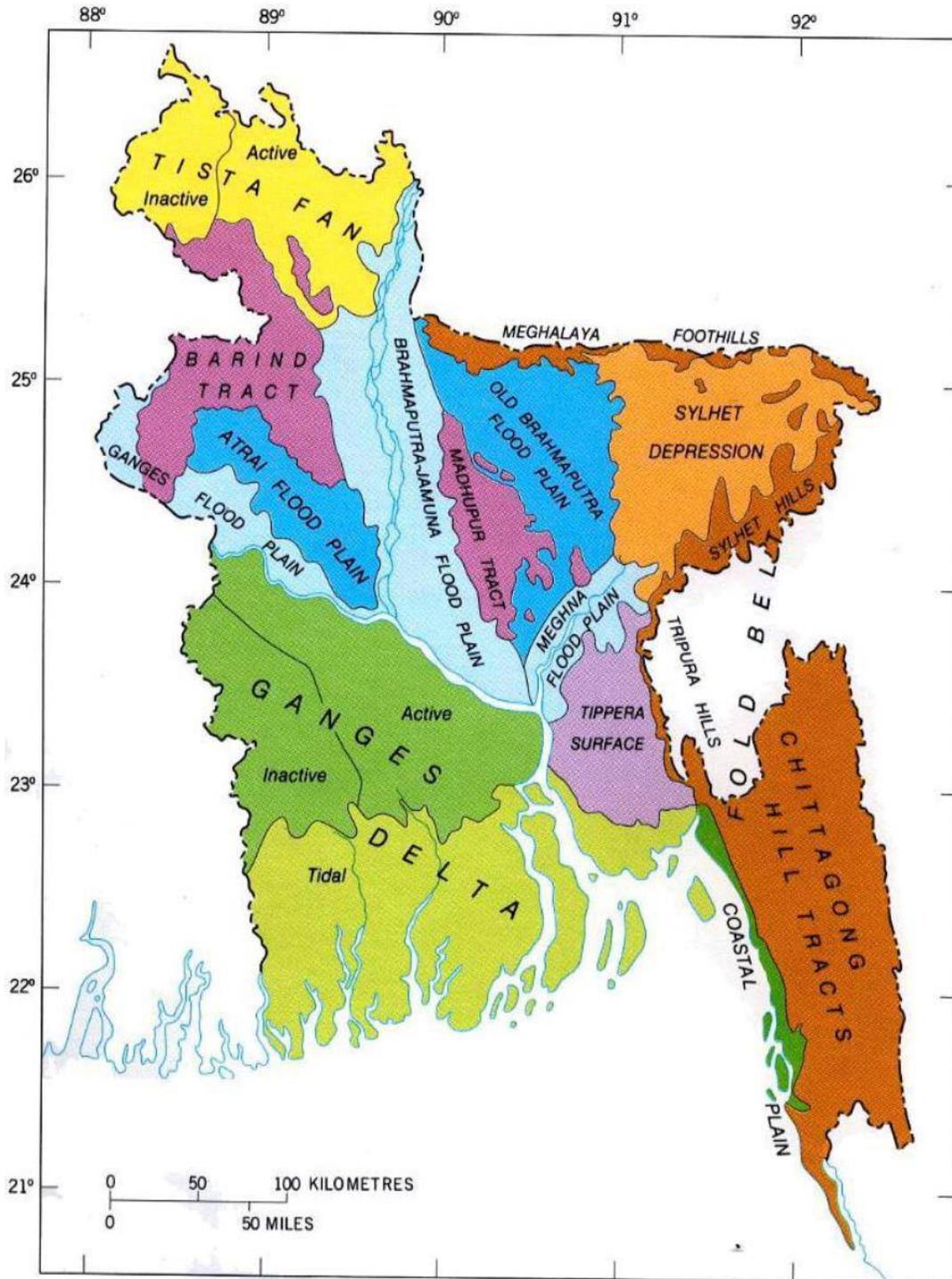


Figure 2.2: Broad physiographic divisions of Bangladesh (Alam et al. 1991).

The Delta Complex covers about 32% of Bangladesh. The area south of a line drawn from the Ganges-Padma as far as the lower course of the Feni River in the southeast belongs to the delta of the GBM Rivers. The Ganges is the greatest builder of the delta (70-80%). The Ganges delta located in the south of the Barind and Madhupur Tract. In the southwest, a part of the delta has been classified as the inactive delta but the major part in the south

and southeast is very active. The elevation of the delta is about 15 to 20 m from the mean sea level in the northwest and 1 to 2 m in the south. Many swamps (depressions) have developed in the substantial part of the delta. Holocene or Recent sediments from a few hundred to thousands of meters cover the Flood plains and the Delta. The tidal delta covers the southern part of the Delta plain. This area is tide dominated and is considered as the active part of the delta. The landforms are characterized by tidal low land with weakly developed natural levees distributed in an irregular pattern. Numerous rivers, channels, tidal creeks have criss-crossed the area. Swamps and depressions are also present in the area. Estuarine deposits of silt, silty clay dominates in this area.

The Sylhet Depression is a tectonic basin subsiding at a very fast rate and is bounded by the hills of frontier strip of Sylhet and Netrokona Districts in the north and the northeastern and Sylhet Hills in the east. Numerous lakes and large swamps (haors) cover the saucer shaped area of about 7,250 sq. km. The elevation of the central part of the depression is about 3 m above the sea level. The inland marshes are found scattered all over the country. Most of them are back swamps, oxbow lakes and abandoned channels formed due to the changes in the courses of the rivers.

2.2 Drainage System and Water Logging

The Bengal delta occupies a unique position among the larger deltas of the world for its varied and complex drainage and river system. The whole delta is criss-crossed by innumerable large and small channels of which some are decaying; some are active, while some others are being drained only by the tidal flow. This drainage pattern also plays an important role on saline water encroachment in both surface water and groundwater environment. Another significant feature of the delta-rivers is their continual shifting of courses. Most of the rivers of the western part of the delta follow a rather south-easterly direction while some of the eastern rivers show a marked south-westerly tendency (Figure 2.3). The main channel of the Ganges-Padma has long been maintaining a southeasterly direction. A number of major streams, however, follow straight courses which can presumably be identified as tectonically controlled channels. In the summer monsoon season when about 3 million cusecs of water passes through the delta, it behaves as a fluvial delta whereas in the winter when the volume of water passing through the delta drops to 250,000 to 300,000 cusecs it behaves as a tide dominated delta. These unusual features make this delta one the most complex in the world. The southwestern portion of the Ganges delta, which includes the world's largest mangrove forest, the Sundarbans, is completely a maze of tidal creeks and channels and carry a substantial amount of water through its various distributaries which join these tidal channels and estuarine creeks (Figure 2.4).

As sea level continues to rise, the associated effects of permanent inundation is likely to increase the salinity near coastal areas. A direct consequence of sea level rise would be intrusion of salinity with tide through the rivers and estuaries. It would be more acute in the dry season, especially when freshwater flows from rivers would diminish. According to an estimate of the Master Plan Organization (MPO 1987), about 14,000 sq. km of coastal and offshore areas have saline soils and are susceptible to tidal flooding. If some 16,000 sq. km of coastal land is lost due to a 45 cm rise in sea level, the salinity front would be pushed further inland. The present interface between freshwater and saline water lies around 120 to 160 km inland in the southwest, and this could well be pushed northward as far as central Jessore region in the event of area level rise. In the rainy season where saline water ingress to 10% of country's area, in the dry season saline water even reaches to country's 40% area. Due to changing climate the ingress of salinity might be increased. The pace of evaporation in winter would increase soil salinity. Downward seepage of saline water from surface may increase salinization of groundwater.



Figure 2.3: Major river network of Bangladesh and hydrological zones



Figure 2.4: Tidal channels and estuarine creeks in the coastal areas of Bangladesh.

2.3 Regional Hydrogeology

Bangladesh is located at the mouth of the Bay of Bengal and occupies much of the Bengal Delta, formed by the deposition of the Ganges-Brahmaputra-Meghna (GBM) river system. The GBM rivers has the largest total sediment load in the world derived principally from the Himalayan and Indo-Burman ranges (Uddin and Lundberg 1998) and the fourth highest water discharges to the oceans (Coleman 1969). Most of Bangladesh had low elevation throughout its geological history that made it very much sensitive to the sea-level changes which influenced geological processes of weathering, erosion and deposition of sediments. These processes were in operation throughout the Plio-Pleistocene and Holocene periods towards the making of the large delta and one of the largest deep sea fan in the world. The Bengal Basin has more than 20 km of Tertiary-Holocene sedimentary fill below ground level, which consists predominantly of the organic sediments derived from both the eastern Himalayas to the north and the Indo-Burman Ranges to the east (Alam et al. 2003). This generalized sequence is not common in all parts of the country and in some places many formations are missing due to depositional, non-depositional, and post depositional erosion. The sediment thickness is shallowest in northern Bangladesh (100 m).

The oldest rocks exposed in Bangladesh belong to the Tertiary Era. Quaternary sediments cover approximately 82% of the country and rocks from Paleocene to the Pleistocene are exposed in 18% of the area in the hilly region. The sedimentary cover of the basin includes three major lithostratigraphic units separated by three major unconformities (GWTF 2002). The western part of Bangladesh is the platform shelf, whereas the folded belt represents the eastern part of the country. The central part representing the most subsided part of the basin comprises two major depressions at the north (Sylhet Trough) and south (Patuakhali Depression). The transition zone from the shelf to basin is represented by the hinge zone—a Eocene shelf/slope break.

During the Pleistocene and Holocene time large volume of sediments were laid down in the GBM Delta Complex by the mighty rivers that built up the delta and aquifer systems. The presence of Toba-Ash-Bed marker on top of the Pleistocene upland surfaces in West Bengal, India (Achryya and Basu 1993), Bangladesh (Abdullah and Hasan 1991) and Bay of Bengal (Kudras et al. 1999) indicates that these Pleistocene upland deposits are older than 75,000 years BP. The base of the Quaternary is difficult to identify, but in many boreholes a sequence dominantly of clay and sand having saline formation water and locally containing microfossils have been assigned Upper Pleistocene age (Sengupta 1966). The bottom of the Pleistocene Clay (top of the Dupi Tila Sandstone) is very much undulated and marked by a prominent unconformity (Khan 1991).

2.3.1 Aquifer system

The unconsolidated near surface Pleistocene to Recent fluvial and estuarine sediments underlying most of Bangladesh generally form prolific aquifers. Thick semi-consolidated to unconsolidated fluvio-deltaic sediments of Miocene age to the Recent form many aquifers. But except the Holocene and the Dupi Tila Sandstone Formation of the Plio-Pleistocene age, others are too deep to consider for groundwater abstraction. From the present available subsurface geological information it appears that most of the aquifers occur between 30 to 130 m depth. These sediments are cyclic deposits of mostly medium to fine sand, silt and clay (Figure 2.5). However, due to arsenic contamination in shallow groundwater and salinity intrusion in upper aquifers, importance of exploitation of deep groundwater (down to 350-400 m bgl) has been increased. The individual layers cannot be traced for long distances, horizontally or vertically i.e. distribution of aquifer sediments in the subsurface is very complex. Aquifer-aquitard alteration is highly variable even within a short distance. Most of the groundwater

withdrawn for domestic or agricultural purposes in the Barind and Madhupur Uplands areas is from the Dupi Tila aquifers. This aquifer is composed of light gray to yellowish brown, medium to coarse sand with pebble beds and dated as about or more than 20,000 years old (Aggarwal et al. 2000). All of the water for Dhaka City is withdrawn from this aquifer and the water is as yet arsenic safe. The Dupi Tila Formation extends all over Bangladesh probably excepting the western two third of the Delta. Other than the Terrace areas, the remaining part of the Bengal Delta consists predominantly of Holocene alluvial and deltaic sediments. Age of Holocene aquifers ranges from 100 to more than 3,000 years (Aggarwal et al. 2000). In the land above tidal inundation, these deposits are composed primarily of silt and sand of appreciable thickness extending to depth of more than hundred meters.

Generally the aquifers of the delta plain and the flood plains of the GBM Delta Complex have been divided on the basis of depth. But it is a well-established fact that the sedimentation rate and subsidence in the whole of the Bengal Basin were not uniform throughout the Quaternary. As such, sediments of very different nature or of different geological age can be found at similar depths. Terminology of aquifer units under different studies is presented in Table 2.1. On a regional basis BWDB-UNDP (1982) described three aquifers, however, these are in many places connected hydraulically (Zahid et al. 2009). Recently, BWDB (2013) identified multi-layered aquifer system in the Coastal Delta down to the depth of 350 m. Aggarwal et al. (2000) on the basis of isotopic studies classified the water at different depths in four types and made a three-tier division of the aquifers. DPHE-BGS (1999) and DPHE-BGS (2001), with slight adjustments of the BWDB-UNDP (1982) study also made a three-tier classification of the aquifers zones.

In coastal area these aquifers can be classified as follows: The shallow i.e. the upper Holocene aquifer, extends down to 50 to over 100 m, in many places below a considerably thick upper clay and silt unit. The aquifer sediments are composed of fine sand with lenses of clay. Aggarwal et al. (2000) and Zahid et al. (2009) mention it as the 1st Aquifer. Age of water from this aquifer is dated as about 100 years old.

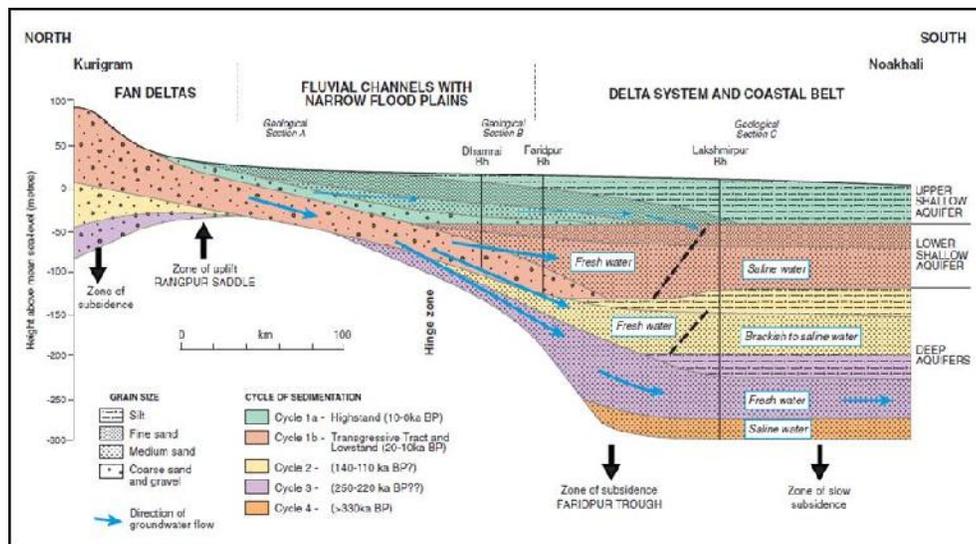


Figure 2.5: Hydrogeological cross-section of Bangladesh from north to south showing Quaternary aquifer system and groundwater flow pattern (DPHE-BGS 2001).

The main water bearing zone extends down to 250-350 m and is generally underlain and overlain by silty clay bed, and composed mainly of fine to very fine sand, occasionally inter-bedded with clay lenses. It is either semi-confined/leaky or consists of stratified interconnected, unconfined water-bearing zones. These Mid- Holocene Aquifers may be considered as in a similar position in the geological section as the Main Aquifer (BWDB-UNDP

1982), the 2nd Aquifer (Aggarwal et al. 2000) and Zahid et al. 2009) or the Lower Shallow Aquifer (BGS-DPHE 2001) in the floodplain and deltaic areas of Bangladesh. Age of water from this aquifer is dated as about 3000 years old. Groundwater is drawn predominantly from these strata. The deep aquifer has been encountered to depths of 300-350 m, generally below a silty clay aquitard. This aquifer is composed mainly of grey to dark grey fine sand that in places alternates with thin silty clay or clay lenses. Appearance of clay or silty clay aquitards are not common in all locations i.e. on a regional basis aquifers down to the investigated depth of 350 m seems hydraulically connected (Figure 2.6). However, in many places 3 to 4 aquifer units are encountered separated by aquitards and limited scale abstraction of groundwater from any aquifer depth does not affect the others. The Late Pleistocene-Early Holocene Aquifers to some extent corresponds to the Deep Aquifer of BWDB-UNDP study (1982), lower part of the Deep Aquifer of the BGS-DPHE study (2001) and the 3rd Aquifer of Aggarwal et al. (2000) and Zahid et al. (2009). Water from this aquifer is dated as about 20,000 years old.

The deep aquifers does not occur in some areas down to the investigated depth of 350 m, e.g. south and southeast of Khulna town, Satkhira, Cox's Bazar and generally consists of a number of different stratigraphic layers. In the Chittagong coastal zone, the Pliocene sediments exposed in the escarpment hills dip under the Quaternary sediments of the coastal plain. Water in the shallow alluvial aquifers is of variable quality and contains pockets of intruded saline water from estuaries or coastal flooding. The erratic occurrence of small fresh water pockets at depth is reported all over the coastal belt. In many areas the deep aquifer is overlain by a clay sequence of 50 to more than 150 m thick which acts as a confining layer and protects the deep aquifer from leakage of saline water from overlying aquifers.

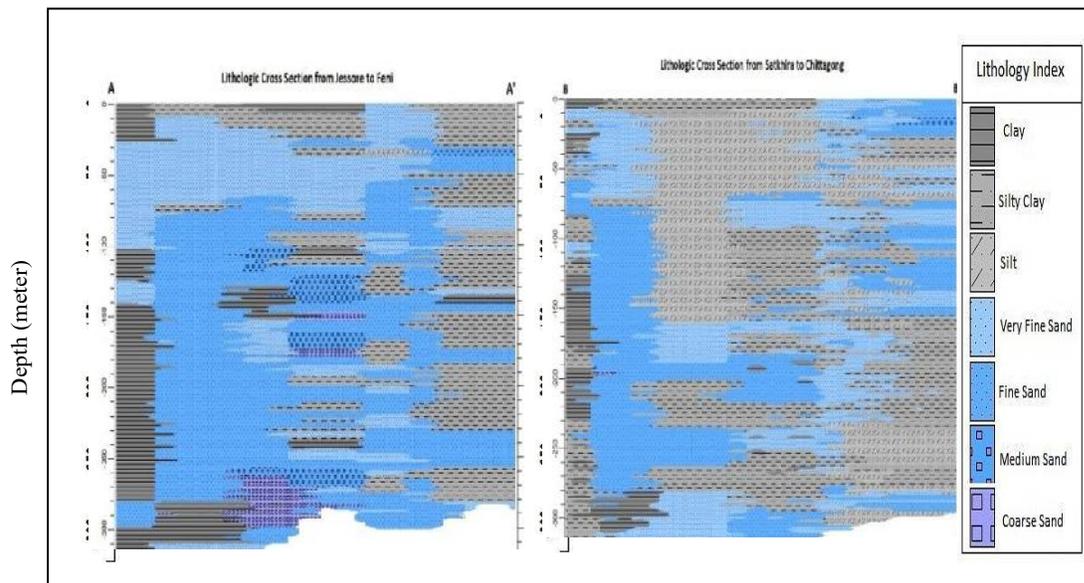


Figure 2.6: Multi-layered aquifer system in the Bengal Delta.

All the above classifications do not take into account the sedimentological parameters or the depositional history of the aquifer sediments. Till now the aquifers of the delta plain and the flood plains of the GBM Delta Complex have been divided on the basis of depth. But it is a well established fact that the sedimentation rate and subsidence in the whole of the Bengal Basin were not uniform throughout the Quaternary. Due to neo-tectonic activity the delta was segmented into several blocks that subsided or uplifted at different rates in relation to one another. As such, sediments of very different nature or of different geological age can be found at similar depths.

The JICA (2002) study states that, "the definition of shallow aquifer and deep aquifer is not clear due to the difference of hydrogeological conditions by place to place. It is said that the shallow aquifer and deep aquifer is bounded by an aquitard at a depth of 150m in central Bangladesh, but the boundary is located more deep portion in the southern coastal districts". Considering the above facts, an attempt has been made to divide the aquifer systems in the GBM Delta Complex from a geological point of view i.e. in line with the proposed divisions of the Late Pleistocene-Holocene sediments. This seems to be comparatively more logical than the conventional divisions based only on depth. The major divisions in this classification are: 1) Plio-Pleistocene Aquifers; and 2) Late Pleistocene-Holocene Aquifers: a) Late Pleistocene-Early Holocene Aquifers; b) Middle Holocene Aquifers and c) Upper Holocene Aquifers.

Plio-Pleistocene aquifers

The Plio-Pleistocene Aquifers of the Dupi Tila Formation lies beneath the Pleistocene Madhupur Clay Formation. This aquifer is composed of light gray to yellowish brown, medium to coarse sand with pebble beds. All of the water for Dhaka City is withdrawn from this aquifer but the water is as yet arsenic safe. This aquifer is confined to semi-confined.

Late Pleistocene-Holocene aquifers

The Late Pleistocene-Early Holocene Aquifers are not continuous all over the country. This to some extent corresponds to the Deep Aquifer of BWDB-UNDP study (1982), lower part of the Deep Aquifer of the DPHE-BGS study (2001) and the Third Aquifer of Aggarwal et al. (2000). Aggarwal et al. has dated water from this aquifer as about 20,000 years old. The sediments of this aquifer to some extent correspond to the Late Pleistocene-Early Holocene Unit of the sediment section. Water within this aquifer is found to be arsenic safe but heavy withdrawal from this aquifer needs further study.

Middle Holocene aquifers

Above the Late Pleistocene-Early Holocene Aquifer lies the fine sand which becomes coarser in the upper part. This sandy sequence varies greatly both vertically and horizontally. The upper part also contains silt and peaty organic matters. These Mid- Holocene Aquifers may be considered as in a similar position in the geological section as the Main Aquifer (BWDB-UNDP 1982), the Second Aquifer (Aggarwal et. al. 2000) or the Lower Shallow Aquifer (DPHE-BGS 2001) in the floodplain and deltaic areas of Bangladesh. Aggarwal et al. (2000) dated water from this aquifer as about 3000 years old. Most of the ground water in Bangladesh is withdrawn from this aquifer and the water is severely affected by arsenic contamination. The sediment from the surface samples in the Chandina Formation areas (Tippera Surface) dates around 6,000 ka. In this area the Middle Holocene aquifer is encountered nearest to the surface, but in most of the river basin and the delta plain areas this is at different depths.

Upper Holocene aquifers

The Upper Holocene Aquifers are developed all over the deltaic and flood plain areas. This does not occur in the Chandina Formation areas (Tippera Surface). The lower part is composed of silt and clay at the bottom, and fine sand at the top. The upper part is composed of silt and clay, and is commonly found to be inter-bedded or mixed with medium sand. In BWDB-UNDP (1982) classification this aquifer is mentioned as Upper Composite Aquifer, in DPHE-BGS (2001) report it is considered as Upper Shallow Aquifers and Aggarwal et al. mentions it as the First Aquifer. Aggarwal et al. (2000) dated water from this aquifer as about 100 years old. Water of this Upper Aquifer is also affected by arsenic contamination. Holocene aquifers contain a number of sand layers/lenses that are stacked and interconnected, which makes them of leaky type.

2.3.2 Hydraulic properties of aquifer sediment

Hydraulic conductivity (horizontal) for the Delta was measured between 2.5×10^{-5} and 7.0×10^{-5} m/sec for lower part (180-230 m depth) of the 2nd aquifer and between 3.43×10^{-5} and 2.3×10^{-4} m/sec for the 3rd aquifer, whereas vertical hydraulic conductivity is 10-100 times lower than horizontal hydraulic conductivity (230-330 m depth). Deep aquitard vertical hydraulic conductivity was measured as about 4.0×10^{-6} m/sec. For the 1st and the upper part of the 2nd aquifers in floodplain areas, vertical hydraulic conductivity ranges between 1.3×10^{-4} and 6.5×10^{-4} m/sec (BWDB-UNDP 1982; BWDB 1989, 1994; DPHE-DANIDA 2001, DPHE-BGS 2001). The geometry of the geologic units assumes that the aquifer layers are relatively flat. Pumping tests reported that the alluvial aquifer system (50-100 m depth) in most parts of Bangladesh is primarily composed of a number of stratified and unconfined aquifers with greater transmissivity (mean $1,270 \pm 770$ m²/day) and specific yield ranging from 0.01 to 0.20 with a national average of 0.06 ± 0.04 (BWDB-UNDP 1982; BWDB 1994; Shamsudduha et al. 2011). The transmissivity of the shallow aquifers in the Brahmaputra floodplains are greater (3,500–7,000 m²/day), and terrace and deltaic aquifers (300–3,000 m²/day) in Bangladesh (Figure 2.7) (BWDB-UNDP 1982; DPHE-BGS 2001).

Hydraulic conductivity values estimated by conducting slug tests ranges between 1 and 25, 1 and 9 and 1 and 9 m/day for the shallow, the main and the deep aquifers respectively that is typical for sandy alluvial aquifers. Transmissivity were estimated between 100-2300, 100-2200 and 100-1600 m²/day (BWDB 2013). Transmissivity values of deep aquifers (250-350 m bgl) from long duration (upto 72 hours) aquifer pump tests conducted by BWDB depict that Chandpur, Jhalokathi, Patuakhali deep aquifers has higher potential with T ranges between 769 and 3224 m²/day, while Barguna, Barishal, Laksmipur deep aquifers show moderate potential with T values between 493 and 916 m²/day and Chittagong, Feni deep aquifers show low potential with T ranges between 144 and 370 m²/day. Storage co-efficient values of deep aquifers for all studied areas were estimated between 0.0044 and 0.00016 that indicates leaky confined to confined in nature.

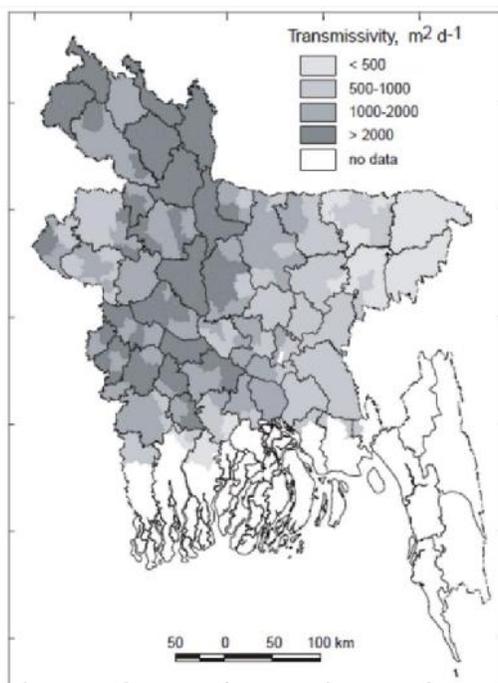


Figure 2.7: Map of upper aquifer transmissivity (BWDB-UNDP 1982).

3. Groundwater Recharge and Resource Availability

3.1 Groundwater Recharge Potential

Rain water is the principal source of groundwater recharge in Bangladesh. Flood water which overflow the river and stream banks also infiltrates into the groundwater. Water from permanent water bodies (rivers, canals, wetlands, ponds, irrigated fields etc.) that lie above the water table also percolates to the groundwater. In the Pleistocene terraces, the recharge occurs through the incised antecedent drainage channels that cut through near-surface clays into the underlying sands. The greatest scope of recharge is within the coarse grained sediments and the least is within the fine grained sediments like clay. Analysis of groundwater level and river-stage hydrographs (Shamsudduha et al. 2011) reveals that water levels in almost all river channels rise above groundwater levels in adjacent aquifers during the monsoon season (May–September); indirect recharge is restricted to lateral river-bank infiltration during the early monsoon time (April–June). Shallow aquifers adjacent to the River Brahmaputra mostly experience greater indirect groundwater recharge. The regional hydraulic gradient is low, reflecting the low topographic gradient. The groundwater flows generally from north to south. Most of the flow probably takes place through the in-filled incised channels under the major rivers.

Past groundwater studies in Bangladesh (BWDB-UNDP 1982; MPO 1987, 1991; WARPO 2000) predicted that increasing groundwater fed irrigation would enhance net recharge in areas where surface geology and soil properties are permeable and thereby favor recharge (**Figure 3.1**). These studies estimated area wise yearly potential and usable recharge between 135 and 1910 mm and 183 and 1287 mm respectively (**Figure 3.2**). The BWDB-UNDP study calculated potential recharge using a hydrological balance where runoff was estimated to be 20–40% of the annual precipitation.

Study conducted by Shamsudduha et al. (2011) estimated groundwater recharge for pre-developed groundwater-fed irrigation period (1975–1980), post-developed groundwater-fed irrigation period (2002–2007), and long-term mean recharge period (1985–2007) (**Figure 3.3**). The results show that actual (net) recharge is higher in northwestern (Dinajpur district) and western parts (Rajshahi district) of Bangladesh than in southern (Khulna district) and eastern parts except for Comilla district. Net recharge is high (300–600 mm) along the Rivers Brahmaputra and Ganges where potential recharge was previously estimated to be 500–700 mm (MPO 1987; MPO 1991). Net recharge in northwestern parts of the GBM Delta ranges from 250 to 600 mm and similarly approximates potential recharge. In southeastern GBM Delta and Sylhet regions where estimated potential recharge is high (400–2000 mm; BWDB-UNDP 1982; MPO 1987, 1991), the net annual recharge is considerably lower (<150 mm). Greater increases in the net recharge are observed in northwestern regions and along the Rivers Brahmaputra and Ganges; changes in recharge are limited in the rest of the country. The substantial difference between actual and potential recharge in these areas suggests that a major fraction of the available recharge is lost through surface runoff and evapotranspiration.

Study by Shamsudduha et al. (2011) shows that recharge has increased substantially (5–15 mm/year) in northwestern and western districts but has slightly decreased (–0.5 to –1 mm/year) or remained unchanged in the rest of Bangladesh. Increases in groundwater recharge may be possible where actual (net) recharge is less than potential recharge estimated previously. The estimates of net recharge in northwestern and western parts of Bangladesh are much greater than in eastern parts where potential recharge is higher due to greater annual rainfall (>2000 mm). Net annual recharge in western parts of the country has substantially increased since the 1980s and now approximates potential recharge. Numerical modeling of regional groundwater flow suggests

that actual (net) recharge increased from around 70 mm/year prior to widespread groundwater-fed irrigation (before 1970s) to around 250 mm/year more recently (Michael and Voss 2009). The estimates of net recharge show that mean recharge in Bangladesh has increased from 132 mm/year over a period from 1975 to 1980 to approximately 190 mm/year for the period 2002–2007.

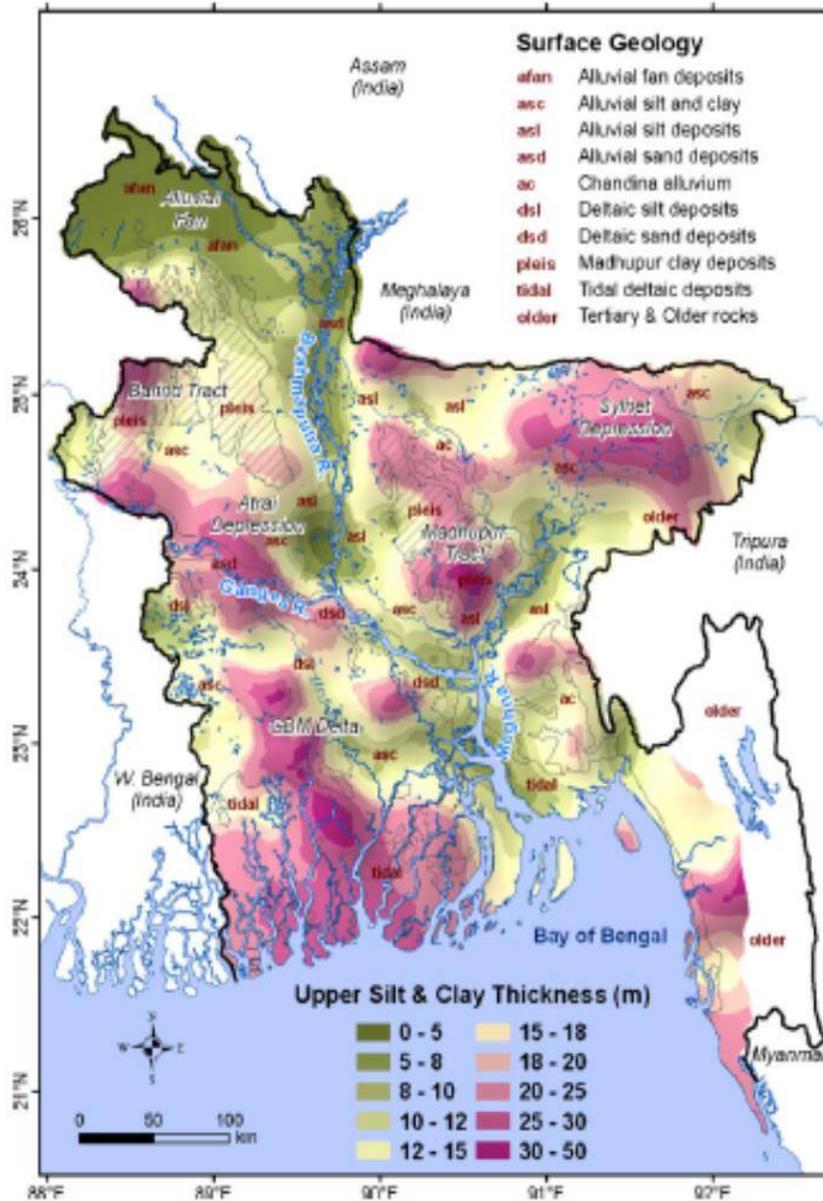


Figure 3.1: Map of the thickness of the upper silt and clay (Shamsudduha et al. 2011).

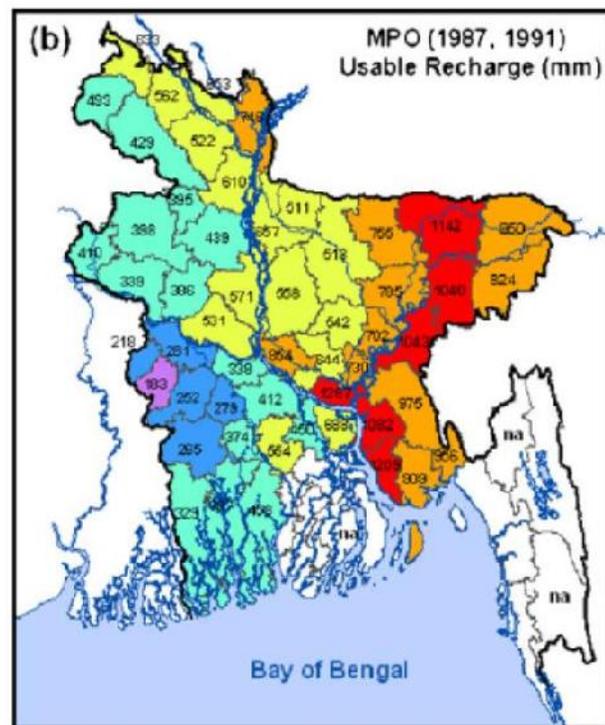
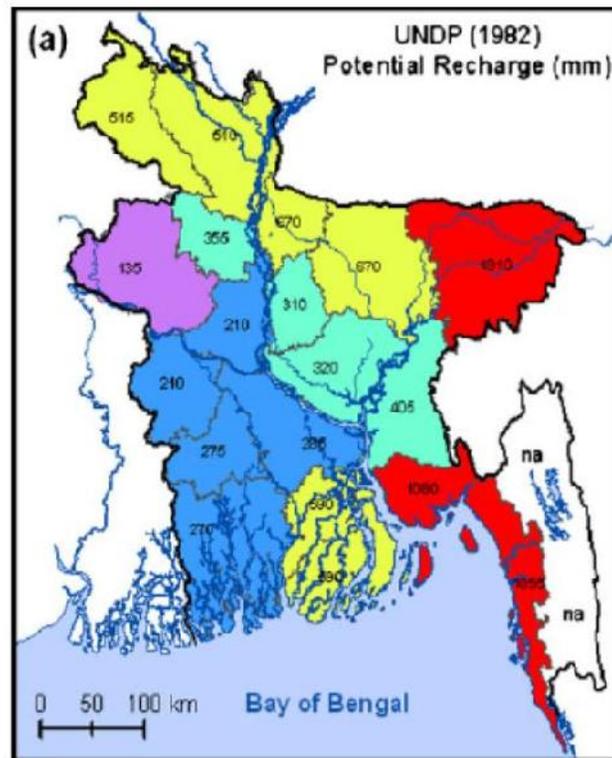


Figure 3.2: Area-wise potential and usable recharge estimated by different studies (Shamsudduha et al. 2011)

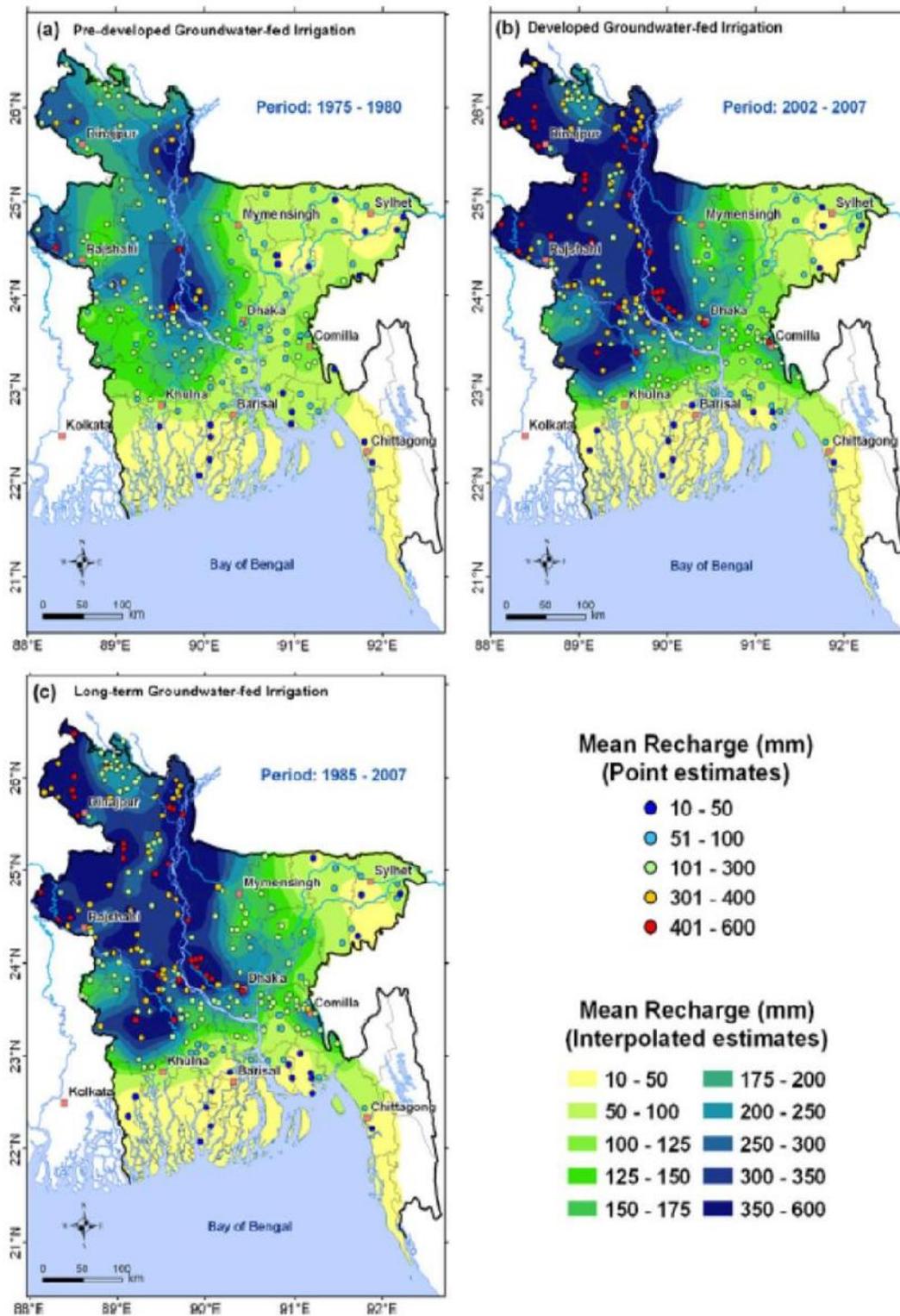


Figure 3.3: Maps showing groundwater recharge for pre-developed groundwater-fed irrigation period (1975–1980), post-developed groundwater-fed irrigation period (2002–2007), and long-term mean recharge period (1985–2007) (Shamsudduha et al. 2011)

Model simulations (Zahid et al. 2015) for south-east Bangladesh show that flow paths and travel time of groundwater to different depth levels down to the depth of 400 m of multi-layered aquifer units are primarily controlled by hydrogeologic characteristics i.e. anisotropy and the pattern of pumping. The recharge zone for different aquifer units under different development stress is about same in different geologic conditions (**Figure 3.4** and **Figure 3.5**). Aquifers are recharged by vertical percolation as well as water from long distance travel from highly elevated eastern hilly areas mainly to deeper aquifers. Huge irrigation and other pumping from the 1st i.e. the shallow (<50 m) and the upper part (50-100 m) of the 2nd i.e. the main aquifer units retards vertical percolation in deeper aquifers (>300 m), resulting increase of travel time in the lower part (100-250 m) of the 2nd and the upper part of the 3rd i.e. the deep aquifer units. Under current trend of groundwater development, the average travel time i.e. age of water for the upper and the lower parts of the 1st and the 2nd and the upper part of the 3rd aquifers at different geologic conditions are estimated between 37 and 234, 133 and 317, 832 and 2485, 1009 and 3027 and 1065 and 3543 years respectively (**Table 3.1**).

Travel time of vertical percolation of recharge water will be decreased in the 1st aquifer with increased irrigation pumping in future from lower part of the 1st aquifer. Average travel time and length of flowlines will be increased for the 2nd and the 3rd aquifers as huge pumping continues from the 1st aquifer. Groundwater level in the shallow aquifer varies place to place mainly due to local-scale lithologic variations and pumping of groundwater. The 1st and the 2nd aquifers are greatly influenced by the irrigation abstraction and local cone of depressions are created depending on intensity of pumping that also influences water level in these aquifer units almost all through the year. Under natural conditions the groundwater gradient is almost flat and horizontal flow is relatively small compared to vertical movement. Therefore, water level does not follow regular trend for the 1st and the 2nd aquifer units. Water from the 1st aquifer may move downward into the deeper fresh water zones through aquitard windows. Groundwater in the 3rd aquifer generally flows laterally.

Table 3.1: Travel times (age) of groundwater to different aquifer units at anisotropic and low anisotropic condition

Unit	Aquifer	Pre-development			2004 Development			2014 Development		
		Max	Min	Ave	Max	Min	Ave	Max	Min	Ave
Anisotropic conditions										
Unit 3	1 st (Upper)	2671	33	1972	121	8	37	30	5	14
Unit 4	1 st (Lower)	2627	91	1983	2557	21	133	165	14	37
Unit 6	2 nd (Upper)	2567	1264	1912	5881	122	2485	8140	130	3312
Unit 7	2 nd (Lower)	2516	1237	1873	4853	1288	2454	8831	865	3527
Unit 9	3 rd (Upper)	2413	1022	1757	3896	1150	2297	7334	1321	3496
Low anisotropic conditions										
Unit 3	1 st (Upper)	2647	4	792	1143	3	234	3309	2	288
Unit 4	1 st (Lower)	3157	11	782	3687	8	317	3899	6	289
Unit 6	2 nd (Upper)	2510	28	883	3194	21	832	3517	19	956
Unit 7	2 nd (Lower)	3006	55	878	3101	45	1009	4365	42	1111
Unit 9	3 rd (Upper)	3027	124	956	2837	116	1065	4396	110	1209

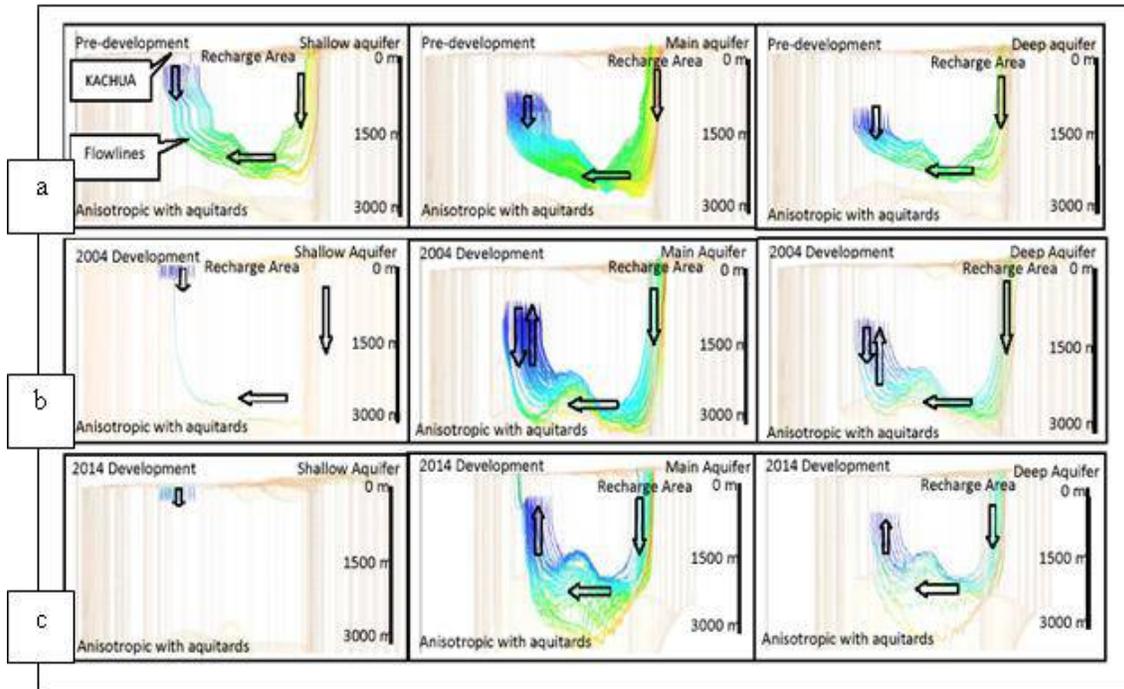


Figure 3.4: Flow paths and recharge zones for aquifer units at anisotropic condition under (a) predevelopment, and (b) 2004 and (c) 2014 development stresses (Zahid et al. 2015)

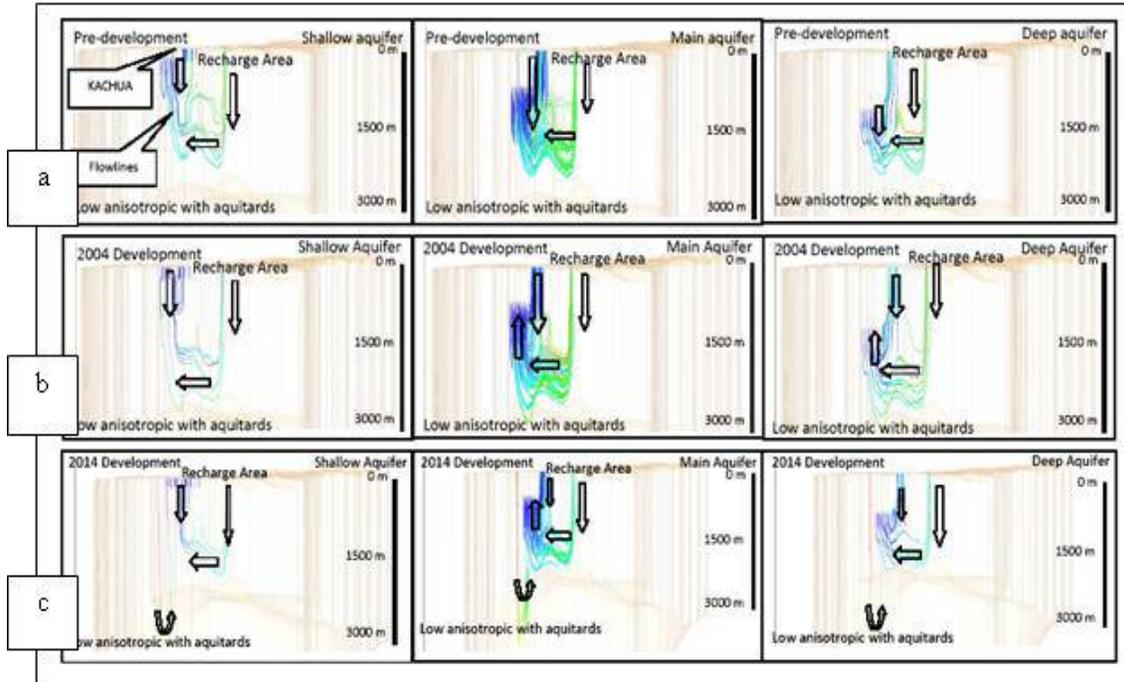


Figure 3.5: Flow paths and recharge zones for aquifer units at low anisotropic condition under (a) predevelopment, and (b) 2004 and (c) 2014 development stresses (Zahid et al. 2015)

3.2 Fluctuation of Groundwater Table

With increasingly growing demands on the groundwater supplies, areas of urban as well as rural Bangladesh have started facing water problems, including the drying up of wells during peak irrigation period and continuous lowering of water table mainly in city areas. Study has estimated that nearly 30 km³ of groundwater was abstracted for irrigation throughout Bangladesh during the *Boro* rice season in 2006 (Shamsudduha 2013). Considering an average daily groundwater use of 50 liters per person for both drinking and domestic uses (total population of 150 million in 2006) an estimated domestic groundwater use is approximately 3 km³ which is an order of magnitude less than irrigation abstraction. Analysis of long-term water table data of BWDB piezometers installed in upper and deeper part of aquifers shows that hydrographs are very variable in different parts of the country (WARPO 2000). On the other hand a degree of similarity is also found between different hydrographs.

The impact of groundwater development can often be observed from hydrographs (**Figure 3.6** and **Figure 3.7**). Groundwater recedes more during the dry season and the rise is often delayed. Generally, groundwater withdrawal from the shallow aquifer for domestic and irrigation purposes during dry periods is balanced with the vertical percolation of rain water and inflow from surrounding aquifers during monsoon when pumping is ceased. No permanent declining of water table is observed, except urban areas and in the Barind tract. Seasonal water table fluctuation is more in the central and northern part of the country where groundwater irrigation is extensive and this fluctuation is low or even nil near the coastline as groundwater irrigation in the southern coast is negligible due to salinity problem in upper aquifers. In Dhaka city, permanent declining trend of groundwater level is observed due to excessive withdrawal for city water supply and around Dhaka city for industrial withdrawal. Groundwater table contour map of greater Dhaka shows that maximum depth to groundwater table in Dhaka city is more than 60 m and in surrounding industrial areas this is within 9 to 18 m during dry period (Figure 3.8). During monsoon, the groundwater table rise steadily until the levels are within 1-2 m of the surface. During the peak irrigation season in March and April, the hydrograph is fairly smooth since years and steepest rise in the hydrograph is observed immediately after the irrigation pumps are switched off rather than at the start of the monsoon as might be expected.

Using weekly monitoring records of groundwater levels throughout Bangladesh (Shamsudduha et al. 2011) shows that shallow groundwater levels are declining at a high rate in the recent time (1985 – 2005). Declining rates are highest (exceeding –0.5 m/year) in and around Dhaka City and Barind Tract region, and high (0 to –0.05 m/year) in areas south of the River Ganges. In the coastal areas, shallow groundwater levels are showing stable to slightly rising trends (0 to +0.1 m/year) over the same period. Withdrawal by shallow irrigation wells may also influence the huge fluctuations in water levels in the deeper aquifers. These levels in the deeper part recover rapidly when seasonal pumping stops. This rapid recovery, parallel to water levels in shallow aquifer, reveals that shallow and lower aquifers are hydraulically connected. Huge irrigation abstraction of shallow groundwater during dry irrigation period has impact on groundwater levels in deeper part of aquifers (down to 350 m) and where abstraction is negligible like in coastal areas groundwater levels in deeper part remain steady and close to the surface (**Figure 3.8** and **Figure 3.9**).

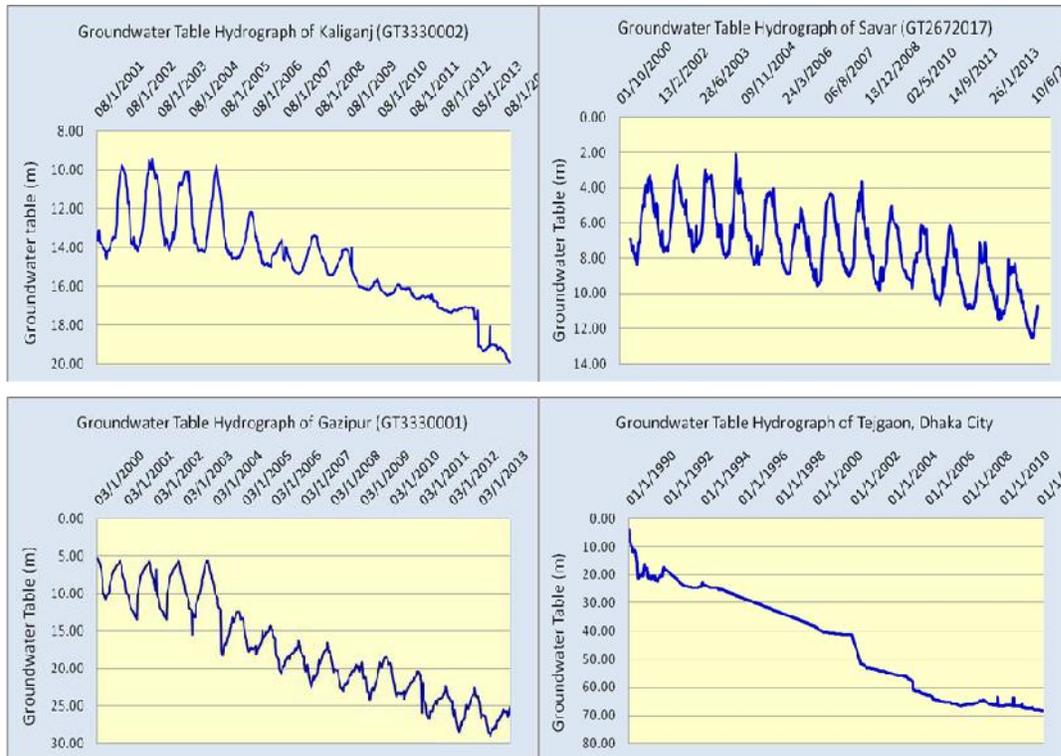


Figure 3.6: Hydrographs showing groundwater table declining trend in and around Dhaka city.

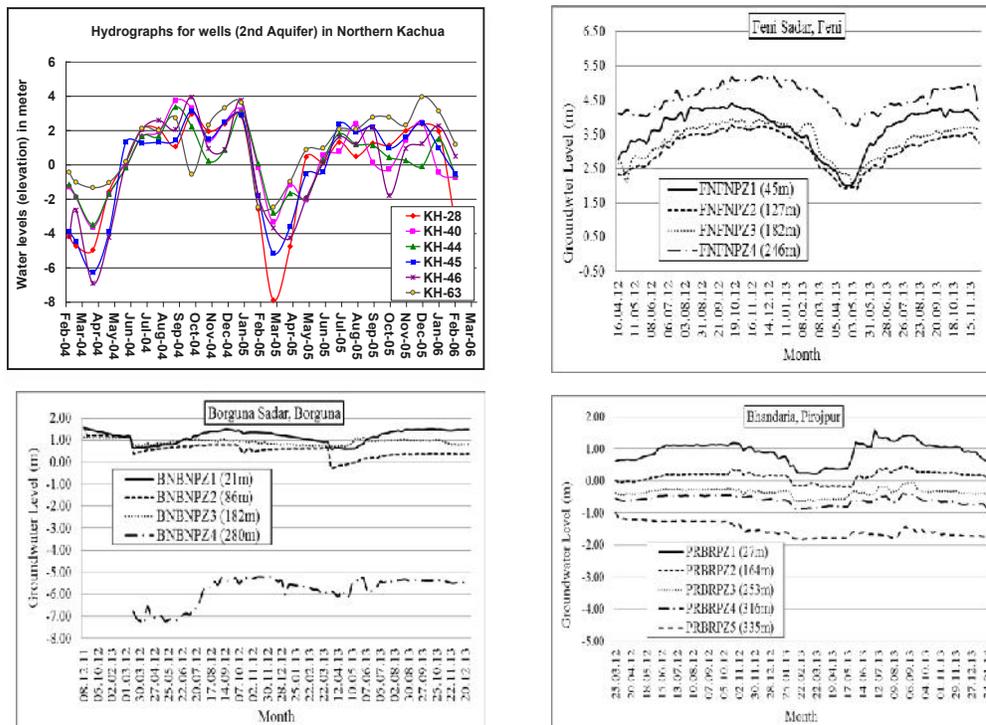


Figure 3.7: Groundwater level hydrographs from different depth levels of aquifers (down to 335 m) in irrigated and low-irrigated areas

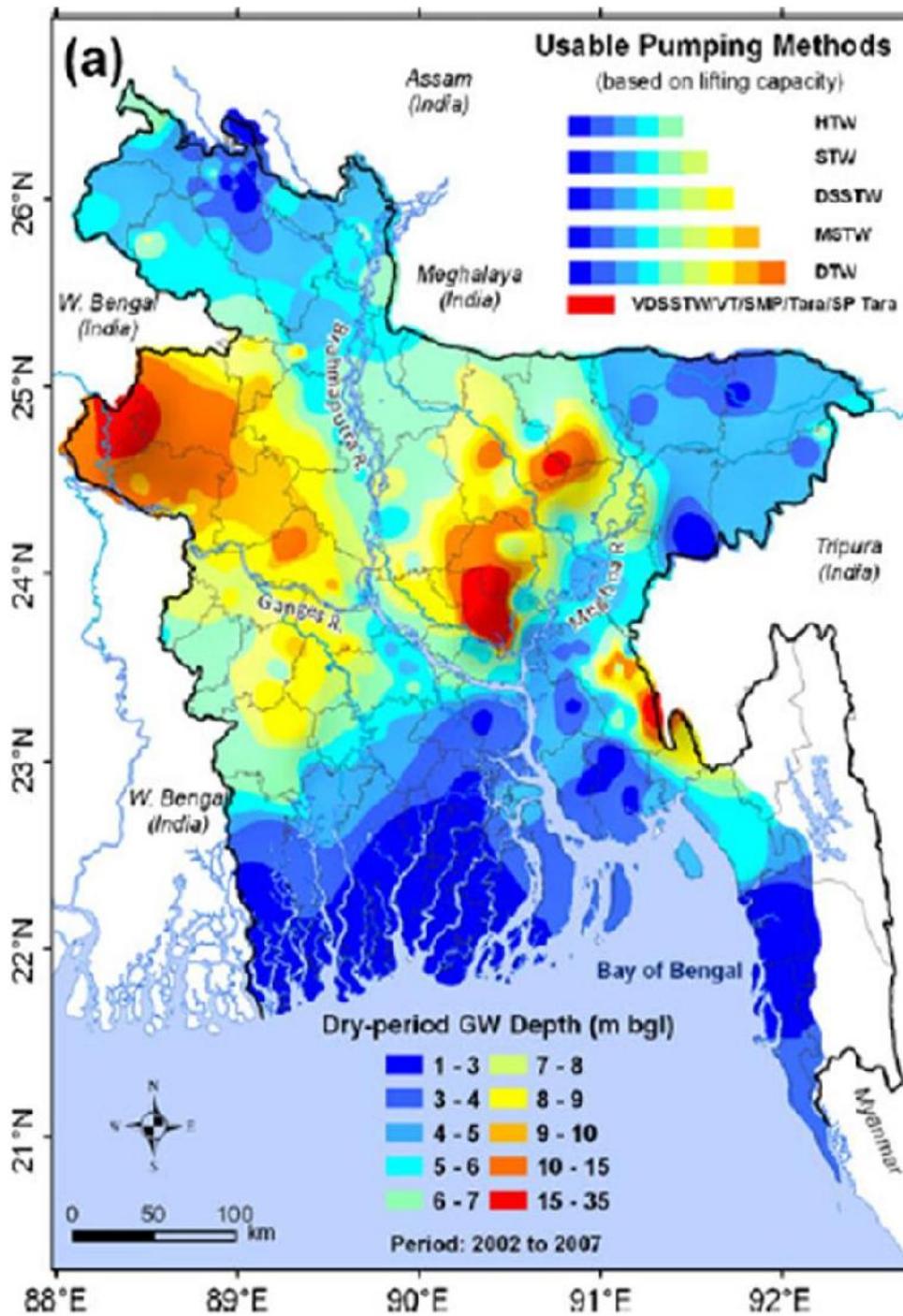


Figure 3.8: Dry period groundwater table contour map of Bangladesh (Shamsudduha et al. 2011)

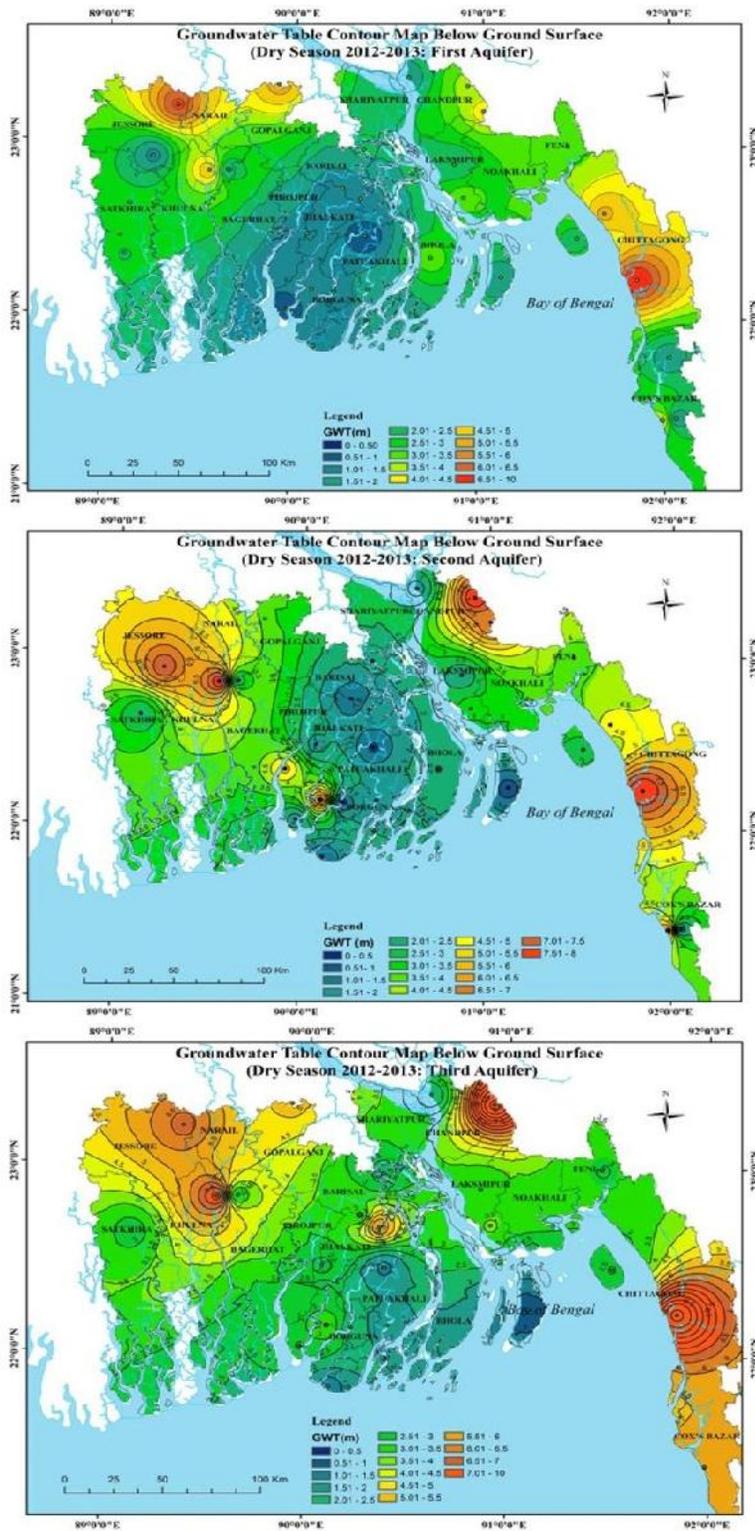


Figure 3.9: Depth-wise seasonal distribution of groundwater table in multi-level piezometers (down to 350 m below ground level) (Zahid et al. 2014)

4. Expansion of Groundwater Irrigation

In a small land area of 147570 km² with about 140 million populations in Bangladesh importance of groundwater irrigation has been increased to meet the food demand for growing population with the introduction of High Yield Varieties (HYV) seeds in late sixties. Groundwater irrigation is rather new in the country though the surface water irrigation by indigenous method was in practice. Until 1950's farmers used only traditional means of irrigation, the swing baskets and doan with the capacity of lifting water up to about 1 to 1.5 m. Persian wheels were also used in many parts of the Indian subcontinent to lift water from the dug wells (**Figure 4.1**).

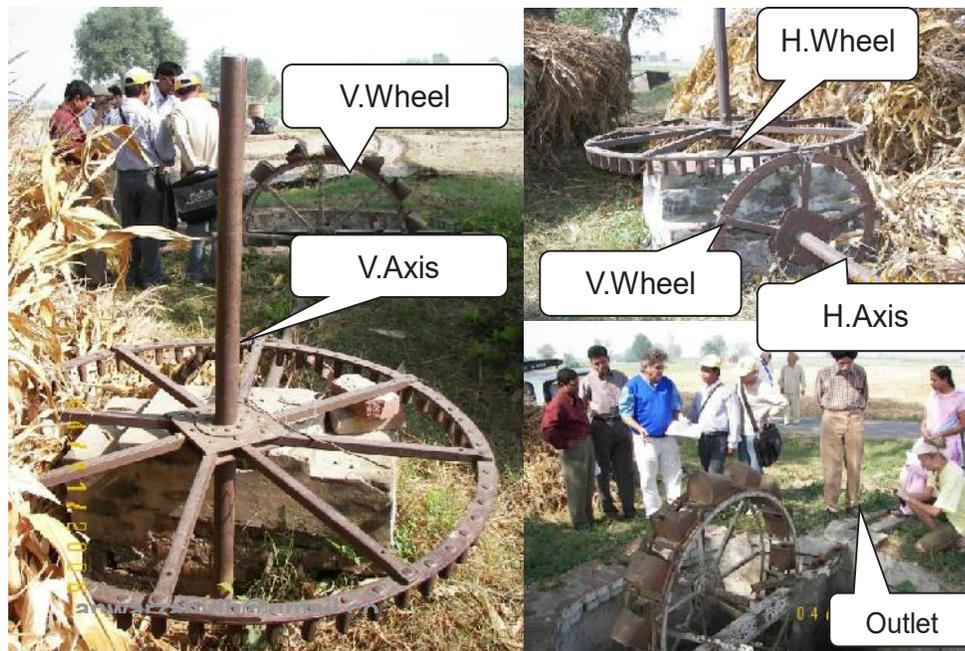


Figure 4.1: Remnants of the previous traditional means of irrigation technology i.e. Persian Wheels in the Indian Sub-continent

The country started emphasizing groundwater irrigation in the mid-seventies with Deep Tube Wells (DTW), and soon shifted its priority to Shallow Tube Wells (STW). Groundwater is the main source of irrigation and one of the key factors making Bangladesh nearly self sufficient in food production using submersible pumps in tubewells (**Figure 4.2**).

BADC was used to install DTWs by reverse circulation drilling method using very costly power rigs and distributed water to farmers, mostly, under subsidized projects. Privatization and expansion of minor irrigation and withdrawal of Government subsidy in irrigation equipment lead to a very rapid growth of farmer financed STWs.

In Bangladesh, people with less than 0.5 acres of cultivable land comprise 66% of the population who are absolutely poor and are rarely benefited of large water development schemes. About 90% of the total irrigated area is under private sector led 'minor irrigation'. The minor irrigation involves different pumping technologies like STW, Deep Set Shallow Tube Wells (DSSTW), DTW, Force Mode Tube Wells (FMTW), Low Lift Pumps (LLP) etc. Majority of the technologies are STW and LLP. Minor irrigation using groundwater has, in fact, been the single most important driving force behind the steady expansion of agricultural output in recent years. Manually driven percussion method became popular for STW installation having depth of 20-45 m. Direct circulation rotary drilling

method with donkey pumps is another low-cost technology for the installation of up to 300 m depth for even larger diameter wells (**Figure 4.3**). Irrigation wells are relatively inexpensive, easy to install using local methods, easy to maintain and are shared between small groups of farmers and leads to uncontrolled installation of wells. The lower costs, the accessibility, and the more stable quality of groundwater have encouraged groundwater pumping. STW has increased in numbers throughout the country from 1,33,800 in 1985 to 11,82,525 in 2006 and about 15,00,000 in 2013 (**Table 4.1**) (Mandal 2006; BADC 2014).

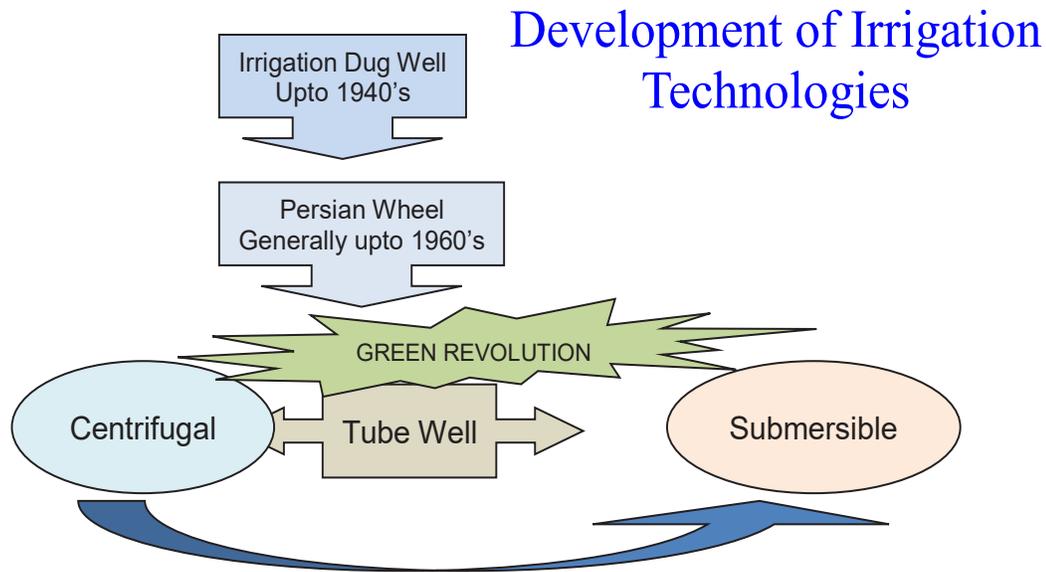


Figure 4.2: Development of groundwater irrigation technologies in Bangladesh since few decades

Total irrigated land in 2006 was 5.4 million hectare (Mha) where 3.8 Mha i.e. 70% was under minor irrigation and total cultivated land was 7.1 Mha (BBS 2006). Currently, the high-yielding *Boro* rice is grown in more than 4.0 Mha of net cultivable land (total of nearly 8.0 million ha) in the country that is primarily groundwater-fed (BBS 2013). In Bangladesh, the proportion of arable land irrigated by groundwater increased from <1% in 1965 to approximately 78% in 2007 (Shamsudduha et al. 2011). By 2006, nearly 78% of the irrigated rice-fields were supplied by groundwater of which approximately 80% of the irrigation water derived from low-capacity (average discharge rate 10 L/s) shallow tubewells (STW; depth <80 mbgl); the rest was irrigated by high-capacity (average discharge rate 56 L/s) deep tubewells (DTW; depth >80 mbgl) to produce *Boro* rice (BWDB-UNDP 1982; BBS 2009). Study (Shamsudduha et al. 2011) shows that during the pre-developed groundwater-fed irrigation period (1975–1980), shallow tubewell (STW) based irrigation covered an average area of 57,000 ha and deep tubewell (DTW) covered an average area of 138,000 ha. The second period (2002–2007) i.e. the developed groundwater-fed irrigation period, STW-based average irrigated area increased to 3,044,000 ha and DTW-supplied area increased to 702,000 ha.

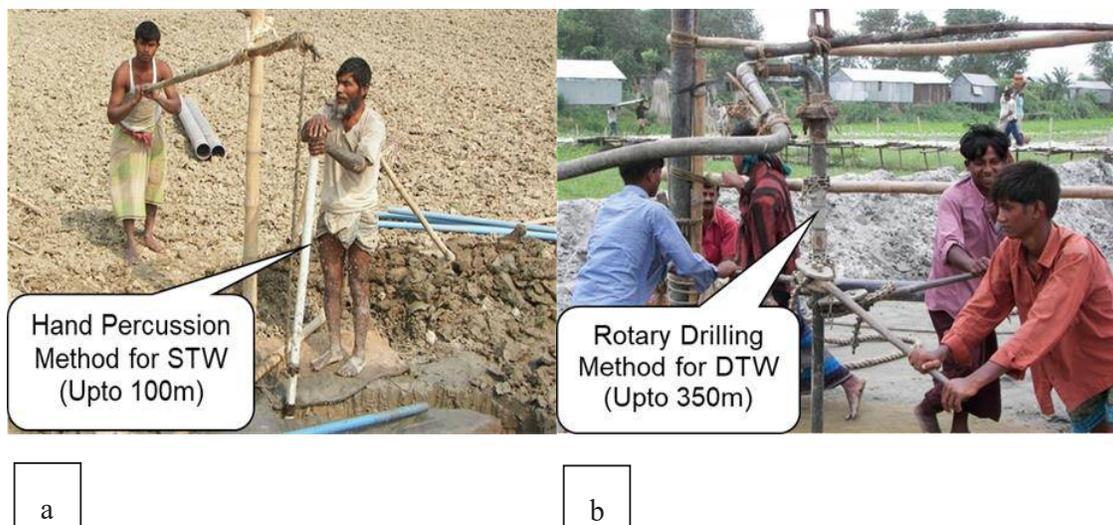


Figure 4.3: Irrigation wells are relatively inexpensive, easy to install using local methods, as well as easy to maintain that leads to uncontrolled installation of wells

Table 4.1: Low cost methods for TW installation causing rapid expansion of groundwater abstraction for Irrigation

Year	Nos. of STW	Nos. of DTW	Year	Nos. of STW	Nos. of DTW
1985	133,844	15,322	1998	664,671	25,354
1988	186,431	23,482	2001	707,574	23,536
1989	217,879	23,352	2004	925,152	24,718
1991	270,309	21,519	2006	1,182,525	28,289
1993	348,875	25,714	2007	1,202,728	29,177
1996	556,383	27,169	2013	1,523,609	35,322

Irrigation expansion based on STWs development is still continuing. The dominant food crop of Bangladesh is rice. HYV seed, application of fertilizer, and irrigation have increased yields, although these inputs also raised the production cost. With the increasing use of irrigation, there has been a focus on Boro rice – growing season extending during the dry season from October to March. Total production of Boro rice in the country in 2005–06 was 13.8 million metric tons (MMT) that was 55% of total rice production (BBS 2006). The development of groundwater for irrigation has had a major positive impact on food grain production in Bangladesh. In Bangladesh, people with less than 0.5 acres of cultivable land comprise 66% of the population who are absolutely poor and are rarely benefited of large surface water development schemes. The growth of groundwater irrigation, especially privately supplied irrigation by STWs purchased by individuals for cash or credit at unsubsidized price led to the emergence of irrigation water market. The expansion of the groundwater market has been created kinds of associated business too establishing local workshop for manufacturing irrigation pumps, pipes, spare parts and development of mechanic skills in rural areas. Hence, groundwater irrigated agriculture plays an important role not only in increased food production but also in poverty alleviation. GDP is highly dependent on the development of water resources in general.

4.1 Groundwater Market

The water market in Bangladesh has significantly contributed to improve in irrigation management, irrigation quality, agronomic practices of irrigated rice production, tillage mechanization and farming integration as well as to improve livelihood of huge rural population. The market is dominated by a dynamic private sector involving about 1.7 million owners and managers of mechanized pumps, 0.76 million owners and operators of non-mechanized and traditional irrigation devices with about 7.6 million irrigator farmers (Mandal 2000) that also creates job and small scale business opportunities in rural areas (**Figure 4.4**). Human labor and animal power are required in various stages of crop production. Peak period for human labor is during transplantation and harvesting while animal labors in land preparation. There is high demand for labor during the *Boro* rice transplantation and harvest. Power tiller is used for land preparation. Field survey shows that the average labor requirement of *Boro* rice production is 35 person-days/acre. Vegetable production is more labor-intensive than rice crops, requiring an average of 70 person-days. Small farmers' share of STW ownership has increased significantly over the years. In the advanced districts of Bogra and Comilla small farmers dominated the ownership of STWs (80% in Comilla and 60% in Bogra). In the less advanced districts, about two-third of the STW owners had cultivated land below 6.42 acre (Mandal 2000). In the prevailing water market, the pump owners installed their wells or pumps in their own plots or other peoples plot to irrigate their own plot and sell excess water to other farmers under varied formal/informal contractual arrangements. There are many pump owners who do not have any land in their tube well command areas and run their pumps with business interest (Mandal 2000). In the Gangetic floodplain area, *sub-marginal* (land holding size <1.23 acre) non-pump owners (WBs) account for 40 %, which is by far the highest, followed by *marginal* (land holding size <1.24–2.47 acre) non-pump owners, represent 17% (Zahid et al. 2009).



Figure 4.4: Agriculture creates job and small scale business opportunities in rural areas

There are generally three modes of payment or purchased water: hourly rates (Tk/ha), area based rates (Tk/ha) and crop share. Two major forms of payment for water are practiced in Bangladesh: fixed cash payment and share of the crop. In a large part of the country a one-fourth crop share payment has been evolved mainly in the context of cash constraints by the irrigator farmers in the beginning of the irrigation season when they also need to pay for fertilizers, seedlings and labor. But, in many areas one-third crop share is practiced. Payment is done at the field directly immediately after harvesting. It may appear a little higher than cash payment but it is not necessarily exploitative when one includes interest on operating capital committed by the water suppliers as well as premium for risk of crop failure or damages. The selection of crops in a cropping pattern depends upon not only agro-climatic situation but also upon home consumption, market demand and the socio-economic condition of the cultivators. The country has achieved an estimated cropping intensity of about 146 to 185% (NWMP 2001; Zahid et al. 2009).

4.2 Impact of Groundwater and Other Inputs on Crop

Besides irrigation, crop production needs various agricultural practices- land preparation, seedling or plantation, application of fertilizers, intercultural operations, plant protection etc for a good harvest those have also impacts on crop economy. A timely cultural operation increases the yield, but in the study area cultural practices are not upto the mark. As a result, yield obtained for different crops are not satisfactory. Bangladesh Rice Research Institute (BRRRI) recommends plant spacing for Aman and Boro as 2-3 seedlings per hill, but the farmers use 7-8 seedlings per hill. The insecticides are applied neither in proper time nor in proper doses. HYV Boro is the main irrigated crop by diesel operated STWs. It is seen that proper care and attention is given to vegetables and onion, as cash money is available. BR-16, BR-28, BR-29 and Hira rice are generally grown in Boro season. The average seed used for Boro rice cultivation is 20 kg/acre for transplanted rice. BRRRI recommends 15-20 kg seed per acre for transplantation of paddy but the farmers use very high seed rate.

Farmers mostly apply chemical fertilizers and only a few are reported to use organic manures. Nitrogen is the most common and widely used nutrient and urea is the major source of nitrogen. Phosphate is next only to nitrogen in total volume of use as fertilizer. The most widely used phosphate fertilizer is TSP. Potash is the third most widely used nutrient, and MP is the only source of potash. Farmers use Urea, TSP and MP at the rate of 110-150, 60-90 and 20-30 kg/acre respectively. In many areas, N, P₂O₅, K₂O ratio used by the farmers was 7:3:1 against the appropriate ratio of 5:4:3 for HYV Boro rice (NWMP 2001). The use of pesticide depends on the degree of pest infestation. Mainly pesticides are used in liquid form such as Diazinon, Basudia Furadon, Melathion etc.

The rice variety has grown in duration of 120 to 130 days. The preferred planting method is transplanting of seedling using wet bed technique. After land is prepared, 35-40 days-age seedling is transplanted to the field and then the irrigation water supply period commences. The 3-day rotation method is practiced for water distribution. In an average, water is applied 35-40 times in the field during rice crop season. It was observed that continuous shallow ponding is needed to obtain rice yield. Most of the farmers are familiar with the rotational irrigation schedule and have accepted it as an equitable program for water sharing.

There is a common understanding among the farmers that the more water depth in the field within limits, the better is the yield of irrigated rice. In fact, this is not true. Even under irrigated conditions, occasional drainage is necessary for aeration. A series of water management studies conducted by BRRRI indicated that a range of water depths ranging from soil saturation only to 10 cm standing water gave statistically insignificant differences in rice yields, provided other management practice were uniform and equal. It was observed that the average groundwater productivities were 0.38-0.43 kg/m³. National Water Management Plan (NWMP) recommended

total required water depth for HYV Boro rice is between 1200 and 1500 mm per season, depending on soil condition. Study showed that considering the maximum value the average water use by farmers was 35-50 % more than the recommended limit that has no use to the growth of crops (Zahid et al. 2009).

4.3 Groundwater Irrigation and Impact on Livelihood

The Barind Integrated Area Development Project (BMDA) has been under taken since 1986 covering 767,900 ha gross area of three Barind districts – Rajshahi, Nawabganj and Noagaon (BMDA 2000). Before the project, Barind Tract was an unfavorable agricultural section of the country. At the beginning of the project, the three Barind districts were marginally surplus food producers, however, with the introduction of DTWs, their surplus over the project period increased substantially. Income level increased because of increasing agricultural production, increased demand for labor and increased wage rates. It is estimated that 62 % of total cultivable area are irrigable utilizing groundwater. With the increased and assured availability of irrigation water, the agricultural scenario has fundamentally changed. Most irrigation development in the project area has taken place through the use of DTWs and STWs, however, due to groundwater table declining trends use of surface water has also been initiated by BMDA authority recently (**Figure 4.5**).

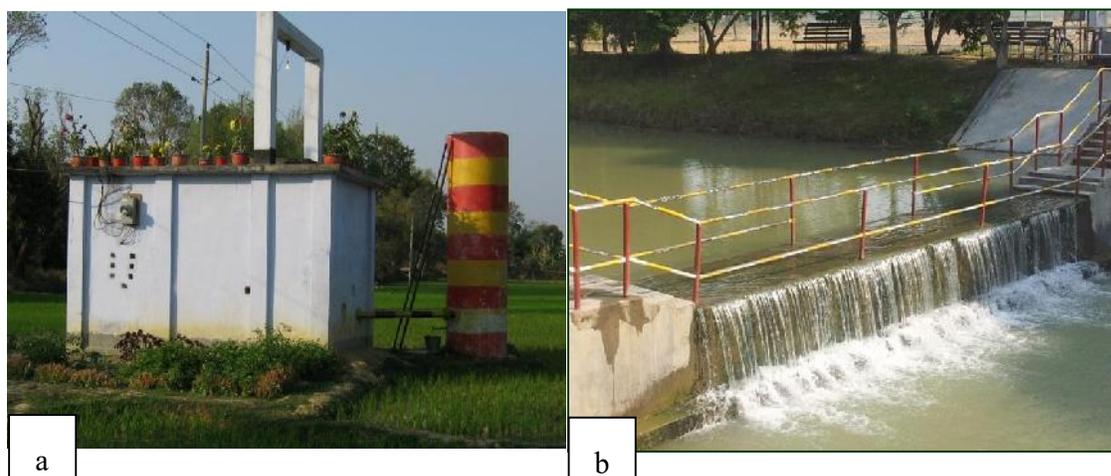


Figure 4.5: Groundwater is the main source of BMDA irrigation schemes (a), however, since few years, use of surface water has also been introduced (b)

The increase in yield of Boro rice is 43 to 120 % in the districts within the project area. Cropping intensity in the area increased from 141 % in 1991 to 200 % in 1998–99. Besides implementing a comprehensive package of agricultural development activities, various associated programs have also been introduced like afforestation, re-excavation of ponds, construction of cross-dams etc. All these components played a positive role in improving the livelihood of the people with positive economic returns. The total cost recovery of the project was worked out to be Tk 1,067 million of which the recovery from the beneficiaries of irrigation interventions was Tk 1013 million which indicates that the investment of the project has been economically and socially profitable that has had direct impact on poverty alleviation.

5. Major Constraints to Groundwater Development

5.1 Quality of Groundwater

Using the pattern on the piper plot the floodplain groundwater was classified into two groups, namely the Na-Cl type and the Na-Ca-Mg-HCO₃ type. The major ion trends of the Na-Cl type are Na⁺>Ca²⁺>Mg²⁺>K⁺, common for all aquifers down to 350 m bgl and Cl⁻>HCO₃⁻>SO₄²⁻, mainly for deeper and HCO₃⁻>Cl⁻>SO₄²⁻ for shallow samples (Zahid et al 2008). Study by Zahid et al. (unpublished) shows that in the coastal delta groundwater samples down to the depth of 200 m, except Cox's Bazar and Feni samples, are distributed in the right central portion of the diagram and classified as Cl⁻-SO₄²⁻, Cl⁻-SO₄²⁻-HCO₃⁻, Na⁺-Ca²⁺, Na⁺-K⁺ types dominated by Na⁺-Cl⁻ and HCO₃⁻ type. Seawater intrusion is the major phenomena till this depth. Deep water (down to 336 m) of Patharghata, Bhandaria and Mukshedpur aquifers is also classified with this cluster. Cox's Bazar and Feni samples of down to 200 m depth shows Na⁺-Ca²⁺ and HCO₃⁻-Cl⁻-SO₄²⁻ types with the signature of the mixture of fresh water and seawater. Most of the deep groundwater samples between 201 and 336 m depth ranges are classified as HCO₃⁻-Cl⁻-SO₄²⁻, Na⁺-K⁺-Ca²⁺ types, dominated by HCO₃⁻ type those are within the limit of fresh water. The major ion trends of the upper Na⁺-Cl⁻ groundwater type are Na⁺>Ca²⁺>Mg²⁺>K⁺ and Cl⁻>HCO₃⁻>SO₄²⁻ and for the deep groundwater ionic trend is Na⁺>Ca²⁺>Mg²⁺>K⁺ and HCO₃⁻>Cl⁻>SO₄²⁻. In Sylhet basin the groundwater is of Ca²⁺-Na⁺ - HCO₃⁻-Cl⁻ type.

The groundwater resource of Bangladesh is facing different problems including quality hazards in many areas where the exposure to pollution from agriculture and arsenic contamination in shallow groundwater makes the water unfit for human consumption. It has been reported that out of 64 districts 61 are affected more or less. Surveys (Ahmed et al. 2004; Zahid et al. 2008) show that about three million tubewells, installed at shallow depths (10 to 50 m), discharge groundwater with arsenic concentrations more than the Bangladesh drinking water standard of 50 µg/l. About 28 to 35 million Bangladeshis have been exposed to drinking water containing arsenic that exceeded the Bangladesh arsenic standard, and 46 to 57 million people have been exposed to drinking water containing arsenic that exceeded World Health Organization (WHO 2008) arsenic standard of 10 µg/L (DPHE-BGS 2001). More than 30,000 people have already suffered from arsenicosis and this number will be increased drastically within next decades if necessary measures are not taken. Deep tube wells, with the depth range between 100 and < 300m, were installed in the main aquifer in recent years as an attempt to find groundwater with insignificant or no arsenic concentration. But, these wells often contain high concentrations of iron, manganese and high salinity. Large-scale groundwater abstraction from deep aquifers could eventually result in contamination of the deeper fresh and safe groundwater resource by inducing relatively rapid downward flow from high-arsenic and saline regions.

High concentrations of dissolved iron (Fe) is common in groundwater in many areas of Bangladesh (DPHE-BGS 2001). However, there are no reported public health effects of high Fe in drinking water. Turbidity and color may develop in piped water systems at concentrations >0.05–0.1 mg/l. The median Fe concentrations in Bangladesh groundwater is 1.1 mg/l and the maximum concentration was recorded at 61 mg/l (Shamsudduha et al. 2011). In Bangladesh, groundwater is commonly treated for high Fe concentrations in drinking and industrial water supplies because of aesthetic reason. High concentrations of dissolved manganese (Mn) in groundwater is another groundwater quality issue in Bangladesh (DPHE-BGS 2001; Hasan and Ali 2010). Study reports that about 73% of surveyed water wells have Mn concentrations exceeding 0.1 mg/l, and nearly 42% water wells exceed a concentration of 0.4 mg/l.

A recent study (Flanagan et al. 2012) reports that over the next 20 years As-related mortality in Bangladesh (1 of every 18 deaths) could lead to a loss of US \$12.5 billion assuming a steady economic growth and an unchanged population exposure to As contamination. The occurrence, origin, release mechanism and mobility have received huge attention. Although adverse neurological effects of inhaled Mn have been well documented in humans the quantitative and qualitative details of exposure necessary to establish direct causation are lacking (WHO 2011). Adverse neurological effects (i.e., reduced children's intellectual function) as well as infant mortality with high exposure to Mn through drinking water have recently been reported from long-term monitoring of Mn exposure and public health impacts in central Bangladesh.

5.1.1 Arsenic contamination in shallow groundwater

Groundwater arsenic contamination has been identified in various parts of the world. Groundwater in the Ganges and Yellow river basin countries, such as, Bangladesh, India (West Bengal), Nepal, and China, contains dissolved arsenic in excess of World Health Organization (WHO) and United States Environment Protection Agency (USEPA) recommended limit of 10 µg/l. Arsenic occurs as a major constituent in more than 200 minerals in association with the transition metals as well as Cd, Pd, Ag, Au, Sb, P, W and Mo (DPHE-BGS 1999). Long-term exposure to arsenic in drinking water has the clinical effects of chronic arsenic poisoning, ranging from skin ailments, through damage to internal organs to gangrene and cancer. In terms of patients affected and populations exposed, some the Ganges and Yellow river basin countries have the worst cases of arsenic related health problems and the occurrences of high-arsenic groundwater is constrained to a restricted range of geological, hydrogeological and geochemical condition in aquifer.

In recent years, the presence of arsenic in groundwater of Bangladesh has disturbed the whole scenario of its use. It has been reported that out of 64 districts 61 are affected more or less (**Figure 5.1**). In 1993, the DPHE first detected the presence of arsenic in tube-well water at Chapai Nawabganj, a northwestern district of Bangladesh. In 1996, BWDB confirmed arsenic contamination in groundwater of the western border belt. Since the identification of arsenic contamination in Bangladesh, the scientists and several agencies have been engaged themselves to carry out local, regional or national surveys to detect and mitigate the problem. Besides scientific study and investigation, wise management and governance of water resources in the arsenic affected areas has become an important issue in Bangladesh.

The contamination of arsenic in Bangladesh groundwater is generally found within 5 to 50 m depths, little is found at lower depths. Arsenic contamination is not uniform in all areas and the broad surface geological divisions have a good correlation with the arsenic distribution. The Holocene floodplain and deltaic sediments are severely affected. There is a distinct regional pattern with the greatest contamination found in the south and southeast and the least contamination in the northern most and in the Pleistocene uplifted terraces of north and central regions of the country. However, variability of arsenic concentration within short distance makes it difficult to predict the level of concentration of a given well even when the concentration of the adjacent wells are known. Salient observations indicate that the shallower and deeper aquifers of the country also have different isotopic signatures (IAEA 2000). The shallow groundwater (< 100 m depth) generally has high arsenic contents and is continually replenished with a residence time of 30-40 years. Deeper aquifer waters (> 100 m depth) are generally arsenic-free and are recharged on a time scale of over 100 years.

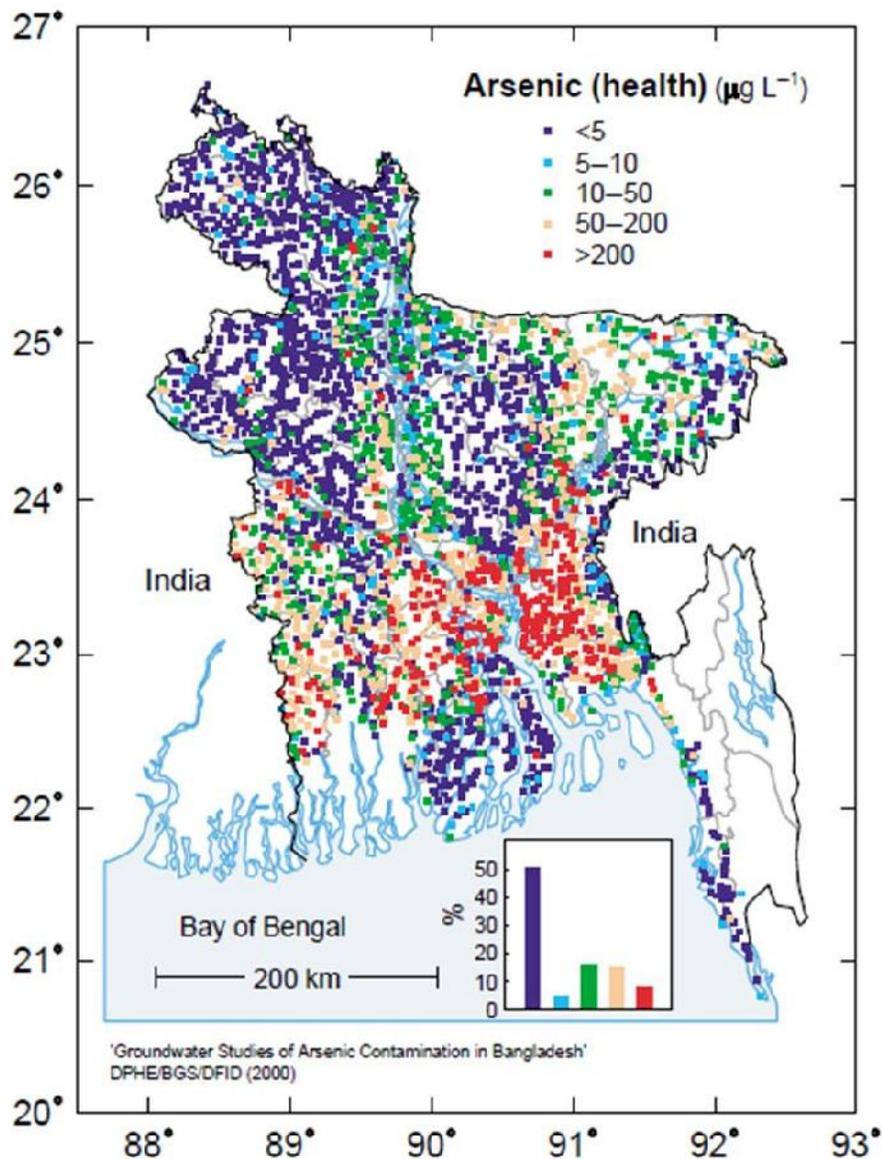


Figure 5.1: Distribution of groundwater arsenic concentrations in tubewells (DPHE-BGS 2001).

Summary statistics of available laboratory analysis results compiled under the project of DPHE-BGS (2001) survey show that out of 9271 samples, arsenic concentration of 3242 samples exceeded the limit of Bangladesh standard of $0.50 \mu\text{g/l}$ which is 35% of all samples examined. The 'Systematic Regional Arsenic Survey' under the study project covered initially 252 upazilas (sub-district) in the country. During phase-I, 2023 samples from 41 districts were collected and analyzed at the laboratories of BGS, UK, and 51% of total samples exceeded WHO guideline and 35% of total samples exceeded Bangladesh standard for arsenic concentration. Phase-II of DPHE-BGS (2001) hydro-chemical survey has been enriched with the results of 3534 tubewell samples covering 433 sub-districts. This number of tubewells is perhaps 0.05-0.1% of all tubewells in the country. From the survey, 25% of the tubewells sampled exceeded $50 \mu\text{g/l}$, 9% exceeded $200 \mu\text{g/l}$, 1.8% exceeded $500 \mu\text{g/l}$ and 0.1% exceeded $1000 \mu\text{g/l}$.

The two most common hypothesis of arsenic release mechanisms in groundwater of Bengal delta is as follows;

- Arsenic is released by oxidation of arsenic bearing minerals (e.g. arseno-pyrite) in the alluvial sediments (Chakraborti 1995; Mallik and Rajagopal 1996). The pyrite oxidation hypothesis assumes that a lowering of groundwater table draws in oxygen, which oxidizes sulfides and thus releases arsenic.
- Anoxic conditions allow reduction of iron oxyhydroxides (FeOOH) and release of sorbed arsenic to solution (Bhattacharya et al. 1997; Nickson et al. 1998; Acharyya et al. 1999; Harvey et al. 2002; Yan et al. 2000; Zahid et al. 2009).

The sediments of delta areas are predominantly silt, clay and fine sand with occasional medium to coarse sand. High concentrations of arsenic are common in alluvial aquifers originating from Himalayan erosion, supplying immature sediments with low surface loadings of iron-oxyhydroxides (FeOOH) on mineral grains to a depositional environment that is rich in organic matter where complete reduction of FeOOH is common. With the better soil aeration, crystalline iron-oxides and their ratio to total iron increase with cultivation age (Zhang and Gong 2003). Content of iron, manganese and aluminum in the area is significantly high and have close correlation with arsenic. Iron-containing minerals (biotite, chlorite, etc.) are common in Holocene alluvial sediments and weather to form FeOOH/FeOH_x coatings containing as much as 800 ppm of arsenic above the water table (Breit et al. 2004). Weathering of arsenic-rich minerals releases finely divided iron-oxyhydroxides, which would strongly sorb co-weathered arsenic (Mok and Wai 1994). Nickson et al. (2000) have mentioned that this process would have supplied arsenic-containing iron-oxyhydroxide to Ganges sediments since the late Pleistocene. Hydrous iron-oxide has a very high specific surface area (around 600m²/g) and thus a very high adsorption capacity (Davis and Kent 1990) to adsorb the bulk of arsenic (Anwar et al. 2003).

Reduction of FeOOH is common in nature and has been invoked to explain the existence of arsenic in groundwater. High content of dissolved iron in aquifers supports the reduction of FeOOH. Reduction of FeOOH is a microbial process that is driven by microbial metabolism of organic matter (Chapelle and Loveley 1992) and is the commonly proposed cause for high arsenic concentrations accompanied by microbial reduction of arsenic (V) to arsenic (III). Zahid et al. (2009) have mentioned that the FeOOH_x enriched sediment functions as a sink for arsenic in the shallow sediment. Reductive dissolution of the FeOOH_x may account for the local 'hot spots' of arsenic contamination in shallow groundwater in the Bengal Basin and has become an alarming health and environmental problem.

Provision of arsenic safe water for people after screening of wells has been the greatest challenge in Bangladesh. Based on 'National Policy for Arsenic Mitigation 2004, arsenic mitigation programs for safe water supply have been promoted giving priority to surface water over groundwater source. Technology options are area dependent and no single option can serve the people having diverse socio-economic background. Villages that have more than 80% of the tubewells contaminated are getting priority. The emergency response to arsenic mitigation is based on a supply driven instead of demand driven approach. Generally, there is no cost sharing for the capital cost of facilities provided by the Government, however, the operation and maintenance cost is to be borne by the community and one of the nearest households is selected as the caretaker family. Major alternative water supply options provided for drinking use are: dug wells, pond/river sand filters, large scale surface water treatment, deep hand tubewell, very shallow hand tubewells, rainwater harvesting, and arsenic removal technology (**Figure 5.2**).

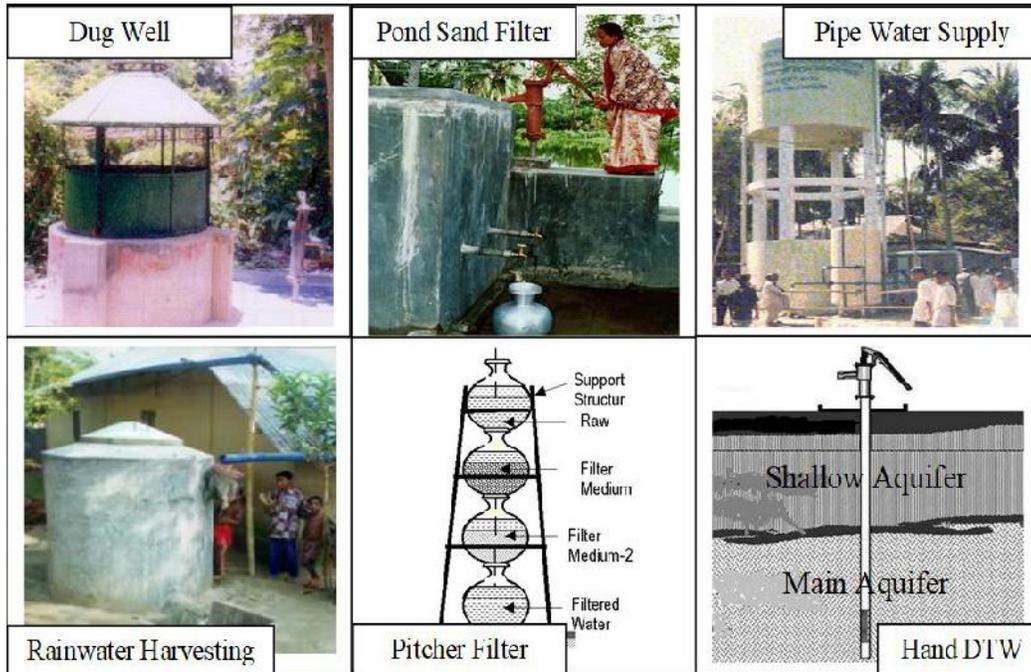


Figure 5.2: Different options of alternate safe water supply in arsenic-prone areas

Model for Potential Aquifer Formation to Mitigate Arsenic Contamination

Arsenic mitigation alternatives in the country have already been initiated by the Government and non-Government organizations but many are short term options and difficult to implement and maintain. Installation of deep wells for both irrigation and domestic supply to tap low-arsenic and non-saline water may seem a prudent alternative, but large-scale groundwater abstraction from deep aquifers could eventually result in contamination of the deeper fresh and safe groundwater resource by inducing relatively rapid downward flow from high-arsenic and saline regions. The water of the 1st aquifer generally has a higher head than water in the 2nd aquifer during irrigation abstraction. Water from the 1st aquifer may move downward into the deeper fresh water zones through aquitard windows. Groundwater in the 3rd aquifer generally flows laterally. The water level of the 3rd aquifer is higher than that of the 2nd aquifer. Arsenic or chloride-rich groundwater in the upper aquifers is not likely to be drawn into the deep aquifer under conditions of moderate use of the deep aquifer water. Under current trend of groundwater abstraction, possibility of advective transport of arsenic in the lower part of the 1st aquifer, just below the arsenic-contaminated zone, will increase in future.

Considering different geologic conditions in 2004 development stress, average travel time i.e. age of recharged groundwater is found between 37 and 317, 832 and 3027 and 1065 and 3543 years respectively for the 1st, the 2nd and the 3rd aquifers (**Table 5.1** and **Figure 5.3**) (Zahid et al. 2015). Minimum travel times indicate that under 2004 development stress, anisotropic condition is the most stable against leakage of water from the arsenic-contaminated layer to the lower part of the 1st, the 2nd and the 3rd aquifers. However, water in the lower part of the 1st aquifer may start to contaminate after 20 years. For the 2nd and the 3rd aquifers minimum travel times are 125-1250 and 1200 years respectively i.e. these aquifers remain safe at least for these time periods. If the recharge area of pumped water is not the shallow contaminated zone i.e. recharge occurring outside the high-arsenic region, the deep aquifer is considered a sustainable source of low-arsenic water. If the aquitards are discontinuous, times will be reduced. Where aquitards are weakly anisotropic, all aquifer units would be start to

contaminate by 150 years, that is less than 10 and 25 years for lower part of the 1st and the 2nd aquifers. Local scale hydrogeologic characteristics, e.g., low prevalence of clay layers, high-capacity municipal or irrigation pumping could result in local downward flow and may cause arsenic arrival earlier than indicated by large-scale analysis (Michael and Voss 2008).

Table 5.1: Minimum and average travel time of recharge water to aquifer units under different development stresses and geologic conditions (Zahid et al. 2015)

	Shallow Aquifer (Upper)		Shallow Aquifer (Lower)		Main Aquifer (Upper)		Main Aquifer (Lower)		Deep Aquifer	
	Min.	Ave.	Min.	Ave.	Min.	Ave.	Min.	Ave.	Min.	Ave.
A	8	37	21	133	122	2485	1288	2254	1150	2297
B	6	43	16	273	45	2346	122	3027	1477	3543
C	3	234	8	317	21	832	45	1009	116	1065
D	5	14	14	37	130	3312	865	3527	1321	3496
E	2	288	6	289	19	956	42	1111	110	1209
F	5	14	14	31	46	1253	416	3194	1386	3872
G	2	41	6	181	16	713	36	590	100	1290
H	5	14	13	35	121	3298	861	3552	1320	3496
I	2	299	6	290	19	953	42	1111	110	1209

Note: A: 2004 development stresses (anisotropic); B: 2004 development stresses (anisotropic, discontinuous aquitards); C: 2004 development stresses (low anisotropic); D: 2014 development stresses (anisotropic); E: 2014 development stresses (low anisotropic); F: 2014: new Shallow Irrigation Wells in upper part of the main aquifer (anisotropic); G: 2014: new Shallow Irrigation Wells in upper part of the main aquifer (low anisotropic)

Maintaining current trend of irrigation abstraction, if only domestic wells are shifted to the 2nd aquifer from the 1st aquifer, the 2nd aquifer will remain safe for a longer period of time. If more irrigation wells are installed in the upper part of the 2nd aquifer, instead of the 1st aquifer, situation would be worsening for the 2nd aquifer. Where weakly anisotropic condition exists in the alluvial aquifers, groundwater from the arsenic-contaminated layer will take very little time to reach in different aquifers. Hence, restriction of irrigation pumping to shallow depths and installation of wells for drinking water supply in the 3rd i.e. the deep aquifer can be the best option for long-term sustainable use of water in the arsenic-affected areas of Bangladesh.

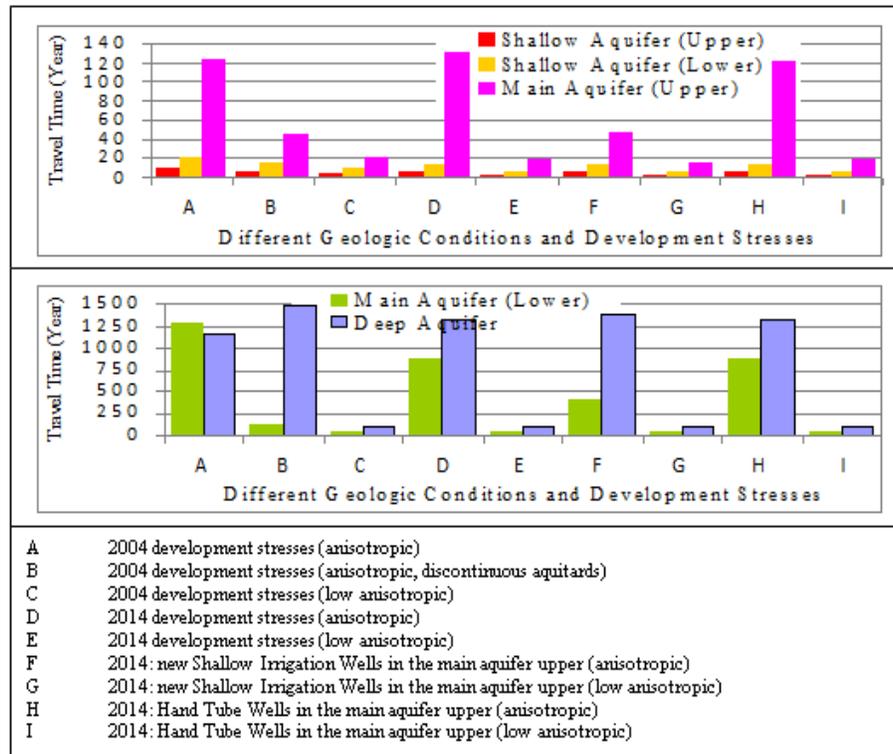


Figure 5.3: Groundwater model predicts trends of future changes under different development stresses at certain geologic conditions (Zahid and Hassan 2009)

5.1.2 Encroachment of sea-water in the coastal belt

Saltwater intrusion has already been occurring in some areas of the coastal belt of Bangladesh 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. Subsurface migration of seawater inland is a very slow process and will reach a state of equilibrium, but only after many thousands of years. In this state, fresh groundwater could only exist at shallow depths (less than 40 to 120 m in the coastal zone, where water table elevations are between 1 and 3 m above mean sea level). However, it was found that vertical infiltration of saltwater due to storm surges or intrusion from brackish tidal rivers can occur more quickly than lateral subsurface migration of saltwater, particularly when inundation events are repetitive (Zahid et al. 2013). All the different depth levels of aquifer units down to the investigated depths of 350 m have been affected by salinity in many areas. This process may explain in part why groundwater in shallow much of the coastal area is brackish; in some parts of this area brackish water may also be relic saltwater deposited at the same time as the sediments. Pumping of fresh groundwater in the coastal aquifer accelerates saltwater intrusion and degradation of water quality along both horizontal and vertical salinization paths. This indicates a clear need for hydrogeologic characterization, management of pumping, and hydrologic and geochemical monitoring of the coastal aquifer in Bangladesh - irrespective of future climate change. It can be seen that the fresh/saline water interface lies about 50 to 75 km inland in the western most part of the area but swings sharply to the south and lies approximately at the coast over most of the rest of the area.

In the coastal zone, salinity of the upper aquifers (down to 200-250 m depth bgl) is extremely variable and changes abruptly over short distances. In most areas, the water is too saline for domestic and irrigation use due

to either to connate salts or estuarine flooding. In some areas, flushing out of the saline water has resulted in fresh water pocket, but the regional pattern of salinity distribution of the deep groundwater is uniform. Study (Zahid et al. 2013) shows that (**Figure 5.4**) the changes from potable water to very saline water is sharp and occurs over a relatively short distances. In the shallow groundwater (<100 m depth bgl) fresh water (Cl <300 mg/l) is noticed in areas of south-central and south-western coast while brackish water (Cl 300-600 mg/l) occurs at north-central and north-eastern Coast. Salinity (Cl >600 mg/l) occurs in the shallow groundwater of the other areas of the coast except higher elevated part of Chittagong district. In the deep groundwater (> 250-300 m depth bgl), fresh water occurs almost in the entire coastal area except some parts of central coast. Seasonal variability of salinity is also noticed and generally, dry season salinity is higher than wet season salinity in groundwater of all aquifer units with the variations of up to 30-60 mg/l of chloride concentrations. In the shallow groundwater, to depths of 100 m, the salinity is extremely variable overlain by very shallow fresh water pockets recharged from recent precipitation and changes rapidly over short distances. Groundwater EC values vary from 31 to 43300 and 38.9 to 46000 $\mu\text{S}/\text{cm}$ in dry and wet seasons respectively in the shallow aquifer. In the intermediate depth (100-200 m bgl), it ranges from 309 to 37300 $\mu\text{S}/\text{cm}$ in dry season and in wet season 109.3 to 34100 $\mu\text{S}/\text{cm}$. The deep groundwater (>250-300 m depth bgl) shows groundwater EC values between 231 and 37000 $\mu\text{S}/\text{cm}$ in dry season and 72.3 and 10340 $\mu\text{S}/\text{cm}$ in wet season. Complex hydrogeology of the Bengal Delta i.e. spatial and vertical variations in the distribution of aquifer-aquitard units plays vital role in the mobility and distribution of salinity, alongwith development stresses.

The BWDB (2013) and DPHE-DANIDA (2001) studies indicate that the erratic occurrence of small fresh water pockets at depth is reported all over the coastal belt. The fresh bodies do not seem to be connected locally with each other, which would be the case if they have been built up by groundwater flow from the hinterland. The protective clay layers is leaky or even absent in some places, so it does not provide the closed conduit necessary for flushing saline aquifers at a large distance from the recharge area. The saline water in the coastal fresh water environment could occur by a variety of mechanisms such as, lateral penetration through relatively high permeability layers; upconing of saline water underneath the fresh water; downconing (leakage through the overlying clay layers) etc.

The salinity appears to be closely related to the relative amounts of saline and fresh water flooding from estuarine tidal effects. The shallow groundwater is generally too saline for domestic or irrigation use due either to connate salts or estuarine flooding. However, sufficient flushing of saline water has taken place in isolated pockets to enable a limited domestic use of fresh water in the shallow aquifer. The variation of shallow groundwater salinity i.e. Electric Conductivity (EC) in the coastal aquifer is about 200-250 $\mu\text{S}/\text{cm}$ in many areas which is higher during dry period (**Figure 5.5**). In the deep aquifer (>225 m) the pattern of salinity distribution is more uniform on a regional basis, as is the continuity of the aquifer. The change from potable water to very saline water is sharp and occurs over a relatively short distance. The lack of reports of salinity changes with depth within the aquifer is unusual. These factors suggest that the fresh water-saline water interface has not reached equilibrium and is still moving.

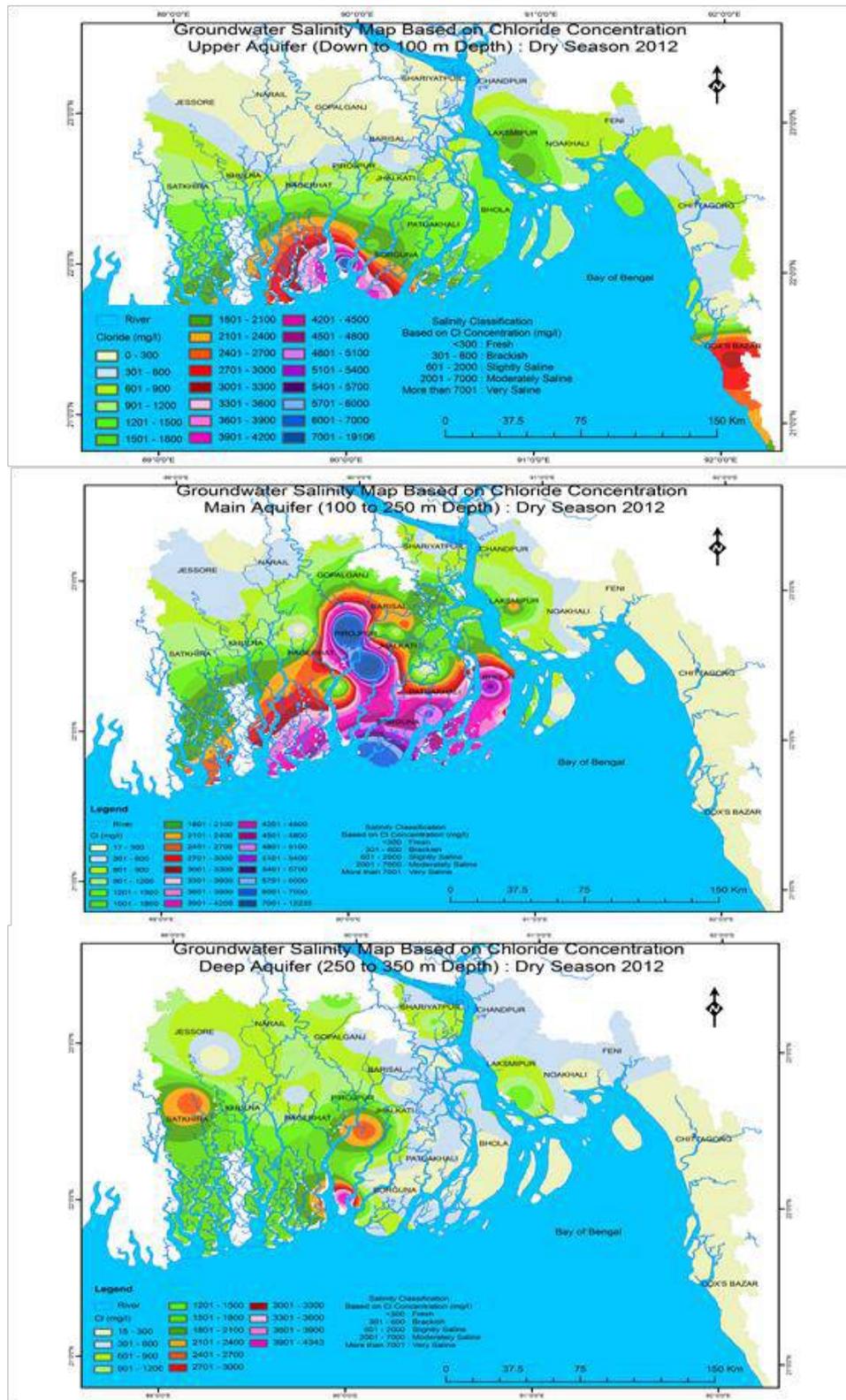


Figure 5.4: Distribution of dry season groundwater chloride concentrations at different depth levels in the coastal aquifers of the Bengal delta (Zahid et. al. 2013)

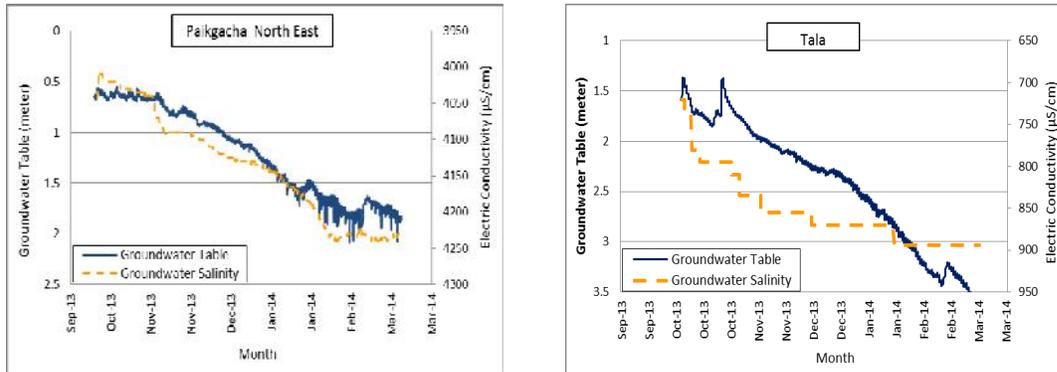


Figure 5.5: Seasonal variability of salinity (EC) of the shallow groundwater in coastal aquifers

The World Bank-USGS study (2010) mentioned that vulnerability to vertical infiltration of saltwater due to periodic storm surge flooding is significant, particularly in parts of the aquifer where clay layers above pumping wells are absent. Vulnerability to lateral saltwater migration due to sea-level rise depends on aquifer hydraulic properties. More permeable regions of the aquifer are more vulnerable than less permeable regions, but this salinization process is very slow. Vulnerability to pumping-induced mixing of preexisting fresh and saline groundwater or increasing saltwater migration rates may be ubiquitous, particularly where pumping occurs from freshwater pockets surrounded by saltwater. Aquifers in areas with lower topographic relief (central delta) are much more vulnerable to all three intrusion pathways than aquifers in higher-relief (eastern delta) areas.

Sea-water Intrusion Model for the Coastal Belt

Sea level rise is the most direct impact of climate change contributing to salinity intrusion or inundation of coastal freshwater resources, particularly for shallow alluvial aquifers. The implications of climate change for salt water intrusion in the coastal region of Bangladesh have not been investigated in great detail. In the coastal area, drinking water is mainly derived from deep wells and irrigation is limited to surface water bodies. Fresh water is also available at shallow depth sourced from seasonal precipitation but turns to brackish condition during dry period. Therefore, assessment and monitoring of development stress and probable impact of climate change on fresh water resource is utmost important where mathematical models can play a vital role. The main purpose of the model study was to assess the impact of climate change and development stresses on the availability of water resources in the coastal area (BWDB 2013). For that purpose integrated hydrological model describing the condition in the unsaturated and saturated zone of the subsurface together with rainfall, overland flow, evapotranspiration and the condition of flow in the river has been used. In addition, issues of climate change have been considered in the study. Groundwater salinity models are developed to simulate salinity transport in the sea, river and through the porous medium of aquifer for a range of existing and possible future conditions.

The calibrated and verified models have been simulated for a number of development options Technicalities of the some probable options are:

Option I: Base Condition i.e. Existing Situation

- Hydrological condition based on design year selected from historical records.
- All existing features i.e. existing crop coverage, domestic purpose, irrigation and industrial demand etc.

Option II: Future Option with Predicted Sea Level Rise due to Climate Change

- Hydrological condition in the year 2030 and 2050 under Option-I has been transformed to year 2030 and 2050 using appropriate climate change parameters.
- Sea Level Rise for future condition i.e. year 2030 and 2050 has been adopted from IPCC model results.

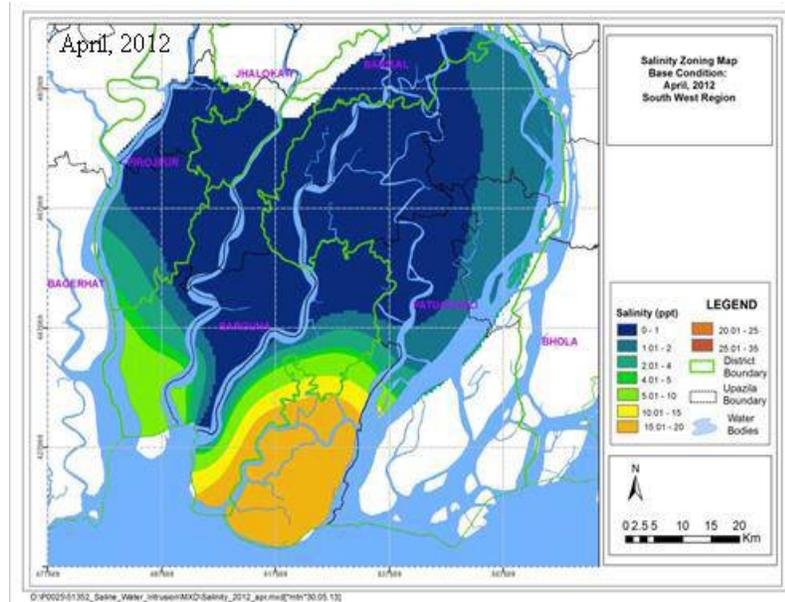
Option III: Future Option with Predicted Sea Level Rise due to Climate Change and Increased GW Abstraction due to Human Intervention

- Hydrological condition would be average condition in the year 2030 and 2050 using appropriate climate change parameters.
- Increased groundwater abstractions for future demand management considering household, irrigation and industrial demand.

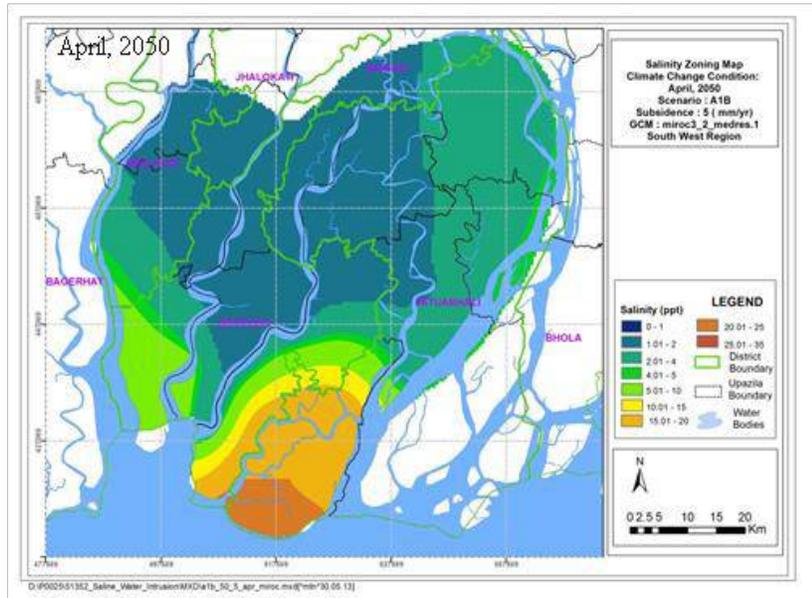
Salinity model has been used to assess the salinity intrusion towards upstream due to the increase of Human activity, reduction of dry period flow and climate change within the project area using existing Bay of Bengal model and southeast regional salinity model (BWDB 2013). Peak salinity maps have been produced to assess the change in salinity distribution pattern for base and different scenarios. Salinity modelling aids to assess the salinity intrusion under known boundary conditions without detailed measurements throughout the entire coastal region.

It has been seen from the simulation result of surface water salinity model that under climate change condition during the month of March and April the salinity increase is highest for all river system within the project area and significant during period from December to June. The climate change scenario illustrate that there is significant impact on groundwater level and less impact on salinity distribution. The groundwater level increases within range of 0.6 m to 0.8m under climate change scenario. The long term simulation for climate change options indicates that the salinity movement from river to aquifer is not significant. Due to the tidal effect of major rivers for the south central coast there is a considerable interaction between surface water and groundwater. There is less interaction between the aquifer and adjacent river in the Chittagong coastal plain.

As to the causes of salinity expansion in the coastal region the BADC study noted that decrease of upstream flow due to Farrakka Barrage on the Ganges River is one of the main reasons for salinity expansion in the region. Other contributing factors include horizontal expansion of shrimp farms and Coastal Embankment Project implemented during the 1960s. The report apprehended that salinity expansion may be exacerbated by climate change and sea-level rise. The study recommended for intensive salinity data collection program, particularly using auto logger, in the coastal region to monitor the trend of salinity movement and to formulate mitigation and adaptation measures to cope with the impending climate change threat.



(a)



(b)

Figure 5.6: Salinity zoning maps of base condition in 2012 (a) and impact of climate change in 2050 (b)

5.2 Excessive Withdrawal of Groundwater in Urban Areas

Although water supply in Dhaka has been organized for more than 100 years, systematic groundwater development started only in 1949 (Chowdhury and Faruqui 1991; Ahmed et al. 1998). Based on the total population of over 12 million, presently more than 2.0 Mm³ of water is required every day to fulfill the municipal demand of Dhaka City. Dhaka is dependent mainly on the groundwater resources of the fluvio-deltaic Plio-Pleistocene Dupi Tila Aquifer, which provides about 78% of the total water supply. Groundwater is the first choice for city dwellers as it is superior in quality and easy to develop. To meet the demand, about 2.0 Mm³ is withdrawn

daily by about 690 DWASA (Dhaka Water Supply and Sewerage Authority) tubewells (**Figure 5.7**) and delivered to the inhabitants by a 2500-km-long pipeline network, in which system loss is assumed to be more than 25%.

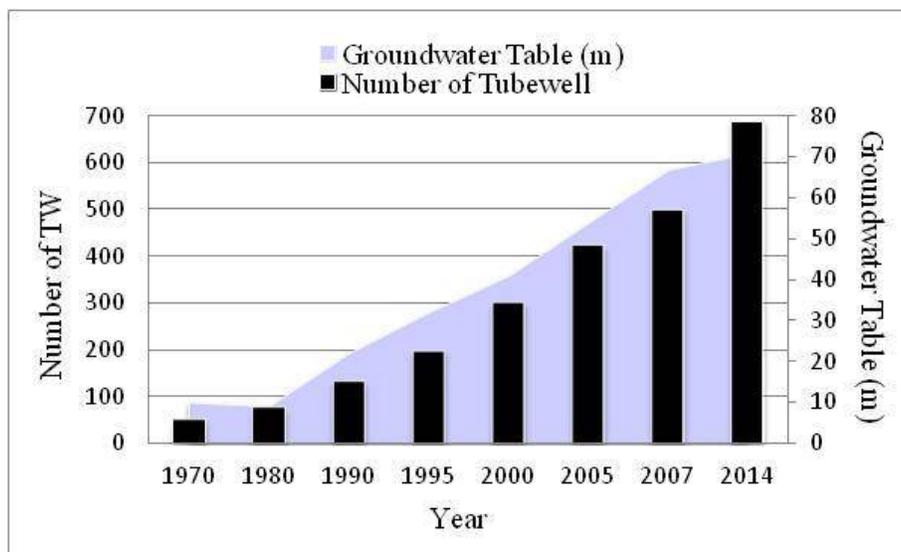


Figure 5.7: Increasing numbers of tubewells with increasing abstraction of groundwater in Dhaka city

Table 5.2: Information on groundwater withdrawal and lowering of groundwater table in Dhaka city since 1970's

Year	1970	1980	1990	1995	2000	2005	2007	2014
Nos. of Tubewell	49	75	130	197	300	423	500	690
Withdrawal (Mm ³ /d)	0.18	0.217	0.516	0.767	1.2	1.5	2.0	2.5
Water Table (m)	0.5-10.5	0.5-9	6-22.5	12.5-32	19-41.5	19-54	19-67	24-71

It is estimated that the volume extracted by more than 900 private deep tubewells in the city area may be more than 50% of the DWASA withdrawal. Compared to the exploitation of groundwater, the renewable recharge to the aquifer is nearly negligible. Natural water recharge to the aquifer has not kept pace with the water withdrawal for more than three decades, causing a drop in the water table. The average annual rates of decline in different parts of Dhaka City range from 0.17 to 0.6 m/yr from 1970 to 1980, 0.15 to 0.69 m/yr from 1980 to 1990, 0.56 to 2.26 m/yr from 1990 to 2000 and 1.0 to 3.0 m/yr since 2000 (Hassan and Zahid 2013). The rate of lowering of the water table over the last 15 years in many parts of Dhaka city has been 3.0 m/yr. In the central part of the city the maximum depth to water table in the upper aquifer is more than 60 m bgl (Figure 5.8) that was within a meter in 1960s. Thus, the aquifer is not being replenished in the city area. Due to alarming declination rate of groundwater table in upper aquifer (125-150 m depth) the depth of tubewells are now being extended to 300-320 m deep, which is generally below a significant aquitard. Already more than hundred tubewells have been installed in this deeper part by DWASA. As a result, groundwater table in the deeper aquifer has also started to decline continuously in many areas (**Figure 5.9**).

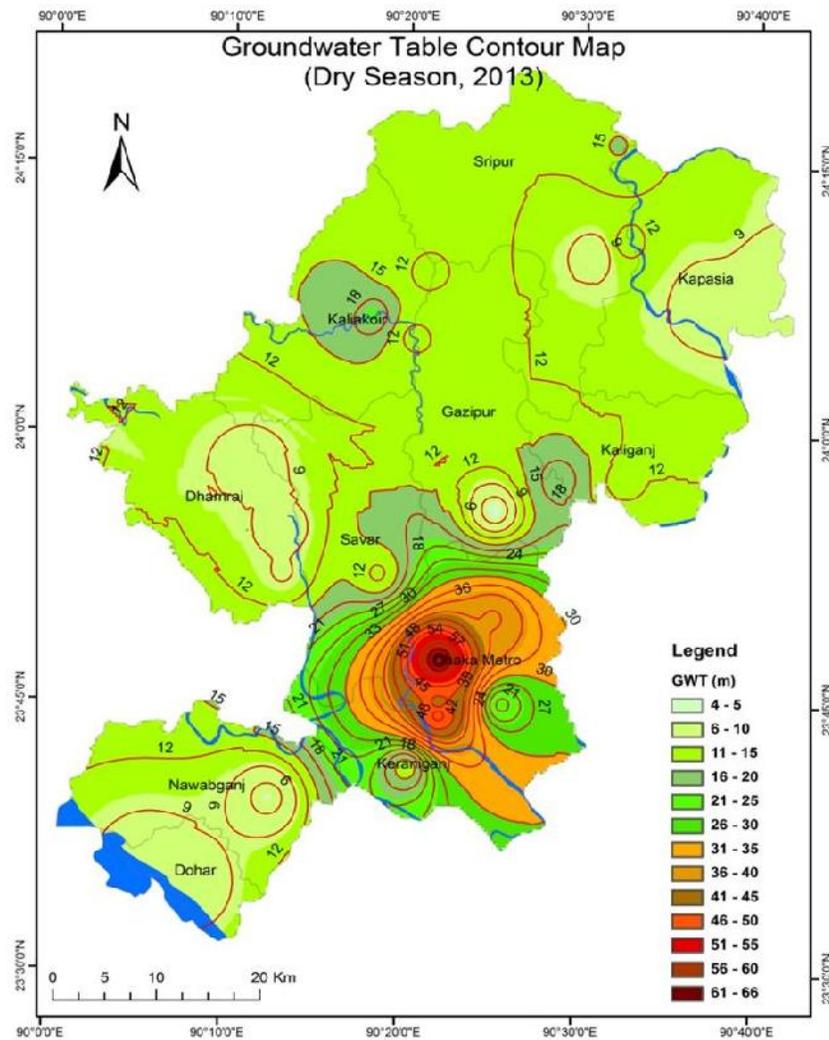


Figure 5.8: Groundwater table contour map of Dhaka city and surrounding areas

The Buriganga River surrounds the city to the south and west, while the Lakhya and Balu Rivers surround the city to the east. The convergence of the Turag and Bansi Rivers forms the northern boundary. The height of the river water above the water table could promote the infiltration of river water, but the siltation of the river beds is not favorable for seepage. Hence, the contribution to the aquifer from the adjoining rivers is not significant.

The future daily demand of water is estimated as 3.05 and 4.42 Mm³ for the years 2015 and 2025, respectively, considering the current trend of growing population (DWASA 2006). The groundwater beneath many large cities in the world has resulted environmental hazards, including water quality problems. If the groundwater table declining continues at such an alarming rate, this will create huge problem in different aspects.

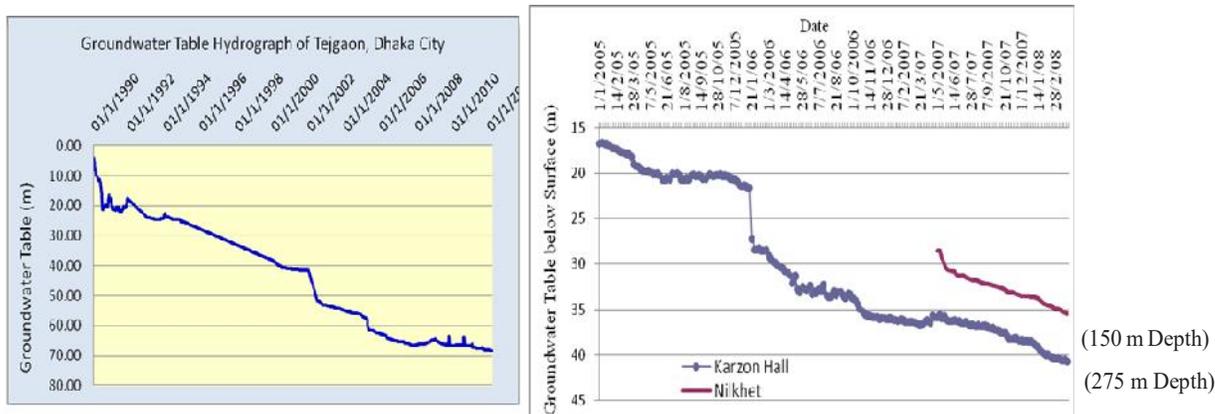


Figure 5.9: Continuous declining trend of groundwater table both in upper and deeper aquifers in Dhaka city

If the present rate of abstraction, unplanned urbanization and silting of riverbeds continues, lateral inflow of water to groundwater aquifer will reduce and groundwater mining will be aggravated. Over-pumping of groundwater also causes compaction and porosity loss in soil and can permanently ruin DupiTila aquifer. Lowering of the water table leads to increased costs of development, the earlier replacement and deepening of wells and pumps, and the need to enlarge energy facilities. Moreover, electricity consumption will be higher to lift water from greater depth. Progressive decrease in river base flow and surface area of wetlands obstructs to compensate for the difference between actual recharge and abstraction. The changing groundwater flow pattern may favor the infiltration of contaminated river water. Changing groundwater head potential in and along wells or boreholes, or discharge area may modify depths or origins mix. Thus, abstracted water quality may be changing progressively (Custodio 2002).

Dependency on groundwater abstracted from the city aquifers needs to be reduced by providing alternate sources of water supply. Installation of well fields in the less developed aquifers, 10 to 15 km away from the city boundary, may be a potential option with water supply to the city by a pipeline network. Transportation of groundwater from potential suburban aquifers to Dhaka City may also be done by truck-lorries as an emergency measure. Rain water harvesting, even if carried out only during the rainy season and used for household purposes other than drinking, can reduce the pressure on groundwater systems. Installation of area wise surface water treatment plants, reuse of treated storm and sewage water mainly for washing, gardening, and toilet flushing purposes, artificial recharge by injecting treated river water and rain water and digging of recharge basins could improve the groundwater table condition. Different recharge technologies are proposed in a recent study (Sultana 2009) mainly based on local physiographic and lithologic conditions (**Figure 5.10**). Treated surface water can be stored in infiltration ponds or basins or pumped into the ground through recharge wells, which could increase the rate of water percolation towards the water table. Installation of a sand pile or recharge well could be included during construction of a new house or building and could be required by new laws and regulation.

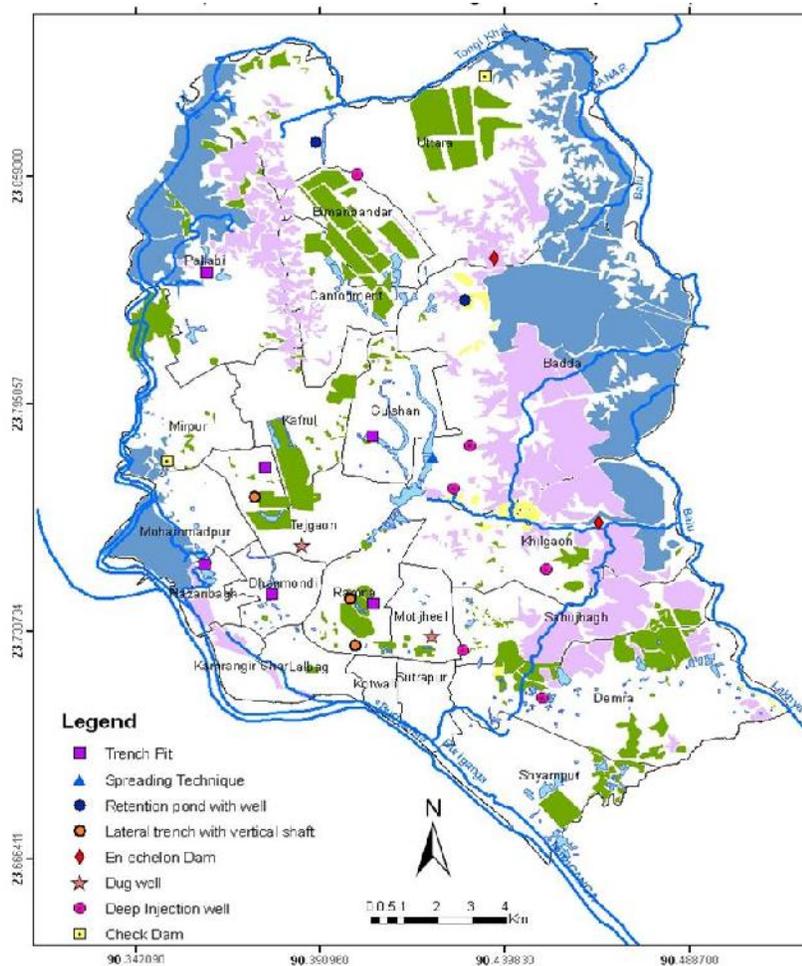


Figure 5.10: Proposed artificial recharge technologies for Dhaka city mainly based on geomorphology and lithologic conditions (Sultana 2009)

Dredging of peripheral rivers is needed to remove clogging of the river beds by fine particles and to allow more flow to aquifers. In all cases of artificial recharge, the quality of recharging water must be ensured. Assessment of groundwater recharge, preparation of the groundwater budget, should be carried out regularly to monitor aquifer status. The present groundwater monitoring network needs to be extended to different depths to observe the increasing rate of water table decline and its probable effects on water quality. There is a prime need for a comprehensive study in assessment of water resources, for the present and the future. It is a great challenge for DWASA to ensure water of adequate quantity and quality year-round for city dwellers with the current increasing population trend.

Groundwater resources can also be protected by reducing the rate of water use. Here, city dwellers can play a very important role. A major portion of the total water consumption is going for bathing, flushing toilets, washing clothes and dishes, etc. Significant savings can be found in these areas. Repairing leaking faucets, showerheads and toilets, stopping use of running water during tooth brushing, etc., can save a huge amount of water. There are many other ways in which every citizen can save water for future generations. With a rapidly growing population, the savings should be much higher in the future. These will reduce stress on the declining water table in the city aquifers.

5.3 Impact of Industrial Activities

Unplanned industrial activities not only decline groundwater table due to excessive use, but also degrade sediment and water quality. Hazaribagh leather processing zone of Dhaka city is a very worse example of manifold problems. About 185 tanneries have been operating their activities on 25 hector areas, processing 220 metric tons of hide a day and about 40 to 50 liters of liquid for each kilo of hide (United Nations Industrial Development Organization 2000). The industries of the 55-year old tannery complex are discharging their solid wastes and liquid effluent containing putrid rotten flesh, fat, blood and skin, toxic chemicals, dissolved lime, chromium sulfate, alkali, hydrogen sulfide, sulfuric acid, bleach, dyes, oil, formic acid, heavy metals, suspended solids, organic matters, etc., directly into low-lying areas and water bodies between the flood protection embankment and residential area without proper treatment. There is, therefore, an obvious risk of percolation of leachate from the open dumping site which may affect the sediment and groundwater as well as surface water of the river Buriganga and Turag.

The tanning process transforms hides and skins to leather. The main raw materials in Bangladesh are cowhides and goatskins. The structure of skin is based on interlaced bundles of micelles and fibrils, the collagen. After removal of flesh and fat, the hides are processed with chemicals, which act on the microscopic collagen fibers to form a stable and durable mineral. Depending on the desired type of the final product, a wide variety of processing steps are undertaken. Chrome tanning is the most common type of tanning where large amounts of chrome powder and liqueur are used. A huge quantity of this chromium is discharged along with the effluent.

Study (Zahid et al. 2006) shows that the industrial effluent of Hazaribagh area is discharged into the environment e.g. in low lands and natural canals (Figure 5.11), with extremely high concentrations of Na^+ , Mg^{2+} , Ca^{2+} , NH_4^+ , Cl^- , SO_4^{2-} and heavy metals, especially Cr, Fe, S, Mn, Zn associated with high content of organic matter. Concentrations of Al, Cr, Pb, Cd of Buriganga River water have also exceeded maximum allowable limits of DoE and WHO for drinking water at some locations due to tanning activities. Since shallower groundwater of most of the areas of Bangladesh is contaminated by Arsenic, excluding Pleistocene terrace areas covering Dhaka city, it is very important to protect this aquifer as well as river water, as alternate water sources, from any sort of contamination.

Concentrations of some of the heavy metals in soil varied between locations and changed with depth. Excessively higher accumulation of Cr is restricted down to 1.5 m. It was also found that Cr and Pb concentrations decreased significantly from the sediment depth of 3.0 m, whereas Al, Fe, Mn, Zn, Ni, Cu concentrations were still enriched to the investigated (6.0 m) depth. Such variations in metal content with location and depth may have occurred due to input from different locations, had different sources, or entered the receiving waters at different times and different bio-geochemical processes.

Concentrations of investigated trace elements of all the groundwater samples (65-90m depth) were found within DoE and WHO limits. However, it is observed from previous investigations that shallow groundwater (10-20 m) of Hazaribagh area has already been affected by high Cr, Pb, etc. It has to be taken into consideration that sand generally allows the contaminant to pass to deeper zones. There is no silt/clay barrier between the upper and lower layers of sand of the main aquifer from where water for the city is being extracted. Hence, there is the possibility of contamination of the deeper groundwater in the future if protection of the soil and groundwater from untreated tannery wastes are not considered. Presence of various heavy metals in groundwater, even in low concentrations, and higher concentrations of Na, Ca, Mg, NH_4 , Cl, SO_4 compared to the average concentrations

of the surrounding areas has been providing evidence of release of some of these heavy metals and increase of ions due to industrial activities in the area.



Figure 5.11: Discharge of untreated industrial effluent of Hazaribagh tanneries to nature

5.4 Water Scarcity at Barind Drought-prone Area

Barind is known for drought prone characteristics where average annual precipitation is low compare to the other part of Bangladesh. Moreover, the upper hard and almost impermeable clay layer has a thickness of 8 to more than 25 m that retards vertical percolation of precipitation water and reduces recharge rates. The BMDA has been implementing large scale groundwater irrigation schemes since few decades that causes decline of groundwater table below the suction limit (7.5 m) of hand tubewells in many areas. The thickness of the lower aquitard i.e. clay is more than hundred meter and drilling with local methods are almost impossible. Therefore, the deep aquifer in the area is not well identified that needs to explore to reduce stress on shallow groundwater. The maximum and minimum groundwater table in Nachole upazila area, measured in BWDB observation wells are recorded between 10.0 and 30.0 m and 7 and 22.0 m respectively with the seasonal fluctuation of about 3-10 m. Therefore, water table in most of the areas declines below the suction limit of hand tubewells (7.5 m) almost round the year which is mainly due to huge irrigation abstraction of groundwater from upper aquifers (Figure 5.12). Permanent declination is also noticed in many areas under Barind. In the High Barind area significant land gradients exist, which influence groundwater movement.

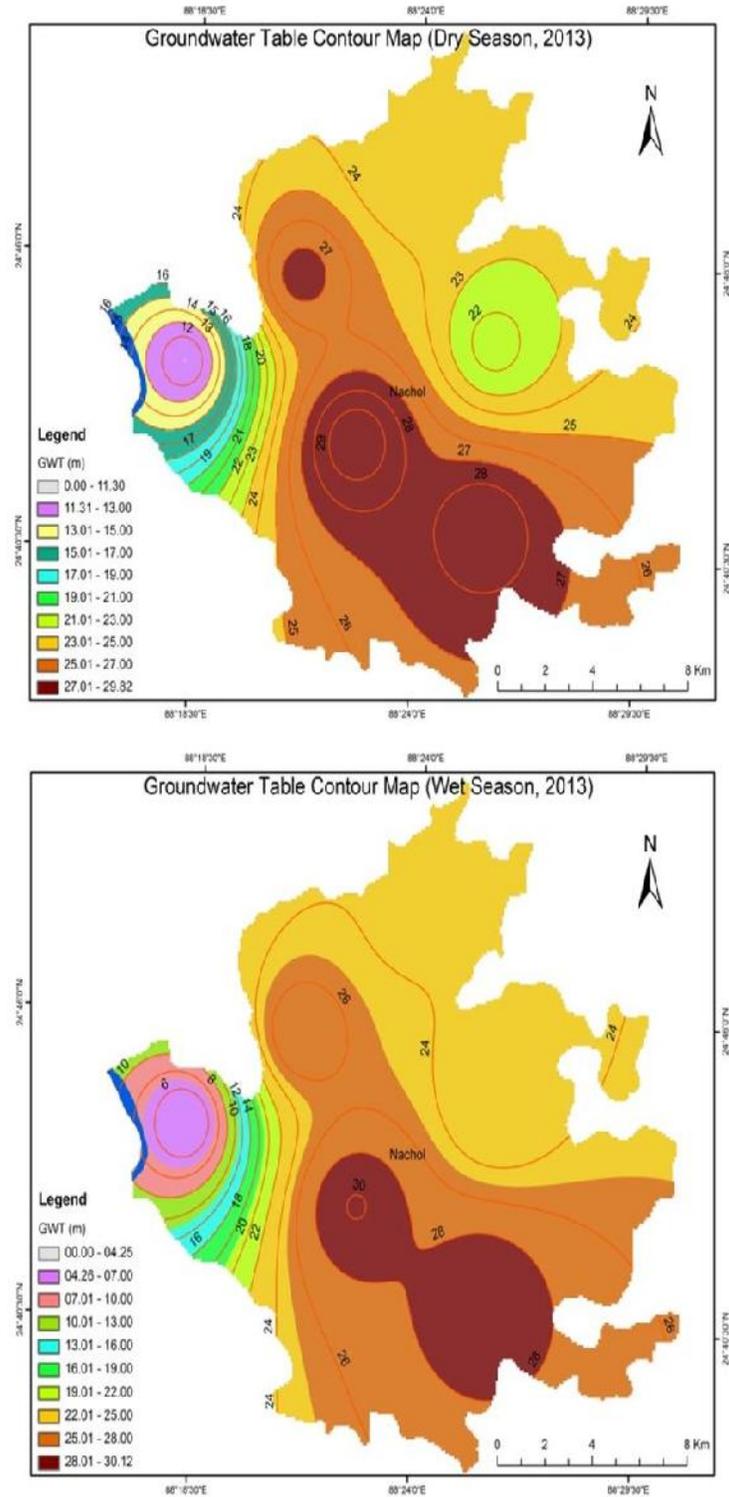


Figure 5.12: Groundwater table contour maps of Nachole upazila both in dry and wet seasons

6. Investigation and Monitoring of Groundwater

6.1 Role of Bangladesh Water Development Board (BWDB)

The hydrogeological data and information are required for understanding of the groundwater conditions. The more of this information the better the assessment results regarding the aquifers, water levels, hydraulic gradients, flow velocity and direction, water quality, and simulations of groundwater models. Analysis and interpretation of these data and information can guide for water resources planning and distribution of water for agriculture, industrial and water supply usage. In broad, success of integrated water resources development and management, protection of water resources, water quality and aquatic ecosystems, sustainable water supply and sanitation in both urban and rural context, and overall resources assessment etc. largely depend on adequate data and information. Adequate meteorological, hydrological and hydrogeological data are also needed to assess the impacts of climate change on groundwater resources obtained through proper monitoring network. Data on water table (water level/head) and water quality are obtained from measurements at observation wells and analysis of groundwater samples. The density of the observation well network is usually planned on the data requirement but in reality is based on the availability of resources for well construction. In the early stages, therefore, the hydrological network starts with a minimum number of stations.

The major success stories of development of groundwater were initiated by the Erstwhile EPWAPDA (present BWDB) in 1962 through the Hydrology Directorate. In 1967, the then EPWAPDA felt the need to increase the development of groundwater with a view to survey the groundwater resources of the country and collect basic data for its systematic and orderly development for different uses. In 1970, Ground Water Circle was then established to undertake a detailed survey of the groundwater resources of the country. The role of BWDB in groundwater management includes fundamental data collection and analysis, basic assessment and process to understand the groundwater system, development of analytical tools for water resource planning and monitoring. In detailed, the responsibilities are,

- Conduct ground water survey and sub soil investigation of different projects of BWDB.
- Conduct qualitative study for the optimum utilization of ground water resources and collection of sediment sample for arsenic source detection for mitigation studies.
- Maintain hydro-geological data (lithologic logs, groundwater table, aquifer test, groundwater quality etc) collection network.
- Co-ordinate the activities of different agencies and organizations involved in groundwater studies and render advice to groundwater planners and end-users.
- Maintain equipment such as drilling rigs, mud pumps, air compressor and other related equipment.
- Review comments on different policy issues, paper clipping on drought conditions and technical reports on ground water resource utilization suggesting probable remedial measure, etc.

With the UNDP assistance the Ground Water Circle executed the schemes in 3 (three) phases (i) Groundwater Survey in Bangladesh (1970–1980), (ii) Groundwater Development Studies in Bangladesh (1980-1985) (iii) and one umbrella project (1985–1990).

Cumulative achievements of physical works are as follows:

- Due to quality problems in shallow and main aquifers and necessity to use deep groundwater, more monitoring wells are needed to be installed at greater different problematic areas. Considering this,

BWDB has installed 42 monitoring well nests and 510 line wells upto the depth of 350 m and 100 m respectively in 19 coastal districts (Figure 6.1) in addition to the permanent monitoring well network all over the country i.e. 1250 groundwater observation wells and 20 auto recorders, mostly installed at shallow depths (<50 m) (Figure 6.2). Monitor groundwater level in Gangetic belt area.

- Monitor groundwater quality all over the country from 117 water quality stations.
- Geo-technical / Subsoil investigation for different hydraulic structures of BWDB (about 11000 m/year).
- Conduct deep/ shallow drilling to know the subsurface lithology to identify sustainable aquifer formations (1280 nos.) and for arsenic contamination study (40 nos.) down to the maximum depth of 350 m (Figure 6.3).
- Aquifer pumping test to know aquifer characteristics (330 nos.) both in shallow and deep aquifers (Figure 6.4).
- Collect soil and groundwater samples for analysis.
- Design, install, develop and rehabilitate DTWs.
- GPS survey of observation wells, drilling points, water sampling stations etc.

BADC and DPHE also have monitoring activities targeting their purposes. Besides programs from the government agencies, irrigators and users can also be involved by installing monitoring wells under regulatory framework.

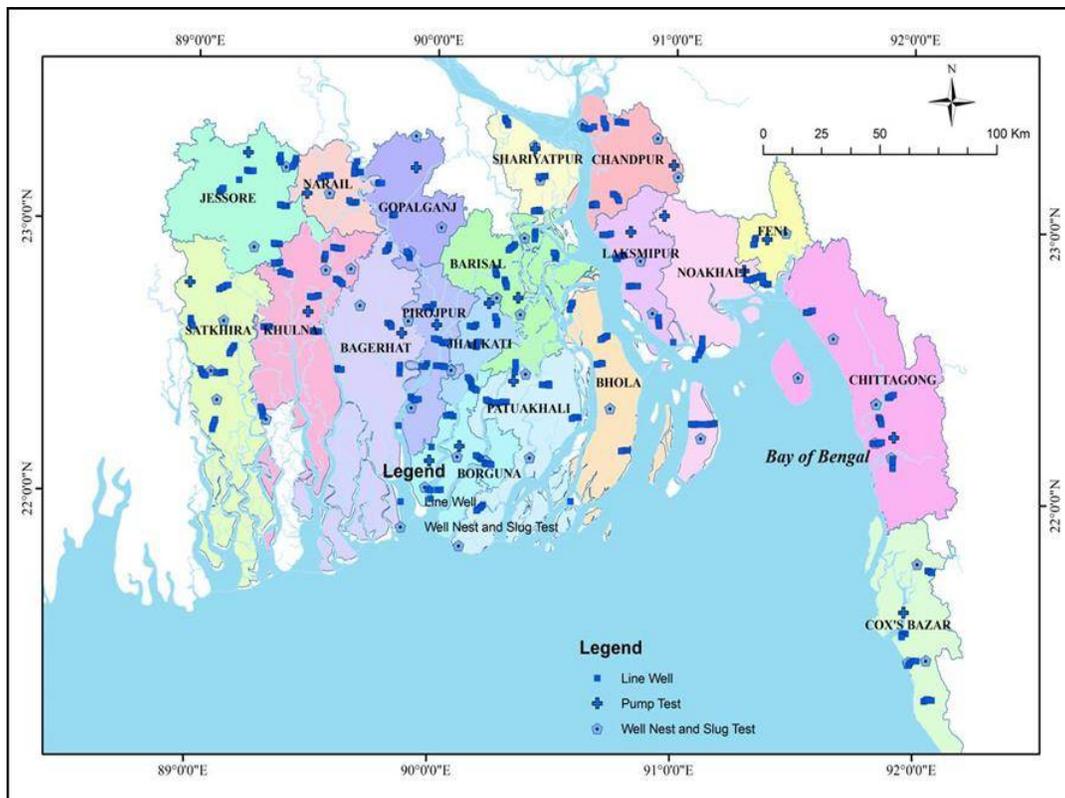


Figure 6.1: Location of BWDB groundwater monitoring wells installed down to the maximum depths of 350 m

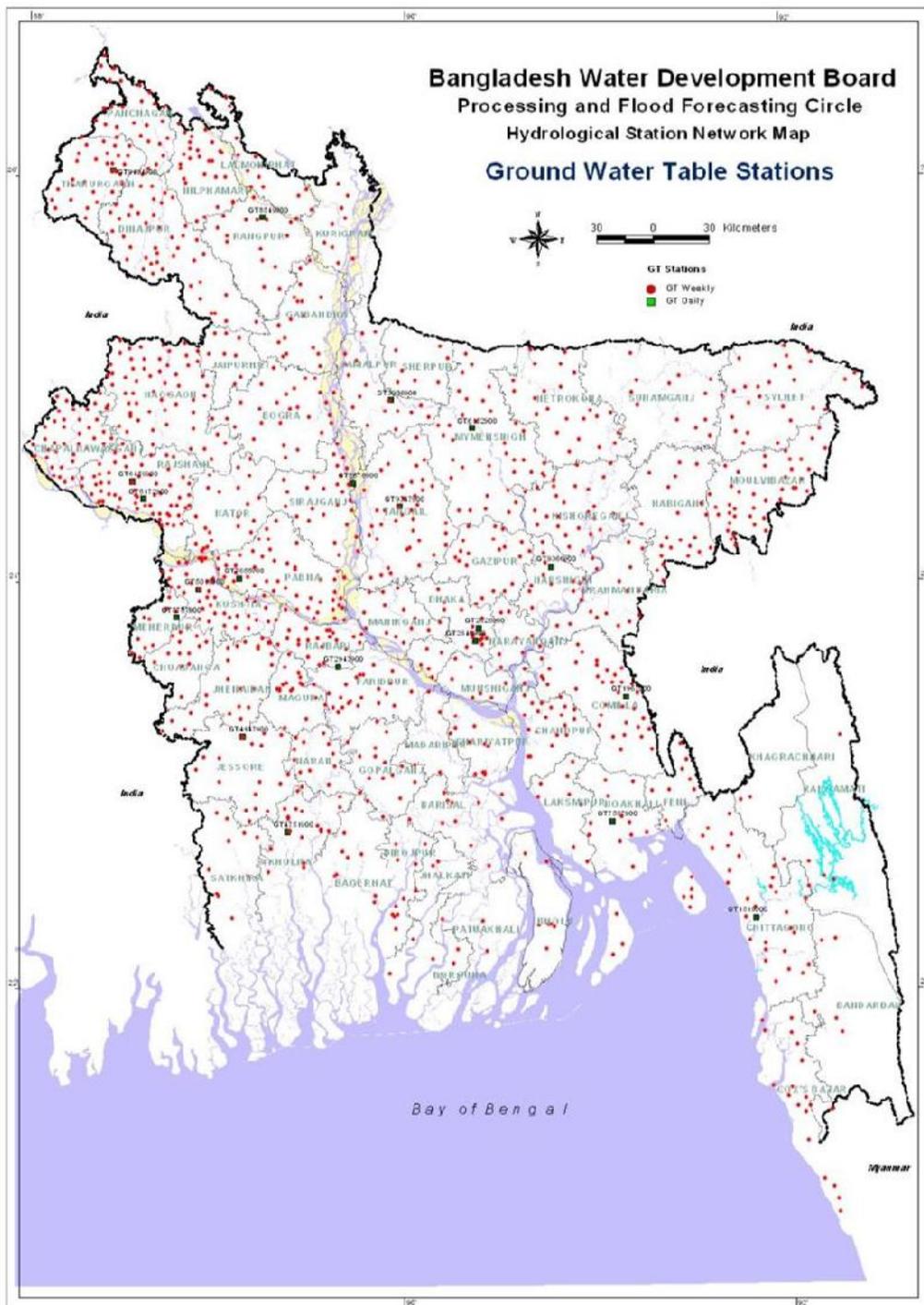


Figure 6.2: Location of BWDB groundwater table monitoring wells installed at shallow depths

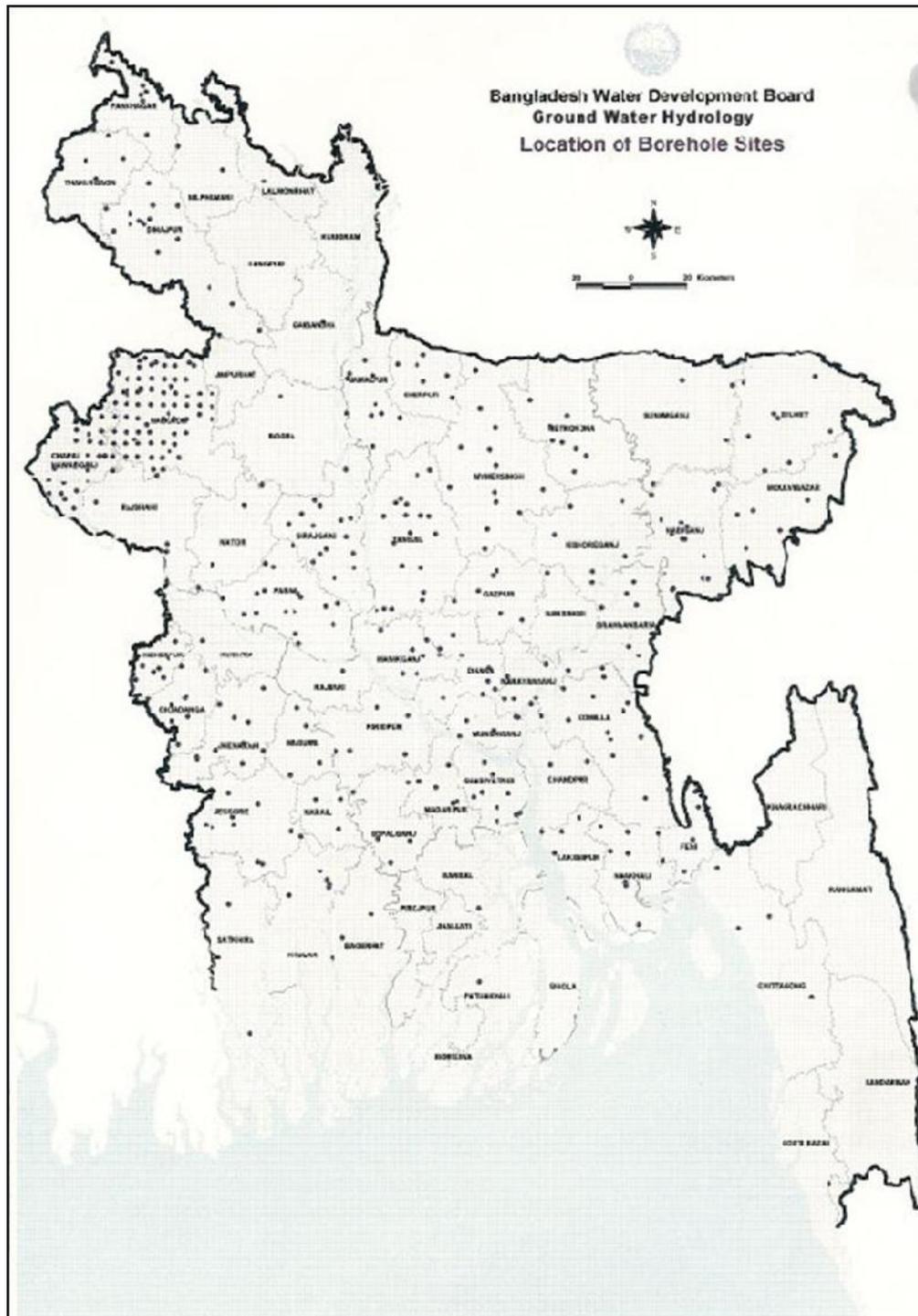


Figure 6.3: Location of BWDB exploratory drilling sites, drilled down to the maximum depths of 350 m

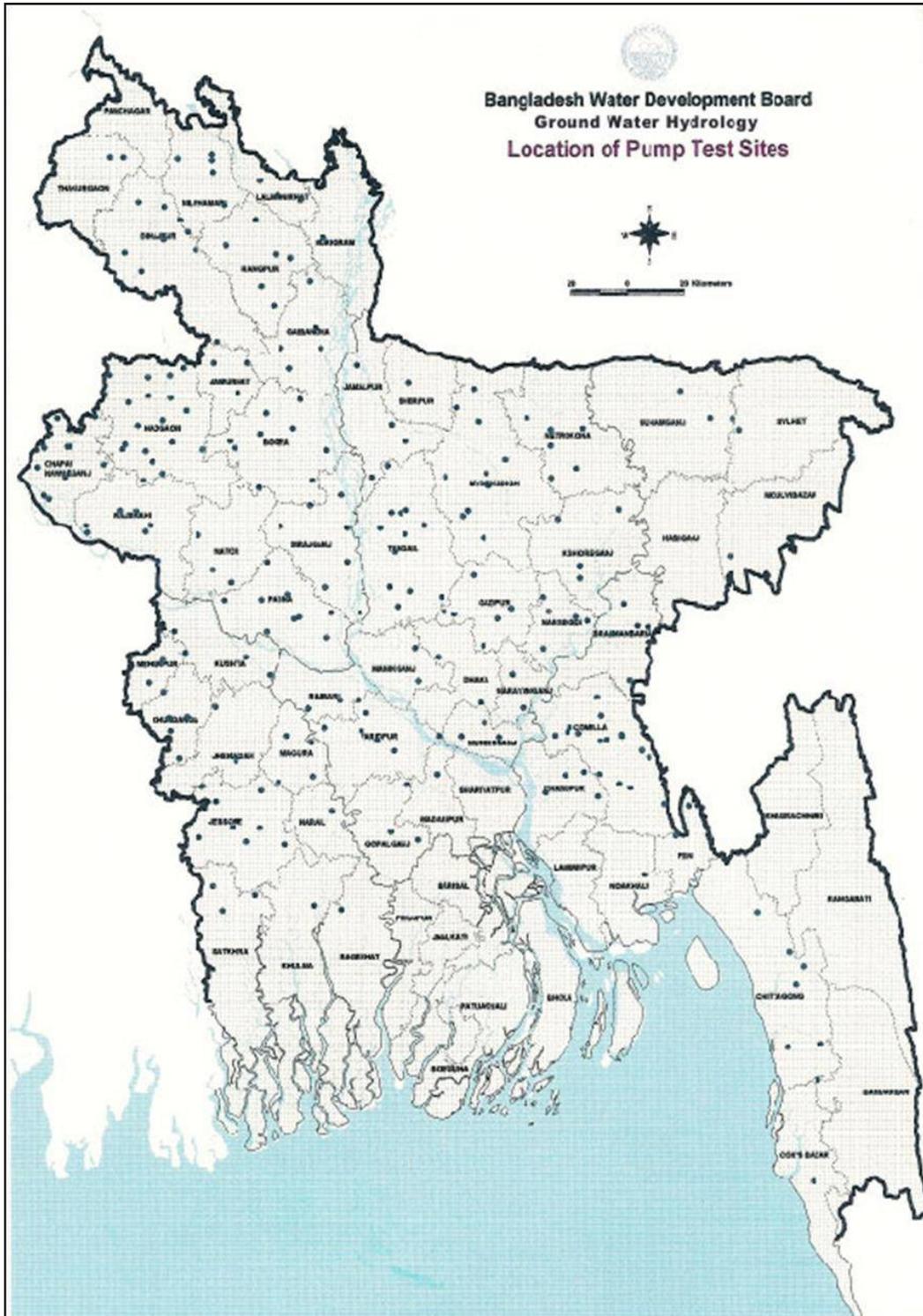


Figure 6.4: Location of BWDB aquifer pump test sites conducted in upper aquifers



Figure 6.5: Groundwater survey and investigation activities i.e. exploratory drilling by BWDB in the field

6.1.1 Observation well nests installed in the coastal belt

Evaluation of the spatial and temporal variations of groundwater levels (potentiometric surface) for each aquifer resulting from natural and man-made processes needs to monitor by installing observation wells i.e. piezometers. In an area several aquifers at different depths may be separated by impervious layers of different thicknesses. Aquitards are sealed off by grouting from the aquifer lying above it. If the geology of the area and the depth to each of the aquifers are well known, it is important to drill and construct separate well in each aquifer i.e. well nests in each aquifer units. In Bangladesh where multi-layer aquifer system exists, installation of observation well nests is important to know water quality and hydraulic behavior of different aquifer units.

The technique of excavating wells to the water table and then deepening the well by drilling is a common practice in many parts of the world. Where groundwater can be reached at depths from 5 to 15 m, hand boring may be practical for constructing observation wells. To overcome the difficulty of boring below the water table in loose sand, a casing pipe is lowered to the bottom of the hole, and boring is continued with a smaller diameter auger inside the casing. In areas where the geological formations consisting of unconsolidated sand, silt or clay are known in advance, small-diameter observation wells up to 10 m depth can be constructed by the drive-point i.e. hand percussion method. To penetrate deep aquifers, drilled wells are constructed by the rotary or percussion-tool methods. As drilling small-diameter wells is cheaper, observation wells with inner diameters ranging from 50 to 150 mm are common.

In Bangladesh 38 mm diameter piezometers are widely used as observation wells. Collection of water samples and measuring water table can easily be done by 38 mm piezometers. But, for many other surveys, e.g. borehole logging etc. 38 mm well may not be adequate if probe diameter is more than 38 mm. Hydraulic rotary drilling with bits ranging in diameter from 115 to 165 mm is often used for small diameter wells. Power rigs are used both for installation of wells and collecting sediment samples. The rotary method is faster than the percussion method in sedimentary formations. Experienced hydrogeologists and drillers can frequently identify changes in formation characteristics and the need for additional samples by watching the speed and efficiency of the drill. The normal diameter of the well drilled by percussion methods ranges from 100 to 200 mm to allow for the observation well casing to be 50 to 150 mm in diameter.

Upper aquifers penetrated during drilling must be isolated from the aquifer under study by a procedure known as sealing (or grouting). The grout may be clay or a fluid mixture of cement and water of a consistency that can

be forced through grout pipes and placed as required. Grouting and sealing the casing in observation wells are carried out to prevent seepage of polluted surface water to the aquifer along the outside of the casing and to seal out water in a water-bearing formation above the aquifer. At least the upper 3 m of the well should be sealed with impervious material.

In the coastal areas where availability of fresh and safe water is a big problem due to arsenic contamination and saline water intrusion in upper aquifers, assessment and monitoring of probable impact of climate change i.e. sea-level rise on fresh water resource is utmost important. In this context this project "Establishment of Monitoring Network and Mathematical Model Study to Assess Salinity Intrusion in Groundwater in the Coastal Area of Bangladesh due to Climate Change" has been undertaken by BWDB, Ministry of Water Resources funded under the Climate Change Trust Fund (CCTF) of the Ministry of Environment and Forest. Under the project a comprehensive data collection program to monitor surface water and groundwater level and water quality including salinity of groundwater and surface water has been conducted. To achieve the project objectives a mathematical modeling study supported by a comprehensive data collection program has been carried out in two representative pilot areas to assess surface water resources and groundwater resources and also assess ground water level distribution due to increased withdrawal of groundwater. Another mathematical model has been developed showing the dynamism of groundwater in the coastal area of Bangladesh. The models allow for simulation of both groundwater flow and the migration of saltwater in the subsurface. The study for assessing the salinity intrusion in groundwater and also surface water has been conducted for two pilot areas of coastal region of Bangladesh.

The main objectives of the study project are as follows:

- (1) Establishment of long term monitoring network (observation well nests and line wells) to assess groundwater salinity and surface water-groundwater interaction;
- (2) Identification of coastal aquifers where ground water is threatened by salt water intrusion;
- (3) Assessment of salinity distribution in the ground water aquifer due to sea level rise in pilot areas;
- (4) Assessment of salinity changes due to increased withdrawal of groundwater at pilot areas.

The project identified the extent of salinity intrusion in groundwater aquifer in the coastal region as well as its present and future intensity and extent of intrusion towards upstream inlands. The overall project results will support planning of sustainable groundwater use for drinking purpose and food production and future adaptation. The major components of the project are presented in **Table 6.1** and **Figure 6.6**.

Table 6.1: Items and number of data monitoring stations established in coastal area of Bangladesh

Sl. No.	Item	Quantity	Remarks
1	Nest Well	123 observation wells	Depth varies upto 350m.
2	Line Well	510 observation wells	Depth varies upto 100m.
3	Lithological Log	690 locations	Depth varies upto 350m.
4	Aquifer Pump Test	18 locations, 20 tests	In deeper (3 rd) aquifer.
5	Slug Test	42 locations, 124 tests	In nested wells.
6	WQ measurement	At all nested and line wells. 957 groundwater and 139 surface water samples.	25 parameters.
7	GW level measurement	At all line wells and 3 wells in each nest.	Once a week.

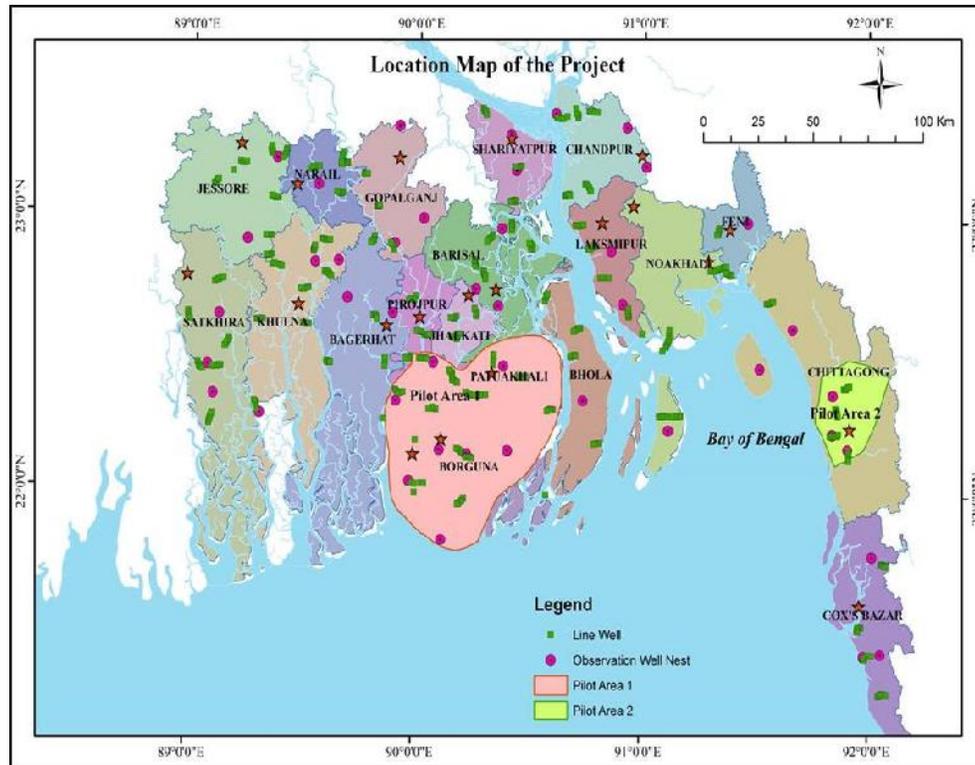


Figure 6.6: Locations of groundwater observation well network and pilot areas for model simulations

Specific objectives of the establishment of monitoring network are:

- Identification and zoning of groundwater aquifers down to 350 m depths based on lithologic logs of exploratory boreholes.
- Monitor both groundwater quality (including distribution of salinity) and quantity (measuring water table) in established monitoring network.
- Characterization of each aquifer units to determine hydraulic and physical properties of aquifer sediments for resource assessment by conducting 20 aquifer pump tests and 124 slug tests.
- Assessment of both groundwater and surface water quality and mapping depth wise distribution of different chemical parameters down to the depth of 350 m highlighting salinity, arsenic etc. by collecting water samples from monitoring wells and coastal rivers.
- Identification of fresh water zone for drinking purpose in the coastal region in Bangladesh.
- Investigate effects of climate change (to include sea level rise, increased storm surges, changes in recharge) on the pattern of groundwater hydrology and saline distribution in the coastal region (i.e. changes in hydraulic head distribution, salinity distribution changes).

All of these are important for sustainable present and future planning and development of coastal water resources in water supply, agriculture and health sector. Policy makers, planners, stakeholders, users as well as population of these Upazilas involved in water supply, agriculture irrigation and health sector will get benefit from the continuous data and information to be generated under the project and long-term monitoring data.

42 groundwater monitoring nests have been installed at 42 locations considering field situation and necessity of the study (Figure 6.6). Each nest consist of 3 to 5 observation wells down to the maximum depth of 350 m (Figure 6.7) for measuring water table, collection of water samples and performing different tests (Figure 6.8). Number of installed line wells are 102 (Each line consists of 5 wells down to the depth of 100 m) to assess surface water – groundwater interaction. Lithologic logs have been prepared from sediment samples of all boreholes of nested and line wells and extension of aquifer units has been defined. Observers were engaged for collection of groundwater table data from the installed wells. RL (Reduced/Reference Level) survey has been conducted to measure RL of all completed observation wells in the project area. All the installed observation points are geo-referenced.

Both dry and wet season groundwater (957 Samples) as well as surface water (139 samples) samples has been collected from the installed observation well nests, line wells and nearby surface water bodies including tidal rivers for detailed analysis of important chemical parameters. Physico-chemical parameters including pH, Eh, EC, Temperature, Arsenic, Total Dissolved Solid etc. were measured in the field during sampling. Detailed chemical analysis of water samples have nearly been completed in the BWDB laboratory using Atomic Absorption Spectrophotometer (AAS) and other standard instruments.

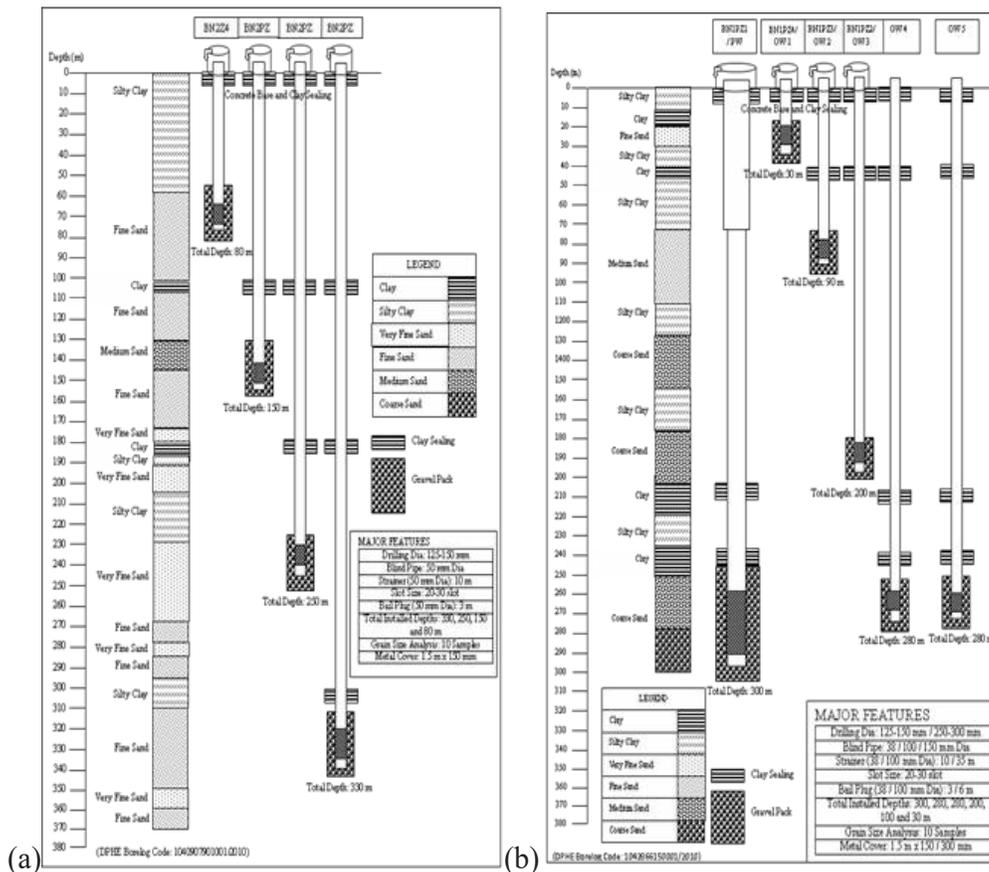


Figure 6.7: (a) Design of installed observation well nest and (b) deep aquifer pump test set-up at Barguna. Both are designed considering borehole lithology and water quality

For conducting aquifer pump tests in the deep fresh water aquifer to determine hydraulic and physical properties of aquifer sediment, 18 production wells down to the maximum depth of 350 m has been installed and 20 aquifer

pump tests have been performed (Figure 6.9). 124 numbers of slug tests have been conducted and data has been analyzed to estimate hydraulic conductivities as well as transmissivities of aquifer sediment.

All the collected data and study findings have been presented in a 12 volume report. As this network has been established to incorporate with the permanent monitoring network of BWDB for continuous monitoring of hydrogeological data, the big challenge is to organize funds for conducting various activities. The similar monitoring network needs to be extended in other parts of the country i.e. remaining 45 districts to monitor the overstressed groundwater resources all over Bangladesh.



Figure 6.8: Measurement of groundwater table and physico-chemical parameters in the field



Figure 6.9: Performance of aquifer pump test (a) and slug test (b) in the field to determine the hydraulic properties of aquifer sediment

7. Specific Water Supply Technologies in Vulnerable Areas

Rural water supply in Bangladesh is predominantly based on groundwater. But detection of arsenic in shallow groundwater causes threat on groundwater based water supply. Sea water encroachment in coastal aquifers is another major threat to the availability of fresh and safe water supply in the coastal belt. On the other hand, perennial surface water source is not available in many parts of the country. Therefore, one technology may not be suitable for an area and also variable in different areas because of different climatic and hydrogeological conditions (**Figure 7.1**). In that case the water technology is required to be identified on priority basis up to specific boundary, such as union level. Considering the situation, DPHE under UNICEF supported Sanitation, Hygiene and Water Supply Project (GOB - UNICEF) proposed water technology options at union level. Different NGOs are also working to provide area-specific safe water supply technologies.



Figure 7.1: Examples of installed area specific water supply technologies in different HtR areas by NGO Forum

Recently, a study was carried-out by NGO Forum for Public Health (Zahid et al. unpublished) to promote decentralized and sustainable context-specific water supply and sanitation facilities through increasing the capacity of the hard to reach (HtR) community and creating their access to water supply services. Considering the climatic hazard and other vulnerabilities such as, economic, physiographic and social context 5 different HtR areas i.e. (a) Drought prone, (b) Flood prone, (c) Char (sand bar), (d) Coastal and (e) Haor (swamp) areas were selected

for the study. It is found from the study that more activities and effort is needed to ensure the water supply facilities for all, mainly in the HtR areas. Still it is required to expand and improve the water supply and sanitation services in order to satisfy the basic needs in these areas.

7.1 Drought-prone Barind Areas

The Barind is known for drought prone characteristics where average annual precipitation is less compare to the other part of Bangladesh. The BMDA has been implementing large scale groundwater irrigation schemes in the area since few decades that lead to increased crop production. But, due to huge irrigation abstraction of groundwater from upper aquifers, groundwater table lowers below the suction limit (7.5 m) of hand tubewells in many areas of Barind including Nizampur study area that causes scarcity of safe drinking water. People are unable to use tubewells with no. 6 hand pumps anymore and deepset hand tubewell (DSHTW) has been introduced since few years to mitigate the problem by abstracting water from greater depths. The upper almost impermeable clay layer below surface has a thickness of more than 8-5 m that is not suitable for percolation of precipitation water and reduces recharge rates of groundwater. The thickness of hard clay below the upper aquifer is hundreds of meters and drilling with local methods is not possible. Therefore, the deep aquifer in the area is not well identified. Groundwater quality under Barind area is safe and no arsenic contamination is noticed till exploitable depth of 50-60 m.

Considering water scarcity at Nizampur area and lowered groundwater table (up to 35 m below surface) below suction limit DSHTWs and groundwater based piped water supply network have been installed for safe water supply. As no. 6 hand tubewell has no use in Barind groundwater table declined localities, DSHTW is the most efficient water supply option in the area. However, piped water supply using large diameter production well may minimize the ultimate cost though the initial investment is high. More RWHS and PSF can also be constructed in the area to reduce pressure on groundwater resource. Arsenic content of groundwater in tested DSHTWs were found less than 0.003 mg/l, i.e. within the allowable limit set by World Health Organization (WHO 2008) and Department of Environment, Bangladesh (DoE 1997).

At Jhenaipukur village, DSHTW has also been using to recharge preserve pond during dry season for community use. Storage of groundwater in a pond should be avoided not to allow loss of water due to evaporation. Piped water supply using 35 m deep 126 mm (5 inch) diameter production well has been installed at Golabari village. Groundwater is withdrawing by submersible pump from the well to the overhead tank. About 225 families are receiving fresh and safe water from 38 stand-posts (water tapes). The maintenance of the technologies has been carried out by Water Management Committees (WMCs) and users themselves. Users are very happy and satisfied with the quality and availability of water round the year in the highly water scarce zone. As per user's opinion, waterborne diseases have been reduced/eliminated after installation of safe water supply facilities in the area. Though the initial investment for installation of production well, storage and overhead tanks and pipeline network is expensive, but considering the large number of beneficiaries and ensured safe water supply, this is a very efficient and feasible option.

7.2 Vulnerable Char Areas

Regular seasonal flood and riverbank erosion are major problems for the Chukaibari study area of Dewanganj upazila, Jamalpur district lies on Brahmaputra river plain. Because of its braided river pattern, the Brahmaputra formed many large and small sand bars locally named as chars in the area. As chars are formed with recent

deposition of river borne sediments dominated by fine and medium sand, the groundwater is generally safe from arsenic contamination. Therefore STW is the most popular source of fresh and safe water supply and groundwater table generally remains within the suction limit of 7.5 m around the year. In the stable and older part of the union, shallow groundwater contains high arsenic above the limit of drinking water standard (10 µg/l of WHO and 50 µg/l of DoE, Bangladesh). In most areas high iron is noticed that can be treated following sand filtration techniques. Due to regular seasonal flood most part of the union submerged under water during monsoon for 5-6 months and many existing tubewells become flooded by polluted surface water.

Considering most visible problems, STWs (15-45 m deep), raised and dual platform tubewells, dug wells, iron removal plants (IRP) and AIRP have been installed in the area. Arsenic content of groundwater and treated water in all tested STWs and AIRPs respectively are found within the allowable limit set by DoE, Bangladesh.

In char areas, STW is the most acceptable and low cost option as shallow groundwater is free from arsenic contamination. Areas with regular seasonal flood, dual platform tubewells should be constructed to get fresh water even during flood. However, the safe distance of STW from nearby pit latrine needs to be considered as the surface clay is not thick enough and leaky permeable. DW is not suitable due to very fine grained silty sand and instability of subsurface sediment during excavation. Where arsenic and iron is problem in more stable areas, people have accepted dug wells and AIRPs very gladly. All technologies including AIRPs are maintained and cleaned by user families under supervision of Village Development Committees (VDCs). 20-30 families are getting benefits from each AIRPs and DWs. Water quality needs to be monitored regularly for dug wells and AIRPs. DTW can be installed where shallow groundwater is contaminated by arsenic. To minimize the cost of DTW installation, piped water network can be constructed in the stable part for community water supply using DTWs.

7.3 Flood-prone Areas

Seasonal flood and arsenic contamination in shallow groundwater are the major problems towards water supply services for the population of Teota union of Shibalaya upazila, Manikganj district, lies on Brahmaputra river plain. The Holocene sediments formed the floodplain aquifers and shallow groundwater contains high arsenic above the limit of drinking water in most of the area. Iron concentration is also high in upper aquifers. On the other hand, due to gravel enriched layers in the subsurface (about 70-100 m depth), installation of DTW is difficult by local manual methods. Groundwater table generally remains within the suction limit of 7.5 m in most of the areas round the year. Due to seasonal flood most part of the union submerged under water during monsoon for 3-4 months and many existing tubewells become flooded by polluted surface water and become defunct. Considering challenges, brick made RWHS, raised and dual platform tubewells, dug wells, AIRP have been installed in the area A. Arsenic content of treated water in all tested AIRPs were found within the allowable limit set by DoE, Bangladesh. Only in few samples arsenic content exceeded slightly above the WHO limit. Except few water samples of STWs, iron concentration of all other wells and AIRPs were detected within allowable limit of 1.0 mg/l. RWHSs and AIRPs are maintained and cleaned by user families under supervision of Village Development Committees (VDCs).

In arsenic affected flood prone areas, DW, PSF, RWHS and groundwater based AIRPs are effective options at different circumstances for safe water supply. 15-30 families are getting benefits from each dug wells and AIRPs. RWHSs are useful for a family or few families with limited use of preserved water in dry season. Safe distance of STWs for AIRPs from nearby pit latrines needs to be considered to avoid bacterial contamination from the pit as the thickness of the surface clay in the areas is not significant and leaky as well as groundwater table during monsoon is very close to the surface. Water quality needs to be monitored regularly for DWs, RWHSs and AIRPs.

DTW (>300 m deep) can be installed for community water supply in the arsenic and iron affected areas. Dual platform DTWs are useful option in the flood-prone areas and usable during flood by moving pumps on higher platforms. PSFs and DTWs can be installed for community water supply too.

7.4 Saline and Disaster Prone Coastal Areas

Natural calamities like cyclones, storm surges, tornadoes, seawater encroachment in the coastal eco-system and saline water intrusion in groundwater are the most common phenomena in the coastal areas of Bangladesh. In addition, coastal areas are also vulnerable to the anticipated impacts of climate changes like sea-level rises. Chila and Chandpai unions of Mongla upazila and Perikhali union of Rampal upazila of Bagerhat district lies on the coastal plain and have been suffering from disasters mentioned above. Amongst all, saline water in upper aquifers and in few areas arsenic contamination in shallow groundwater limits the availability of safe water in the region. Water of surrounding tidal rivers is also saline to brackish both in wet and dry seasons. Preserved ponds for fresh water supply suffer during storm surges when the area is inundated by saline and brackish water. However, harvested rain water and pond water is the main source of fresh water supply in the area. People collect rainwater during monsoon in motkas (earthen pots) and preserve for a shorter period of time. Considering fresh water scarcity in the studied unions and salinity encroachment both in tidal rivers and upper aquifers PSFs, both RWHSs with and without filter and community based RWHSs, pond water based piped water supply and desalination plant at Perikhali (by reverse osmosis) have been installed for safe water supply.

Piped water supply using privately owned treated pond water has been constructed at Chila. Pond water is withdrawing by submersible pump from the filtration system to the overhead tank. Solar power is used to operate the pump. About 250 families are receiving fresh and safe water from 20 stand-posts (water tapes). PSFs are also very effective in the area and more than 200 people are getting benefits from a PSF having fresh water supply. Many families are using RWHSs and community based RWHSs almost round the year. The maintenance of the technologies has been carried out by Water Management Committees (WMCs) and users themselves. Users are very happy and satisfied with the quality and availability of water in the highly water scarce zone. However, regular monitoring of water quality for PSFs, RWHSs, piped water supply are required. At Perikhali, desalination plant having the fresh water production capacity of 1000 liter/hour has been installed. Reverse osmosis method is used to treat saline groundwater as raw water with the EC value of about 6000 $\mu\text{S}/\text{cm}$. More than 200 families are currently collecting water from this point that can be expanded for more families. Use of electricity in future instead of petrol as power source would reduce the production cost of treated fresh water.

Where preserved pond is available, PSF can be the most cost effective and suitable option for coastal water supply as groundwater in upper aquifers is saline. RWHS can also be constructed with limited use during dry season. Desalination plant can be constructed where preserved pond is not available. As the groundwater in upper aquifers contain high salinity, deep aquifer (>300 m) may contain fresh water. Therefore, DTWs may be installed for community water supply. Artificial recharge i.e. managed aquifer recharge (MAR) may be augmented in coastal area to improve shallow groundwater quality by reducing salinity concentration above arsenic contaminated layer and can be used for drinking purpose.

7.5 Water-logged Haor Areas

Haor areas are characterized by numerous lakes and large swamps and water logging for 6-8 months is a major challenge. Seasonal flood and arsenic contamination in shallow groundwater are the threats to water supply

services for the population of Shimulbak study area of South Sunamganj upazila, Sunamganj district. Clay and silty clay dominates the aquifer system in the area. The deep aquifer is encountered at about 180 m depth below ground surface and is the main source of fresh and safe drinking water supply in the area. Groundwater table generally remains within the suction limit of 7.5 m in most of the areas round the year.

Considering fresh water scarcity and non-availability of adequate dry lands in the studied union RWHSs, DTWs and multi outlet DTWs have been installed at Shimulbak for safe water supply. Arsenic content of groundwater in all tested DTWs were found within the allowable limit set by DoE, Bangladesh, only in few samples arsenic content exceeded slightly above the WHO limit. Except few water samples of DTWs, iron concentration of all other wells were detected within allowable limit for drinking water supply.

At Shimulbak area, DTWs and RWHSs are useful technologies for safe water supply. Regular monitoring of water quality for RWHSs, piped water supply is required. However PSFs can be used too as fresh surface water is available round the year. At Khidirpur village, multi outlet DTW has been installed having the depth of about 230 m with about 1000 m pipeline network to connect multiple outlet of hand pumps. About 130 families are getting fresh water from this network and DTW is the first choice of the villagers for fresh water supply.

Because of arsenic contamination in shallow groundwater, DTW is the best option for water supply. Construction of multiple outlet head and piped water network can minimize the ultimate cost. PSF can be constructed as fresh surface water is available in haor areas round the year. RWHS can be constructed with limited use during dry season.

7.6 Very Shallow Tubewell with Managed Aquifer Recharge (MAR)

Managed Aquifer Recharge (MAR) is a part of the groundwater management tools, which may be useful for repressurising aquifers subject to falling water levels, declining yields, saline water intrusion or land subsidence (Dillon 2005; Scanlon et al. 2002). Areas where groundwater is either already over-exploited or saline, like the study area, recharge enhancement has potential to store excess runoff and reduce salinity concentration level. Techniques of both direct recharge i.e. water added to the groundwater reservoir in excess of soil-moisture deficits and evapotranspiration by direct vertical percolation through the vadose zone and indirect recharge i.e. percolation to the water table through the beds of surface-water courses, can be introduced to add additional water storage and reduce salinity content. As such design of Recharge Tank and Recharge Pond is proposed to increase fresh water discharge of very shallow wells (upto 5-8 m) in the arsenic and salinity affected coastal areas of Bangladesh (Figure 7.2).

Evapotranspiration and precipitation are the major time variant factors affecting the various processes to recharge. Recharge is not only highly dependent on climate, but also on surface and sub-surface conditions i.e. type and characteristics of aquifer sediments. A problem can also exist when transit i.e. travel time until recharge is long and land-use changes are known to have occurred in an area. Expanding shrimp cultivation in coastal landform using brackish or saline water on land surface can obstruct availability of very shallow fresh water in the vicinity by adding higher salinity concentration. Limitations are associated with the well-established recharge-estimation methods, however, water-balance methods, empirical formulae, isotope-tracer techniques, and Darcian approaches generally use for this purpose. Field measurements are a necessary component of a recharge investigation to realistically determine recharge processes. Where a significant aquitard i.e. clay layer exist in the surface (at least 3-5 m thick), the very shallow groundwater will be less vulnerable to surface contamination and recharge technologies removing this clay by filling sand will contribute additional storage to the aquifer. However,

these recharge devices and very shallow tubewells must be kept far enough to avoid bacterial contamination from the nearby pit latrine.

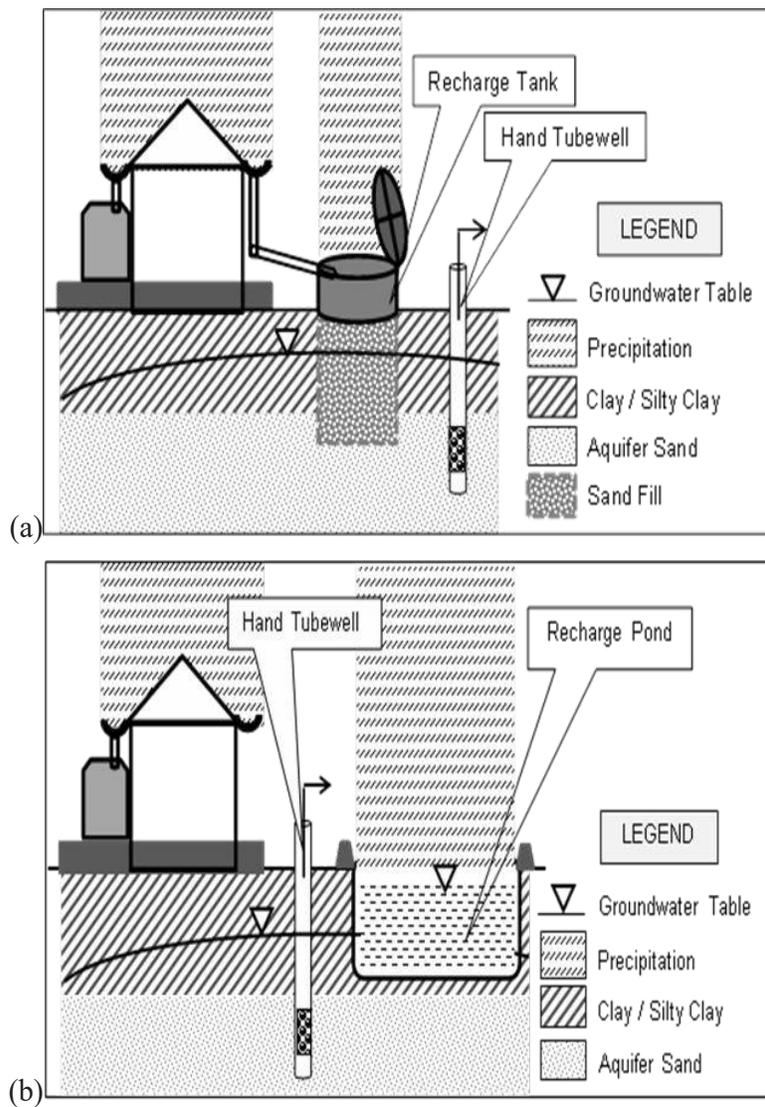


Figure 7.2: Proposed design of (a) Recharge Tank and (b) Recharge Pond to increase fresh water discharge of very shallow wells (up to 5-8 m) in the arsenic and salinity affected coastal areas

8. Management and Governance of Groundwater

Because of importance of water for the welfare and prosperity of people, Governments (central, provincial and local) undertook responsibilities in water resource management in the past. Landlords had a role in building and maintaining water infrastructure with taxes collected from beneficiaries. The first step in establishing Government role was taken in 1930s, when the DPHE was established to provide safe drinking water. A United Nations Technical Mission (Krug Mission) was invited in 1956 to study the flood problems, resulted in the creation of the then East Pakistan Water and Power Development Authority (EPWAPDA-present BWDB) in 1959, which also absorbed the provincial irrigation department. The first major step in water plan formulation was the preparation of the 1964 Master Plan, which focused predominantly on flood control for agriculture. However, projects had largely overlooked their impact on the ecosystem and over emphasized large sector surface water interventions. It overlooked the country's groundwater resources too.

In 1972, the World Bank supported in the preparation of a land and water sector study that emphasized integrated development of land and water resources with special focus on small scale (minor) irrigation. During this period, private sector irrigation using shallow tube-wells expanded in a big way. In 1983-84, work began on a National Water Plan with the aim to consolidate the existing information base, rationalize ongoing and planned activities and guide future investment. In 1986, Master Plan Organization (MPO) under the Ministry of Water Resources provided an assessment of water resources and future demand by different users and emphasized the groundwater use for agriculture. MPO developed planning models, recommended strategies and programs, presented a draft water law, and proposed means to institutionalize the process of long-term water management and planning. The Plan focused on structural measures mainly for surface water development for agriculture and groundwater issues were neglected again.

Existing laws and regulations regarding water resources in Bangladesh do not cover sufficiently in areas such as the rights, powers, and duties of individual users and the government, registration and leaving of right to water and administrative structure to execute laws and regulations. However, Bangladesh has already approved a National Water Policy (NWP 1999), that provides the framework for formulating the National Water Management Plan (NWMP). The key policies related to water resources are, the Irrigation Act, 1876, the Irrigation Water Rate Ordinance, 1983, the Ground Water Management Ordinance, 1985, the Water Resources Planning Act, 1992, the National Environment Policy, 1992, the National Energy Policy, 1996, the Water Supply and Sewerage Authority Act, 1996, the National Policy for Safe Water Supply and Sanitation, 1998, the National Agricultural Policy, 1999, the Industrial Policy, 1999, the National Policy of Arsenic Mitigation in Bangladesh, 2004 and its implementation plan. Very recently 'Bangladesh Water Act, 2013' has been enacted by the Government of Bangladesh for integrated development, management, abstraction, distribution, use, protection and preservation of water resources. Many of these policies would require updating and extension. Environmental resources are linked to water resources and it is vital that the continued development and management of the nation's water resources should include the protection, restoration, and preservation of the environment and its bio-diversity.

8.1 National Water Policy 1999

A milestone in formulating policy and planning for the water sector was the adoption of the National Water Policy (NWP) in 1999. This was done in consultation with stakeholders, sector agencies, NGOs, the civil society and major donors. The Policy defines the sector policy objectives and lays out broad guidelines and institutional framework to achieve those objectives. Major water resource management issues addressed by the NWP are, River Basin

Management; Water Rights and Allocation; Public and Private Investment; Water Supply and Sanitation; Water and Agriculture; Water for Environment; Stakeholder Participation; Legislative Framework etc. The NWP also defines major institutional reform and the role of the government, the private sector and the civil society in the management of water.

The main objective of NWP is to improve water resource management and protect the environment and to provide direction to all agencies working in the water sector for achievement of specified objectives. The need of conjunctive use of surface and groundwater is highlighted in the NWP. The NWP has provided broad principles of development of water resources and their rational utilization under different constraints. The NWP has given consideration to environmental protection, restoration and enhancement measures consistent with the National Environmental Management Action Plan (NEMAP) and the National Water Management Plan (NWMP).

The objective directed to groundwater resources development are broadly to, address issues related to the harnessing and development of all forms of surface and ground water and management in an efficient and equitable manner; ensure the availability of water to all elements of the society and to take into account the particular needs of women and children; accelerate the development of better water delivery systems with appropriate legal and financial measures including delineation of water rights and water pricing; bring institutional changes that will help decentralize the management of water resources and enhance the role of women in water management; develop a state of knowledge and capability that will enable the country to design future water resources management plans with economic efficiency, gender equity, social justice and environmental awareness; strengthen monitoring organizations for tracking groundwater recharge, surface and groundwater use and changes in surface and groundwater quality etc.

While moving towards the attainment of basin-wide plans in the long run, it will be necessary to concentrate on the development of individual hydrological areas to meet requirements. The NWP emphasizes collaboration with co-riparian countries to establish a system for exchange of information and data on relevant aspects of hydrology, morphology, water pollution, changing watershed characteristics, flood warning etc. and to help each other understanding the current and emerging problems in the management of the shared water resources.

National Water Resources Council (NWRC) is formed as the highest national body chaired by the Prime Minister and consists of 47 members. The mandate of NWRC is to, coordinate all water resources management activities in the country and particularly to formulate policy on different aspects of water resources management, provide directions for optimal development and utilization of water resources, oversee the preparation and implementation of the NWMP, provide directions on the development of institutions in the water sector and policy directives for appropriate coordination among different agencies, and look after any other matter that may require its attention in the water sector. To support the NWRC, an Executive Committee of the NWRC (ECNWRC) has been formed with 15 members, chaired by the Minister of Water Resources. It is required to arrange adequate meetings of these committees in order to play vital role in water sector activities.

8.2 National Water Management Plan

The draft National Water Management Plan (NWMP), which provides a framework to guide future approach and investment in WRM, was prepared in 2001. The draft NWM Plan was prepared to provide guidance to future investment for WRM in the light of NWP. The plan has focused on the institutional development and enabling environment, along with urgent programs such as metropolitan flood protection, urban and rural water supply and sanitation, preparation of national pollution control plan and various other studies to fill the knowledge gaps.

The NWMP proposes separation of planning and regulatory functions from implementation and operational functions at each level. One prominent step is to withdraw the central government agencies from activities that will be performed by local institutions and the private sector. The decentralization of decision-making will take place with stakeholders' participation. For integrated water resource management, the Government will create an enabling environment through legal and regulatory reforms, research, reliable information flow and capacity building. The main rivers will be developed and managed comprehensively for multipurpose use through a variety of structural and non-structural measures. Safe and reliable potable water and sanitation services will be provided to all people in a phased manner and attempts will be made to protect bio-diversity.

The goal of the Poverty Reduction Strategy (PRS) of the Government is to setup a vision for poverty reduction based on the understanding of key issues of the present state of the economy. Reviewing and considering NWP and NWMP objectives and actions, PRS recognized the need for promoting rational management and optimal use of water resources, improving the quality of life by ensuring equitable, safe and reliable access to water, availability of clean water in sufficient quantities and reservation of the aquatic and water dependent eco-systems. In PRS, specific programs have been identified for different key institutions. Planning and management of water resources is undertaken with comprehensive and integrated analysis within the context of hydrological regions. With declaration of state ownership of water, the Government reserves the rights to allocate water. Water Resources Planning Organization (WARPO) will prepare NWMP addressing the issues in each region and the country short to long term basis. Sector agencies and local bodies will prepare and implement sub-regional and local WMP in conformance with NWMP. The local government will be developed as the principal agencies for coordinating the process of planning, design, implementation, and O and M of mainly publicly funded surface water resources schemes, with participation of all stakeholders.

The regional WRM Plan (RWRMP) can be formulated under NWMP considering hydrological or physiographic divisions for easy planning and implementation of water resources activities and general policies to facilitate NWP objectives. The key partners for achieving this Plan are, landholders, water users, community groups and individuals, industry sector, economic development bodies, research and educational institutions, contractors and consultants, professional bodies and association. The RWRMP may identify a 50-year vision and sets out policies, milestones and strategies to achieve that vision with the aims to prevent the degradation of water resources by identifying causes and preferences to rehabilitation and treating symptoms, to manage resources within relevant natural resources system boundaries, to seek involvement of all parties with interest in a natural system in open planning and decision making, understanding and knowledge, develop ownership and ensure improved management practices.

Water Allocation Plan (WAP) needs to be prepared to outline the rules for allocation, transfer and use of available groundwater from prescribed sources. WAP must be consistent with the NWMP and RWRMP (**Figure 8.1**). Water licenses and water permits may be given through the development of WAPs for controlling the allocation, use and management of water resources in a prescribed area both for surface or groundwater. The WAP also includes assessment of quantity and quality of water needed for dependent ecosystems, assessment of resource capacity, rules to allocate and transfer water for environmental, social and economic needs, resource monitoring etc. A WAP sets the limits on the amount of water that can be taken and used. All of these tools can be implemented under the authority of recently enacted Water Act 2013.

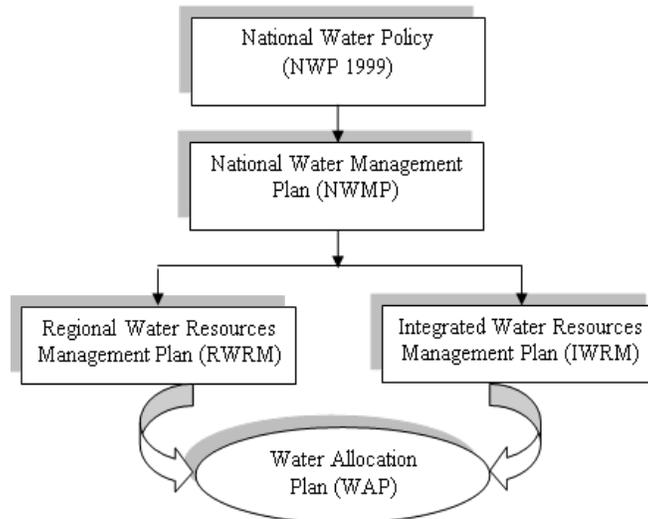


Figure 8.1: Steps of water management and allocation plans

Extension of irrigation is emphasized with efficient management of water resources, increase irrigation coverage especially to less developed areas and use of more surface water. PRS highlights to increase profit margins from rice irrigation, develop policies for market liberalization to already encouraged minor irrigation, rationalize performance and cost recovery, continue pro-market policies for irrigation development, improve quality of irrigation water and increase profitability of irrigated crops. Rationalize utilization of groundwater is emphasized ensuring supply of safe water for domestic use, regulation of industrial and agricultural use and conjunctive use of water. Mainly surface water irrigation projects are under implementation. Conjunctive use or groundwater-surface water interaction has not been considered. To accelerate PRS Plan, steps have been taken by the government to improve governance of water resources.

For the sustainable management of available fresh water resources without harming the eco-system, upazila and/or union level water budget should be prepared (**Figure 8.2**). Based on demand and availability of water resources (surface water, groundwater, rainwater harvesting) water allocation for different uses and sectors would be made as per priority mentioned in Water Act 2013.

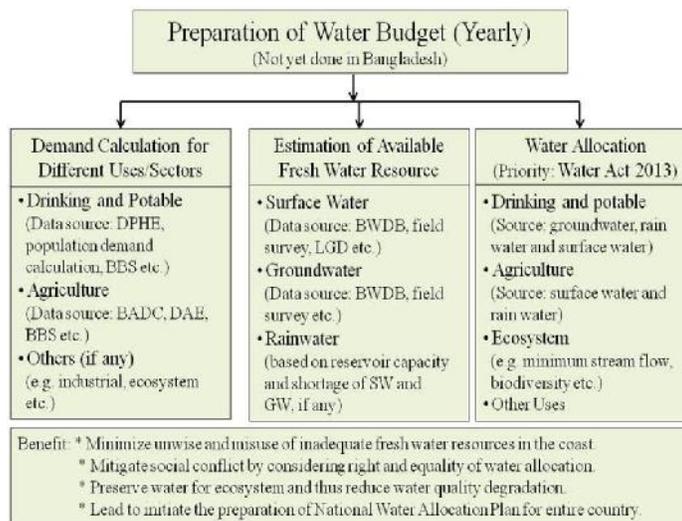


Figure 8.2: Chart for water budget analysis

8.3 Policy and Institutional Reforms

Important roles for national governments to ensure strong state/provincial level agencies include (Varady et al. 2012): allocating sufficient financial resources and removing bureaucratic obstacles to hiring the required professionals, and recommending adequate salaries and career development; establishing guidelines to address the management of trans-state and internationally-shared aquifer systems; providing minimum reference standards for the identification, characterization, monitoring and evaluation of groundwater basins 'at risk', and defined procedures for the specification and implementation of management measures appropriate to the level of risk involved. Science can play a role in addressing groundwater management through local and regional scale studies, particularly where the potential for groundwater depletion is included in a management strategy (USGS 2003).

The governance and management of the national water resources require coordination of existing institutions. Government should coordinate stakeholder activities based upon approved strategy. Policy, planning, and regulatory functions should work separately from implementation and operational functions. Properly functioning institutions are essential for effective implementation and administration of the country's water and related environmental management policies and directives. The existing institutions need to be restructured and strengthened, where appropriate. There is no single organization in the country that deals with groundwater activities. The government should create or identify an organization like Bangladesh Groundwater Authority or Board (Figure 8.2) bringing all the units working at different public agencies on groundwater under one umbrella and strengthen appropriate monitoring institutions for tracking groundwater recharge, surface and groundwater use, and changes in water quality.

Reform issues include establishing institutions for preparing integrated water resources plans at local levels with effective involvement of local governments, preparing master plans for specific issues including regulatory mechanisms for water quantity and quality management, standards for effluent disposal, establishing effective institutional mechanism to support the management transfer and local O and M financing, improving laws and regulations for O and M cost recovery; improving transparency and accountability in agency management, improving regulatory framework. The water markets give irrigation access to those farmers too who do not have their own source of irrigation and have been very crucial in alleviating rural poverty. In areas where the groundwater resource base is nearly over developed, water markets could hasten resource depletion. Thus, the institutional framework under which the resource is appropriated and used, needs to be developed for regulated use of groundwater.

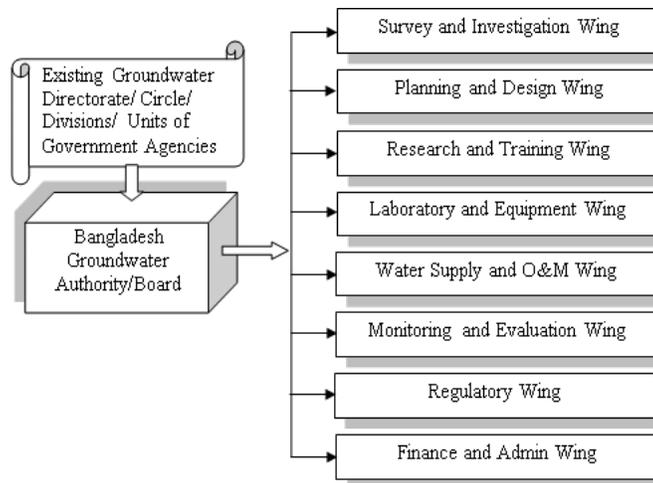


Figure 8.3: Proposed structure of groundwater organizational reform

9. Conclusion and Recommendation

The demand of water use has significantly been increasing to meet the planned irrigation, domestic and industrial needs in Bangladesh, where the development of water resources is very high. In a small land area with about 140 million populations, where more than 75% are directly involved in agriculture, it is really difficult to govern water resources for sustainable use. The challenge is not solely one of groundwater management, but one of comprehensive water management. Effective means to optimize water resources are conjunctive use of groundwater and surface water and artificial recharge in overstressed aquifers.

Bangladesh has formulated good numbers of policies, plans and acts in the sectors related to water development and uses. Many of the important and essential related issues have been covered by and well written in these documents. The main weakness of most of these tools is inadequate implementation and application. Existing laws and regulations do not cover sufficiently in areas such as the rights, powers, and duties of individual users and the government. There is also lack of research-based education and advocacy campaigns. Scientific and institutional approach analyzing research outputs for sustainable water use is still far behind. Most of these policies and plans were never reviewed though many years have passed after implementation.

Though the Government has already developed National Water Policy in 1999, the social views of groundwater lag behind the formal policy. Appropriate and timeframe institutional arrangements under legal and regulatory framework would reduce the pressure on ecological, socio-economic and scientific factors. Proper legislation, enactment and implement of law, efficient organizational strength are essential tools to regulate unwise use of groundwater. Governments should ensure strong division/district level agencies by supporting professional development, establishing management guidelines for shared aquifers, and providing monitoring standards for the available fresh water resource.

Practices, techniques and technologies can be improved for improved efficiency of water use to reduce wastage of water and ensure optimum economic and social benefits. Strong regulatory control mechanisms are urgently needed to enable proper management of the resource. Faced with the difficulties in enforcing water abstraction limits and in view of the negative impacts of over-pumping of this critically valuable resource, implementation of

the water policy is needed to move towards the introduction of new water management approaches. Water sector institutions must have a legal and regulatory framework under Water Act 2013 which they will operate.

In Bangladesh, climate change impacts are expected to be very high. By affecting environment, livelihood activities, food security and important ecosystem, climate change imposes a real threat to the stability of Bangladesh. Climate change is one of many factors that would influence future water stress in most regions. In Bangladesh, water sector means a lot for its livelihood and socio-economic development as water has a very close link to dependent agriculture. Keen attention is needed to adopt appropriate and sustainable strategy to combat climate change impacts and ensure food security and safe water supply for all.

Regarding safe water supply for rural, urban and industrial demand, both of the quantity and quality of water resources including groundwater has already posed a threat in many areas. With respect to fresh water availability, the costs of climate change will outweigh the benefits globally as precipitation variability is expected to increase, and more frequent floods and droughts are anticipated. The extent of these impacts mentioned above will depend, in a large part, on the ability of inhabitants to respond and adapt to future climate conditions.

Sustainable use of available safe water can be planned by analyzing data and information of the components of the hydrologic cycle. Inadequate hydrological data limits the scientific capacity to assess changes relevant to climate and to determine the causes of variability and change in the hydrological regime. The amount of groundwater available for withdrawal is a function of runoff, groundwater recharge, aquifer conditions and water quality. In Bangladesh where groundwater is the principal source of irrigation and potable water supply, monitoring of this resource establishing appropriate and adequate monitoring network is very important. Monitoring setup is also required to analyze water budget assessing surface water – groundwater interaction for conjunctive use. No systematic program exists for monitoring deep groundwater levels and quality, with the exception of the recently initiated BWDB program for monitoring water levels at depths of 350 m in the coastal zone that needs to be extended to other parts of the country. There is a clear consensus for the critical importance of monitoring, which should be required at pumping boreholes, at observation boreholes in depth profile (shallow and intermediate depths), and at abstraction depths in the local vicinity of pumping boreholes. There is an urgent need to install management structures and regulatory frameworks for groundwater control, and strengthen institutional technical capacity in hydrogeology in Bangladesh. The 'Groundwater Regulatory Agency or Authority' would be required to develop a policy for managing and monitoring deep groundwater pumping that can be done under Water Act 2013.

Groundwater is one of the most valuable natural resources and plays a vital role in the development process of the country. Its sustainable development and proper management can be done with a clear understanding of the groundwater system, its geology, hydrogeology, the subsurface flow and the response of the system considering seasonal, tidal and pumping stresses. As such, investigation of the aquifer systems, understanding of formation behavior, regular monitoring of groundwater storage and quality are important for the development and integrated management of water resource. Few specific recommendations are provided in following sections.

9.1 Management

Matching long term withdrawals of groundwater to recharge is the principal objective of sustainable groundwater resource planning. Maintaining the water balance of withdrawals and recharge is vital for managing human impact on water and ecological resources. Management of groundwater resources, projecting the future

development possibilities and socio-economic as well as environment impact assessment, can be achieved covering following aspects;

- ◆ Because of increasing demand of water and to reduce dependency on limited fresh groundwater resources, utilization of available surface water and conjunctive use should be stressed as per NWPo and other guidelines of the Government. This will minimize the seasonal fluctuation rate of water table and lessen stress on groundwater resource.
- ◆ Excessive withdrawal of groundwater for irrigation, industrial and domestic use needs to be controlled. Groundwater resources that can safely be abstracted from both upper and deeper aquifers need to be assessed properly
- ◆ Regional modelling of the groundwater systems has to be developed for effective water resource management to plan agricultural, rural and urban water supplies and to forecast the groundwater situation in advance for dry seasons
- ◆ Assessment of maximum or most valuable utilization of groundwater resources by developing priorities for long-term use considering widespread droughts, shifting populations and agricultural expansion to minimize the increasing stress on groundwater supply in an area. Assess groundwater pollution and alternative measures of protecting the resource in the future and safeguarding the public health
- ◆ Better operation and maintenance of tubewells, operating the installed and installable DTWs under an appropriate system acceptable to farmers, improving the management efficiency, crop diversification, increase in electrification of DTW, sinking new DTWs in the potential areas may increase crop production.

9.2 Investigation

In present scenario, besides proper investigation of shallower aquifer formations, exploration on the deeper formation of aquifer systems (250-400 m deep), probable potential safe source of drinking water in many areas, is very important. But its development needs detailed study to avoid saltwater intrusion and other possible water quality and quantity degradation. As such, following studies might be emphasized;

- ◆ Investigation on aquifer system at least up to union level and understanding of aquifer behavior; identification of the subsurface lithologic units, lateral and vertical extent of the aquifers, delineate fresh and saline groundwater interface in the coastal areas and characterization of the properties of aquifer sediments
- ◆ Assessment of groundwater resources; determination of the performance characteristics of wells and the hydraulic parameters of the aquifers; the impact on withdrawal; the chemical characteristics and potability of the aquifers and identification of arsenic, iron and chloride distribution patterns in the aquifers
- ◆ Investigation of the recharge mechanism of water in the deeper confined aquifers; evaluation of the impact of hydrogeologic heterogeneity and temporal variability in the flow system on the practical use of the aquifer for water supply
- ◆ Preparation of water budget and water allocation plan up to union level based on available data and information as well as conducting required survey and investigations.

9.3 Monitoring

- ◆ Extend existing network of groundwater monitoring wells spatially and vertically in different aquifers for calculating recharge, monitoring fluctuation of water table and movement of groundwater
- ◆ Increase the number of groundwater sampling stations and water quality laboratories for monitoring water quality and any possibility of saline water encroachment or quality hazards

- ◆ Prepare models to simulate the movement of groundwater flows and mass transport system in the region and finally an evaluation of hydrogeology of safe aquifer of the area
- ◆ Zoning of groundwater aquifers, STW/DTW areas, saline encroachment areas, initiation and implementation of small-scale irrigation project, establishment of water resource information system, strengthen and upgrade the existing groundwater data centers.

9.4 Capacity Building

- ◆ To facilitate the actions for sustainable development and management of groundwater resources of Bangladesh, strengthening and capacity building of appropriate organizations is required
- ◆ Creation or identification of an organization like 'Ground Water Board/Agency/Authority' as recommended by the Ground Water Task Force (GWTF), 2002 and other experts. As Bangladesh Water Development Board has the mandate of investigating and monitoring the status of groundwater all over the country and is working in this field since about 4 decades, field and laboratory facilities as well as appropriate man power of this organization should be strengthen for effective management plan of groundwater resources to agricultural, rural and urban water supplies
- ◆ Addition to Water Act 2013, formulation of 'Groundwater Act', recommended by the GWTF and experts would support to ensure sustainable long term use and governance of groundwater.

10. References

- Abdullah, S.K.M. and Hasan, A.K.M.S. (1991) Quaternary Volcanic ash bed (?) in Bangladesh. *Jour. Geology Soc. Bangladesh*; 10, 41-42.
- Acharyya, S.K. and Basu. P.K. (1993) Toba ash on the Indian sub-continent and its implications for correlation of Late Pleistocene alluvium. *Quaternary Research*, 40; pp10-19.
- Acharyya SK, Chakraborty P, Lahiri S, Raymahashay BC, Guha S, Bhowmik A (1999) Arsenic poisoning in the Ganges delta. *Nature* 401: 545
- Aggarwal PK, Basu AR, Kulkarni KM, Froehlich K, Tarafdar SA, Ali M, Ahmed N, Hussain A, Rahman M, Ahmed SR (2000) A report on isotope hydrology of groundwater in Bangladesh: implications for characterization and mitigation of arsenic in groundwater. Work performed within an IAEA—TC Project (BGD/8/016), p 61.
- Ahmed KM, Bhattacharya P, Hasan MA, Akhter SH, Alam SMM, Bhuyian MAH, Imam MB, Khan AA, Sracek O (2004) Arsenic enrichment in groundwater of the alluvial aquifers in Bangladesh: an overview. *Applied Geochemistry* 19:181-200.
- Alam MK, Hasan AKM, Khan MR, Whitney JW (1990) Geological map of Bangladesh. GSB, Dhaka.
- Alam MGM, Snow ET, Tanaka A (2003) Arsenic and heavy metal contamination of vegetables grown in Samta Village, Bangladesh, *Sci Total Environ* 308(1/3):83–96.
- Anawar HM, Akai J, Komaki K, Terao H, Yoshioka T, Ishizuka T, Safiullah S, Kato K (2003) Geochemical occurrence of arsenic in groundwater of Bangladesh: sources and mobilization processes. *J of Geochemical Exploration* 77: 109-131.
- BADC (2014) Survey report on irrigation equipment and irrigated area in Boro 2004 season. Bangladesh Agricultural Development Corporation

- Bakr MA (1977) Quaternary Geomorphic Evolution of the Brahmanbaria-Noakhali Area. Geological Survey of Bangladesh. Rec. V. I, 2.
- BBS (2013) Statistical Year Book of Bangladesh, Bangladesh Bureau of Statistics, Government of the People's Republic of Bangladesh, August 2013, 554p.
- BBS (2009) Statistical Year Book of Bangladesh, Bangladesh Bureau of Statistics, Government of the People's Republic of Bangladesh.
- BBS (2006) Statistical Year Book of Bangladesh, Bangladesh Bureau of Statistics, Government of the People's Republic of Bangladesh.
- Bhattacharya P, Chatterjee D, Jacks G (1997) Occurrence of arsenic contaminated groundwater in alluvial aquifers from the delta plains, eastern India: options for safe drinking water supply. *Water Resour Dev* 13: 79-92.
- BMDA (2004) Data Bank: Groundwater and Surface Water Resources Bangladesh. Barind Integrated Area Development Project (BIADP). Barind Multipurpose Development Authority, Ministry of Agriculture.
- Breit GN, Foster AL, Perkins RB, Yount JC, King Trude, Welch AH, Whitney JW, Uddin N, Muneem AA, Alam M (2004) As-rich Ferric oxyhydroxide enrichments in the shallow subsurface of Bangladesh, in Wanty, R.B., and Seal, R.R. II., eds. *Proceedings of the Eleventh International Symposium on Water-Rock Interaction WRI-11*, Saratoga Springs New York, p. 1457-1461.
- BWDB (2013) River of Bangladesh. Bangladesh Water Development Board.
- BWDB (2013) Hydrogeological study and mathematical modelling to identify sites for installation of observation well nests, selection on model boundary, supervision of pumping test, slug test, assessment of different hydrogeological parameters collection and conduct chemical analysis of surface water and ground water, Final Report (Main Volume, Package 3), Bangladesh Water Development Board and Institute of Water Modelling.
- BWDB (1994) Report on the compilation of aquifer test analysis results as on June, 1993, BWDB Water Supply Paper no. 534.
- BWDB (1989) Report on the compilation of aquifer test analysis results as on June, 1988, BWDB Water Supply Paper no. 502.
- BWDB-UNDP (1982) Groundwater Survey: the Hydrogeological Conditions of Bangladesh. UNDP Technical Report DP/UN/BGD-74-009/1, 113p.
- Coleman JM (1969) Brahmaputra river: channel processes and sedimentation. *Sedimentary Geology* 3: 129– 239.
- Chapelle FH, Lovley DR (1992) Rates of bacterial metabolism in deep coastal-plain aquifers. *Appl Environ Microbiol* 56: 1865-1874.
- Custodio, E. (2002) Aquifer overexploitation: what does it mean? *Hydrogeol. Jour.*, v. 10, pp. 254–277.
- Davis JA, Kent DB (1990) Surface complexation modelling in aqueous geochemistry. *Rev Miner* 23: 177-260.
- DoE (1997) Environment Conservation Regulation, the Government of Bangladesh, 48pp.
- DPHE (1999) Groundwater Studies for Arsenic Contamination in Bangladesh. Final Report, Rapid Investigation Phase. Department of Public Health Engineering, Government of Bangladesh. Mott MacDonald and British Geological Survey.
- DPHE-BGS (2001) Arsenic contamination of groundwater in Bangladesh. British Geological Survey and Department of Public Health Engineering, Govt. of Bangladesh; rapid investigation phase, Final Report.

- DPHE-DANIDA (2001) Hydrogeology summary report. Department of Public Health Engineering–Danish International Development Assistance Water Supply and Sanitation Components, Ministry of Foreign Affairs, Government of Bangladesh.129p.
- DWASA (2006) Water Utility Services in Dhaka City: Present and Future. Presentation by H. Al-Mamoon, Workshop on Partnerships for Improving the Performance of Water Utilities in the Asia and Pacific Region, 25 – 27 July, 2006, Bangkok, Thailand.
- Flanagan, S.V., Johnston, R.B., Zheng, Y. (2012) Arsenic in tube well water in Bangladesh: health and economic impacts and implications for arsenic mitigation. *Bulletin of the World Health Organization*, Vol. 90: 839-846.
- GWTF (2002) Report of the Ground Water Task Force, Ministry of Local Govt. Rural Dev. And Co-operatives, Govt. of the Peoples Republic of Bangladesh
- Harvey CH, Swartz CH, Badruzzaman ABM, Keon-Blute N, Yu W, Ali MA, Jay J, Beckie R, Niedan V, Brabander D, Oates PM, Ashfaque KN, Islam S, Hemond HF, Ahmed MF (2002) Arsenic mobility and groundwater extraction in Bangladesh. *Science* 298:1602–1606.
- Hassan, M.Q., Zahid, A. (2013) Management of overexploited Dhaka city aquifer. *Journal of Nepal Geological Society*.
- IAEA (2000) A Report on Isotope Hydrology of Groundwater in Bangladesh: Implications for Characterization and Mitigation of Arsenic in Groundwater. Work Performed within an IAEA – TC Project (BGD/8/016), 61p.
- JICA (2002) The Study on the Ground Water Development of Deep Aquifers for Safe Drinking Water Supply to Arsenic Affected Areas in Western Bangladesh, Final Report. Kokusai Kogyo Co., Ltd., Mitsui Mineral Development Engineering Co., Ltd.
- Khan, F.H. (1991) *Geology of Bangladesh*, The University Press Limited, Dhaka, Bangladesh.
- Kudrass, H.R., Hofmann, A., Doose, H., Emeis, K., and Erlenkeuser, 1999. Modulation and amplification of climatic changes in the northern hemisphere by Indian summer monsoon during the last 80,000 years. BGR Final Report, Bengal shelf, SONNE Cruise-SO126.
- Mallik S, Rajagopal N (1996) Groundwater development in the arsenic effected alluvial belt of West Bengal-some questions. *Current Science* 70: 956-958.
- Mandal MAS (2006) Groundwater irrigation issues and research experience in Bangladesh. Presentation at the international workshop on Groundwater Governance in Asia, Indian Institute of Technology, Roorkee, India, 12–14 November 2006.
- Mandal, M.A.S. (2000) Dynamics of Irrigation Market in Bangladesh. In: Mandal M.A.S. (ed) *Changing Rural Economy of Bangladesh*. Bangladesh Economic Association, Dhaka. Pp: 118-128.
- Michael HA, Voss CI (2009) Controls on groundwater flow in the Bengal Basin of India and Bangladesh: regional modelling analysis. *Hydrogeology J* 17:1561–1577.
- Michael HA, Voss CI (2008) Evaluation of the sustainability of deep groundwater as an arsenic-safe resource in the Bengal Basin. *PNAS*, Vol. 105 (25): 8531-8536
- Mok, W.M. and Wai, C.M. (1994) Mobilization of arsenic in contaminated river sediment. In: *Arsenic in the Environment; Part 1: Cycling and Characterization*, J. Nriagu (ed.), J. Wiley and Sons, 1994, 99-118.
- MPO (1987) Technical Report No. 5, The Groundwater Resource and its Availability for Development, Ministry of Irrigation, Water Development and Flood Control, Dhaka.
- MPO (1991) Final Report, National Water Plan Project Phase II. Master Plan Organization, Dhaka. Hazra, USA; Sir M MacDonald, UK; Meta, USA; EPC, Bangladesh.

- Nickson R, McArthur J, Burgess W, Ahmed KM, Ravenscroft P, Rahman M (1998) Arsenic poisoning of Bangladesh groundwater. *Nature* 395: 338.
- Nickson RT, McArthur JM, Ravenscroft P, Burgess WG, Ahmed KM (2000) Mechanism of arsenic release to groundwater, Bangladesh and West Bengal. *Applied Geochemistry* 15: 403-413.
- NWP (1999) National Water Policy, Ministry of Water Resources, 1999, Dhaka, Bangladesh.
- Scanlon BR, Healy RW, Cook PG (2002) Choosing appropriate techniques for quantifying groundwater recharge. *Hydrogeology Journal*, 10: 18–39 DOI 10.1007/s10040-0010176-2.
- Sengupta, S. (1966) Geological and geophysical studies in western part of Bengal basin, India. *Bull. Am. Assoc. Pet. Geol.* 50, 1001–1017.
- Shamsudduha (2013) Groundwater-fed Irrigation and Drinking Water Supply in Bangladesh: Challenges and Opportunities. *In*. Zahid A, Hassan MQ, Islam R, Samad QA, Khan MS, Haque R (Editors), *Impact of Climate Change on Socio-economic Conditions of Bangladesh*. Published by German Academic Exchange Service (DAAD), German Development Cooperation (GIZ), Alexander von Humboldt Foundation and Alumni Association of German Universities in Bangladesh, pp. 150-169.
- Shamsudduha, M., Taylor, R., Ahmed, K., Zahid, A. (2011) The impact of intensive groundwater abstraction on recharge to a shallow regional aquifer system: evidence from Bangladesh. *Hydrogeology Journal*. doi:10.1007/s10040-011-0723-4.
- Smedley PL, Kinniburgh DG (2002) A review of the source behavior and distribution of arsenic in natural waters. *Appl Geochem* 17: 517-568.
- Sultana, S. (2009) Prospects of Artificial Recharge and Other Options for Augmentation of the Upper Dupi Tila Aquifer in Dhaka City, Bangladesh. M.Sc. Thesis, Department of Geology, University of Dhaka, Dhaka 101p.
- Uddin A, Lundberg N (1998) Cenozoic history of the Himalayan-Bengal system: Sand composition in the Bengal Basin, Bangladesh. *Geol. Soc. Am. Bull.* 110: 497–511.
- USGS (2003) *Evolving Issues and Practices in Managing Ground-Water Resources: Case Studies on the Role of Science*, USGS Circular 1247, 73p.
- Varady, R.G., van Weert, F., Megdal, S.B., Gerlak, A., Iskandar, G.A., House-Peters, L. (2012) *Groundwater Governance: A Global Framework for Country Action*. FAO Thematic Paper No. 5, Commissioned by UNESCO IHP.
- Water Act (2013) Bangladesh Water Act, Government of the People's Republic of Bangladesh, November 6, 2013.
- WARPO (2000) Draft Development Strategy (DDS), Estimation of groundwater resources, Annex-C, Appendix 6, National Water Management Plan, WARPO, Dhaka, Bangladesh, 2000.
- WHO (2011) *Manganese in drinking-water: Background document for development of WHO guidelines for drinking-water quality*. WHO/SDE/WSH/03.04/104/Rev/1.
- WHO (2004) *Guideline for drinking water quality, 3rd edition, vol. 1: Recommendations*, World Health Organization, Geneva pp 515.
- World Bank-USGS (2010) *Implications of Climate Change for Fresh Groundwater Resources in Coastal Aquifers in Bangladesh*. The World Bank, South Asia Region, Sustainable Development Department, 105p.
- Yan X-P, Kerrich R, Hendry MJ (2000) Distribution of arsenic (3), arsenic (5) and total inorganic arsenic in pore waters from a thick till and clay rich aquitard sequence, Saskatchewan, Canada. *Geochim Cosmochim Acta* 62: 2637-2648

- Zhang GL, Gong ZT (2003) Pedogenic evolution of paddy soils in different soil landscapes. *Geoderma* 115: 15-29
- Zahid, A., Hassan, M.Q., Ahmed, K.M.U. (2015) Simulation of flowpaths and travel time of groundwater through arsenic contaminated zone in the multi-layered aquifer system of Bengal Basin. *Journal of Environmental Earth Sciences*, DOI 10.1007/s12665-014-3447-7.
- Zahid, A., Hassan, M.Q., Nahar, M.N.K. (2010) Assessment of hydraulic connectivity of the multi-layered aquifers. *The Dhaka University Journal of Earth and Environmental Sciences*. Volume 1 (1): 13-17.
- Zahid, A., Hassan, M.Q., Breit, G.N., Balke, K.D., Flegr, M. (2009) Accumulations of iron and arsenic in the Chandina Alluvium of the lower delta plain, southeastern Bangladesh. *Journal of Environmental Geochemistry and Health*, Volume 31: 69–84.
- Zahid, A., Haque, M.A., Islam, M.S., Rashidul Hasan, M.A.F.M. (2009) Development of groundwater under lower Gangetic plain of Bangladesh: The impact of shallow tubewells on irrigation water availability, access, crop productivity and farmer's income. In: *Groundwater Governance in the Indo-Gangetic and Yellow River Basins: realities and challenges*. Eds. Mukherji, A., Villholth, K. G., Sharma, B. R., Wang, J. International Association of Hydrogeologists (IAH) Selected Papers Series, CRC/Balkema Press, Netherlands, 141-162.
- Zahid, A., Hassan, M.Q. (2009) Flowpaths and travel time of groundwater from arsenic contaminated zone to deeper aquifer units under different development stresses. *Proceedings of the 2nd International Conference on Water and Flood Management*. Bangladesh University of Engineering and Technology (BUET), Volume 1: 151-161.
- Zahid, A., Hassan, M.Q., Balke, K.-D., Flegr, M., Clark, D.W. (2008) Groundwater chemistry and occurrence of arsenic in the Meghna floodplain aquifer, southeastern Bangladesh. *Journal of Environmental Geology*, Volume 54: 1247–1260.
- Zahid, A., Balke, K.-D., Hassan, M.Q., Flegr, M. (2006) Evaluation of aquifer environment under Hazaribagh leather processing zone of Dhaka city. *Journal of Environmental Geology*, Volume 50 (4): 495-504.
- Zahid, A., Rahman, A., Hassan, M.R., Ali, M.H. (unpublished) Differentiate sources of groundwater salinity of the multi-layered aquifers of the Bengal delta using bromide and chloride ratios. Submitted to: *Journal of Hydrology: Regional Studies*.
- Zahid, A., Rashid, S.M.A., Salam, M.A., Tazneen, F (unpublished) Selection of Area Specific Water Supply Technologies for Different Geomorphologic Regions of the Bengal Basin.

BASELINE STUDY: 05

Coast and Polder Issues

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Executive Summary: Study 05

Coastal Zone and polder management is one of the 19 Thematic Studies of the Bangladesh Delta Plan 2100 and focuses on delta problems including those in the coastal polders. The baseline study supports joint fact-finding, contributing project ownership and partnership development, contributes to the creation of a common knowledge base and identifies interventions towards a more sustainable development in view of long term perspectives and drivers of change.

The coastal zone of Bangladesh is a disaster prone area. Cyclones, storm surges, droughts, floods, water-logging and salinity intrusion have a huge impact on people and their livelihood. Poor communication, lack of education and health care facilities, prolonged absence of safe drinking water, insufficient cyclone shelters contribute and multiply the dimension of vulnerability. Furthermore, increasing population pressure increases the competition for limited resources. Nevertheless it also has a tremendous potential to create opportunities – such as intensification of agriculture and aqua culture, marine fishery, exploration of gas and oil resources, ship building industry, eco-tourism, renewable energy and deep sea port development. However, in order to unlock these potentials, existing and new interventions are required in an integrated and inclusive way, calling for a distinct and integrated coastal development plan.

The report describes the main problems some of which are inherent to living in the coastal zone, while others resulting from past human interventions which always have repercussions in the dynamic coastal environment.

Waterlogging is a problem in large parts of the coast, especially in the southwest (Satkhira, Jessore, Khulna and Bagerhat) and south east (Noakhali, Feni), but their causes are different. In the southwest region the reduction of dry season flow caused by water withdrawal operations of the Farakka barrage in the Indian part of the Ganges contributed to increased salinity and subsequently more sedimentation in tidal rivers that forms the drainage systems of the polders. Construction of polders also reduced the tidal prism since it prevents tidal flooding into the tidal plain and accelerated the river siltation. These tidal rivers cannot effectively drain the nearby lands and polders anymore because of reduced drainage capacity due to siltation, which results in waterlogging. In the southeast zone, the drainage path has become long and drainage pattern has been changed after cross dams were constructed for land reclamation. Also the natural sedimentation process in the Meghna estuary, construction of roads and water control structures contributed to the waterlogging problem in the South-east region.

Bangladesh is a global hotspot for tropical *cyclones*, which hit the country's coastal regions in the pre-monsoon i.e. during April–May or post-monsoon during October–November. During the period 1960–2015, 19 severe cyclones have hit the coast of Bangladesh. Tropical cyclones can cause significant phenomena which can adversely impact on communities and the environment. The most common features are destructive winds, heavy rainfall and cyclone induced storm surges that can lead to flooding. In November 1970, the most severe cyclone of the century, with respect to surge height, inundation and loss of life occurred and about 300,000 people lost their lives. The construction of cyclone shelters and community preparedness plans have greatly contributed to a reduction in casualties. Nevertheless, the recent Cyclone Sidr (2007), with an average wind speed of 223 km per hour, still caused 4,234 casualties and 55,282 injuries.

Average *salinity* concentrations of the rivers generally increase almost linearly from October to late May concurring with the gradual seasonal reduction in upstream fresh water inflow. A reduction in freshwater inflows from the trans-boundary Ganges River, siltation of its tributaries and siltation of other rivers following the construction of the polder system have resulted in a significant increase in dry season river salinity over the past

decades (e.g. in the Rupsa river at Khulna, which rose from 0.7 ppt in 1962 to 16.8 ppt in 2011). The rise in salinity has resulted in a decrease of agricultural production in many parts of the coastal zone, notably in the Khulna region and the extreme south of the Patuakhali region, and locally in the Noakhali and Chittagong regions. Sea level rise is likely to cause significant changes in river salinity in the southwest coastal area of Bangladesh during dry season (October to May) by 2050, which will likely to lead to significant shortages of drinking water in the coastal urban areas, scarcity of water for irrigation for dry-season agriculture and significant changes in the coastal aquatic ecosystems (IWM, 2014). Furthermore, the salinity increase is damaging the freshwater fish habitat and has adverse impact on the Sundarban ecosystems. The number of people in the southwest coastal region affected by salinization is likely to increase with +15 to +100% (2.9 to 5.2 million people), again disproportionately affecting the poor (+23 to +130%), S. Dasgupta, blog post, 2015

In the coastal area shallow groundwater is generally too saline for domestic or irrigation use either due to connate salts or tidal flooding. During monsoon, sufficient flushing of saline water has taken place in isolated pockets to enable a limited domestic use of fresh water in the shallow aquifer. In the deep aquifer the pattern of salinity distribution is more uniform on a regional basis, as is the continuity of the aquifer. The change from potable water to very saline water is sharp and occurs over a relatively short distance (IWM, 2014). Coastal salinity and localized high dissolved iron in the alluvial aquifer was considered the major problem before detection of arsenic in groundwater. Saline groundwater can be found up to 100 km inland (IWM, 2013).

Although *coastal erosion* is a common problem along the coastlines of mainland Bangladesh and its islands, the delta as a whole is still increasing. Every year the Ganges, Brahmaputra and Meghna rivers transport about a billion ton of sediment, part of which is contributing to land accretion. The average annual growth rate in the Meghna Estuary is in the order of 19 km². With the building process the major islands are growing to the south. Subsequently the north and east parts of some islands are eroding. For instance, about 40% of Sandwip island in the east was eroded and there were considerable losses in the north of Hatia, north-east of Bhola and the south-west of the former Ramgati island. These land losses cause huge local problems for the people and their livelihoods. Erosion prevention is taken place but is difficult due to the highly dynamic nature of especially the Meghna estuary.

There are at least seven policies and strategies relevant for the coastal zone. Of them the Coastal Zone Policy and the National Water Policy are the most important. The *CZ Policy* was approved at the cabinet meeting on January 17, 2005. This policy document was formulated through a process of multi-level consultation over a period of two years. The Policy is built on different sector policies of the Government of Bangladesh. Subsequently, a Coastal Development Strategy was defined that selected nine strategic priorities and actions in implementation of the Coastal Zone Policy with emphasis on the creation of the institutional environment that will enable GoB to embark on a continuous and structured process of prioritization, development and implementation of concerted interventions for the development of the coastal zone. In 2005 also a Priority Investment Plan was issued as the operational arm of the Coastal Development Strategy. It contains 24 projects grouped under the strategic priorities mentioned in the CDS with a total estimated cost of 398 million USD. Unfortunately, the coastal zone management initiative has seemingly died off after 2005-2006. After a decade of adoption of the policy most targets still remain in the to-do-list.

The *National Water Policy* (NWPo) was enacted in 1999 to address the objectives of improved water resources management and protection of the environment recognizing that every public agency, every community, village and each individual has an important role to play in ensuring that the water and associated natural resources of

Bangladesh are used judiciously for the benefit of present and future generations. The policy recognizes that the process of planning and managing water resources requires a comprehensive and integrated analysis of relevant hydrological, topographical, social, political, economic, environmental and institutional factors across all related water-using sectors. Specifically relevant for the coastal zone are the objectives to de-silt water courses to maintain navigation channels and proper drainage, to delineate water-stress areas for managing dry season demand, to take steps to protect the water quality and ensure efficiency of its use, to develop early warning and flood-proofing systems to manage natural disasters and to plan and implement schemes for reclamation of land from the sea and rivers.

The impacts of *climate change* for Bangladesh are most critical because of its geographical location, high population density, high levels of poverty, and the reliance of many livelihoods on climate-sensitive sectors, such as agriculture, fisheries. For example one of the IPCC scenarios (A1B) shows increases in mean annual and monsoon precipitation by 0.64 and 1.40 mm per day, respectively, during the 2011-2041 time slice relative to the baseline period (1961-1990). However, mean winter precipitation may decrease by 0.05mm per day during 2011-2041 compared to the baseline period.

Relative sea level change is the local change in sea level relative to the elevation of the land at a specific point on the coast. Its change is variable along the coast of Bangladesh depending upon the local and regional factors. Trend analysis of water level along the coast of Bangladesh shows an increase of annual mean water level in the southwest coast (Hiron point), Meghna estuary (Khepupara) and Chittagong coast (Rangadia) by 6.8mm, 3.7mm and 4mm per year, respectively. Unfortunately, there has been no detailed scientific research to project future relative mean sea level rise along the coast of Bangladesh. However, the impacts on water management (salinity intrusion), coastal erosion and flood risks are considered to be substantial. Current water management practices may not be robust enough to cope with the impacts of climate change. It demands improved incorporation of information about current climate variability and climate change into planning and design of water infrastructure.

Equally important and related to sea level rise is land *subsidence*. The lower deltaic area of Bangladesh is located on two active troughs, Faridpur Trough and Hatiya Trough. Although most of the Bengal Basin is slowly subsiding, the troughs are subsiding more rapidly. The area shows evidence of three different types of subsidence: tectonic, anthropogenic, and that resulting from the compaction of peat layer. Available evidence suggests that most of the region is currently subsiding at less than 2 mm/year except near the coast where rates may be up to ca. 6 mm/year.

Current upstream developments (e.g. Farakka Barrage) as well as future plans for new dams and diversions in the catchments of Ganges, Brahmaputra and Meghna will lead to significant *changes in river flows* and dynamics that will change the seasonal availability of freshwater in the coastal zones. Of specific concern is the plan to execute the Jogighopa-Tista-Farakka Link Project or National River Linking Project (NRLP) in India.

The enormous amount of annual sediment discharged by the rivers provides a huge *potential of land reclamation* in the coast. Actually this has been an on-going development over the past decades. The first cross dam was constructed in the Lower Meghna in 1957 and many projects would follow suit (e.g. Land Reclamation Project, Meghna Estuary Study, Estuary Development Programme).

A major integrated land development project was the *Char Development and Resettlement Project* (CDSP) which started in 1994 and is now in its fourth phase. The overall objective of CDSP-IV is to improve the economic situation and living condition of the population in the coastal areas of south-eastern Bangladesh with special reference to the poorest segment of the population. It started in March 2011 for the period of 6 years. The project has a number of innovative features, with opportunities of learning by the implementing agencies, the

government and the donors. Unlike earlier char development projects, over half the area to be covered will not be protected by embankment (as it is too immature and unstable for impoldering). To generate benefits for people living in these very vulnerable chars, innovations such as salt-adapted agricultural technologies, house plinth raising and house strengthening will be needed. CDSP IV also plans to construct killas as refuges for livestock on such chars – something that earlier char development programmes have not done. The CDSP projects have over the years evolved into a rather successful formula of coastal development.

To protect low lying land from salinity intrusion and tidal waves construction of coastal embankment started from early 1960s, which ultimately led to a total of 139 *polders* today. A polder is a low-lying tract of land enclosed by embankments known as dykes that form an independent hydrological entity which has no physical connection with outside water other than through manually operated devices (water control structures). In 2008 the polders supported a total population of 8 million people living on 1.2 million hectares of land. The immediate socio-economic consequences were very impressive and positive. This positive situation persisted for about two decades or so, but by the early 80s the secondary effects of polderisation in terms of sediment deposition began to be serious. Lack of proper maintenance of infrastructure combined with the sediment deposition in the peripheral rivers of polders/drainage channels created restricted drainage and consequent waterlogging which is now a major issue in many parts of the coastal zone.

In order to tackle the problem of water logging *Tidal River Management* (TRM) was introduced, which involves taking advantage of natural tidal movement in the river and adjacent low lying flood plain. TRM allows natural movement of tide from the river to an embanked low lying area (beel) through a link channel. During flood tide, sediment laden water enters to the low-lying area where the sediments are deposited due to reduced velocity and long duration of storage. During ebb tide the tidal water flows out of the low-lying area with reduced sediment load and erodes the river bed and bank downstream. The natural movement of flood and ebb tide in the river and low-lying area increases the drainage capacity/conveyance of the river through scouring and maintains the river navigability. Subsequently the low-lying area is raised considerably due to deposition of silt. The TRM process is an example of building with nature and a resilient measure for water-logging, river sedimentation and subsidence. TRM is applied in several projects, such as the Khulna-Jessore Drainage Rehabilitation Project (KJDRP).

After cyclones Sidr and Aila struck the coastal zone causing severe damage to the infrastructure, life and property, the Government of Bangladesh (GOB) obtained an IDA/credit for Emergency Cyclone Recovery and Restoration Project (ECRRP), 2007 and some proceeds from this credit were used to meet the expenses for carrying out the Feasibility Study of the *Coastal Embankment Improvement programme* (CEIP). As an outcome of the study a project Phase-1 (CEIP-1) is conceived. Under this project selected 17 coastal polders will be upgraded and rehabilitated with the financial support from the World Bank (USD 400 millions). This project has been approved by the ECNEC on 1 October 2013.

Another project to improve the livelihood and sustainability of the coastal polders is called *Blue Gold*. The essence of the Blue Gold Program is first to establish and empower community organizations to sustainably manage their water resources and based on the priorities set by these community organizations deliver the services (in the area of agriculture, livestock and fisheries development) for which they have expressed a demand. The Program aims to create strong cooperatives that will interact with public and private organizations that play a role in the development of the area. Participatory water resources management is the entry point and the initial driver of the community organization process.

Besides these typical coastal projects also a number of river improvement projects are of relevance for our baseline, such as the Gorai River Restoration Plan, the Ganges Barrage Plan, Bhairab River Plan and Kobadak River

Basin Plan. Other major projects relevant for coastal development are the Southwest Area Integrated Water Resource Planning and Management, Noakhali Drainage improvement, Sundarbans Biodiversity Conservation Plan, Cyclone Preparedness Programme (CPP) and Deep Sea Port Development Plans (Sonadia and Payra Port).

Following the BDP2100 perspective of a holistic, integrated and inclusive development, progress in coastal Bangladesh should address the imminent problems in a sustainable manner while unlocking the potentials for economic development. The physical conditions pose huge challenges. Harnessing these conditions through land reclamation and embankments has indeed improved living conditions of millions of people. At the same time these structural developments have created new problems, such as waterlogging. Likewise, the social environment is dynamic and compounded with structural inequalities. Often such social conflicts can be directly linked to the physical environment, such as the conflict between shrimp culture and rice growing. Ignoring these conditions and relations could jeopardise development projects and programmes, which has been experienced in the past. It is therefore encouraging to see that in the past decade or so most government-led programmes took up these lessons and base their interventions on a more inclusive and integrated way.

Along the Bangladesh' coast one can see all stages of development unfolding in space and time:

1. Emergence of new land (chars) with pioneer vegetation, but still daily inundated by the tides
2. Colonizing chars by landless people, letting their livestock graze on land above mean high water level
3. Embanking land, creating polders and allowing for growing crops
4. Full-fledged polders with a certain level of water management, but also with increasing drainage problems.

It is clear that each of these stages requires its own approach. It is also evident that this development has a risk of becoming locked in: once a polder has been created, natural processes of tidal flooding and sedimentation are blocked. Although this has created favourable conditions on the short term, a continuous rising sea level will probably lead to the need for higher embankments. Compaction will lower polder levels and tidal creeks will be silted up, increasing drainage congestion. A key question for BDP2100 therefore is how to cope with this seemingly inevitable pathway. Is there an adaptation strategy available?

A *long term vision* for the coast needs to be rooted in the official goal of the GoB for the coast. This goal is formulated in the Coastal Zone Policy and reads: *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.* A vision, then, could be described as i) an idealized future state of the coast, and ii) a set of principles and mechanisms through which this future state can be realized. Such principles and mechanisms are listed in the Baseline study. Importantly, not only the longer term is considered, but also more immediate measures and interventions are highlighted. This includes the recommendation to revitalise the Meghna Estuary Development Plan, up scaling of TRM and specific attention for drainage improvements and water storage measures.

Based on the analysis and identified (no regret) measures, a number of concrete plans and projects can be formulated as input to the 7th Five Year Plan. These are all in line with the general strategy described earlier and are ready to be implemented in the next five years: *CSDP V, Cross dam Urir char for land reclamation (Design is ready); Barisal Irrigation Project; Deep sea port at Sonadia Island; Payra Bandar at Patuakhali; Navigability Improvement of Mongla Port; TRM up scaling and monitoring (BD Water Board plan); Tidal energy feasibility study; Noakhali drainage improvement; Bhairab river basin development (detailed feasibility study already done); Detailed investigation of reservoir/dam in small river for water storage; Detailed study on development of an integrated and holistic plan for TRM in the whole southwest region including the existing discrete plans; Development of Water Management Infrastructure in Bhola Island; Coastal Embankment Improvement Project Phase-I; and Development of freshwater reservoir between Hatia and Nijhum Dwip.*

The Meghna Estuary is a very dynamic estuarine and coastal system. Updated data and knowledge are essential for planning and implementation of land reclamation program. In order to do that a number of knowledge gaps have been identified, pertaining to a better understanding of the physical behaviour of the estuary, including the impact of a possible reduction of sediment load due to upstream developments. Other knowledge gaps in the coastal zone include the projection and long term impacts of relative Sea Level Rise on coastal morphology, sedimentation and erosion and the long term effects of bio-physical, economic and socio-political drivers on Water Resources, Polder Management, Aquaculture, Agriculture Land Reclamation, potential of renewable energy and marine fisheries. There is also a knowledge gap on safe yield of groundwater and salinity intrusion.

1. Introduction

1.1. Background

Coastal polders and coastal zone management is one of the 19 Thematic Studies of the Bangladesh Delta Plan 2100. Thematic studies (TS) play an important role in the project. They provide the knowledge backbone of the Delta Plan. The present baseline study focuses on delta problems as well as problems in the coastal polders, describes existing knowledge and practices and identifies knowledge gaps.

The coastal zone of Bangladesh is a disaster prone area. Cyclones, storm surges, droughts, floods, water-logging and salinity intrusion cause huge damage to people, animals, crops, fishery, vegetation. Poor communication, lack of education and health care facilities, prolonged absence of safe drinking water, insufficient cyclone shelters contribute and multiply the dimension of vulnerability and make embankments, roads, culverts, bridges, homesteads, and other communication infrastructures hazardous. Although the coastal zone is plagued with multiple problems and constraints, it has also a tremendous potential to create opportunities – such as improved agriculture, marine fishery, exploration of gas and oil resources, ship building industry, eco-tourism and renewable energy.

Increasing population pressure, competition for limited resources, natural and man-made hazards, lack of economic opportunities, important ecological hot spots, all call for a distinctive coastal development plan.

1.2. Objectives and deliverables

- To evaluate existing problems, developments and (government) plans in view of the long term (socioeconomic and climate) changes
- To facilitate the identification of challenges and opportunities for the BDP2100 (also priority ranking). Translate towards building blocks for Delta Vision and development, as well as 7th 5-year plan.
- To identify (additional) (no-regret) measures and strategies
- To support joint fact-finding (contributing to trust and project ownership)
- To create a common knowledge base
- To identify knowledge gaps and research needs
- To identify projects for implementation

Deliverables

- Fact sheets for coastal polders, climate features, key drivers and bottlenecks, existing and planned projects, and potential measures and possible strategies to overcome the identified bottlenecks;
- Maps and/or figures on salinity intrusion water availability at present and climate change impact on salinity intrusion, land reclamation potentials, port development
- GIS layers as input to the Delta Ateliers/Hot Spot analysis
- Model results, data, input to information portal;
- Draft and Final Baseline Study Reports

1.3. Approach and Methodology

The Baseline Study is mainly a desk study based on existing documents, knowledge and information from resource persons. A rough indication of tipping points will be prepared which give insight in future problems and extent of the problem. The analysis confronts the existing strategies and policies described in Chapter 3 with long term challenges and drivers presented in Chapter 4. For instance tipping points could be prepared for various land use activities or crops related to salinity. The proposed tipping points were discussed in workshops and Delta ateliers to get feedback from stakeholders.

2. Coastal Bangladesh – a brief description

2.1. Geography and environment

The landward boundary of the Bangladesh coastal zone is defined by three hydrological indicators: tidal influence, salinity intrusion and the influence of cyclones and storm surges. The exclusive economic zone (EEZ) is regarded as the seaward coastal zone. The coastal land zone extends over 32% of the country and includes 147 Upazillas under 19 districts with 26% population of entire country (Figure 1; Table 1). It covers an area of 47,150 sq. km with a population of 38.5 million (BBS 2011) resulting in an average population density of 817 persons per sq. km.

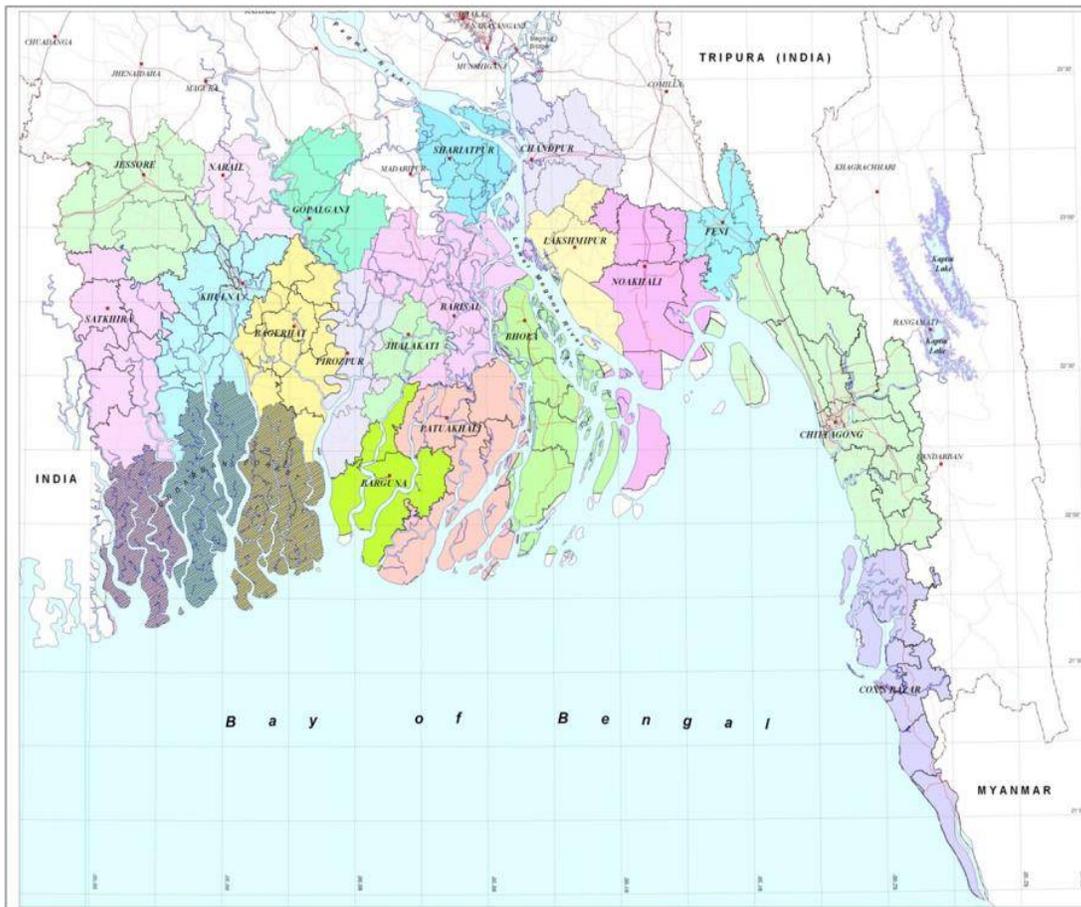


Figure 1: Map of the coastal zone of Bangladesh (Source: WARPO)

The delineation of coastal zone is based on salinity, cyclonic storm surge and tidal amplitude. Because of the diversity of conditions across the coastal zone, it is useful to subdivide it into four areas, each of which has a distinct typical set of conditions and problems (Figure 3; BWDB 2000, Brammer 2014):

- South West (Ganges Tidal Floodplain – West)
- South Central (Ganges Tidal Floodplain – East)
- South East (Young Meghna Estuarine Floodplain)
- East and Hill (Chittagong Coastal Plains)

The coastal area is one of the most dynamic areas in Bangladesh. The vast inflow of sediments from the Ganges, Brahmaputra and Meghna are subject to coastal dynamic processes generated by tides, waves and currents that lead to accretion and erosion. Tidal amplitude ranges from approximately 1.5 m in the west to over 4 m in the east (up to 8 m at spring tide near Sandwip). In the western part one of the world's largest mangrove forests, the Sundarbans, is situated.

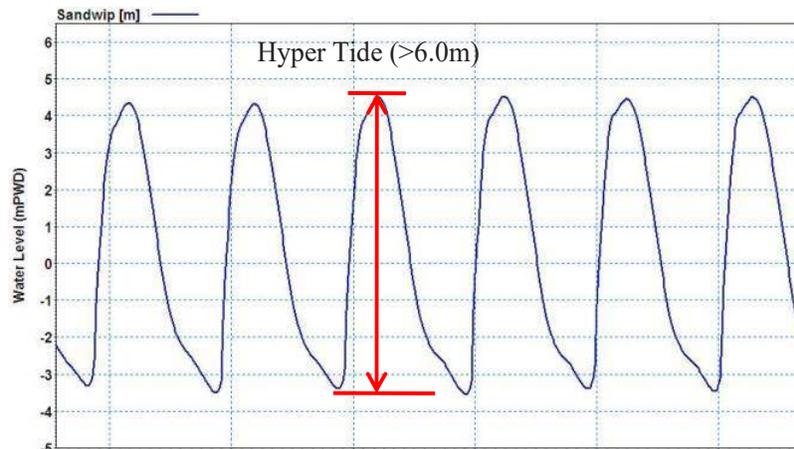


Figure 2: Tidal range at Sandwip island

It is useful to distinguish between the four areas in terms of the dominant and subsidiary physical and morphological processes and problems in each of them.

Ganges Tidal Plain West (GTPW)

This part of coastal area has the Sundarbans forest covering the first 60 to 80 km inland from the coastline, which provides the hinterland to the north with a considerable degree of protection from cyclonic surges. This area is characterized as moribund delta formation, the area has long drainage routes of low gradient and very little fresh water flow from the parent river (the Ganges). Tidal flows extend far inland, and many polders have been constructed, some of them 150 km from the coast. The dominant problem is therefore restricted drainage, and navigation is also severely affected. The area is also attributed with the transverse depressions (sometimes called *beels*) running roughly parallel to the coast: these are especially difficult to drain for agriculture but can offer other possibilities, like use for tidal basin for tidal river management for restoring the drainage conditions by increasing the tidal prism. River floods are not a major problem, since the catchments of the rivers passing through this area are relatively small and flat but the area has been experiencing severe water-logging.

Ganges Tidal Plain East (GTPE)

This area is characterized by a younger stage of estuary development, the land being intersected by a number of rivers receiving water from the Lower Meghna river, and from the Padma river via the Arial Khan river. There is no substantial forest area, and polders extend about 60 km inland from the coastline. Those facing the sea are subject to erosive attack in some places, and elsewhere thalweg migration of the rivers is eroding some polder embankments. Siltation of some rivers is causing navigation problems. River floods are not a major problem in this area, most of which is primarily subject to tidal effects. This zone is vulnerable to cyclonic storm surges and eventual damages of infrastructures, agriculture and aquaculture.

Table 1: Overview of the Districts in the Coastal Zone

No.	Districts	Area (km ²)	Population (2011)	Salinity	Tidal fluctuation	Cyclone risk
1	Barguna	1,832	8,92,781	√	√	√
2	Barisal	2,791	23,24,310	√	√	√
3	Bhola	3,403	17,76,795	√	√	√
4	Bagerhat	3,959	14,76,090	√	√	√
5	Chittagong	5,283	76,16,352	√	√	√
6	Chandpur	1,704	24,16,018		√	√
7	Cox's Bazar	2,492	22,89,990	√	√	√
8	Feni	928	14,37,371	√	√	√
9	Gopalganj	1,490	11,72,415	√	√	
10	Jessore	2,567	27,64,547	√	√	
11	Jhalokati	758	6,82,669	√	√	√
12	Khulna	4,395	23,18,527	√	√	√
13	Lakshmipur	1,458	17,29,188	√	√	√
14	Narail	990	7,21,668	√	√	
15	Noakhali	3,601	31,08,083	√	√	√
16	Patuakhali	3,205	15,35,854	√	√	√
17	Pirojpur	1,308	11,13,257	√	√	√
18	Satkhira	3,858	19,85,959	√	√	√
19	Shariatpur	1,181	11,55,824		√	
CZ total		47,203	38517698			
Bangladesh		147,570	14,97,72,364			
CZ (%)		32	26			

Source: BBS, PDO-ICZM

Meghna Deltaic Plain (MDP)

The area is morphologically very active and land accretion is higher than erosion. Most of the islands are vulnerable to cyclone storm surges and erosion. New land is being formed at a rate faster than the erosion of older land in this area. The newly accreted areas are initially too low and vulnerable for human settlement and agricultural use. Population pressure and urgent need for land is, nevertheless, leading people to settle on these recent deposits, and sometimes people demands to empolder them before the natural deposition process has built them high enough for adequate drainage.

The north-east and east sides of Bhola island, north and west sides of Hatia, west side of Manpura, and west side of Sandwip islands have been experiencing severe erosion. This erosion is mostly caused by thalweg migration in the lower Meghna and its branches, namely the Shahbazpur and Hatia channels.

Some of the mainland areas on the east of the Meghna estuary such as Ramgati and Carring char are also subject to erosion due to thalweg migration which is undermining and outflanking polder embankments on the left bank of the Meghna and on both the right and left banks of the Feni river. Some areas are also increasingly subject to prolong water-logging due to encroachment and land reclamation by closing the tidal channels. River floods are severe in some parts of the mainland near the Meghna estuary, especially in the districts of Chandpur, Lakshmipur, Noakhali and Feni.

Chittagong Coastal Plain (CCP)

This area along the eastern side of the Bay of Bengal is directly exposed to the Bay and vulnerable to cyclone and storm surges. A problem that is not seen in the other three areas is flash floods from the hills immediately to the east: the steep gradients, and the usual tendency of hills to generate intense rainfall, produce rapid increases in discharge which the rivers and other drainage channels across the flat coastal plain cannot convey safely. Several rivers exhibit extensive meandering in the coastal plain.

Bangladesh Water Development Board (BWDB) built 139 polders in the coastal area of Bangladesh in the early sixties and seventies to protect low lying area from salinity intrusion and flooding for growing more food. The Coastal Embankment Project (CEP) in the 1960-1970 has been the largest physical intervention in the coastal area of Bangladesh. Coastal polders enabled to bring 1.2 million hectares of land under agriculture or aquaculture and provided protection of lives and properties of coastal communities against flood, storm surge and salinity intrusion. However, there have been unintended consequences such as river sedimentation and water-logging that has become increasingly problematic in the last three decades in certain parts of the coastal area.

The name of the coastal districts under different morphological zone is presented in **Table 2**.

Table 2: Morphological zone wise coastal districts

Morphological Zone	Coastal Districts
Ganges Tidal Plain (West)	Jessore
	Satkhira
	Narail
	Khulna
	Bagerhat
	Pirojpur (West part)
Ganges Tidal Plain (East)	Gopalganj
	Pirojpur (East part)
	Jhalikati
	Barisal
	Barguna
	Patuakhali (West part)
	Sharitpur
Meghna Deltaic Zone	Patuakhali (East part)
	Chandpur
	Lakshmipur
	Bhola
	Noakhali
	Feni
	Chittagong (Sanwip island)
Eastern Hill Region	Chittagong
	Cox's Bazar

2.2. Coastal ecosystems

The coastal area is very rich in flora and fauna and thus very important for biodiversity on the national and even international level. The most important features of the coastal area are the wetlands, including marine mudflats and mangroves, and also fresh water creeks and ponds.

There are a number of declared or proposed protected areas in the coastal zone. In addition, the National Water Management Plan has listed a few environmentally valuable and sensitive areas in the coastal zone.

The world's largest uninterrupted stretch of mangrove ecosystem, the Sundarbans, has been declared World heritage site in 1997, whereas coral ecosystems are found around St. Martin Island. These ecosystems are not only biodiversity hotspots, but they also provide the ecological foundation for an important common property resource.

In the south-eastern parts of the country in Chakoria and Teknaf (Naf estuary), a very significant share of the mangrove forests have been destroyed, mainly because of the expansion of shrimp and salt production.

New mangrove forest is being established on the newly accreted land naturally or through planting. The Forest Department reports that over 100,000 ha has been planted since the 1960s, but the actual area of successful plantations is clearly less than this. The islands Kukri-Mukri and Njihum Dwip in the Meghna estuary have been identified as environmentally the most valuable of these new mangrove areas. Plants growing on the deposited sediments of the delta play an important role in its morphology. They help to stabilise the soil (both by the binding effect of their roots and by the organic matter they contribute), and they dissipate some of the energy of the water currents and waves which cause erosion. Because of the fine soils, and the tropical climate with high rainfall, both natural and human-introduced plant growth is strong and relatively quick to establish itself.

The Bay of Bengal is rich with coastal and marine ecosystems such as fishes, shrimps, mollusks, crabs, mammals, seaweeds as shown in **Table 3**. The important fish families are Sciaenidae, Ariidae, Nemipteridae, Carangidae, Mullidae, Synodontidae, Trichiuridae, Leiognathidae, Pomadasysidae and Clupeidae. These ten families make up about 47% of the total biomass (Lamboeuf 1987), Croakers (Sciaenidae) and catfishes (Ariidae) being the dominant groups, each with around 12%.

Table 3: Coastal and marine fisheries resources of Bangladesh

Category	Number of species (reviewed by)		
	Hossain 2001	Islam 2003	Ahmed <i>et al.</i> 2012
Bony fish	475	475	442
Cartilaginous (soft-boned) fish	50	–	–
Shrimp	25	24	56 ^a
Crab	15	50	16
Lobster	5	–	3
Mollusc (Oyster)	301 (6)	301 (3)	336
Algae/Seaweed	56 ^b	20-22 ^c	168
Coral	13	–	66
Starfish/Echinoderms	3	–	4
Whale/Dolphin	11	–	–
Squids (Cuttlefish)	–	7 (2)	–

Source: (Hossain et al 2014)

2.3. Problems and challenges

Previous description of the coastal zone and its distinct areas provides the background for the problem analysis in this section.

2.3.1. Waterlogging

Waterlogging is a problem over large parts of the coast, especially in the southwest (Satkhira, Jessore, Khulna and Bagerhat) and south east (Noakhali, Feni) coastal zones. The reason of this problem is complex as will be discussed below. **Figure 4** shows the polders facing waterlogging problems.

The southwest region of Bangladesh is characterized by numerous morphologically active tidal rivers, which are the main drainage network for coastal polders and low lying beels. Thus, the natural drainage pattern of the area is predominantly characterized by the influence of the incoming tide from the sea. Tidal flow brings huge quantity of silt from the sea into the river systems of the coastal area. Before polderisation in early sixties and seventies, major parts of this incoming silt deposited naturally on the low-lying land (beels). On the other hand, there was significant amount of fresh water flow from the Ganges which helped to maintain a perennial tidal river in this part of Bangladesh. The continued fresh water flow from the Ganges helped to flush the incoming sediment with high tide from the sea and thus, the proper drainage capacity of these tidal creeks was maintained naturally. After polderisation and significant reduction of fresh water flow from the Ganges, these natural processes have been hindered significantly. The presence of coastal polders prevents the spreading of the natural tidal flows and restricts sedimentation on the low lying lands. This leads to large scale river bed sedimentation in the peripheral rivers of polders and reduced the tidal prism. Reduction of tidal volume or tidal prism of the surrounding rivers due to confinement of the flow within the river territory due to construction of embankment along the bank of peripheral rivers caused decrease of drainage capacity or conveyance of the rivers, which implies these rivers have been adjusting with the changing tidal prism.

Also the reduction of dry season flow in the downstream of Ganges and its distributaries due to withdrawal of water upstream by operation of Farrakka barrage contributed to increased sedimentation in the distributaries tidal rivers. This reduction of fresh water had increased the salinity concentration which proportionately increased sediment concentration and simultaneously silt deposition in the peripheral rivers during tidal movement.

This continuous siltation process over the years resulted rise of river bed level and thereby reduction of the conveyance capacity of the peripheral rivers of the coastal polders significantly leading to large scale water logging problems inside the polders particularly in the Satkhira, Jessore, Khulna and Bagerhat districts. As a result, many polders are suffering from water logging and drainage congestion for quite long periods and that in turn caused large scale environmental, social and economic degradation. The Upazila of Jessore Sadar, Manirampur, Abhaynagar, Keshabpur of Jessore district and Dumuria, Fultala, Batiaghata and Daulatpur of Khulna District were under long standing water logging problems. To solve this long-standing water-logging problem in the above area, the well-known Khulna-Jessore Drainage Rehabilitation Project (KJDRP) was implemented by Bangladesh Water Development Board during 1994-2002. Currently the polders 1-2,6-8, 34/2 and 36 under Satkhira, Khulna and Bagerhat districts are experiencing long standing water-logging.

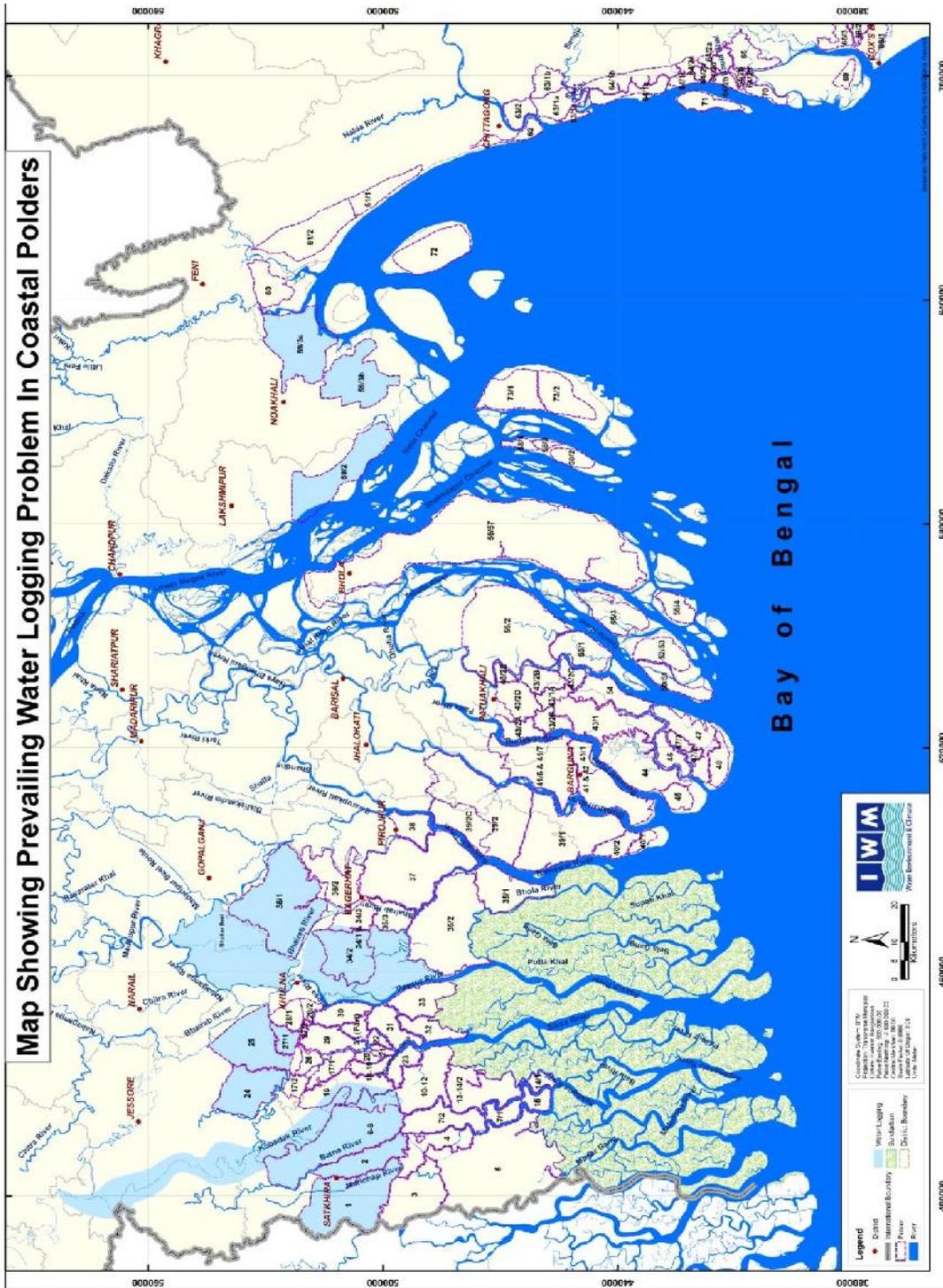


Figure 4: Map showing prevailing water logging in the coastal polders

2.3.2. Cyclonic storm surges

Bangladesh is a global hotspot for tropical cyclones, which hit the country's coastal regions in the early summer i.e. during April–May or late rainy season from October–November. A tropical cyclone is a low-pressure system which develops in the tropics and is sufficiently intense to produce sustained gale force winds of at least 63 km/h. If the sustained wind reaches hurricane force of at least 118 km/h the system is defined as a severe tropical cyclone. Tropical cyclones can cause significant phenomena which can adversely impact on communities and the environment. The most common features are destructive winds, heavy rainfall and cyclone induced storm surges that can lead to flooding. The Bay of Bengal is one of the hotspots for the generation of tropical cyclones. About one-tenth of the global numbers of cyclones that form in different regions of the tropics occur in the Bay of Bengal (Gray, 1968; Ali, 1980). Most of the cyclones hit the coasts of Bangladesh with a north-eastward approaching angle. In recent years cyclones Aila and Sidr hit the south western coastal zone, which implies that the whole coastal area is vulnerable to cyclones and storm surges. During the period 1960-2009, 19 severe cyclones have hit the coast of Bangladesh as shown in **Figure 5**.

The high risk of the coastal area to a cyclonic storm disaster is caused by a combination of great hazard, exposure and a vulnerable coastal population. The continental shelf is long and shallow and the shape of the coast tends to concentrate and amplify the surge in the northern part of the Bay. The coastal zone is highly exposed because it is low-lying; 62% of the land has an elevation of up to 3 metres and 86% up to 5 metres from mean sea level. On this exposed land live more than 800 people per sq. km, many of them without physical protection.

In November 1970, the most severe cyclone in the century, with respect to surge height, inundation and loss of life occurred. The cyclone produced a surge height of up to 10 meters, which hit the coast at high spring tide, causing inundation of nearly every low lying coastal area in Bangladesh. The loss of life was estimated to 300,000-500,000 (SMRC, 1998). In April 1991, a cyclone produced a surge height of more than 6 meters along a coastal stretch of 240 km in Bangladesh, inundating large coastal areas and offshore islands (SMRC, 1998). Especially since the deadly cyclone of 1991 (with nearly 5 million people affected and over 130,000 people dead) a large scale program of cyclone shelters was launched (Choudhury et al., 1993).

Cyclone Sidr (November 2007) and Cyclone Aila (May 2009) provide recent examples of devastating storm-surge in Bangladesh. In 2007, Cyclone Sidr, a 10-year return period cyclone with an average wind speed of 223 km per hour resulted in 4,234 casualties and 55,282 injuries (EMDAT –CRED). Livelihoods of 8.9 million people were affected and damages and losses from Cyclone Sidr total led US\$1.67 billion (GoB 2008). In 2009, Cyclone Aila, a 1.2 year return period cyclone with an average wind speed of 95 km per hour caused 190 deaths, 7,103 injuries and affected 3.9 million people. The estimated damage of assets from Aila is US\$270 million (EMDAT -CRED).

More than 2000 cyclone shelters were built and an extensive network of radio communication contributes in cyclone preparedness of coastal communities (GoB, 2006). This has greatly contributed to a reduction in casualties due to cyclones. Disaster management has greatly improved over the past decades [see Theme Disaster Management].

Current flood standards are low. CEIP standards take into account 25 years return period for storm surge, wave incidence and monsoon floods.

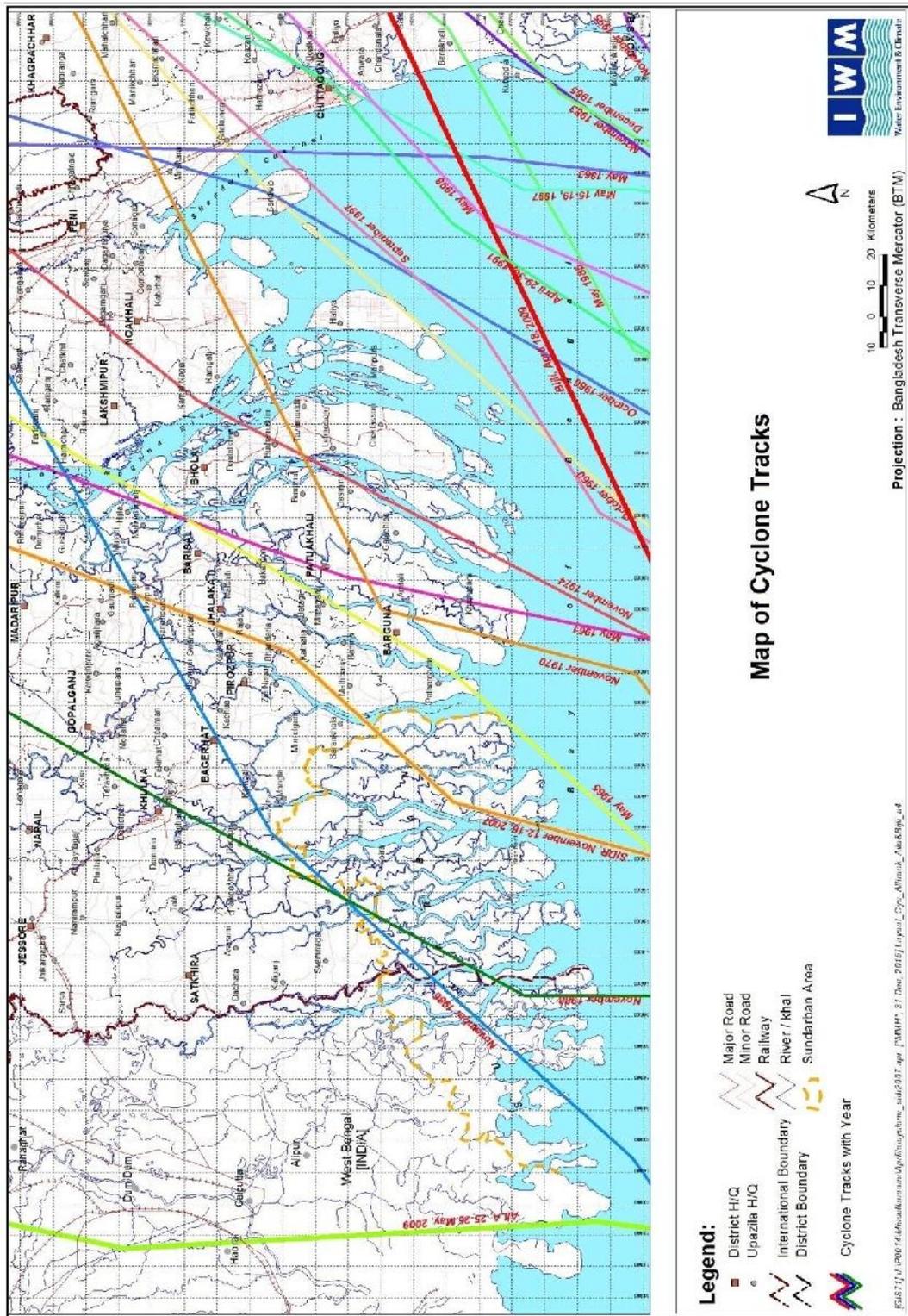


Figure 5: Tracks of major cyclones affected Bangladeshi coast during the period 1960-2009

2.3.3. Salinity intrusion

River water salinity in coastal Bangladesh depends on the volume of freshwater discharges from the upstream river systems, the salinity of the Bay of Bengal near the coast, and the circulation pattern of the coastal waters induced by the ocean currents and the tidal propagation to the river systems. A reduction in freshwater inflows from the trans-boundary Ganges River, siltation of the tributaries of the Ganges, and siltation of other rivers following the construction of the polder system has resulted in a significant increase in river salinity in coastal Bangladesh during the dry season. Average salinity concentrations of the rivers in the coastal area are higher in the dry season than in the monsoon because of lack of freshwater flow from upstream. Salinity level generally increases almost linearly from October to late May with the gradual reduction in the freshwater flow from the upstream. Observation of salinity shows an increase of salinity at Khulna from 0.7ppt to 16.8 ppt in the Rupsa River from 1962 to 2011. The variation of salinity over the years at Khulna is shown as function of upstream flow and presented in the **Figure 6**.

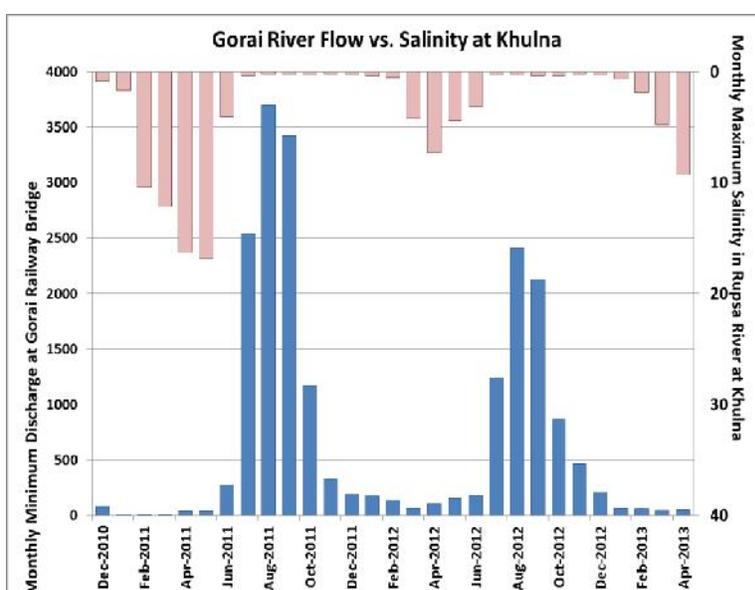


Figure 6: Monthly Salinity variation with upstream freshwater flow (source: IWM)

The maximum river salinity from field measurements during the dry season i.e. from October 2010 to May 2011 is shown in **Table 4**.

Table 4: Maximum river salinity of coastal area during dry season

Location	River	Maximum measured Salinity (ppt)
Amtali	Buriswar	0.9
Badurgasa	Darunmollik	22.9
Bamni/ Char Elahi	Meghna	19.8
Bardia/ Nabaganga	Noboganga	9.8
Bashantapur	Isamoti	22.6
Bishkhali DS	Bishkhali River	11
Burhanuddin	Tetulia	3.5
Chapailghat	Modhumati	5.3

Location	River	Maximum measured Salinity (ppt)
Chandpur	Lower Meghna	0.1
Char Doani	Baleswar	8.5
Daulatkhan	Lower Meghna	6
Gangrail	Shundor mohol	23.2
Habour Khali	Darunmollik Miesha Ghat	9.9
Haridashpur	Madaripur Beel Route	2.1
Hilsha	Ganeshpura	4.6
Hiron Point	Pusure	27.3
Kaikhali	Modan Gauga	28.2
Khepupara Kolapara	Adhanmanik	19.8
Khulna	Rupsha	16.8
Kobadak	Kobadak	27.3
Madaripur	Arialkha	0.2
Madhupara	Andharmanik	13.9
Mohipur	Shibbaria Khal	22.8
Muju Chowdhury Hat	Lower Meghna	1.5
Mongla	Pusure	20.7
Musapur	Little Feni	21.2
Nalian	Shibsha	23.4
Patgati	Modhumati	3.9
Pirojpur	Baleswar	0.6
Ramgati Jarirdona Regulator	Lower Meghna	12.7
Shalta	Thanibuina	20.3
Sharankhola	Vola	5.3
Swarupkathi	Swarupkathi	0.2

Source: IWM 2013

The water from the Ganges River flows through the Gorai River, which is the only major source of freshwater to the southwest zone. The offtake of the Gorai almost remains dry during the dry season (December to May) if it is not restored by dredging. The salinity level at the Bay of Bengal during the dry season is also comparatively high; and saline water intrudes through the major rivers, namely the Baleswar, Jamuna, lower Meghna, Malancha, Pussur, Sibsa, and Tentulia, through tidal effects. The land topography of the region is very flat; strong tidal effects at times travel up to 200km upstream of the coast. Consequently, the region is severely affected by salinity intrusion. Spatial variation of river salinity within the southwest region, however, depends on tidal amplitude, the extent of landward penetration of tides, and the volume of freshwater flow from the upstream rivers. **Figure 7** presents the spatial variation of the maximum river salinity level during 2011–2012 in the southwest zone.

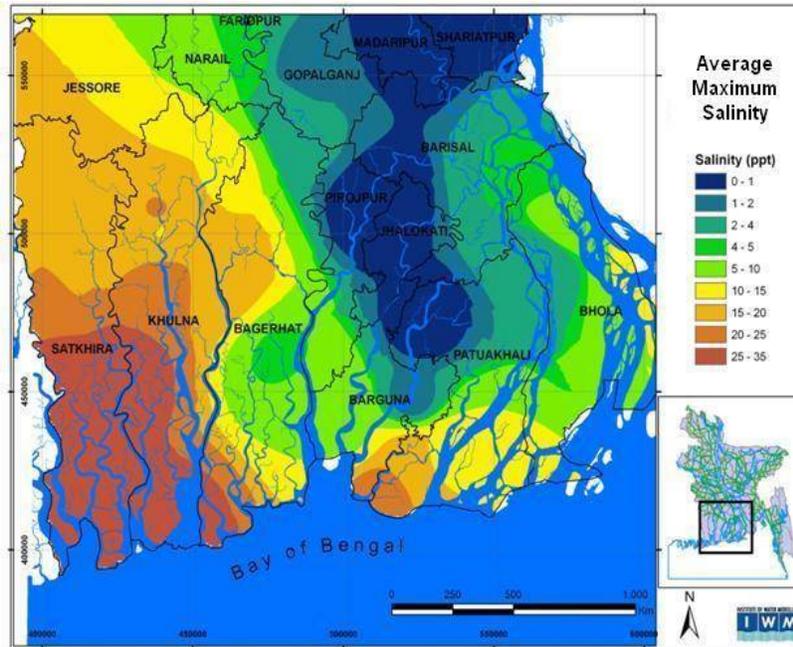


Figure 7: Map of Average Maximum River Salinity in the Southwest Region of Bangladesh

However, the levels of river salinity in the adjacent south-central and south east coastal zones remain low. The low salinity (0 to 2ppt) level in the south-central zone in the much of the Barisal area over the whole year is due to the significant volume of freshwater flow from the Padma River and the Lower Meghna River through the Arialkhan, Buriswar, and Bishkhali Rivers. The Feni, Little Feni, and Bamni Rivers in the southeast region are controlled by regulators at the outfalls to prevent landward movement of saline water during high tides.

In the eastern-hill zone, the water in the Bay along the Chittagong to Cox’s Bazar is always saline. Water is also saline in the downstream stretches of the Karnaphuli and Sangu Rivers throughout the wet season; and, with the onset of the dry season. Salinity is very less in the upstream stretches depending of upstream freshwater flow. The water in the Sandwip Channel is saline since the tidal flow is quite significant compared to upstream freshwater flow from the rivers. The flow from the Naf River is not adequate to reduce the level of salinity at Teknaf.

The problem of river salinity is most severe in the southwest zone. The water resource system of the southwest zone has degraded considerably over time, primarily because of the reduction in freshwater inflows from the Ganges due to withdrawal of fresh water at Farakka.. Of special relevance are the problems that arise at the bifurcation between Ganges and Gorai River. During the dry period the Gorai inflow is severely decreased, creating problems of downstream freshwater availability. Salinity intrusion reduces the freshwater area that results in decrease of agricultural production in many parts of the coastal zone, especially the Khulna region and the extreme south of the Patuakhali region, and locally in the Noakhali and Chittagong regions. Increase of salinity is damaging the freshwater fish habitat and has adverse impact on the Sundarban ecosystems.

Although the Ganges Coastal Zone is besieged with multiple problems and constraints it has tremendous potential to create innumerable opportunities for agricultural and aquacultural production through improved use of available water resources. River salinity in the Tentulia, Bishkhali, Buriswar and upstream stretch of Baleswar rivers (i.e., most of Barisal Division) was found to be very low throughout the year. The availability of water (high river flows) is high; simulation results show that the minimum flow in the Payra River (the peripheral river of polder 43/2F) during the dry season is 5400m³/s (Z.H. Khan 2015). Irrigation can also be practiced during the dry season

by filling the canals at high tide using gravity, storing the water in the canal systems and pumping from the canal systems using low lift pumps (Z.H. Khan 2015).

Soil salinity

Soil salinity has also increased over the years in the coastal area. The observed data shows and increase of soil salinity over the years in the southwest zone.

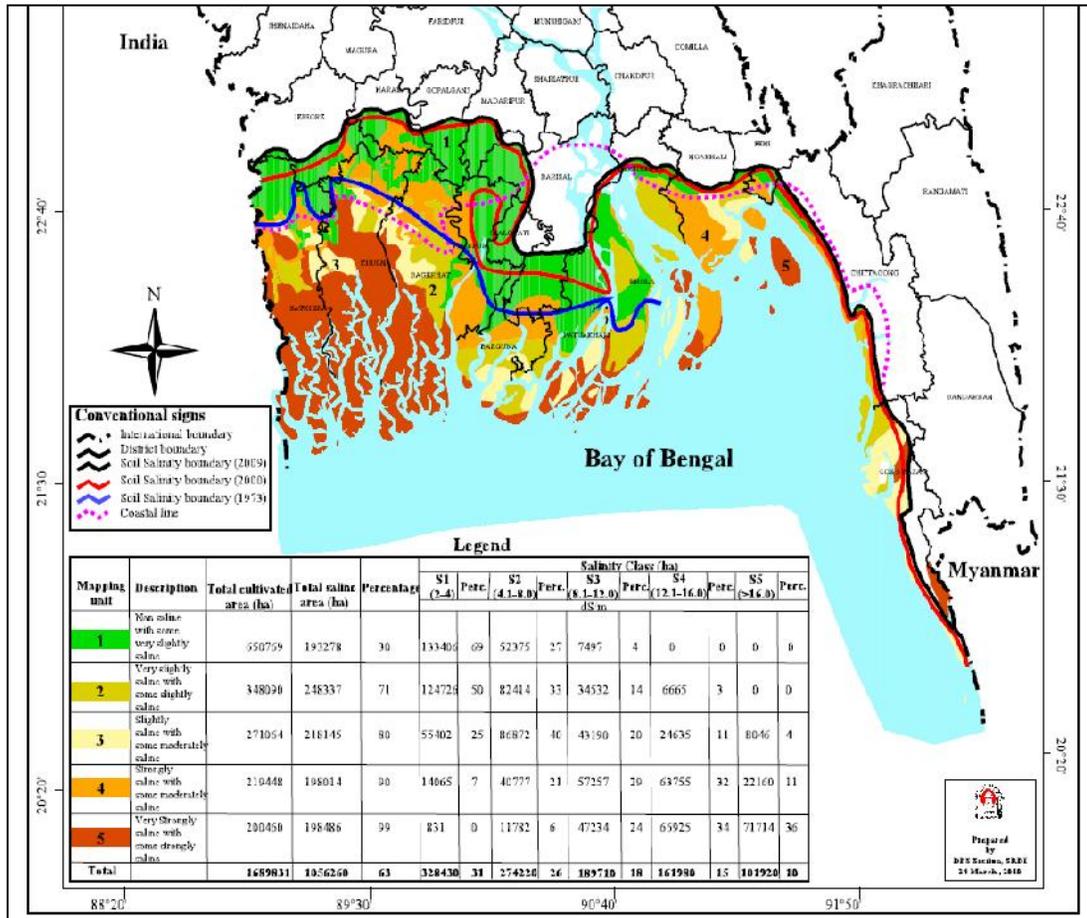


Figure 8: Movement of soil salinity front

Source SRDI

SRDI assessed the spatial distribution of soil salinity in 2009 through ground survey following reconnaissance soil survey technique using different base materials such as aerial photographs, topo sheets, Upazila Soil and Landform Maps, and published soil salinity maps. In **Figure 8** Soil salinity map of SRDI, 2010 shows soil salinity with different degree of salinity. The survey shows that about 0.328, 0.275, 0.189, 0.161 and 0.101 million hectares of land are affected by very slight (S1), slight (S2), moderate (S3), strong (S4), and very strong (S5) salinity respectively (Delta Plan Baseline Study: Land Resources Management). Some of the new lands in Satkhira, Patuakhali, Borguna, Barisal, Jhallakathi, Pirajpur, Jessore, Narail, Gopalganj, and Madaripur districts have been affected significantly by different degrees of soil salinity during the last four decades.

The change of the soil salinity over the decades (1973-2009) based on SRDI results in the coastal areas is presented in **Table 6** and **Table 6**.

Table 5: Increase of soil salinity affected area over the years (1973-2009)

Year	Salinity class and area (000'ha)				Total Salt affected area
	S1 2.0-4.0 dS/m	S2 4.1-8.0 dS/m	S3 8.1-16.0 dS/m	S4 >16.0 dS/ m	
1973	287.37	426.43	79.75	39.90	833.45
2000	289.76	307.20	336.58	87.14	1020.68
2009	328.43	274.22	351.69	101.92	1056.26

$S_3 = 8.1-12.0$, $S_4 = 12.1-16.0$ dS/m; Source: SRDI, BDP2100 Baseline Study Land resources management

It is seen that the salt affected area between 1973 and 2009 has been increased about 26.7% with different degrees of salinity.

Table 6: Increase of the salt affected area between 1973 and 2009 in Bangladesh

Salt affected area (000'ha)			Salt affected area increased during last 9 years (000'ha) (2000-2009)	Salt affected area increased during last 36 years (000'ha) (1973-2009)
1973	2000	2009		
833.45	1020.75	1056.26	35.51 (3.5%)	222.81 (26.7%)

Source: Baseline Study Land resources management, SRDI, SRMAF Project, Ministry of Agriculture, 2010

Monsoon rainfall is generally sufficient to reduce topsoil salinity so that transplanted aman can be grown throughout most of the zone, but crops on the non-embanked coastal fringe can be affected by saline-water incursions during exceptional high tides (Bhuiyan, 2005).

2.3.4. Groundwater Salinity

The coastal belt of Bangladesh has a very complex and highly variable hydrogeology as well as distribution of aquifer sediments in the subsurface. Based on lithologic logs multi-layered aquifers are classified as:

- the upper or shallow (i.e. the 1st) aquifer extends down to 50 to over 100 m from the surface, in many places below a considerably thick surface clay and silty clay unit. The aquifer sediments are composed of gray coloured fine sand with lenses of clay.
- The main or the 2nd aquifer extends down to 250-350 m and is generally underlain and overlain by silty clay bed, and composed mainly of grey fine to very fine sand, occasionally inter-bedded with clay lenses.
- The deep (i.e. the 3rd) aquifer has been encountered to the investigated depths of 300-350m, generally below a clay or silty clay aquitard (IWM, 2014).

The shallow groundwater is generally too saline for domestic or irrigation use due either to connate salts or estuarine flooding. However, sufficient flushing of saline water has taken place in isolated pockets to enable a limited domestic use of fresh water in the shallow aquifer. In the deep aquifer the pattern of salinity distribution is more uniform on a regional basis, as is the continuity of the aquifer. The change from potable water to very saline water is sharp and occurs over a relatively short distance (IWM, 2014).

Several groundwater quality monitoring studies by Bangladesh Water Development Board, 2006, Department of Public Health and Engineering (1999) and the hydro-geological investigation by the British Geological Survey (1999) revealed that groundwater is generally fresh outside the coastal zone. However, 25% of the population was exposed to contamination exceeding Bangladesh standards in 2001 (NWMP, 2001). Coastal salinity and

localized high dissolved iron in the alluvial aquifer was considered the major problem before detection of arsenic in groundwater. Saline groundwater can be found up to 100 km inland (IWM, 2013). Local consumer tolerance to salinity is high however Bangladesh standards do not allow salinity higher than 600mg/l in drinking water (see also Baseline Study Water Supply and Sanitation sections 2.3 and 6.1). Studies demonstrate that most tolerant crops do not grow well when irrigated with water with salinity higher than 2500mg/l. About 14 districts are affected by salinity in the coastal belt with an affected population of about 12 million people in accordance with the study of BWDB, 2013. The saline water intrusion due to well over extraction in Bangladesh is still questioned, however several wells in the coastal but also inland areas have been abandoned due to salinization of the groundwater. There is no sharp boundary between fresh and saline groundwater zones, rather a patchy pattern of fresh and saline groundwater lenses distributed irregularly in areas close to the coast. The sparse distribution of the salinity makes it difficult to say a homogeneous saline front. **Figure 9, Figure 10** and **Figure 11** show Groundwater EC Distribution, Shallow, middle deep Aquifer for dry period Season (BWDB, 2013).

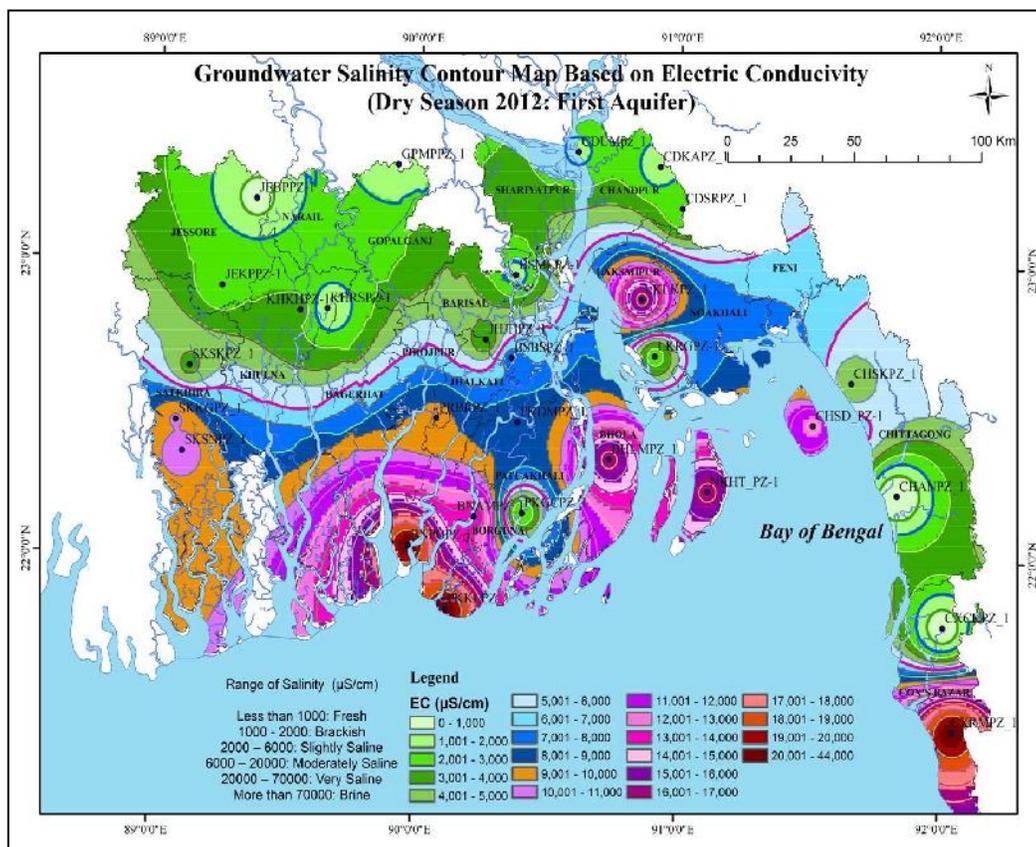


Figure 9: Groundwater Salinity Contour Map Based on EC (Dry Season 2012: First Aquifer)

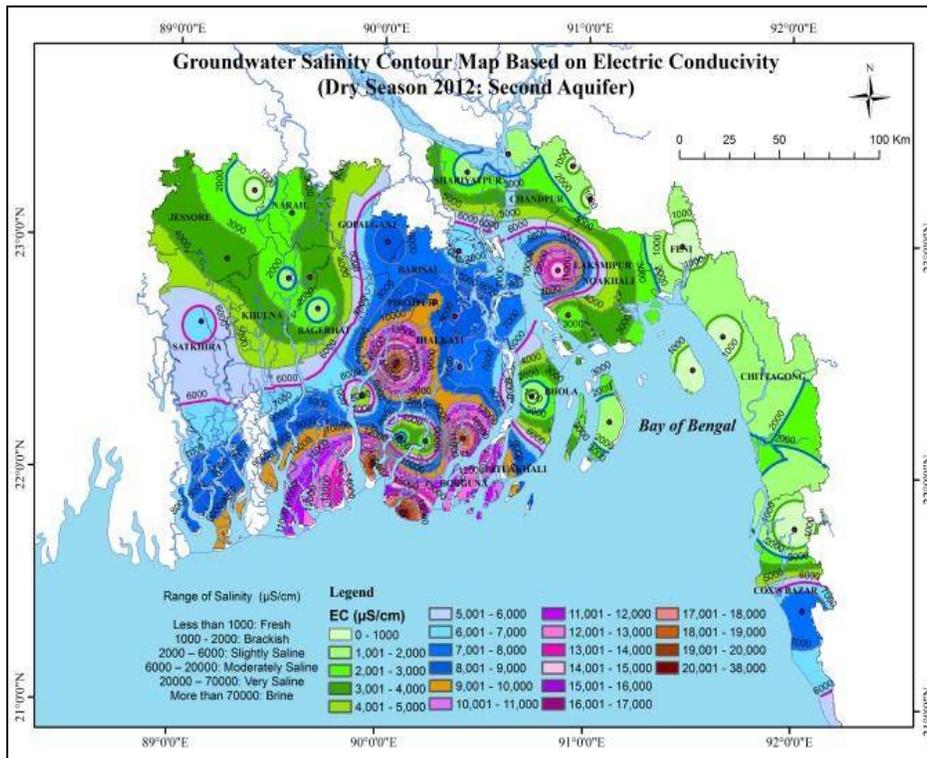


Figure 10: Groundwater Salinity Contour Map Based on EC (Dry Season 2012: Second Aquifer)

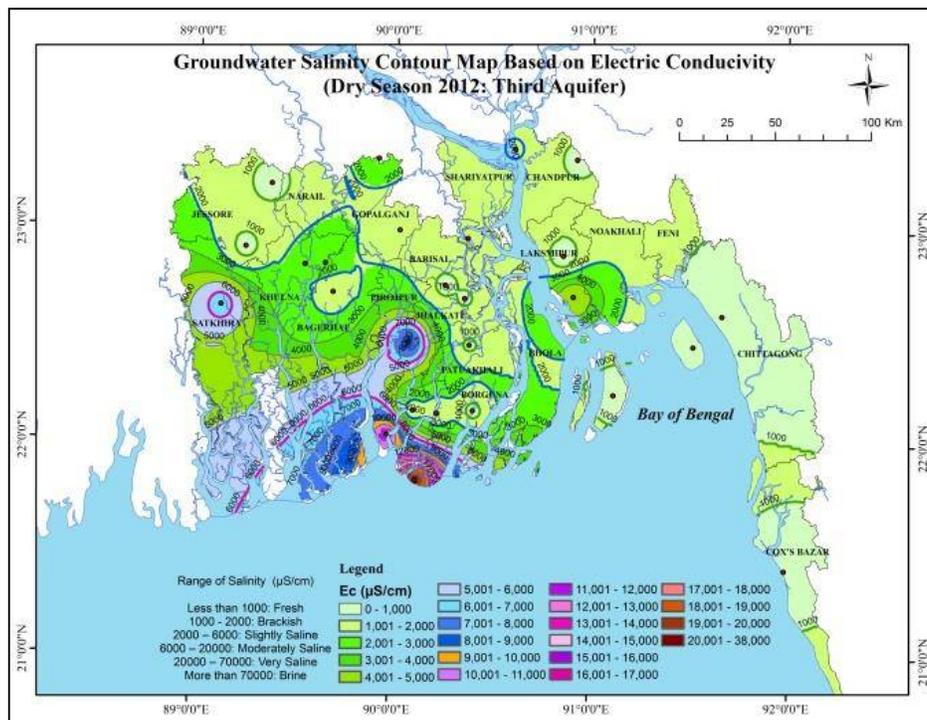


Figure 11: Groundwater Salinity Contour Map Based on EC (Dry Season 2012: Third Aquifer)

2.3.5. Arsenic

Arsenic contamination is now widespread, with between 35 million and 77 million people being at risk of drinking arsenic contaminated water (A. H. Smith et al, 2000). In addition, some (deeper) aquifer systems are characterized by high manganese concentration and increasing trends of chloride are observed, even up to 16000 mg/l (see also Baseline Study Water Supply and Sanitation section 2.3). The occurrence of arsenic is related to younger alluvial aquifers (Holocene age) containing finer sediments. The distribution of arsenic is highly variable both at a local and regional scale. Arsenic contamination above the permissible limit of 50 ppb is found in 61 out of 64 districts (**Figure 12**). Most of the contaminated aquifers are within 20 – 60 m depth (NWMP, 2001). Cost-effective means of arsenic removal have not yet emerged, although many technologies have been tested and developed.

Arsenic contamination is a big problem in accessing to safe water for drinking and cooking purposes. In Bangladesh tube wells in the delta and flood plains area that comprise 72% of the land area are more or less affected by arsenic contamination as referred to National Policy for Arsenic Mitigation, 2004. No special reference was made to address the arsenic problem in the coastal areas. This problem received attention, in general, in NSAPR II (Policy Matrix 16, NSAPR II 2009) in which under the strategic goals – ensuring safe water facilities some arsenic related actions were taken/underway, such as National Policy for Arsenic Mitigation formulated, Plan for Arsenic Mitigation adopted, arsenic testing kits introduced, creating awareness of people on arsenic issues. However, there was a policy agenda for the NSAPR II 2009 in order to develop technological options to replace arsenic contaminated tube wells during FY 2009-FY2011. No mention regarding arsenic problem is found in the Sixth Five year Plan FY2011-2015, Perspective Plan of Bangladesh 2012 and National Sustainable Development Strategy 2013.

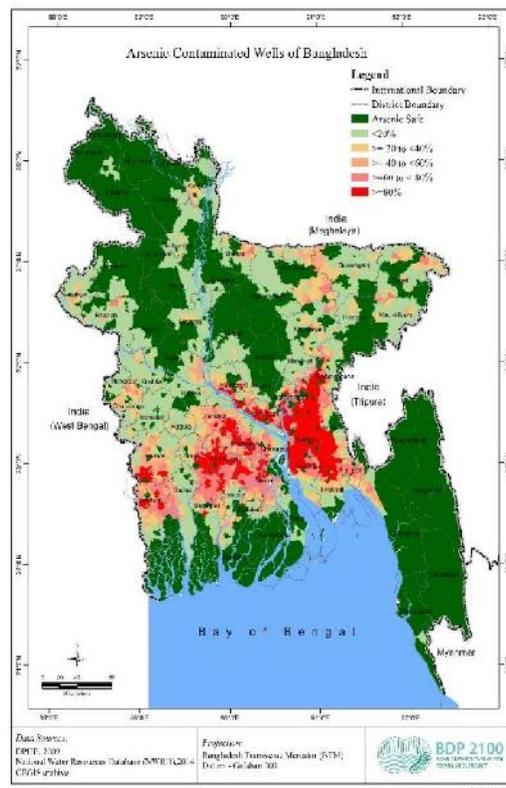


Figure 12: Percentage of Arsenic contaminated wells (CEGIS, from the NWRD, 2014) by CEGIS

2.3.6. Water supply

According to the Coastal Development Strategy, the availability of fresh and safe water is considered as the most critical issue (GoB, 2006). Water supply (domestic and industrial) in the coastal area is low compared to the rest of the country. Upper groundwater aquifers are often saline and fresh water is usually available only at greater depths. Fresh surface water is scarce (see also Baseline Study on Water Supply).

2.3.7. Coastal erosion

The combined inflows of all transboundary rivers is about 1260 km³ (186 km³ in the dry season). The rivers receive further inflows of about 113 km³ (almost all the wet season) from the combined regional runoff (CSIRO, 2014). This huge amount of water transports about a billion tons of sediment every year. The estuary is building towards the south over the last hundreds of years. With the building processes of the estuary the major islands are expanding at south, which is shown in **Figure 13**. Subsequently north part of some islands are eroding.

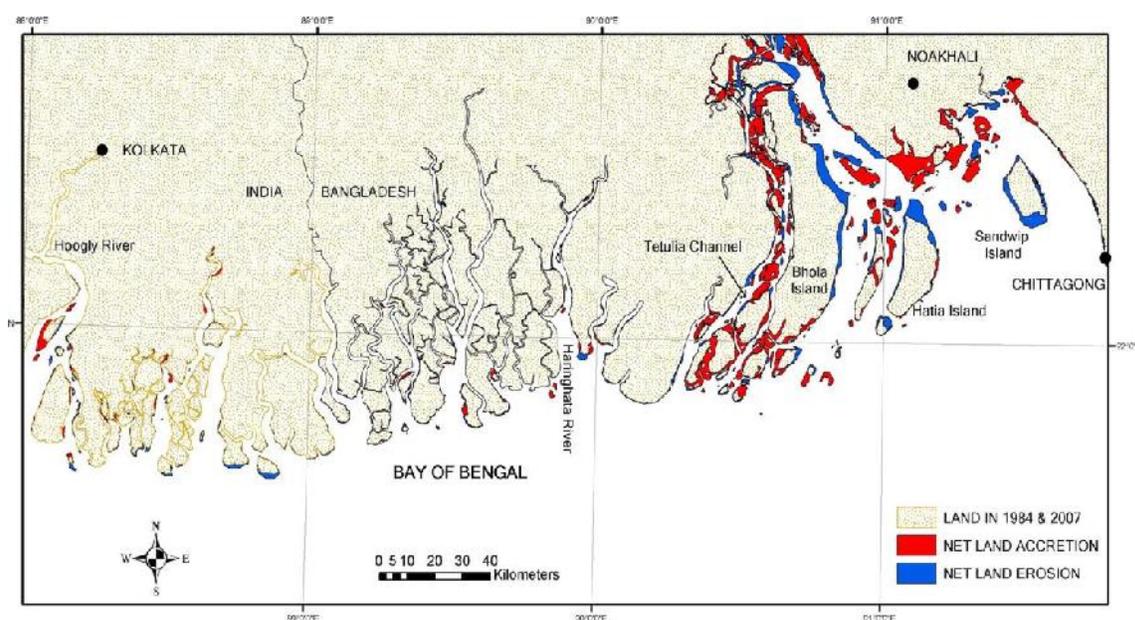


Figure 13: Gains and losses of land between 1984 and 2007 (source: Brammer, 2013)

Average annual growth rate in the Meghna Estuary is in the order of 19 km². Figure 8 shows that, although there was a net gain of land, there were also considerable land losses in the Meghna estuary. For instance, about 40% of Sandwip island in the east was eroded and there were considerable losses in the north of Hatia, north-east of Bhola and the south-west of the former Ramgati island. Beyond the estuary, rates of coastal change are small or undetectable. On the south-western coast there have been small amounts of erosion locally, with amounts generally increasing westward towards the Hooghly estuary in India (Brammer, 2013). Prevention of erosion in the Meghna estuary is difficult due to the highly dynamic nature of the estuary.

The eastern shoreline of Bhola island has been experiencing erosion over a length of 80km and about 5640 ha of land was devoured to the river from 2003 to 2014 (Haskoning, 2014). The productive land is lost due to erosion and that impact on the livelihood of the coastal community. The erosion accretion of Bhola Island is shown in the **Figure 14**.

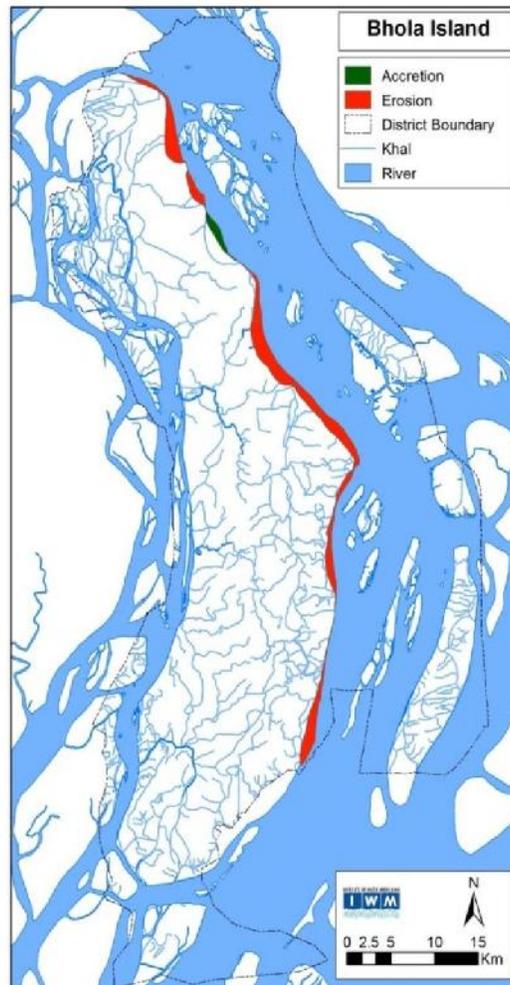


Figure 14: Erosion of Bhola Island

The most common processes of bank failure along the Lower Meghna Estuary is due to shearing, caused by flow attacking the bank or over-steepening of the bank by a thalweg approaching the bank. In that case the flow in a river bend attacks the toe of the riverbank, removing the sediment from the toe, resulting in an over-steepening of the riverbank and causing the bank failure by slumping. An important factor of erosion is the near bank flow pattern, which is determined by the flow and the channel geometry. The lower Meghna river is eroding the left bank along the Ramgati and Kamalnagar Upzilla under Laxmipur district and the erosion rate is in the range of 11-27ha/km/yr over a length of 31km (IWM, 2013).

Conclusion: erosion is a local problem, with high social costs of the victims involved. At the scale of the entire coast there is land accretion, even in a situation with sea level rise (see UNESCO-IHE & IWM, 2014).

2.3.8. Biodiversity resources

The coastal zone has diverse eco-systems, such as mangrove forests, marine and estuary ecosystems, mudflats, coral reef, sandy beaches, sand dunes and has both 'world heritage sites' and 'ecologically critical areas' The extended forest of the Sundarban (and, to a lesser degree, the mangroves of Chakaria in the Cox's Bazar District) not only provide the country's largest supply of wood, but also of a number of other products, including honey,

wax, cane, bamboo, herbs, and ornamental plants. Moreover, these mangroves play an irreplaceable role in the life cycle of economically important fish, shrimp and crab species (Bhuiyan, 2005). Current status of the forests can be found in the Forests and Biodiversity Baseline Study.

2.4. Past and current socio-economic developments

2.4.1. Polders

The coast provides many natural resources, such as fertile lands, fresh and brackish water, forest and fish but living conditions are demanding due to freshwater limitations, salinity intrusion and frequent cyclonic storms which can create huge surges of up to 6 m height. From the beginning in the 1960's construction started of embankments to protect land from tidal waves which ultimately led to a total of 139 polders today (**Figure 10**). In 2008 the polders supported a total population of 8 million people living on 1.2 million hectares of land (BBS, 2010).

A polder is a low-lying tract of land enclosed by earthen embankments known as dykes that form an independent hydrological entity which has no physical connection with outside water other than through manually operated devices (water control structures). Polderization started in early 60s in Bangladesh as a follow up activities of the erstwhile Zamindar's (landlords) local initiatives taken up during pre-polderization era.

Historical background of polder development

A Statistical Account of Bengal (1877) describes how modifications were being made to the natural levees beside some rivers: small embankments were constructed, and gaps in them were closed at high tide and opened at low tide so as to achieve partial drainage of the land behind, along with reduced salinity. Before formal polderization by BWDB, much of the coastal area used to suffer from tidal flooding and salinity intrusion twice a day and the occasional cyclonic storm surges. Salinity problems were worst in the dry season. Most of the coastal area was a marshy and unproductive wetland. Population pressure was moderate and few human settlements were on high ground and local transportation was by country boats plying across flooded plains or along tidal creeks. The seaward parts of the coastal zone supported extensive mangrove forests but very little in the way of agriculture. Winter crops and the first summer rice such as Rabi and Aus or Kharif I respectively were hardly grown because of the prevailing saline conditions, and the second summer rice such as Aman or Kharif II was dominant. Further inland where tidal effects were weaker, the picture gradually changed, but agricultural production was very low and uncertain (almost nil in some years) because of tidal flooding. During this period the coastal economy was dominated by fishermen, who traded fish for rice and other necessities. In order to increase food production, and make it more secure, local farmers under the leadership of landlords (zamindars) began to erect simple low-cost earthen dykes to protect the land from tidal flooding and salinity intrusion. This process was well established by 1900. The dykes or dwarf embankments remained fragile and were often damaged by high tides or cyclonic storms, so the people had to undertake considerable amounts of repair and rebuilding every year. Drainage was sometimes inadequate, so that heavy rainfall or river floods often resulted in severe crop losses. Despite these limitations, agricultural production was much higher than in the previous situation, and enabled the coastal lands to support more and more people.

Coastal Embankment Project

Following the abolition of the Zamindari system after 1954, this practice of embankments using simple technology with local initiative and maintenance gradually ceased to operate. Increasing population and hence, need for land and food, led eventually to the initiation of the *Coastal Embankment Project* (CEP) in late 50s. Accordingly the CEP was designed and implemented with the aim of preventing tidal flooding and salinity intrusion in vast areas of low-lying land and thereby to increase the agricultural yields by rebuilding existing

bunds and constructing new ones. This was perhaps the first large scale human intervention in the southwest coastal region of Bangladesh. About 139 coastal polders were constructed during 1960 to early 70s as mentioned earlier shown in **Figure 15**. The immediate socio-economic consequences were very impressive and positive. The construction of a polder itself provided massive employment opportunities and stimulated local economies and trade. Transportation infrastructure were dramatically improved, integrating new roads with navigation facilities, which enabled products to be marketed over long distances. Outputs of crops in all seasons were higher than in any time before and much more secure. At this time better and more reliable control of water opened the door to other improvements in agricultural inputs and practices. Fishing remained significant, and the age-old tensions between fishermen and farmers persisted, but within acceptable tolerance. In all, a backward area of the region was transformed for the better incomes and living standards. New productive land was created by encouraging or accelerating the natural evolution of estuarine channels, sometimes by cross-dams.

This positive situation persisted for about two decades or so, but by the early 80s the secondary effects of polderisation in terms of sediment deposition began to be serious. The rivers of south-western coastal Bangladesh are characterized by active deposition of sediment causing significant reduction in their drainage capacity. Besides the construction of coastal polders, the drastic reduction of upstream flushing flow due to the commissioning of the Farakka Barrage during the dry season deteriorated the sedimentation problem in the region. The restricted drainage and consequent waterlogging is now a major issue in many parts of the coastal zone. Lack of proper maintenance of infrastructures combined with the sediment deposition in the peripheral rivers of polders/drainage channels seems to be one of the major causes to create such problems. Due to shortage of human resources in the field, lack of timely maintenance, poor maintenance budget and inadequate policy of proper participation of local community and LGI for internal water management, the smooth infrastructure operation began to break down. Some influential people also built cross dam across drainage channel inside the polder for fishing and encroach khals and river for agriculture and build infrastructure that also impede the drainage. The removal of protective forests and other vegetation left the embankments of polders vulnerable in many places. In addition, a series of severe cyclonic storms after 1970 coupled with the enormously increased population in this region made the situation even more complicated.

The construction of polders generally produced independent hydrological units with embankments all the way round each one. In parts of the zone the waterways between the polders continued to silt up and in some places this was deliberately hastened by the construction of cross-dams to close such channels for fisheries and promote sedimentation such as in Kobadak river.

Though still built to protect land for agriculture, the engineered embankments of the CEP were usually higher and more robust than earlier banks and bunds, and in most places served also the subsidiary purpose of reducing damage and loss of life during floods and cyclonic storm surges. After the very severe cyclone of 1970 this purpose of the embankments began to be seen as a major one, though it was only after the 1985 cyclone that this changed perception led to new design approaches and some upgrading and rehabilitation efforts.

The major problem of polders is water logging due to siltation of the peripheral river, which is likely to deteriorate in future with the combined effect of precipitation increase, sea level rise and subsidence. The height of peripheral embankment of polders is not adequate to prevent the overtopping of storm surge since it is designed based on monsoon spring tide level not storm surge level. Governance issue of polder management involving multi institutions and local community is crucial for successful functioning of polders in intensification of agriculture, aqua culture and other related economic activities. The knowledge gaps are rate of subsidence inside polder, medium to long term morphological conditions of peripheral rivers, available water resources, and land-use changes under different external drivers of change in future.



Figure 15: Polders in the coastal zone

2.4.2. Char development

The continuous process of accretion and erosion along the rivers and estuaries result in the loss of valuable land at one place and new land at another. Every year thousands of families become landless. Especially riverbank erosion is the predominant reason for households to migrate to the unprotected islands or chars (Raza et al., 2011). Many people live on these chars and are subject to the fury of storms and coastal erosion. Consolidation of newly accreted land on these islands is hampered by quick colonization of people and cattle, preventing succession of vegetation which would otherwise stabilize the soil. Land reclamation is enhanced by cross-dam techniques, which yielded substantial new land over the past half century. More than 100,000 ha of land was reclaimed along the Noakhali coast through Meghna cross dams, cross-dam-1 and cross-dam- 2 (GoB, 2006).

2.4.3. Poverty and economic growth

Official poverty indicators show a slightly higher percentage of the population living below the absolute poverty line in the coastal zone compared to the country as a whole (52% vs 49%), while GDP per capita and the annual GDP growth rates in the coastal zone are more or less similar to the national averages. There is, however, a substantial regional differentiation: in 15 out of the 19 coastal districts, the GDP per capita is below national or coastal zone averages. High vulnerabilities in terms of insecurity of food, income, water, health and poverty are prominent in Bhola, Noakhali, Satkhira and Bagerhat district. According to projections, CZ population will increase from the current (2011) 38.5 million to 60.8 million in 2050 (GoB, 2006).

Current unemployment rate in the country is around 30%. An increasing share of population of Bangladesh migrates to urban areas in search for employment opportunities outside agriculture and into industrial enterprises or the services sectors, migration from coastal area also takes place due to multiple natural disasters.

Inability of the agriculture sector to provide sufficient employment or sufficiently high household incomes to cope with a growing number of dependents can encourage people to seek employment outside agriculture. The lure of employment opportunities existing in these cities is another reason for urban migration (GoB, 2012).

2.4.4. Diversity of natural resources and economic activities

Besides agriculture, fisheries and aquaculture, economic activities include salt making, shipping (ports), shipbreaking and ship building as well as eco-tourism (mainly in the Sundarbans). The zone has a diversity of natural resources including coastal fisheries and shrimp, forest, salt and minerals. It has sites for Export Processing Zones, harbours, airports, land ports and tourism complexes and opportunity for other industries. This zone also has high potential for exploitation of both onshore and offshore natural gas. Some of these resources still remained untapped while there are opportunities for using many of them for their significant expansion potentials (GoB, 2005).

Fisheries

The harvest of marine capture fisheries was 379,497 tons during 2000-2001, which was increased up to 588,988 tons in 2012-2013 (DoF 2014). Hilsa shad (*Tenuosia ilisha*) is the largest and single most valuable species with annual catch of 340,000 MT, and generates employment and income for 2.5 million people valuing \$US 1.3 billion per year (Hossain et al. 2014). At present 50-60% of global hilsa catch is taken place in the coastal and marine waters of Bangladesh, 20-25% in Myanmar, 15-20% in India and the remaining 5-10% in other countries. Further reference is made to the Baseline study Fisheries and Livestock.

Aquaculture

From the early 1980s, the Government of Bangladesh has been endeavouring to improve the shrimp farming. Shrimp farming rapidly expanded in the coastal districts including Shatkhira, Khulna, Bhagerhat and Cox's Bazar and it has made Bangladesh one of the major exporting countries of shrimp (*P. monodon* and *M. rosenbergii*) in the world (Azad et al., 2008).

Every year, for a few months, many coastal poor people including women are engaged in catching of wild prawn post larvae along the coastline. This is an important livelihood activity. But, number of by-catch (i.e. larvae/ juvenile of non-target fish/ shellfish species) is high in prawn larvae fishing, posing significant negative impacts on the production and biodiversity of coastal ecosystems (Hossain et al., 2014).

Ship breaking and ship building

The ship breaking and recycling industry (SBRI) converts end-of-life ships into steel and other recyclable items. Ship recycling offers the most environmentally sustainable way of disposing of old vessels. Ship breaking activities are being practiced in the coastal areas of Bangladesh and gained importance in the macro and micro-economy of Bangladesh. At present the SBRI in Bangladesh is mainly concentrated at Chittagong. This activity began in 1969 and since then it has earned a good reputation for being profitable but at a great environmental cost. Various disposable materials are being discharged and spilled from scrapped ships and often get mixed with the beach soil and sea water which in turn has a negative impact on our coastal environment and biodiversity. The ship breaking and recycling industry plays a significant economic role in Bangladesh supplying a substantial quantity of scrap steel for the iron and steel industries and also for ship building of international standard. SBRI provides more than half of Bangladesh's steel supply, for example, making it a strategic industry in that country e.g. it contributed 50% of Bangladesh steel production (WB, 2010). The industry also creates hundreds of thousands of direct and indirect jobs for some of the poorest and most marginalized segments of the population in the. The work force in each country varies with the volume of ship breaking but may range from 8,000–22,000 workers in the ship recycling yards to 200,000 in the supply chain, shops, and re-rolling mills—with dependents in extended families estimated to reach over 500,000 in Bangladesh (WB, 2010).

The SBRI also has a major social impact in that region. Most workers in the ship breaking yards are migrant workers from poorer regions of the country. Working conditions have historically been poor for the majority of these workers, with limited use of personal protective equipment, frequent exposure to hazardous materials, and unsafe conditions. Accidents causing fatalities and injuries are frequently reported in the local media. Environmental protection is limited in most yards and the sound management of asbestos, polychlorinated biphenyls (PCBs), ozone-depleting substances (ODS), and a range of heavy metals is virtually non-existent. Of late, some efforts at minimizing the release of such pollutants in the environment are emerging in Bangladesh due to intervention by the courts. This growth in ship breaking activity is due to both supply side attributes and demand conditions. A large labour supply, low labour costs, and a relative lack of environmental and occupational health regulation have all been vital. SBRI contribution in Bangladesh is presented in the following **Table 7**.

Table 7: SBRI contributions in Bangladesh 2008/2009

Type of activity	quantity
National steel production	2.2–2.5 m tons
Scrap steel from ship breaking	Up to 1.5 m tons
Ship breaking steel's contribution to production	50%
No. of re-rolling mills	250 to 350
Scrap yards (total no.)	40 active 2)
Estimated no. of workers in yards	22,000

The SBRI location and industrial practices make it highly vulnerable to the impacts of climate change and especially to sea level rise. The industry's legacy pollution could pose significant threats and challenges at both local, particularly in Chittagong and regional scales as rising tide levels in the Bay is likely to submerge beach and near-shore ship breaking areas, washing out accumulated pollutants. In storm surge events, a sudden release of quantities of the contaminated landside beach material into the marine zone may severely affect local fisheries. The ship breaking under the prevailing environmental and occupational health regulatory conditions is a competitive industry in Bangladesh. The level of profitability for SBRI is about 16%, which indicates the scope for developing more-sustainable practices in Bangladesh without damaging the overall competitiveness of the industry—and without increasing the risk of relocation of the industry (WB, 2010).

Salt production

Salt production is an ancient industry begun in the coastal zones of Bangladesh especially in Chittagong and Cox's bazar areas. Salt is produced seasonally from December to mid-May. Recently salt cultivation has also begun in the coastal belts of Khulna and Satkhira. This industry was developed by people traditionally specialized in it and was known as *Mulunghee*. They used to produce salt by evaporating water by boiling the saltwater. The salt production field has been known as *Tofol*. In the 16th century, the salt manufacturing was a source of income for the government.

According to a survey conducted by BSCIC in 1964 there were 16,541 salt growing units over 11,769 acres of land across the coastline of Chittagong, Noakhali, Barisal and Khulna. Annual production of those units engaged 50854 workers generating an annual income of 20 million taka. In 1990, BSCIC with an estimated cost of 377 million taka took up a project named Special Product Development Programme. It included three components of which salt production was one. There was also an allocation of 118.9 million taka for the development of salt sub-project, which aimed at achieving self-sufficiency in salt production, improving quality of salt, and to extend technical knowledge of salt production. The project was implemented between 1990 and June 2000 and continued as a revised project from 1990 to 2005.

In 2006-2007 the project was included in the revenue budget with its centres at 7 thanas of Cox's bazar district: Cox's Bazar Sadar, Chokoria, Pekua, Kutubdia, Teknaf, Maheshkhali, Ramu and Banshkhali thana of Chittagong district. The centres are: Uttar Nolvilla, Gorokgata, Matarbari, Gomatoli, Choufaldandi, Darbeshkata, Dulhazara, Fulchhari, Purba Borogona, Sorol and Teknaf .

Table 8 shows Description of Demand and Production over the years.

Table 8: Description of demand and production of salt over the years

Financial year	Year wise demand	Production target (in m ton)	Actual production (in m ton)	Imported (in m ton)	Total cultivated land (acres)	Number of salt cultivators
2000-2001	8.91	9.00	9.91	-	51541	37293
2001-2002	8.82	9.00	7.75	-	54717	36638
2002-2003	9.00	9.20	8.10	1.00	58653	38328
2003-2004	11.44	9.50	9.70	1.00	61502	40595
2004-2005	11.44	11.50	7.82	1.00	63655	42000
2005-2006	11.44	12.00	15.75	1.53	70050	44574
2006-2007	11.44	13.00	10.65	-	70754	45000
2007-2008	12.65	13.00	12.22	-	68101	43627
2008-2009	12.98	13.20	13.72	-	71190	47460
2009-2010	13.33	13.50	17.07	-	67757	43553

Source (BSCIC)

Under this programme, salt production, market price and information collection including movement, imparting training to salt farmers and research works were done. There are 4 production cum display centres at Lemoshikhali, Choufaldandqi, Matarbari and Baldarchar. At present 43,553 cultivators are engaged in 67,751 acres of land in Cox's Bazar and Chittagong district to produce salt in solar method. Salt is contributing about 120 million taka in the national economy every year (BSCIC). About 1 to 1.5 million people of coastal belt is dependent economically and socially on salt cultivation. Production of salt in solar method depends completely on nature. If the climate is conducive the production target can be achieved. In 2009-10, salt production was 1.7 metric tonnes against the target of 1.33 tonnes.

With the increase of population, cattle heads, and growers of industries, the demand of salt is also rising. To meet the growing demand of salt and to achieve self-sufficiency in salt production, BSCIC has extended its salt production areas to Khulna and Satkhira through a new project costing over 13 million taka. Under the project, four experimental salt training and production centres were established in Madinabad in Kaira upazila of Khulna district, Bet Kashi of Dakop upazila, and Burigoalini of Shyamnagar upazila, and Pratabnagar of Ashasuni Upazila of Satkhira district. Later during the period 1992-2002, the second phase of the 19 million taka project was implemented. The implementation of the third phase concluded in 2009 at a cost of over 28 million taka.

The project named as Control of Iodine Deficiency Disorder was taken as a pilot project on 1989 to eradicate the iodine deficiency. The government enacted a law on 11 December 1994 to prevent iodine deficiency diseases. Under this Act, from 31 June 1995 onward fortification of all edible salt with iodine made compulsory and storage and marketing of non-iodine salt were prohibited. With cooperation of UNICEF, 267 iodised salt plants were set up and each of the factory was provided with an iodine mixture machine free of cost. [Masood Reza]. Local non-iodized raw salt has substantial demand in the various non-edible industrial sectors, especially in the leather (Tannery), agriculture, fishery and many other chemical industries which are able to absorb the total domestic production. Needless to mention here that domestic demand is increasing with the pace of fast industrialization in the above mentioned sectors.

Most of the salt farms are small-scale using manually operated local equipments and lease the land from landowners, or sometimes from the government on a yearly basis (Hossain et al. 2006). Community focused land leasing system, sufficient credit facility, using mechanical equipments (water pump, leveler, etc.) and reliable weather forecasting can enhance salt production. Moreover, formation of salt farmers' cooperative can ensure bargaining power and maximum economic return (i.e. salt price) for their standard of living (Hossain et al., 2014).

Oil and gas mining

Bangladesh is yet to assess the true potential of its offshore oil and gas prospect (Imam 2013, cited in Hossain et al., 2014). While an impressive gas success ratio of 3:1 (3 exploration wells drillings result 1 discovery) was observed in the onshore area, the success ratio in the offshore is less impressive, i.e. 9: 1. Some 26 Tcf (trillion cubic feet) gas reserve has so far been discovered in Bangladesh, of which only about 1 Tcf is located in the offshore areas. Until 2014, 19 exploratory wells were drilled in the Bay of Bengal, resulting in only two gas discoveries, i.e. the Sangu and the Kutubdia, with small reserves. The Sangu reserves 0.8 Tcf has already depleted, where the Kutubdia reserves 0.04 Tcf is yet to be developed. Moreover, the drilling of the Magnama (3.5 Tcf) and Hatia (1.0 Tcf) in late 2007/early 2008 were disappointing due to non-commercial volumes of hydrocarbons (Blakeley 2010, cited in Hossain et al., 2014).

The shallow offshore blocks of Bangladesh adjacent to the Myanmar blocks are considered an area of particular interest because of the recent discoveries of several large gas fields (Shwe, Shwe phu, Mia) in the Arakan offshore of Myanmar. Due to close proximity to the discovered gas fields of Myanmar, these Bangladeshi blocks are likely to have comparable geological structures and gas/oil prospects (Hossain et al., 20'14).

3. Current Policies and Strategies

3.1. Coastal zone policy and coastal zone strategy

The Coastal Zone Policy (CZPo) was approved by the Government of Bangladesh (GoB) in 2005. This policy document was formulated through a process of multi-level consultation over a period of two years. The Government has made the coastal zone policy statements in relation to development objectives. These policies provide general guidance so that the coastal people can pursue their livelihoods under secured conditions in a sustainable manner without impairing the integrity of the natural environment. The Policy is built on different sector policies of the Government of Bangladesh. Subsequently, a Strategy was developed as to select strategic priorities and actions in implementation of the Coastal Zone Policy with emphasis on the creation of the institutional environment that will enable GoB to embark on a continuous and structured process of prioritization, development and implementation of concerted interventions for the development of the coastal zone. The Coastal Development Strategy was approved by GoB in 2006.

Integrated Coastal Zone Management (ICZM) was the key to Coastal Development following the principles the Government declared the coastal zone policy. Following this policy, all concerned Ministries, Agencies, Local Government Institutions, NGOs, private sector and the civil society are putting their efforts for the development of the coastal zone. The main principles in ICZM approach include:

- integration through harmonization and coordination;
- adoption of a process approach;
- linkage to national planning mechanisms;
- implementation through respective line agencies;
- co-management and participatory decision;
- gender equality;
- participatory monitoring and evaluation;
- supporting national policy of decentralization and development of the private sector;
- interventions based on the best available knowledge; efforts to fill knowledge gaps;
- priority setting on issues of the coastal zone.

The reduction of vulnerabilities was considered an important component of policy framework. Disasters like cyclone, drainage congestion, land erosion and drought that take toll on life and property and depletion of natural resource base that supports particularly the poor. Majority households are vulnerable to climate change. In the coastal zone, agriculture continues to be a major source of employment, which is seasonal in nature. In this regard, Government policy was as follows:

- a. Reduction to vulnerability to natural disasters was an integral aspect of the national strategies for poverty reduction;
- b. Integration was to be made with 'Comprehensive Disaster Management Plan' on aspects concerning the coastal zone;
- c. Effective measures were to be taken to enhance coping capacity of the poor during the period of disaster and to initiate insurance scheme for improving their social security;
- d. Effective measures were to be taken for protection against erosion and for rehabilitation of the victims of erosion;

- e. Safety measures were to be enhanced by combining cyclone shelters, multi-purpose embankments, killas, road system and disaster warning system. It should include special measures for children, women, the disabled and the old;
- f. Sea-dykes were to be regularly maintained as first line of defence against storm surges and afforestation on it according to the existing policy;

The Coastal Development Strategy (CDS) focuses on the implementation of the coastal zone policy. The CDS was approved at the second meeting of the Inter-Ministerial Steering Committee on ICZMP held on 13 February 2006. Nine strategic priorities, evolved through a consultation process, guides interventions and investments in the coastal zone:

ensuring fresh and safe water availability : Zoning regulations is necessary to establish for location of new industries in consideration of fresh and safe water availability and effluent discharge possibilities for pollution control;

safety from man-made and natural hazards: The coast of Bangladesh is known as a zone of vulnerabilities as well as opportunities. It is prone to natural disasters like cyclone, storm surge and flood. The combination of natural and man-made hazards, such as erosion, high arsenic content in ground water, water logging, earthquake, water and soil salinity, various forms of pollution, risks from climate change, etc., have adversely affected lives and livelihoods in the coastal zone and slowed down the pace of social and economic developments in this region.

optimizing use of coastal lands: To control unplanned and indiscriminate use of land resources and reclamation of balanced land (new chars) from the sea and rivers and its development planning is needed under land use policy.

promoting economic growth emphasizing non-farm rural employment: To enhance standard of living of coastal communities by investing in different sectors like marine fisheries, salt production, shrimp culture, crab culture, shell culture, pearl culture, livestock development, area-based agricultural development and agro-based industries, transport, ship building, ship-breaking, tourism, extraction of beach minerals, renewable and non-renewable energy, etc. Priority has been accorded to (i) labour-intensive and low technology investments should be given importance where the poor and the disadvantaged can find employment, as well as (ii) to promote those industries and activities that will reasonably use manmade coastal resources as basic raw material;

sustainable management of natural resources: exploiting untapped and less explored opportunities

improving livelihood conditions of people; especially women: Special attention has been paid towards employment generation for women, the promotion of women entrepreneurs as well as the removal of restrictions on women's employment and economic opportunities, allocation of land titles to women during distribution of newly accreted khas lands, special projects has been suggested to implement for livelihoods enhancement and empowerment of disadvantaged women;

environmental conservation: Meaningful conservation have been enforced of critical ecosystems including ECAs, heritage sites and marine reserves, steps to stop activities that have direct adverse consequences on bio-diversity and specific mitigation measures, have been taken to minimize those effects;

empowerment through knowledge management: Equal participation of all stakeholders has been ensured and establishing effective co-operation between the government agencies, local government institutions and non-governmental organizations, Co-management procedures has been established that bring decision-making power to the grass root levels;

creating an enabling institutional environment: Measures has been taken to formulate an appropriate institutional framework and to enact necessary laws and regulations in order to harmonize and coordinate all development activities in the coastal zone.

The interventions under second strategic priority “safety from man-made and natural hazards” include improvement of coastal polders and sea dykes. The proposed CEIP project interventions are in line with this strategy.

In 2005 also a Priority Investment Plan was issued as the operational arm of the Coastal Development Strategy. It contains 24 projects grouped under the strategic priorities mentioned in the CDS with a total estimated cost of 398 million USD.

The coastal zone management initiative has seemingly died off after 2005-2006, and failed to show any great promise.

3.2. National Water Policy

The National Water Policy (NWPo) was enacted in 1999 to address the objectives of improved water resources management and protection of the environment recognizing that every public agency, every community, village and each individual has an important role to play in ensuring that the water and associated natural resources of Bangladesh are used judiciously for the benefit of present and future generations. The policy recognizes that the process of planning and managing water resources requires a comprehensive and integrated analysis of relevant hydrological, topographical, social, political, economic, environmental and institutional factors across all related water-using sectors.

The nature of drainage systems within the country requires that planning and management of river systems is undertaken within the context of hydrological regions. The principal river systems create natural boundaries for these regions. The hilly areas of the east form another hydrological region.

To address these issues through its responsible agencies, the policy of the Government, among others, will be as follows:

- Undertake comprehensive development and management of the main rivers through a system of barrages and other structural and non-structural measures.
- Develop water resources of the major rivers for multipurpose use, including irrigation, fisheries, navigation, forestry, and aquatic wildlife.
- De-silt water courses to maintain navigation channels and proper drainage
- Delineate water-stress areas based on land characteristics and water availability from all sources for managing dry season demand.
- Take steps to protect the water quality and ensure efficiency of its use
- Develop early warning and flood-proofing systems to manage natural disasters like flood and drought.
- Designate flood risk zones and take appropriate measures to provide desired levels of protection for life, property, vital infrastructure, agriculture and wetlands.
- Undertake survey and investigation of the problem of riverbank erosion and develop and implement master plans for river training and erosion control works for preservation of scarce land and prevention of landlessness and pauperization.
- Plan and implement schemes for reclamation of land from the sea and rivers etc.

3.3. National Land Use Policy and Land Use Changes

National Land Use Policy

Land is a basic natural resources and source of everyday food requirement, industrial product, recreation, safety of human health etc. The National Land Use Policy (NLUPo), enacted in 2001, was aimed to managing land use effectively to support trends in accelerated urbanization, industrialization and diversification of development activities. The NLUPo urges that increasing the land area of the country may be not possible through artificial land reclamation process, which is cost-effective only in the long run. Therefore, land use planning should be based on the existing and available land resources. The policy recommends the establishment of land data banks where, among others, information on accreted riverine and coastal chars will be maintained, forests declared by the Ministry of Forests and Environment will remain as forest lands; reclassification of forest lands will be prevented; and effective green belts will be created all along the coast.

The main objectives of the policy are as follows;

- To control the decreasing rate of agricultural land as the agricultural land for food production is decreasing at an alarming rate with the increasing population
- To control unplanned housing extension, industrial and commercial activities in a logical way through land zoning considering different type of land in different areas of the country
- Settlement of landless people on emerged chars in the river, Haor and Estuary ensuring the best utilization of these land
- Preservation of Government Khash land for future development work
- Ensuring best utilization of land for poverty alleviation and creating employment opportunities.

Land Use Change

Land use in Bangladesh is generally determined by physiography, climate and land height in relation to water level (Brammer, 2002).

In the coastal area of Bangladesh land use is diverse, conflicting and competitive. Agriculture, shrimp culture, forestry, ship-breaking yards, salt production, ports, industry, settlements and wetlands are some of the uses. Land uses in the coastal area have changed over the decades. In the early 1950s, paddy cultivation was the main land use. In order to enhance the agriculture production, Bangladesh water development board in the early 1960s and 1970s constructed polders in the coastal area.

The population is increasing and the land is being converted from directly productive purposes, such as crop cultivation, to other uses such as housing, roads and urban development, and this trend is expected to continue (PDO-ICZMP, 2004b). Some of the statistics provide an alarming picture:

- Some 220 ha of arable land is being lost daily to uses such as road construction, industry, houses, etc. (Islam *et al.*, 2004).
- At least 86,000 ha of land was lost to river/estuarine erosion between 1973 and 2000 (MES, 2001).
- Some 70% of the land of Barisal and Khulna divisions is affected by different degrees of salinity, which reduces agricultural productivity (Rahman and Ahsan, 2001).
- Some 50% of the coastal lands face different degrees of inundation, thus limiting their effective use. This situation is expected to worsen further because of the effects of climate change.

In the coastal zone also, the population is expected to increase from 36.8 million in 2001 to 43.9 in 2015, and to 60.8 million by 2050 (PDO-ICZMP, 2005a). Present per capita agricultural land of 0.056 ha will decrease to 0.025 ha by 2050. On top of this, about 54% of the people of coastal Bangladesh are functionally landless and more than 30% are absolutely landless.

Land use changes reflects the socio-economic changes of a country, the land use change in Bangladesh is to meet the dynamic demand of the communities that exerts pressure on natural environment.

The shifting rate of agricultural land to non-agricultural use is said to be about 1% per year (South Asian Human Resources Development Report, 2003 by UNDP)

In accordance with BBS, the decrease rate of agricultural land is about 0.383% annually from 1980-81 to 2006-2007 (27 years average), 0.75% annually from 1983-1984 to 1993-1994 (10 years average) and 0.40% annually from 1993-1994 to 2003-04(10 years average).Figure 16presents the trend of land use change over the years.

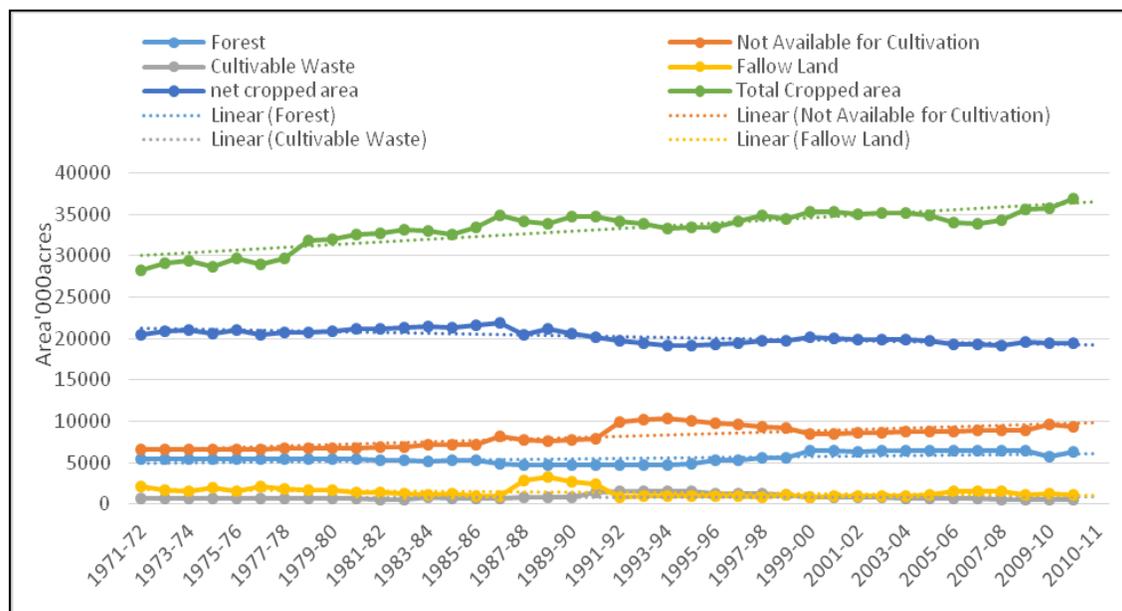


Figure 16: Trend of land use pattern of Bangladesh (1971-2011)

[Source: Bangladesh Delta Plan 2100; Baseline Study Agriculture and Food Security]

3.4. Perspective Plan of Bangladesh 2010-2021

This plan was published by General Economics Division of the Planning Commission of Bangladesh in April 2012. The perspective plan is a strategic articulation of the development vision and mission of the government, which provides the road map for accelerated growth and lays down broad approaches for eradication of poverty.

Strategies associated with coastal issues

There are a number of long term strategies that set in the perspective plan relating to water resources management. Among them those which are concerned with coastal issues are given in the following:

- Examination of large scale operation and maintenance activities on embankments and polders in order to prevent salinity intrusion. It pointed out that for such activities different options should be identified and compared; and hence the best option to move forward should be determined

- Rehabilitation of coastal embankment should be viewed in the light of impact of climate change.
- Desalination activities
- Land reclamation activities

However, strategy for long-term land use planning, institutions and governance issues are not elaborated in the perspective plan.

3.5. National Strategy for Accelerated Poverty Reduction II (Revised)

This document is commonly called as Poverty Reduction Strategy Paper –II. This paper was prepared by General Economic Division of the Planning Commission of Bangladesh. It was revised in December 2009 with update and modification taking information from other relevant documents and in the light of election manifesto of Bangladesh Awami League in 2008. It was prepared for the duration of FY 2009-2011.

Coastal Issues as Mentioned in Policy Matrices in NSAPR II

NSAPR II set 18 policy matrices in which the Policy Matrix 4 is on Water Resources Development and Management. Each policy matrix has four columns with the headings 'strategic goals', 'key targets', 'actions taken/underway' and 'PRSP policy agenda 2009-2011'. The stuff that is related/on the coastal issues are picked up in the following:

Under strategic goal: Expanding utilization of surface water, including coastal polders and arsenic prone areas, PRSP policy agenda 2009-2011 are:

- Develop supplementary irrigation in coastal areas
- Undertake Matamuhuri Irrigation Project Phase II

Under strategic goal: Protecting from flood, improving drainage and reducing vulnerability to water related disasters including sea erosion and cyclonic surges, one of the key targets was set as rehabilitation of polders for protection of land from tidal flood.

Under strategic goal: Protect wetland, haor, baor, Sundarban, saline water intrusion, promote accretion of land from the sea, the set actions are:

- Char Kukri Mukri FCD salinity control
- Char development and settlement
- Afforestation programme for ecological balance

Under strategic goal: Managing erosion of major rivers and protect large and small towns, implementation of Integrated Coastal Zone Management Plan (ICZM) was underway. PRSP policy agenda were:

- Undertake a study on Detailed Coastal Land Zoning with two Pilot District Plain Lands (WARPO)
- Construct cross dam for land reclamation

Under strategic goal: Reviewing existing policy and legislation and finalization of National Water Act. Coastal related PRSP policy agenda was:

- Institutionalize and operationalize coastal zone management

3.6. National Sustainable Development Strategy 2010-21 (NSDS, 2013)

National Sustainable Development Strategy (NSDS) pointed out that Bangladesh coastal zone contains a number of ecosystems - marine zone, mangrove forest, estuary, chars and islands, coral, sandy beaches and dunes. It provides a huge biodiversity, immense natural resources, and ecological foundation as well to the country. Being

the world's largest mangrove ecosystem UNESCO, upon considering its importance of conservation, declared Sundarban as a World Heritage Site in 1997. Having obtained the verdict of International Tribunal on Law of the Sea, Bangladesh sustained its claim over 200-nautical mile as economic zone and territorial rights which opens up a peaceful possibility of harnessing marine resources – gas, fisheries etc. Though erosion and accretion phenomena both are operating, however, accretion of land is a remarkable feature in the coastal zone. Notably, more than 50000 ha of land accreted in response to the Noakhali cross dam. Forest department started coastal afforestation in 1966, and coastal green belt is a concept that has been instrumental in protecting life and property from the hit of cyclone and surges.

Polders are now natural features in the coastal region with huge economic activities although it has some adverse impacts on coastal environment. Land use in the coastal zone is diverse – settlements, infrastructure developments, forestation, shrimp culture by making gher, natural fisheries, salt production, tourism etc. These so many uses in an unplanned way made conflicting situation. On the one hand desalinization is the purpose by construction of polders, again shrimp culture inside polders due to economic profit are seen. The honourable High Court in February 2012 declared harnessing salt water on agricultural and forest land as illegal.

Key Challenges

National Sustainable Development Strategy recognizes challenges in three main aspects – protection of overall ecosystem in the coastal zone (estuarine, coastal and marine), reducing land use conflict, integrated and efficient management of ecosystem and resources.

Strategies set in NSDS to meet the challenges

Regarding protection of ecosystems

- Conservation effort should be continued
- Services provided by the ecosystems should be evaluated and appreciated. Research should be carried out in coastal universities such as Khulna and Chittagong Universities.

Regarding land zoning

- Detailed coastal land zoning could be prepared

Regarding integrated management of coastal water infrastructures

- Polders should be managed in an integrated manner that should include a system of embankment maintenance, afforestation in the foreshore, fisheries and agriculture development, also alleviate permanently water logging in the south west region.

NSDS rightly recognizes evaluating and appreciating of services given by ecosystems. Also, pointed out the research need. However, unplanned and over harnessing are issues. After evaluation and research there should be policy implementation in this regard. Research shall not be limited to particular universities. However, universities in the coastal region can get priorities. Also, Barisal, Patuakhali, Noakhali Universities can carry out research along with Khulna and Chittagong Universities.

3.7. National Agriculture Policy (NAP, 1999)

Ministry of Agriculture (MoA), which is responsible for the crop sub sector, prepared this policy statement in 1999.

The overall objective of the National Agriculture Policy is to make the nation self-sufficient in food through increasing production of all crops including cereals and ensure a dependable food security system for all. The main specific objectives of the National Agriculture Policy are to:

- ensure a profitable and sustainable agricultural production system and raise the purchasing power by increasing real income of the farmers;
- preserve and develop land productivity;
- reduce excessive dependence on any single crop to minimize the risk;
- increase production and supplies of more nutritious food crops and thereby ensuring food security and improving nutritional status;
- preserve existing bio-diversity of different crops;
- take up programmes for the introduction, utilization and extension of bio-technology;
- take necessary steps to ensure environmental protection as well as 'environment-friendly sustainable agriculture' through increased use of organic manure and strengthening of the Integrated Pest Management (IPM) programme

NAP has 18 subsidiary objectives and 18 programme areas. The 18 specific objectives are also articulated in general terms and thus gives general guidelines or directions about how the crop sector is to evolve to achieve the overall objective of food self-sufficiency and food security. NAP also identifies 18 programme areas where actions or policies might be undertaken for achieving these goals: crop production, seeds, fertilizer, minor irrigation, pest management, agricultural mechanization, agricultural research, agricultural marketing, land use, agricultural education and training, agricultural credit, government support for production and contingency plan, food-based nutrition, environmental protection, women in agriculture, coordination among government agencies, NGOs and the private sector and reliable database. The list of programme areas shows that NAP underlines all input and support sectors involved with crop production and identifies issues that need to be addressed to improve their efficiency.

3.8. Master Plan for Agricultural Development in Southern Region of Bangladesh

The Master Plan for Agricultural Development in the Southern Region of Bangladesh was prepared by the Ministry of Agriculture in 2013 in Collaboration with the Ministry of Fisheries & Livestock and Ministry of Water Resources, and with technical assistance from the Food and Agricultural Organization (FAO) of the United Nations. The preparation process included a multi-disciplinary team of national experts; backstopped by FAO's technical divisions and continuous consultations with the government line ministries and departments, National Agricultural Research System (NARS) institutes, Consultative Group on International Agricultural research (CGIAR) centers, development partners and other stakeholders including farmers, local government institutions, the academia, community-based organizations (CBOs) the private sector and the civil society.

The agricultural master plan has the following objectives:

- increasing agricultural production and productivity;
- improving water management and infrastructure for surface water irrigation;
- improving productivity of brackish water shrimp and capture fisheries;
- promoting smallholder poultry and dairy development.

The Master Plan formulated a set of programmes and activities across all branches of agriculture and other related fields. A list of interventions is identified under 26 programmes across ten thematic areas;

1. Crops, horticulture and agro-fishery
2. Fisheries
3. Livestock
4. Nutrition
5. Water management
6. Polder management
7. Drainage improvement
8. Agri-business
9. Agriculture credit
10. Capacity building

Total investment need is estimated at BDT 578,026 million for period of 10 years and beyond.

3.9. National Fisheries Policy (NFiPo, 1996)

The National Fisheries Policy (NFiPo), 1996 recognizes that fish production has declined due to environmental imbalances, adverse environmental impact and improper implementation of fish culture and management programs. The policy particularly focuses on coastal shrimp, aquaculture and marine fisheries development. The policy suggests the following actions:

- Shrimp and fish culture will not be expanded to the areas which damage mangrove forest in the coastal region
- Biodiversity will be maintained in all natural water bodies and in marine environment
- Chemicals harmful to the environment will not be used in fish shrimp farms
- Environment friendly fish shrimp culture technology will be used
- Expand fisheries areas and integrate rice, fish and shrimp cultivation
- Control measures will be taken against activities that have a negative impact on fisheries resources and vice-versa
- Laws will be formulated to ban the disposal of any untreated industrial effluents into the water bodies.

The CEIP project interventions may facilitate fisheries production in coastal area. The guidelines of NFiPo may be integrated while designing and implementing the CEIP interventions. However, conflicts over agriculture and fisheries cultivation may accelerate in future¹.

3.10. Bangladesh EACC Report, World Bank 2010

The Bangladesh report on the Economics of Adaptation to Climate Change (World Bank, 2010) takes a broad view of the actions that are needed to adapt the Coastal Zone of Bangladesh not only to the challenges of Climate Change but also to inherent physical and environmental vulnerabilities accumulated over a long period of partial neglect and poor maintenance of the coastal embankment system. Some of the broad conclusions and recommendations of this report are well worth re-iterating before embarking on the preparation of a Strategic Plan.

Table 9: Cost of Adapting to Tropical Cyclones by 2050 (EACC, 2010) USD Millions)

Adaptation Option	Baseline Scenario (existing risks)		(additional risk due to CC)		CC Scenario (total risk= existing + CC)	
	IC	ARC	IC	ARC	IC	ARC
Polders	2,462	49	893	18	3,355	67
Afforestation			75		75	
Cyclone shelters	628	13	1,219	24	1,847	37
Resistant housing			200		200	
Early warning system			39	8	39	8
Total	3,090	62	2,426	50	5,516	112

CC = climate change; IC = investment cost; ARC = annual recurrent cost

Table 9 shows that of the projected cost of the total cost of USD 5.5 billion consists of USD 3 billion for the existing risks and USD 2.4 billion for additional climate change risks. If one was to look only at the polder improvement component a full 70 percent of the total investment will account for dealing with the present risks.

These costs have been refined somewhat for the Ganges Tidal Plain Zones by the present CEIP-1 study. However, it is clear that in the case of polder improvement there is much investment required just to meet the existing risks. An additional investment of only around 30 percent is required to meet Climate Change effects as they are understood at present.

3.11. Infrastructure, port and industrial development

Bangladesh has two (2) sea ports: Chittagong and Mongla ports. International sea borne trade of Bangladesh has been using two existing sea ports, with about 92% passing through Chittagong Port. The Main port installations of the Chittagong Port are situated along the banks of the river Karnaphuli about 16 km from its outfall into the Bay of Bengal. The Mongla Port is located at the confluence of Pussur River and Mongla Nulla about 131 km inland from the Bay of Bengal.

The Port of Chittagong is the largest seaport in and located by the estuary of the Karnaphuli river in Patenga, near the city of Chittagong It is a deep-water seaport dominated by trade in containerised manufactured products (especially garments, jute and jute goods, leather products, fertilisers and seafood), raw materials and to a lesser extent passengers. Window berthing system was introduced at the seaport in August 2007, enabling the sea port to provide the arrival and departure times of all ships. Two berths at the port terminal are kept in reserve for emergency. In 2011, the port handled 43 million tonnes of cargo and 1.4 million tonnes of containers [1]. The port handled 1.5 million TEUs (twenty equivalent units) containers in 2010-11, up from 12.12 lakh TEUs in the previous year, according to the CPA Traffic Department. Port of Chittagong is ranked as world's 90th busiest port in the world. The important role of Chittagong Port for Bangladesh underlines the necessity of investigating how the port should be developed best to meet the future challenges. All previous development plan for the port outdated and the last Chittagong Port Master Plan covered the period 1995-2010. Against this background the government of Bangladesh has approached ADB with the aim of preparing a new Chittagong Port Master Plan for the coming 25-30 years.

Mongla port is located along the Pussur River and 131 km upstream from the Fairway Buoy. However, the port has been experiencing multiple problems, which are as follows:

- Shallow approach channel draft of 8.5 m and draft at berth of 7 m. No rail connection from Dhaka to Mongla Port
- Inefficient road connection to major hinterlands in the Dhaka region. Ferry crossings are required between Dhaka and Mongla.
- Limited captive goods hinterland. Goods from Dhaka region is shipped almost exclusively through Chittagong Port due to availability and frequency of shipping line services and established logistics network and facilities
- High dredging cost required to maintain draft in channel and at berth

A master plan has been developed for future development of Mongla Port with the assistance of ADB.

There is a need of new port development since import and export quantities are likely to be very high in future as predicted by Ministry of Shipping (MoS) (**Table 10**).

Table 10: Summary of Demand Forecast of Conventional and Potential Cargo Medium Growth Scenario

Medium Case	2006 (Share %)	2020 (Share %)	2035 (Share %)	2055 (Share %)
Import+ Export				
Bulk Cargo	16,356 (59%)	35,726 (57%)	74,584 (54%)	157,994 (53%)
General Cargo	11,224 (41%)	27,134 (43%)	62,357 (46%)	138,349 (47%)
(Subtotal)	27,580 (100%)	62,860 (100%)	136,941 (100%)	296,343 (100%)
New Users	0	8,000	8,660	8,880
Transit Cargo	0	1,544	3,588	10,447
(Subtotal)	0	9,544	12,248	19,327
Total	27,580	72,404	149,189	315,670

3.12. Long Term Disaster Risk Management

Multi Hazard Risk Vulnerability Assessment Modelling and Mapping Project

One of the objectives was to increase the reliability and availability of appropriate disaster-related information to the public and disaster management agencies in all regions, as set out in the relevant provisions of Johannesburg Plan of Implementation (JPOI). Again, following the cyclone Sidr occurred in November 2007, a team for Joint Damage, Loss and Needs Assessment (JDLNA) was formed, they developed a 15-year long term strategic plan of action for strengthened disaster risk reduction and mitigation. In this plan, the Component D is titled 'Long Term Disaster Risk Management Programme' under which the Sub-component D1 is 'Disaster Risk Mitigation and Reduction'. D1 supports the startup implementation of activities as outlined under Pillar 3 of the 5 strategic pillars of JDLNA's long term programme. Also, Component D1 was to contribute towards the project development objective of 'building long-term preparedness through strengthened disaster risk management', through the strengthening and enhancement of the long term disaster risk mitigation and reduction ability of Department of Disaster Management (DDM). The subcomponent D1.2 was to support towards Detailed National Level Multi Hazard Risk and Vulnerability Assessment Modelling and Mapping. The project, hence, stemmed from this subcomponent, was undertaken by DDM with financial support from WB. The Asian Disaster Preparedness Centre (ADPC) in partnership with the Institute of Water Modelling (IWM), the Norwegian Geotechnical Institute (NGI), the Asian Institute of Technology (AIT), and the Faculty of Geo-information Science and Observation of the University of Twente (ITC) was entrusted to carry out consulting services to conduct this MRVA project.

The main objectives of this study are as follows:

- Identify all hazard prone areas of Bangladesh specifically district, City Corporation, municipality, upazila and unions covering geological, hydro-meteorological and technological hazards;
- Assess the exposure of people, property, infrastructure and economic activities to the above mentioned hazards;
- Assess the full range of vulnerabilities of the exposed elements experienced throughout the country with reference to the above hazards; and
- Influence sectoral development strategies towards recognizing the highly dynamic form of vulnerabilities and factoring an understanding into institutional, legislative and organizational systems for preparedness, planning and mitigation.

Eight major hazards were selected for the study in this project. They are – flood, cyclone-induced storm surge, earthquake, tsunami, landslide, drought, technological hazard, health hazard. The study followed the work-sequence as making inventory relevant data sources, hazard assessments, exposure assessment, vulnerability assessment, risk estimation and profiling, identification of high risk districts. Also, a work component was to provide training and capacity building of relevant government officials and stakeholders. The elements at risk that were considered in this project are: population (gender, age, ethnicity, employment, education, disability, poverty), housing (types: pucca, semi-pucca, katcha, jhupri), livelihoods (agriculture, industries), critical facilities (health care, education institution, first responders [fire and police stations], cyclone shelters, infrastructure (road, bridge, railway, air, sea and river ports, power lines)).

The hazard assessment was done in a probabilistic way i.e., return period-wise occurrence of events for the hazards under consideration. Flood hazard assessment for flood prone areas across the country (except hilly areas in the south east) was done by using mathematical modelling for return periods – 25, 50, 100 and 150-year. For the hazard cyclone induced storm surges the assessment was also done by using mathematical modelling for return periods – 25, 50 and 150 year. Drought hazard assessment was done for pre-monsoon, monsoon and winter for the return periods of 10, 50 and 100 years. GIS was used in spatial modelling in drought hazard assessment. In this study seismic hazard assessment was carried out with return periods 100, 200 and 1000 years. Landslides are investigated against two triggering agents – rainfall and earthquake source area susceptibility map and run-out area susceptibility map – are overlaid. Hence, overall 'landslide susceptibility map' is produced. A drought map is provided in Figure 17. Using individual hazard assessment maps developed in GIS environment and GIS database was developed at country level for the elements at risk are combined to assess exposure. Using exposure data vulnerability assessment was carried out by the damage curves developed for Bangladesh. Using the hazard and vulnerability individual risk of the elements was assessed. Hence, comprehensive multi hazard risk assessment maps would be helpful for the government and relevant stakeholders in disaster management.

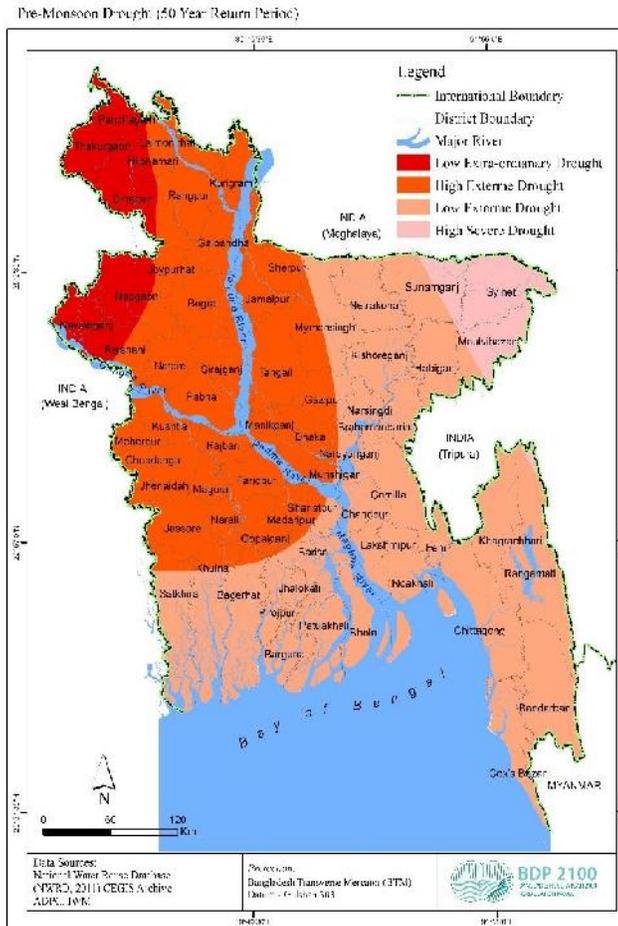


Figure 17: 50-year return period drought map

4. Outlook and Long Term Challenges

4.1. Drivers of change

4.1.1. Climate change and sea level rise

The impacts of climate change for Bangladesh are most critical because of its geographical location, high population density, high levels of poverty, and the reliance of many livelihoods on climate-sensitive sectors, such as agriculture, fisheries.

Analysis of measured temperature (1948-2010) at 34 locations shows that the overall trend in all –Bangladesh annual temperature is rising at a rate of about 1.2C per century. This trend has become stronger in recent years. The trend in recent mean annual temperature (1980-2010) is almost the double of the longer-term (CDMP, 2014). Trend analysis of observed rainfall indicates that the annual rainfall in the country is free from significant changes and trend (CDMP, 2014).

Future climate change (A1B scenario) has been projected as a difference from the baseline period by CDMP. The differences of mean annual temperature and precipitation during 1911-1941 and 1971-2100 from the baseline

period of 1961-1990 were computed. A summary of the average difference of mean annual, monsoon and winter temperatures from the baseline to future period is presented in the following Table. The mean annual and monsoon precipitation is likely to increase by 0.64 and 1.40 mm per day, respectively, during 2011-2041 from the baseline period. However, mean winter precipitation may decrease by 0.05mm per day during 2011-2041 compared to the baseline period. The mean annual, monsoon and winter precipitation is likely to increase by about 0.90, 1.43 and 0.03 mm per day, respectively, during 2071-2100 (**Table 11**).

Table 11: Difference of mean annual, monsoon and winter temperature and precipitation from baseline period 1961-1990 to 2011-2040 and 2071-2100

Variable	From 1961-1990	Annual	Monsoon (Jun-Sep)	Winter (Dec-Feb)
Temperature (°C)	2071-2100	4.34	3.43	5.37
	2011-2041	1.49	1.50	1.80
Precipitation (mm/day)	2071-2100	0.90	1.43	0.03
	2011-2041	0.64	1.40	-0.05

Source (CDMP, 2014)

The level of the sea observed along the coast changes in response to a wide variety of astronomical, meteorological, climatological, geophysical, and oceanographic forcing mechanisms.

Global (eustatic) sea level change is often caused by the global change in the volume of water in the world's oceans in response to three climatological processes:

1. Ocean mass change associated with long-term forcing of the ice ages ultimately caused by small variations in the orbit of the earth around the sun;
2. Density changes from total salinity;
3. Heat content of the world's ocean, which recent literature suggests may be potentially accelerating due to global warming.

The global mean sea level rise in accordance with the IPCC is presented in **Table 12**.

Table 12: Projected change in global mean sea level rise (m) for the mid- and late 21st century relative to the reference period of 1986–2005 (IPCC, AR5 2014)

Climate Change Scenario	2046-2065		2081-2100	
	Mean	Likely range	Mean	Likely range
RCP 2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
RCP 4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
RCP 6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
RCP 8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Relative sea level change is the local change in sea level relative to the elevation of the land at a specific point on the coast. Relative sea level change is a combination of both global and local sea level change due to changes in estuarine and shelf hydrodynamics, regional oceanographic circulation patterns, hydrologic cycles (river flow) and local and/or regional vertical land motion (subsidence or uplift). Thus, relative sea level change is variable along the coast of Bangladesh depending upon the local and regional factors.

Trend analysis of water level along the coast of Bangladesh shows that increase annual mean water level in the southwest coast (Hiron point), Meghna estuary (Khepupara) and Chittagong coast (Rangadia) by 6.8mm, 3.7mm and 4mm per year respectively (IWM, 2014).

There is no detailed scientific research to establish relative mean sea level rise along the coast of Bangladesh for the climate scenarios presented in AR5. It is also important to establish the projection on temperature and precipitation on RCP scenarios. The projected sea level rise and, temperature and precipitation are needed to assess the likely impacts on flood, storm surge, water availability, salinity intrusion, agriculture, fisheries and infrastructure etc.

For the coastal area one of the main questions will be how changes in climate will affect the frequency and severity of cyclone induced storm surges. Furthermore, changed patterns of rainfall and temperature over the seasons will have an impact on the agricultural productivity. See Climate change Baseline Study Report.

The anticipated effect of climate change on coastal polders and chars as far as water management is concerned, is overtopping of embankment, damage of drainage systems, water-logging, crop damage and decline of livelihood opportunities for farmers and fishers. Current water management practices may not be robust enough to cope with the impacts of climate change. It demands improved incorporation of information about current climate variability and climate change into planning and design of water infrastructure. Increase of precipitation and sea level rise in the changing climate may cause prolonged drainage congestions in the proposed project area, if these drivers are not included in designing the drainage systems. The consequence of a sea level rise of 22 cm in 2050 and 5% increase of cyclonic wind speed would be an increase of the crest level for sea facing embankments of 31 cm (Euroconsult MMD, 2014).

4.1.2. Subsidence

The lower deltaic area of Bangladesh is located on two active troughs, Faridpur Trough and Hatiya Trough. Although most of the Bengal Basin is slowly subsiding, the troughs are subsiding more rapidly. The area shows evidence of three different types of subsidence: tectonic, anthropogenic, and that resulting from the compaction of peat layer (Bucx et al., 2011).

Available evidence suggests that most of the region is currently subsiding at less than 2 mm/year except near the coast where rates may be up to ca. 6 mm/year (Brammer, 2013). Observed and estimated subsidence rates vary according to region as well as reference (see **Table 13**).

Table 13: Subsidence rates

Source	Area	Subsidence Rate (mm/year)
Nicholls and Goodbred (2004)	Bengal Delta	0.1 - 0.4
Brammer (1996)	Patuakhali, Gopalganj and Khulna	<1.0
CEGIS (2010)	Bangladesh excluding Sylhet	1
Dhaka University Earth Observatory (2012)	Khulna	13.94±1.14
	Patuakhali	9.16±1.10
	Chittagong	2.31±1.38
Syvitski et al. (2009)	GBM Delta	8 – 18
Pethick (2012)	Hiron Point	12
	Mongla	26
	Khulna	19

4.1.3. Changing river discharges (water quantity and quality)

Upstream developments (e.g. Farakka Barrage and other dams in the catchments of Ganges, Brahmaputra and Meghna) will lead to significant changes in river flows and dynamics that will change the seasonal availability of freshwater in the coastal zone. Of specific concern is the plan to execute the Jogighopa-Tista-Farakka Link Project or National River Linking Project (NRLP) in India (see **Figure 18**). More details on river dynamics and plans can be found in the Baseline Study Rivers.

Water diversion from the Brahmaputra and Ganges could initiate a process of environmental degradation in Bangladesh. A 30% diversion of the Brahmaputra and 20% of the upper Ganges diversion in combination with climate change would generate a 22% in monsoon flow for the 2090s but with a significant 48% reduction in low flows (Whitehead et al., 2012). Adverse impacts can be expected on hydraulics and river morphology, water resources, agriculture, domestic water supply, fisheries, forestry, navigation, industry, biodiversity, and socio-economy. Reduced flow in the Lower Meghna as a result of reduction in Brahmaputra flow will increase salinity intrusion in the Lower Meghna, with a disastrous possibility of salinity intrusion into the freshwater wetland ecosystem. Reduction in the Ganges flow due to transfer of Ganges water to the Indian peninsular region is likely to worsen the existing environmentally-stressed condition of the southwest region of Bangladesh. It could also lead to a significant reduction in sediment load of the river, which could cause more river and coastal erosion in Bangladesh (Bhaduri & Barbier, 2008; Chowdhury, 2005). In 2005, the International Water Management Institute (IWMI) and the Challenge Program on Water and Food (CPWF) started a three year research study on the "Strategic Analysis of India's River Linking Project (SAIRLP)". It showed that many factors were not yet considered, or the factors considered are not relevant or not realistic (Joshi, 2013).

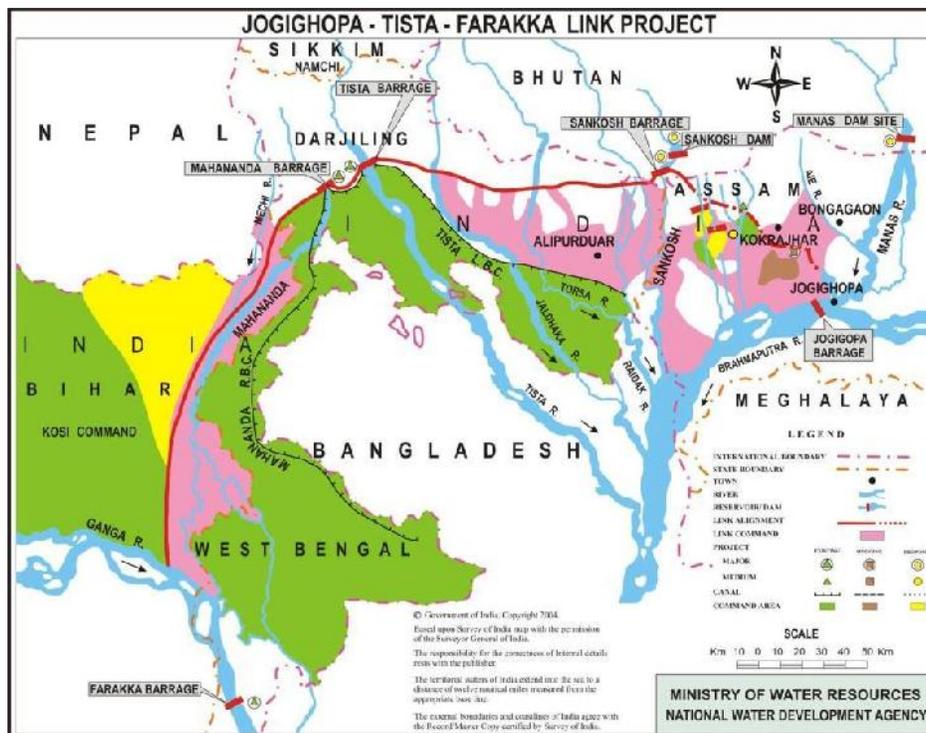


Figure 18: Jogighopa-Tista-Farakka Link Project or National River Linking Project (NRLP) of India

4.1.4. Population trends / urbanization

Fertility is still playing major role in population growth. With the current rates of fertility and mortality, the population size is expected to be about 280 million before it stabilizes (GoB, 2012). However, this growth will probably not be uniform over the regions. It is quite possible that there will be a net outward migration from the rural areas towards the cities, especially younger people.

BBS shows that the total fertility rate (TFR) of the country is 2.3 at national level (rural 2.7 and Urban 2.1). Comparing the TFR rates from year 1974 to 2011, the overall total fertility rate (TFR) has declined from 6.3 to 2.3, which is illustrated in the **Figure 19**.

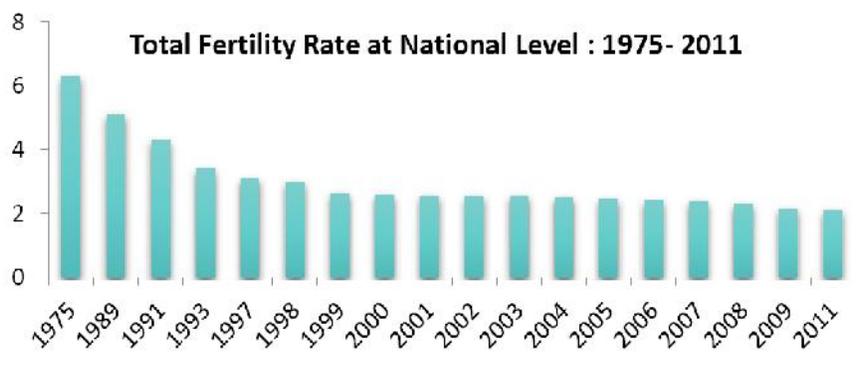


Figure 19: Total Fertility rate at national level (Source Baseline Study: Growth of Population and Management)

The present population of Bangladesh is 157 million in accordance with BBS and population density of more than 1,115 persons per square km. The population has been increased over the years from 50 million in 1961 to 149 million in 2011. The trend of increase of population is presented in the **Figure 20**.

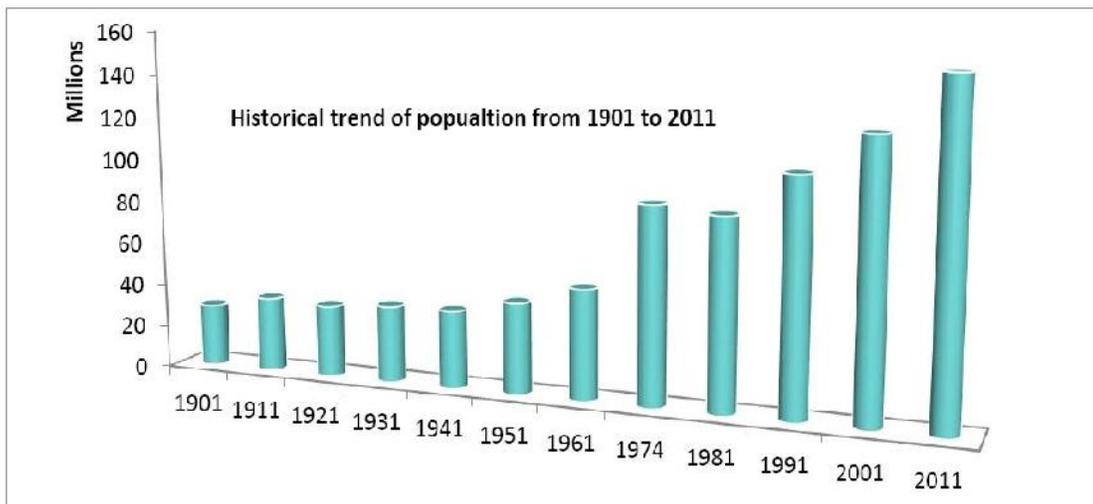


Figure 20: Historical Trend of Population

(Source: Baseline Study: Growth of Population and Management, BBC Statistical Yearbook 1991-2013)

Increasing demand for land for urban and other infrastructure needs will drastically reduce availability of land for agriculture. Per capita availability of net cultivable area will decline to less than half, from 0.53 ha (2001) to 0.24

ha (2050). This will have tremendous pressure on land use, economic and social infrastructures and food security (GoB, 2006).

Together with Dhaka the coastal cities of Chittagong and Khulna already account for 54% of the total urban population of the country (GoB, 2006). Further growth of these coastal cities is expected.

In 1974 people living in urban areas accounted for only 8.8% of the population where in 2011 this urban population was 28% of total population. The trend of increase of urban population is shown in the **Figure 21**.

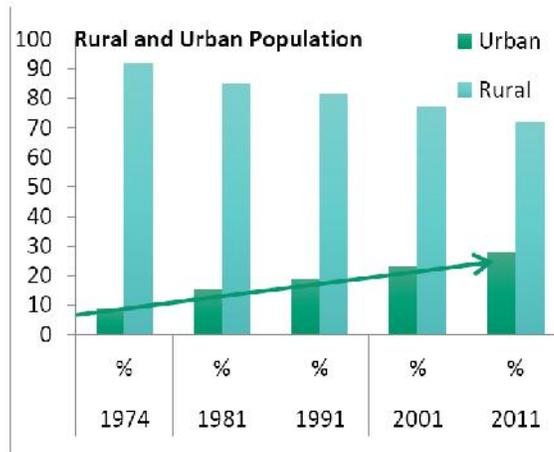


Figure 21: Total Rural and Urban Population Trend

(Source Delta Plan Baseline: BBS: Statistical Year Book 1991-2013 & World Bank WDI)

Population Projection

There are several methods to estimate the future population of Bangladesh. The United Nations (UN) had been publishing country level population estimates and projections since 1951. These population projections have been prepared by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat.

In 2013 the “2012 Revision” of the World Population Prospects²⁹ was published, containing among others **three fertility variants** (medium, high and low) up to 2100, each sharing the assumptions made with respect to mortality and international migration. Starting year for the projections is 2010.

For Bangladesh the assumptions about the three fertility variants are as follows:

- *Medium variant:* the total fertility rate (TFR) declining to 2.20 in the period 2010-2015, and further declining to 1.69 (lowest level) in the period 2040-2055 and slightly increasing in the next 45 years 1.82. By 2050, the total population of Bangladesh will be about 200 millions.
- *High variant:* the TFR is projected to reach a fertility level that is 0.5 children above the total fertility rate in the medium variant. By 2050, the total population of Bangladesh will be about 236 millions.
- *Low variant:* the TFR is projected to reach a fertility level that is 0.5 children below the total fertility rate in the medium variant. By 2050, the total population of Bangladesh will be about 172 millions.

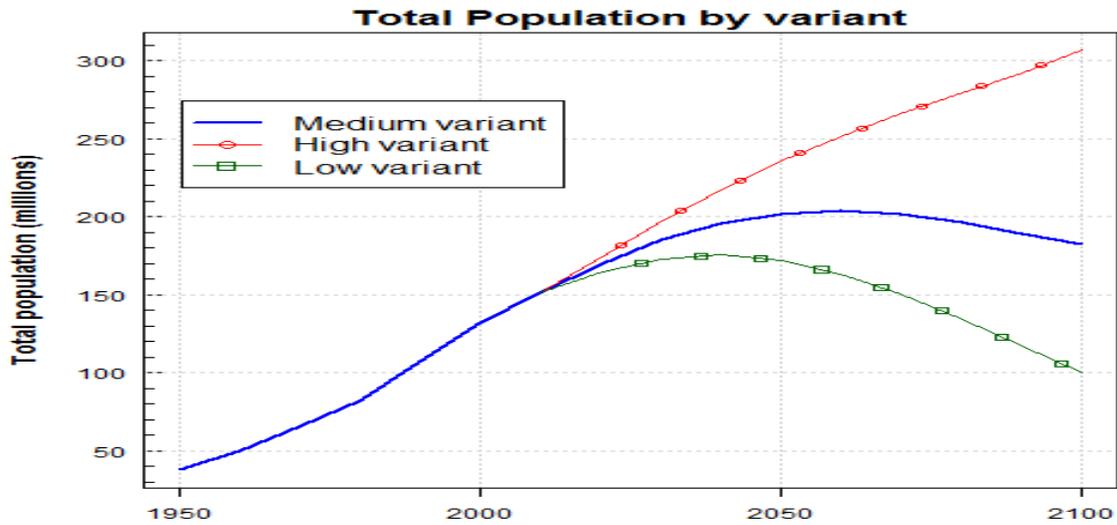


Figure 22: Total Population of Bangladesh by variant

Source: UN, World Population Prospects, the 2012 Revision: Volume II: Demographic Profiles

In the recent study namely “Ganges Basin Development Project” by IWMI (2014) the population of 19 coastal districts had been derived from the population census 2011 of BBS. The district-wise annual population growth rate had been calculated as well as future projection has been made accordingly. The **Figure 23** shows district-wise annual population growth rate calculated from the census between 2001 and 2011 for the coastal area of Bangladesh. The analysis shows that the growth rate in the coastal area of Bangladesh is varying from -0.48% to 2.58%. The highest annual growth rate is found in Cox’s Bazar followed by Noakhali, Lakshmipur, Feni and Chittagong districts, where the negative annual growth rate is found in the Bagerhat, Barisal, Jhalokhati and Khulna districts. Under the same study the future population had been projected considering the calculated district-wise annual growth rates where for every 5 years the future growth rate is varying. The projection is indicating that from 2011 to 2050 the population will be increased from 38,517,698 to 42,107,836 in the 19 coastal districts which are shown in **Figure 24**.

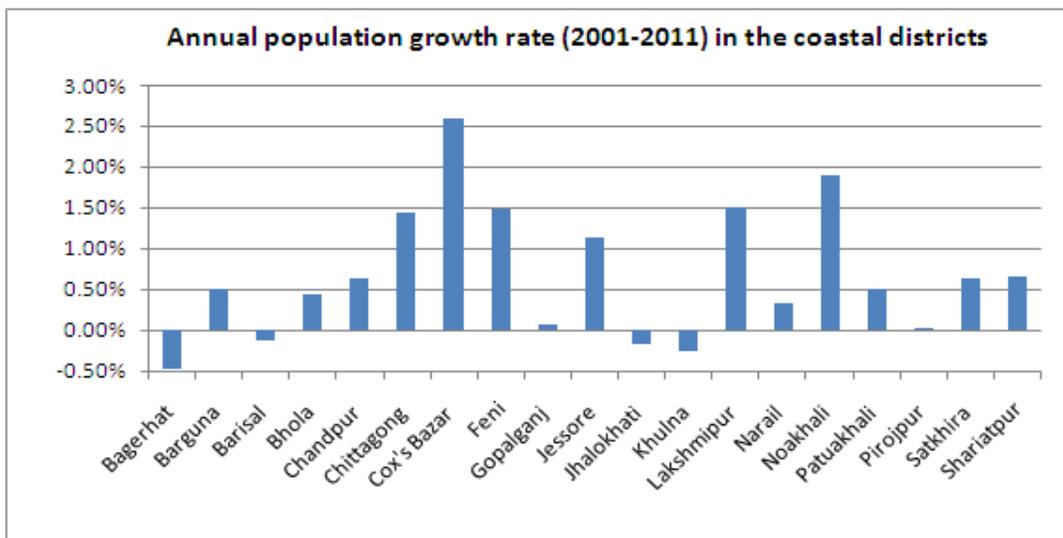


Figure 23: Annual population growth rate from 2001 to 2011 in the coastal districts

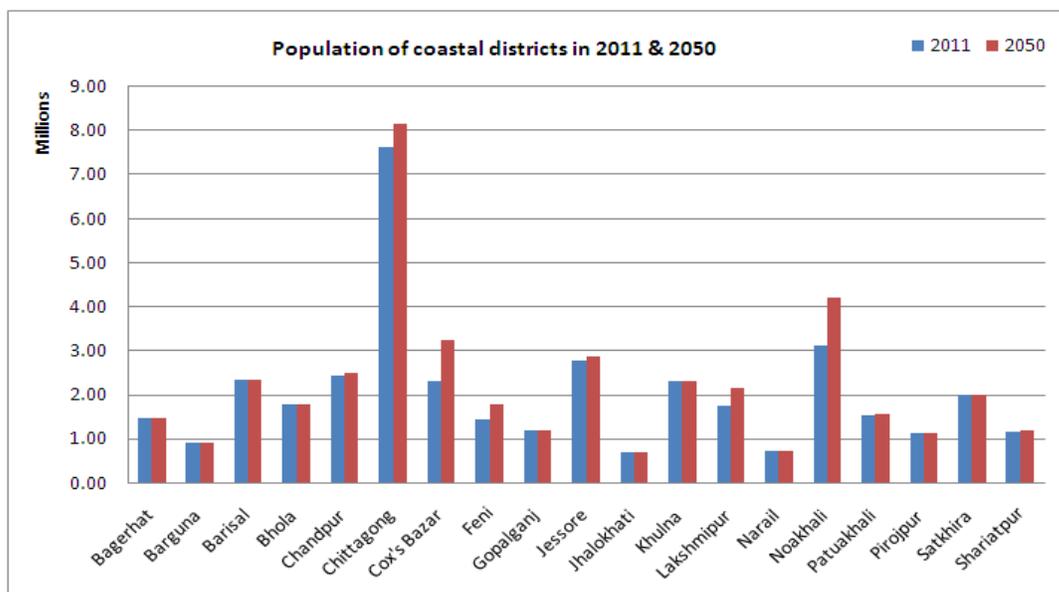


Figure 24: Population in the coastal districts in 2011 and 2050 (projected by IWMI)

4.2. Consequences and tipping points

Below a number of key concerns are raised from a *long term perspective*, in view of the changes due to the drivers described in the previous section.

4.2.1. Salinity intrusion biggest problem to face in future

Salinization of river water in the coastal area is a major risk from climate change. Sea level rise is likely to cause significant changes in river salinity in the southwest coastal area of Bangladesh during dry season (October to May) by 2050, which will likely lead to significant shortages of drinking water in the coastal urban areas, scarcity of water for irrigation for dry-season agriculture and significant changes in the coastal aquatic ecosystems (IWM, 2014). Changes in river salinity and the availability of freshwater may affect the fish habitat and productivity freshwater fisheries. In addition, increase in salinity is expected to change the mangrove pattern of Sundarbans. For the south-western area the reduced inflow of fresh water from the Ganges has *already* created a tipping point.

Simulation of salinity intrusion with sea level rise of 52 cm in 2050 shows that the freshwater zones in the Bagerhat, Barguna, Barisal, Bhola, are likely to be lost. Khulna, Jhalokati, Pirojpur, and Satkhira Districts will also be most adversely affected by the increase in river salinity in times of climate change. It is seen that an area of 7000 sq km is likely to be affected by more than 1 ppt and about 8400 sq km would be affected by more 2 ppt salinity in the southwest and south central zones by 2050 under 52 cm sea level rise (IWM, 2014). The 2 ppt salinity front moves about 65 km in the much of Barisal division, as shown in **Figure 25**. This will create a tipping point for many agricultural activities in this zone, i.e. many farmers have to choose a new farming strategy.

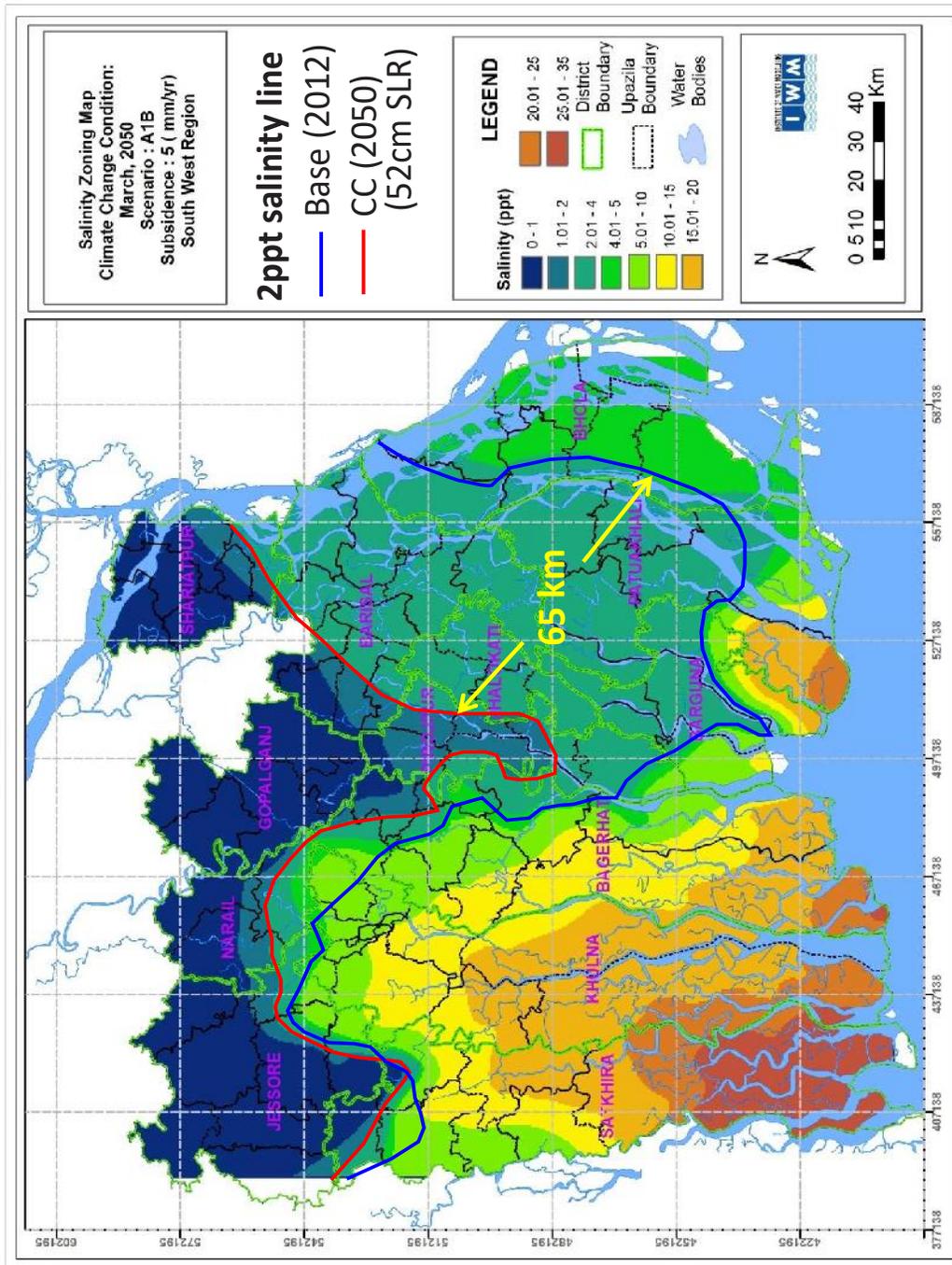


Figure 25: Effect of Sea Level on 2ppt Salinity contour (A1B, 2050)

The number of people in the southwest coastal region affected by salinization is likely to increase with +15 to +100% (2.9 to 5.2 million people), again disproportionately affecting the poor (+23 to +130%), S. Dasgupta, blog post, 2015.

Salinity may thus become the biggest problem in the coastal zone for the next 50 to 100 years, due to Accelerated Sea Level Rise (ASLR) and uncertainty in river flows. This requires a comprehensive approach to water supply. Target is to make the country less dependent on river flows by i) water storage; ii) sustainable use of groundwater through active groundwater recharge in monsoon season; iii) saline resistant crops; iv) small scale water desalination using solar power; v) Construction of the Ganges Barrage, vi) Joint collaboration and negotiation with upper riparian countries for sharing of river water to ensure fresh water flow through the trans-boundary rivers etc.

4.2.2. Sea level rise: land loss or land gain

Land loss due to sea level rise can be prevented by building with nature. Even in an accelerated sea level rise scenario, it is conceivable that the Bangladesh delta could still be growing (seaward). This largely depends on the availability of enough sediment. Multiple measures that actively support new land formation, such as land reclamation, cross dams, building with nature techniques, protection of pioneer (mangrove) vegetation and erosion protection should be promoted.

4.2.3. Waterlogging a major problem

Waterlogging will become a major problem. The combine effect of sea level rise and increased precipitation in the changing climate, subsidence inside polders and sedimentation of peripheral rivers will deteriorate the drainage condition. Restoration of tidal plain for tidal inundation in increasing the tidal prism of the tidal river, sediment management allowing free movement of tide into Polders for certain periods of the year to raise the low lying land are very likely measures for solving water logging problems. In order to obtain faster drainage in times of climate change pumping might be required in addition to gravity drainage of polders. It is important to asses where this tipping point lies.

Tidal river management (purposely regular inundation of polders whereby sediment is deposited) could become standard procedure for all coastal polders. This would counterbalance subsidence and reduce the problem of waterlogging.

4.2.4. Safety against coastal floods too low

Currently, safety against storm surges in the coastal regions is too low (only against 8-year to 10-year return period storm surge level) and implies that investments will stay away, more people will migrate to urban areas and agricultural growth will remain marginal. Current design standards for storm surges are 1:25 per year. An increase to 1 in 250 years for the coastal polders should be considered for key investment areas first and later for the entire Bangladesh coast considering integrating water management.

4.2.5. How to use economic opportunities

Economic opportunities should be fully exploited in a sustainable way. Deep sea port development, renewable energy, ship breaking and ship building will provide employment and economic growth, but their planning and management should comply with environmental and social safeguards.

4.2.6. O&M remains weak

Operation and maintenance of coastal embankments and other water infrastructure is too weak. A sustainable cost recovery mechanism should be in place for monitoring, operation and maintenance of the embankments.

5. Evaluation of past, existing plans and projects

5.1. Land reclamation

5.1.1. Potential of land reclamation in Bangladesh

The average total annual sediment discharge of the Brahmaputra and Ganges over the period 1966-1991 is about 1,100 million ton/year. The annual mean sediment transport of the Upper Meghna is negligible compared to the sediment discharge of the Brahmaputra and Ganges [J.M. Coleman]. It is assumed that the net gain of land in the southern part of Bangladesh is related to the amount of river borne sediment discharge; during high periods of river borne sediment discharge (monsoon), the net gain of land and intertidal areas is higher than during low periods of river borne sediment discharge.

Based on the analysis of satellite images Meghna Estuary Study II estimated erosion and accretion for the period 1973-2000. During this period 86,366 ha were eroded while 137,168 ha were accreted resulting in a net accretion of 50,802 ha which is equivalent to the net accretion rate of 18.8 km²/year.

The magnitude of erosion and accretion in the Meghna Estuary area from 1973 to 2008 is calculated in the coast line delineation study under Estuary Development Program. During this period the extent of erosion was 1045 km² while that of accretion was 1642 km² with a corresponding net accretion of 598 km². The rate of net accretion was 17.07 km². Compared to the volume of sediment transported through the estuary, only a portion is being deposited in the estuary [EDP]. Results of previous study indicate that the estuary is potential for land reclamation and it can be achieved by planned and study based physical intervention.

Accretion and erosion in the Meghna Estuary is a continuous and gradual natural process interfered by the dynamics of the ever-changing courses of its channels. During 1940- 1950 in the lower Meghna estuary, Shahbazpur channel has been developed as the main branch reducing the discharge rates in the other branch. As a result, sedimentation in the eastern branch of the lower Meghna main channel started. Finally the channel lost its course completely when the first earthen cross-dam (Cross dam No. 1) was constructed over the lost course connecting main land of Lakshmipur with the island, north Hatiya (presently Ramgati) in 1957 in order to reclaim land from the estuary.

Encouraged at the result of land accretion due to construction of first cross dam, the cross dam no. 2 was constructed connecting main land of Sonapur with char Jabbar in 1964. Muhuri closure dam was constructed on flowing channel over Muhuri River outfall in February, 1985. As a result, more than 1000 sq. km of land reclaimed in the south of Noakhali (**Figure 26**).

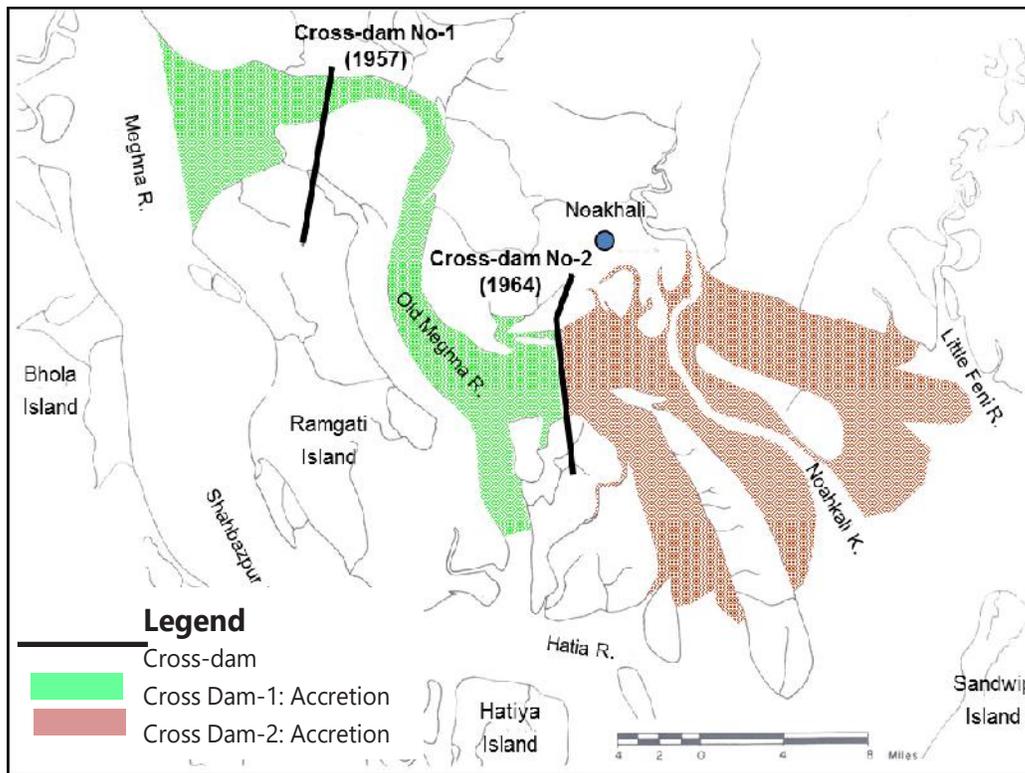


Figure 26: Reclaimed area in the old course of the Lower Meghna

Source: LRP Technical Report No.15, 1983

5.1.2. Land Reclamation Project (1980)

In 1975, the Bangladesh Water Development Board proposed technical cooperation with the Netherlands in the fields of land reclamation and estuary control. Following the recommendations of an identification mission a technical cooperation between Bangladesh and The Netherlands, was signed on May 1977. Afterwards, Land Reclamation Project (LRP). LRP activities started from 1980.

Objectives

The objectives of LRP were:

- To set up an organization within the Bangladesh Water Development Board to carry out survey and studies in order to develop a long term policy for land accretion works in the south-eastern coastal area of Bangladesh.
- To try out various methods to accelerate the accretion of land, in order to define those methods that are feasible in Bangladesh.
- To implement an experimental test scheme with the purpose to promote a quicker and more effective use of newly gained land, so that food production is increased and conditions are viable for poor farmers.

Main activities conducted under LRP are as follows:

- Hydrographic survey and data collection in the estuary.
- Accretion trial by implementation of pilot sedimentation field.
- Implementation of Daria Nadi closure for land reclamation.
- Research plot on char Baggar Dona in view of land development for agriculture use.

Feasibility level studies were conducted on:

- i. Sandwip Cross dam Development Scheme;
- ii. Char Majid Polder;
- iii. Char Bhatir Tek Polder;
- iv. South Hatia- Nijhum Dwip cross-dam

Achievements

- Hydrographic survey and data collection in the estuary
- Accretion trial by implementation of pilot sedimentation field
- Implementation of Daria Nadi closure for land reclamation
- Research plot on char Baggar Dona in view of land development for agriculture use

5.1.3. Meghna Estuary Study (MES), 1991-1998

After Land Reclamation Project (LRP) emphasis was given more to the development of the new land rather than to the accretion of land. By the end of LRP, in 1991, both the Government of Bangladesh and the Netherlands, in recognition of the two distinct approaches decided to continue the LRP project under two separate projects namely:

1. Char Development and Settlement Project (Land based); and
2. Meghna Estuary Study (Water based).

Objectives

The objectives of the Meghna Estuary Study were as follows:

- Planning the development of the project area, giving due attention to: Survey and Studies in the estuary, Master Plan of the area, Land and water use.
- Enhancing understanding of the natural forces that shape the physical properties of the area and which largely determine the potential for settlement and development (**Figure 27**).
- An early start to implementation of priority projects and programs that is compatible with the phased long term and / or development plan. Implementation works beyond the stage of practical experiments is not included in MES.
- Practical solutions for an effective continuation of survey and studies, aimed at sustained and coordinated actions to update and progressively implement the long term plan.

Achievements

Main achievements of MES were as follows:

- Hydrographic survey (marine) by M.V. Anwasha about 9600 sq km out of 1100 sq km.
- A Master Plan and a Development Plan for the Meghna Estuary;
- Implementation of pilot trials for erosion control and land accretion by cross dam;
- Evaluation of the effectiveness of the various pilot schemes for erosion control;

- Update knowledge on morphology and hydro-dynamics and the predictions of future developments;
- Identification of potential cross dam: based on MES study and relevant data, BWDB task force team identified 19 potential cross dams at different location of estuary (**Figure 28**).

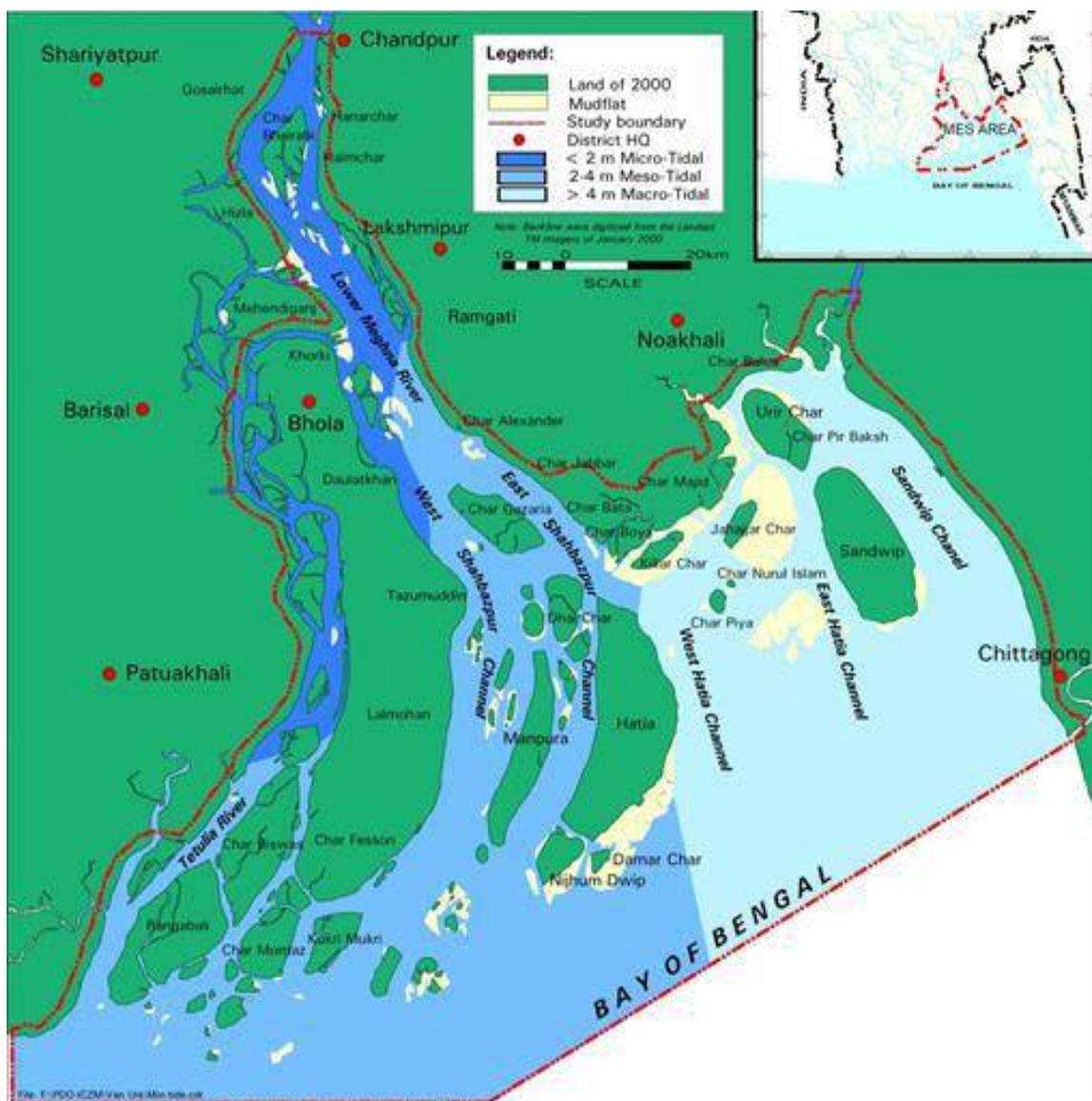


Figure 27: Study area of Meghna Estuary Study (MES)



Figure 28: Potential Cross Dams for land accretion

5.1.4. Estuary Development Program EDP (2007-2009)

Because of rapid natural changes and changes induced by human interventions, the plan has to be adjusted and revised as a rolling process. Consequently attention was given to a continuation of surveys and monitoring as well as updating of models and studies beyond MES. Therefore, a new 5 years program, the Estuary Development Program (EDP) was formulated. EDP Started in 2007 as a follow up of the Meghna Estuary Studies. It included an investigation, design and implementation of potential cross dams and erosion control and accelerated land accretion schemes.

Objectives

Objectives of EDP were as follows:

- i. Updating of bathymetric survey data and micro-level survey for viable investment oriented project and databases, Hydro-survey of entire coastal area for understanding of dynamics & morphological process by establishing Survey & Study Support Unit (SSSU) ;
- ii. Investigation and Design of potential cross dam;
- iii. Investigation and implementation of potential erosion control and accelerated land accretion schemes.

Achievements

- Repair of Survey Unit Anwasha (SUA) , procurement of survey & navigational equipments including modern survey software;
- Implementation of 11 nos. of Hydrographic survey cruise.;
- Delineation of coastline;
- Updating Bay of Bengal Hydrodynamic model;
- Design of Char Mainka- Char Islam-Char Montaz cross dams (South of Bhola);
- Conceptual design of (i) Urir Char-Char Clark (ii) Sandwip - Jahajer Char – Noakhali cross dam.
- Implementation of Bestin closure (Near Char Montaz);
- Environmental Impact Assessment (EIA) study

5.1.5. Char Development and Resettlement Project (CDSP-IV)

The first Char Development Project started in 1994 (CDSP-I; 1994-1999) and included 3 polders in Noakhali District. Subsequently CDSP-II (1999-2005) regarded 7 areas, including unprotected areas, in Lakshmipur, Noakhali, Feni and Chittagong District. CDSP-III (2005-Dec.2010) focused on 2 areas (Boyer Char and Baggar Dona upstream) in Noakhali District.

Objectives

The overall objective of CDSP-IV is to improve the economic situation and living condition of the population in the coastal areas of south-eastern Bangladesh with special reference to the poorest segment of the population. It started on March 2011 for the period of 6 years. The following Chars of Noakhali and Chittagong Districts of Southern Bangladesh will be under this project: *Caring Char Char Nangulia, Char Ziauddin, Noler Char, Urir Char*. Total Land = 30,000 Hectares; Households: 28,000; Population: 155,000.

Participating agencies and funding

In CDSP-IV, as in the previous project, the following agencies are participating:

- Bangladesh Water Development Board

- Local Government Engineering Department
- Department of Public Health Engineering
- Ministry of Land
- Department of Agriculture Extension
- Forestry Department

The project is financed by the Bangladesh Government, IFAD and the Netherlands Government. The total project cost is estimated at USD 89.2 million. Of this USD 47.3 million will be funded via an IFAD loan, USD 20.6 million by a grant from the Netherlands Government, USD 15.6 million from the Government of Bangladesh, USD 4.9 million from participating NGOs (for micro-credit), and about USD 0.81 million from the beneficiaries.

Land titles

Land settlement is an essential component of the CDSP-project, right from the start of CDSP I in 1994. The ultimate aim of this component is to provide hitherto landless households with a title on the land in newly developed chars. Since 1994 a total of 20,827 *khatians* (land title documents) have been distributed by the Ministry of Land in the framework of CDSP. Monitoring exercises indicate that over a period of on average 12 years, 80% of the original settlers still lived in the area and of these, 85% still had their original allocation of land.

According to Government regulations, newly emerged land has to be distributed to the landless (Policy for settlement of agricultural khas land of 1997), including a title on the land to a maximum of 1.5 acre per household. It is the task of the Government to apply the law and initiate and complete the process of land settlement (providing eligible households with a title). In the project innovative procedures are followed which bring the whole settlement process closer to the people, are more transparent, shorten the duration and make it far less costly for the settlers.

Providing a title directly contributes to the main objective of CDSP: improving the livelihoods of settlers in coastal char areas. Families in these new chars come from different areas, often from locations where erosion occurred and land was lost. It considerably broadens the asset base of the households. The legal security that the document gives to the settlers will stimulate them to invest in their newly acquired land, which will have a positive effect on the agricultural production. Being landowners, the social status of the households is enhanced and the self-confidence of the settlers is increased.

Innovations

The project has a number of innovative features, with opportunities of learning by the implementing agencies, the government and the development partners. First of all, unlike earlier char development projects, over half the area to be covered will not be protected by embankment (as it is too immature and unstable for empoldering). To generate benefits for people living in these very vulnerable chars, innovations such as salt-adapted agricultural technologies, house plinth raising and house strengthening will be needed. CDSP IV also plans to construct killas as refuges for livestock on such chars – something that earlier char development programmes have not done (IFAD, 2010).

Achievements

The CDSP projects have over the years evolved into a rather successful formula of coastal development. Based on a household survey conducted by BRAC it was found that the programme intervention significantly increased the per capita income of the char dwellers. They were found to have a higher standard of living (measured by housing condition, asset holding, and food expenditure) compared to their counterparts. Furthermore, income generating assets such as rickshaws/vans, boats, small shops and fishing nets showed remarkable improvement

due to the intervention. Consequently the working-aged members were found to rely less on day labouring, and more on self-employment in livestock and poultry rearing. Respondent women's awareness on various social and legal issues was also found to be affected positively by programme intervention. The BRAC researchers also performed in-depth interviews which revealed that many of the livelihood improvements were directly attributable to the intervention through the development of infrastructure in the area besides the remarkable performance of microfinance. It was found that the development of roads, some educational institutions, provision of safe drinking water in the char, and foremost, the level of security provided by driving out the pirates from the area had contributed significantly in improving the quality of livelihood the char dwellers experience. The study concluded that the community level intervention is immense and the Boyer Char (which was surveyed) can be referred to as a microcosmic case study for the rest of the nation (Reza et al., 2011).

More generally, the success factors of CDSP could lie in a combination of the following (pers.com. Mafuz 16-09-2014):

- Focus on the ultra-poor
- Visibility
- Small-scale
- Continuity

Follow-up

Although CDSP-IV is still ongoing till 2017, ideas are being investigated for CDSP-V. Issues which could be of much relevance for the coming years are (pers.com. Jan van der Wal, 15-09-2014):

- Enhanced land reclamation using cross dams;
- Making more use of mangroves for protection and land accretion;
- Solving the drainage congestion in the older, developed chars in Noakhali;
- Options for freshwater retention;
- Safeguarding food security under climate change in the CDSP 1-4 areas

What are consequences of possible reduction in sediment load?

5.2. Polder improvement and tidal river management

5.2.1. What is tidal river management (TRM)

Tidal River Management (TRM) involves taking advantage of natural tidal movement in the river and adjacent low lying flood plain. TRM allows natural movement of tide from the river to an embanked low lying area (beel) through a link channel. During flood tide, sediment laden water enters to the low-lying area where the sediments are deposited due to reduced velocity and long duration of storage. During ebb tide the tidal water flows out of the low-lying area with reduced sediment load and erodes the river bed and bank at the downstream. The natural movement of flood and ebb tide in the river and low-lying area increases the drainage capacity/conveyance of the river through scouring and maintains the river navigability. Subsequently the low-lying area is raised considerably due to deposition of silt. The TRM process is an example of building with nature and a resilient measure for water-logging, river sedimentation and subsidence.

5.2.2. Khulna-Jessore Drainage Rehabilitation Project (KJDRP)

The Khulna-Jessore Drainage Rehabilitation Project (KJDRP) of BWDB was initiated in the year 1994 by the Government of Bangladesh with the financial and technical assistance of Asian Development Bank (ADB). In the early 90s agricultural land in two polders including the homestead area under Jessore and Khulna districts

remained submerged for a long duration causing sufferings and economic loss of the communities due to siltation of the rivers. In the post monsoon huge sediment is brought into the river system naturally by tidal pumping and deposits at the dead end of the river but ebb tide can't erode this deposited sediment. This process results in river sedimentation.

The proposed solution was with re-orientation and re-excavation of the drainage network and constructing additional sluices where necessary. This was easily implemented in the Khulna area to remove the water-logging from beel Dakatia of polder 25. But this structural solution could not be implemented in polder-24 of Jessore area due to strong opposition from local communities, LGI and NGOs. It was thought by the local stakeholders that construction of Bhabadaha sluice across the Hari river was the main cause of water-logging in that area, so they would not allow to construct another large regulator at the further downstream of the same river to create water-logging in a greater area.

Tidal River Management (TRM): Water-logging scenario in this region was aggravated in 1997 flood (monsoon) season. In post flood season local people had cut the embankment at the right bank of polder-24 of beel Bhaina for quicker drainage needed for Boro-rice cultivation on their land. Although rapid drainage occurred from beel Bhaina due to much head difference between the C/S and R/S water levels but the beel could not be brought under Boro-rice cultivation by closing the cut-point to prevent tidal flooding twice a day which became gradually wider and deeper and went beyond the capacity of the local farmers to close. But at the end of dry season they observed that land level of beel Bhaina was raised, on the other hand depth of Hari river increased significantly. The local people, LGI and local NGO's drew attention of the donor agency to apply this phenomenon (which they called Tidal River Management or TRM) in all the beels adjacent to Hari river sequentially as a tool to remove water-logging from the inundated beels. BWDB adopted the technique of TRM for increasing tidal prism and raising low-lying beels.

The people of beel Kedaria were very much in favour of operation of TRM just to raise their land, but actually it did not happen as per their expectation at the end in 2004 due to operation of TRM through the Bhabodah sluice gate. Although there was no water logging in the area during 2002 to 2004 but the land owners lost their interest to operate TRM by submerging their land without getting any yield at least for three years. This created a negative impact on TRM and ultimately BWDB could not find any beel to operate TRM in the year 2005. As a result the Hari river again became silted-up in the dry season to reveal water-logging in the area during the monsoon of 2005.

TRM in Beel Khuksia: People realized that the area will remain under water if TRM is not operated in any of the beels adjacent to Hari river. The challenges of TRM operation are social and institutional. People are unwilling to provide their land for TRM operation since they cannot cultivate agriculture crop during operation of TRM. To overcome this challenge a compensation mechanism for crop and fisheries has been established. However, the process of providing compensation is very complex and needs further improvement. Everyone supported operation of TRM to get rid of water logging but except on his own land. Having no other alternate solution, 3rd TRM in beel Khuksia was started in November 2006. About 2.5 meter depth of water was removed from 18100 hector of land of 193 villages, 21 unions and 2 municipalities and the area was brought under Boro cultivation at the end of year 2008. The Hari river was restored and the land of the beel also was raised about 2 to 4 feet. The next beel for TRM is Beel Kapalia in accordance with the long-term plan prepared by IWM, BWDB has started consultation with land owners for obtaining land on compensation basis and expected to start in the year 2016.

5.2.3. Coastal Embankment Improvement Project (CEIP)

Bangladesh Water Development Board completed 139 polders and by means of which about 1.2 million hectares of land is under permanent agriculture within the coastal embankment system. The polders were designed to keep the land safe from the daily tide to allow for agriculture activities. But the coastal embankment system of Bangladesh was originally designed to protect against the tides and the associated salinity intrusion, without much attention to storm surges. Recent devastating cyclones brought substantial damage to the embankments and further threatened the functionality of the coastal polders. In addition to breaching of the embankment due to cyclones, siltation of peripheral rivers surrounding the embankment caused the coastal polders to suffer from water logging, which lead to large scale environmental, social and economic degradation. Poor maintenance and inadequate management of the polders have also contributed to internal drainage congestion and heavy external siltation. As a result, in some areas soil fertility and good agriculture production are declining because of water logging and salinity increase inside polders. Currently the coastal polders can protect the hinterland against 8-year to 10-year cyclonic storm surge level. The present safety level of coastal polders against cyclonic storm surge is shown in the Figure 29.

The above reasons have led the Government to re-focus its strategy on the coastal area from one that only protects against high tides to one that provide protection against frequent storm surges. After cyclones SIDR and AILA struck the coastal zone causing severe damage to the infrastructure, life and property, the Government of Bangladesh (GOB) obtained an IDA/credit for Emergency Cyclone Recovery and Restoration Project (ECRRP), 2007 and some proceeds from this credit were used to meet the expenses for carrying out the Feasibility Study of The Coastal Embankment Improvement programme. The main objective of the consultancy services was to support Bangladesh Water Development Board (BWDB) in preparation of comprehensive Coastal Embankment Improvement programme (CEIP) and implementation of first phase project CEIP-1 to be carried out. As an outcome of the study a project in the name of Coastal Embankment Improvement Project Phase-1 (CEIP-1) was conceived. Under this project selected 17 coastal polders will be upgraded and rehabilitated with the financial support from the World Bank (USD 400 millions). This project has been approved by the ECNEC in October 2013.

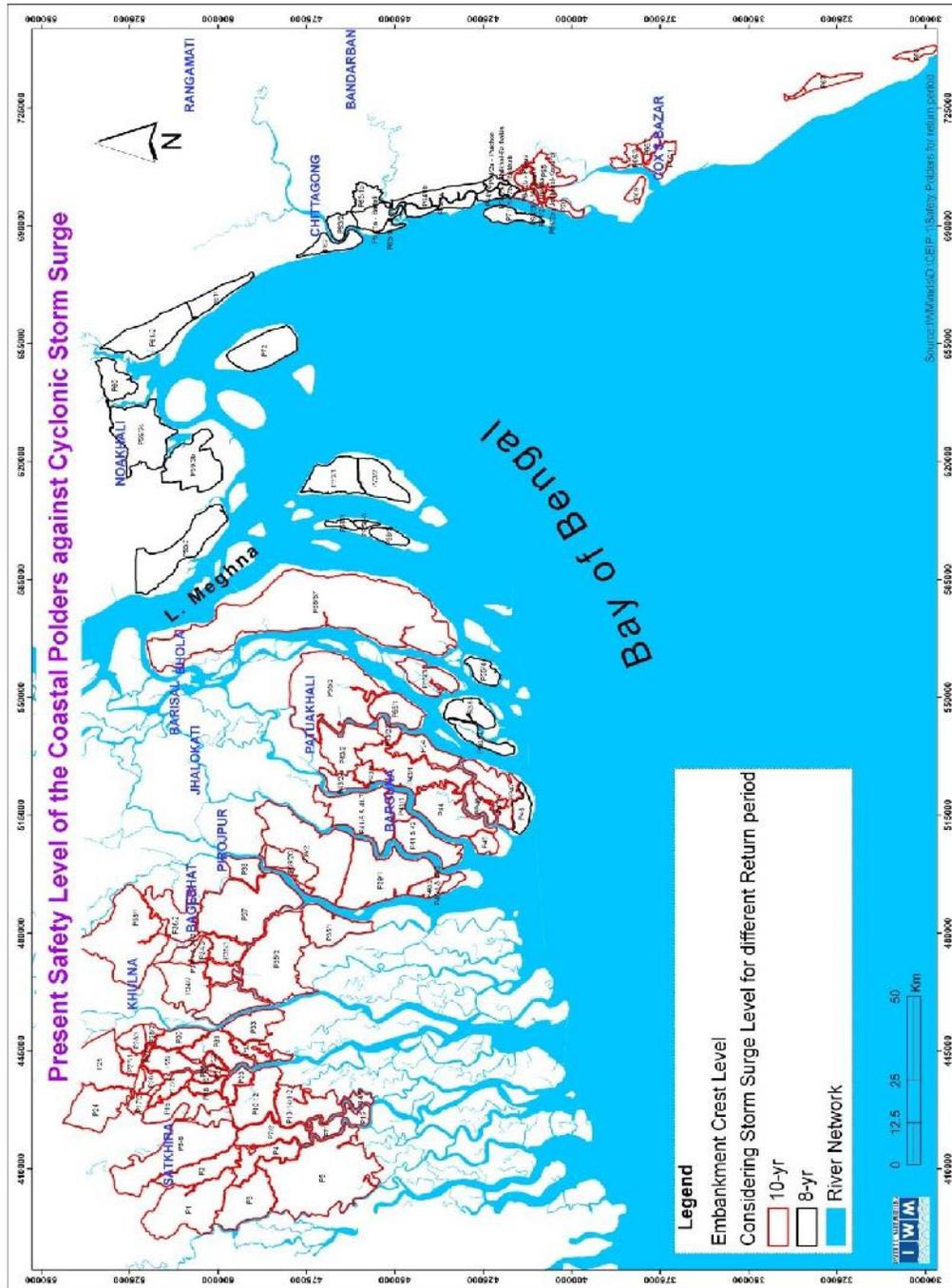


Figure 29: Map showing the present safety level of coastal polders against cyclonic storm surge

Objectives

Main objectives of the project are as follows:

- Reducing the loss of assets, crops damage and livestock during natural disasters;
- Reducing the time of recovery after natural disaster such as cyclone;
- Improving agricultural production by reducing saline water intrusion which is expected to worsen due to climate change; and
- Improving the Government of Bangladesh's capacity to respond promptly and effectively to an eligible crisis or emergency.
- The existing embankment systems of the polders will be upgraded and rehabilitated to protect the climate change induced cyclones and storm surges.
- A net area of about 100,817 ha of the project would be protected against events of 25 years return period for climate change conditions that would exist in 2050. Additional safety factors have also been built in by allowing for the higher estimates of subsidence and sea level rise. The actual level of protection soon after project completion (say 2020) would be more than a 50 year return period.
- To increase agricultural production of the net cultivable area of 86,382 ha through construction of embankments, drainage regulators, flushing sluices and drainage channels of the Polders.
- To increase crop yield through reduction of crop damages resulting from spring tidal flooding and cyclonic storm surges of the magnitudes of Sidr & Aila.
- Switch over from local to HYV paddy cropping under a comprehensive irrigation network by using surface water through construction of proposed flushing inlets, and
- Improve the existing drainage system of the project area for fish culture, expansion of Boro crops and T-Aman cultivation.

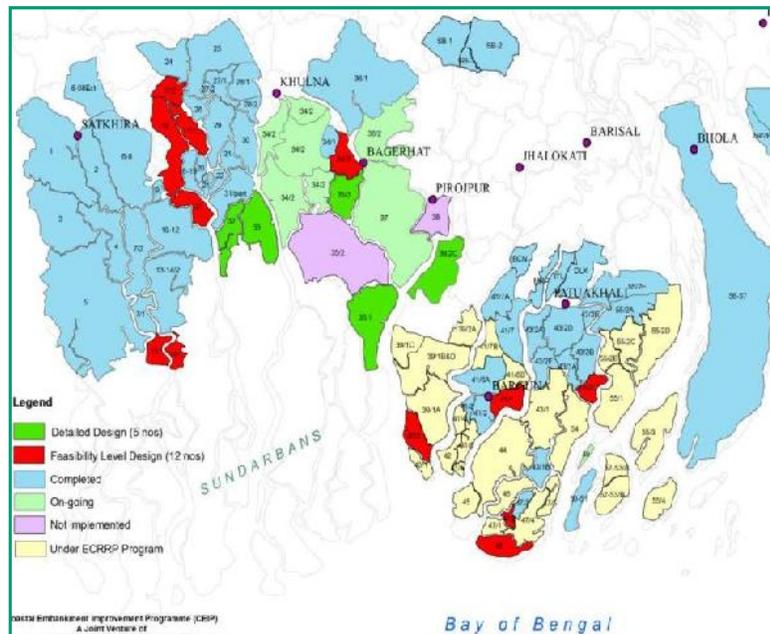


Figure 30: CEIP polders

The implementing agency is Bangladesh Water Development Board. The total budget is BDT 3,280 crores in BDT funded by World Bank. It consists of 17 polders in 6 coastal districts **Figure** . The list of the polders under CEIP is presented in **Table 14**.

Table 14: The list of the polders under CEIP

Division	District	Upazila	Polders
Khulna	Satkhira	Koira, Shamnagar & Tala	15, 16 (part)
	Khulna	Dacope, Paikgacha & Dumuria	14/1, 17/1, 17/2, 23, 32, 33 & 16 (part)
	Baferhat	Bagerhat Sadar, Swaronkhola, Morelganj & Rampal	35/1, 34/3 & 35/3
Barisal	Pirojpur	Bhandaria & Motbaria	39/2C
	Barguna	Barguna Sadar & Patharghata	40/2 & 41/1
	Patuakhali	Golachipa & Kalapara	43/2C, 47/2 & 48

5.2.4. Blue Gold

The Blue Gold Program builds on the results obtained and lessons learned from previous programs and projects, especially the Integrated Planning for Sustainable Water Management (IPSWAM) program. Its concept is consistent with the priorities of the Dutch cooperation policy with Bangladesh, as formulated in the Multi-Annual Strategic Plan (MASP) 2012-2015. The essence of the Blue Gold Program is first to establish and empower community organizations to sustainably manage their water resources and based on the priorities set by these community organizations deliver the services (in the area of agriculture, livestock and fisheries development) for which they have expressed a demand. The Program aims to create strong cooperatives that will interact with public and private organizations that play a role in the development of the area. Participatory water resources management is the entry point and the initial driver of the community organization process. **Figure** shows the project areas under Blue Gold Program.

Important challenges identified for the Blue Gold program are: the result of hydrological dynamics (partially influenced by climate change), the characteristics of the production systems (mainly based on paddy cultivation) in the area and an inadequate enabling institutional environment (with inadequate provision of services).

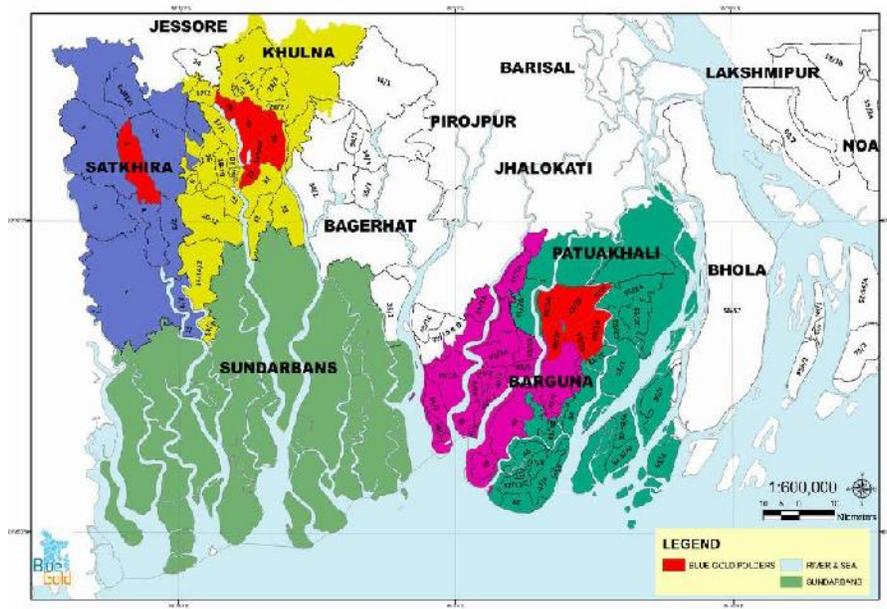


Figure 31: Blue Gold polders

Objectives

The Blue Gold programme will cover 25 polders with a combined area of 160,000 ha and will establish and empower rural community co-operatives to sustainably manage their defence, drainage and irrigation infrastructure. Overall objective of the Program is: "To reduce poverty by creating a safe living environment and a sustainable socio-economic development for 150,000 household living on the 160,000 ha of polders."

The programme consists of 5 components:

- Component 1 - Community Mobilisation and Institutional Strengthening.
- Component 2 - Water Resources Development (six-step approach to participatory water resource management)
- Component 3 - Food Security and Agricultural Development (support to WMGs in responding to existing or potential market demands for the end goal of generating additional income for rural households).
- Component 4 - Business Development and Private Sector Involvement (market development for the farmers in the polders)
- Component 5 – Livelihood Improvement and Cross Cutting Issues

The plan is to create 600 new co-operatives – to work alongside the 250 that have already been formed – and equipping them with technical, advocacy, communication and project management skills to strengthen water management assets. Furthermore, advice will be given on irrigation, drainage, land and fisheries management techniques to improve agricultural and aqua-cultural productivity to create more income.

5.3. River improvements

5.3.1. Gorai River Restoration Project

The project aims at preventing environmental deterioration in the south-western region (SWR) of Bangladesh, especially around the Khulna District, the Mongla Port, the coastal areas, and the mangrove forests in Sundarbans. It is expectedly achieved by (1) increasing the dry-season inflow volume from Ganges River and maintaining the water volume by dredging at the inflow point, (2) improving the system to effectively utilize the inflowing freshwater, and (3) increasing the organizational power, based on sustainability, to manage and maintain the restored water systems.

5.3.2. Ganges Barrage Plan

The proposed Ganges Barrage will create a reservoir with a capacity of about 2900 million M³ of water. The length of the reservoir is 165 km and area is 62,500 ha. Reservoir water would be diverted by the proposed distribution systems (Gorai, Hisna, Chandana, Baral etc.) in the 26 districts through 123 regional rivers in south west area of Bangladesh.

In the dry season 1365 cumec of Ganges reservoir water will be diverted through 8 off-take structures. This will be used in different seasons of the year through the channel networks with water control structures at the mouth of the channels to meet the requirements of irrigation, fisheries, navigation, salinity control etc. Figure shows the different channel systems through which the water will flow downstream.

Release of upland flow from the reservoir through river systems in the GDA will reduce siltation problem in the channels, mitigate drainage congestion of the areas, preserve biodiversity and forest resources in the Sundarban. Implementing agency is the Bangladesh Water Development Board (BWDB). The estimated cost of implementation is Tk. 31,414 crore.

5.3.3. Bhairab River Basin

The Bhairab river originally flowed from Kobadak river at Taherpur (in between Kotchandpur and Chougha Upazillas) and was flowing through Jhenaidah, Jessore, Narail to finally meet the Rupsa river in Khulna district. The Kobadak river was originally linked with the distributaries of the Ganges. But after commissioning of Kerew & Co. distillery industry during the British regime the linkage was cut-off to use the dead canal as a waste discharge outlet of the industry. The stretch of the Bhairab river from Taherpur to Jessore city is almost dead now due to upstream sedimentation and has no perennial flow for years. The river is now being used as a seasonal drainage canal for local rainfall only during monsoon season. The stretch of Bhairab river from the confluence of Rupsa to Afra ghat (The confluence of Vairab & Afra khal) experiences tidal influence up to Basundia bridge. The magnitude of tide is quite suitable for navigation up to Nawapara (Avaynagar U.Z) where cargo ships land regularly.

Potential Development Strategy: The main problem of the Bhairab river is non-availability of perennial water which was lost during establishment of Kerew & Co. distillery across the Kobadak river. The linkage can be re-established by excavation of a new by-pass link canal of about 16 km length from Gopalkhali (about 3 km upstream from the Kerew Kheya Ghat) to Botkhola via Dosterbottola, Uzzalpur & Akandabaria and re-excavation of 17 km of Upper Bhairab from Botkhola to Kashipur (Jibannagar). The proposed link canal will ensure additional flow at least for 4 months during monsoon in the present situation and through the year after implementation of Ganges Barrage Project in future. Dredging and excavation of 96 km stretch of the river from Taherpur to Afraghat will increase the conveyance and storage capacity of the river to reduce dependency on ground water. An additional 24 km of excavation of four lateral khals will enable distribution of water to a wider area. This was proposed in the Study Report “-Detail Feasibility Study for Drainage Improvement and sustainable Water Management of Bhairab River Basin” submitted by IWM on May 2013.

5.3.4. Kobadak River basin

The river Kobadak originated from Upper Bhairab at Taherpur and was linked to the Kholpetua river at Niamatkathi crossing about 240 km downstream. The Kobadak was a major river (more than 300 feet wide) and was linked with the Ganges through the Upper Bhairab and Mathavanga rivers. But its perennial flow was disconnected by commissioning of Kerew & Co. distillery across the river during the British regime. Since then the river is acting as a seasonal drainage route during the monsoon season only and about one-third of the upper river length has no flow during the rest of the year. The middle part of the river is semi active due to some tidal fluctuation and is susceptible to siltation. Over the years this siltation process has reduced the depth of the river significantly. A study was conducted by the Institute of Water Modelling in 2010, suggesting dredging and excavation of the river, operation of TRM and restoration of the additional drainage routes as the main components.

5.3.5. Rubber Dam

Rubber Dam is normally useful to use it during dry season irrigation of Boro rice, wheat or pulses according to the land classification or maximum available yield. “Matamuhuri Irrigation Project (Phase-II)” has two main components: Bag-Gujra Rubber Dam and Palakata Rubber Dam. The main aim and objective for construction of Rubber Dams was to retain water during post monsoon and First rubber dam of this project was constructed at a cost of BDT 2012 lakh on Bola khal and functioning well and providing anticipated benefit to the farmers as well as to the adjacent villagers for domestic use of water during dry season when water is scarce. Direct benefits of the first rubber dam inspired and initiated for implementation of the Bag-Gujra and Palakata rubber dam under “Matamuhuri Irrigation Project (Phase-II)”. Before construction of the rubber dam

local people tried to build earthen cross-dam across the channel during post monsoon to retain water for agricultural and domestic use. But construction of a cross-dam is very difficult across a flowing channel.

Construction of a Rubber Dam is suitable across a hilly river or creek having mild slope. More than one Rubber –Dam may be constructed if the river has adequate length and discharge with usable agricultural land. Rivers and creeks of Chittagong, Cox's bazaar, Comilla and Hobiganj has the above characteristics. Location of potential rubber dams across the rivers and creeks in these districts need to be explored after an extensive study.

5.3.6. Southwest Area Integrated Water Resource Planning and Management

The overall objective of the project is to enhance economic growth and poverty reduction in the rural areas of some selected districts (Jessore, Narail, Magura, Faridpur, Gopalgang and Rajbari) and rehabilitation of damages caused by Aila (Cyclone) in 2009 in the districts of Khulna and Satkhira. The secondary objective is to enhance and sustain water security and livelihoods of rural people within the hydrological boundaries of some existing underperforming projects and Aila damage-structures through participatory Integrated Water Resource Management Plans and strengthening institutional capacity for planning, implementation, operation, maintenance and monitoring.

The implementation of the rehabilitation programme for the study area will enable the stake holders to gain full benefits by smooth functioning and operation of the Chenchuri beel & Narail sub projects which were non-functional due to prolonged use salinity effects and river erosion etc. Rehabilitation of 4 polders (Polder 5 & 15 of Satkhira district and polder 31 & 32 of Khulna District) damaged during the natural calamity of Aila will result to gain benefits as was stipulated in the original project concept paper.

5.3.7. Noakhali Drainage

In the coastal region of Bangladesh drainage problem is one of the major problems. The drainage problem is to be found in Comilla, Noakhali, Laksmipur, Chandpur, Feni districts. The study area covers a gross area of 320,019 ha bounded by the Chandpur-Cornilla road and Comilla town in the north, Char Baggardona and Shudharam Projects and Sandwip channel in the south, Indo-Bangladesh Border and Kazirhat road in the east and Meghna River and Chandpur Irrigation Project in the west. This area suffers from the problem of flooding and drainage congestion. The area contour is almost plain and suffers from deep flooding in the monsoon due to heavy rainfall as drainage does not occur to desired level through the existing regulators and drainage channels. There are five major outfalls to drain out the whole project area of which (1) Little Feni river (2) Bamni river (3) WAPDA-Rahmatkhali khal have gated regulators while (4) New Dakatia river and Noakhali Khal are open. Noakhali Khal is almost silted up at its lower accreted reaches.

It may also be mentioned in this connection that the drainage regulators which were constructed, long ago, at the outfall of some main drainage channels are now overloaded due to extra drainage discharge from newly formed lands as well as from the charges & overlapping of catchment areas. Other phenomena which dictate the drainage of the project are the water level stages of the lower Meghna and the Bay of Bengal at the out falls of the main drainage channels of the project. It is to be noted that during monsoon the average water level of the lower Meghna at Chandpur rises in the order of about 2m and that at Rahmakhali about 1m. (above the average of the dry periods). Siltation and alleged illegal encroachment of some of the drainage channels have also reduced the drainage capacity to a great extent. As a result large portion of the study area remains waterlogged, resulting crop damage and delay in plantation.

To mitigate the drainage problems in the study area the study suggested construction of 2 regulators at Rahmatkhali (one existing & one new); 2 regulators at Bamni (one existing & one new); re-excavation of

existing channels about 357 km; Closure across Noakhali Khal downstream of Algir Khal offtake; One loop cut in the Little Feni river and another in Noakhali Khal and construction of the new Musapur regulator along with closure, diversion channel and link embankment.

5.4. Sundarbans biodiversity conservation plan

IUCN Bangladesh will develop a strategy and action plan for the management and biodiversity conservation for Sundarbans.

5.5. Cyclone preparedness programme (CPP)

After the cruellest cyclone in human history in 1970, by the request of UN, a Cyclone Preparedness Programme was established in 1972 with the help of League of Red Cross. Government took the programme in July 1973. It is now a joint programme of Bangladesh Government and Bangladesh Red Crescent Society. It is to be noted that CPP is the sole organization which disseminate warning signals in coastal area. For more information reference is made to the Baseline Study Report on Disaster Management.

5.6. Infrastructure: port developments

5.6.1. Deep Sea Port Development Plan Sonadia

In the period 2006-2009, a comprehensive master plan was developed for a green field deep sea port project near Sonadia, Bangladesh (Figure). With increasing cargo volumes, the need for a deep sea port in Bangladesh is becoming more urgent and therefore the Government of Bangladesh wishes to revive the Sonadia Deep Sea Port project.

Deep sea ports in Bangladesh will work as a regional network providing opportunities to the land locked countries like Nepal and Bhutan for economic development, as well as for North-east India. Moreover, the proposed 'Asian Highway' connecting deep sea port at Sonadia Island of Chittagong through Myanmar to the Yunnan Province of China will also add extension of regional economic integration and development. It is the intention of the GoB to make the country a regional hub through the establishment of the port and cater to the need of neighbouring countries.

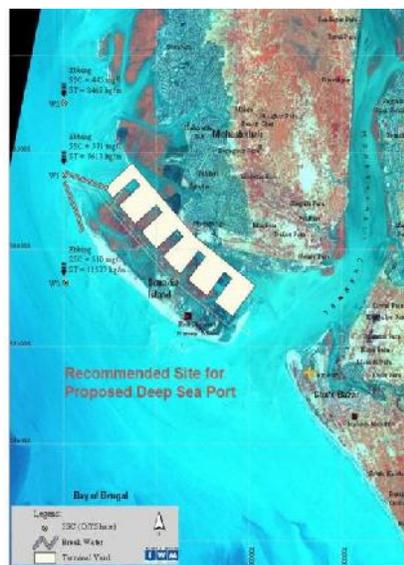


Figure 33: Recommended Site for Sonadia Deep Sea Port

5.6.2. Payra port

Development of a Sea Port at the Rabnabad Channel in the Patuakhali District is under active consideration of the GoB. The coast line of Bangladesh is about 710 km and there is no port in the central coastal zone. Economic and social development would be enhanced rapidly in this zone if a sea port is established. The development of Payra port will bring benefits such as:

- generation of opportunities of industrial development;
- faster and easier export of agricultural goods;
- easy fish processing and export will enhance employment opportunity;
- enhance economic network in the country, and
- enhance international trade facilities.

6. Towards a Vision for the Coast

6.1.1. Towards an integrated and inclusive development

Following the BDP2100 perspective of a holistic, integrated and inclusive development, progress in coastal Bangladesh should address the imminent problems in a sustainable manner while unlocking the potentials for economic development. As described in the previous chapters, the physical conditions pose huge challenges. The coast is not a particular gentle environment to live in, with its frequent flooding and surges, saline groundwater and dynamic coastlines. Harnessing these hazards through land reclamation and embankments has indeed improved living conditions of millions of people. At the same time these structural developments have created new problems, such as waterlogging and river siltation due to decrease of tidal prism. Likewise, the social environment is dynamic and compounded with structural inequalities. Often such social conflicts can be directly linked to the physical environment, such as the conflict between shrimp culture and rice growing. Ignoring these conditions and relations could jeopardise development projects and programmes, which has been experienced in the past. It is therefore encouraging to see that in the past decade or so most government-led programmes took up these lessons and base their interventions on a more inclusive and integrated way involving multi-stakeholders. Perhaps one of the best examples is the Char Development and Settlement Project, which is now in its fourth phase.

Along the Bangladesh' coast one can see all stages of development unfolding in space and time:

1. Emergence of new land (chars) with pioneer vegetation, but still daily inundated by the tides
2. Colonizing chars by landless people, letting their livestock graze on land above mean high water level
3. Embanking land, creating polders and allowing for growing crops
4. Full-fledged polders with a certain level of water management, but also with increasing drainage problems

It is clear that each of these stages requires its own approach. It is also evident that this development has a risk of becoming locked in: once a polder has been created, natural processes of tidal flooding and sedimentation are blocked. Although this has created favourable conditions on the short term, a continuous rising sea level will probably lead to the need for higher embankments. Compaction will lower polder levels and tidal creeks will be silted up, increasing drainage congestion. A key question for BDP2100 therefore is how to cope with this seemingly inevitable pathway. Is there an adaptation strategy available?

The pathway of polderization which has started in the 60s of the previous century has created a *fait accompli*: the concept of polder should be accepted as a basis for the future development of most of coastal Bangladesh. This raises the question how to renew and modify the polder concept in such a way that it becomes robust for ensuring food security and economic development and can withstand the long term challenges. Evidently, there will not be a one size fits all solution. As mentioned earlier, Bangladesh' coast is highly diverse and therefore, a multi-faceted strategy will be needed which accounts for the place-dependent conditions and development phase (see also Brammer, 2014).

6.1.2. Long term vision

A long term vision for the coast needs to be rooted in the official goal of the GoB for the coast. This goal is formulated in the Coastal Zone Policy and reads: *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* (GoB, 2005). A vision, then, could be described as i) an idealized future state of the coast, and ii) a set of principles and mechanisms through which this future state can be realized.

An idealized future state of the coast

Considering the diverse nature of the coast, as described earlier, an ideal future state of the coast would look like a mosaic of areas, some of which are highly developed into modern urbanized areas linked to low carbon emitting industrial zones and ports, others with high value aqua- and agricultural production regions enabling food security for the masses as well as economic profit, both fringed with coast-sea interfaces which enable growing with the sea and providing tourism hot spots as well as biodiverse ecosystems. In terms of infrastructure, the coastal zone would contain a modernized multi-modal transportation system with roads, bridges, navigable water-, and railways. Hazards are harnessed through a combination of flood control, natural protection belts, preparedness and early warning systems. Typical coastal resources such as oil and gas, tidal energy, wind energy, marine fisheries and salt making are optimally and sustainably exploited.

Surely, such a future will not be turned into reality overnight and not without the inevitable conflicts raising from differences in interest. Therefore, it is equally important to describe the pathways through which such state can be reached.

Principles and mechanisms

Future will not be borne out of a blueprint or master plan. Instead, it is a result of the interplay of factors and agents active in the human-environment system. People's actions, enterprises, the private and public sectors together are shaping development.

Because of the inherent uncertainties bestowed on projected developments it is essential to have policies and steering mechanisms in place that can be used when unforeseen events and developments take place. It is here where the role of the government comes into the picture. In general its tasks would be:

- To provide stability and security (in terms of policies, law and order, safety against natural disasters)
- To do large scale investments where private sector can't work
- To make regulations where the market fails

Besides these generic instruments and policies for the government (see Baseline Governance), the specific mechanisms in the coastal setting would be

- To secure the rights and opportunities for the poor and ultra-poor;

- To provide stability by guaranteeing continuity of programmes/projects;
- To secure a certain level of safety against disasters (risk based);
- To plan and implement large scale investments in infrastructure (esp. optimized water management in polders; embankments, land reclamation, ports, transport);
- To provide necessary conditions for diversification in land use/crops (through credit, extension, etc.);
- To assist in innovative, alternative production methods (e.g. through research, as launching customer);
- To start pilots for building with nature making optimal use of natural resources and processes;
- To ensure funding mechanisms for operation and maintenance;
- To start pilot programme on renewable energy for encouraging private investment; and
- To enforce environmental regulation and legislation.

6.1.3. Measures and strategies (incl. no regret)

In terms of strategies, it seems logical to distinguish between the most dynamic coastal area, i.e. the Meghna Estuary and the coastal plains stabilized by the existing polders. With regard to the Meghna Estuary, an update or *revitalization of the Estuary Development Plan* is recommended considering all sectors in an integrated and holistic way. This update should include specific measures and projects for:

- Land reclamation
- Char development
- Restoration and maintenance of ecosystem services
 - Economic zones and ports / island development
 - Tidal energy Sandwip channel
 - Water storage / salinity control in smaller rivers
 - Creating freshwater reservoir between two cross dams at Nijhum Dwip
 - Big cross dams in SE and/or South central part of estuary for more rapid land reclamation
 - Detailed integrated study for tapping wave energy and wind energy and desalinization in the coastal area
 - Development of Economic Zones
 - Development of forecasting and warning systems for round the year on coastal inundation for tide and cyclonic storm surges at community level
 - Conducting research in generating new knowledge and technology for integrated development of coastal area

With regard to the *coastal polders*, a continuation of on-going improvements including the CEIP and Blue Gold projects is suggested. It is seen that the present polder is safe only for 8-year to 10-year return period of cyclonic storm surge level, polders were overtopped in recent cyclone SIDR and Aila (IWM 2014). The damaged cost of Sidr is 1.7 billion US\$ (World Bank, 2010). Also Tidal River Management should be scaled up and improved to tackle current problems of siltation and waterlogging in and integrated and holistic way considering subsidence, sea level rise. The BWDB already has plan (short and medium term) that can be used as a start. What needed are implementation and monitoring as well as a plan for the whole SW region for management of sediment, water-logging and salinity control. Strategy needs to be formulated for long term

sustainability of polders by restoring tidal plains for increasing tidal prism in the tidal rivers and allowing tide for sediment deposition in the polders for building low-lying area and counter acting the subsidence. Further more a drainage management plan has to be developed for Noakhali district.

Standards for embankment designs should be based on risk based flood safety analysis. In other words, they should be made flexible depending on the hazard magnitude (frequency of high water levels) and kind of investments that need to be protected. Typically such standards should range between 1: 25 for low investment areas up to 1: 250 y for urban and industrial areas considering economic issues.

In view of climate change, structural improvements are required for the irrigation projects in the coastal area for intensification of agriculture such as *Barisal Irrigation Project*. Although there is sufficient freshwater now, this is likely to change on the long term. This would require new irrigation facilities and perhaps salinity regulators in estuaries. It is also suggested to address the Blue Economy through researches and pre-feasibility study. Research and long term monitoring is also important to investigate the morphological condition of the peripheral rivers of polders, main drainage network of polders, under external drivers of change in future.

It is further recommended to prepare feasibility studies for *water storage measures*, such as for the Ganges and Brahmaputra with installation of barrages.

6.1.4. Input to 7th Five Year Plan

Based on the analysis and identified measures in the preceding section, a number of concrete plans and projects can be formulated as input to the 7th Five Year Plan. These are all in line with the general strategy described earlier and are ready to be implemented in the next five years:

- CSDP V, with the following elements: 20 chars out of 72, cross dams, mangrove feasibility, tackling drainage congestion, freshwater retention, climate change/food security in previous (CSDP-4) areas.
- Cross dam Urir char for land reclamation (Design is ready)
- Barisal Irrigation Project
- Deep sea port at Sonadia Island
- Payra Bandar at Patuakhali
- Navigability Improvement of Mongla Port
- TRM up scaling and monitoring (Water Board plan)
- Tidal energy feasibility study
- Noakhali drainage improvement
- Bhairab river basin development (detailed feasibility study already done);
- Detailed investigation of reservoir/dam in small river for water storage;
- Detailed study on development of an integrated and holistic plan for management of sediment and water-logging and salinity control for the whole west region including the existing discrete plans
- Development of Water Management Infrastructure in Bhola Island
- Coastal Embankment Improvement Project (CEIP) Phase-I
- Development of freshwater reservoir in between Hatia and Nijhum Dwip

Box: Integrated Development of Nijhum Dwip and Reclamation of land in surrounding areas:

National Water Policy has given emphasis on "Plan and Implement schemes for reclamation of land from the sea and river." The proposed first track study can be carried out and suggested measures on pilot project need to be adopted in this context and it is obvious that land increase will contribute to the reduction of poverty, enhancing the ecosystem services and will create enabling environment.

Activities under the project:

- (i) Construction of two cross dams at both ends of Nijhum dwip channel and development of 5 sq km fresh water reservoir;
- (ii) Construction of Cross dam between Nijhum Deep and Damar Char for Land Reclamation
- (iii) Establishment of mangrove afforestation for disaster reduction and land accretion
- (iv) Raising and reclamation of about 40 sq km of sub-aqueous delta shallow delta by dredge fill

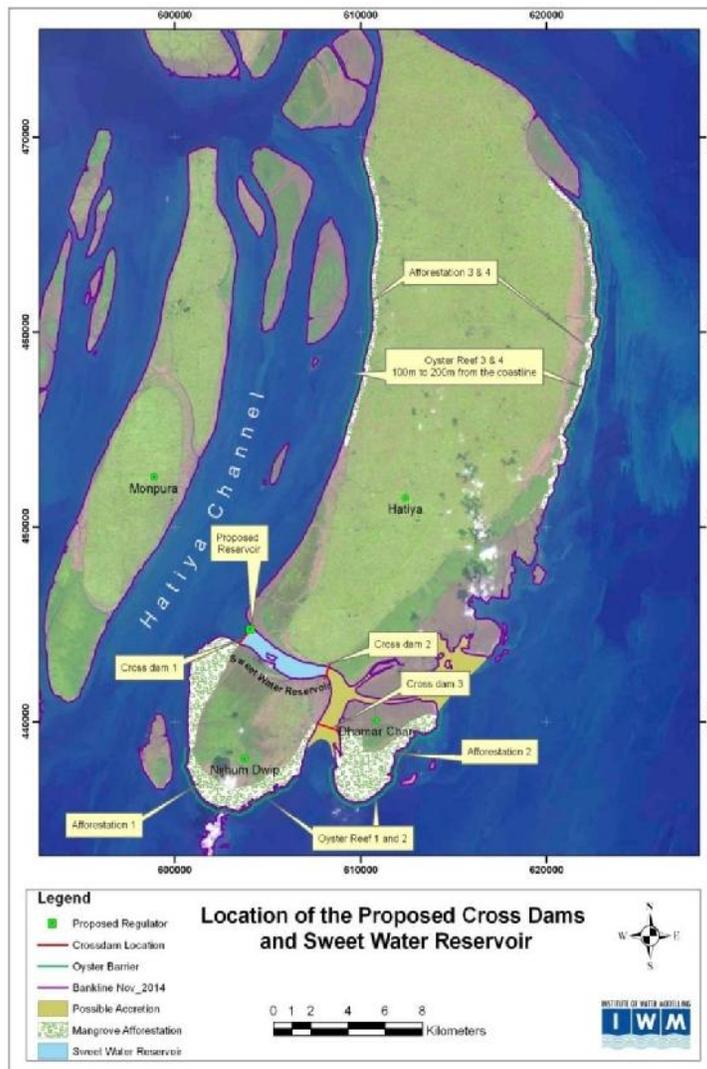


Figure 34: Location of the Proposed Cross Dams and Sweet Water Reservoir

7. Knowledge gaps and next steps

7.1. Knowledge gaps:

The Meghna Estuary is a very dynamic estuarine and coastal system. The Lower Meghna River conveys the combined flow of the Ganges, Brahmaputra (Jamuna) and Meghna rivers. The sediment discharge from the Lower Meghna is the highest and the water discharge the third highest (after the Amazon and the Congo rivers) of all river systems in the world. In changing climate and due to human interventions system will be more dynamic. So, updated data and knowledge are essential for planning and implementation of land reclamation program.

Knowledge gaps;

- Relative Mean Sea Level Rise (RMSLR) along the coast line of Bangladesh and long term impacts on coastal morphology, river sedimentation and erosion
- Understanding the effects of Bio-physical, economic, socio-political drivers on Water Resources, Polder Management, Aquaculture, Agriculture and Land Reclamation in the long term perspective
- Impact of possible reduction in sediment load
- Delay in rehabilitation of polders after damage due to cyclones
- Groundwater salinity intrusion and hydro-geologic setting
- Sediment load, Sediment budgeting and sediment distribution in the rivers and estuaries
- Effects in the coastal area due to human interventions at the trans-boundary rivers by upper riparian countries
- Management of sediment and water-logging in the polders for its long-term sustainability
- Long-term morphology of estuaries and peripheral rivers of polders under different drivers of change
- Understanding relationship between bio-physical changes and ecosystem services
- Sub-poldering of the polders to improve sub-catchment water management involving community and impact on conflict between fishermen and farmer.

In order to do that following activities are necessary to fulfil present knowledge gaps:

- Modern survey, data collection equipment and software;
- Details hydrographic survey, hydro-morphological data collection, sediment budget and regular monitoring in the estuary;
- Updating existing hydrodynamic and morphological models;
- Investigation & updating of potential location of cross dams / interventions;
- Potentials of wave, tidal and wind energy
- Prospect of Blue Economy
- Training & technology transfer and institutional developments;

7.2. Next steps

A next step of the study includes the following:

- Discussion among stakeholders regarding the possible tipping points, strategies and long- and short term measures proposed in this report;
- Quantification of tipping points, such as the relation between waterlogging and sea level rise;
- Socio-economic analysis of TRM;
- Costs of measures;
- Linkage with other projects, such as ESPA;
- Interaction with the other baseline study groups concerning activities in the coast;
- Preparation of Delta Ateliers for hot-spot discussions.

8. Linkage with other baseline studies and research projects

The Coastal Polders and Coastal Zone Management theme is also linked with the other themes of Bangladesh Delta Plan 2100 study and these are as followings:

- **Climate Change Issues**
The climate change theme highlighted the change of climate parameters and climate extremes over the decades. The lightly impacts of climate change on agriculture, fisheries infrastructure. As well as in coastal area. However, the projection on climate change specially temperature precipitation and sea level rise based on assessment report 5 of IPCC have not been analysed. It is expected that the projection of precipitation, temperature, sea level rise under different RCPs would be established. The Coastal Polders and Coastal Zone Management theme requires these projections for assessing the likely impacts in the coastal area and consequently devising adaptation strategies under different scenarios in future. Since climate is a crosscutting issue it is important also for other things in assessing the likely impacts applying consistent climate change projections.
- **Water Resources**
Water resources theme focuses the whole Bangladesh including the coastal area. So, there are some common issues challenges and long-term interventions both in coast and water resources theme, which demand integration of these themes. The propose interventions and strategies under these themes should not be conflicting rather to be consistent. The future interventions and strategies are important to know in order to assessing the benefit in the coastal area. It is also important to integrate the proposed measures under water recourses and coastal zone management theme in assessing the benefits and avoiding duplications of interventions. However, both the themes emphasize the need of Ganges and Brahmaputra barrages for salinity control at present and in times of climate change which is also useful for storing water for irrigation at upstream for intensification of agriculture and aquaculture.
- **Disaster Management**
Coastal zones and coastal infrastructures are prone to disaster. Coast and disaster management themes are interlinked and it is seen both the themes focus the problems and disaster risks at the coastal area such as cyclones, salinity intrusion and coastal flooding. The assessment of vulnerability in the coastal area and adaptation strategies should be based on disaster risk otherwise the development activities may not sustain for long term. The future interventions and strategies of coastal themes are linked with the risk of hazards as identified in the disaster management theme, which are improvement of existing polders in the coastal area and salinity control.
- **River Systems Management including Morphological Dynamics of Bangladesh Delta and Transboundary Cooperation**

The issues of river morphology, sedimentation and erosion and long-term changes are in both the themes. The rivers and estuaries are the life of coastal zone and any changes of its course may impact negatively in these area. The trans-boundary issues are more important for the morphological dynamics of coastal river systems and salinity control. The southwest region is experiencing scarcity of freshwater due to decrease of dry season flow of Ganges River which is one of the major trans-boundary rivers of Bangladesh. The tidal and sediment dynamics of the coastal area are different from the non-tidal rivers like Ganges and Brahmaputra, so the river systems and estuaries should be dealt in the coastal theme not in river theme.

The Coastal Polders and Coastal Zone Management theme is also linked with the following ongoing projects:

- Coastal Embankment Improvement Project (CEIP)
- Blue Gold
- Char Development and Settlement Project (CDSP)
- Port Development
- **Governance and institutional development**

The coastal problems are diverse and conflicting and many ministries and institutions are involved to address these issues and coastal development. There is huge lack of coordination and linkage with the programs of different ministries and institutions working for coastal development. Government has also developed policies and plan for coastal development even then there is a gap between the institutions to make an integrated and holistic approach for coastal program. This demands strengthening of governance and institutional issues.

Under the governance an institution development theme a draft Delta Frame Work has been formulated, which will focus also coast as a hot spot.

An indicative Bangladesh Delta Framework, based on the Dutch Delta Framework is discussed and presented in this theme; the following section focuses on some issues of framework. This framework will be finalized after consultations at various national, sub-national and local levels.

- Delta Act: constitutes the statutory basis for a Delta Plan, fund, institution and Program;
- Delta Fund: to finance the future delta interventions and investments;
- Delta Plan: approval and endorsement of proposed delta vision, strategy, institutional framework, and investments;
- Delta Program: sets out annual and 5-year investment proposal linking with national 5-Year Plans & annual budgets;
- Delta Institution/Secretariat: the government secretariat for the Delta Program.

Bangladesh Delta Act will provide a sound legal basis for a very long term BDP 2100 including establishment of the Delta Fund, establishment of delta institutions/secretariat, the Plan itself and indicative investment priorities and approaches through identified hot spots & priority sectors.

Bangladesh Delta Fund will be a separate dedicated fund for the finances involved in implementing the Delta Programme. Both Govt. of Bangladesh and development partners can commit and allocate block or annual funding and they have done so previously.

9. References

- Anik Bhaduri and Edward Barbier (2008). *Linking Rivers in the Ganges-Brahmaputra River Basin: Exploring the Transboundary Effects*. In: Amarasinghe, U.A.; Sharma, B.R., eds. 2008. Strategic analyses of the National River Linking Project (NRLP) of India, series 2. Proceedings of the Workshop on Analyses of Hydrological, Social and Ecological Issues of the NRLP. Colombo, Sri Lanka: International Water Management Institute. 500 p.
- Azad, A.K., C. Kwei Lin, K. R. Jensen (2008). Coastal aquaculture development in Bangladesh: un-sustainable and sustainable experiences. *IIFET 2008 Vietnam Proceedings*.
- BBS (2010). *Census of agriculture 2008*. Bangladesh Bureau of Statistics.
- BDP2100,(2015). Baseline Study on Agriculture and Food Security Theme- Draft Final Report
- BDP2100, (2015). Baseline Study on Climate Change Theme- Draft Final Report
- BDP2100,(2015). Baseline Study on Disaster Management Theme- Draft Final Report
- BDP2100, (2015). Baseline Study on Growth of Population and Management Study Theme- Draft Final Report
- BDP2100, (2015). Baseline Study on Land Resources Management Study Theme- Draft Final Report
- BDP2100, (2015). Baseline Study on River systems management including morphological dynamics of Bangladesh Delta Theme- Draft Final Report
- BDP2100,(2015). Baseline Study on Socioeconomic and Demographic Condition Theme- Draft Final Report
- BDP2100, (2015). Baseline Study on Urbanization and Settlement Theme- Draft Final Report
- BDP2100, (2015). Baseline Study on Water Resource Theme- Draft Final Report
- Bhuiyan, M. A. (2005). *Lecture notes ICZM*. BUET. Dhaka.
- Brammer, H. (2013). "Bangladesh's dynamic coastal regions and sea-level rise." *Climate Risk Management 1*: 51-62.
- Brammer, H. (2014). Bangladesh's dynamic coastal regions and sea-level rise. *Climate Risk Management 1* (2014) pp. 51-62.
- Brammer, H. (1996). *Geography of soils of Bangladesh*, University Press Ltd. Dhaka, Bangladesh.
- Bucx, T., M. Marchand, A. Makaske, C. van de Guchte (2010). *Comparative assessment of the vulnerability and resilience of 10 deltas – synthesis report*. Delta Alliance report number 1. Delta Alliance International, Delft-Wageningen, The Netherlands
- CEGIS (2010). *Final Report on Impacts of Climate Change on the morphological processes of the main rivers and Meghna Estuary of Bangladesh, Dhaka, Bangladesh*. Mimeo.
- Chowdhury, A.M., A. U. Bhuya, A. Y. Choudhury and R. Sen (1993). The Bangladesh Cyclone of 1991: why so many

people died. *Disasters*. Vol. 17, No. 4.

Chowdhury, J.U. (2005), '*Impact of Indian Plan of Inter-basin Water Transfer on Bangladesh*', Paper presented at the workshop on River Basin Management, organized by Directorate of Continuing Education, Bangladesh University of Engineering and Technology (BUET), Dhaka, 21–22 April.

CSIRO, 2014, Bangladesh Integrated Water Resources Assessment: final report (Page-10). A report prepared by CSIRO, WARPO, BWDB, IWM, BIDS and CEGIS for the Department of Foreign Affairs

Australia Aid – CSIRO Research for Development Alliance

Ericson, J.P., C.J. Vörösmarty, S.L. Dingman and L.G. Ward and M. Meybeck. 2006. Effective sea-level rise and deltas: Causes of change and human dimension implications. *Global and Planetary Change*. Vol 50. Issue 1-2. 53-82.

Euroconsult Mott MacDonald, BETS, Socioconsult (2014). *Feasibility Study of Cluster of Chars – Integrated Main Report*. Char Development and Settlement Project Phase IV. Dhaka April 2014.

GED, 2013. *National Sustainable Development Strategy 2010-2021*. General Economics Division, Bangladesh Planning Commission, the Government of the People's Republic of Bangladesh, May 2013

GED, 2012. *Perspective Plan of Bangladesh 2010-2021: Making Vision 2021 A Reality*. General Economics Division, Bangladesh Planning Commission, the Government of the People's Republic of Bangladesh, April 2012

GED, 2013. *Steps Towards Change: National Strategy for Accelerated Poverty Reduction II (Revised)*. General Economics Division, Bangladesh Planning Commission, the Government of the People's Republic of Bangladesh, December 2009

GoB (2005). *Coastal Zone Policy*. Ministry of Water Resources. Government of the People's Republic of Bangladesh.

GoB (2006). *Coastal Development Strategy*. Ministry of Water Resources. Government of the People's Republic of Bangladesh.

GoB (2012). *Perspective Plan of Bangladesh 2010-2021. Making Vision 2021 a reality*. General Economics Division, Planning Commission, Government of Bangladesh. April 2012.

Hossain MS, Hossain MZ and Chowdhury SR (2006). An Analysis of Economic and Environmental Issues Associated with Sea Salt Production in Bangladesh and Thailand Coast. *International Journal of Ecology and Environmental Sciences* 32:159-172.

Hossain, Md. Shahadat & C. Kwei Lin (2001). *Land Use Zoning for Integrated Coastal Zone Management -Remote Sensing, GIS and RRA Approach in Cox's Bazar Coast, Bangladesh*. ITCZM Monograph Series No.3, 25 pp. Pathumthani.

Hossain, Md. Shahadat, Sayedur Rahman Chowdhury, Umme Kulsum Navera, Mostafa Ali Reza Hossain, Badrul Imam, S M Sharifuzzaman (2014). *Opportunities and strategies for ocean and river resources management*. Background paper for preparation of the 7th Five Year Plan. Submitted to Food and Agriculture Organization of the United Nations Bangladesh Country Office, Dhaka, Bangladesh.

- IFAD (2010). *Char Development And Settlement Project (CDSP) Design Completion Report – Appraisal Main Report*.
- Islam, M. R. (2004). *Where land meets the Sea: a profile of the coastal zone of Bangladesh*. WARPO, The University Press Limited, Dhaka.
- IWM, 2014. CEIP: Coastal Embankment Improvement Project, Technical Report
- Nicholls, R. J. and Goodbred, S. L. (2004). Towards integrated assessment of the Ganges-Brahmaputra Delta. Paper for Proc. 5 International Conference on Asian Marine Geology and 1st Annual Meeting of IGCP475 Delta MAP and APN Mega-Deltas.
- N.M. Joshi, 2013. National River Linking Project of India. Hydro Nepal 12, January 2013.
- Pethick, J. (2012). *Assessing Changes in the Landform and Geomorphology due to sea-level rise in the Bangladesh Sundarbans*. Report to the World Bank. Mimeo.
- P. G. Whitehead, E. Barbour, M.N. Futter, S. Sarkar, H. Rodda, J. Caesar, D. Butterfield, L. Jin, R. Sinha, R. Nicholls, M. Salehin (2012). *Impacts of Climate Change and Socio-economic Scenarios on Flow and Water Quality of the Ganges, Brahmaputra and Meghna (GBM) River Systems: Low Flow and Flood Statistics*. Environmental Science: Processes & Impacts. DOI: 10.1039/x0xx00000x
- Raza, W., A. Bhattacharjee & N. C. Das (2011). *Impact of Char Development and Settlement Project on Improving the Livelihood of Char Dwellers*. Working Paper No. 17. BRAC, Dhaka.
- Syvitski, J.P.M., Kettner, A.J., Overeem, I., Hutton, E.W.H., Hannon, M., T., Brakenridge, G.R. Day, J. Vörösmarty, C. Saito, Y. Giosan, Nicholls, R.J. (2009). *Sinking deltas due to human activities*. *Nature Geoscience* 2, 681-686.
- Warner, J. (2010). "Integration through Compartmentalization? Pitfalls of 'Poldering' in Bangladesh." *Nature and Culture* 5(1): 65.
- World Bank, 2014. EACC: Economics of Adaptation to Climate Change Study
- World Bank, 2010 SBRI
- Z.H. Khan, F.A. Kamal, N.A.A. Khan, S.H. Khan and M.S.A. Khan, *Present Surface Water Resources of Ganges Coastal Zone in Bangladesh*
- Z.H. Khan, F.A. Kamal, N.A.A. Khan, S.H. Khan, M.M. Rahman, M.S.A. Khan, A.K.M.S. Islam, and B.R. Sharma *External drivers of change, scenarios and future projections of the surface water resources in the Ganges coastal zone of Bangladesh*

BASELINE STUDY: 06

Water Supply and Sanitation

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Executive Summary: Study 06

Water supply and sanitation is a burning issue of Government of Bangladesh. GoB targeted to achieve 100% water supply and sanitation coverage in both urban and rural areas of Bangladesh within 2015. So far, the achievement is appreciable. Bangladesh Delta Plan 2100 Formulation Project is to extend and continue the progress in more sustainable way up to 2100.

According to Joint Monitoring Program (JMP) 2012 Report, the improved water supply coverage in urban and rural areas are 86% and 84% respectively but due to the presence of arsenic in groundwater, the safe drinking water source is reduced by about 12.5%. The water supply mainly depends on groundwater. But in urban areas the shifting of groundwater to surface water is increasing. According to JMP 2012 report the improved sanitation coverage in urban and rural areas is 55% and 58% respectively. There is no open defecation in urban areas and only 5% defecation in rural areas. Looking at this report the achievement in Bangladesh in sanitation is very good compared to many developing countries. The Governmental bodies, DPHE, WASAs, LGIs, private sector, NGO and CBO's role in WSS sector made it possible. These statistics however, are difficult to 'confirm', and should not obscure a situation where many deprived communities lack suitable improved water supply and sanitation services.

The policy documents in the Water Supply and Sanitation (WSS) sector have been well established. The sector development plan is for the period 2011-25, which has investment plans for short, medium and long term. The investment in this sector is about 1,465,520 million BDT. The National Strategy for Water Supply and Sanitation (yet in draft format) overlay an effective pathway for the future needs. The New Sector Development Framework has been prepared to plan, coordinate and implement the development activities by the Government of Bangladesh (GoB) and the Development Partners (DPs) in the WSS sector.

While sector stakeholders are clearly defined, their respective roles and mandates, and particularly their effective conduct needs further improvement. In essence the water supply and sanitation sector continues to be substantially donor dependent, which, as a matter of principle, weakens effective governance. Cost recovery principles are key to further sector development.

There are many challenges which play a vital role in the development of the WSS sector. Some important challenges are as follows:

- Rapid urbanization aggravating pressure on service, and increasing (sanitation related) environmental constraints
- Limited resources and further lowering of groundwater increasing sector competition and costs of abstraction
- Pollution of surface water as well as groundwater increase treatment costs. Lack of awareness and enforcement of law is aggravating situation day by day
- Inadequate infrastructure and institutions for better management of faecal sludge
- Due to inefficient O&M of the water supply system, wastage is more which lead to high production cost and poor level of service
- Arsenic contamination is aggravating owing to over exploitation of groundwater
- Water supply source problem in geo-physically and hydro-geologically hard to reach (HtR) areas
- Salinity problem in coastal areas which may be acute for climate change related trends
- Effects of environment, climate change and disaster

There are many drivers which have impact on WSS sector. Some drivers are as follows:

- Population growth is increasing system pressure which is constraint on water resources
- Land use change and urbanization putting pressure on water resources, aggravating environmental constraints relative to sanitation
- Economic growth is enabling development
- Technical developments is also enabling development
- SW and GW contamination due to Salinity, Arsenic and manganese, as well as many anthropogenic contaminants which demands more technical solution and proper enforcement of law
- Climate change
- Groundwater level depletion Increasing costs and adverse environmental effects
- Institutional weakness increase dependency on DPs

To overcome the challenges and fulfil the target of SDG's, the stakeholders undertook many initiatives and projects of national interest. Many medium and long term initiatives need to be taken up for further development of this sector as follows:

Planning issues short/medium term	Planning issues long term
<ol style="list-style-type: none"> 1. Groundwater resource management needs to be strengthened to prevent over-exploitation and to control groundwater abstraction 2. Water supply development plans are required in each city and town 3. Sanitation concepts will need to be re-framed by introducing sewer systems, and/or efficient and effective collection, handling and disposal or re-use of septic sludge 4. A better balance with environment needs to be enforced to control GW and SW contamination as well as economic progress by industrialization and agro economy 5. Water and sanitation services need to be designed and constructed in flood resilient concepts 6. Mitigation of arsenic groundwater is a crucial issue 7. For the mitigation of salination in coastal groundwater, rainwater based concepts need to be adopted 	<ol style="list-style-type: none"> 1. Surface water and ground water allocation and regulation measures for water supply, agriculture, navigation, industrial use need to be prepared 2. More expensive treatment technology and the spatial planning should be adopted 3. With continued urbanization more advanced sanitation solutions are required for improved sanitation services, healthy living environment, and environmentally sustainable development 4. Freshwater storage, aquifer recharge, rainwater harvesting concepts or desalination may be the long term solution for coastal water supply

Reflecting on the planning issues in medium term some initial steps into the 7th 5-yearplan need to be addressed are as follows:

- New tariff structure for urban water supply (WASA's)
- Full metering coverage to reduce losses and Non Revenue Water (NRW)
- Industrial zones have to be identified for the effective collection, treatment and discharge of industrial wastewaters
- 'Water pricing' is required for water resources (financial) regulation

In the coastal area, groundwater is contaminated by saline water in three paths (1) intrusion of saline water by sea (2) downward vertical movement of saline surface water to the aquifer which are carried inland by storm surges or transgression (3) migration of pre-existing pockets of saline water in the subsurface. Knowledge on the deep alluvial aquifer is limited and then can be contaminated by arsenic, iron and/or manganese. The river water

is also saline which tend to go upstream with reduced river runoff and with increased sea level rise. Thus deep aquifer is the preferred option for water supply in the coastal zone. Rainwater harvesting is also a preferred option for domestic uses. Most people are not aware of the contamination of stored water.

In Dhaka city 87% water supply is abstracted from groundwater resources and the remaining from surface water resources. Due to over-exploitation the groundwater table is lowering down very rapidly (2-3 m per year in some places). Recently DWASA has taken the strategy to decrease the dependency on groundwater by taking many surface water related projects. The surrounding river water is being polluted by industrial and domestic effluent discharge without or after little treatment, DWASA decided to transport the water from Padma and Meghna Rivers, where the water quality and quantity is still quite satisfactory, to meet the growing demand of water in Dhaka city.

Only 20% area in Dhaka city is covered by separate sewerage system and in many household have septic tank. So huge portions of the faecal sludge directly discharge into khals, drainage channels, and rivers and even in the open areas, which is polluting the water bodies and the surrounding environment. There is absolutely no formal sewage collection system in other major cities. Inhabitants of the cities discharge sewage directly into inadequate surface drains while retaining (often partially) faecal sludge in septic tanks. Systematic faecal sludge management is practically absent.

Apart from the major cities other urban areas include 359 pourashavas/municipalities/towns in Bangladesh. Unfortunately, statistics reveals that only around 59% population are within the so-called improved sanitation coverage. For the rural areas, 55% of the rural population use improved sanitation means and 40% shared or unimproved sanitation. Around 3% are still opting for open defecation. The HtR (hard-to-reach) areas are usually geographically remote and the people living there are least likely to have access to benefits from mainstream development activities. About 21% of the total geographical areas of Bangladesh are found to be hard-to-reach with about 28.62 million people living in these areas.

Haors have their unique hydro-ecological characteristics. Haors are located in the north-eastern region of Bangladesh with about 1.99 million ha of area and accommodating about 19.37 million people. Improved water supply and sanitation is one of the major challenges in haor areas due to lack of wetland policy, inaccessibility, frequent flooding, arsenic contamination, economy etc. Some strategy has been formulated in the Haor Master Plan to improve the WSS situation based on the following principles:

- Participation of public- private sector, NGOs, CBOs and women groups and trained them properly
- Gradual community cost-sharing and introduction of economic pricing for services
- Prioritization of under-served and un-served areas
- Improvement of existing technologies
- Alternative source of water in acute arsenic problem areas
- Social mobilisation and awareness raising
- Capacity building at local/community level as well as CBOs
- Regular qualitative and quantitative monitoring
- Wherever feasible surface water sources may be given consideration
- Provision of sanitation facilities to the poor free of charge and a tax levy to the well-to-do people
- Community-type latrines where individual households cannot afford latrines due to poverty
- Community contribution in cash or kind ensuring ownership of facility
- Formulating appropriate policies and programmes
- Management of faecal sludge and producing compost and bio-gas

Some key findings:

- In the past decades Bangladesh has made good progress in water supply and sanitation coverage. However, average success should not obscure regional disparity and sector challenges. Many people still lack suitable access to safe and improved water supply and sanitation services;
- The WSS sector in Bangladesh is well established with many stakeholders in well-defined position. We commend the activities of Policy Support Unit, which provides the sector with relevant information and policy development. For future challenges, further sectoral reform will be required. The rural water supply and sanitation needs require technical and organizational capabilities which may not be catered from decentralized competence. Inter-sectoral co-ordination, also outside the sector (BWDB, Agriculture) may warrant a review on mandates and responsibilities. Urban sanitation needs require both mandates (who is responsible) and co-ordination (environment, industry, spatial planning);
- At present and in the (near) future the WSS sector in Bangladesh has major challenges:
 - Comprehensive introduction of (full) cost recovery principles throughout WSS sector;
 - WSS provision to LIC groups and HtR (hard-to-reach) areas;
 - Arsenic proliferation;
 - Declining groundwater tables;
 - Salination of groundwater and surface water resources;
 - Water pollution;
 - Effective faecal sludge management and urban sanitation concepts;
 - Industrial water supply and wastewater treatment.
- The BDP 2100 programme will proceed to liaise with WSS sector stakeholders to discuss and address challenges at stake. In doing so, BDP 2100 will engage WSS focus on 2 of the identified hot spots: major cities, and coastal zone. For these hot spots, and also for the WSS sector at large, effective strategies and pathways for future proof resilient WSS provision will be explored and elaborated.

1. Introduction

1.1. Background

Government of Bangladesh and Government of the Netherlands have embarked on a programme to prepare a long-term Delta Plan for Bangladesh (BangladeshDeltaPlan2100, BDP). Within this programme 'Baseline Reports' are prepared for main issues and sectors, relative to Bangladesh's delta. This report constitutes the baseline study for the Water Supply & Sanitation Sector. In this baseline study it is aimed to evaluate existing problems, developments and (government) plans in view of the long term (socioeconomic and climate) changes. One of the leading principles in the BDP 2100 programme is not to duplicate existing programmes and policies but rather to co-ordinate, amplify and align existing initiatives. For the Water Supply and Sanitation sector the GoB has drafted the Sector Development Plan 2011-2025. For a more extensive review on the existing situation, trends and policies SDP has been referred. As a matter of principle the information has been briefly reported in this Baseline Report.

This report has been preceded by a quick scan report¹ on the water supply & sanitation sector.

1.2. BDP position in Water Supply & Sanitation Sector

The water supply & sanitation sector in Bangladesh is very well established in terms of institutions, policies and practice, and implementation. The BDP2100 has no intention to duplicate the strategies and guidelines that are in very good hands in the sector. The MoLGRD&C and especially DPHE, LGED and WASA's, are in effective control of the sector. Both GoB stakeholders, donor partners and NGO's work together towards further fulfilment of the sector's ambitions. The BDP team has noted the excellent policy documentation within the sector (see section 2.5 of this report and fact sheets of Annex-A) with the Sector Development Plan (FY 2011-2025) as over-arching initiative.

The existing strategies and policies of the sector have been endorsed for incorporation in the BDP2100 planning process. It is the desire of BDP2100 to contribute to further inter-sector co-ordination and to shed light on long-term perspective beyond the reach of usual policy strategies to the 2100 horizon.

1.3. Sector consultation

This Baseline Report will be subject to consultations within the water and sanitation sector: BDP wishes to share insights and gain feedback from relevant sector stakeholders. In the initial preparation of the Baseline Report, apart from consulting documented policies and studies, we have appreciated the welcome of numerous reconnaissance visits and interviews with relevant officials and stakeholders. They are:

- Engr. Md. Nuruzzaman, Chief Engineer, DPHE;
- Engr. Mohammed Golam Muktadir, Executive Engineer Planning Division, DPHE;
- Engr. Monwar Ali, Additional Chief Engineer (Planning), DPHE;
- Mr. Md. Serajuddin, Dept. Managing Director, DWASA;
- Mr. Kazi Abdul Noor, Project Director (joint secretary), PSU, LGD

¹ The information is incorporated in the baseline study. The quick scan has now been 'superseded'.

- Mr. Md. Mohsin, Asst. Project Director, PSU, LGD;
- Dr. Engr. Kazi Ali Azam, DPHE project;
- Mr. Carel de Groot, First Secretary Water Section, Netherlands Embassy;
- Mr. Michiel Slotema, WASH policy advisor, Netherlands Embassy;
- Nr. Dostogir Harun, Project Research Manager, Centre for Communicable Diseases, ICDDR,B,;
- Dr. Azharul Islam Khan, Chief Physician, Centre for Communicable Diseases, ICDDR,B,;
- Dr. Babar Kabir, PhD, Senior Director, BRAC;
- Mr. Rezaul Karim, Senior Programme Manager, BRAC;
- Mr. Folkert de Jager, Resident Project Manager, WOP-project DWASA-VEI;
- Mrs. Nishat Shahid Chowdhury, Dept. Program Mhr., IFC-IBRD;
- Mr. Zainal Abedin, Deputy Team Leader, CDSP-IV;
- Mr. Mark Ellery, Water & Sanitation Specialist, WSP - World Bank;
- Mr. Charlie Hrachya Sargsyan, Chief WASH, UNICEF;
- Mrs Fiona Ward, Wash Specialist, UNICEF;
- Mr. Simon de Haan, Team Leader, DMC-DWASA;
- Mr. Alok Kumar Majumder, Country Coordinator, WASH Alliance.

1.4. Objective

The objectives of the Thematic Baseline Report are to:

- evaluate existing problems, developments and (government) plans in view of the long term (socioeconomic and climate) changes
- Facilitate the identification of challenges and opportunities for the BDP2100 (also priority ranking). In doing this it is aimed to focus on interventions that translate towards building blocks for Delta Vision and development, as well as 7th 5-year plan.
- provide a basis for the identification of (additional) (no-regret) measures and strategies
- support joint fact-finding (contributing to trust and project ownership), with relevant stakeholders in the water & sanitation sector (and its connections to other sectors)
- create a common knowledge base
- identify knowledge gaps and research needs
- provide a basis for the identification of exemplary projects for implementation

1.5. Organization of the Report

- o *Chapter One* discusses the general introduction and background of the study, BDP position in Water Supply and Sanitation, Sector consultation and objectives of this study;

- o *Chapter Two* describes the present status of WSS position in Bangladesh, stakeholders in this sector, current policies and strategies related to WSS;
- o *Chapter Three* includes the sector challenges, sector position and investment forecast, trends, forecast and drivers of WSS sector, ongoing and forecasted programmes which are significance in national scale, planning issues in medium term and long term, reflection of WSS programs on 6th five year plan and invents some initiatives for 7th five year plan.
- o *Chapter Four* includes the WSS focus within BDP2100. It describes on hotspot selection criteria, challenges, current position of WSS and mentions some strategies to improve WSS sector in Haor areas.
- o *Chapter Five* identifies the sector challenges and actions needed to be taken to overcome the knowledge gaps.
- o *Chapter Six* describes water resources assessment, industrial waste use and waste water discharge, surface water quality constraints, urban waste water system and industrial waste water treatment system, service connection and full cost recovery objectives for Dhaka city.
- o *Chapter Seven* describes the water supply constraints, trend and some solutions for coastal areas.
- o *Chapter Eight* briefly discuss the findings of the study and give some recommendations.

2. Existing situation

2.1. Description of present status

Water supply and sanitation coverage in Bangladesh has improved substantially over the past decades. The majority of the population avails of minimum acceptable provisions.

While the following sections reveal encouraging evidence of the progress achieved, the following chapters will confirm that the WSS sector in Bangladesh has by no way completed its goals. In generic terms this could reflect:

- Positive aggregate average figures may obscure various regional disparities;
- Trends in pollution, arsenic proliferation and salinity intrusion may negatively impact on previous achievements;
- The target service levels for both water supply & sanitation will require adjustment (upgrade) to keep pace with both public demand, and development pressure (like urbanization and population growth).
- The WSS sector incorporates intrinsic weaknesses: heavy dependency on development partners, weak cost recovery practice and a need to (further) develop stakeholder mandate and conduct
- Service facilities need to be upgraded and regular O&M of exiting infrastructures have to be ensured

2.1.1. Water supply

Improved Drinking Water Source

Improved drinking-water sources are those using the following types of water supply:

- Piped water into dwelling
- Piped water to yard/plot
- Public tap or standpipe
- Tubewell or borehole
- Protected dug well

- Protected spring
- Rainwater

Bottled water is considered as an improved water source only if the household is using an improved water source for hand washing and cooking.

Unimproved Drinking Water Source

Unimproved drinking-water sources are those using the following types of water supply:

- Unprotected spring
- Unprotected dug well
- Cart with small tank/drum
- Tanker-truck
- Surface water (without treatment)
- Bottled water

The total improved water supply coverage has increased in Bangladesh from 68% to 85% among 1990 to 2012 according to WHO & UNICEF report (Joint Monitoring Programme Report 2014). In urban area the coverage is slightly higher than in rural areas, but the achievement is higher in rural areas. The JMP estimates are based on fitting a regression linear trend line to a series of data points from household surveys and censuses. Linear regression is deemed the best method for the limited amount of often poorly comparable data on file, especially given the relatively short time frame. The water supply coverage as in JMP report 2014 is given in Table 2.1.

Table 2.1: Water supply coverage according to JMP report 2014

URBAN WATER					
Estimated coverage 2014 update					
Year	Total improved	Piped onto premises	Other improved	Other unimproved	Surface water
1990	81%	23%	58%	17%	2%
1995	82%	25%	57%	16%	2%
2000	83%	27%	56%	16%	1%
2005	84%	29%	55%	15%	1%
2010	85%	31%	54%	15%	0%
2012	86%	32%	54%	14%	0%

RURAL WATER					
Estimated coverage 2014 update					
Year	Total improved	Piped onto premises	Other improved	Other unimproved	Surface water
1990	65%	0%	65%	28%	7%
1995	69%	0%	69%	25%	6%
2000	74%	0%	74%	22%	4%
2005	78%	1%	77%	19%	3%
2010	83%	1%	82%	16%	1%
2012	84%	1%	83%	16%	0%

TOTAL WATER					
Estimated coverage 2014 update					
Year	Total improved	Piped onto premises	Other improved	Other unimproved	Surface water
1990	68%	5%	63%	26%	6%
1995	72%	6%	66%	23%	5%
2000	76%	7%	69%	21%	3%
2005	80%	8%	72%	18%	2%
2010	83%	9%	74%	16%	1%
2012	85%	10%	75%	15%	0%

In the MICS 2012-13 report (Submitted in 2015), the coverage shows slight different than that in JMP report 2014. In this report it is surveyed that the coverage in urban area is 99.1% and in rural area is 97.6%.

Table 2.2: Water supply coverage according to MICS 2012-2013 report

Location		Improved water source		Unimproved water source
		Piped water	Other improved source	
Division	Barisal	0.7%	94.6%	4.7%
	Chittagong	3.6%	93.4%	3.0%
	Dhaka	16.5%	83.4%	0.1%
	Khulna	2.3%	92.1%	5.6%
	Rajshahi	4.2%	95.1%	0.7%
	Rangpur	0.7%	99.2%	0.1%
	Sylhet	3.5%	90.3%	6.2%
Area	Urban	28.7%	70.4%	0.9%
	Rural	1.3%	96.3%	2.4%
Total		7.0%	90.9%	2.1%

At present rural water supply is predominantly hand pump tube well based and, in a minority of cases, some other water points like pond sand filters (PSFs), ring wells and rainwater harvesting units are used. The number of private shallow hand pump tube wells in rural areas is eight times that of the public ones, the number of private deep tube wells and Deep Set Pump (DSP) tube wells is about one-third of the public ones, and the number of other private water points like different alternative technologies (for example, PSF and rainwater harvesting) is one tenth of the public ones.

In urban areas the existing water services heavily relies on groundwater. In Dhaka about 78% of water produced by DWASA is currently sourced from aquifers. The dependency on ground water to be further reduced to stop the continuous decline of the water table in many urban areas including Dhaka where the declination is 1-2m per year. The allowable limit of groundwater abstraction in Dhaka from the upper dupitila aquifer is around 1,640 MLD including Singair and Tetuljhara-Bhakurta groundwater well fields. Such allowable limit of groundwater abstraction is not yet studied in other cities.

While overall statistics imply a positive situation in coverage, there is some problem with quality of water. Arsenic is a major thread of water supply. Arsenic was discovered in groundwater in Bangladesh in the 1990s. in MICS 2012-13 report it is shown that 25.5% of the population had drinking water source with arsenic above the WHO provisional guideline value of ≤ 10 ppb, and 12.5% exceeded the Bangladesh Standard of ≤ 50 ppb. The source water quality is given in Table 2.3.

Table 2.3: Water quality in source (MICS 2012-2013 report)

Location		Arsenic in source water		E Coli in source water > 1cfu/100ml	Arsenic ≤ 50 ppb and E. coli < 1cfu/100ml	Arsenic ≤ 50 ppb and E. coli ≥ 1 cfu/100ml	Arsenic >50 ppb and E. coli < 1cfu/100ml	Arsenic >50 ppb and E. coli ≥ 1 cfu/100ml
		>10 ppb	>50 ppb					
Division	Barisal	2.8%	0.1%	32.7%	67.2%	32.8%	0%	0%
	Chittagong	34.8%	22.8%	48.1%	41.7%	33.4%	10.2%	14.8%
	Dhaka	30.1%	11.2%	50.9%	44.1%	44.6%	5.2%	6.1%
	Khulna	39.6%	21.5%	34.3%	51.7%	27.7%	13.8%	6.8%
	Rajshahi	12%	4%	31.4%	65%	30.4%	3.6%	1.1%
	Rangpur	8%	1.3%	28.2%	71.2%	28.3%	0.5%	0%
	Sylhet	42.5%	30.2%	61.9%	31.1%	38.8%	6%	24%
A	Urban	19.5%	6.8%	55%	42.1%	50%	355	4.9%

Location	Arsenic in source water		E Coli in source water > 1cfu/100ml	Arsenic ≤50ppb and E. coli < 1cfu/100ml	Arsenic ≤50ppb and E. coli ≥ 1cfu/100ml	Arsenic >50ppb and E. coli < 1cfu/100ml	Arsenic >50ppb and E. coli ≥ 1cfu/100ml
	>10ppb	>50ppb					
Rural	21.1%	14%	38.2%	55%	31.1%	6.8%	7.1%
Total	25.5%	12.5%	41.7%	52.3%	35%	6%	6.7%

It is needed to stress both the regional disparity and future threats from ongoing developments. In section 2.3 the prevalent sector challenges are outlined.

2.1.2. Sanitation

Improved Sanitation Facilities

Improved sanitation facility is defined as one that hygienically separates human excreta from human contact.

- Flush toilet
- Piped sewer system
- Septic tank
- Flush/ pour flush to pit latrine
- Ventilated improved pit latrine (VIP)
- Pit latrine with slab
- Composting toilet

Unimproved Sanitation Facilities

Unimproved sanitation facilities include the following types of methods:

- Flush/ pour flush to elsewhere
- Pit latrine without slab
- Bucket
- Hanging toilet or hanging latrine
- Shared sanitation

Shared Sanitation Facilities

Shared sanitation refers to the sanitation facilities (although of an improved kind) which are shared between two or more households and all public facilities.

The progress in sanitation started mainly in 1990's. A national sanitation goal of "100 percent Sanitation by 2010" was initially set. However, realizing the practical situation, in 2009, the goal was subsequently revised to achieving "100 percent sanitation by 2013." Based on the WHO-UNICEF JMP report the national sanitation coverage, is shown in Table 2.4.

Table 2.4: Sanitation coverage according to JMP report 2014

URBAN SANITATION				
Estimated coverage		2014 update		
Year	Improved	Shared	Other unimproved	Open defecation
1990	46%	25%	19%	10%
1995	48%	26%	18%	8%
2000	50%	27%	17%	6%
2005	52%	28%	17%	3%
2010	54%	29%	16%	1%
2012	55%	30%	15%	0%

RURAL SANITATION				
Estimated coverage		2014 update		
Year	Improved	Shared	Other unimproved	Open defecation
1990	30%	15%	15%	40%
1995	36%	18%	14%	32%
2000	43%	21%	13%	23%
2005	49%	24%	12%	15%
2010	55%	27%	11%	7%
2012	58%	28%	11%	3%

TOTAL SANITATION				
Estimated coverage		2014 update		
Year	Improved	Shared	Other unimproved	Open defecation
1990	33%	17%	16%	34%
1995	39%	19%	16%	26%
2000	45%	22%	14%	19%
2005	50%	25%	13%	12%
2010	55%	27%	13%	5%
2012	57%	28%	12%	3%

The sanitation coverage figures deviate while the JMP standard focuses on individual latrines, whereas Bangladesh figures include coverage by shared facilities. The vast majority of sanitation facilities consist of pit latrines with slab and water seal.

In contrast to the economic development trend and consequently the demand for better living condition, the sanitation and hygiene situation of the country is still lagging behind. Although the MICS report (2012-13) cites that the improved sanitation coverage is around 56%, the reality is different, as explained below.

Major cities

Of the seven major cities, Dhaka, Chittagong, Sylhet, Khulna, Barisal, Rajshahi and Rangpur, only Dhaka has a limited separate sewerage system and a conventional Sewage Treatment Plant (STP) of capacity 120,000 m³/d. This STP can serve 20% of the Dhaka population. However, dysfunctional collection system in many parts due to sedimentation or damage to sewer lines only allows about 10% of generated load to reach the Pagla STP. The sewage which cannot reach the STP is spilled and accumulates in various city areas causing major concern to public health. Around 33% of household in Dhaka city dispose their sewage/waste water by connecting to storm water drainage network and water bodies. This untreated sewage/waste water flows directly to the surrounding river system causing major deterioration of water quality. These rivers are presently the main sources of surface water treatment plants in Dhaka and Narayanganj. Therefore, this cannot be considered as an improved sanitation system because of its potential threat to public health. Improved on-site sanitation system (flush or pour-flush toilets to septic tanks or pit latrines) is utilized by 25% of the population. Faecal Sludge Management (FSM) is practically absent in these areas. It is estimated that 22% of the population are still using unhygienic on-site sanitation means.

There is absolutely no formal sewage collection system in other major cities. Inhabitants of the cities discharge sewage directly into inadequate surface drains while retaining (often partially) faecal sludge in septic tanks.

Systematic faecal sludge management is practically absent. Occasionally some of the septic tanks are cleaned and sludge is disposed into drains which ultimately discharge into water bodies, khals and rivers. A significant number of the population in these cities use shared sanitation (18%) and unimproved sanitation (22%) measures, while open defecation is also practiced by 5% population.

Therefore, it is evident that the major cities of Bangladesh lack sanitation facilities proper for metropolitan areas. Also the current sanitation practice totally ignores the environmental consequences which are already demonstrated by significant pollution of the surface water bodies and rivers. The problem with inadequate sanitation and sewerage in the major cities will increase with the growth of the city areas and its population. Predictions from various studies show that the population in the major cities will increase from 30 million in 2011 to 42 million in 2030 and 57 million in 2050. With demand for better living conditions the demand for improved sewerage system and sanitation will increase. This will be major challenge which needs to be tackled head-on.

Pourashavas/Municipalities/Towns

Apart from the major cities other urban areas include 359 pourashavas/municipalities/towns in Bangladesh. With economic development in the country which is associated with industrialisation and growth of service sector significant migration from the rural to the urban centres are very evident. Recent projections shows that the growth of population from the 2011 figure of 18 million will be around 30 million in 2030 and 64 million in 2050. As the present pourashavas/municipalities are taking shape of more formalised modern urban centres, demand for improved sewerage and sanitation facilities are becoming a general requirement. Unfortunately, statistics reveals that only around 59% population are within the so-called improved sanitation coverage. The rest are either using shared or unimproved sanitation facilities. As is the case for major cities, improved sanitation here means on-site flush or pour-flush toilet to septic tanks, pits or unknown places, pit latrines with slab or ventilated improved pit latrines. Faecal sludge management is a major problem in all the urban centres. Disposal of sludge remains an issue much neglected which is causing significant health, economic and environmental damages. In the long run the situation seems unsustainable.

Rural areas

Rural areas may be divided into areas which are having piped water supply and secondly those which are using point sources for water supply. In recent times DPHE is implementing rural piped water supply schemes in 37 rural areas where population density is sufficient for such schemes. DPHE has carried out pre-feasibility studies of 200 of such schemes and feasibility study of 150 schemes. It is envisaged that 9500 such rural piped water supply schemes will be implemented by 2050 covering around 50% of rural population. Piped water supply schemes will allow flush toilets to sewers or septic tanks. In areas which are having point water sources, it is likely that the inhabitants would go for pour flush toilets to septic tanks or pits. At present, 55% of the rural population uses improved sanitation means and 40% shared or unimproved sanitation. Around 5% are still opting for open defecation. The challenge is big, although it is understood that rural areas will have limited piped sewerage facilities and will mainly depend on flush or pour-flush toilets to septic tanks on pits.

Hard-to-reach areas

The National Strategy for WSS in Hard to Reach Areas of Bangladesh (2012) defined hard-to-reach (HtR) areas as "areas having poor water and sanitation coverage due to adverse hydro-geological condition, having poor and inadequate communication network, and frequent occurrence of natural calamities which in turn results in higher rate of child mortality and accelerates the vicious circle of poverty." The HtR areas are usually geographically remote and the people living there are least likely to have access to benefits from mainstream development

activities. The Strategy divided HtR areas into six different geographical categories. They are: (1) Barind, (2) Beel, (3) Char, (4) Coast, offshore Islands and Saline areas, (5) Haor, and (6) Hilly areas. The National Strategy for WSS (2014) identified 1,144 unions as hard-to-reach unions for water supply & sanitation in 257 upazilas of 50 districts. About 21% of the total geographical areas of Bangladesh are found to be hard-to-reach with about 28.62 million people living in these areas. The strategy provided directions for separate development projects or separate components within development projects specifically for the hard-to-reach areas and for the vulnerable people and to adopt different approaches considering the local infrastructure, cultural values and socio-economic status. It emphasised on addressing area specific needs when considering and developing technologies, such as sanitation technology requiring less flushing water and light weight construction materials for hilly areas.

Urban Slums and squatter Settlements

As migration from rural to urban centres are increasing at a rapid pace due to economic reasons, so does the urban slums and squatter settlements growing to accommodate the large influx of marginalised poor and vulnerable people from disaster prone areas. Most of the latrines in slum areas are unhygienic, families use mainly shared latrines, which are unhygienic; also many practice open defecation. In many slums open defecation is practiced by as much as 20% of slum population (OXFAM and ITN-BUET 2014). According to Appropriate sanitation in urban areas, especially in the low income communities, is a burning issue, yet to be resolved. Main problems of facilitating improved sanitation in urban slums are (1) most of the slums are on private lands in mainly low lands or wetlands without proper running water or good drainage facilities; (2) authorities are oblivious of the needs for better living conditions of the slum dwellers on the plea of illegal construction/occupation; (3) lack of understanding and knowledge about the ill effects of unsafe water and unhygienic sanitation. The National Strategy for WSS in HtR areas (2012) focussed on formulation and implementation of appropriate policy and strategies for water supply and sanitation improvement. It emphasised that basic services including water and sanitation must be made accessible to slum dweller irrespective of legal status of lands. It stressed on community water points and community sanitation blocks to be managed by community based organizations (CBO).

In the MICS 2012-13 report (Submitted in 2015), it is mentioned that 86.3% of the population in urban areas and 74.4% in rural areas are using improved sanitation facilities (Table 2.5). The open defecation in urban areas is 1.5% and in rural areas 4.6%.

Table 2.5: Sanitation coverage according to MICS 2012-2013 report

Location		Improved sanitation	Shared sanitation	Unimproved sanitation	Open defecation
Division	Barisal	52%	6.8%	39.9%	1.3%
	Chittagong	59.4%	15.6%	22.7%	2.3%
	Dhaka	54%	26.1%	18.1%	1.8%
	Khulna	58%	24%	17.2%	0.8%
	Rajshahi	52%	28.4%	13.2%	6.4%
	Rangpur	57.4%	17.2%	9.9%	15.5%
	Sylhet	58.6%	14.4%	26.2%	0.8%
Area	Urban	58.6%	27.8%	12.2%	1.4%
	Rural	55.2%	19.1%	21.1%	4.6%
Total		55.9%	21%	19.2%	3.9%

Only 20 % of Dhaka city is reported to be connected by sewerage system (whereas for technical status, the major part of the system is dysfunctioning) and the rest of Bangladesh is served by on site sanitation facilities of pit

latrines and septic tanks. Faecal sludge management for these on site sanitation facilities is scarcely present in an institutionally organized conduct. Whereas sanitation should include both the facilities at household level as well as the full technical and institutional (sludge) cycle, the conclusion has to be that sanitation “coverage” is still way off track from achieving 100 % achievement goal. Without major interventions the situation from environmental health perspective could be feared to deteriorate in the next 10 to 20 years.

2.1.3. Goals for water supply and sanitation

While good progress has been achieved in water supply and sanitation coverage, goals for further improvement need to be pursued. For sanitation service levels will need to climb up the ‘sanitation ladder’ (Figure 2.1) and faecal sludge management needs substantial development both in terms of institutional development and effective implementation. For both water supply & sanitation the MTR report of GoB-UNICEF’s WASH programme (June 2014) reveals that ‘effective’ coverage for both sectors leaves substantial scope for further increase and improvement.

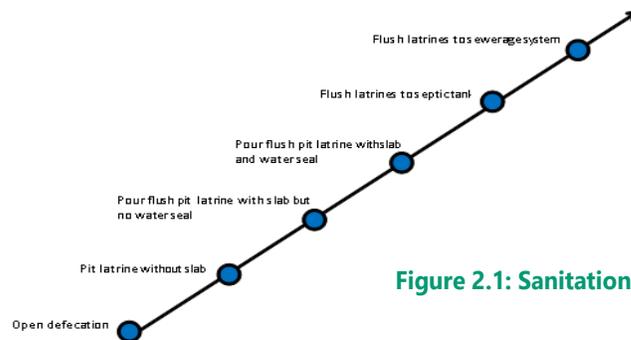


Figure 2.1: Sanitation Ladder in Bangladesh

2.2. Stakeholders in the water supply and sanitation sector of Bangladesh

In Bangladesh, water supply, sanitation and urban drainage are government responsibility. Most of the relevant stakeholders come under the realm of the Ministry of Local Government, Rural Development and Cooperatives (MoLGRD&C). For major infrastructure development and operations DPHE (for towns) and WASA’s (for major cities) are principal stakeholders in both water supply and wastewater services. At the national level, MoLGRD&C is responsible for overall planning, identification of investment projects and coordination of activities of agencies under it (viz. DPHE, LGED, WASAs) and LGIs, private sector, NGOs and CBOs.

In rural areas local and international NGO’s have an important pro-active position in water supply & sanitation, as service providers, often addressing underserved areas not reached by GoB.

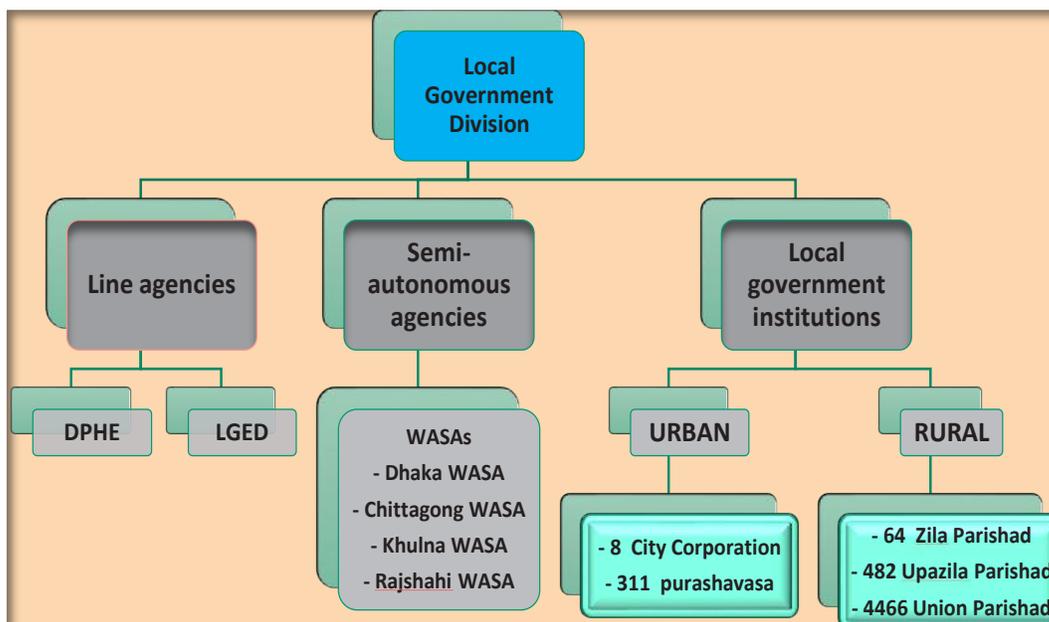


Figure 2.2: Organizational structure of the organizations under LGD (Source: SDP 2011-2015)

Department of Public Health Engineering (DPHE):

The DPHE is responsible for implementation of the WSS projects in the public sector in the rural and urban areas outside the areas covered by the WASAs. DPHE is responsible for assisting the Pourashavas and City Corporations (except WASA areas) through infrastructural development and technical assistance. Besides, both in rural and urban areas, DPHE collaborate with private sector, NGOs and CBOs.

Local Government Engineering Division (LGED)

In particular foreign aided projects where it is specifically required as a component of overall infrastructure package, LGED undertake water supply and sanitation related activities. In such project-based cases LGED assists the concerned Pourashavas in the implementation and provide technical assistance.

Water Supply and Sanitation Authority (WASA)

Relevant WASAs are responsible for water supply, sanitation and drainage in Dhaka, Chittagong, Narayanganj, Khulna, Rangpur and Rajshahi city areas.

Local Government Institute (LGI)s

Local Government institutions are provided with more scope to contribute in the activities of this sub sector. In most of the cases, these institutions lack adequate budgets, fail in governance conduct and pay insufficient attention to operation and maintenance issues, user involvement and hygiene promotion for behavioural changes resulting in

- inappropriate service delivery mechanisms,
- lack of ownership by the end users,
- low health impact and
- reduced sustainability of the services

The activities of the Pourashavas Water Supply Sections (PWSS) are mostly restricted to operation pumps and reactive maintenance of the existing systems. There is no provision for staff development and continuing education in Pourashavas, these agencies remain project and hardware-based lacking orientation in process-based approaches.

Private sector, NGOs and CBOs

Congenial atmosphere is created and necessary support is provided to facilitate increased participation of the private sector, NGOs and CBOs in the activities. Private sector and NGO investment is encouraged in manufacturing, sale and distribution of different types of WSS components. They are also encouraged to participate in the installation of piped water supply system where feasible. It is relevant to note that substantial proportion of rural installed water & sanitation facilities are from private initiatives.

But there is insufficient coordination in installation of water points by NGOs. Many of such are not installed properly (such as, installed in arsenic contaminated aquifer) or there may be duplication. These should be properly coordinated.

2.3. Current Policies and Strategies

Bangladesh Government has many plans and policy related to water supply and sanitation sector as listed below:

1. National cost sharing strategy for Water Supply And Sanitation in Bangladesh, Nov 2012
2. National Hygiene Promotion Strategy for Water Supply And Sanitation in Bangladesh, Dec 2011
3. National Strategy for Water And sanitation Hard to Reach Areas of Bangladesh, Dec 2011
4. National Sanitation Strategy, Nov 2011
5. Sector development plan (FY 2011-25), Water supply and sanitation Sector in Bangladesh, Nov 2011
6. Water Safety Framework (WSF) in Bangladesh, Oct 2011
7. Sector Development Programme, Water and sanitation Sector in Bangladesh, Dec 2005
8. Pro Poor Strategy for Water and sanitation Sector in Bangladesh, Feb 2005
9. Sector Development Framework, Water Supply and sanitation Sector, May 2004
10. National Water Management Plan, December 2001
11. National Water Policy, 1999
12. National Policy for Safe Water Supply & Sanitation, 1998

The National policies, strategies and programme have been reviewed and fact sheets are prepared for some important policies, strategies and programme which are given in Annex-A.

While the sector, its policies and its stakeholders are well established and organized, some particular challenges on long-term developments may be noted:

- Even more than today, the competition for scarce water resources will be inter-sectoral. Adequate provision for municipal water supply will need to be ensured;
- The sector management is, at present, water supply dominated especially where towns and cities are concerned. With increasing urbanization there is an urgent need for effective collection of municipal and industrial wastewater and faecal sludge;
- At present the sector has a strong dependency on Development Partners. Financial sustainability is deemed feasible in view of Bangladesh economic development. To effectively cater for investment needs, especially with the scale-up with further urbanization, arrangements for private participation in the sector may need to be re-considered.

The National Strategy for Water Supply and Sanitation (2014, available in draft final) paves a promising pathway for these future needs in its focus:

WSS Interventions

- 1: Ensure safe drinking water
- 2: Give priority to arsenic mitigation
- 3: Undertake specific approaches for hard to reach areas and vulnerable people
- 4: Move ahead on the sanitation ladder
- 5: Establish faecal sludge management
- 6: Manage solid waste judiciously
- 7: Improve hygiene promotion
- 8: Mainstream gender
- 9: Facilitate private sector participation

Emerging Challenges

- 10: Adopt integrated water resource management
- 11: Address growing pace of urbanization
- 12: Cope with disaster, adapt to climate change and safeguard environment
- 13: Institutionalize research and development

Sector Governance

- 14: Undertake integrated and accountable development approach
- 15: Recover cost of services while keeping a safety net for the poor
- 16: Strengthen and reposition institutions
- 17: Enhance coordination and monitoring

3. Outlook and challenges

3.1. Identified challenges

Many of the generic challenges to Bangladesh also affect the water supply & sanitation sector.

- Dual problems of water management. In monsoon, there is too much water and, in the dry season, shortage of (surface) water creates a drought-like situation.
- Growing pace of urbanization as well as increased population is putting pressure on the already stressed water supply and sanitation systems.

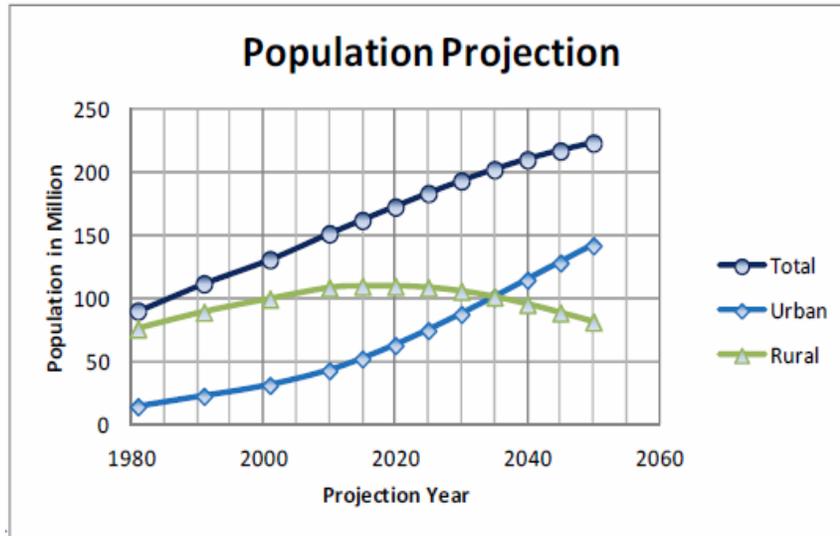


Figure 3.1: Population projection (ref. SDP 2011-2025)

- Limited piped water supply coverage in urban areas. When these systems will be expanded, water resources constraints will be a challenge. Aquifer yields to meet the growing demand for water in those cities have already become limited. As a result, the new source will mostly have to be surface water, which will, however, require higher investment than the groundwater-based systems would. Moreover, NWPo as well as NWMO call for optimum utilization of surface water and restrict development of groundwater. Surface water based water supply systems require larger scale infrastructure and constitute higher complexity in O&M. Moreover, in urban context surface water is polluted to the extent that water treatment by conventional technology may fail to produce water to drinking water standard;
- Inadequate and inappropriate urban sanitation. Inadequate infrastructure and institutions for dealing with faecal sludge from households and institutions;
- Due to inefficient O&M of the water supply system it is estimated that Unaccounted for Water (UfW) is around 40%. Also iron and manganese content of groundwater pose significant challenge to functional water supply operations, particularly of piped systems (clogging of pipes, taste & odour for consumption).
- Major parts of rural Bangladesh exist in a situation where the water source is contaminated by arsenic (20 % of population is estimated to be affected. The number may increase with increasing arsenic proliferation and/or adjustment to stricter arsenic levels).
- Due to further lowering of GW levels and seasonal variation, the shallow tube wells cannot yield water especially in dry season, causing a serious threat as at present the shallow tube well dominant rural water supply system. This trend has affected rural Bangladesh for a long time, and it continues today.

Groundwater table (dropping)

Already during the 90-ies Bangladesh had achieved successful rural coverage of water supply by HTW's (Hand Tube Wells). Once agriculture turned to mechanized groundwater abstraction for irrigation, groundwater tables quickly dropped below HTW capability levels. Subsequently HTW's needed to be re-fitted enabling them to abstract groundwater from greater depth. This is a clear example of inter-sectoral 'competition' for scarce resources.

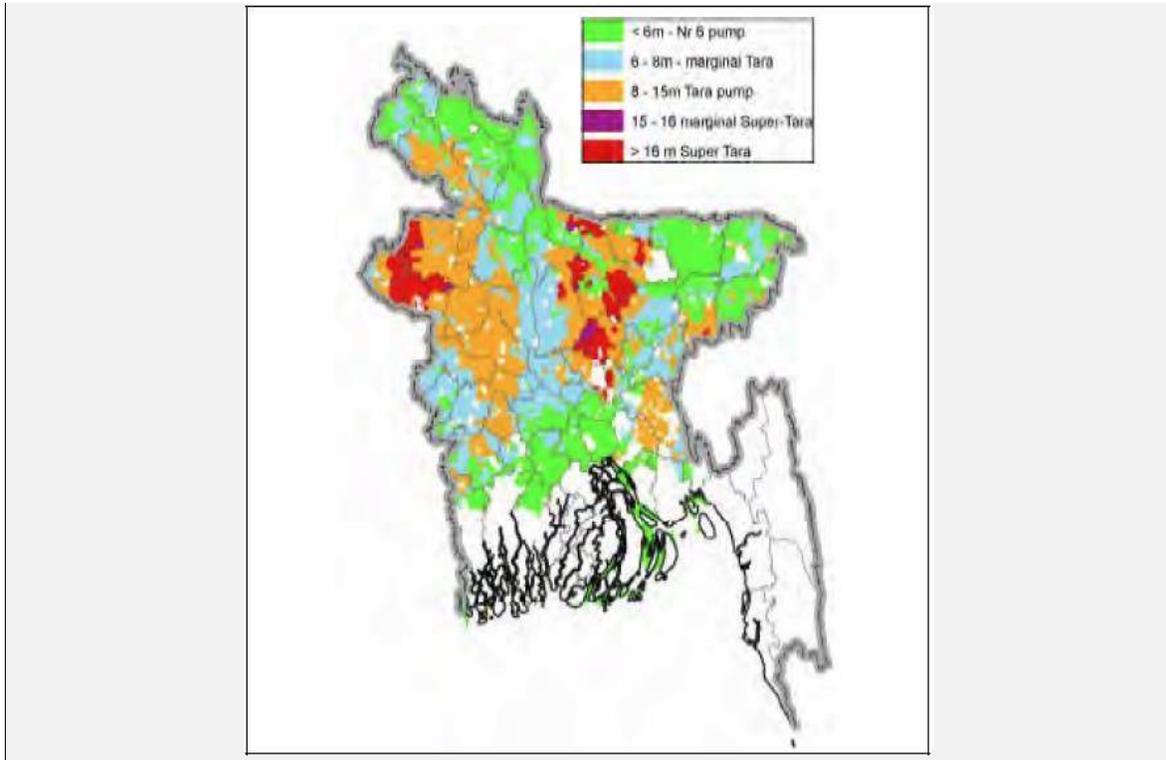


Figure 3.2: Lowest water levels depths measured in 2009 by DPHE

Arsenic in groundwater

Bangladesh water supply is faced with arsenic contamination, which has become apparent since 1993. Water supply turns to deeper aquifers (relatively) free of arsenic. While moderate abstraction for potable use could be sustainable, the situation that agriculture (while crops and fields are also affected by arsenic contamination) is turning to these same aquifers, may constitute a new threat: over exploitation of deeper aquifer and/or a situation where arsenic contamination to deeper aquifer is triggered.

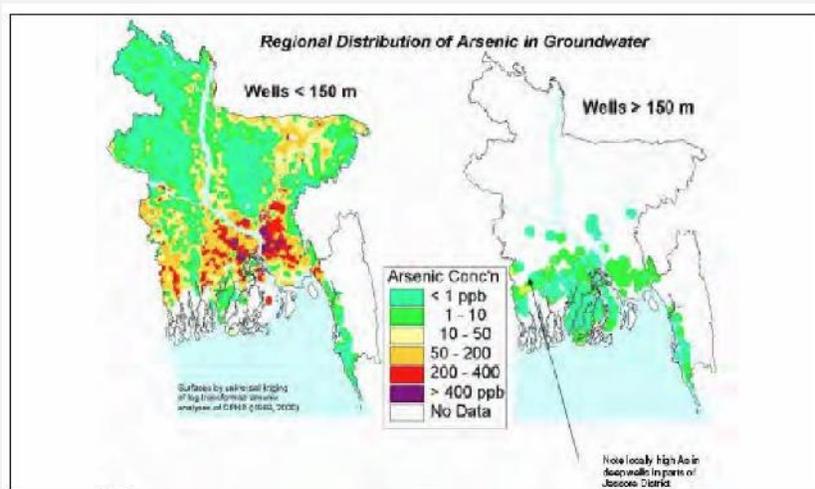


Figure 3.3: Distribution of arsenic in tubewells with depths within 150m (left) and above 150m (right)

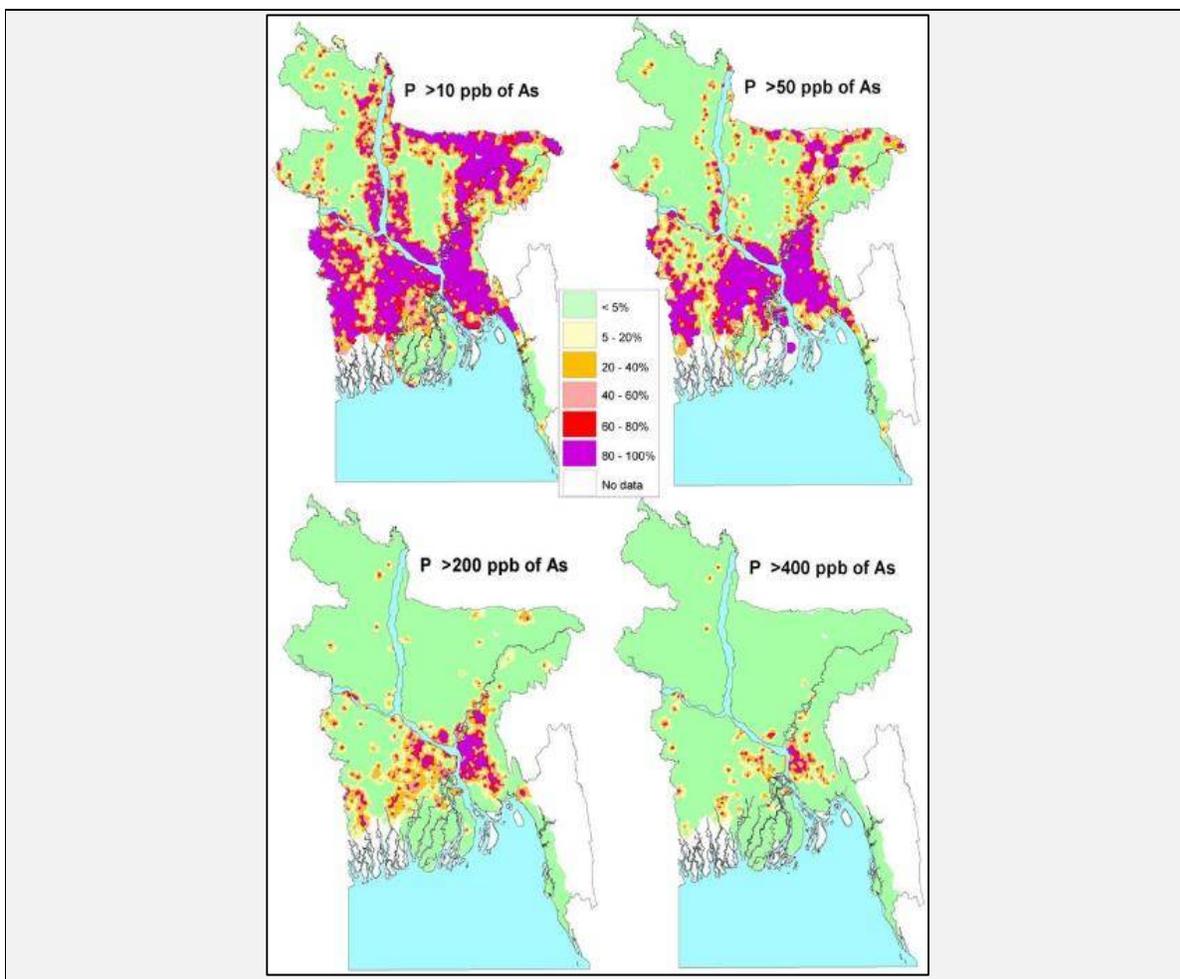


Figure 3.4: Distribution of population in arsenic contamination areas

- Due to geophysical and hydro-geological factors like frequent inundation, hilly areas and unavailability of suitable water sources, there are some hard-to-reach areas in the country where water and sanitation services cannot be provided easily.

The 'National strategy for Water and Sanitation for Hard to Reach Areas of Bangladesh', December 2012. identified 1144 HtR unions (21%) under 6 different geographic categories were identified which spreads over 257 Upazilas and 50 districts in Bangladesh as shown in Table 2.3.

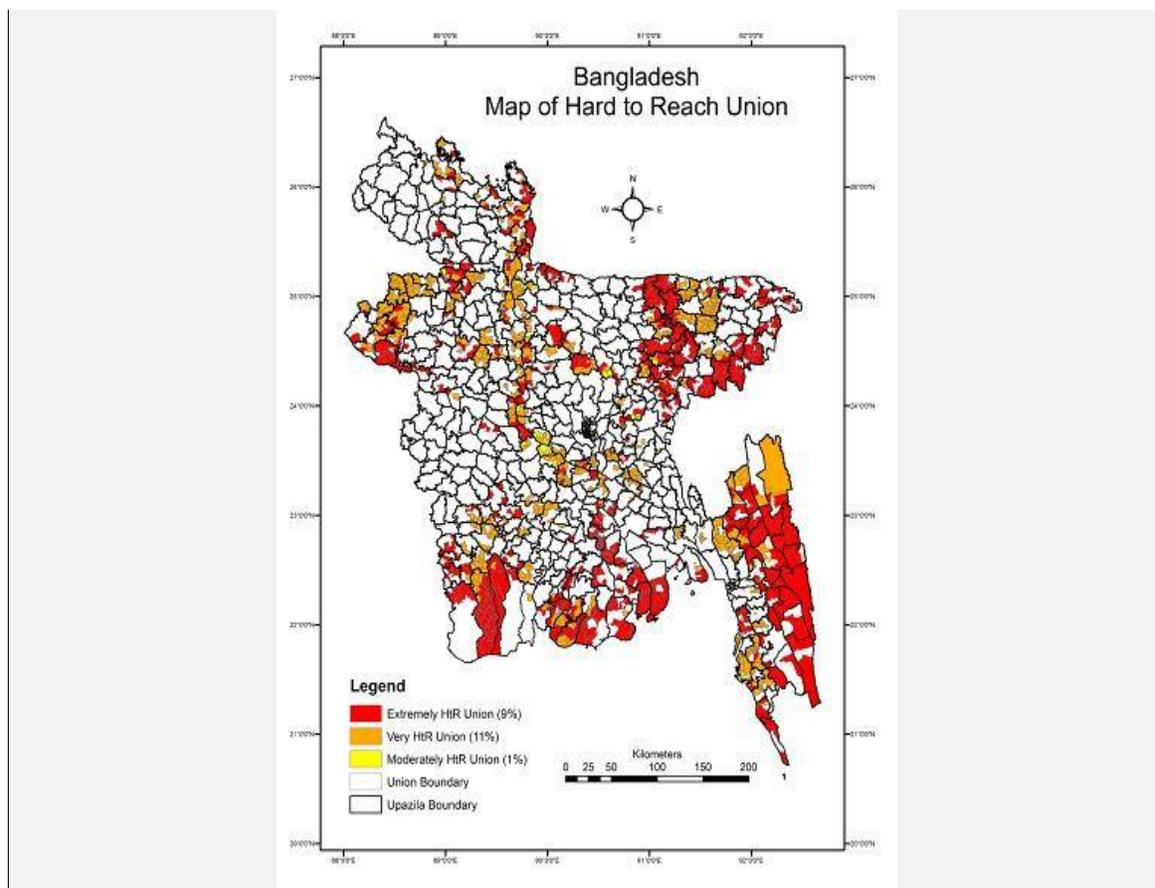


Figure 3.5: Map of Bangladesh showing HtR areas

Local Government division had so far identified some challenges and strategies to provide water and sanitation services in these HtR areas as shown in Table 3.1.

Table 3.1: HtR areas based on physiographic conditions and spatial distribution of Bangladesh

Hard to Reach Areas	Challenges	Strategies for Sustainable Solutions
Barind	<ul style="list-style-type: none"> • Dry season water scarcity • GW level declination • SW sources dry up, and rain water storage has not been given due attention. • Sanitation options become unhygienic due to water scarcity. • poverty 	<ul style="list-style-type: none"> • Subsurface rainwater recharge, excavation, regeneration and protection of rain fed ponds, excavation of dried up canals and • storage of surface and rain waters for lean Balanced use of GW and SW • ecological sanitation • Campaigns on water conservation, use of surface and rain water and eco-sanitation. • Change in cropping pattern. Cultivate crops which require less water • Reduce boro cultivation
Char	<ul style="list-style-type: none"> • Regular inundation due to monsoon rain and upstream flash flood 	<ul style="list-style-type: none"> • Planned development

Hard to Reach Areas	Challenges	Strategies for Sustainable Solutions
	<ul style="list-style-type: none"> • Extreme poverty 	<ul style="list-style-type: none"> • Some portion needs to be raised with flood protection • The remaining area would be available for seasonal agriculture, fisheries and other livelihood opportunities. • Strict policy framework is required • Small scale pipe network distribution is required with rainwater harvesting, community level arsenic/iron removal unit and filtration units • Twin off-set pit pour flush technology, individual or community eco-toilet system, community septic tank system or biogas plant.
Coast, offshore Island & Saline	<ul style="list-style-type: none"> • Saline intrusion • Water and sanitation infrastructure damage due cyclone, tidal surge and inundation of low lands and off-shore islands. 	<ul style="list-style-type: none"> • Raised grounds type drinking water and sanitation infrastructures. • Desalination plants and rainwater harvesting with underground reservoirs • Twin off-set pit pour flush latrines, ecological sanitation facilities and community septic tank systems
Haors and Beels	<ul style="list-style-type: none"> • Natural disasters • Arsenic contamination in groundwater • Absence of adequate road communication network • Absence of an appropriate wetland policy 	<ul style="list-style-type: none"> • Wetland protection policy to safeguard the rich ecosystems • Roads and communication systems need to be improved • Planning and implantation of electricity connection with national grid or generation of power • Cluster homesteads on raised lands with community water, sanitation and other service • combination of surface water, groundwater and rainwater sources • Individual twin off-set pit pour flush technology, multiple off-set pit pour flush facilities for community sanitation, and community septic tank systems • Small scale surface water treatment plant
Hilly	<ul style="list-style-type: none"> • Challenges due to geographic, socio-cultural and hydro-geologic conditions • Springs, chharra and streams have seasonal fluctuations that exacerbate due to climate changes • Pollution on SW • GW unavailability due to varying altitude, rocky formation and seasonal WL fluctuation • Situation and cultural beliefs 	<ul style="list-style-type: none"> • Developing water reservoirs at appropriate altitude • Infiltration galleries, protected dug wells and tube wells where feasible, should be developed as community water points. • Eco-toilet facilities or twin or multiple off-set pit pour flush latrines are to be promoted, through motivational campaign and demonstration • Rigorous campaign are needed

Hard to Reach Areas	Challenges	Strategies for Sustainable Solutions
	<ul style="list-style-type: none"> Lack of proper sanitation and hygiene knowledge 	

- Groundwater (and surface water!) salinity is an increasing problem for coastal zone water supply provision.
- Due to leakage problem and intermittent supply, in many piped supply systems, the water quality is at high risk.
- Hygiene is a weak link in the sector. A common approach towards hygiene promotion that should be followed by all stakeholders and projects is absent.
- Effects of environment, climate change and disaster issues have strong interdependency on WSS (Figure 3.6).

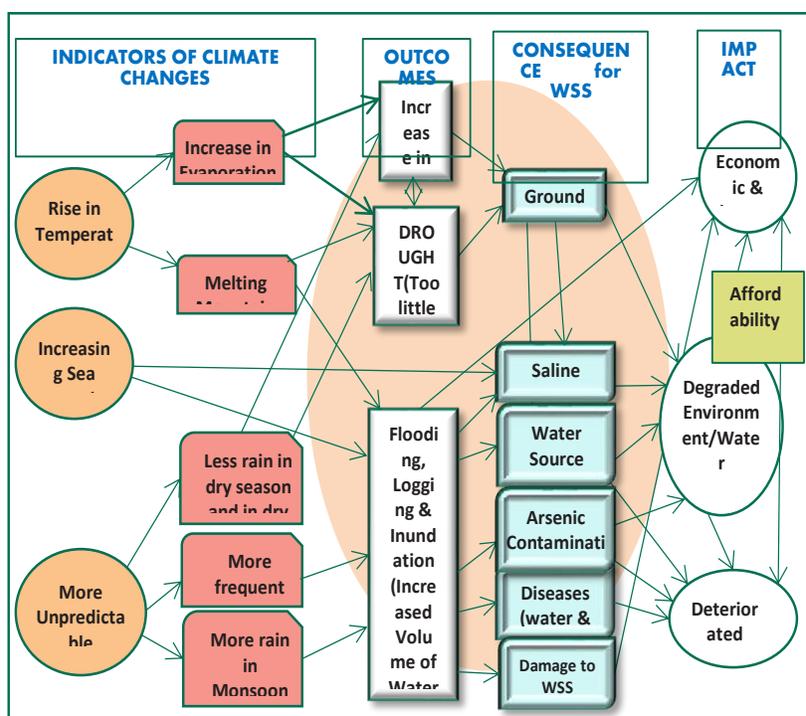


Figure 3.6: The cause-effect diagram of climate changes on WSS and human life

3.2. Sector position and investment forecast

Sector Opportunity:

- Supportive sectoral, national and international policies, strategies, plans and goals
- Strong political commitment
- International pledge
- Access to funds

- Experience of health and education sector- wide approaches
- A vibrant private sector in several sub-sectors
- Successful community- based approaches

The New Sector Development Framework

The SDP 2005 analysed the relevant national and international policies, strategies and targets, and prepared a framework for the development of the WSS sector. The development activities by the Government of Bangladesh (GoB) and the Development Partners (DPs) in this sector would be planned, coordinated and implemented under the New Sector Development Framework.

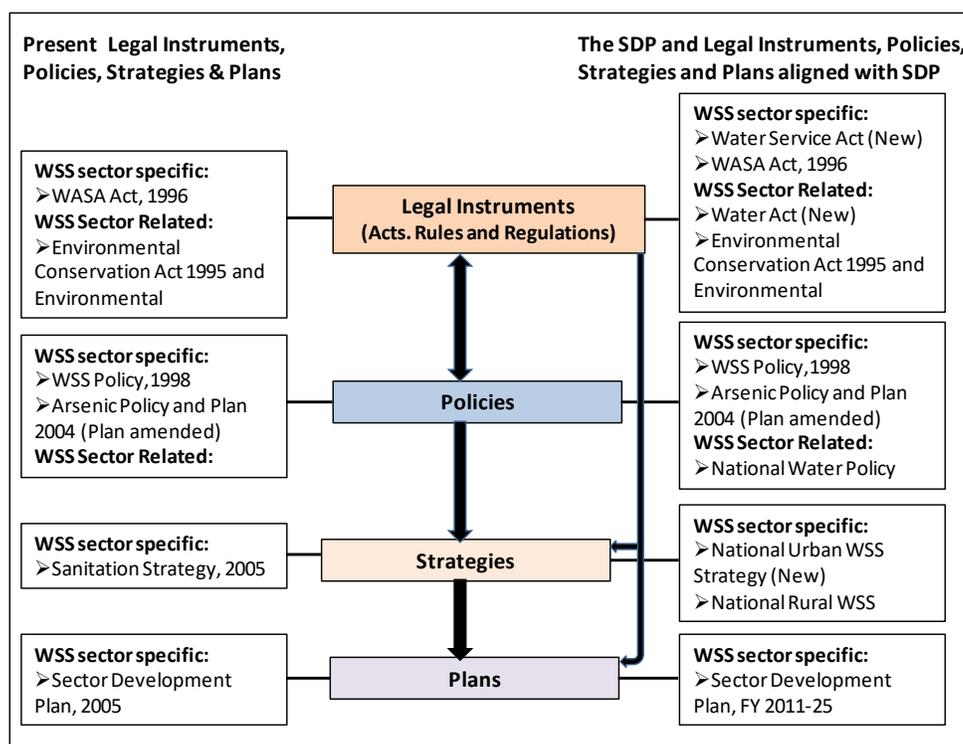


Figure 3.7: Sector development framework

(Source: SDP 2011-2015)

Sector Investment

The source of investment required to achieve the objectives of the water supply & sanitation sector (as set out in the SDP 2011-2025) is broadly classified into three groups:

- **public sector** (including the ADP allocations by the government and the DPs, and rev-enue generation by the WSS utilities like WASAs and pourashava water supply sec-tions);
- **private sector** (including community contribution as cost sharing, private household investment and private entrepreneurs); and
- **NGOs** (including direct funding from the donors and their own funds).

The Sector Development has prepared budget forecast for sector investments as summarized in Table 3.2.

Table 3.2: Investments required in different categories and terms of the SDP

(BDT million)

Categories	Short- term (2010- 15)	Medium- term (2016- 20)	Long- term (2021- 25)	Total
Urban water supply	165,220	280,467	269,257	714,945
Urban sanitation	133,999	173,004	209,361	516,364
Rural water supply	44,687	42,824	55,111	142,622
Rural sanitation	36,504	27,726	27,360	91,590
Total	380,410	524,021	561,089	1,465,520

(Source: SDP 2011-2015)

3.2.1. Gender and WATSAN

Women and girls are most often the primary users, providers and managers of water in their households and are the guardians of household hygiene. If a water system falls into disrepair or is damaged by natural calamities (flood, salinity, drought) women are the ones forced to travel long distances over many hours to meet their families' water needs. Also, long distance of toilet creates violence and raises question of dignity; makes women vulnerable to sexual harassment and violence; menstrual management faces problem, pregnant women and adolescent girls suffer most. Women and children particularly, girls are the most susceptible to water borne diseases due to their roles in water collection, washing clothes and other domestic activities. So, easy access and improved user friendly water facility is a requirement.

Technology and design of the WATSAN facilities need to be compatible with the differential needs of women and men, girls and boys, physically handicapped and elderly men and women; and women of reproductive age. Hence strengthened emphasis is needed on women's empowerment through their appropriate representation and effective participation in decision-making bodies (water point management committees and community groups). A better water system in the sense of convenient location and routinely maintained, benefits the whole family, women, men, girls, boys and differently able persons in terms of quality water, better health, hygiene and sanitation; water, sanitation and hygiene to be addressed together.

An efficient water system ensures women's economic, social, political and physical empowerment by allowing her time to engage in income earning activities, by giving her easy and safe access to water points, by ensuring her participation in decision making, by supplying safe water to her family. Freed from the drudgery of water collection and management, children especially girls, can go to school. Because of women's task in water provision they know much about the local water management, hence, it is important to utilize that knowledge and involve them in decision making.

3.3. Identified trends, forecasts and drivers of change

There are many drivers which have impact on WSS sector. Some drivers are as follows:

- Population growth
 - Increasing system pressure, constraints on water resources
- Land use change / urbanization
 - Pressure on water resources, aggravating environmental constraints relative to sanitation

- Economic growth
 - Enabling development
- Technical developments
 - Enabling development
- SW and GW contamination due to Salinity, Arsenic and manganese, as well as many anthropogenic contaminants
 - Pressure on technical needs and related cost of service
- Climate change
 - Pressure on water resources. Related environmental constraints
- GW level depletion
 - Increasing costs. Increasing adverse environmental effects.
- Land Subsidence
 - Challenging sustainable use of existing WSS facilities.

For each of these drivers secondary data (and if available also primary data) will need to be acquired, trends will need to be analysed and spatial distribution mapped (if relevant). These descriptions will provide building blocks for future scenarios within BDP2100 framework (for 2050 and 2100). Essential links to other problem fields / themes will need to be identified (regarding both impact and causal relations).

3.4. Ongoing and forecasted programmes with national scale significance (size and prototyping)

Both from GoB and from international development partners, water & sanitation has been a focus sector. Both in completing minimum service provision and in order to cope with new and aggravated challenges, inputs in the water supply & sanitation sector will need to be continued.

The list of some proposed projects in water & sanitation sector in Bangladesh are listed in Table 3.3 and factsheet of some important projects are given in Annex-C.

Table 3.3: List of ongoing/proposed projects in WSS sector

Si. No.	Name of Projects	Actor/ Stakeholder
1.	Implementation of Singair Well Field Phase-II & primary and secondary mains; expansion of distribution network	Dhaka WASA
2.	Implementation of Saidabad WTP III & primary and secondary mains; expansion of distribution network	Dhaka WASA
3.	Implementation of Padma WTP I & primary and secondary mains; expansion of distribution network	Dhaka WASA
4.	Implementation of Padma WTP II & primary and secondary mains; expansion of distribution network	Dhaka WASA
5.	DTW performance Assessment and future recommendations for sectors	Dhaka WASA
6.	Construction of intake for Godnail WTP	Dhaka WASA
7.	Renovation of Sonakanda WTP & primary and secondary mains	Dhaka WASA
9.	Shifting of intake for of Chandnighat WTP from Buriganga to Dhaleshwari	Dhaka WASA
10.	Implementation of Gandharbapur WTP I & primary and secondary mains; expansion of distribution network	Dhaka WASA
11.	Implementation of Gandharbapur WTP II & primary and secondary mains; expansion of Distribution	Dhaka WASA
12.	Implementation of Gandharbapur WTP III & primary and secondary mains; expansion of distribution network	Dhaka WASA

Si. No.	Name of Projects	Actor/ Stakeholder
13.	National Water Supply project	DPHE
14.	Union Council Supported Village Pipe Water Supply	DPHE
15.	National Water Supply and Sanitation Census Project (July 2011 – July 2012)	DPHE
16.	Arsenic Free Safe Water Supply Project	DPHE
17.	Feasibility Study on Water Supply and Sanitation System Development in Haor Areas	DPHE
18.	Water Supply and Sanitation Study and Development Project in Deprived and Hard-to-reach Areas	DPHE
19.	National Sanitation Project (July 2013 – July 2017)	DPHE
20.	Bangladesh Water Supply, Sanitation and Health Education project	DPHE
21.	The Project for Improvement of Comprehensive Management Capacity of DPHE on Water Supply	DPHE
22.	Capacity Building of Urban Water Supply Service (GoB-IDB)	DPHE
23.	Water Supply, Sanitation, Drainage and Solid Waste Management for Small Pourashava (GOB-IDB)	DPHE
24.	Pipe Water Supply & Sanitation in Upazila Sadar (50 Upazila Sadar in Phase-I)	DPHE
25.	The Programme for Improvement of Capabilities to withstand Natural Disaster Caused by Climate Change	DPHE
26.	Improvement Project of the Drainage System in Growth Centers	DPHE
27.	Water Supply System Expansion and Improvement Program in District and Upazilla Sadar	DPHE
28.	Safe Drinking Water Source Identification and Monitoring Project in the Entire Country	DPHE
29.	30 Small Pourashava Water Supply & Environment Sanitation Project	DPHE
30.	Water Supply and Environmental Sanitation in Municipalities and Chittagong Hill Tracts.	DPHE
31.	Construction of intake, transmission and distribution system of Madhumati WTP for Khulna city, Phase-I, 110MLD treatment plant	Khulna WASA
	Construction of intake, transmission and distribution system of Madhumati WTP for Khulna city, Phase-II-78MLD treatment plant	
32.	Construction of 4 STP in Khulna city-175 MLD capacity	Khulna WASA
33.	Construction of Godagari WTP for Rajshahi city-126MLD treatment plant	Rajshahi WASA
34.	Construction of 1 STP in Rajshahi city-163 MLD capacity	Rajshahi WASA
35.	Construction of Teesta River water WTP for Rangpur city-90MLD treatment plant	Rangpur WASA
36.	Construction of 1 STP in Rangpur city-127 MLD capacity	Rangpur WASA
37.	Karnaphuli Water Supply Project Phase 1 – 143 MLD treatment plant, two reservoirs and transmission line	Chittagong WASA
38.	Karnaphuli Water Supply Project Phase 2 – 143 MLD treatment plant, one reservoirs and transmission line	Chittagong WASA
39.	Modunaghat WTP – 90 MLD treatment plant	Chittagong WASA
40.	PANI project – reduction on non-revenue water by rehabilitation of distribution system, house connections, management system etc.	Chittagong WASA
41.	PANI project – reduction on non-revenue water by rehabilitation of distribution system, house connections, management system etc.	Chittagong WASA

3.5. Planning Issues for Medium Term

In medium term perspective the WSS sector deals with numerous planning issues:

- Groundwater resource management needs to be urgently strengthened to prevent further over exploitation, to control competing interests to groundwater abstraction (domestic, industrial and agriculture) and possibly to create a new source of revenue;

- Importance of agriculture (food security), political will (it may not be popular to introduce water pricing), also in view of limited public understanding (aquifer, safe yield, recharge) will make it challenging to promote sectoral change.
- Water supply development plans are required for individual cities and towns to improve service level and to increase coverage. In aggregated terms new concepts need to be embraced in urban water supply for Bangladesh, particularly where a shift to surface water sources may be involved;
 - WASA's of Dhaka, Chittagong, Khulna, Rangpur and Rajshahi have master plans prepared or under preparation that incorporate a relative shift from groundwater to river water sources. In certain parts of Bangladesh there will be seasonal scarcity of surface water as well. Adequate quantities need to be ensured for potable water abstraction, and water quality policies need to be adopted and enforced to ensure suitable raw water quality.
- Major cities will need to re-frame their sanitation concepts either by the introduction of sewer systems, or in ensuring efficient and effective collection, handling and disposal or re-use of septic sludge from latrines and septic tanks. The technical, institutional and financial arrangements for faecal sludge management need to be prioritized to mitigate health and environmental pressure from current sanitation practice;
- Nationally priorities need to be matched where economic progress and environmental protection is concerned. Pollution of groundwater and especially surface water with municipal, industrial and agrochemical contaminants is an increasing problem (urgent in certain areas, while looming in general). While economic progress needs to be sustained, a better balance with environmental restrictions needs to be enforced;
- In medium term it is difficult to imagine Bangladesh without flooding. Water & sanitation services both large-scale and household scale, need to be designed and constructed in flood resilient concepts. On household level elevated facilities for latrines and HTW-s are being adopted. On communal level solutions are being considered in facilities for community services like schools cum shelters and mosques that may serve broader purpose during disasters.
- (continued) mitigation of arsenic groundwater;
- Mitigation for salination of coastal groundwater, with a likely focus on rainwater based concepts, aquifer recharge (technical complications) and local surface water retention (land use constraints and water quality restrictions) based concepts.

3.6. Planning issues for long term

In long term perspective the WSS sector deals with numerous planning issues:

- Surface water allocation and regulation measures for urban water supply, as well as other demands (agriculture, navigation, cooling water), especially in view of dry season scarcity. The true need for water regulation between sectors and individual users will intensify, the need to use more expensive technology (deeper aquifers, increased treatment needs) will become paramount, and the spatial planning may become further 'water-driven' in several dimensions of the water cycle (water availability, flood resilience). It is for these long term phenomena that on the medium term the right policies need to be adopted, particularly water regulation/pricing, and 'water-aware-spatial-planning';

- Groundwater allocation and regulation for domestic, industrial and agriculture needs. What is true for surface water, counts for groundwater similarly. Moreover, sectoral preferences need to be established as to the allocation of groundwater availability;
- Long-term solutions for urban sanitation. The combination of continued urbanization, and the development demand for improved sanitation services, healthy living environment, and comprehensive environmentally sustainable development will be drivers for more advanced sanitation solutions;
- Sustainable solutions for water supply in coastal zones: freshwater storage, aquifer recharge, rainwater harvesting concepts. Ultimately desalination may become part of coastal water supply.

3.7. Reflection on 6th Five-Year Plan

The water supply & sanitation sector is well embedded in the 6th 5 year plan (SFYP). In reviewing the SFYP, the following may be noted:

- The progress on water supply & sanitation is well noted, to be ahead of MDG targets, and to include improved coverage in rural Bangladesh. It is noted that further coverage on sanitation is required, and increase on the ‘sanitation ladder’ is to be aimed for. The ambition is for 100 % effective coverage, including ‘safe use’ (which involves hygiene education);
- The WSS sector is reflected to be well established, and the SFYP connects to the GoB policy framework specifically referring to Sector development plan (FY 2011-25), Water supply and sanitation Sector in Bangladesh, Nov 2011;
- Particular challenges in terms of arsenic in groundwater, and governance skills to be transferred from DPHE to LGI are well noted;

It may be noted that budget allocation for LGED has been awarded an increasing trend in SFYP, whereas budget breakdown has been referred from MoLGRD&C (page 243 of part 2 SFYP). In budget respect it must be noted that budget allocation to metropolitan urban areas (WASA’s) and the rest of Bangladesh (DPHE) may not be in optimum balance.

It will be good if the 7th 5 year plan may proceed along policies and strategies of the 6th 5 year plan. To accommodate the actual views, it is recommended to incorporate The National Strategy for Water Supply and Sanitation (2014, available in draft final) which paves an effective pathway for future needs in its focus.

In general terms it is advocated that in its mid-term horizon the 7th 5 year plan may bear long-term sectoral challenges and ambitions in mind.

3.8. Initiatives for consideration into the 7th five-year plan

Reflecting on the planning issues in short term perspective it will be important to take initial steps into the 7th 5-year plan. Initiatives that may be considered in this regard include:

New tariff structure for urban water supply (WASA’s)

- Review existing tariff structure;
- Maintain a tariff structure which accommodates a ‘safety net’ for low income consumers, while progressively charging high volume users;
- Prepare economic analysis to establish tariff settings for:

- Achieving full operational cost recovery including regular maintenance;
- Achieving full comprehensive cost recovery including depreciation and re-investments;

Programme a tariff escalation schedule (for real increase, on top of inflation) to achieve full operational sustainability in 5 years and full comprehensive sustainability in 15 years.

Establishment of Faecal Sludge Management arrangements

- Major cities will need to re-frame their sanitation concepts either by the introduction of sewer systems, or in ensuring efficient and effective collection, handling and disposal or re-use of septic sludge from latrines and septic tanks. The technical, institutional and financial arrangements for faecal sludge management need to be prioritized to mitigate health and environmental pressure from current sanitation practice. For the 7th 5 year plan focus would need to be:
 - Propagate initiatives where technical systems for FSM are explored, including the conduct of re-use principles considering aesthetic and cultural values and norms;
 - Confirm governance principles relative to FSM: tasks and responsibilities relative to environmental health, public sanitary services, and day-to-day operations;
 - Ensure that major cities formulate sanitation master plans with an eye for governance and cost recovery principles;

Full metering coverage

Both for monitoring water use, reducing losses and Non Revenue Water (NRW) and to facilitate effective and accurate cost recovery, water metering is required. At present the status of full effective metering coverage has not been achieved.

- Assess existing coverage and status of metering in all WASA operated water supply systems;
- Prepare a programme of achieving 100 % coverage in a 5 year schedule;
- For each of the WASA's, prepare an assessment of the existing system of metering zones, and prepare a master plan to achieve effective meter district operations in all WASA's within 10 years. Dhaka & Chittagong WASA has taken initiatives for introducing District Metered Area (DMA) system. Other WASA's can also take initiatives within next 5years.
- Define slum areas in cities and establish community based water source point so that people can collect water for domestic uses.

Industrial zones

The effective collection, treatment and discharge of industrial wastewaters would strongly benefit from clustering industrial activity into industrial zones. In this regard:

- Prepare urban master plan for Greater Dhaka, where industrial zones are allocated;
- Establish legal and financial incentives to discourage industrial activity outside designated zones for new industries;
- Establish legal and financial incentives to gradually (10 year transition period?) encourage existing industries to move to industrial zones. Incentive should preferably be penalty (rather than subsidy) based to avoid budget constraints;

- Licensing on environmental sustainability should be further developed and applied, where dirty behaviour is penalized and *cleantech* applications are favoured

Water resources (financial) regulation

Water being a scarce commodity its abstraction and use need to be regulated. While the existing Bangladeshi legal framework accommodates for 'water pricing', it is not commonly applied.

- Use the pricing policy to regulate water use practice to a desired level.

4. WSS focus within BDP2100

4.1. Hotspot selection

The challenges to the (future) water supply & sanitation sector are immense and multi-dimensional. Many, if not most, of these challenges are related with developments and parallel stakeholders in the delta. However, in its conception, the BDP is not a 'water supply & sanitation project', but a comprehensive delta vision programme that incorporates the needs and challenges of the water supply & sanitation sector.

It is for this reason that, within the scope of trends, issues and challenges of the WSS sector, in the inception stage it has been advised to focus on some of the challenges that are both most relevant to the WSS sector as well as most dependent on the broader delta domain. From the quick scan, 5 principal challenges have been summarized:

- Water resourcing urban mega cities: shift to surface water with all of its repercussions;
- Predicaments on coastal water supply, in view of salinity and flood risks;
- The bigger picture of water resources, including arsenic, sectoral competition for scarce resources, fresh water retention, abstraction regulation and abstraction pricing;
- Re-classes of depleted water table; stoppage of further depletion of water table;
- Sanitation: challenges in urban situations (sewerage and WWTP), in rural areas and towns (septic sludge) and for industries.

While, within the scope of BDP, there is a need for focus as well as a desire for holistic and comprehensive approach, it was advised to incorporate some of generic issues into 2 exemplary 'hot spots' where it is recommended to adopt the following approach for water supply and wastewater:

1. To focus on long term solutions for safe water supply and sanitation in the coastal zone, correlated to parallel BDP coastal aspects;
2. To adopt Dhaka city as prototypical hot spot for water and wastewater related (future) challenges.

These hot spots have been selected based on the extent of the problems, and the relevance in Delta Plan perspective.

Issues and challenges to coastal zone water supply & sanitation

The coastal zone serves as an exemplary area for numerous challenges to Bangladesh water supply & sanitation, both in generic perspective (country wide relevance) perspective as well as in coastal specific perspective:

- Poverty prevalence limits sustainable affordability;
- Coastal zone aquifers are heavily affected by arsenic content;
- Both surface water (tidal flows and flooding) and groundwater are predominantly brackish or saline;
- The coastal zone has a proportionally high degree of informal settling (no basic infrastructure including WSS) except some urban areas of Chittagong and Khulna;
- The coastal zone, and particularly pioneer settling areas, is severely affected by flooding from both monsoon run off and cyclone weather. Infrastructure, and particularly (communal) WSS facilities need to be flood resilient.

The challenges of water supply & sanitation provision require feasible, disaster & climate resilient solutions, which are strongly inter-related with (any) proposed physical developments of the coastal zone.

Dhaka water supply & wastewater: prototypical challenges for cities in Bangladesh

The issues and challenges that Dhaka is dealing with are exemplary for (future) situations in Chittagong, Khulna and other cities.

- Is the Dhaka shift to surface water really needed? To what extent? The groundwater systems of Dhaka need to be re-assessed in relation to existing and future water demand. It's safe yield will be assessed, both at existing groundwater levels and at deeper equilibrium levels, to advise on sustainable abstraction rates;
- How to provide clean drinking water and sanitation facilities to the slum area and for hard core poor people;
- Moving to middle income status water supply provision will need to be financially sustainable (full cost recovery), what does it imply? What is the route (political/institutional/financial). A situation of what should be established in 20 years will be discussed, followed by suitable steps/measures to move in that direction;
- Assessment of (illegal) industrial abstraction: how much, where, non-regulated. What is the future: connect to DWASA, or price industrial abstraction?
- Review DWASA's plans on wastewater/sewerage and urban drainage: in what configuration can solutions be both technically feasible and effective (environment) as well as financially sustainable;
- Special focus on clean-up of industrial wastewater: how to regulate/impose?
- Other?

Both the sustainable coastal water supply and the Dhaka prototypical approach are elaborated in this baseline study. And in doing input was provided to the vision on coastal physical planning, and on water & wastewater services to Bangladeshi urban conglomerates. In chapters 6 and 7 the selected hot spots have been elaborated to some further detail. The other hot spots take a different position in this WSS baseline study. While Barind bears WSS relevance in terms of water resources 'competition', some of the other challenges are relatively parallel to the coastal zone hotspot. The Mighty Rivers hot spot bears limited WSS specific challenges, other than those covered in the selected hot spots. The major cities hot spot coincides with the Dhaka focus, and information on numerous cities has been included in the appendices to this WSS baseline study. The HRT areas have not been included as BDP2100 hot spot and they have been covered in the GoB report National strategy for Water and Sanitation for Hard to Reach Areas of Bangladesh', (2012), and referred to in section 3.1 of this WSS Baseline

Report. The hot spot Haor and Wetlands represent some particular challenges to WSS sector; have been elaborated in section 4.2 below.

4.2. Haor & wetlands

Haors have their unique hydro-ecological characteristics with large bowl shaped floodplain depressions. Haors are located in the north-eastern region of Bangladesh with about 1.99 million ha of area and accommodating about 19.37 million people. There are about 373 haors/wetlands located in the districts of Sunamganj, Habiganj, Netrakona, Kishoreganj, Sylhet, Maulvibazaar and Brahmanbaria covering an area of about 858,000 ha which is around 43% of the total area of the haor region (Ref: Master Plan of Haor Area, 2012) .

4.2.1. Challenges of the Haors and Wetlands Areas

- Any development activities in the haors and wetland areas need to consider the ecology and hydrology for economic importance. These are the breeding and spawning grounds of numerous fish and other faunal species, and also the habitat of many species of indigenous and migratory waterfowls.
- There is no appropriate wetland policy
- Haors and beels are mostly inhabited by the poor and disadvantaged people who lack access to basic services including drinking water and sanitation.
- Inaccessibility to services is compounded by the absence of adequate road communication network in these areas, primarily due to large fluctuations in water levels ranging from 3/5 meters deep water to dry land.
- Monsoon floods, flash floods from May to October and river erosion are common natural disasters which flash away or damages homesteads, crops as well as water and sanitation infrastructures.
- Drinking water tube wells get polluted due to inundation and people resort to unhygienic practices including open defecation which lead to groundwater pollution, and create constraints in environmental hygiene and public health.
- Alternate sources of drinking water supply such as the Pond Sand Filter (PSF), ring wells, Rainwater Harvesting system (RWH) etc. are still insufficiently available or used in the area, especially during flood periods.
- Groundwater arsenic contamination is widespread without adequate remedial measures in many wetland areas.

4.2.2. Prioritization of WSS Problems

The major water supply and sanitation problems are shown in order of level of priority in the problem matrix in the Table 4.1 which have been prioritized based on people's perception. Three categories have been assigned to the problems: very highly significant (in more than 50% of the upazilas), highly significant (in 15-50% of the upazilas) and significant (in less than 15% of the upazilas).

Table 4.1: Sanitation problems in Haor areas (Master Plan of Haor Area, 2012)

Problem/ Challenges	No of Upazillas														Level of Significance																						
	Sunamganj				Sylhet				Kishoreganj				Netrokona		Habiganj		Mouliviba		Brahmanbar		S	HS	VHS														
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8				9	10	1	2	3	4	5	6	7	8	1	2	3	4
Majority of unhygienic sanitation system	S				S				S				S		S		S		S		S		HS														
Floodwater intrusion into the sanitation system	S				S				S				S		S		S		S		S		HS														
Absence of public awareness	S				S				S				S		S		S		S		S		HS														
High percentage of outbreak of water borne diseases	S				S				S				S		S		S		S		S		HS														
Poverty	S				S				S				S		S		S		S		S		HS														
Weak sewerage system	S				S				S				S		S		S		S		S		HS														
Unaffordability to buy ring slab	S				S				S				S		S		S		S		S		HS														
Unavailability of GO and NGO intervention	S				S				S				S		S		S		S		S		HS														
Inadequate number of factory to make ring slab	S				S				S				S		S		S		S		S		HS														

S: Significant
HS: Highly Significant
VHS: Very Highly Significant

4.2.3. Water Supply Situation in Haors Areas

The major drinking sources of water are the Shallow Tube Well (STW), Deep Tube Well (DTW), ring wells, Shallow Tara Pump, Deep Tara Pump, piped water supply, Very Shallow Shrouded Tubewell (VSST), Shallow Shrouded Tubewell (SST) and Pond Sand Filter (PSF) etc. About 50% of the households depend on surrounding river/pond water for domestic uses. Due to absence of suitable water source and collection system, haor people are affected by many water borne diseases. Presently every water source has to cover 105 people on average which is many more than the standard (population/water source/technology 50 in number). Out of 7 districts, 3 have a very low coverage of drinking water sources of more than 100 people/tube wells. Sunamganj district has the maximum low coverage of more than 150 people/water source.

Table 4.2: District wise water supply coverage in Haor areas (Master Plan of Haor Area, 2012)

District	No. of Water source/Technology	No of population per Water source/Technology
Sunamganj	16,446	152
Habiganj	20,485	93
Netrokona	24,848	98
Kishoreganj	30,420	93
Sylhet	26,235	107
Moulivibazar	18,828	99
Brahmanbaria	26,158	126
Total	163,420	105

4.2.4. Sanitation Situation in Haors Areas

The sanitation facilities are very poor in Haor areas compared to other parts of the country. On average 11 persons use one latrine. About 49% of the households have latrines with inadequate capacity. About 99% of latrines were

constructed without any skilled supervision. Flooding, high water table, excessive rainfall and loose soil formation are the causes of overflow and collapse of pit latrines. Every year most of the areas remain under water for about 4 to 7 months and many existing sanitation systems are washed away. It is almost impossible for the hard core poor to reconstruct toilets on a regular basis. In fact, the main reasons for poor sanitation coverage in the haor area are lack of proper awareness and financial constraints. Only 44.25% of people on average use sanitary latrines in the haor region with Netrokona having the poorest coverage of 35%.

Table 4.3: District wise use of sanitary latrines in Haor areas (Master Plan of Haor Area, 2012)

District	Use of sanitary latrines %
Sunamganj	40
Habiganj	41
Netrokona	35
Kishoreganj	49
Sylhet	57
Moulivibazar	55
Brahmanbaria	46
Total (average)	44

The provision of physical sanitation facilities alone is not enough for the haor inhabitants to protect themselves from diseases or the environmental degradation. Specific and specialised hygienic sanitation systems are essential for the haor people. There are several sanitation technologies, such as the Earth Stabilised Raised Pit (ESRP) latrine, step latrine, mound latrine, Sand Enveloped Latrine (SEL) for high water areas near foothills and high raised villages and Sand Enveloped Raised Pit (SERP) latrine etc. These technologies have potential for the development of hygienic sanitation facilities in the haor region.

4.2.5. Strategies to Improve WSS sector in Haor Areas

The strategy for improving drinking water supply and sanitation in the haor area has been formulated in the Haor Master Plan based on the following principles:

- Development of WSS sector through local bodies, public- private sector, NGOs, CBOs and women groups involving local women, particularly elected members (of local bodies) in sector development activities;
- Gradual community cost-sharing and introduction of economic pricing for services
- Assigning priority to under-served and un-served areas
- Adoption of water supply and sanitation technology options appropriate to specific regions, geological situations and social groups
- Improvement of existing technologies, and continuous research and development activities to develop new technologies
- Provision of arsenic free water to mitigate arsenic toxicity and protect health and wellbeing of people living with acute arsenic problem in the haor area
- Social mobilisation through publicity campaign and motivational activities using mass media, among other means, to ensure behavioural development and change in safe water through hygiene practice
- Capacity building at local/community level to deal effectively with local water and sanitation problems
- Regular qualitative and quantitative monitoring and evaluation to review progress of activities and revision of the strategy based on experiences

- Wherever feasible safe water from surface water sources may be given consideration compared to the constraints of other sources
- With a view to controlling and preventing contamination of drinking water, regular and coordinated water quality surveillance and monitoring by the Department of Public Health Engineering (DPHE) and other government organizations
- The local people and groups of people concerned including members of local authorities, VSC, NGOs and CBOs trained in technology of low cost sanitation options particularly for high-water table and flood-prone areas, and transfer of technology
- Provision of sanitation facilities to the poor free of charge and a tax levy to the well-to-do people
- Community-type latrines built for high-water table and flood prone areas where individual households cannot afford latrines due to poverty
- Community contribution in cash or kind ensuring ownership of facility
- More local and mobile Village Sanitation Centres (VSC) established to motivate people
- Awareness raising on health and hygiene through different methods
- Community leaders and religious leaders play an active role in motivating people to change their habits and start using improved sanitation facilities
- Rallies and communication techniques applied to intensify social mobilisation for changing existing sanitation practices for the better
- An integrated approach combining water, sanitation and hygiene education for achieving overall success in the improvement of general health, quality of life and environment
- Sanitation facilities improved through formulating appropriate policies and undertaking programmes in this area
- Capacity building of the local authority as well as CBOs towards sustainable development of the overall sanitation programmes
- CBOs, NGOs and the private sector involved effectively in sanitation programmes and they are promoted in the production and sale of sanitary latrines in terms of providing soft loans or grants;
- Private sectors encouraged and supported to establish sanitation production centres in critical areas (remote villages, high-water table and flood-prone areas) for effective coverage;
- Establishment of facilities for producing compost and bio-gas from human and animal excreta which will provide improved cultivation and supplemented energy as well as reduce environmental pollution

5. Identification of Knowledge Gaps

The knowledge gaps in WSS sector form a barrier for proper planning and pose constraints to programmes. Some knowledge gaps are as:

- There are 310 rivers in Bangladesh. BWDB, Port Authorities, BIWTA, PDB & JRC collect some water level and discharge data in these rivers. But the data collection is mainly in monsoon season. In dry season many of the rivers become dry. The time of the dry spell runoff is not known and thus there is a gap in dry season data in the rivers. Moreover, the large pattern of river run off within country is defined by international (upstream) measures in the river catchments.
- Urbanization is going on without adequate planning. Proper urbanization mapping is not yet developed. So the demand and projection of WSS system cannot be planned properly.

- The sustainable utilization of groundwater resources at different urban areas has not yet been confirmed. Many shallow tube well become abandoned as the groundwater level lowering down in many areas of the delta. The water demands of different competitive water users such as agriculture, industries or drinking purpose not yet have been estimated to protect the safe yield uses of GW by different users. However, NWMP gave some indication on the issue.
- Lithological information, resource analysis, mapping is available for upper aquifer (less than 200m). Now there is no such mapping, resource availability or recharge system information for the deeper aquifer (greater than 200m) which would be a major source of drinking water in future.
- Groundwater salinity intrusion, mixing system of saline water to fresh water is not yet known for major coastal areas.
- Groundwater contamination due to industries and domestic sludge, solid waste disposal in urban areas is not yet studied.
- Recently Manganese is found in upper aquifer but there is no data on manganese level or no mapping of manganese affected areas.
- Surface water contamination level monitoring is absent in most of the rivers. DoE have some water quality monitoring station in some major rivers only around the year. But the data is not sufficient to gain understanding of the spatially and temporal variation along the rivers and around the urban areas.
- There is no monitoring of sludge disposal system. Therefore master planning in sanitation sector in urban and rural areas cannot be done.
- There is not sufficient data for calculating Unaccounted for Water (UfW). No monitoring system yet developed to identify the linkage in water supply system. So water loss due to administrative loss or linkage loss cannot be estimated.
- Climate change issues were not sufficiently incorporated in the national programs, plans and policies in the past. There is no comprehensive study to identify or estimate the change in salinity intrusion in GW and SW, the change in water availability, GW level depletion, and recharge pattern due to climate change.

5.1. Activities to be taken to overcome the knowledge gaps

In its substance, knowledge gaps require appropriate studies and research to arrive at desirable outcome. Sector stakeholders, knowledge institutions and universities may actively participate in achieving these goals. Some activities that should be taken to overcome the knowledge gaps are:

- To provide solid planning context to suitable water resources assessment and development there is a need for improved river run off forecasting.
- For all of the measures proposed within the BDP arena, co-ordinated town and country planning is required. National spatial development plan needs to be drafted where the BDP can both find its basis, as well as contribute water related spatial planning issues.
- Regional groundwater models need to be further developed in order to understand the characteristics of deep aquifer, assess and confirm sustainable safe yield groundwater abstraction for different user groups.
- To support environmental policy for clean-up of surface water, a monitoring protocol needs to be established for major rivers in Bangladesh: spatial distribution, frequency and parameter selection for water quality monitoring system.
- Both in terms of district meters as well as metering of individual connection, a 100 % metering coverage needs to be implemented, starting with the major urban centres.

5.2. Strategy Formulation

5.2.1. Ground Water Management Activities

- Decrease the dependency on groundwater for irrigation
- Investigation, assessment and monitoring of deep aquifer
- Monitoring and licensing of groundwater abstraction
- Protection of ground water quality by controlling waste disposal and proper sludge management
- Augmentation of surface water bodies and ecologically sensitive wetlands
- Implement artificial recharge process to protect the declination of groundwater level
- Increase groundwater resource by subsurface dams

5.2.2. Arsenic Mitigation Activities

- Prepare separate Implementation programme for water supply under Arsenic Policy 2004
- Support the local initiatives to promote the testing, marking and switching of wells where feasible as the lowest cost mitigation option
- Set priority to the highly arsenic contaminated and low safe water coverage areas
- Carry out deep aquifer management study
- Conduct Research & Development projects for disposal of arsenic-rich sludge and in-situ arsenic removal techniques
- Carry out detail analysis to determine safe water source for the arsenic contaminated areas at alternate water supply option

5.2.3. Surface Water Management Activities

- Monitoring of effluent discharge from industrial areas to surface water bodies to control the pollution in the rivers surrounding the urban areas
- The waste water disposal standard according to Bangladesh EQS 1997 is 50mg/l but there is no limit of the total waste water loading which need to be revised
- Domestic waste disposal into river, khal or open water bodies need to be controlled by introducing proper sanitation facilities
- Take mitigation measures to safe the surface water from being polluted

5.2.4. Activities for Hygiene Promotion

- Prepare an integrated -Information, Education and Communication (IEC) guideline for communities which will include hygiene promotion WASH in schools, proper O&M of water and sanitation facilities and water safety plan.
- Hygiene promotion should be integrated with water and sanitation interventions.
- Coordination of hygiene promotion works with the activities of MoHFW, MoPHE, Ministry of Education and Ministry of Environment.

5.2.5. Action Points for Public-Private Sector Participation

In the development of the WSS sector in Bangladesh, both the public sector and the private sector (PPP) are involved in a variety of ways. The benefits of private sector participation in the WSS sector include: (i) mobilizing private resource for the sector to meet growing investments need (ii) competition because of the entry of more

investors; (iii) increased innovation and efficiency (iv) lower prices; and (iv) universal coverage. Action points for the development of private sector are:

- continue encouraging the private sector to play a major role in rural WSS scenario
- motivate the consumers to use higher quality of water and sanitation services
- monitor and ensure the quality of WSS services
- provide technical and management support to strengthen the existing businesses and develop new businesses
- prepare a guideline for the PPP for the WSS sector
- appoint a facilitating agency to gradually introduce the PPP

5.2.6. Activities on Environment, Climate Change and Disaster Management

- Create specialized units within sector agencies like WASAs and DPHE for dealing with environment, climate change and disaster management, and providing training on those subjects;
- Build community capacities and resilience through raising awareness and training
- Take up R&D activities and pilot projects on climate change and disaster resilient WSS technologies, considering the needs of the people, particularly the women, children and the physically challenged persons in the affected areas.
- Introduce a regular monitoring system on sea level rising, saline water intrusion, depletion of the ground water level, flow reduction in rivers, and change in rainfall patterns to forecast adaptation approaches of WSS.
- Take up R&D activities and pilot projects on climate change and disaster resilient WSS technologies, considering the needs of the people, particularly the women, children and the physically challenged persons in the affected areas.

5.2.7. Action Points on Water Safety Plan

- Advocacy and awareness is required at policy level and operational level.
- Water safety plan should be incorporate in the ongoing and new development projects especially in urban areas.
- The water safety training courses should be strengthened. A pool of master trainers should be created.

5.2.8. Sector Capacity Building

For the sustainable development capacity buildings are needed at individual, organizational and environmental level. The environmental factors are the legal and policy framework of WSS sector as well as economic, social, cultural, political and administrative sectors. The capacity building of the LGD and the organizations working on or related to this sector and in individual level are very important.

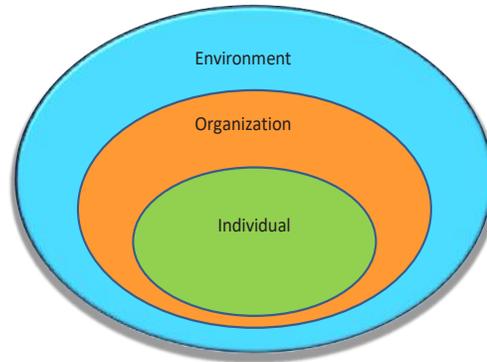


Figure 5.1: Capacity building framework by UNESCO

6. Surface water & wastewater needs for major cities: prototypical challenges of Dhaka city

Dhaka is one of the world's mega cities. Even by its sheer size, the challenges on water & wastewater are tremendous. While water supply now relies on groundwater, this is not deemed sustainable to serve the city's growing population. Adjacent rivers are heavily polluted from municipal and industrial sources, and may further deteriorate and cleanup are required. Sustainable groundwater abstraction, allocation of scarce water resources, restoration of water quality, aiming for cost recovery, and alignment of institutional stakeholders in the water cycle: the Dhaka water & wastewater casus is an exemplary arena to our BDP project.

6.1. Water resources assessment

Water supply development plans are required for individual cities and towns to improve service level and increase coverage. In aggregated terms new concepts need to be embraced in urban water supply for Bangladesh, particularly where a shift to surface water sources may be involved.

WASA's of Dhaka, Chittagong, Khulna, Rangpur and Rajshahi have master plans prepared or under preparation that incorporate a relative shift from groundwater to river water sources. The fact sheets of Dhaka, Chittagong, Khulna, Rangpur and Rajshahi WASAs are given in Annex-B. In certain parts of Bangladesh there will be seasonal scarcity of surface water as well. Adequate quantities need to be ensured for potable water abstraction, and water quality policies need to be adopted and enforced to ensure suitable raw water quality.

The situation of Dhaka city has been assessed, as it may prove to be typical for future further urbanization in Bangladesh. From these assessments, generic issues and requirements have been identified.

6.1.1. DWASA (Dhaka) production projections

DWASA is in the process (2014) of compiling a master plan to meet the challenges of future demand, infrastructure development and overall service. From this master plan it may be derived that DWASA is going to increase production to fulfil future demand.

Future water demand has been estimated for domestic, fire-fighting and other uses based on population projection up to 2035. A demand management strategy will be developed which include introducing of a 3-slab increasing block tariff (IBT) structure by 2015 and advocacy of the adaptation of water efficient gadgets. It has

been planned that DWASA will expand its service area from the present 401 km² to 617 km² and the total demand will rise from 1,476 MLD in 2011 to 4,741 MLD in 2035. Considering leakage and other losses the total required production capacity will increase from the 2,108 MLD in 2011 to 5,268 MLD in 2035. Figure 5.1 gives an over view of demand projection of DWASA service area.

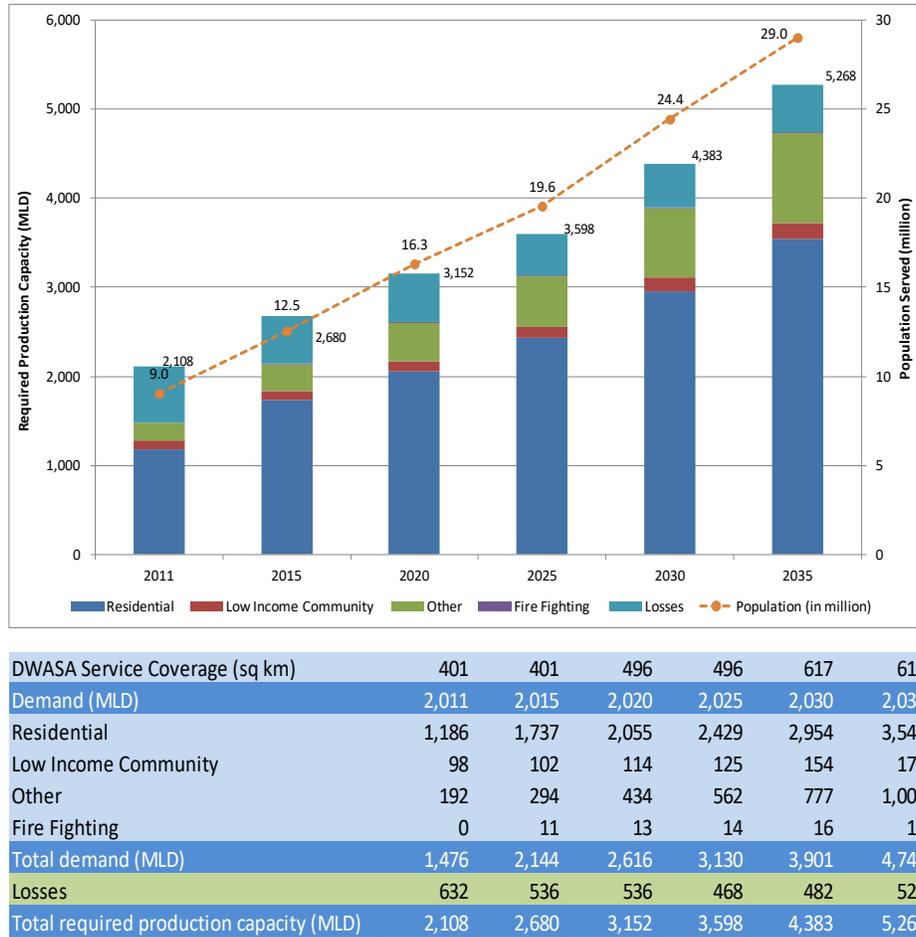


Figure 6.1: Water demand and required production capacity for Dhaka master plan area

To meet the future demand DWASA plans to construct Padma and Meghna (Gandharbapur) WTP. Total supply from the Padma and Meghna could be planned for 900 MLD and 2525 MLD respectively by the year 2035. The allowable groundwater abstraction from the upper Dupitila aquifer is estimated at around 1,640 MLD including Singair and Tetuljhara-Bhakartha groundwater well fields. It is recommended that around 75% of the total resource is harnessed for water supply to Dhaka master plan area. Around 97 MLD will be available by rehabilitation and expansion of the Chandighat WW, Godnail WTP and Sonakanda WTP. Figure 5.2 shows different level of production capacity and deficit all through the planning horizon up to 2035.

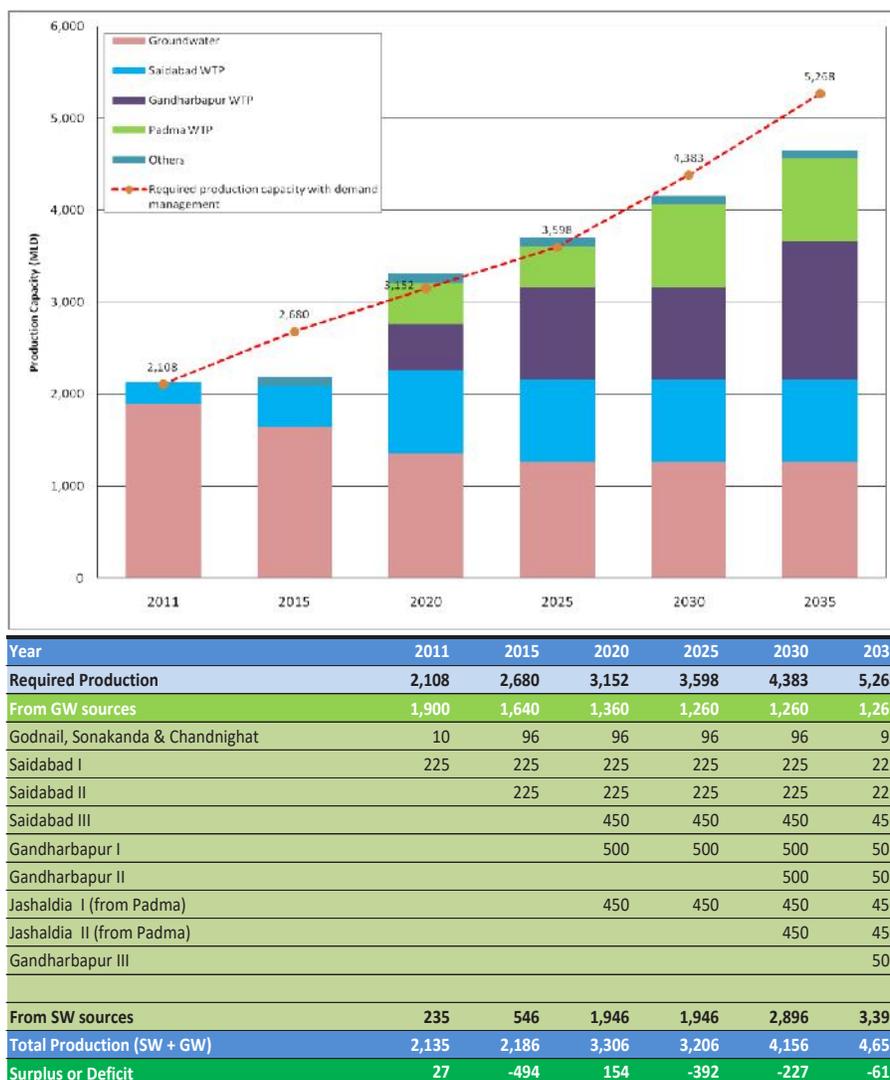


Figure 6.2: Strategy of meeting the supply-demand gap by DWASA

From the projections it may be noted that the increase of water supply capacity will be tremendous even on a mid-term planning horizon to 2035. Further projections on a national/regional level need to be made up to a horizon of 2100 and a national water balance of water needs and water availability needs to be drafted, bearing future development scenario's for climate change and economic development in mind.

Our initial assessment for Dhaka is included in sections 6.1.2 and 6.1.3.

6.1.2. Safe yield for groundwater in Dhaka

Groundwater level data of Upper Dupitila aquifer system of Dhaka city demonstrates a steady downward trend. Due to mining, the groundwater level is falling by about 2-3 meters per year (IWM 2008). Figure 5.3 shows overall declining trend due to over extraction than annual replenishment at Diabari well.

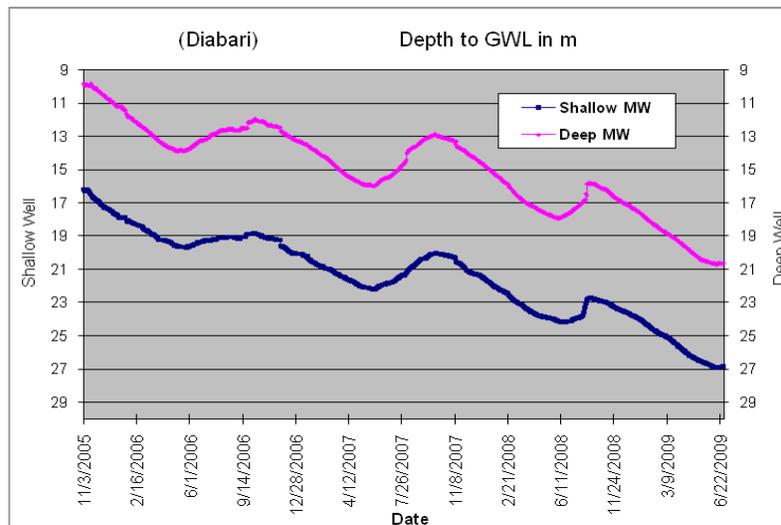


Figure 6.3: Hydrograph of shallow and deep monitoring well at Diabari, Well ID: DMW-2

The recharge in the upper Dupitla aquifer is estimated at about 604 Mm³ and water volume available without causing further depletion is approximately 600.00 Mm³/yr or 1650MLD considering maximum potential recharge.

In DWASA -IWM Resource Assessment report it is proposed to consider 15m rated drawdown for abstraction of groundwater from the deeper aquifer system. Based on this, it is estimated that the total available drainable storage from Lower Dupitla aquifer system is about 139 Mm³/yr or 380 MLD.

Evidence confirms that current groundwater abstraction (by DWASA and others) represents an over exploitation. A better understanding of Dhaka's geohydrology is desirable:

- Generic geological and aquifer composition in Dhaka greater region;
- Scientific estimate of sustainable abstraction rates at standstill groundwater table (as is);
- Scientific estimate of equilibrium abstraction rates if (much) deeper groundwater tables were to be accepted (*"sustainable over abstraction with lateral regional influx"*).

6.1.3. Availability of surface water

Considerable volume of water is available in the peripheral rivers of Dhaka city even in dry periods after considering around 40% flow for in-stream demand. Assessment of water availability was made based on historical simulated data from January to March. Result from the assessment is given in Table 6.1. But the water quality of the peripheral rivers is very poor and the condition is deteriorating day by day due to increase in pollution load from various domestic and industrial sources.

Table 6.1: Water Availability in Peripheral Rivers (January to March)

River	50% dependable flow	80% dependable flow	Minimum depth
Buriganga at Chandnighat	48.1 m ³ /s	21.0 m ³ /s	12.5 m
Lakhya at Majhina	71.1 m ³ /s	36.2 m ³ /s	12.0 m
Kaliganga at Taraghat*		13.40 m ³ /s	1.55 m

*IWM (2006)

DWASA will shift from groundwater to major rivers (Meghna and Padma) in view of raw water quality and water availability. These two major rivers have significant flow available and the water quality is also acceptable. The dry seasons (January to March) water availability of Padma and Meghna river is given in Table 6.2.

Table 6.2: Water Availability in Major Rivers

River	80% Dependable Flow	Available Flow after Withdrawal	Environmental Flow
Padma at Jashaldia	6226.1 m ³ /s	6215.1 m ³ /s	2490.4 m ³ /s
Meghna at Bisnondi	210 m ³ /s	190 m ³ /s	84.2 m ³ /s
Meghna at Haria	176 m ³ /s	165 m ³ /s	78 m ³ /s

6.1.4. Generic conclusions

- In mid-term perspective quantity of water resources is sufficient to meet Dhaka’s potable water supply needs, bearing in mind that DWASA intends to shift to Padma and Meghna Rivers;
- The sustainable safe yield of groundwater abstraction for Dhaka needs to be studied further;
- The long-term perspective for water demand, sectoral competition, and national water availability needs to be studied further;
- Assessment of raw water quality is hampered by lack of data.

6.2. Industrial water use and wastewater discharge

The 2030 Water Resources Group drafted an excellent analysis on industrial water use in Bangladesh (draft published February 2015: “An analysis of industrial water use in Bangladesh, with a focus on the leather and textile industries”). As data are relatively scarce and difficult to obtain, we have gratefully used text and data from this analysis.

In Dhaka it is common for industries to have individual, private (borehole) water supply systems. At present, there are over 3000 industrial installations within the main Dhaka city area and over 7000 (Source: SMEP-GD) in Dhaka watershed (approximately 1500sqkm). Mainly dyeing, washing and garment textiles are blooming in and around Dhaka.

2030 WRG:

The average factory water consumption in Bangladesh is estimated to be up to 250 to 300 litres of water per kilogram of fabric produced. This is the equivalent to the daily water use for two people in Dhaka. For comparison, the global benchmark for fabric production is 100 litres of water per kilogram. In terms of the overall supply chain for textile garments the water used in the processing and garment production phase has previously been estimated to be close to 50% of the overall water use.

	Fiber Production	Fiber Processing	Clothing & apparel production	Distribution & warehousing	Marketing & sales	Consumer
	Agriculture petrochemical supplies	Dyeing & fabric finishing	Confection of clothing & apparel	Transport	Shops	Washing
	Yarn/fibre/producing/spinning miles	Weaving		Stock/man management	Marketing	
		Knitting			Advertisement	
Consumptions	52%	43%	1%	4%	0%	No data
Withdrawals	46%	47%	1%	6%	0%	No data

The effluent discharges from the WDF (washing, dyeing, finishing) factories, in particular, are heavily polluted with high levels of dissolved solids and chemicals. Estimates on the number of factories with Effluent Treatment Plants (ETPs) vary from 40 to 80% although it is widely acknowledged that many of the installed plants are poorly designed or not operated in an appropriate and responsible manner. The 2030WRG have identified industrial clusters in Dhaka and surrounding area. The clusters are shown in the figure below.

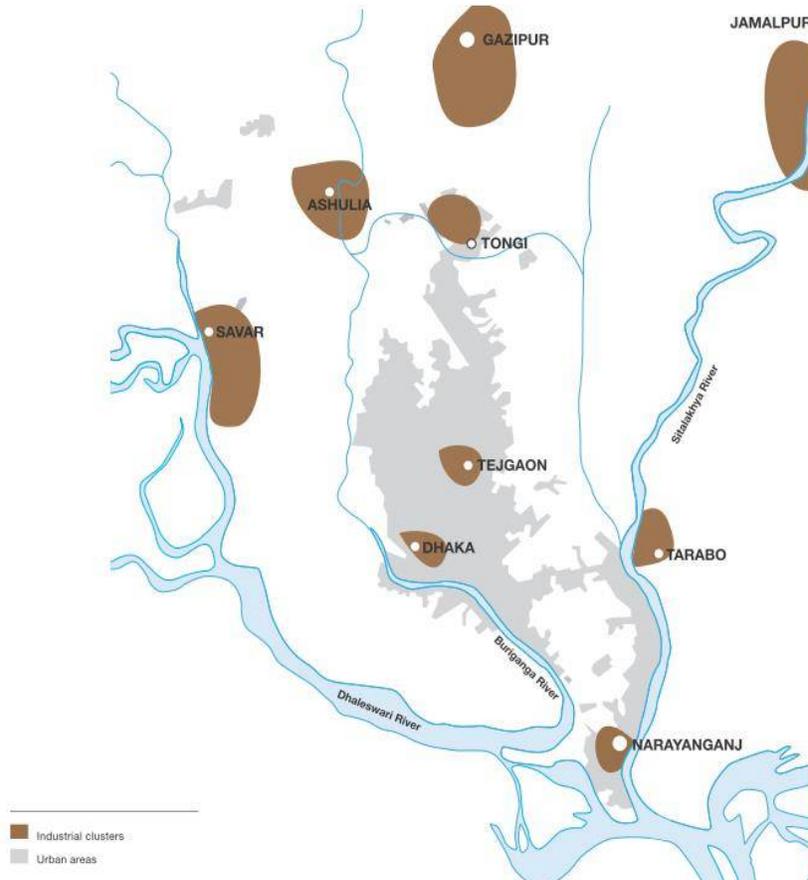


Figure 6.4: Industrial cluster of Greater Dhaka (2030WRG)

Water demand for most of the textile manufacturing processing and dyeing industries is extensive. The high demand can put pressure on domestic consumptions of DWASA. The private DTW extraction can also put stress upon groundwater resources. The non DWASA abstraction in Dhaka (both by industries, communities and households) represents a substantial percentage of the total groundwater abstraction.

Apart from textile industries, the leather industry represents heavy significance to the urban water cycle. 2030WRG: There are reportedly around 155 tanneries operating in Bangladesh. Over 90% of the tanneries are located in the Hazaribagh area in Dhaka in a highly congested area of less than 30 hectares of land.

Most of the leather produced at present is non-compliant with international social, ethical, safety and environmental standards and is therefore not attractive to North American and European brands and buyers. Skins processed at Bangladeshi tanneries are traditionally sold to other markets as part finished leather which has a lower value.

It is estimated that approximately 40 m³ of water are required to process a tonne of wet salted hides (Figure 6.4). For comparison, modern processes utilised in Europe are able to reduce the water use to 20 m³ or less. In addition to the water use, more than 450kg of chemicals are used in the process. As only a fraction of the chemicals are retained in and on the leather, the majority is discharged to the environment in various forms including wastewater discharges.

The total volume of effluent discharged from tanneries is estimated at 20,000 cubic metres per day which is in line with the capacity of the new centralised effluent treatment plant (CETP) currently being constructed in Savar. At the moment, all effluent generated from Hazaribagh is discharged untreated to the sewer passing through the area leading to the Buriganga River, the main river through Dhaka. Therefore, the industry contributes significantly to poor river water quality and the associated environmental and health impacts.

Both the textile and tannery sectors discharge highly polluted effluent which has the potential to harm humans and pollute the environment if discharged untreated. Textile factories discharge chemicals including salts, dyes and bleaches, while effluent from tanneries is significantly stronger and contains a range of heavy metals, including chromium. The effluents, heavy on hazardous chemical and biological agents discharged untreated into surrounding rivers or water bodies which further create pressure on SWTPs. Though there are DOE directives for treatment at Effluent Treatment Plants (ETP), but the practice is absent in many industries. Most of the industrial effluents and domestic sewage are discharged to the environment without treatment. Factories show a reluctance to invest money in effluent treatment as it is considered that it is a non-productive use of investment in a highly competitive local and global market.

Even where industries have effluent treatment plants, there is an unwillingness to operate the plant appropriately to reduce operational costs. The industry itself acknowledges the lack of experience and knowledge to effectively install and run ETPs. There is no separate distribution system for domestic and industrial/commercial uses from DWASA. The charge is 3 times higher for and industrial/commercial uses, compared to domestic tariff.

Detailed Area Plan (DAP) of Dhaka city recommends shifting the Hazarabagh Tannery Industries (approved by Government) and Tejgaon Industrial areas (after 2015) to new locations out of Dhaka city to some habitable environment. DAP also recommends that industries in Tongji, Narayanganj and Tarabo areas should not be developed in hazardous way but in a confined area of EPZs or Industrial parks by strict enforcement of environmental regulations. No further land should be designated for industries unless these serviced plots are fully utilized under a legal mechanism.

In its analysis, the 2030WRG comes to a set of specific recommendations. BDP2100 would concur with most of these recommendations, with particular focus on:

- Facilitate a review to identify opportunities and possible locations for CETPs for existing industrial clusters. The review should also explore opportunities for Public Private Partnerships in effluent treatment.
- Support the review of alternative water sources for use in industrial clusters.
- Work with stakeholders to promote water efficiency equipment and stimulate the cleaner production market.
- Gather local knowledge and establish the evidence base on the impact and cost of water saving and effluent treatment interventions and to disseminate the knowledge to the industrial sectors for proper actions
- Increase public and industry awareness on implications of future “business as usual” scenarios through sensitisation and marketing campaigns.
- Promote improvements to the groundwater licensing for industrial users
- Support stakeholders with the identification of incentives for the textile factories and other industrial sectors to reduce water use and untreated effluent discharges to surface waters
- Encourage involvement of the civil society in the enforcement of environmental regulation and effluent discharge standards

6.3. Surface water quality constraints

Domestic, industrial and agricultural pollution put surface water potential and the treatment efforts required for drinking water quality, under increasing strain. Especially in the direct vicinity of Dhaka and Chittagong rivers suffer from deteriorating qualities. Overall, surface water quality in Bangladesh’s rivers is deteriorating.

Water quality of the major rivers e.g. Padma, Meghna, Jumuna, Dhaleshwari, Surma, Korotoa etc. are within the limit of Environmental Quality Standards (EQS) while rivers around greater Dhaka are highly polluted particularly in the dry months in terms of pH, DO, BOD and COD value. No dissolved oxygen is usually found from January to May at different location of Buriganga, Balu, Shitalakhya and Turag River. High value of chloride (62 mg/l), TDS (2050 mg/l), BOD (44 mg/l) and COD (150 mg/l) were found at different locations of Buriganga River from January to April.

Level of chloride, TDS, turbidity was found higher in Moyuri, Rupsha, Pashur and Kakshiali rivers. Highest level of chloride (11,380 mg/l) and TDS (17,750 mg/l) are found in Pashur River. Rupsha River showed highest turbidity (200 NTU). More than 500 mg/l COD is found in Karnaphuli, Bakkhali, Moyuri and Mathabhanga River. DO, BOD and COD of Mathabhanga river water were beyond the Environmental Quality Standard from January to April. (Ref: DoE, River Water Quality Report, 2010)

In the next stage of BDP2100 an agenda needs to be set for:

- municipal sewerage and wastewater treatment;
- industrial wastewater treatment;
- legislation on industrial discharges and agriculture restrictions (fertilizers and pesticides)

6.4. Urban wastewater system and industrial wastewater treatment

6.4.1. Sewerage and municipal wastewater treatment

Part of Dhaka is already provided with a sewerage system, and DWASA has plans to further increase sewerage coverage. New Sewage Treatment Plants (STP's) are projected to be constructed, dividing Dhaka in a number of 'sewage catchment zones'. As a matter of principle, sewerage and storm water drainage are separated in Dhaka (monsoon rains would severely over load sewer system). However, where no sewerage exists, sewage and sullage water often end up in the storm water drainage system.

The issues that need to be addressed in the next stage of BDP2100 include:

- Cost recovery principles for sewerage and wastewater treatment; review of present pricing policy, system and practice
- Effluent quality targets (phased over time) to ensure environmental sustainability;
- Collection, treatment and disposal (or re-use) of sludge from septic tanks and pit latrines; keeping in mind the aesthetic and social/cultural norms of the country.

Where there is no sewerage system, people typically utilise septic tanks and pour-flush sanitation systems. Septic tank effluent disposal is very sporadic and almost all domestic and industrial wastewater enter Dhaka, surface water untreated, with some risk of infiltration to the ground. Thus pollution level in the groundwater and surface water are increasing.

Table 6.3: Sanitation system coverage in DWASA service area (Source: DWASA Master Plan)

	% current population estimated to be covered by various sanitation systems				
	Separate Sewerage	Combined Sewerage	Small bore System	Improved On-site Sanitation	Unhygienic Sanitation
2010 population	2,110,000	3,200,000	320,000	2,600,000	2,300,000
% of total population	20%	30%	3%	25%	22%

Note: As a matter of principle, BDP2100 refers to GoB established information and statistics. This table is abstracted from the DWASA master plan, furnished with DWASA data. In our view the existing situation in Dhaka may deviate from this table. It is unclear to what extent combined sewerage and/or small bore systems are well established in Bangladesh. In summary, urban sewerage and wastewater treatment present tremendous challenges to Bangladesh.

6.4.2. Industrial wastewater treatment

While municipal wastewater can be typically characterized by its BOD/COD content and nutrient loading, industrial wastewater will vary in chemical composition according to the type of industry, and may contain serious environmental threats. The wastewater discharges from the industrial clusters are summarized in Table-6.4.

Table 6.4: Wastewater loading of industrial clusters in Dhaka and Narayanganj

(Source: BKH, 2001)

Cluster Name	Type of Industries	No of Industries	Total Wastewater Discharge (m ³ /d)	Total BOD load (kg/d)	Discharge Point
Hazaribagh	Leather	136	15,800	17,600	Turag

Tongi BSCIC	Textiles	13	4,300	4,400	Tongi khal
Fatullah	Textiles	6	3,400	3,850	Buriganga
Tejgaon	Textiles, Chemical	16 27	3,350 535	1,960 475	Begunbari khal
Kanchpur	Textiles	9	4,300	3,480	Lakhya
Tarabo	Textiles	14	1,150	1,475	Lakhya

In Dhaka industries are expected to operate their own 'Effluent Treatment Plants' (ETP's), whereas in industrial zones the effluent may be treated further in a central treatment plant. It is widely recognized that both the installation and operation of ETP's is often inadequate or nonexistent. Authorities fail to impose compliance on industries, expertise in industrial wastewater treatment is limited, and same is true for operational skills.

The challenges for industrial wastewater include:

- Ensure effective zoning of industrial activities;
- Prepare inventory of current practice in industrial wastewater;
- Categorize principal fields of industry in occurrence, and wastewater characterization, including inventory of suitable treatment technology;
- Inventory of governance principles to improve industrial compliance to environmentally sustainable practice;

6.5. Service connections

For Dhaka's population of over 15 million, DWASA's maintains only 311,784 service connections (Source: DWASA Annual Report 2011-12). This is explained by the fact that some connections may 'serve over 1000 households'. DWASA is in a complicated position to serve illegal settlements and low income communities. Together with GoB, NGO's and community representative's effective arrangements are being developed to ensure safe and suitable provision of water supply and sanitation services.

It is commonly acknowledged private deep wells are widespread in Dhaka, and seriously add to aquifer over exploitation. Strategies need to be elaborated to:

- Ensure co-ordinated service provision: 1 connection for 1 household, with regulated arrangements for complexes and apartment buildings;
- Implement DWASA policy on block tariffs (low income tariff concession);
- Proceed on DWASA strategies to serve illegal settlement and LIC groups;
- Severe restrictions on private deep well abstractions.

6.6. Full cost recovery objective

Bangladesh has shown successful economic development. In its ambition to gain middle income status, financial sustainability will become more of an issue. Starting with Dhaka, water supply service will need to generate adequate revenue for full cost recovery (including capital cost). With DWASA and relevant government stakeholders both the present financial situation and perspectives to a desirable future will need to be reviewed. In financial year 2011-2012 DWASA's total water revenue stood at just under BDT 5 billion and as of 2013 domestic water rate stands at BDT 7,33/m³. Both figures are too low to allow financial sustainability which is also acknowledged by DWASA's managing director Mr Engr. Taqsem A. Khan:

The major concern faced by Dhaka WASA due to low tariffs is that it results in insufficient revenue to cover the costs of supplying water. Full cost recovery is essential for successful management of water supply. The appropriate water tariff is very much required for Dhaka WASA to balance the benefits and costs of water usage, and to ensure sufficient

revenue for the long-term financial sustainability of the water supply business. However, low revenues limit the utility's capacity to make a higher contribution to investments..... (Source: DWASA web site).

GoB has recognized the need for cost recovery principles in drafting the 'National Cost Sharing Strategy for Water Supply and Sanitation in Bangladesh 2012' (November 2012). This further confirmed in Strategy no. 15 of The National Strategy for Water Supply and Sanitation (2014, available in draft final): Recover cost of services while keeping a safety net for the poor.

7. Water supply opportunities in the coastal zone

In Bangladesh Delta Plan perspective, the coastal zone is of crucial relevance. This is where Bangladesh's mighty rivers drop their sediment, where cyclones hit the country, and where human development interferes with natural morphological sedimentation phenomena (for instance resulting in water logging). For decades the coastal zone has been known for its harsh water supply conditions (salinity, high iron content, arsenic). While fresh water supply for municipal and agricultural use pose a challenge today, the expected developments (increasing population and economic development will increase demand, climate change is apprehended to aggravate the problems) will only increase the challenge.

While coastal development is core to the BDP, the water supply provision of the coastal zone will be typical to problems in other parts of Bangladesh as well. In addressing coastal zone water supply options, the BDP may identify pathways to generic issues in Bangladesh municipal water supply.

7.1. Constraints on (existing) water supply

Groundwater salination (shallow)

In view of local rainfall infiltration, in many coastal areas fresh water shallow groundwater aquifers are available as a matter of principle. However, the deeper groundwater is brackish or saline (with freshwater being available at, again, greater depths). There are three main paths of salination in the coastal aquifer, (i) intrusion of saline water in the coastal groundwater with sea as the sources of saline water that could be accelerated either by sea level rise and/or falling ground water level, (ii) downward vertical movement of saline surface water to the aquifer. This saline surface water could be brought inland by storm surges or transgression of the coast, (iii) migration of pre-existing pockets of saline water in the subsurface (World Bank, 2010). It can be seen that the fresh water-saline water interface lies about 50 to 75 km inland in the western most part of the coastal region but swings sharply to the south and lies approximately at the coast over most of the rest of the area (BWDB, 2013). The occurrence of brackish and saline water does not follow any regular pattern spatially or vertically. Over abstraction of shallow groundwater tends to draw the saline water into the shallow aquifer rendering a fast deterioration of its quality. In many locations salination of shallow groundwater (first & second aquifer) has occurred.

Due to salinity the shallow groundwater is generally not suitable for domestic uses. Flushing of saline water takes place in some isolated pockets to enable a limited domestic use of fresh water in the shallow aquifer. The combination of over abstraction and salt water intrusion from the sea is apprehended to deteriorate when sea level is rising.

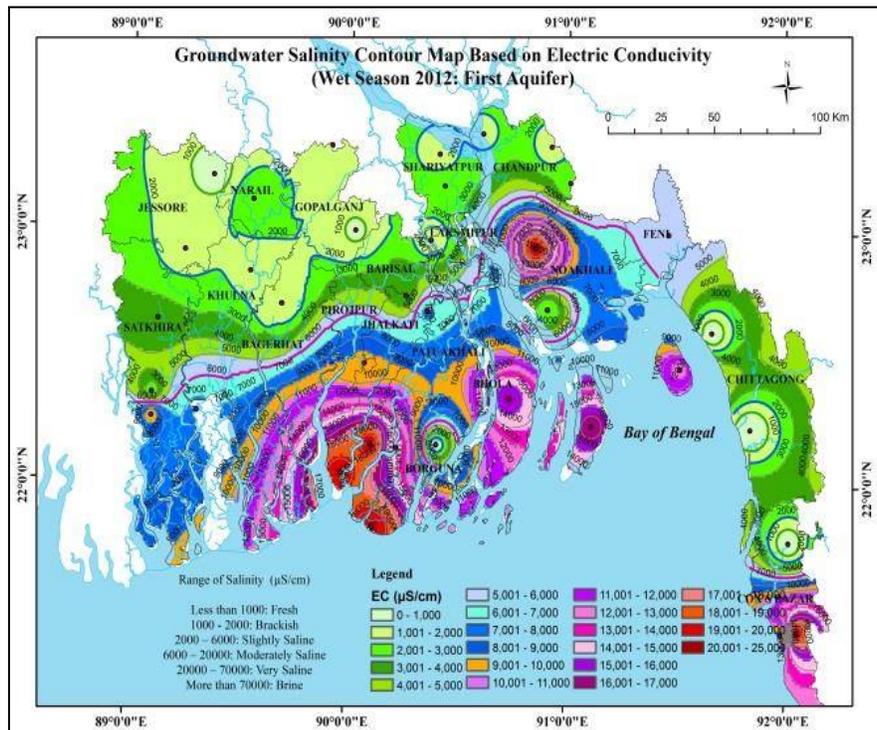
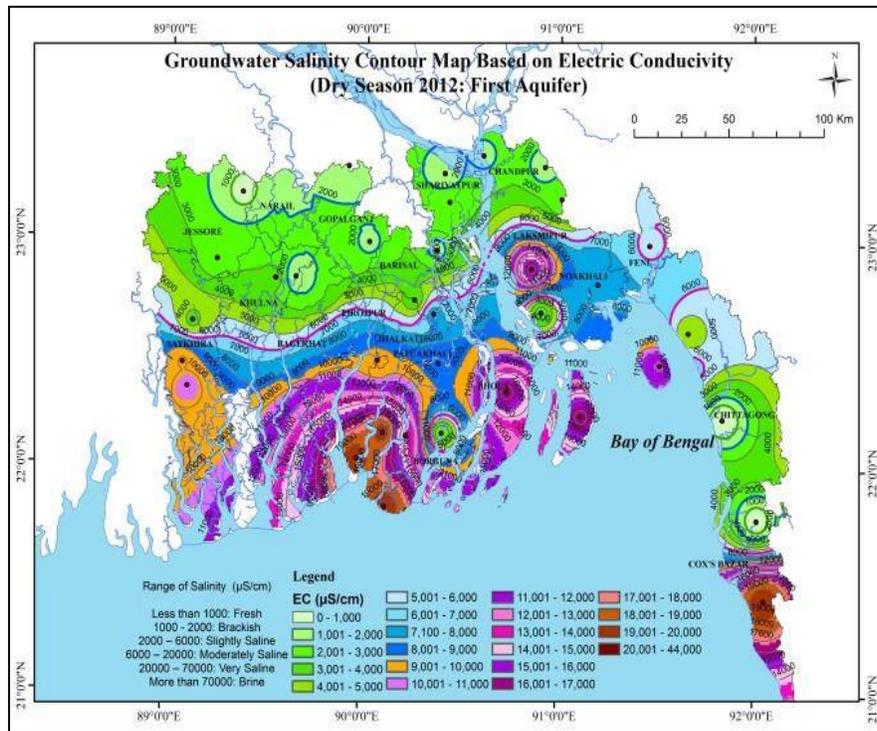


Figure 7.1: Groundwater EC Distribution, Shallow Aquifer, in Wet Season 2012 (BWDB, 2013)

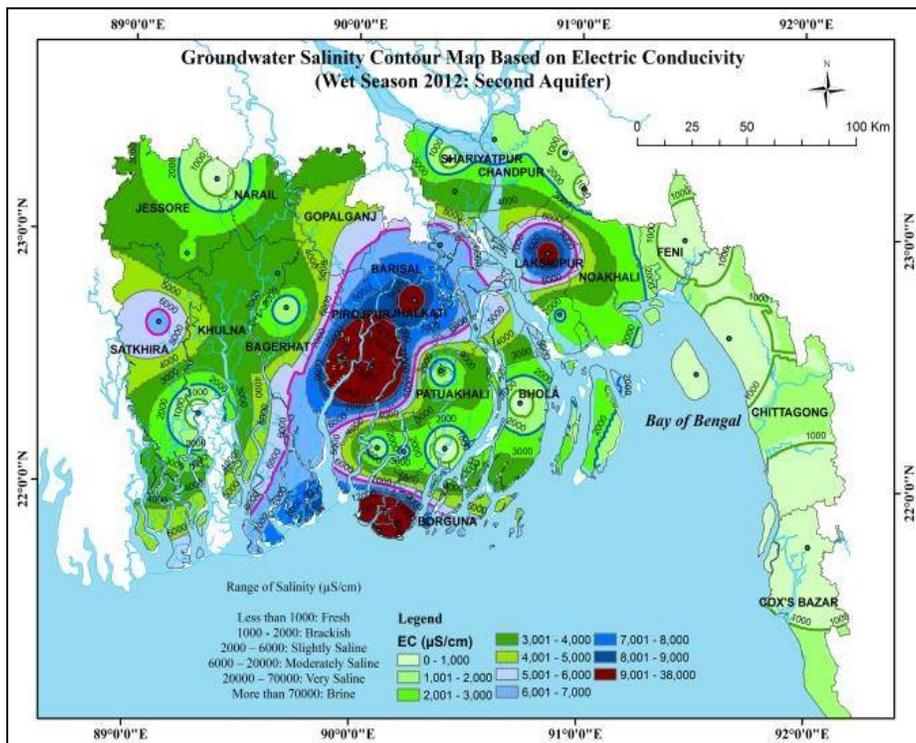
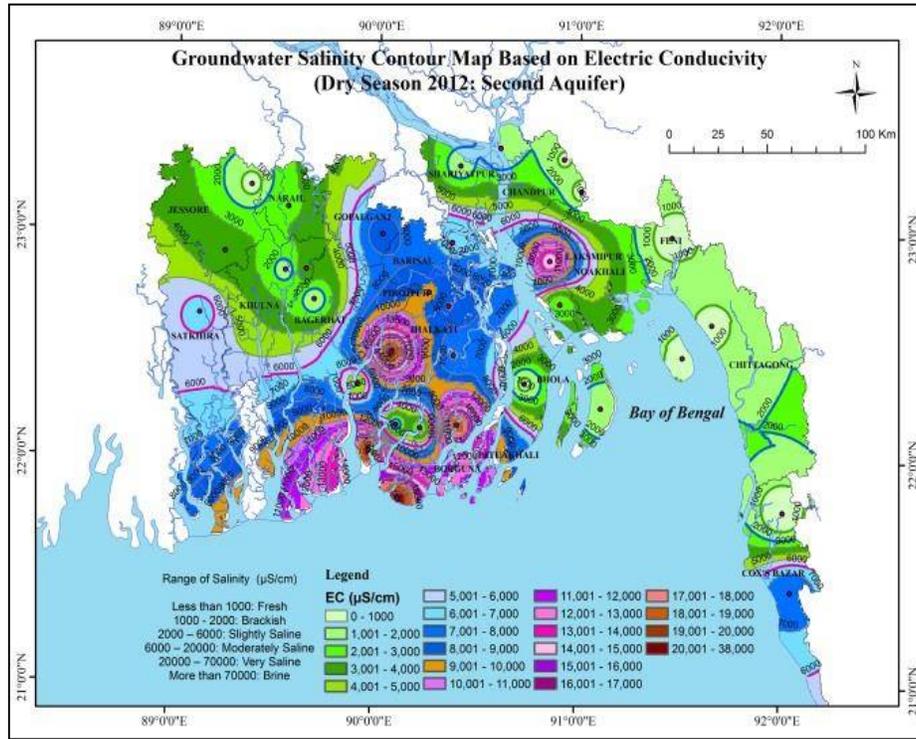


Figure 7.2: Groundwater EC Distribution, Shallow Aquifer, in Dry Season 2012 (BWDB, 2013)

This has been described in details in Water Resources and Coast & Polder thematic area Baseline Reports.

Deep groundwater

The deep alluvial aquifer in the coastal area exists within average depth range of 250m - 360m. Knowledge on these aquifers is limited, and operational practice has revealed that the safe yield from these aquifers is often (very) low (over abstraction tends to draw salt water into the aquifer). Furthermore, the groundwater quality is often affected by elevated content of arsenic, iron and/or manganese, rendering the water unsafe or unsuitable for drinking water.

Despite these drawbacks, deep groundwater is generally seen as the preferred option for water supply in the coastal zone. Where hand tube wells are adopted, the risk of aquifer depletion is low. However, if and when mechanized pumping is adopted, the risk of aquifer depletion is high. In Khulna area, deep aquifer is the main source of drinking water which is free from salinity and arsenic contamination. According to DPHE, the piezometric pressure of the artisan aquifer has decreased in Khulna which indicates a reduction of the recharge rate.

This has been described in details in Coastal and Water Resource thematic area Baseline Report.

Surface water

In the coastal zone there is a transition from fresh water (inland) to salt water (sea). The salt water will tend to reach further inland with reduced river run off and with increased sea level rise.

Large populations in the coastal zone have no access to freshwater from rivers. The alternative option for fresh surface water is local impoundment in ponds.

Pond water supply systems, including Pond Sand Filters (PSF's) have generally proved not to be very effective. The public is reluctant to trust the PSF produced water, and O&M practice of PSF's is generally poor.

This has been described in details in Coastal and Water Resource thematic area Baseline Report.

Rainwater harvesting

In coastal areas rainwater harvesting method is used to store water for domestic usage. Many people are not aware of the contamination of the stored water. Many of the household use rainwater without any purification. Usually rainwater is purified by alum mixing and boiling to remove various harmful bacteria and polluting contaminants.

A package of software and hardware activities should be implemented for the improvement of rainwater harvesting system. Software activities mainly include various motivation tasks for better management and use of hygienic rainwater for consumption. Hardware activities may include modern technique of rainwater harvesting system.

7.2. Trends

While the existing WSS situation in the coastal zone is already 'pressing', in mid and long term perspective certain trends may further deteriorate the WSS service to coastal communities:

- Reduced river run off → salinity moves upstream
 - In relation to (upstream) water management interventions as well as Climate Change trends, reduced (seasonal) river run off may decline. This will then extend the salinity constraints. In terms of problems and solutions, this would not change the 'principle', but the scale/scope of principle;

- Sea level rise → saline groundwater table rises
 - Although the impacts may be moderate and slow, the existing groundwater salinity constraints are expected to gradually deteriorate;
- Population growth → strain on WSS infrastructure
 - Bangladesh has a generic spatial planning dilemma: which areas are suitable to what purpose. It may be feared that even in fragile coastal zone area, population density may increase. This will aggravate existing WSS constraints;
- Increased water demand by agriculture & fisheries → reduced availability and/or source pollution. (Unless co-development can create win-win situation)
 - Further development in Bangladesh is likely going to increase overall water resources pressure from 'competing' water demand from potable, industrial and agriculture sectors.
- More frequent extreme events (e.g., cyclones, tidal surges) due to climate change leads to more frequent damage to WSS infrastructure.

7.3. Solutions

There is no easy solution to the (future) coastal WSS challenges. In further BDP2100 hot spot planning activities options will be explored and further developed. Solutions may include:

- Seawater desalination (costly and complex)
- Rainwater harvesting: typically for low per capita usage. Extended dry spell strains capabilities;
- Piped water supply: difficult to find suitable sources Surface water retention:
 - Larger lakes: irrigation competition, land use issue
 - Ponds: land use issue, water quality
- Aquifer recharge:
 - Through ponds, land use
 - Through injection, very complicated
 - Capacity constraint, relative to abstraction (restrict to DTW abstraction?)
- For long term, sustainable solutions, planning for construction of disaster resilient houses in clusters on raised grounds, and transportation infrastructure to facilitate communication, along with individual or community type drinking water and sanitation infrastructures would be needed.

8. Findings and Recommendations

- In the past decades Bangladesh has made good progress in water supply and sanitation coverage. However, average success should not obscure regional disparity and sector challenges. Too many Bangladeshi lack suitable access to safe and improved water supply & sanitation services;
- The WSS sector in Bangladesh is well established with many stakeholders in well-defined position. We commend on the PSU, which provides the sector with relevant information and policy development. For future challenges, further sectoral reform will be required. The rural water supply and sanitation needs

require technical and organizational capabilities which may not be catered from decentralized competence. Inter-sectoral co-ordination, also outside the sector (BWDB, Agriculture) may warrant a review on mandates and responsibilities. Urban sanitation needs require both mandates (who is responsible) and co-ordination (environment, industry, spatial planning);

- At present and in the (near) future the WSS sector in Bangladesh has major challenges:
 - Comprehensive introduction of (full) cost recovery principles throughout WSS sector;
 - WSS provision to LIC groups and HTR areas;
 - Arsenic proliferation;
 - Declining groundwater tables;
 - Salination of groundwater and surface water resources;
 - Water pollution;
 - Effective faecal sludge management and urban sanitation concepts;
 - Industrial water supply and wastewater treatment;
- In our Baseline Report we have registered knowledge gaps that have been noted in our sector. In section 5.1 activities have been included to overcome these gaps, and these need to be duly incorporated in the further “strategy formulation” in the water supply & sanitation sector.
- The BDP2100 programme will proceed to liaise with WSS sector stakeholders to discuss and address challenges at stake. In doing so, BDP2100 will engage WSS focus on 2 of the identified hot spots: major cities, and coastal zone. For these hot spots, and in doing so for the WSS sector at large, effective strategies and pathways for future proof resilient WSS provision will be explored and elaborated.

9. Reference

2030 Water Resource Group, 2015, An Analysis of industrial water use in Bangladesh with a focus on the leather and textile industries, Draft report

BKH Consulting Engineers, et al, March 2001; *Techno-economic Study for Setting up a Common Effluent Treatment Plant (CETP) in the Tannery Cluster of Hazaribagh*; United Nations Industrial Development Organization (UNIDO) and Government of Bangladesh.

BWDB 2013, Hydro-geological Study and Mathematical Modelling to Identify Sites for Installation of Observation Well Nests, Selection of Model Boundary, Supervision of Pumping Test, Slug Test, Assessment of Different Hydro-geological Parameters Collection and Conduct Chemical Analysis of Surface Water and Groundwater (Package-3)

CEGIS, 2012, Master Plan of Haor Area, Volume I, Bangladesh Hoar and wetland Development Board, Ministry of Water Resource, DWASA, Annual Report 2011-2012, Government of the People's Republic of Bangladesh

DoE, 1997, The Environmental Conservation Rules

Grontmij, DHI & IWM, 2013, Dhaka Sewerage Master Plan Project (Package DS-1A), Master Plan Report, Dhaka Water Supply and Sewerage Authority

IWM, 2014, Bangladesh Integrated Water Resources Assessment Supplementary report: Review of Groundwater Quality in Bangladesh

IWM & DevCon, 2014, Water Supply Master Plan for Dhaka city, Dhaka Water Supply and Sewerage Authority

JMP, 2014, WHO & UNICEF, Progress of Drinking Water & Sanitation

LGD, December 2011, National Strategy for Water and Sanitation- Hard to Reach Areas of Bangladesh, Ministry of Local Government, Rural Development and Cooperatives, Government of the People's Republic of Bangladesh

LGD, November 2011, Sector Development Plan (FY 2011-25), Water Supply and Sanitation Sector in Bangladesh, Ministry of Local Government, Rural Development and Cooperatives, Government of the People's Republic of Bangladesh

UNICEF, 2012-13, Multi Indicator Cluster Survey, Bangladesh Bureau of Statistics (BBS), Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh

National Strategy for Water and sanitation Hard to Reach Areas of Bangladesh, Dec 2011

WB, 2010 Implication of Climate Change for Fresh Groundwater Resources in Coastal Aquifers in Bangladesh

BASELINE STUDY: 07

Part A- Sediment Management

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Executive Summary: Study 07 (Part A)

Most of the large deltas in the world are highly intervened and are in eroding phase due to lack of sediment supply from upstream. The case of Bengal Delta is different, till now it is able to be in accreting phase. The sediment carried by the Ganges, Brahmaputra and the Meghna river systems from their catchments have formed a delta, where the land is very fertile and is able to support food and water security for 1100 people/km². Due to different types of natural events such as very large flood, neo-tectonics and seismic events, sediment load and texture of sediment may vary temporally and spatially. Human interventions, at both upstream and downstream, may have large influences on the morphological metamorphosis of the rivers. Due to the characteristics of deposition pattern, the role of sediment texture play an important role. Coarse sediment generally forms the riverbed of the sand-bed rivers and determines the morphology of the fluvial- process-dominated rivers. On the other hand, fine sediment determines the morphology of the floodplain and also the estuary.

The data used for sediment analysis has been taken from the Bangladesh Water Development Board (BWDB) (1966 to 1969) and FAP 24 (1993-1996) which are the latest available data. In both the cases, coarse and fine sediment were separately analyzed. Method of gauging and the instruments used were different. Total sediment load in the Brahmaputra-Jamuna and the Padma system, has increased in the period from 1960s to 1990s, while bed material load (Coarse sediment) has decreased more than 50%. The morphology of the rivers thus responded strongly, with aggradation and degradation of the riverbed, widening of the river and decreasing of braiding intensity. As a result, flow area within bank level increased significantly.

Sediment balance within the river system indicates an aggrading system in 1960s, while it turned into degrading system in the 1990s. During the reducing phase of coarse sediment, river responded by widening and lowering its riverbed. Rate of river bank erosion and widening was very high in the Jamuna and the Padma rivers.

From the observations of measured sediment, it is clear that bed material load had reduced from 1960s and 1990s. Due to lack of routine sediment gauging, it was not possible to assess the present status of the of the sediment input. Investigation of time-series satellite images assess the planform changes and experience gained on the river responses to the changes of sediment load, it could be reasonably considered that present coarse sediment load is close to that of 1990s.

Net accretion in the Meghna estuary however, depends on the sediment load in the river. Reflections of fine sediment measured at Bahadurabad and Hardinge Bridge, could be found in the estuary within few months. But for the coarse sediment, processes of propagation and deposition are different. It may take 15 to 20 years to demonstrate its effects in the estuary.

Sources of sediment depends on its texture, for example, bed materials are generated from their sources and river bank. Fine sediment generally comes from their floodplain. Large number of dams at upstream, mining of sediment would reduce the coarse fraction of the sediment. On the contrary, afforestation and better management of land at upstream may also reduce the fine sediment. On the other hand, land development for construction of infrastructures will increase with the economic development of the country. It is likely that in near future, supply of sediment would reduce, on the contrary, demand of coarse sediment will be increased. Increasing of temperature due to climate change, may cause increased rainfall and increased sediment yield. Earthquake and large-scale landslides also cause increased coarse sediment yield.

Strategy of sediment (coarse) management could be outlined based on the knowledge gained from the analysis of sediment data and also recent understanding on the responses of the river to the changes of sediment quantity

and quality. It is needed to recognize that sediment is a resource, but it is not unlimited. Supply of coarse sediment will reduce where on the other hand, mining of those deteriorate the situation.

In case of the Jamuna and the Ganges rivers, it is likely that coarse sediment would reduce further, mainly due to upstream anthropogenic interventions. Responses of the Jamuna and the Ganges might be different, but increase in river bank erosion and scour depth would be common for both the rivers. It will increase coastal erosion as well.

There is a high demand for coarse sediment. This demand is now met by extracting sand from the riverbeds for land development and construction works (road, railway, embankment, township and industrial park) etc. Also, the river beds are dredged to remove the coarse sediment to maintain navigation route

During the last few decades, a huge amount of sediment has been extracted from the rivers around the Dhaka city. These rivers are the Upper Meghna and few under-fit distributaries, such as the Dhaleswari, the Kaliganga, the Turag, the Bansi, and the Sitlakhya. As Dhaka is a rapidly growing city, demand of sand is very high for land development. Unplanned mining of coarse sediment is rapidly diminishing the sediment storage, which would not be replenished anymore. On the contrary, demand of coarse sediment will be increased. Imposing levy on sediment mining may reduce the extraction and planned extraction could reduce the river bank erosion and suffering of the population living on the natural levees.

Capital dredging may not be effective for the large and high energy rivers like the Jamuna, Ganges, Padma, Teesta and the Dharla. Instead, annual recurrent dredging would be more effective to maintain the river navigability. In a very wide river, the dredged-coarse sediment may be dumped into the riverbed in a strategic suitable locations, so that it cannot return back into the dredged channel before the onset of the monsoon, unless the sand users are ready to pay. In the natural fluvial system, the sediment is required to maintain a natural healthy river.

1. Introduction

Most of the large deltas in the world are highly intervened and are in eroding phase due to lack of sediment supply from upstream. The case of Bengal Delta is different, till now it is able to be in accreting phase. The sediment carried by the Ganges, Brahmaputra and the Meghna river systems from their catchments have formed a delta, where the land is very fertile and is able to support food and water security for 1100 people/km². Other than food and water security, several constituents such as safe and comfortable shelter, education, communications and health are also considered as basic needs of the citizens. To meet the increasing needs, people have been intervening in the biophysical system of the delta. These interventions alter flow, sediment and flood and tidal plain regimes. Extreme natural events like large flood, seismic events, and neo-tectonics also cause extreme changes in the river and flood plain morphology.

The alluvial rivers in the deltas have three functions: i) drain water from its catchments, ii) to transport sediment, and most importantly, iii) to develop land in the delta. Among several other factors, sediment size and quantity determine the morphologies of the rivers, the floodplain and the tidal plains. The transported sediment in the major rivers of Bangladesh comprised of fine sand, (henceforth referred to as coarse sediment or only sand), and silt+clay, (henceforth referred to as fine sediment). Generally, coarse and fine sediments are differentiated by 0.06 mm size. Bed materials of the large rivers are coarse sediment, size and concentration of which, generally, play major roles in the process of metamorphosis of the river and estuary morphology. Whereas, fine sediment has very minor role to play but it has the active role in developing and maintaining flood and tidal plains, and in determining morphology of the estuary.

A change in quantity and texture has noticeable effects on river bank erosion, such as widening of rivers, aggradation/degradation of riverbed, and changes in flood regime. In 1970s to 1990s, the major river systems such as the Brahmaputra-Jamuna-Padma-Lower Meghna systems have gone through enormous metamorphosis due to the changes in sediment regime. The Jamuna and the Padma have widened by 3 to 4 km. River bank erosion was very severe along the Jamuna. The annual average erosion was 5,000 ha/y in 1980s; it has reduced to 2,000 ha/y in the recent past (**Figure 2.1**). Net 100,000 ha of floodplain was lost from 1970s to the end of last century. As a result, millions of people became landless and homeless.

Due to the physical and mineralogical characteristics of the sediment, unconsolidated boundary layers (river bed and bank) and high sediment load, most of the rivers in Bangladesh are very dynamic. To manage such rivers effectively, sediment management has become a prime issue. The main constraint is the limited knowledge on the interaction of sediment and flow with boundary layer that determines planform, width and river bank erosion of the very dynamic large rivers system in Bangladesh.

Prior to going into the details for sediment management issues, this report elucidate recent understating on the responses of the rivers and estuaries to the changes of quantity and textures of sediment. Analysis of available sediment gauging data, time-series satellite images and subsequently generated knowledge by recent research studies on the rivers and estuary morphologies (Sarker and Thorne, 2006; Sarker, 2009; Sarker et al., 2011) used in outlining the main issues of sediment management.

2. Study Area

Characteristics of the rivers and the accompanying sedimentation processes depend on several factors, such as topography of the terrain, neo-tectonics, characteristics of the boundary layers, sources of flow and sediment. Flow and sediment process of the tributaries like the Teesta and the Dharala, are quite different than those of the

distributaries like the Old Brahmaputra and Dhaleshwari. Sedimentation and morphological behavioral processes of the tidal rivers like the Pussur and Sibsra are different than the fluvial- process dominated rivers like the Jamuna and the Ganges. Furthermore, a river may behave differently, if the characteristics of the terrain, on which they are flowing, changes. For example, morphological processes of the Kushiyara and Surma rivers differ when they flow in their floodplain than while they flow in the subsiding Sylhet Basin. In different types of rivers and environments, sedimentation processes are different and thus, the sediment management would also be different.

To address the sedimentation issue of the rivers of Bangladesh is a huge task. This report limits itself to the major part of sediment input through the Brahmaputra and the Ganges rivers, and makes sediment balance considering exit through the Dhaleshwari, Padma, Arial Khan and the Gorai. A link between fluvial input crossing Mawa and response of the Meghna estuary has also been established.

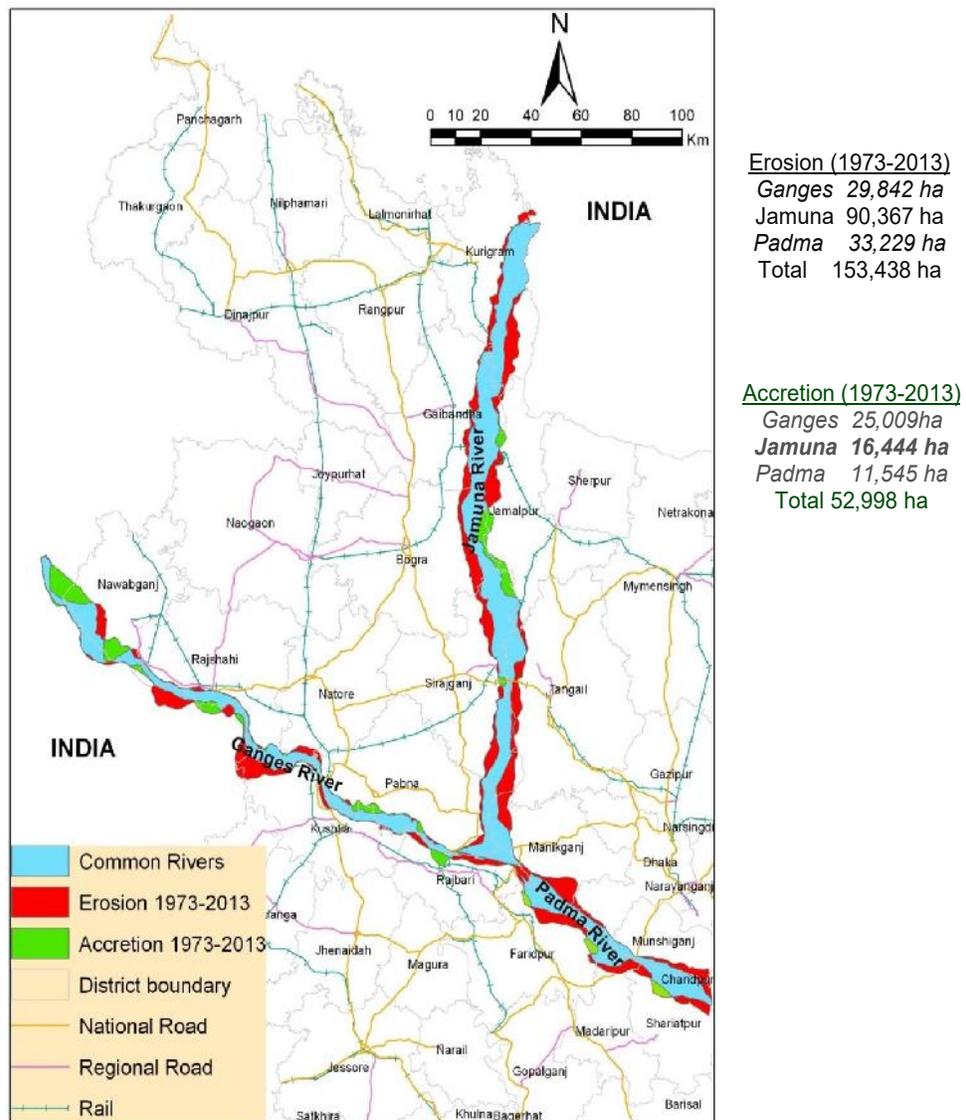


Figure 2.1: Erosion and accretion along the banks of the Jamuna, Ganges and the Padma rivers from 1973-2013

3. Sediment Gauging

Sediment gauging by Bangladesh Water Development Board (BWDB) from 1966 to 1969 and FAP 24 from 1993-1996 have been used to illustrate the temporal variation in sediment concentration of the Jamuna, Ganges and the Padma rivers and their textures. Sediment gauging of BWDB was initiated during 1966-1969, and the latest reliable sediment gauging from 1993-1996 was found in FAP 24 surveys. In both the cases, coarse and fine sediment were separately analyzed. Method of gauging and the instruments used were different. Joint measurement of BWDB and FAP 24 survey data showed that during the monsoon, BWDB measured less sediment than that of FAP 24. Analysis of the BWDB measured data from 1966 to 1989 indicates that coarse sediment had decreased by 60% (**Figure 3.1**).

Suspended coarse sediments in the Jamuna and the Ganges rivers decreased substantially, but while the fine sediment (washload) in the Jamuna declined, it increased significantly in the Ganges. . This is mainly due to deforestation and intensive agriculture in the upper riparian countries (CEGIS, 2010). From 1960s to 1990s, the total sediment load of the Jamuna decreased while it increased in the Ganges and the Padma rivers. Total coarse sediment (bed material) load in the early 1990s is less than a half of that in the 1960s in the Jamuna and the Ganges (**Table 3.1**). This variation in coarse sediment amount however, has pronounced effects on the morphological processes. For long term planning and also for scenario development, present status of sediment load is required to be assessed based on the sediment gauging in the 1960 and 1990s. No systematic reliable sediment gauging data are available for the last twenty years. Identifying the river responses in changing their planform to the large variation of sediment quantity and quality have been used to assess the present status of the Sediment regimes in the rivers and estuaries.

Table 3.1: Total sediment load of the Ganges, the Jamuna and the Padma Rivers in the 1960s & 1990s

Period	Type of sediment	Jamuna	Ganges	Padma
1966-1969	$S_{wash\ load}$ (m ton/y)	332	330	498
	$S_{susp. bed}$ (m ton/y)	221	164	257
	Total S_s (m ton/y)	553	494	755
Period	Type of sediment	Jamuna	Ganges	Padma
1994-1996	$S_{wash\ load}$ (m ton/y)	277	558	721
	$S_{susp. bed}$ (m ton/y)	125	76	227
	Total S_s (m ton/y)	402	634	948

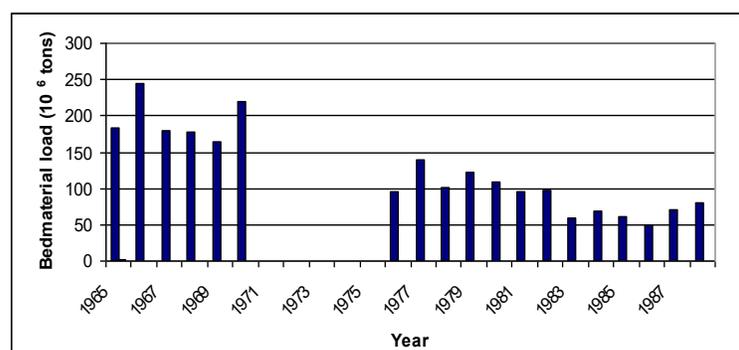


Figure 3.1: Annual variation of bed material (coarse sediment) through time at Bahadurabad (Sarker, 2009).

4. Sediment balance within fluvial system

Sediment balance within the fluvial process was made by FAP 24 (Delft Hydraulics and DHI, 1996) using BWDB measured data in the 1960s and sediment balance was made between sediment entering in the Jamuna at Bahadurabad and the Ganges at Hardinge, and sediment out from Mawa in the Padma, Tilly in the Dhaleswari, Gorai Railway Bridge in the Gorai, and Choudhury Hat in the Arial Khan River (**Figure 4.1**). The balance can be expressed as:

$$Q_s(\text{Baha}) + Q_s(\text{Hard}) = Q_s(\text{Baruria}) + Q_s(\text{Tilli}) + Q_s(\text{Gorai}) \pm \Delta Q_s$$

Where Q_s is sediment, 'Baha' within parenthesis represents Bahadurabad, 'Hard' represents Hardinge Bridge and ΔQ_s is storage of coarse sediment on the riverbed and fine on the floodplain and also on the declining riverbed. To make balance, transported sediments were divided into two fractions i) coarse (bed material generally stored in the riverbed) and ii) fine (wash load generally stored in the floodplain), based on their process of deposition

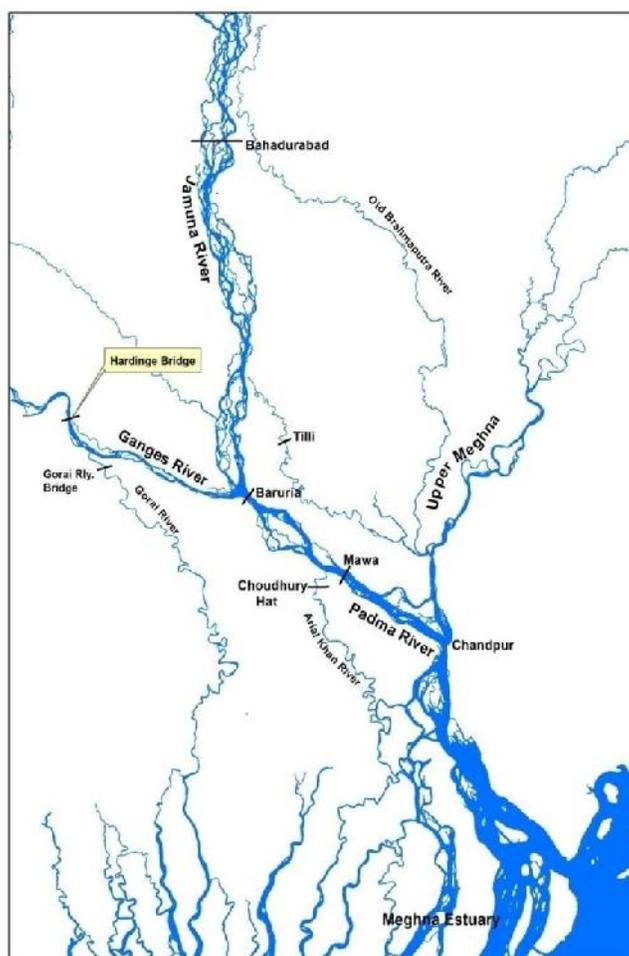


Figure 4.1: The main rivers and sediment gauging stations

Sediment balance based on BWDB sediment gauging in 1966-69 can be expressed as

$$221 (\text{Baha}) + 164 (\text{Hard}) - 20 (\text{Gorai}) = 257 (\text{Baruria}) + 5 (\text{Tilli}) \pm \text{Storage}$$

$$\text{Storage} = 365 - 257 = 108 \text{ million tons/y} \sim 65 \text{ million m}^3/\text{y}$$

Table 4.1: Sediment balance within the fluvial system in the 1960's and 1990's

Period (1)	Texture (2)	Jamuna (3)	Ganges (4)	Padma (5)	Gorai (6)	Dhaleshwari (7)	Storage (3+4-5-6-7)
1966-69	Sand (10 ⁶ ton/y)	221	164	257	20	5	108*10 ⁶ ton/y ~ 65*10 ⁶ m ³ /y (riverbed)
	Silt+clay (10 ⁶ ton/y)	332	330	498	33	26	106*10 ⁶ ton/y ~ 64*10 ⁶ m ³ /y (flood plain)
1994-1996	Sand (10 ⁶ ton/y)	125	76	227	5	1	-65*10 ⁶ ton/y ~ 40*10 ⁶ m ³ /y (riverbed)
	Silt+clay (10 ⁶ ton/y)	277	558	721	15	5	97*10 ⁶ ton/y ~ 57*10 ⁶ m ³ /y (floodplain)

Sediment balance (fine, million ton/year)

$$332 \text{ (Baha)} + 330 \text{ (Hard)} = 498 \text{ (Baruria)} + 33 \text{ (Gorai)} + 26 \text{ (Tilli)} \pm \text{Storage}$$

$$\text{Storage} = 662 - 557 = 105 \sim 10^6 \text{ ton/y} \sim 64 \cdot 10^6 \text{ m}^3/\text{y}$$

The result suggests that the bed material load in the Jamuna and the Ganges in the 1966 to 1969 period was much higher than the rivers could carry. As a result, a large amount of sediment nearly 65 million cubic meter per year was stored on the riverbed.

Sediment measured by FAP 24 about three decades later was used for computing sediment balance. Quantity and quality of sediment have changed by this time (**Table 4.1**).

Sediment balance (fine sand, million ton/y) based on the sediment gauging from 1994 to 1996 by FAP 24

$$125 \text{ (Baha)} + 76 \text{ (Hard)} = 227 \text{ (Baruria)} + 5 \text{ (Gorai)} + 1.0 \text{ (Tilli)} \pm \text{Storage}$$

$$\text{Storage} = 201 - 260 - 5 = -65 \text{ million ton/y} \sim -40 \text{ million m}^3/\text{y}$$

This negative storage suggest that in-coming coarse sediment is less than the sediment transport capacity, i.e. riverbed was degrading during this phase.

Sediment balance (silt+clay, million ton/year)

$$277 \text{ (Baha)} + 558 \text{ (Hard)} = 721 \text{ (Baruria)} + 15 \text{ (Gorai)} + 5.0 \text{ (Tilli)} \pm \text{Storage}$$

$$\text{Storage on the floodplain} = 835 - 741 = 94 \sim 57 \cdot 10^6 \text{ m}^3/\text{y}.$$

Floodplain sedimentation during this period was $57 \cdot 10^6 \text{ m}^3/\text{y}$.

Floodplain storage of the fine sediment are found to be very close over the years such as $64 \cdot 10^6 \text{ m}^3/\text{y}$ and $57 \cdot 10^6 \text{ m}^3/\text{y}$ during 2nd half of 1960s and first half of 1990s respectively. But the storage of coarse sediment in the riverbed during the same period varies significantly, for example, there were positive storage $65 \cdot 10^6 \text{ m}^3/\text{y}$ in 1966-1969 and negative storage $40 \cdot 10^6 \text{ m}^3/\text{y}$ during 1994-1996.

To explain the changes of the positive and subsequent negative storage could be explained using the process-response model developed by Sarker and Thorne (1950) and Sarker (1950). The model has been developed to demonstrate the river responses to the changes of coarse sediment. There were a huge landslides in the Himalayas induced by 1950 earthquake in Assam, India. A major part of the 45 billion cubic meter debris was poured into the Brahmaputra River. This Process-response model shows the riverbed aggradations of the Jamuna/Brahmaputra at Bahadurabad initiated in the early 1960s and reached its peak in the middle of 1970s (**Figure 4.2**).

Coarse sediment measurement in the 1960s used for sediment balance laid in the period of riverbed aggradation. Riverbed of the Padma was in dynamic equilibrium condition (**Figure 4.3**), suggesting of positive increase of storage i.e. net sedimentation in the Jamuna and the Ganges Rivers.

Sediment balance for the first half of 1990's suggested degradation of riverbed of the Jamuna River and this finding supports the process-response model (**Figure 4.2** and **Figure 4.3**). Changes in flow area at bankfull stage of the Jamuna and the Padma Rivers (**Figure 4.4**) also matches with the findings of sediment balance.

Results of the analysis of time-series Standard Cross-sections surveyed by BWDB have been presented in (**Figure 4.4**) after a thorough checking the consistency and accuracy of the survey data. Flow area at bankfull stage was adjusted for the deviation of perpendicular alignment of the sections with the main channel by Sarker (2009) and Delft Hydraulics and DHI (FAP 24, 1996). Average flow area of the Jamuna was about 30,000 m² in the late 1960s and mid-1970s. It increased to 36,000 m² during the first half of the 1990s. This observation indicates the removal of 6,000 m³ sediment from one meter length of riverbed and adjacent floodplain. Analysis of bank materials (depth???) along the banks of the Jamuna shows that nearly 80% of bank material is fine sand i.e. during 1977-78 to the mid 1990s, total eroded fine sand was 4,800 m³ per meter length of the river. Similar result was observed from the Padma River from where about 4,000 m³ bank material (out of which sand was 3,200 m³) was removed from the river bed and adjacent floodplain during 1984 to 2002. Total 1.32 billion m³ of bank materials had been removed from the Jamuna and the Padma rivers. This amount of sediment is equivalent to 165 km² of net accretion of land in the Meghna Estuary.

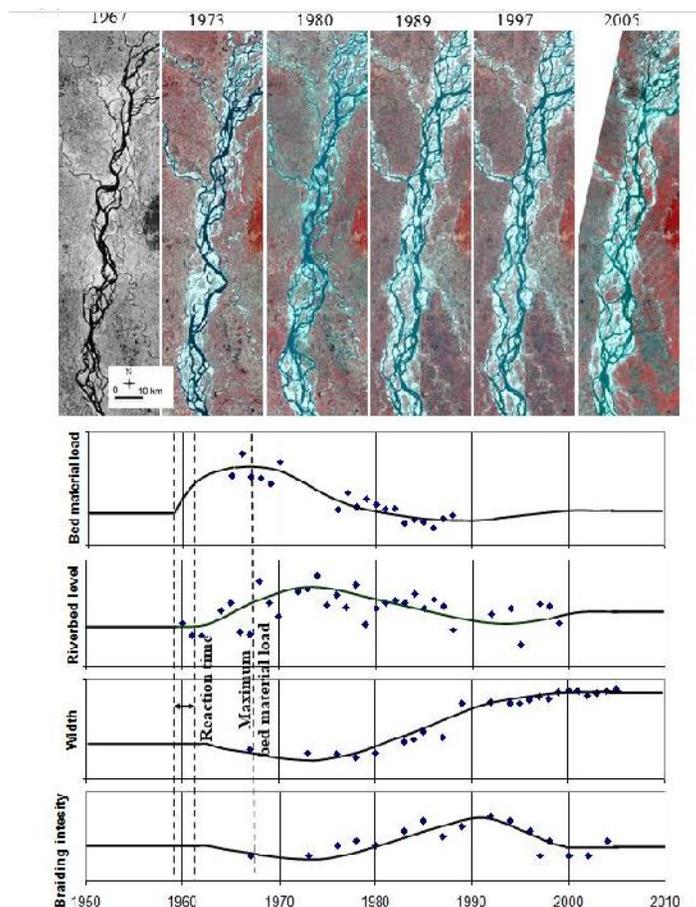


Figure 4.2: Process-response model Jamuna/Brahmaputra at Bahadurabad

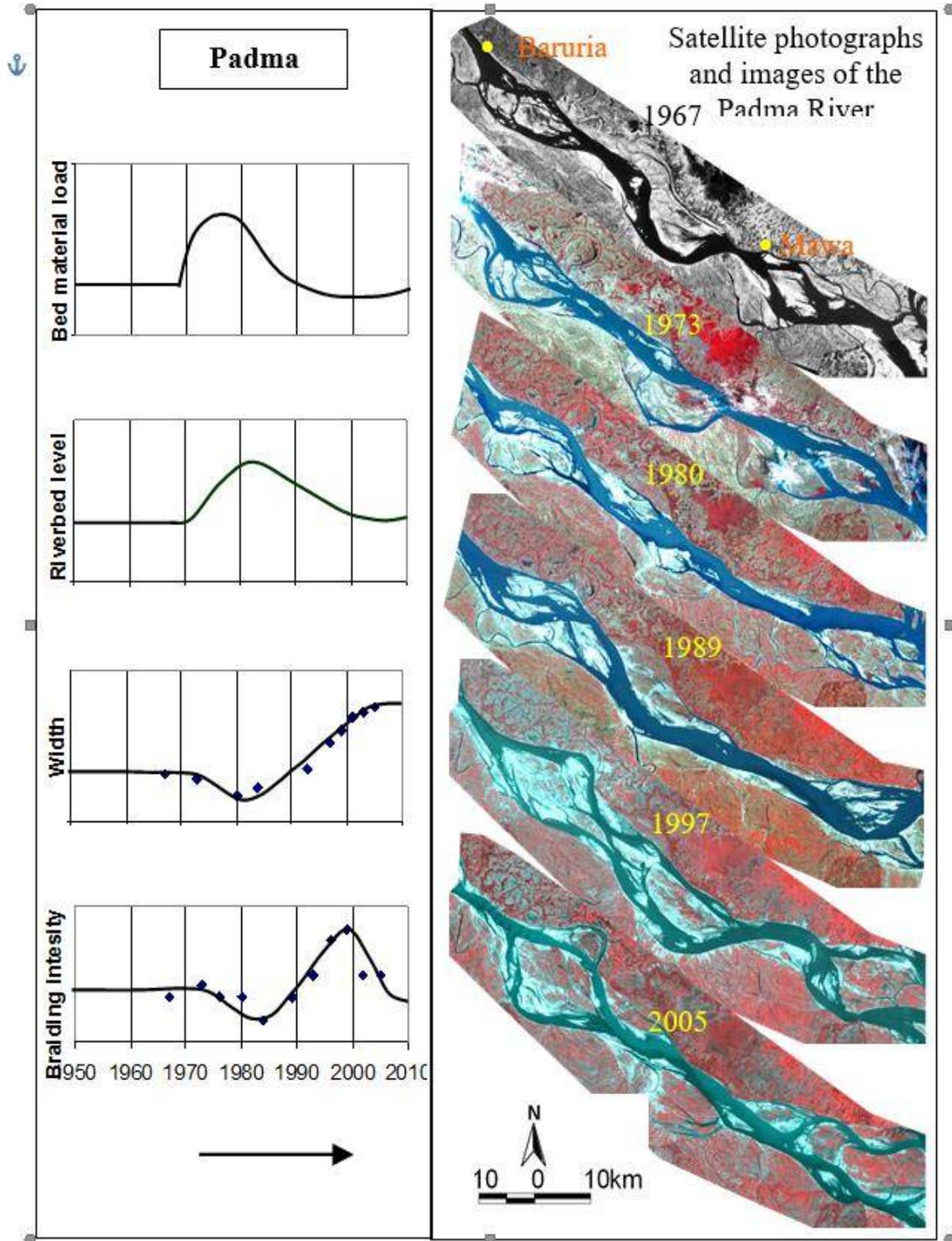


Figure 4.3: Net sedimentation in the Jamuna River

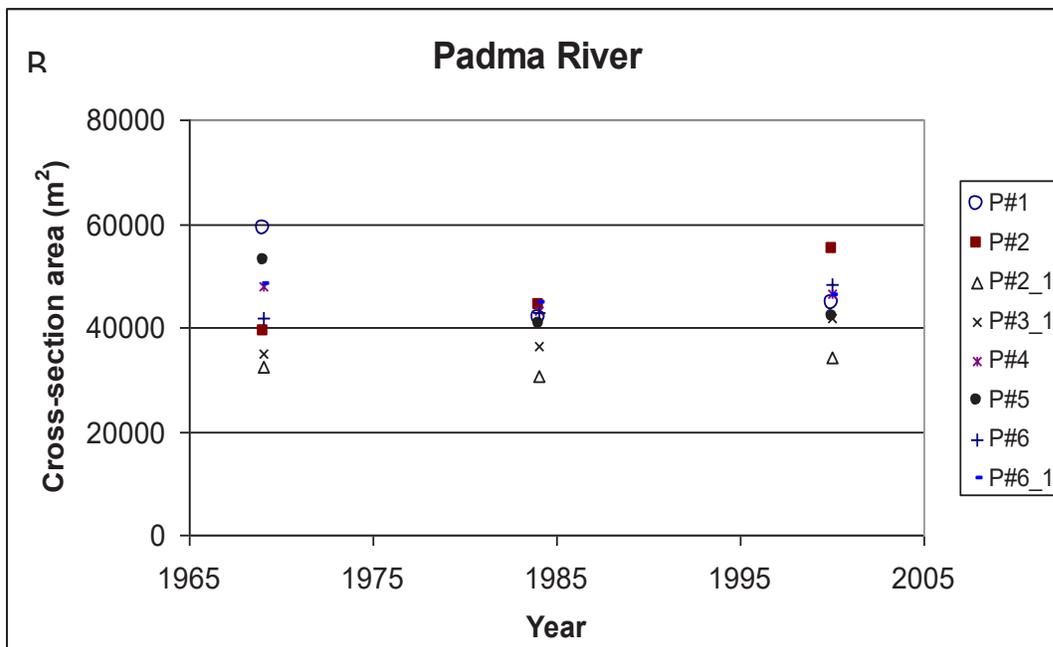
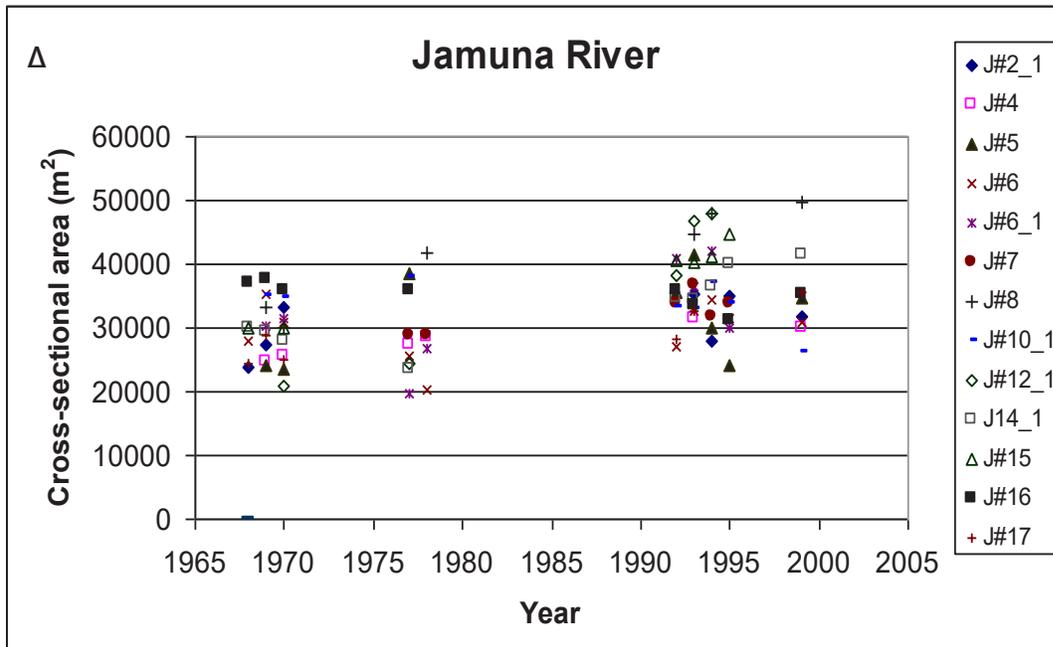


Figure 4.4: Temporal variation of flow area below bankfull stages determined by the analysis of time-series Standard Cross-sections of the Jamuna and the Padma Rivers surveyed by BWDB

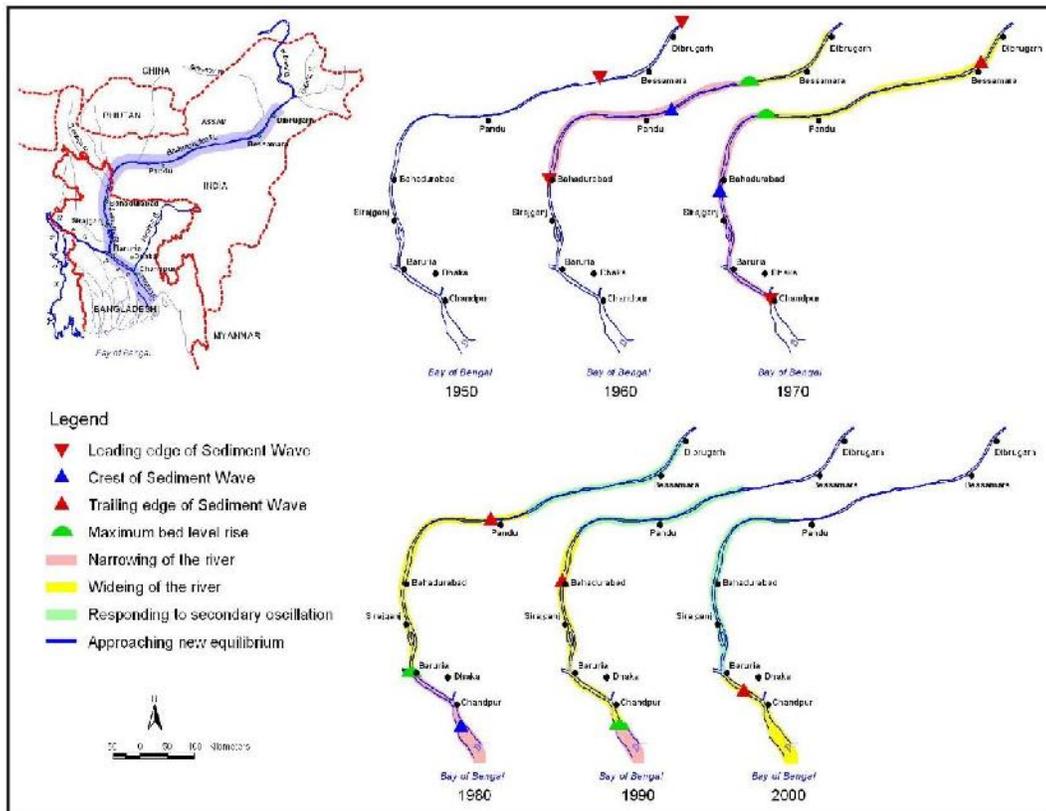


Figure 4.5: Responses of the river in changing bed level, width and braiding intensity to the propagation of sand wave

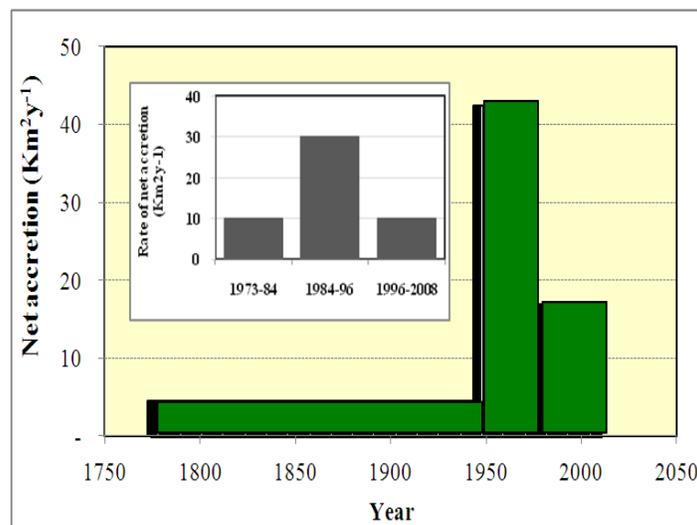


Figure 4.6: Rate of net accretion in different time periods

Sediment balance between fluvial to marine systems

There is no systematic routine measurement of flow and sediment in the Meghna Estuary, however, bathymetry of the estuary area can be used for assessing storage (\pm) in the estuary. Storage is assessed using time-series satellite images, from where erosion/accretion is quantified and storage is assessed by multiplying the net

accreted area with an average depth of 8 m. From the bathymetry surveys in the 1997 and 2000, it was calculated that average elevation difference between tidal plain and estuary bed is about 8 m. In the estuary, both sand sized sediment and silt+clay, play their roles in forming the shape of the estuary.

Responses of the river in changing bed level, width and braiding intensity to the propagation of sand wave at different periods are presented in **Figure 4.4**. It shows that the propagation of sediment wave took several decades to travel from Assam to the Meghna estuary. Leading edge of the sediment wave entered in the estuary in 1970s and crest of the sediment wave in 1990s.

A very high rate of erosion and accretion process is prevailing in the estuary area since the last several years. Out of several tens of km²/y erosion and accretion, net accretion is the dominating morphological processes. Very high rate of net accretion (< 40 km²/y) during 1940s to 1960s was mainly due to the entrance of fine sediment, immediate after the 1950 Assam earthquake (**Figure 4.5**). This process, however, was expedited by the construction of two Noakhali Cross Dams in the late 1950s and early 1960s. Net volume of depositing sediment in 1950 to 1973 is about 7,360*10⁶ m³.

Entering the high rate of coarse sediment into the estuary also caused high rate of net accretion during 1984 to 1996 (**Figure 4.6**). During this period, rate of net accretion of land was 30 km²/y, equivalent to 2,640 *10⁶ m³ deposition of sediment. Fine sediments, those may deposit in the estuary, starts their journey from upstream origin towards to the bay within the same year. But in case of coarse sediment, situation is different, it took about 15 to 20 years to travel from Bahadurabad to the Meghna estuary. This implies that high pulse of coarse sediment deposited in the estuary is the sum of sediment measured at Bahadurabad and Hardinge Bridge in 1960s. The storage in the riverbed that occurred in the late 1960s and 1970s also washed away during the erosion phase of the riverbed and finally destined to the estuary and the bay.

Thus coarse sediment 4,235*10⁶ m³ and fine sediment 7,930*10⁶ m³, total 12,165*10⁶ m³ entered in a period of 12 years from 1984 to 1996. Efficiency of the estuary during this period in trapping the sediment is about 22%.

5. Summary

Due to different types of natural events such as very large flood, neo-tectonics and seismic events, sediment load and texture of sediment may vary temporally and spatially. Human interventions, at both upstream and downstream, may have large influences on the morphological metamorphosis of the rivers.

Due to the characteristics of depositional pattern, the role of sediment texture play an important role. Coarse sediment generally forms the riverbed of the sand-bed rivers and determines the morphology of the fluvial-process-dominated rivers. On the other hand, fine sediment determines the morphology of the floodplain and also the estuary.

Total sediment load in the Brahmaputra-Jamuna and the Padma system, has increased in the period from 1960s to 1990s. But material load been decreased more than 50%. The morphology of the rivers thus responded strongly, with aggradation and degradation of the riverbed, widening of the river and decreasing of braiding intensity. As a result, flow area within bank level increased significantly.

Sediment balance within the river system indicates an aggrading system in 1960s, while it turned into degrading system in the 1990s. During the reducing phase of coarse sediment, river responded by widening and lowering its riverbed. Rate of river bank erosion and widening was very high in the Jamuna and the Padma rivers. Substantial drop of annual riverbank erosion from 5,000 ha/y to 2,000 ha/y was occurred in the Jamuna River, similar case was observed in the Padma River.

All the observed responses of the rivers, during the process of propagation of sediment, can only be explained by the process-response model developed by Sarker and Thorne (2006).

From the observations of measured sediment, it is clear that bed material load had reduced from 1960s and 1990s. Due to lack of routine sediment gauging, it was not possible to assess the present status of the of the sediment input. Investigation of time-series satellite images assess the planform changes and experience gained on the river responses to the changes of sediment load, it could be reasonably considered that present coarse sediment load is close to that of 1990s.

Net accretion in the Meghna estuary however, depends on the sediment load in the river. Reflections of fine sediment measured at Bahadurabad and Hardinge Bridge, could be found in the estuary within few months. But for the coarse sediment, processes of propagation and deposition are different. It may take 15 to 20 years to demonstrate its effects in the estuary.

Future status of sediment load

Sources of sediment depends on its texture, for example, bed materials are generated from their sources and river bank. Fine sediment generally comes from their floodplain. Large number of dams at upstream, mining of sediment would reduce the coarse fraction of the sediment. On the contrary, afforestation and better management of land at upstream may also reduce the fine sediment. Land development for construction of infrastructures will increase with the economic development of the country. It is likely that in near future, supply of sediment would reduce, on the contrary, demand of coarse sediment will be increased.

Increasing of temperature due to climate change, may cause increased rainfall and increased sediment yield. Earthquake and large-scale landslides also cause increased coarse sediment yield.

Outlines of Sediment Management

There is a general consensus that all rivers of Bangladesh are heavily sediment-charged and that it has increased during the last few decades. This situation has been identified as the prime cause of increase of flooding, eroding riverbank and widening of the affected rivers. It is true that from 1960s to 1990s, the total sediment input had increased, and may be it remains the same till date. Where river morphology is concerned, coarse fraction is the main actor to shape and maintain the rivers, and this has reduced and would continue to reduce in the future.

Strategy of sediment (coarse) management could be based on the knowledge gained from the analysis of sediment data and also recent understanding on the responses of the river to the changes of sediment quantity and quality. It is needed to recognize that sediment is a resource, but it is not unlimited. Supply of coarse sediment will reduce on the other hand mining of those is gradually diminishing. There are several under-fit rivers, mainly the poorly connected distributaries which are not receiving coarse sediment from their parent rivers. In case of the Upper Meghna, the major part of the sediment transported by its tributaries is deposited in the Sylhet basin.

In case of the Jamuna and the Ganges rivers, it is likely that coarse sediment would reduce further, mainly due to human interventions upstream. Responses of the Jamuna and the Ganges might be different, but increase in river bank erosion and scour depth would be common for both the rivers. It will increase coastal erosion as well.

There is high demand for coarse sediment. Thus human activities focus on extracting sand from the riverbed for land development and construction works (road, railway, embankment, township and industrial park), dredge to remove the coarse sediment to maintain navigation route

During the last few decades, a huge amount of sediment has been extracted from the rivers around Dhaka city. These river are the Upper Meghna and few under-fit distributaries, such as the Dhaleswari, Kaliganga, Turag,

Bansi, and the Lakhiya. As Dhaka is a rapidly growing city, demand of sand is very high for land development. Unplanned mining of coarse sediment is rapidly diminishing the sediment storage, which would not be replenished anymore, on the contrary, demand of coarse sediment will be increased. Imposing levy on sediment mining may reduce the extraction and planned extraction could reduce the river bank erosion and suffering the residents on the natural levee.

There should be a policy regarding the amount of coarse sediment that could be extracted for development works from the riverbed without causing noticeable erosion along the downstream riverbed erosion and degradation of upstream river bed including the increased erosion along the coast. But the beneficiaries should have also to pay for extracting coarse sediment.

Capital dredging may not be effective for the large high energy rivers like the Jamuna, Ganges, Padma, Teesta and the Dharla rivers. Annual recurrent dredging would be more effective to maintain the navigation routes. In a very wide river, dredged -coarse sediment should be dumped into the riverbed in a suitable location, so that it cannot return back into the dredged channel prepared for navigation before the monsoon, unless people are ready to pay for the coarse sediment. In the natural fluvial system, sediment is required to maintain a natural healthy river. There are few extreme natural events or human activities that could generate an excess sediment load, in such cases, extraction of sediment would be a better prescription for the river to maintain its good health and riverine ecosystem.

6. References for Part A: Sediment Management

- Ahmed, A. U. (2006) Bangladesh Climate Change Impacts and Vulnerability: *A Synthesis*. *Climate Change Cell, Bangladesh Department of Environment, Dhaka, Bangladesh*.
- Allison, M. A. (1998) Historical changes in the Ganges-Brahmaputra Delta Front. *J. Coastal Res.* 14(4), 1269–1275.
BDP 2100 Baseline Study Report: Water Resources
BDP 2100 Baseline Study Report: River Systems Management
- Bird, E. (2008) *Coastal Geomorphology: An Introduction*. John Wiley & Sons Ltd, UK
- EGIS (1997) Morphological dynamics of the Brahmaputra-Jamuna River. Prepared for Water Resources Planning Organization (WARPO), Dhaka, Bangladesh.
- Flood Action Plan (FAP), 1996
- Sarker, M. H. & Thorne, C. R., (2006) Morphological response of the Brahmaputra-Padma-Lower Meghna river system to the Assam Earthquake of 1950, In: *Braided Rivers: Process, Deposits, Ecology and Management* (ed. by G. H. S. Smith, J. L. Best, C. S. Bristow, & G. E. Petts), 289–310. *Special Publication 36 of the IAS, Blackwell Publishing, UK*.
- Sarker, M. H. (2009) *Morphological response of the Brahmaputra-Jamuna-Padma-Lower Meghna River to the Assam earthquake of 1950, PhD thesis, University of Nottingham, UK*.
- Sediment dispersal processes and management in coping with climate change in the Meghna Estuary, *Bangladesh*
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- Goodbred, Jr. S. L. & Kuehl, S. A. (2000) *Enormous Ganges-Brahmaputra sediment discharge during strengthened early Holocene monsoon. Geology 28, 1083–1086.*
- Goodbred Jr., S., Kuehl, S., Stecler, M., & Sarker, M. (2003). *Controls on facies distribution and stratigraphic preservation in the Ganges-Brahmaputra delta sequence. Sedimentary Geology, 155, 301-316.*
- CEGIS (2009) *Monitoring planform developments in the EDP area using remote sensing. Prepared for BWDB, Dhaka, Bangladesh, 01-79.*
- CEGIS (2010) *Impacts of climate change on the morphological processes of the main rivers and Meghna Estuary of Bangladesh. Prepared for Asian Development Bank (ADB), Manila, Philippines, 1-123.*
- Umitsu, M. (1993) *Late Quaternary Sedimentary Environments and Land Forms in the Ganges Delta. Sedimentary Geology 83, 177–186.*
- Walling, D. E. & Webb, B. W. (1996) *Erosion and sediment yield: a global overview. In: Erosion and Sediment Yield: Global and Regional Perspective (ed. by D. E. Walling, & B. W. Webb), IAHS Publ. 236. IAHS Press, Wallingford, UK, 3–20.*

BASELINE STUDY: 07

Part B- Meghna Estuary Study

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Executive Summary: Study 07 (Part B)

Under this additional study for the Bangladesh Delta Plan 2100, an attempt has been made to develop an investment plan in order to reclaim some land based on the overall morphological process of the Meghna Estuary area. This estuary area have undergone a lot of changes during the last 250 years since the avulsion of the Brahmaputra. In the early 20th century, the estuary was easterly aligned. However, in the last few decades, eastern Meghna branch of the Meghna estuary totally dried up and subsequently the western distributary, named the Shahbajpur channel, became enlarged.

At present, every year about one hundred billion cubic meter of fresh water is brought into the Meghna Estuary by the three major rivers which is carried by three distributary channels, namely the Tetulia, Shahbajpur and Hatiya channels. This huge water brings enormous sediments to the estuary every year. This deposited sediment resulted in vertical accretion and horizontal progression of the delta. These sediments enter estuary area during monsoon and take momentary residence in the lower limit of Shahbajpur channel. The maximum sediment concentration variation between 0.5 and 9 gm/l was observed near the Urir Char - Char Balua area and Manpura – North Hatiya area by Meghna Estuary Study.

Erosion and accretion in the estuary area has been a continuous process going on for several centuries and observed by many studies. Results from all these studies show accretion as the dominant process during last 200 years. During 1973-2008 the net accretion rate was about 15.1 km²/yr. But during 2008-2015 it increased to about 11.0 km²/yr. Accretion rate in Noakhali is the highest whereas in Lakshmpur, Bhola and Feni districts erosion is the dominating process.

These accreted lands have to undergo land formation process before it can be called as reclaimed land. This process can take several years some times over two decades. From satellite image analysis, the fastest land development observed in the Shahbajpur Channel is 8 years, whereas in some parts of the Tetulia Channel, it was found to be 25 years.

From all the analysis, there is some scope to reclaim land from the 710 km long Bangladesh coast. LRP's study (1987) on the Sandwip-Urir Char-Noakhali Cross Dam mentioned that the cross dam may reclaim new land of about 18,000 ha (above + 2.2 mPwD) in 15 years and another 18,000 ha land in next 15 years. This huge land mass would benefit more than 180,000 people directly.

MES proposed a Master Plan (1998) and a Development Plan (2001) to aid accretion process in three planning zones by measures like mangrove planting, settling basins and cross dams etc. Analysis of the recent satellite images by CEGIS revealed that those selected locations are still accreting without any interventions. This indicates that the prediction of the Master Plan and Development Plan were reasonable except one location at Hatia-Moulavir Char-Dhal Char-Char Parvez. Some prioritized cross dam locations have been selected on this note based on analysis. However, the result of the analysis should be considered as preliminary one. A rigorous investigation on the morphological processes is recommended to assess the impact of different interventions and to suggest different interventions for enhancing the sediment trapping capacity of the Meghna Estuary in order to make the process fruitful.

1. Introduction

Land reclamation in the estuaries is almost everyday news in the social media. Based on the possibilities, Bangladesh Government has many measures regarding land reclamation. Accordingly, the Government has been investing money in this sector for their formation. The Ganges-Brahmaputra-Meghna (GBM) system is carrying huge volume of sediment to the Bay of Bengal through several estuaries; among them the Meghna estuary is the biggest. Estuaries are the place where sweet water mixes with saline water. The sediment particle drops here to form land. The GBM system carries sediment mainly during monsoon and deposits in the Meghna and tides redeposit the sediment during dry season. The Passur and Baleshwar rivers form their estuaries in the west coast of Bangladesh. Due to lack of fresh water flow from the Ganges and Padma rivers, these estuaries have less sediment from the riverine source, rather they receives some sediment from the east of the coast. The abundance of sediment in the Meghna estuary gives Bangladesh an opportunity to reclaim lands within the vicinity of Bangladesh territory in the Bay of Bengal.

The objective of this study is to understand the development criteria of the Meghna estuary area and to find out some investment plan to add few lands with the existing area of Bangladesh.

This report has been prepared mainly based on literature review and existing knowledge of experts. Series of meeting have been conducted for gathering data and information. Historical maps and time series satellite images have been used from CEGIS archives for analysing erosion accretion. Findings of Meghna Estuary Study are the basis for this note. **Figure 1** shows the location of the Meghna estuary in Bangladesh where potential land reclamation is possible.

2. Meghna estuary

The Meghna Estuary is the present active estuary of the GBM system, where delta is progressing vertically and horizontally towards the sea. This estuary is the downstream continuation of the Lower Meghna River that collects flow and sediment from the Ganges, Brahmaputra and Upper Meghna rivers, as shown in Figure 1. The boundary of the estuary has been defined by many studies, like Meghna Estuary Study (MES). Mainly MES defined area will be considered for this report which is shown in **Figure 2**. The eastern boundary started from Chittagong and followed the coastline from the left bank of the Karnaphuli River at its outfall in the Bay of Bengal. The western boundary followed the right bank of the Lower Meghna, the Tetulia Rivers and the coastline to the sea.

This area is less intervened, unlike other estuaries in developed countries. So, rather than proper utilizing the natural resources of the estuary system, it brings misery to the stakeholders due to continuous erosion-accretion, although accretion is the dominating process in the Meghna Estuary. For the dynamic behaviour of the estuary morphology through development and abandonment, huge land along the riverbank is eroding every year. On the other hand, it takes several years for bringing production from a newly reclaimed land. So, a precise investment plan is required for sustainable development and management of the estuary. Several studies have been carried out on coastal erosion-accretion in Bangladesh. A brief description will be provided here based on past studies and finally an investment plan will be developed.

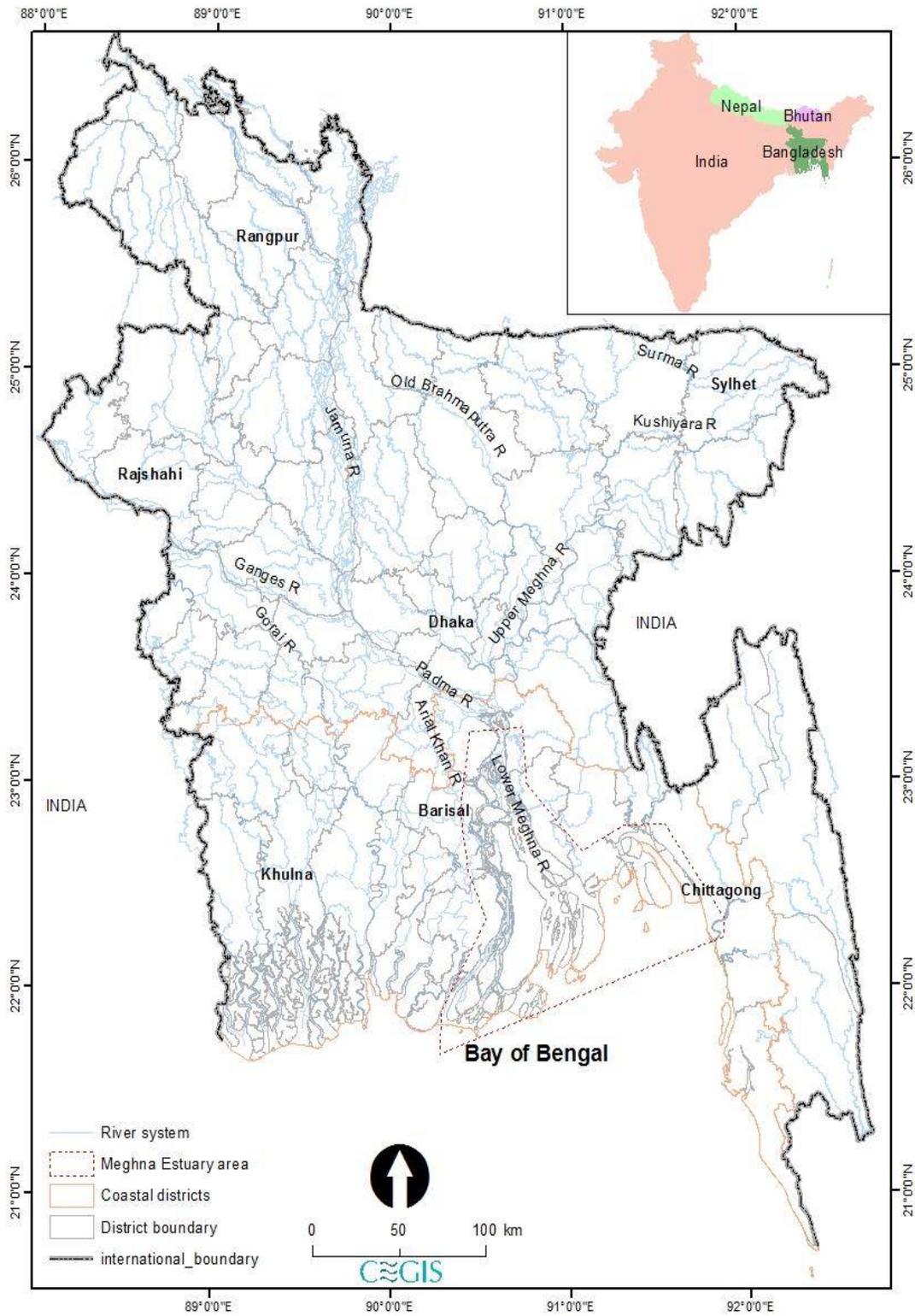


Figure 1: Map showing the Meghna estuary area in Bangladesh

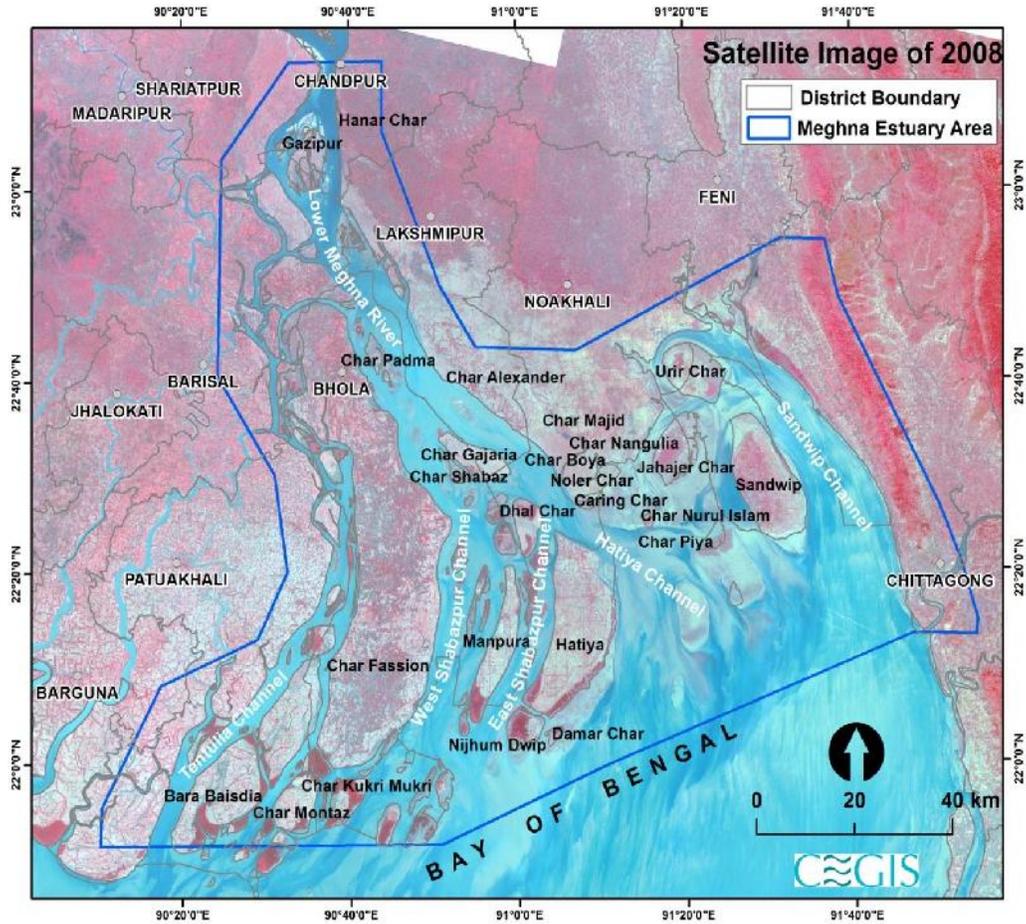


Figure 2: Meghna estuary area bounded by blue line

3. Related Studies

For socio-economic development of the coastal area, Government of Bangladesh (GoB) and Government of Netherlands (GoN) initiated Land Reclamation Project (LRP) in 1978 and ended in 1991. After that LRP was divided into two projects: Meghna Estuary Study (MES) and Char Development and Settlement Project (CDSP). The MES I and MES II were carried out during 1996-2002. CDSP-I was done in Noakhali and Laxmipur districts during 1994-99, CDSP-II in Noakhali, Laxmipur, Chittagong and Feni districts during 1999-2005, CDSP-III in southeast part of Bangladesh during 2005-2010, and CDSP-IV in Noakhali, Laxmipur, and Chittagong districts during 2011-2018. All these projects are not for land reclamation programs. But CDSP-V (2019-2024) and CDSP-VI (2025-2030) are proposed to be focused on land reclamation.

Presently, CDSP-IV is the fourth phase which has duration from 2011 to 2018 and is being co-financed by the Government of Bangladesh, the Government of the Netherlands, and the International Fund for Agricultural Development (IFAD). The project activities of CDSP-IV focus on the water management development of five new chars: Char Nangulia, Noler Char, Caring Char, Urir Char and Char Ziauddin through empoldering and infrastructure development. CDSP-IV is investigating on a feasibility study on Dhal Char (Hatiya), Char Kalatia (Monpura), and Char Mozammel (Char Tazumuddin) by the technical support of Institute of Water Modelling (IWM) and Development Design Consultants Ltd. (DDC). The implementation phase of this feasibility study (2015-

16) will be approached for CDSP-V phase. The land reclamation study of CDSP-III 'feasibility study of Noakhali and Urir Char' is waiting for implementation approval from the GoB. Six government organizations (GOs), like BWDB, LGED, DPHE, DoF, DAE and MoL, and four non-government organizations (NGOs) under CDSP-IV are involved for distributing khash land to the stakeholders and their socio-economic development.

The Estuary Development Programme (EDP) during 2007-2009 aimed to increase the physical safety of the people living in the Meghna estuary. Blue Gold (March 2013 – March 2019) is a collaboration program between the GoN (donor) and the GoB. The program is implemented by the Ministry of Water Resources, through Bangladesh Water Development Board (BWDB, lead agency) and the Department of Agricultural Extension (DAE). This program establishes and empowers community organizations to sustainably manage their water resources, and based on their priorities, delivers the services for which those community organizations have expressed a demand. Blue Gold builds on the results and lessons learned from previous programs and projects in Bangladesh, notably the Integrated Planning for Sustainable Water Management (IPSWAM) program (2003-2012), Southwest Area Project, CDSP-IV etc. and the Bangladesh and Dutch experiences and expertise in participatory water management in polders. This program focuses on the districts of Patuakhali, Khulna and Satkhira.

Other than these, presently another project namely Emergency 2007 Cyclone Recovery and Restoration Project (ECRRP) is working on rehabilitation of embankments in seven polders in Barguna and Patuakhali districts and Coastal Embankment Improvement Project (CEIP) in different phases working in Bagerhat district. All these are not for land reclamation programs.

4. Historical development

In line with the evolution of the river and estuary system during the Holocene, the rivers and their estuaries have changed their courses several times during last few centuries. About 250 years ago when the Bhramaputra-Jamuna was flowing along the present course of the Old Brahmaputra, the estuary was getting Meghna flow combined with the Brahmaputra flow to the east; and the Ganges was getting off to the estuary separately to the west, as shown in **Figure 3**, keeping Bhola as a middle bar. But, when the Brahmaputra avulsed to the present Jamuna in the early 19th century and merged with the Ganges, it caused many significant changes to the rivers and estuaries of Bangladesh. Tassin's map (1840) shows that a significant amount of the Brahmaputra flow was diverted to the present Jamuna River to meet the Ganges. The combined flow of the Ganges and the Brahmaputra met the Meghna at Chandpur and finally off to the Bay of Bengal. The old course of the Ganges, the Arial Khan River, had become the right bank distributary of the Ganges River, as shown in Figure 3.

Sarker et al (2013) mentioned that by the early 20th century, most of the Brahmaputra flow was diverted to the Jamuna River. Consequently, most of the Padma flow was also diverted to the Meghna River abandoning its old course. In that period, the Meghna estuary was at its most easterly aligned. The main flow of the Lower Meghna River had started to divert through the Shahbajpur channel. Both the Meghna and Shahbajpur channels attained equal width and several new right bank distributaries started to flow in the southwesterly direction.

In the last few decades, considerable changes have been observed in the river systems and their estuaries. The eastern Meghna branch of the Meghna estuary totally dried up and subsequently the western distributary, Shahbajpur channel became enlarged. Several right bank distributaries from the Meghna and Arial Khan rivers developed in the south-westerly direction.

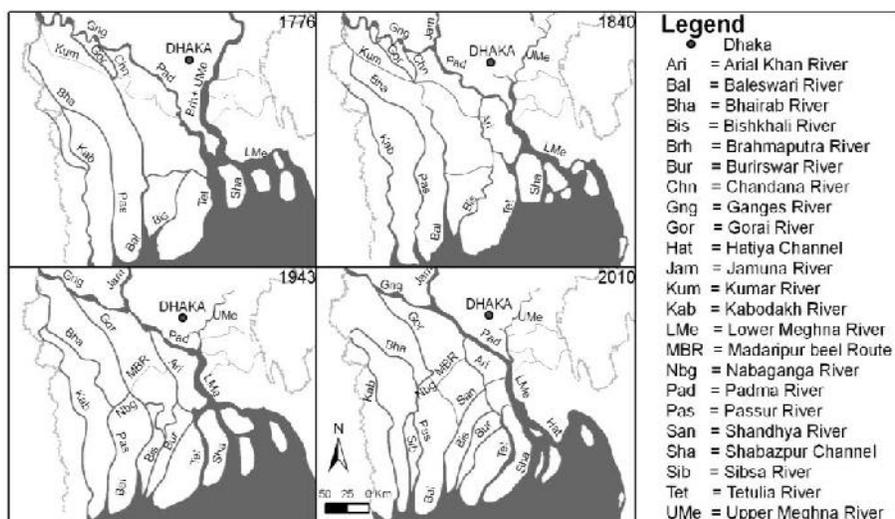


Figure 3: Development of the main rivers in Bangladesh over time (Sarker et al, 2013)

The major changes during the last 250 years in the Bengal delta are the avulsion of the Brahmaputra River from the east of the Madhupur Tract to its present course and its joining with the Ganges River at Aricha. Instead of two separate estuaries, it became a unified delta building estuary, Meghna estuary, during this period and shifted to its most easterly course. During the late 18th and early 19th century all the distributaries and the main course of the Ganges flowed in the southeast direction. The major natural changes included shifting of the delta building estuary to the west, progradation of the delta (growth of the river delta farther out into the sea over time) by several tens of kilometres towards the south and development of several south-westerly distributaries from the Lower Meghna and the Arial Khan (Sarker et al, 2013).

5. Drivers and Challenges

Avulsion of the Brahmaputra and the Teesta, gradual shifting of the Ganges, tectonic subsidence and uplifting, deltaic subsidence, and delta progradation are the main drivers that influence the hydro-morphological development of the river systems of Bangladesh. In addition, human intervention, like- construction of dams, barrage, coastal polder, flood embankment, unplanned landuse changes and ground water abstraction, has also triggered the changing processes. However, the active functioning of those drivers varies greatly depending on the regional physical characteristics as well, like the Madhupur Tract and the Barind Tract. Moreover, seismic events, like- 1950 Assam earthquake (8.5 Richter scale), have pronounced effect on the delta building process. Huge sediment generated by the earthquake has expedited the delta building process through delta progradation, which is also responsible for floodplain and tidal plain development through river morphology adjustment process. An alteration of one driver causes a series of alterations. In general, avulsion of the Brahmaputra River, tectonic activities (like 1950 Assam earthquake, subsidence), deltaic subsidence, and human interventions, along with delta progradation are the main drivers which have influenced the overall river characteristics of Bangladesh in different scale.

However, the main drivers and challenges of the Meghna estuary area are the part of the total delta building process. Hence active delta building process through the Meghna is the main driver. Natural disturbances, like landslides, in the catchment area or extensive agricultural practices at upstream would produce more sediment; whereas landuse management or human intervention, like dam construction, would limit sediment production in the catchment. These more production of sediment or less production will disturb the general trend of the

development. Rivers will be more dynamic in increase of sediment scenario along with delta progradation, riverbank erosion, deterioration of navigability, vertical accretion in the tidal plain and estuary area. Due to present delta development trend of the delta, all right bank distributaries of the Lower Meghna River and the Arial Khan River are developing in terms of depth and width.

6. Morphological Process in the Meghna Estuary

Every year about one hundred billion cubic meter of fresh water is brought into the Meghna Estuary by the three major rivers: the Ganges, the Jamuna and the Upper Meghna. This water is distributed into the estuary by three distributary channels, namely the Tetulia, Shahbajpur and Hatiya channels. However, the ratio of the distribution of fresh water varies with the season and also over a period of decades, depending on the channel developing processes in the Meghna Estuary.

The distribution of river and tidal flows in the estuary (**Figure 4**) changes over time and has been reported in the past studies. MES I (1998) reported that about 27% of the total river flow entered into the east part of the estuary during mid-1990s, whereas it reduced to 10% during 2000s as mentioned by MES II (2001). It is supported by substantial reducing width of the Hatiya Channel found from the satellite image and cross-section data analysis. Likewise, flow pattern have also been changed in other distributary channels.

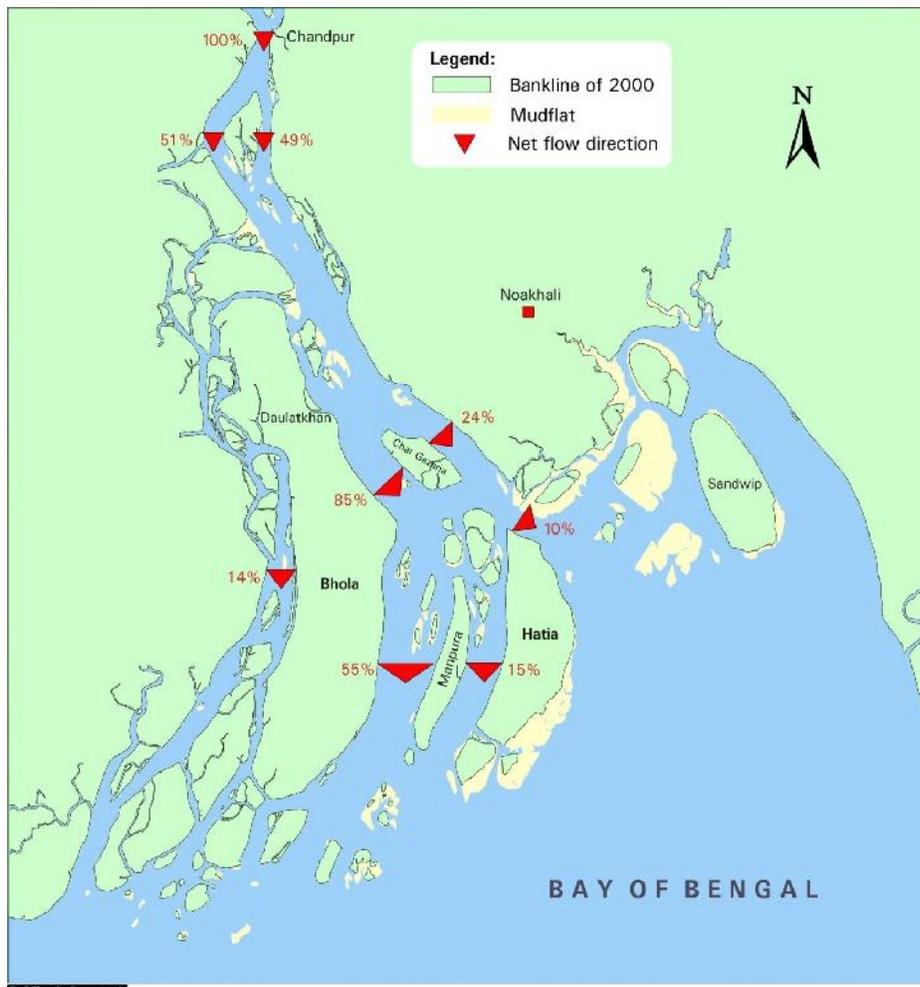


Figure 4: Net flow distribution in percentage (%) of flow at Chandpur during monsoon (MES II, 2001)

As indicated by the EDP study, some exogenous and indigenous factors have significant influence on the Meghna estuary development. Among the exogenous factors, shifting of the river mouths as a consequence of the delta building process, changing of bed level and climate change have long-term (hundred to thousand year scale) effect on the estuary development. Other short term (decade scale) exogenous factors are sediment transport changes, and natural hazards, like earthquake/land slide. Long shore sediment transports have some year scale impact, but this measurement is unknown in this estuary. Apparently long shore sediment transport is significantly smaller than the riverine sediment. Tidal forces, tidal circulation and salinity are the governing indigenous factors for the development of the estuary. Details description has been given in the EDP (2009) reports.

The semidiurnal tide in the estuary varies from micro (west part) to macro (east part) ranges. Tidal ranges in the Tetulia river- Chandpur, South Bhola - Hatiya North, and East Hatia –Sandwip are 0-2, 2-4, and >4m respectively. Hence the net flow circulations during monsoon and dry seasons determine the sediment and salinity distribution in the estuary. So the area of turbidity maxima within the salinity range of 1 to 5 ppt varies seasonally. High sediment concentration along with higher salinity is an indicator for land reclamation in the estuary area. The Urir Char, where the turbidity is very high and salinity is more than 5 ppt, has a deposition environment in last decades. The EDP (2009) and MES II (2001) also show that the tidal circulation plays an important role in sediment distribution in the Noakhali-Sandwip area.

7. Sedimentation process

This enormous amount of water brings hundreds of million tons of sediment every year to the estuary. So, a huge amount of sediment has been brought to the system during the Holocene period. Roughly, one third of the Holocene sediment was deposited on the floodplain, one third was trapped in the sub aqueous delta and rest was destined to the deep ocean floor. The deposited sediment in the floodplain has been using to balance the subsidence (like the Sylhet basin) and the compaction (like the southwest delta plain). The deposited sediment in the subaqueous delta has been resulting in vertical accretion and horizontal progression of the delta.

A mixture of (very) fine sand and silt are continuously moving back and forth along the Bangladesh coast and through the tidal inlets into the system. The major part of the sediment transport is the transport of vertically well-mixed suspended material. MES study reported that maximum concentration was found near the Urir Char - Char Balua area and Manpura -North Hatia area. The maximum depth-averaged sediment concentration varies between 0.5 - 9 gm/l.

The sediment distribution process in the estuary is mainly governed by the sediment characteristics, the tidal range and its characteristics, waves and the estuary planform (Palinkas et al., 2006; Bird, 2008). Seasonal variation of the fresh water input into the estuary ranges from 20 to 30 times, a similar range to that of sediment input. Most of the river-borne sediment enters the estuary during the few months of the monsoon. A major part of the sediment, especially the finer fraction, takes temporary residence in the zone of the turbidity maximum, which is close to the lower limit of the Shahbajpur Channel (Sokolewicz & Louters, 2007). Sediment concentrations at those locations are very high at about 2000 ppm (MES II, 2001). The maximum turbidity generally occurs in the low salinity zone and shifts its location with the changes in flood discharge (Grabemann *et al.*, 1995). Before reaching its final destination, fine sediment moves with the changes of the turbidity maximum and also back and forth with the tide. During the dry season the sediment supply from the catchment becomes insignificant, but sediment concentrations in the north-eastern tide dominated part remain close to that of the monsoon (IWM, 2009, 2010). The temporary storage of sediment during the monsoon in the zone of the turbidity maximum is the main source of sediment redistribution during the dry season.

The relative strength of flood and ebb tide determines the locations for sedimentation build up (Bird, 2008). Generally, higher flow velocity during flood tide in the shallow estuary brings sediment to the landward inter-tidal areas to settle. This is known as the so-called tidal pumping process. A tidal circulation process disperses fresh water and river-borne sediment into the north-eastern part of the estuary. Tidal residual flow in the Meghna Estuary, as obtained from a mathematical model and field observations, showed that a part of fresh water that enters through the Shahbajpur and Hatia channels makes nearly a U Turn and forms loop-type circulations around Sandwip, Urir Char and Jahajer Char (**Figure 5**). Based on the MES II (2001) and Sokolewicz & Louters (2007), the relative importance of river and tidal flow with respect to sediment discharge has been drawn on satellite images of 2010 (Figure. 5). It shows the tidal meeting points and subsequent sedimentation in the north-eastern part of the estuary. It can be seen in the following sections that a very high sedimentation rate is associated with this type of tidal circulation process.

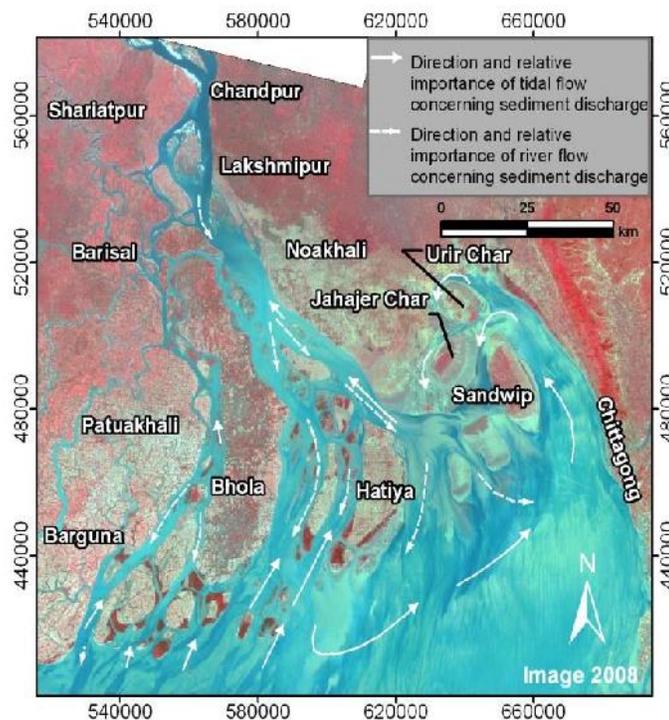


Figure 5: The direction and relative importance of river and tidal flows in influencing sediment discharge (based on Sokolewicz, & Louters, 2007)

The maximum flow velocity of 4 m/sec was also observed in the north-eastern part of the estuary in the Sandwip Channel (MES II, 2001) with a maximum sediment concentration of about 9000 ppm. Recent measurement shows that the values of maximum flow velocity and sediment concentration are very similar in the monsoon and the dry seasons (IWM, 2009), although the riverine sediment input during the dry season is negligible during this period. The monsoon sediment was moved temporarily by the river flow and was forced to remain close to the southern boundary of the estuary (downstream of the Shahbajpur Channel), having been brought to the north-eastern side by tidal circulation and tidal pumping process. The fine fractions of the sediment dominate the sediment redistribution process (Sokolewicz & Louters, 2007).

8. Erosion accretion

From a few years to several centuries erosion and accretion in the Meghna Estuary have been studied by Eysink (1983), EGIS (1997), Allison (1998), MES II (2001), EDP (2009), Sarwar and Woodroffe (2013), Brammer (2014), and Akter et al (2015). The results of all these studies show that accretion is the dominant process during the last 200 years in the coastal areas of Bangladesh. Based on the analysis of satellite images, MES II estimated that 86,400 ha were eroded while 137,200 ha were accreted during 1973-2000, resulting in a net accretion of 50,800 ha, which is equivalent to the net accretion rate of 18.9 km²/yr. The EDP has studied erosion accretion until 2008. Under this present study, an attempt was made to find the erosion-accretion status of the Meghna estuary until 2015.

According to Sarker (2009), the rate of net accretion was very low during the 167 years extending from 1776 to 1943. The net increase in land area was 760 km², which is equivalent to a mean annual accretion rate of 4.6 km²/yr. In the following 30 years (from 1943 to 1973), the net accretion became very high, with the land area increasing by 1100 km². This is equivalent to a mean annual net accretion rate of 42 km²/yr (**Figure 6**). Figures 7 to 10 show the erosion and accretion rates in the Meghna Estuary during the periods of 1973–2015. This analysis indicates that the Noakhali district is the most sediment deposition prone area. Accretion rate is almost three times than the erosion rate in Noakhali district during 1973-2015. Presently (2008-2015) erosion rate is more than accretion in Lakshmipur, Bhola, Barishal and Feni districts. In Chandpur and Shariatpur districts, erosion was dominating during 1973-2008, but after that period accretion has become dominating. The net rate of accretion was 14.4 km²/yr during the period of 1973 to 2015. The rate was higher (15.1 km²/yr) during 1973 to 2008 while it decreased to 11.0 km²/yr for the period 2008 to 2015.

If the period from 1973 to 2008 is split into three nearly equal time-spans, based on the availability of satellite images in the CEGIS archives (Figure 6). After 1973, the rate of accretion in the next 11 years was found to 10 km²/yr. In the following 12 years, extending from 1984 to 1996, the net accretion rate increased to 30 km²/yr. This period of high net accretion was followed by a 12-year period extending from 1996 to 2008 with a net rate of accretion of only 10 km²/yr. The higher rate of accretion of 30 km²/yr for the period 1984–1996 coincides with the arrival in the estuary of the sediment wave generated by the Assam earthquake, as indicated by Sarker (2009).

However, the difference is very large, suggesting that the rate of net accretion was very low until 1943 and that there was a sudden increase in net accretion during the subsequent three decades, followed by a substantial decrease. The rate of accretion immediately after the earthquake was much higher than the rates estimated by several different studies

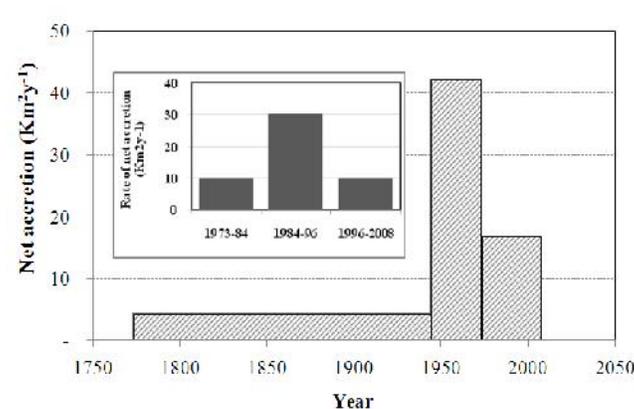


Figure 6: Net accretion in the Meghna Estuary during the last 232 years.

Source: Sarker (2009).

Figure 7 shows the erosion and accretion rate graphically in the Meghna Estuary during the period: a) 1973–2015, b) 1973–2008 and c) 2008–2015.

Figures 8, 9 and 10 show the erosion and accretion rate in the Meghna Estuary on satellite imageries during the period 1973–2015, 1973–2008, and 2008–2015 respectively.

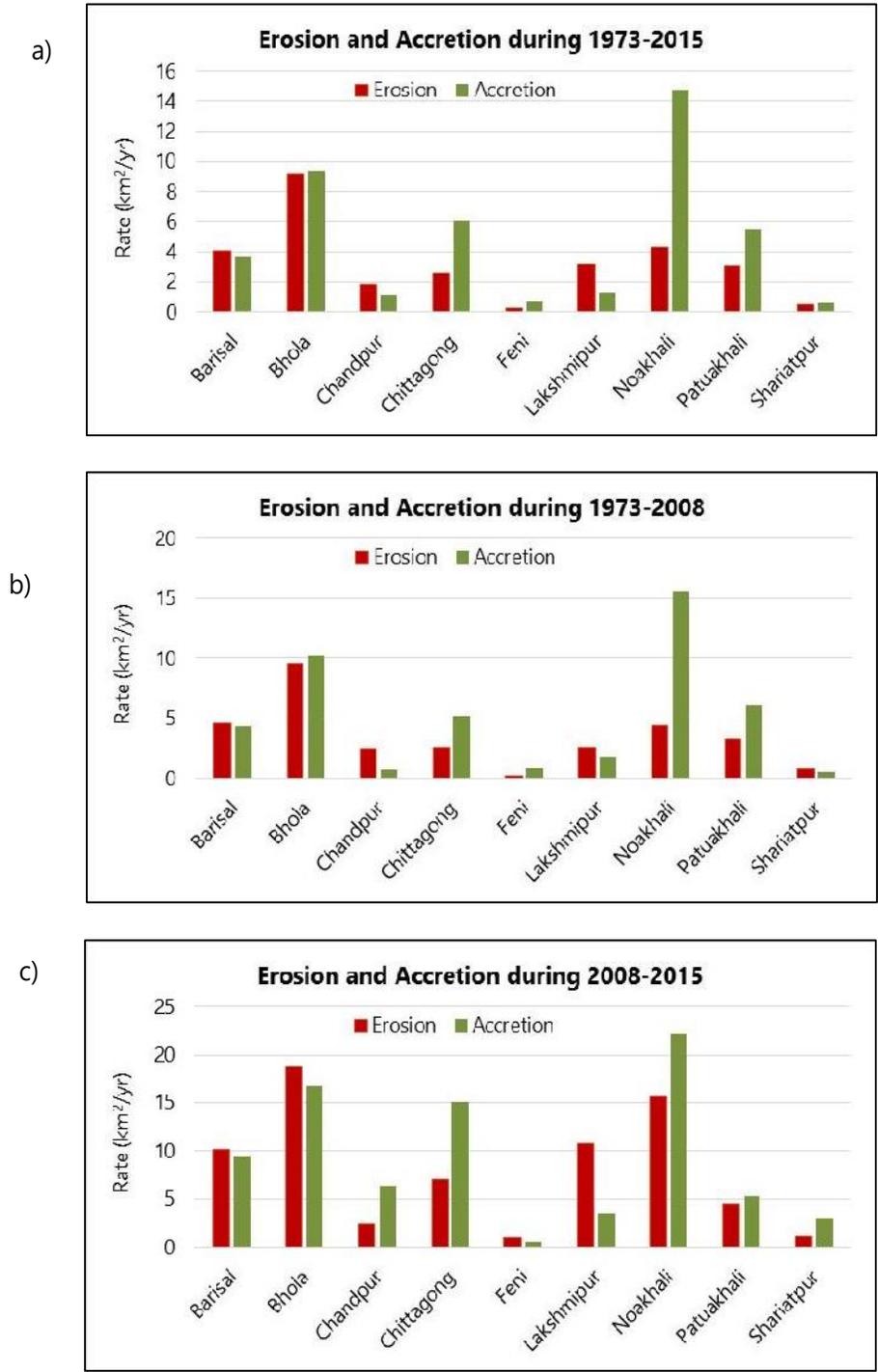


Figure 7: Erosion and accretion rate in the Meghna Estuary during the period a) 1973–2015, b) 1973–2008 and c) 2008–2015

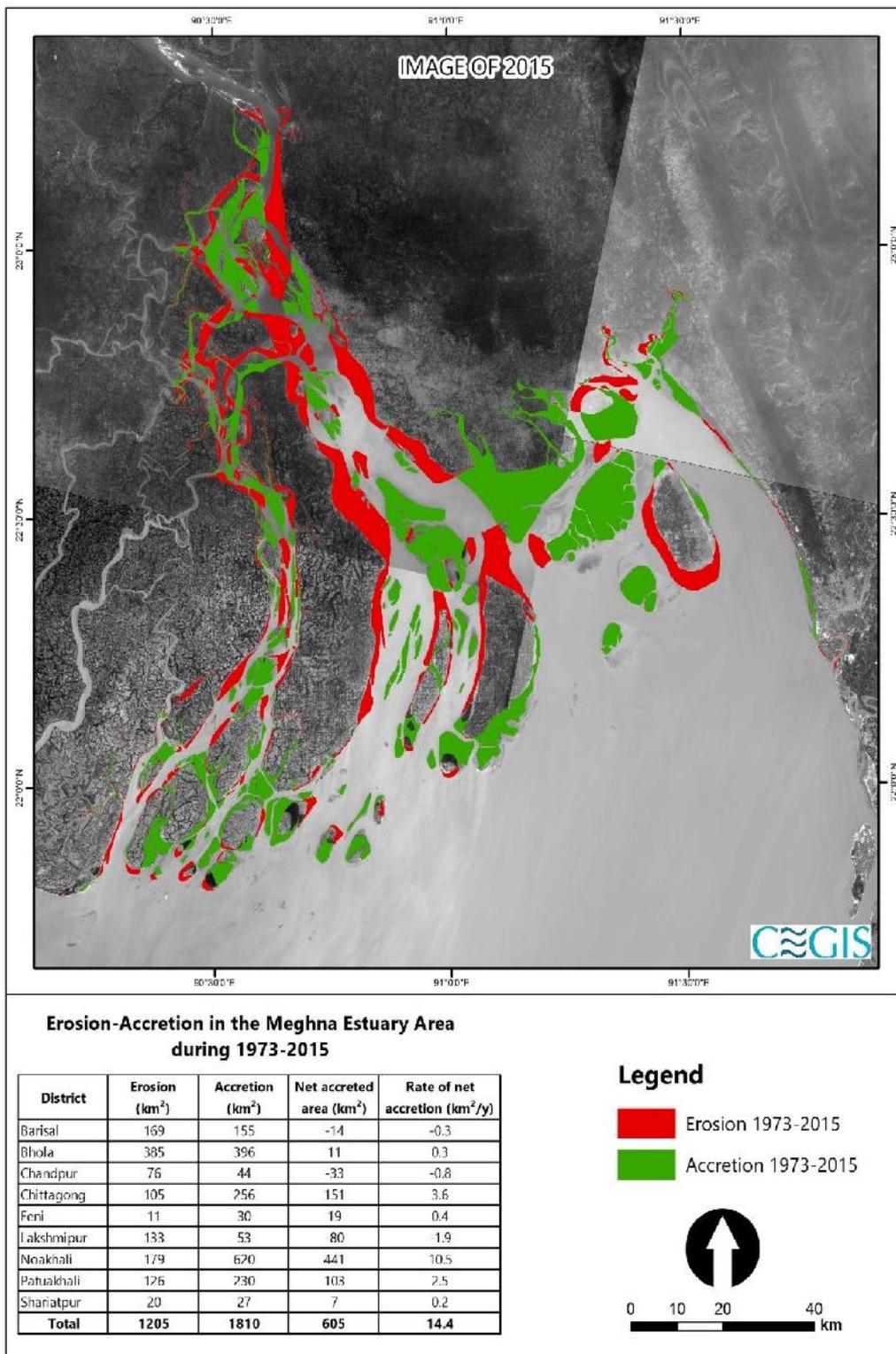
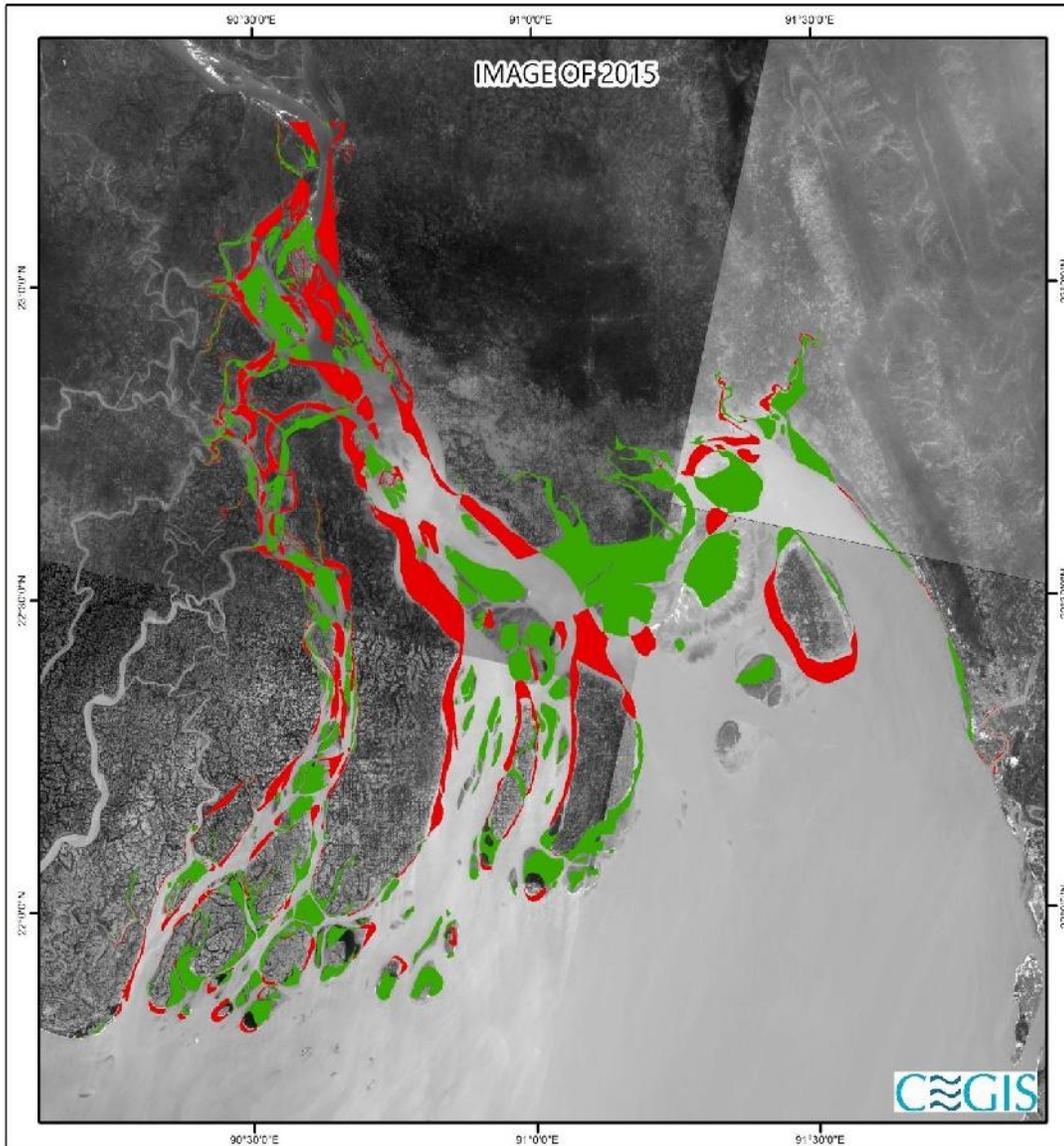


Figure 8: Erosion accretion in the Meghna Estuary during 1973-2015



Erosion-Accretion in the Meghna Estuary Area during 1973-2008

District	Erosion (km ²)	Accretion (km ²)	Net accreted area (km ²)	Rate of net accretion (km ² /y)
Barisal	162	152	-10	-0.2
Bhola	334	358	24	0.6
Chandpur	87	26	-61	-1.5
Chittagong	89	184	95	2.3
Feni	9	31	22	0.5
Lakshmipur	92	63	-29	-0.7
Noakhali	152	547	395	9.4
Patuakhali	116	214	98	2.3
Shariatpur	28	21	-7	-0.2
Total	1068	1596	527	15.1

Legend

- Erosion 1973-2008
- Accretion 1973-2008



Figure 9: Erosion accretion in the Meghna Estuary during 1973-2008

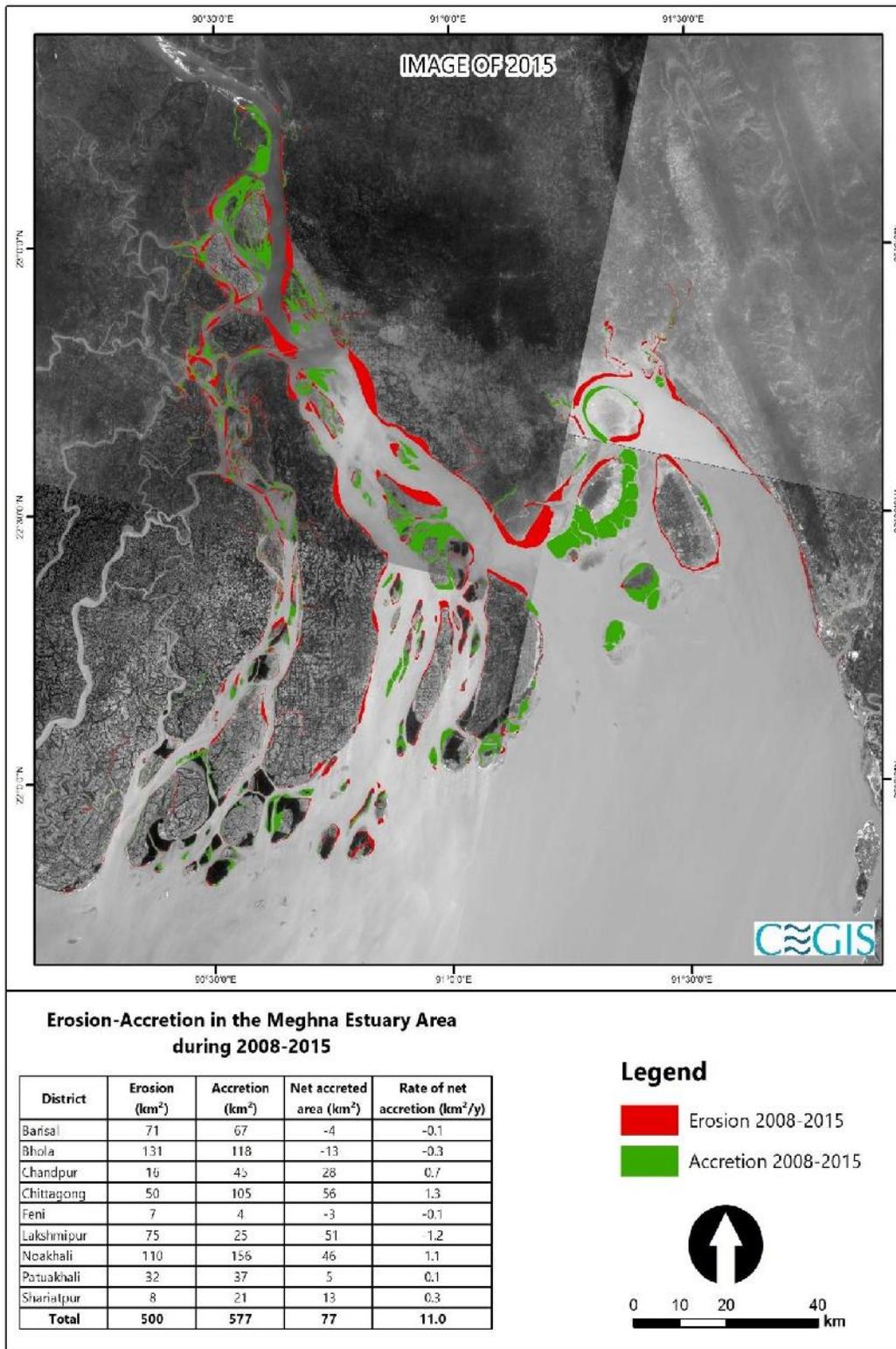


Figure 10: Erosion accretion in the Meghna Estuary during 2008-2015

Table 1: Area of islands at Meghna estuary during different time

Year	Area (km ²)			
	Hatia	Sandwip	Bhola	Urir Char
1973	5.0	2.7	15.6	0.0
1996	4.5	2.2	14.4	0.7
2015	4.4	2.1	13.7	1.2

The erosion accretion status of different islands of the Meghna estuary are given in **Table 1**. Total land area of Hatia, Sandwip and Bhola gradually decreased from 1973 to 2015. The north face of Hatia Island is eroding and the main land is prograding towards the island (**Figure 11**). For Sandwip Island, the south face is eroding during the period of 1973 to 2015. The eastern side of Bhola Island is continuously eroding from 1943 to present. The main reason of erosion is mainly due to the shifting of Meghna river flow through the Shahbajpur channel. Urir Char has been persistently migrating towards north resulting in the retreat of the mainland at Companiganj. The rate of migration of Urir Char towards north is higher than the rate of retreat of the mainland thus reducing the gap between Urir Char and the mainland at its northern tip.

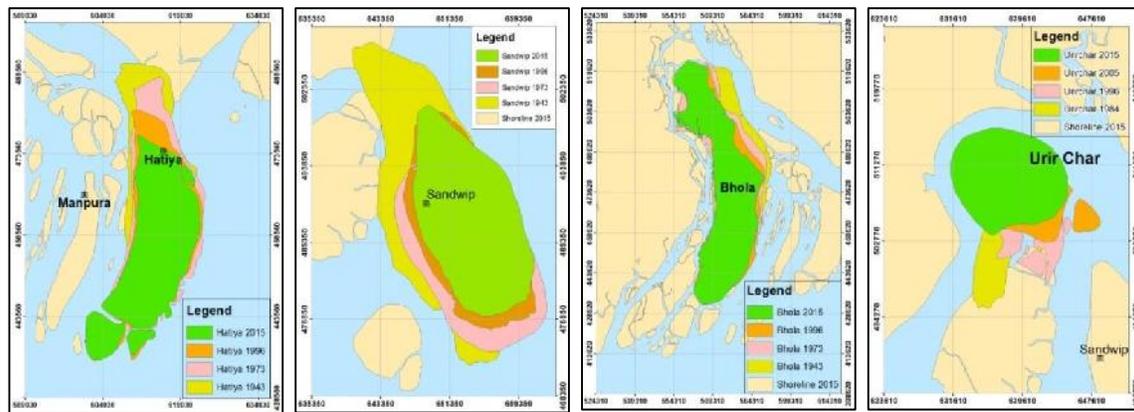


Figure 11: Dynamics of islands at the Meghna estuary

9. Impact of the Previous Initiatives

A major channel of the Meghna used to flow between Ramgati and the Noakhali mainland. The channel gradually silted up over a period of 20 to 30 years. In 1957, a 12-km long embankment, known as Meghna Cross Dam 1 was constructed across the channel to divert the flow westward. As a result, a new land area of 207 sq km was formed in the slack water adjacent to the cross-dam up to 1964. In 1964, Bangladesh Water Development Board (**BWDB**) constructed another cross-dam having a length of 16 km, Meghna Cross Dam 2, between Char Jabbar and mainland of Noakhali. This led to reclamation of another 563 sq km of land up to 1985 and the total reclaimed land area increased to 717 sq km. Land Reclamation Project (LRP) observed that the Lower Meghna River branch was already shifting to its present course into the Shahbajpur Channel when the Meghna cross dams were being constructed. The role of the dams was to accelerate the sedimentation process. Huge accretion was mainly due to the availability of sediment caused by the landslides generated by the Assam earthquake (1950).

A 3.41-km closure dam known as Feni closure dam, constructed across the Feni River in 1985 to divert the flow through the Feni regulator. This closure dam is located in Mirsharai and Sonagazi, respectively in the Chittagong and Feni districts. The Feni regulator with 40 gates was constructed to prevent saline water intrusion from downstream and retain fresh water upstream for use in the Muhuri Irrigation Project. It was estimated that there was net land reclamation of 37 km² area from 1984 to 2015 surrounding the project area.

10. Process of land formation

The process of land reclamation in the Meghna Estuary is described by Sarker et al (2011) based on satellite image analysis. After a certain level of land formation, a bar composed sand, silt and clay comes visible during low tide, but its level is slightly higher than the average low tide level. Initially, the bar is colonised by Uri-grass (*Porteresia coarctata*). The level of the bar surface then increases. In Bangladesh, Department of Forest transplant mangroves after a certain development of the bar. When the level rises to average high tide level, mangrove forest dominates the land surface. Then the land mass becomes ready for human settlement. Tidal range in the estuary varies from micro to macro and thus the time required for land development from its initial emergence to its inhabitation also varies from place to place, **Figure 12**.

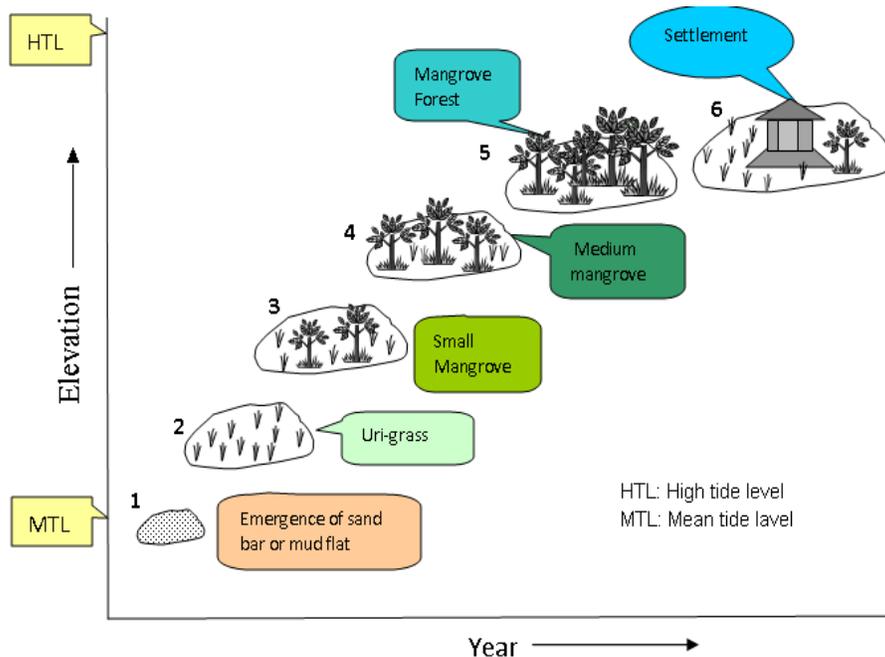


Figure 12: The process of land formation in the Meghna Estuary

From satellite image analysis, the fastest land development observed in the Shahbajpur Channel is 8 years, whereas in some parts of the Tetulia Channel, it was found to be 25 years. The average time required for land development at different locations is shown in Table 2, with the mean tidal range of the location concerned. It is found that the time required for land development is not dependent on the tidal range, although higher tidal range demands higher amount of sediment for the same magnitude of land development. The land development process is relatively rapid where both riverine and marine processes are active, although sediment availability is an important factor. The Tetulia Channel at its outfall is dominated by a marine process and the time required for land development is the highest compared to other locations. But the situation is different in Urir Char where

marine dominated processes also prevail. Very active tidal circulation and sediment pumping processes ensure the availability of sediment for land formation in the south of the Noakhali and Urir Char area.

Table 2: Time required for land development at different locations in the Meghna Estuary

Locations	Dominated process	Mean tidal range (m)	Time required for land development (year)
Outfall of Tetulia Channel	Marine	2	22
Shahbajpur Channel	Mixed energy	2	12
South of Noakhali	Mixed energy	3	12
Urir Char	Marine	6	16

11. Future developments

As indicated in the MES reports, the coastline of the Noakhali mainland area has extended to the south while the shoreline of the islands around Manpura and Hatia have extended in a southeast direction. The main islands of Manpura and Hatia were predicted to shift to the southeast, but a huge land mass has been developed at the north of these two islands. The net accretion rate in this area is more or less similar. The eastern part of the two islands in the Shahbajpur channel has been eroding in last few decades. In last decade, erosion occurred along the border of the Noakhali district, whereas accretion occurred in the Jahajer Char and Char Nuru area. Without protection measures along these islands, the land mass accretion may not sustain or may become vulnerable to erosion. The erosion trend along the north east boundary of the Bhola shows that this coast is very much vulnerable to erosion in coming years unless erosion protection measures are taken. Very few changes have been found along the Tetulia River. The long term morphological trend around Sandwip-Urir Char indicates to be accreted. The Sandwip Channel is silting up, although the rate is relatively low. MES and EDP studies reported that the rate of land formation in the Meghna Estuary is less than the huge volume of sediment coming to the system through GBM Rivers. A substantial amount of sediment is assumed to be accreted in the deeper part of the delta and Bay of Bengal.

From researches, it is found that there are obvious relation between the sediment concentration and the saline water. River discharge as well as water level has seasonal variation and so the zone of the salt concentration in the estuary varies. In addition, the changes of salt content increases with the increasing distance from the river discharge. The tidal range increases significantly from west to east, representing its energy decreasing from west to east. The most easterly chars (Urir Char, Sandwip) are subjected to relative high current velocities and wave heights and higher salt and sediment concentrations. The age of the chars and tidal flats located on the eastern part of the estuary are younger than the chars located in the west. Based on the understanding of the morphological processes of the Meghna Estuary, MES suggested to build 21 cross dams to exaggerate the natural sedimentation process; as shown in **Figure 13**.

Out of those 21 proposed cross dams (**Table 3**), two dams have already been constructed. MES study found that around Char Montaj and Nijhum Dwip, the process of sedimentation dominates and the prospects for new land reclamation are favourable. So, the Government has given priority to construct two cross dams in between Char Rutsom and Char Montaj (during 2011-12) and Banglar Char and Char Montaj (during 2013-14). The construction periods have been mentioned based on satellite image analysis.

Meghna Estuary under Bangladesh Delta Plan

Some large scale and comprehensive developments in the coastal zone are heavily debated in Bangladesh. Bangladesh Delta Plan primarily deals with water aspects, and as such these developments and decision-making, mostly driven by economic growth, is not strictly part of the Delta Plan. However, these developments should be supported by the interventions suggested in the Delta Plan.

During the Delta Plan formulation, a large scale land reclamation program in the Meghna Estuary was suggested. Accelerating the natural accretion processes with cross dams and other infrastructure in the highly dynamic environment, may offer a large piece of newly gained land, free to be developed in the preferred way. The Delta Plan advises to start a full-fledged (pre-) feasibility study to investigate the environmental, institutional and financial feasibility. For a short term measures (2021), BDP recommends to continue the Char Development and Settlement Project (CDSP). For medium term (2030-2050), BDP suggests to distinguish between the aspects *Infrastructure*, *institutions* and *Innovation*. Infrastructure measures focus mostly on hard physical interventions; *Institutional* measures consist of mostly soft measures related to water management organisation, legislation, finance and capacity building. Last but not least, *Innovation* measures focus on addressing the knowledge gap and stimulating technological development.

Besides, deep investigations into the sediment budget of the estuary, the technical suggestion should include ample attention for mitigation or adaptation to wind and storm surge hazard – and probably needs cyclone-robust developments and high elevated platforms (> 10m), freshwater availability issues (drinking water supply) and the impacts on the sediment balance in the Meghna Estuary. When this program would be commenced, it should focus on direct development of high added-value economic activities and circumvent the traditional approach (e.g. CDSP) to enable poor farmers/fishermen to explore the possibilities. Such a costly investment in a dynamic system, is only justified with large economic growth in mind. To minimize resettlement cost (as well as its primary advantage over other areas in Bangladesh) the area needs to be developed directly from the start as a large special economic zone. In contrast, when the feasibility study concludes, if Bangladesh is not yet ready for such a program, short-term 'stepping stones' projects where small-scale improvement of living conditions and the location of islands are secured in the Bay of Bengal in order to be supportive to the large scale program should be considered.

The Meghna Deltaic Plain is morphologically very active and land accretion exceeds erosion. On average, 17km² per year is accreted. Most of the islands are vulnerable to cyclonic storm surges and erosion. The newly accreted areas are initially too low and vulnerable for human settlement and agricultural use. Population pressure and urgent need for land is nevertheless, leading people to settle on these recent deposits, and sometimes people demand to empower them before the natural deposition process has built them high enough for adequate drainage. The north-east and east side of Bhola island, north and west side of Hatia, west side of Manpura, and west side of Sandwip islands have been experiencing severe erosion. This erosion is mostly caused by thalweg migration in the lower Meghna and its branches, namely the Shahbazpur and Hatia channels. Some of the mainland areas on the east of the Meghna estuary such as Ramgati and Carring char are also subject to erosion due to thalweg migration which is undermining and outflanking polder embankments on the left bank of the Meghna and on both the right and left banks of the Feni river. Some areas are also increasingly subject to prolonged water-logging due to encroachment and land reclamation by closing the tidal channels. River floods are severe in some parts of the mainland, especially in the districts of Chandpur, Lakshmipur, Noakhali and Feni. After 2050, depending on the prevailing situation (high climate, high economic development etc), the government can choose for further continuation of the strategy or may decide to invest in large storm-surge barriers or cyclonic storm surge proof (climate resilient) embankments in the south-eastern river mouths (e.g. narrower rivers Baleswar, Tetulia, etc).

Opportunities in the coastal zone: The coastal zone also offer a lot of opportunities, among others, include land reclamation, particularly in the Meghna Estuary. The coastal zone is traditionally used for agricultural cropping, fisheries and forestry; nowadays aquaculture, as shrimp and crab farming is growing in Khulna, Bagerhat and Cox’s Bazar districts. Specific regional economic activities, like ship breaking and recycling and salt production mainly occurs on the Chittagong and Cox’s Bazar floodplain. Recently, salt production is also explored in Noakhali, Barisal, Khulna and Sathkira districts. There is an offshore potential for gas mining, as well as renewable energy exploration, for example tidal and wind energy. Nature and tourism (or recreation) is more and more valued, as well as some large urban areas have been developed as well.

By 2100, the coastline of Bangladesh would be totally different from what it used to be. Building further on the successes of different land reclamation projects of the past, the government may choose to fully exploit the potential of the area, by accelerating natural sedimentation processes, through developing cross dams and other physical and biological interventions in the Meghna Estuary at strategic locations. In 2050, the first phase of huge land reclamation projects comes to an end. After 2050, enough sediment is still coming down the estuary (this estimation is possible due to improved monitoring sites and modelling capability), the government may decide to continue and increase the land surface substantially up to 2100, leading to the development of a new coastline.



Figure 13: Locations of the cross dams in the Meghna estuary as proposed by the MES study

Table 3: Locations of cross dams in the Meghna estuary as proposed by MES study

Proposed cross dam			
ID	Name	ID	Name
1	Hatia-Nijhum Dwip	12	Bara Baisda-Char Halim
2	Hatia-Damar Char	13	Char Halim-Choto Baisda
3	Hatia-Moulavir Char-Dhal Char-Char Parvez	14	Rangabali-Choto Baisda
4	Sandwip-Urir Char-Noakhali	15	Choto Baisda-Char Biswas
4	Sandwip-Urir Char-Noakhali	16	Char Kajal-Char Biswas
5	Char Rustam-Char Haldor	17	Char Kajal (Shibar Char)-North Char
6	Char Haldor-Char Burhan	18	North Char (Char Nilkamal)-Kasher Char
7	Char Burhan-Bhola	19	Rangabali-Char Kashem
8	Char Kukri Mukri-Char Alcha	Completed cross dam	
9	Char Montaz-Char Tapashi	A	Char Rustam-Char Montaz (2011-12)
10	Char Montaz- Andarchar	B	Banglar Char-Char Montaz (2013-14)
11	Bhola-Kukri Mukri		

12. Immediate future expectations of land reclamations

There is a scope to reclaim land from the 710 km long Bangladesh coast. LRP's study (1987) on the Sandwip-Urir Char-Noakhali Cross Dam mentioned that the cross dam may reclaim new land of about 18,000 ha (above + 2.2 mPwD) in 15 years and another 18,000 ha land in next 15 years. This huge land mass would benefit more than 180,000 people directly. BWDB Task Force Report (2003) as well as Mater Plan (1998) and Development Plan (1998) of MES recommended construction of the Sandwip-Urir Char-Noakhali Cross Dam as a priority project that is commensurate with all the related national policies and plans.

Presently, the channels between Sandwip and Noakhali are gradually being silted up and shrinking in width and depth as a continuous natural process. The present ground levels (above mean sea level) of Urir Char Island are between 4 and 5 m (due to tidal amplification) whereas those of Noakhali coast varies between 3 and 4 m. MES's (1998) anticipation of natural building up of a connection between Sandwip and Noakhali mainland seems to be true now a days.

The purpose of the Sandwip-Urir Char-Noakhali Cross Dam Project is to closing of channels between Sandwip-Urir Char and Urir Char-Noakhali. The sites of the closure dams have been selected at the meeting places of tides coming from both sides. Presently, a substantial amount of channel dries up during winter neap tides. The cross dam is expected to raise lands of more than 360 sq km within 30 years and would join island of Sandwip, Urir Char and others with Noakhali mainland. These cross dams would not hamper this region considerably.

13. Investment Plan

A Master Plan (1998) and a Development Plan (2001) were prepared by MES for 25 year rolling programme and five to ten year time horizon respectively. The aim of those plans was to draw up a phased management and intervention strategy for the long term development of the Meghna Estuary. Several structural and non-structural measures, like mangrove planting, settling basins and cross dams, were proposed in three planning zones for enhancing the accretion process. Structural interventions were proposed for those locations where hydro-morphological changes were stable and predictable. An attempt has been taken to check if those interventions

in the Meghna Estuary proposed by the MES are still valid. Mainly satellite images of different years from CEGIS archive have been used for this analysis.

Those locations for dams were proposed mainly based on localised sedimentation trend. After comparing satellite images of 2001 and 2015, it is observed that the locations are still accreting even without building any cross dam. This indicates that the prediction of the Master Plan and Development Plan were reasonable except one location at Hatia-Moulavir Char-Dhal Char-Char Parvez. This proposed cross dam seems to be unsustainable, as long term trend of this location is prone to erosion. This proposed dam would be sustainable if additional measures are taken, like bank protection of the islands.

Another exercise has been done for prioritizing the cross dam. The prioritization or sequence of building cross dams could follow from internal (within the small islands) to external (exposed to the sea) sides. Apparently it is believed that connecting small islands may reclaim land quickly, but detailed feasibility study is required for any type of coastal development or improvement. If there were detailed data and information (like- residual tides, sediment movement, sediment concentration, etc) available, that could help to prioritize building cross dams. But few criteria can be set for prioritizing the list. Connecting two mangrove forests by cross-dam may not be economically viable. We have to give emphasis on how many people will be benefitted from the construction, how much useable land can be reclaimed for economic purposes. Another criterion could be at which location the works are easily implementable. Above all, accretion should be the governing process in the location. In this regard, cross dams at Sandwip-Urir Char-Noakhali and Hatia-Moulavir Char-Dhal Char-Char Parvez may not be feasible, because the land formation pattern is not stable. In few locations, some cross dams have been developed by the local people for fisheries, like Bara Baisda-Char Halim. Cross dam at Hatia-Damar Char may not also be sustainable due to its rapid changing pattern, although accretion is the governing process in this location.

An analysis has been conducted and given in **Table 4** below for prioritizing the cross dam locations (proposed by MES). Each cross dam has been judged in terms of three indicators: people benefitted, easily Implementable and accretion prone location. Qualitative scores are assigned in terms of +ve /0/-ve, where +ve indicates good impact, -ve indicates bad impact, and zero indicates negligible or almost no impact. Then a prioritization has been done, where '+++' sign indicates priority 1 and '---' sign indicates lowest priority, as shown in Table 4 and **Table 5**.

Table 4: Analysis for prioritizing the cross dam locations

ID	Name	People benefitted	Easily Implementable	Accretion prone location	Scores
1	Hatia-Nijhum Dwip	+	-	+	++-
2	Hatia-Damar Char	-	+	+	++-
3	Hatia-Moulavir Char-Dhal Char-Char Parvez	-	-	-	---
4	Sandwip-Urir Char-Noakhali	+	-	+	++-
5	Char Rustam-Char Haldor	+	+	+	+++
6	Char Haldor-Char Burhan	-	+	0	0
7	Char Burhan-Bhola	0	+	+	++
8	Char Kukri Mukri-Char Alcha	0	+	+	++
9	Char Montaz-Char Tapashi	0	-	0	-
10	Char Montaz- Andarchar	+	-	0	+-
11	Bhola-Kukri Mukri	+	-	+	++-

ID	Name	People benefitted	Easily Implementable	Accretion prone location	Scores
12	Bara Baisda-Char Halim	Implemented			
13	Char Halim-Choto Baisda	+	+	+	+++
14	Rangabali-Choto Baisda	Implemented			
15	Choto Baisda-Char Biswas	+	+	+	+++
16	Char Kajal-Char Biswas	Implemented			
17	Char Kajal (Shibar Char)-North Char	+	+	+	+++
18	North Char (Char Nilkamal)-Kasher Char	+	-	+	++-
19	Rangabali-Char Kashem	+	-	+	++-
20	Char Rustam-Char Montaz (2011-12)	Implemented			
21	Banglar Char-Char Montaz (2013-14)	Implemented			

Table 5: Prioritized cross dam locations

ID according to Table 3	Name	Priority after analysis
5	Char Rustam-Char Haldor	1
13	Char Halim-Choto Baisda	
15	Choto Baisda-Char Biswas	
17	Char Kajal (Shibar Char)-North Char	
7	Char Burhan-Bhola	2
8	Char Kukri Mukri-Char Alcha	
1	Hatia-Nijhum Dwip	3
2	Hatia-Damar Char	
4	Sandwip-Urir Char-Noakhali	
11	Bhola-Kukri Mukri	
18	North Char (Char Nilkamal)-Kasher Char	
19	Rangabali-Char Kashem	4
6	Char Haldor-Char Burhan	
10	Char Montaz- Andarchar	
9	Char Montaz-Char Tapashi	5
3	Hatia-Moulavir Char-Dhal Char-Char Parvez	6

From the prioritized Table 4, it is found that Char Rustam-Char Haldor, Char Halim-Choto Baisda, Choto Baisda-Char Biswas, and Char Kajal (Shibar Char)-North Char are the top four cross dams that can be implemented as a priority basis. On the other hand, cross dam at Hatia-Moulavir Char-Dhal Char-Char Parvez has the lowest priority. However, detailed investigation is required in this regard.

14. Conclusion

The Meghna Estuary is the present active estuary of the GBM system, where delta is prograding vertically and horizontally towards the sea. For the dynamic behaviour of the estuary morphology through development and abandonment, huge land are is accreting and eroding every year. So, an attempt was made to understand the

development criteria of the Meghna estuary and to find out some investment plan to add few lands with the existing area of Bangladesh.

This estuary area have undergone a lot of changes during the last 250 years starting from the avulsion of the Brahmaputra. In the early 20th century, the estuary was easterly aligned. However, in the last few decades, eastern Meghna branch of the Meghna estuary totally dried up and subsequently the western distributary, Shahbazpur channel became enlarged. From 1776 to 1943, the net accretion rate in the Meghna Estuary was about 5 km²/yr. The Assam earthquake of 1950 caused huge landslides in the Himalayas, which caused the net accretion of about 1100 km² (46 km²/yr) from 1943 to 1973. After the effect of the Assam earthquake diminished, the prevailing rate of net accretion in the estuary reached about 10 km²/yr.

These accreted lands have to undergo land formation process before it can be called as reclaimed land. This process can take several years some times over two decades. From satellite image analysis, the fastest land development observed in the Shahbazpur Channel is 8 years, whereas in some parts of the Tetulia Channel, it was found to be 25 years.

From all the analysis it has been found that there is some scope to reclaim land from the 710 km long Bangladesh coast. LRP's study (1987) on the Sandwip-Urir Char-Noakhali Cross Dam mentioned that the cross dam may reclaim new land of about 18,000 ha (above + 2.2 mPwD) in 15 years and another 18,000 ha land in next 15 years. This huge land mass would benefit more than 180,000 people directly.

A Master Plan (1998) and a Development Plan (2001) were prepared by MES for 25 year rolling programme and five to ten year time horizon respectively. Several structural and non-structural measures, like- mangrove planting, settling basins and cross dams, were proposed in three planning zones for enhancing the accretion process. An attempt has been taken to check if those proposed cross dams in the Meghna Estuary by the MES are still valid. It is observed that the locations are still accreting even without building any cross dam. This indicates that the prediction of the Master Plan and Development Plan were reasonable except one location at Hatia-Moulavir Char-Dhal Char-Char Parvez. It is found that, Char Rustam-Char Haldor, Char Halim-Choto Baisda, Choto Baisda-Char Biswas, and Char Kajal (Shibar Char)-North Char are the top four cross dams that can be implemented as a priority basis. On the other hand, cross dam at Hatia-Moulavir Char-Dhal -Char-Char Parvez has the lowest priority. However, detailed investigation is required in this regard.

15. References for Part B: Meghna Estuary Land Reclamation

Chowdhury, J.U. and Haque, A. (1988), *Numerical Simulation of Tides and Saline Water Intrusion in the Meghna Delta*, IFCRD, BUET, May 1988.

Coleman, J.A. (1969). *Brahmaputra River: channel processes and sedimentation*, *Sedimentary Geology*. 3, 129-239.

BDP 2100 Baseline Study Report: Water Resources

BDP 2100 Baseline Study Report: River Systems Management

Eysink, W. D. (1983) *Basic considerations on the morphology and land accretion potentials in the estuary of the Lower Meghna River*. LRP Technical Report no. 15. Land Reclamation Project, BWDB, Dhaka, Bangladesh.

Hussain, M.A., Hossain, M.A., and Haque A. (2009), *Seasonal Variation Of Residual Currents in the Meghna Estuary of Bangladesh*, *Coastal Dynamics 2009*, Paper No. 30.

- IWM (2010) *Updating of hydrodynamic & morphological models to investigate land accretion & erosion in the Estuary Development Program (EDP) Area, Draft Final Report. Prepared for Estuary Development Programme, BWDB, Dhaka, Bangladesh.*
- MES II (2001) *Hydro-morphological dynamics of the Meghna Estuary, Meghna Estuary Study (MESII). Prepared for BWDB, Dhaka, Bangladesh.*
- Mirza, M. M. Q., Warrick, R. A., Ericksen, N. J. & Kenny, G. J. (2001) *Are floods getting worse in the Ganges, Brahmaputra and Meghna basins? Environmental Hazards 3, 37–48.*
- Sarker, M. H. (2009) *Morphological response of the Brahmaputra-Jamuna-Padma-Lower Meghna River to the Assam earthquake of 1950, PhD thesis, University of Nottingham, UK.*
- Sarker, M. H. & Thorne, C. R., (2006) *Morphological response of the Brahmaputra-Padma-Lower Meghna river system to the Assam Earthquake of 1950, In: Braided Rivers: Process, Deposits, Ecology and Management (ed. by G. H. S. Smith, J. L. Best, C. S. Bristow, & G. E. Petts), 289–310. Special Publication 36 of the IAS, Blackwell Publishing, UK.*
- Sokolewicz, M & Louters, T. (2007) *Hydro-morphological processes in the Meghna Estuary, Bangladesh. In: Proc. International Conf. on Water and Flood and Management (Dhaka, Bangladesh), 327–334.*
- Survey and Study Support Unit (SSSU) (2002) *Considerations on Morphological Processes in the Meghna Estuary, Technical Note SSSU-6. Prepared for BWDB, Dhaka, Bangladesh, 01-36.*



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