MINISTRY OF WATER RESOURCES

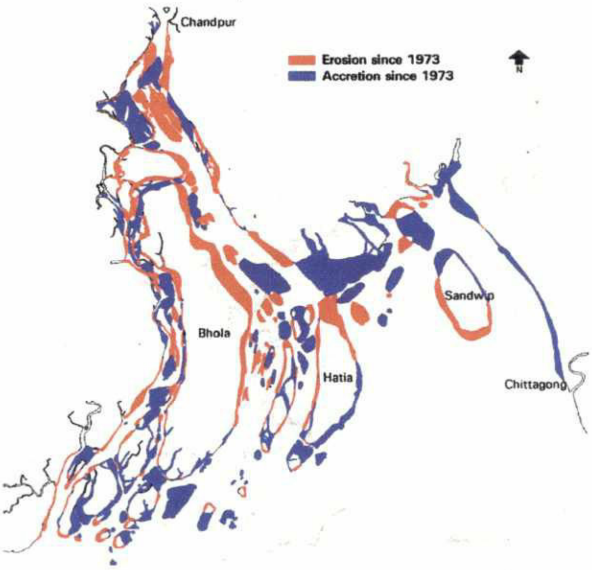
BANGLADESH WATER DEVELOPMENT BOARD

M E S II

Meghna Estuary Study

HYDRO-MORPHOLOGICAL DYNAMICS OF THE MEGHNA ESTUARY

Executive Summary



July 2001

GoB-MoWR
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DHV CONSULTANTS BV

in association with

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SURFACE WATER MODELLING CENTRE

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Executive Summary

of the report on

HYDRO-MORPHOLOGICAL DYNAMICS OF THE MEGHNA ESTUARY

July 2001

Project Name: **M E S II, Meghna Estuary Study**

Client: MINISTRY OF WATER RESOURCES
Bangladesh Water Development Board
Water Resources Planning Organisation

Financiers: Government of Bangladesh
Government of The Netherlands

Consultant: DHV Consultants BV, The Netherlands in cooperation with:
- DEVCON, Bangladesh
- Surface Water Modelling Centre, Bangladesh

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1. INTRODUCTION

The Meghna Estuary Studies (MES I and MES II) are supporting studies under FAP 5B of the Flood Action Plan. The area has been delineated in Figure 1. The project has been implemented under a co-operation programme between the Governments of Bangladesh, the Netherlands (MES I and II) and Denmark (MES I). The executing agency is the Bangladesh Water Development Board (BWDB). The co-ordination with other projects under the Flood Action Plan was maintained by the Flood Plan Co-ordination Organisation (FPCO), which evolved into WARPO during the process.

The main goals of the Meghna Estuary Studies (MES) are as follows:

- to gather hydrological and morphological data,
- to increase knowledge of the hydraulic and morphological processes in the Meghna estuary.
- to develop appropriate techniques for efficient land reclamation and effective erosion control, and
- to provide a Master Plan and a Development Plan for the estuarine area.

To enhance the knowledge of the complex morphological processes in the Meghna estuary, a morphological study has been carried out within the framework of MES I and II.

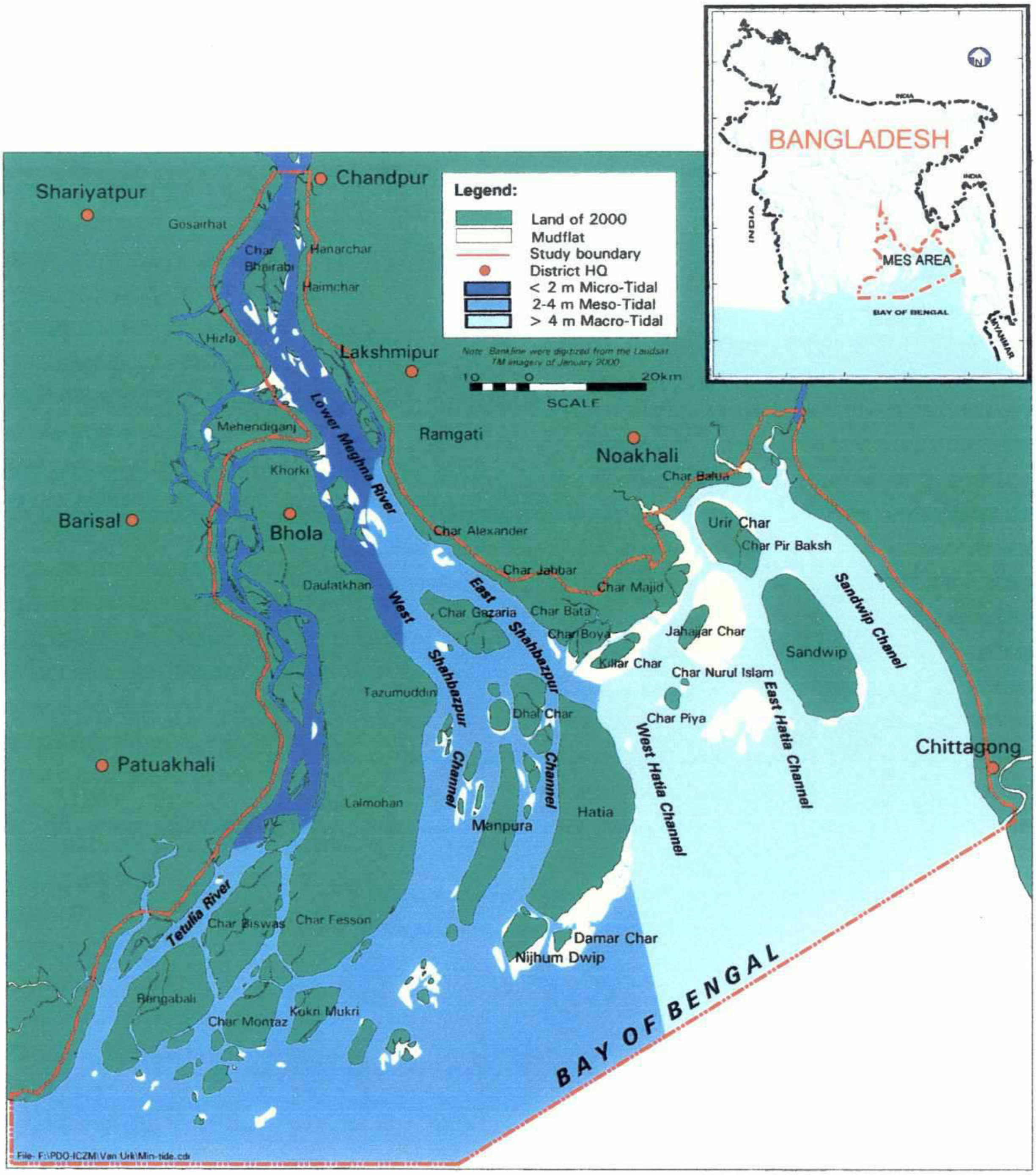
The main objectives of the present study are as follows:

- to improve the understanding of the estuarine and coastal morphological behaviour and hydro-morphological processes with the aid of remote sensing imageries, historical bathymetric maps and field data on the processes of geo-morphological development,
- to assess long-term changes in coastal morphology and to discern patterns and tendencies,
- to improve the knowledge and understanding of land formation and char development.

The results of the study are based upon analyses of remote sensing imageries, bathymetric data and historical coastline maps, and field surveys and numerical modelling. Hydraulic and morphological conditions and processes that shape the estuary have been studied with regional and detailed local 2D-numerical models. Simulations for characteristic flow and tidal conditions (monsoon and dry period, full tidal cycle) were used to determine the behaviour of the entire estuary system. Based upon the findings of the field data and numerical model simulations, hypotheses are formulated on the dominant hydraulic and morphological processes underlying these changes.

An very indicative prediction of land formation and char development in the Meghna Estuary system for a time scale of 15-30 years is given based upon an extrapolation of present trends and on the knowledge and understanding of the dominant hydrodynamic and morphological processes.

Figure 1 Meghna Estuary Study area and mean tidal range



2 HYDRAULIC AND MORPHOLOGIC CHARACTERISTICS

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. The average annual sediment load of Lower Meghna amounts to more than a billion tons and consists mainly of silts and fine sand. The river discharge varies between approximately 10,000 m^3/s during dry-season to more than 100,000 m^3/s during monsoon. Erosion and accretion rates are high and the area is periodically subject to severe storms and cyclones, these latter accompanied by tidal bores and storm surges.

The changes in tidal flow direction and channel topography, the appearance of new channels and newly accreted land and quitting of old courses are the rapid building and destroying processes that shape the estuary. These processes trigger changes in sedimentation and erosion rates, which are directly related to the change in discharge and sediment content. The study area is characterised by extensive shallow (mud)flats, numerous small and vast islands (e.g. Hatia, Bhola and Sandwip) and chars. The major distributary system of the Lower Meghna includes the Tetulia River, the Shahbazpur and the Hatia channels. The total study area is approximately 11,210 km^2, out of which 61.5 % is water, 29.6 % is land and 8.9 % are mud flats.

Tides

The tide along the coast of Bangladesh is of semi-diurnal type. The area around Sandwip island is macro-tidal with variation in tidal range of about 3 to 6 m (Figure 1). The area between Bhola and Hatia (Shabhazpur Channel) is meso-tidal, with tidal range of 2 to 4 m. Tetulia River and the upper reach of the Lower Meghna upstream of Char Gazaria are micro-tidal, with tidal range less than 2 m. The maximum current velocities in the study area vary from approximately 0.1-4 m/s in the tidal channels to about 0.2 - 0.5 m/s in the shallow areas.

Water Level

The mean water level shows a marked seasonal variation along the Bangladesh coast. The seasonal variation of the mean high water level (from dry to the wet season) decreases significantly along the Lower Meghna Estuary in southwards directions. The seasonal variation of the mean high water level at Chandpur is about 2.7 m. The variation in the southern part of the Bangladesh coast is about 0.7 to 1.7 m. The mean water level increases during the monsoon due to increased fresh water flow in the Lower Meghna and due to low air pressure, causing an increase of the mean water level in the Bay of Bengal with more than half a meter.

Wind and cyclones

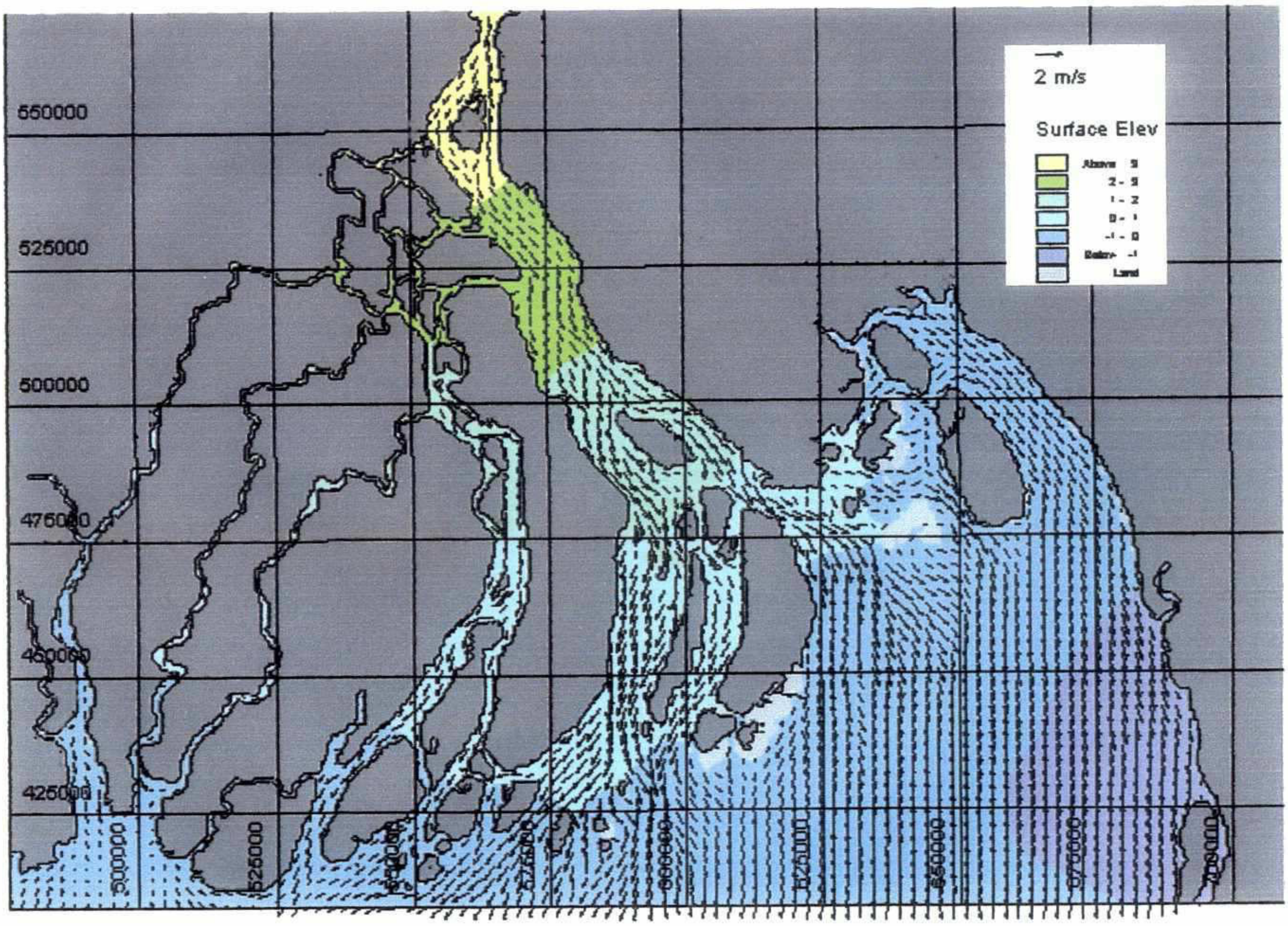
The wind regime along the Bay of Bengal shows a typically seasonal variation between the dry season (November-March) and the monsoon season (June-September). During the dry season the prevailing winds are calm and offshore. The prevailing winds during the monsoon season are from the S-SE direction, with an average velocity of about 8-12 m/s. During severe storms and cyclones, very high wind velocities can occur. The highest wind speed, reported during the April 1991 cyclone is 225 km/h. Most cyclones occur during April-May and October-November, which are the transitional periods between the dry season and the monsoon season.

Waves

No wave heights have been recorded during severe storms until now. Wave models indicate, that under the prevailing S-SE winds (with a average wind speed of about 8 m/s), the average significant wave height varies between 0.6-1.5 m in the near-shore zone to 0.1-0.6 m in the landward part of the project area. In the dry season the waves are generally less than 0.6 m with peak periods of 3 - 4 seconds. During the monsoon season wave heights can exceed 2 m with periods greater than 6 seconds.

Higher waves occur mainly in the pre and post monsoon periods during cyclones. Under these conditions, waves higher than 5 m can be expected in the outer part of the estuary. Wave measurements over the period December '96 - March '97 indicate that the wave heights in the landward part of the project area do not exceed 0.4 m due to the moderate wind conditions.

Figure 2 Simulated flow pattern during monsoon period



Flow features

The flow distribution in the Meghna Estuary is determined by the combined action of tides and fresh water flow. Figure 2 shows the surface elevation and velocity distribution during spring tide (ebbing) in monsoon. The flow in the western part (upper and mid-estuary, Tetulia and the Shabhazpur Channel) is dominated by the fresh water flow from the Lower Meghna. The eastern part of the estuary is mainly influenced by the tide and much less by the fresh water flow from the river system. Most of the fresh water discharge is conveyed to the Bay of Bengal through the Shabhazpur Channel, while the Hatia Channel is mainly a tidal channel. A prominent counter-clockwise residual circulation is present around Sandwip. The water flow is generally very strong and turbulent. Current velocities up to 4 m/s have been observed in the Sandwip Channel during spring tide and in the upper reach of the Lower Meghna during high monsoon.

Salinity

Salinity distribution in the estuary is strongly influenced by the seasonal changes in the fresh water discharge from the Lower Meghna River. During monsoon, the salinity in the estuary drops considerably and the water becomes almost completely fresh. After the monsoon, the salinity rises again and the seawater intrudes into the estuary. However, even during the period with low river discharges the salinity in the area never approaches normal seawater salinity (34 g/l) but always remains distinctly lower. Penetration of saline water during dry period stops north of Char Gazaria, where salinities less than 1 g/l are found.

Sediment Characteristics

The bed of the Lower Meghna River consists of silt and fine sand with a median bed material grain size varying from 0.016 mm to 0.200 mm. The bed material size varies in both the transverse and downstream direction of the river. A major part of the bed-material (70%) has a median grain size less than 75 μm.
The maximum depth average sediment concentration varies between 0.5 and 9 g/l. During spring tide the concentration is about 2-5 times higher than during neap tide. Highest sediment concentrations have been found in the areas Urir Char-Char Balua and Manpura-North Hatia.

Sediment transport

The average total annual sediment discharge of the Jamuna and Ganges over the period 1966-1991 is about 1,100 million t/y. The sediment discharge of the Upper Meghna is negligible compared to the discharge of the Jamuna and Ganges. 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 periods of high river borne sediment discharge (monsoon), the net gain of land and inter-tidal areas is the highest in the year.

Sediment budget

Approximately overall sediment budget in the study area over the period 1997-2000 indicates that the deposition processes exceed the erosion processes. Net accretion during this 3-year period amounts to approximately 300 million m^3. However, the net change in the sedimentation volume is small (about 6%) compared to the total accretion and erosion volumes. Erosion dominates in the northern part of the river system. Erosion of the channel bed in the Lower Meghna from Chandpur down to the northern head of Hatia is about[1] 0.1 - 0.2 m/yr. High rate of accretion (approximately 0.2 m/y) is found in the northeast of the estuary, between Noakhali mainland, Urir Char and Sandwip. In addition, the area between Bhola and Hatia, and the south-west end of the estuary are accreting, with an accretion rate of 0 - 0.1 m/y. In other areas in the estuary, erosive and depositing processes are more or less in balance.
Compared to the volume of sediment transported through the estuary, only a small portion (max. about 10%) is being deposited in the estuary.

Transition from Braided River to Tide-Dominated Morphology

The Upper Tetulia River and Lower Meghna River between Chandpur and North-Bhola show the morphology of a braided river type. The area around Char Gazaria forms a transitional zone between the braided river dominated morphology and the southern area, which has more a micro and meso tidal character. The Lower Shahbazpur channel and Hatia channel as well as the Lower Tetulia River show linear tidal ridges and islands, indicating reworking of sediments by tidal currents. The eastern part of the estuary has a distinctly macro-tidal character (see also Figure 1).
The Meghna Estuary system has a funnel shape. The river influence becomes progressively larger in stream upward direction as friction drains tidal energy. Tidal influence extends substantially farther upstream than salt intrusion. There is an appreciable upstream transport of bed-load and suspended load sediment as a result of deformation of tide propagation. Sediment is received from both the river and from Bay of Bengal, yet most of the sediment received by the river ends up being transported and deposited by tidal currents.

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[1] Presented net erosion and net accretion rates are calculated over very large areas. Locally, much larger changes occur.

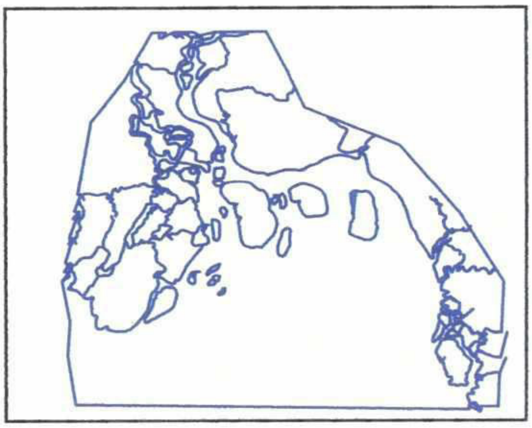
3 MORPHOLOGICAL DEVELOPMENT

Morphological changes during the last century

Comparison of a present shape of the Meghna Estuary with the map prepared by James Rennell in 1779 (Figure 3) shows that net gain of land area is about 2,200 km^2, i.e. approximately 10 km^2 per year as an average rate of land area increase over the last 220 years. Rennell's map of 1779 indicates a completely changed system of channels and river courses but a more or less stable coastline west of the Tetulia River. East of the Tetulia River, however, a general tendency of seaward growth of the coastline can be recognised, particularly in the region Bhola island- Hatia island and in the Noahkali district. Although the overall process of accretion is dominant, areas of erosion can be recognised, particularly on the riverbanks in the north-western part of study area (North Bhola-Chandpur), on Sandwip and the mainland of Chittagong.

Figure 3 Meghna Estuary (a) Anno 1999; and (b) Anno 1776 (after J. Rennel)

3(a)



3(b)

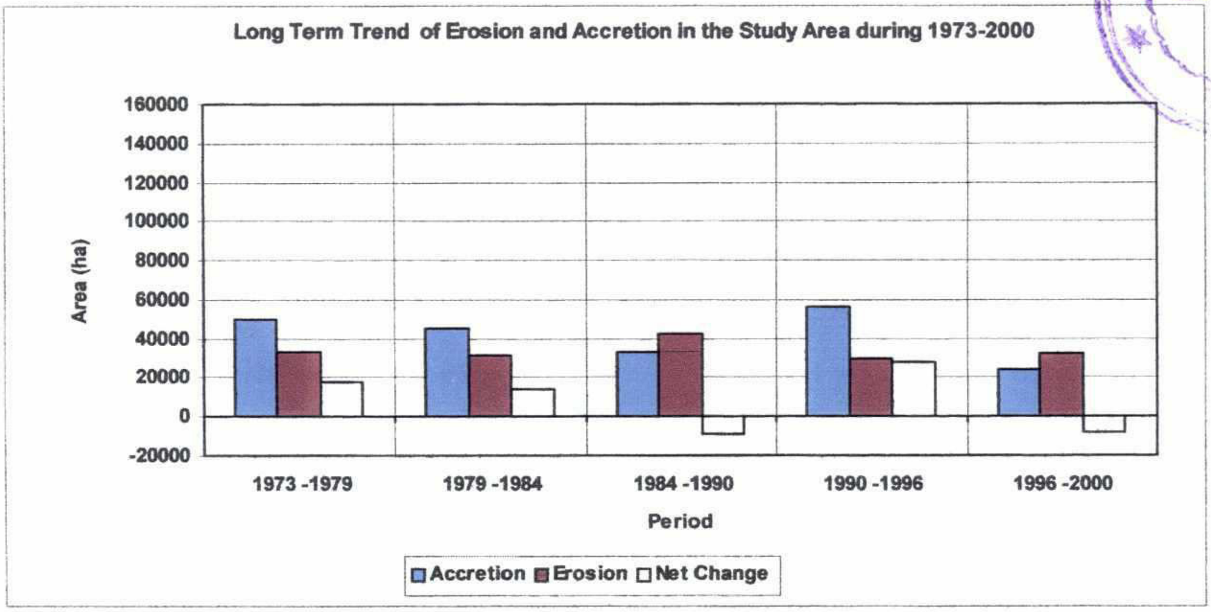
Morphological changes during the last decades

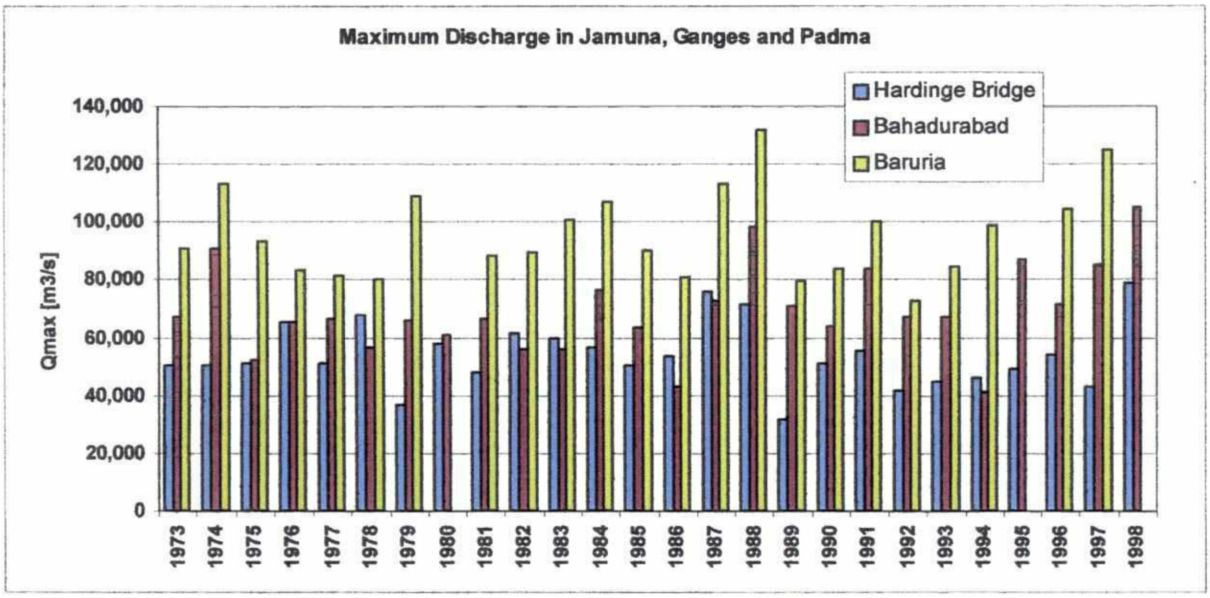
<u>Gain of Land</u>

The net change by period shows an overall land gain in the Meghna estuary system as a whole, for the period 1973-2000 of about 50,800 ha. The net change over the considered period shows that generally gain of land took place, with exception of two periods: 1984-1990 and 1996-2000, when a net loss of land is found.

The annual change for the entire study period ranged from a loss of over 2,100 ha/y during 1996-2000 period to a gain of over 4,500 ha/y during the period 1990 to 1996. The average annual gain for the entire study period is 1,900 ha/y. There is a clear relation between the magnitude of the high discharges in the estuary and the net change of land (Figure 4). Periods of net loss of land coincide with occurrence of very high monsoon discharges (1986, 1988, 1996, 1998), while gain of land coincides with the periods of lower monsoon discharges in the river system.

Figure 4 (a) Accretion and Erosion in selected period during 1973-2000
(b) Maximum discharge in Jamuna, Ganges and Padma (SWMC, 2001)





<u>*Areas dominated by natural accretion*</u>

In the period 1973 to 2000 a vast area of new land emerged off the southern coast of Noahkali, which is associated with an even larger area of mud flats, which appears to be emerging land. A distinct sedimentation trend can be observed around the southern coast of Noahkali over the last decades. There are new char areas and new areas of mudflat north-west of Sandwip island. Other large areas of accretion include the very extended char at the head of Shahbazpur Channel, which appears to be consolidation and extension of Char Gazaria, the

extensive area north of the Tetulia off-take, and the filling and enlargement of the chars in the extreme south-west of the study area, including Char Rangabali, Char Biswas, Char Montaz and Char Kukri Mukri. New chars are forming in the northern extension of Manpura and in the West Shahbazpur Channel. There is a significant accretion at the northeast of Nijhum Dwip, extending this island towards Hatia. With respect to the large areas of accretion in the south-west part of the study area, it is seen that the major gain of land took place in the period 1984 to 1990 and 1993 to 1996. This might be explained by the extremely high river discharges carrying huge amounts of sediment load during 1988 and 1995.

Areas dominated by natural erosion

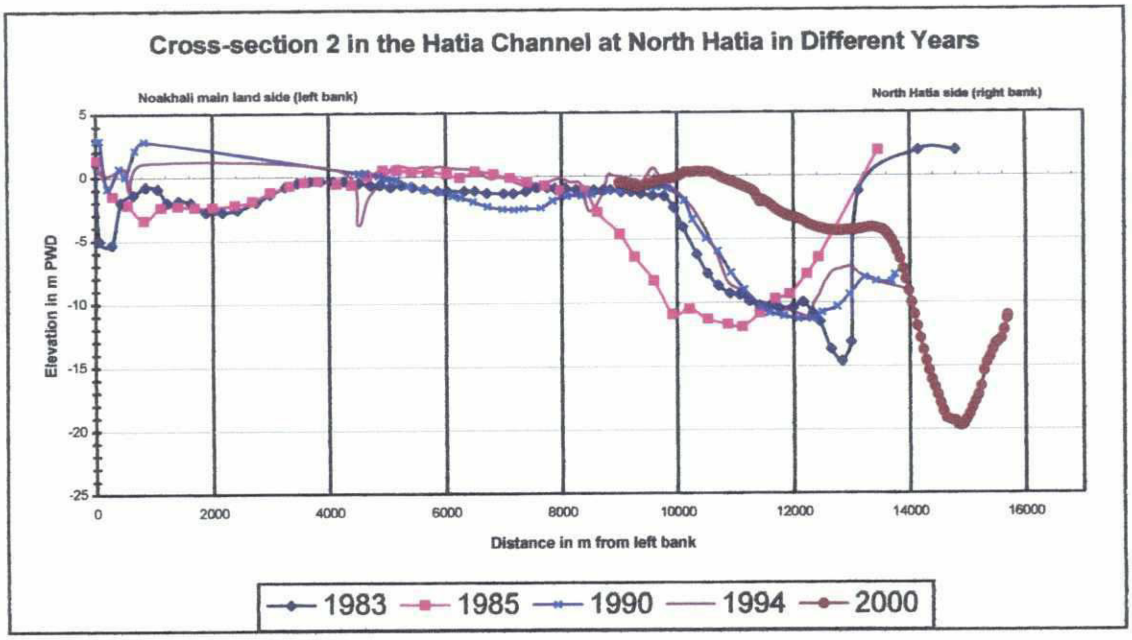
Most areas of erosion are associated with widening and migration of bank lines of the main Lower Meghna, Shahbazpur, Hatia and Sandwip Channels. The retreat of the west bank and east bank of the Lower Meghna varies from 50 m to more than 300 m/y. Other locations with erosion are shown in Figure 7. Largest erosion on the west bank is found at the level of Char Bhairabi near Gosairhat, and at the level of Char Gazaria north of Tazumuddin. Erosion of the east bank of the Lower Meghna around Haim Char is about to engulf the already retired embankment of the Chandpur Irrigation Project. Also the east bank near Char Alexander is severely eroded. The north and northeast banks of the Hatia and Bhola to downstream of Tazumuddin are affected by erosion. The entire north and west coast of the Hatia island is experiencing erosion except the extreme small south-west part located at the north of the entrance of the Nijhum Dwip channel from the Shahbazpur channel. Retreat of the northern head of Hatia is about 300 m/y. Southeast, south and the entire west coast of Sandwip are erosion-affected areas. The retreat of the west side of Sandwip is in the order of 10 to 100 m/y.

The natural development in the past as shown by the historical maps clearly indicates that most of the land gains and losses can be explained by the migration of main "conveyance" part of the channels, which is the part with the highest erosive forces. Migration of islands mainly results in the replacement of valuable old land by new land elsewhere in the course of time.

Channel Geometry

The West Hatia Channel at the tip of the Hatia Island undergoes dramatic changes. Once 15 km wide, it is now reduced to only 5 km (Figure 5). However, the cross-sectional area has remained more or less unchanged over last 18 years. A very deep (more than 20 m), narrow channel migrates towards the northern head of Hatia causing heavy erosion of the riverbank.

Figure 5 Changes to the shape of Hatia Channel at North Hatia



The cross-sectional area of the East-Shahbazpur channel between Char Gazaria and Noahkali mainland increased by 250% compared to 1990. However, the channel with the highest erosive forces (conveyance) became much narrower and deeper, and shifted close to the east bank. The cross-sectional area of the West-Shahbazpur Channel between Char Gazaria and Bhola shows a distinct trend to increase over the period 1981-2000. The main conveyance channel becomes deeper and migrates towards Bhola causing erosion of the riverbank. The observed trends and changes in the channel geometry might be the result of a long-term change of the major distributary system of the Lower Meghna River. After the 1998 monsoon, a tendency of widening of the river can be observed, with large chars and shallows emerging in the mid-channel and deep channels moving towards the banks undermining their stability.

4 ACCRETION AND EROSION TRENDS AND EXPECTED DEVELOPMENT

Observed trends

Accretion and erosion has two aspects which are only partly interlinked:
- Accretion and erosion of dry land and chars what can be seen from the air or from satellite images
- Deepening and/ or shoaling of the channel system, which can result in erosion of dry land or formation of new land. This can only be seen with the help of bathymetric survey techniques.

The processes also depend on the extend of human interference. For example, if the land would be fully protected against erosion only the second process of deepening and shoaling remains. However, in the Meghna Estuary both processes are present as most riverbanks are unprotected.
The processes have been analysed as follows:

Accretion and erosion of land:

The dynamics of the estuary with major changes to the shoreline and the dry land due to erosion and accretion can be very well seen in Figure 6 and 7. In Figure 6, six satellite images covering the period 1973-2000 are presented. Figure shows the change to the shoreline over that period derived from the satellite images. It shows the dynamics and the significant changes clearly.

Deepening and/or shoaling of the channel system:

Comparison of the results of the bathymetric surveys from 1997 and 2000 shows that deposition processes in the study area exceed erosion processes. An overall sedimentation trend can be seen near the edge of the delta front where new island and inter-tidal area are formed and silted up. Furthermore, the following can be observed:
- The largest erosion is found in the upper reach of the estuary, in the Lower Meghna between Chandpur and Char Gazaria. There, the river widens, chars appear in the middle river section. The main flow in these areas is deflected towards the banks, which suffer severe erosion, as the deep channels tend to move very close to bank.
- Alternate erosion and sedimentation patterns along the lower Meghna River, in particular in the area between Chandpur and north-Bhola, might indicate that the channel is very mobile and sensitive to variation in river discharges and tidal conditions. North Bhola faces dominant erosion.
- The morphological development of the Upper Tetulia River is relatively stable compared to that of the Meghna estuary.
- The East-Shahbazpur Channel is, compared to the West-Shahbazpur Channel, relatively stable and tends to silt up slowly. In both channels a tendency of silting up associated with development of deep channels along the bank can be seen.
- The same process is observed in the North-Hatia Channel, resulting in a dominant erosion trend of North-Hatia.
- The east side and southeast side of Hatia tend to silt up slowly.
- The Sandwip Channel remains quite stable. A slight tendency of silting up in the northern part and erosion in the southern part is observed.
- Sedimentation is dominant in the shallow areas around Nijhum Dwip and the area around Rangabali-Kukri Mukri.
- Excessive sedimentation and forming of mudflats and new land south of Noakhali mainland is observed.

In the recent years, an overall tendency of widening of the river system can be observed. This is associated with development of large chars in the middle of the main channels. The main river flow is pushed towards the riverbanks. The main "conveyance" channels, once located more in the midsection of the river, now are located very close to the banks. Migration and deepening of these channels causes severe erosion in many places in the river system.

Figure 6 Satellite images of the Meghna Estuary in the period 1973 – 2000

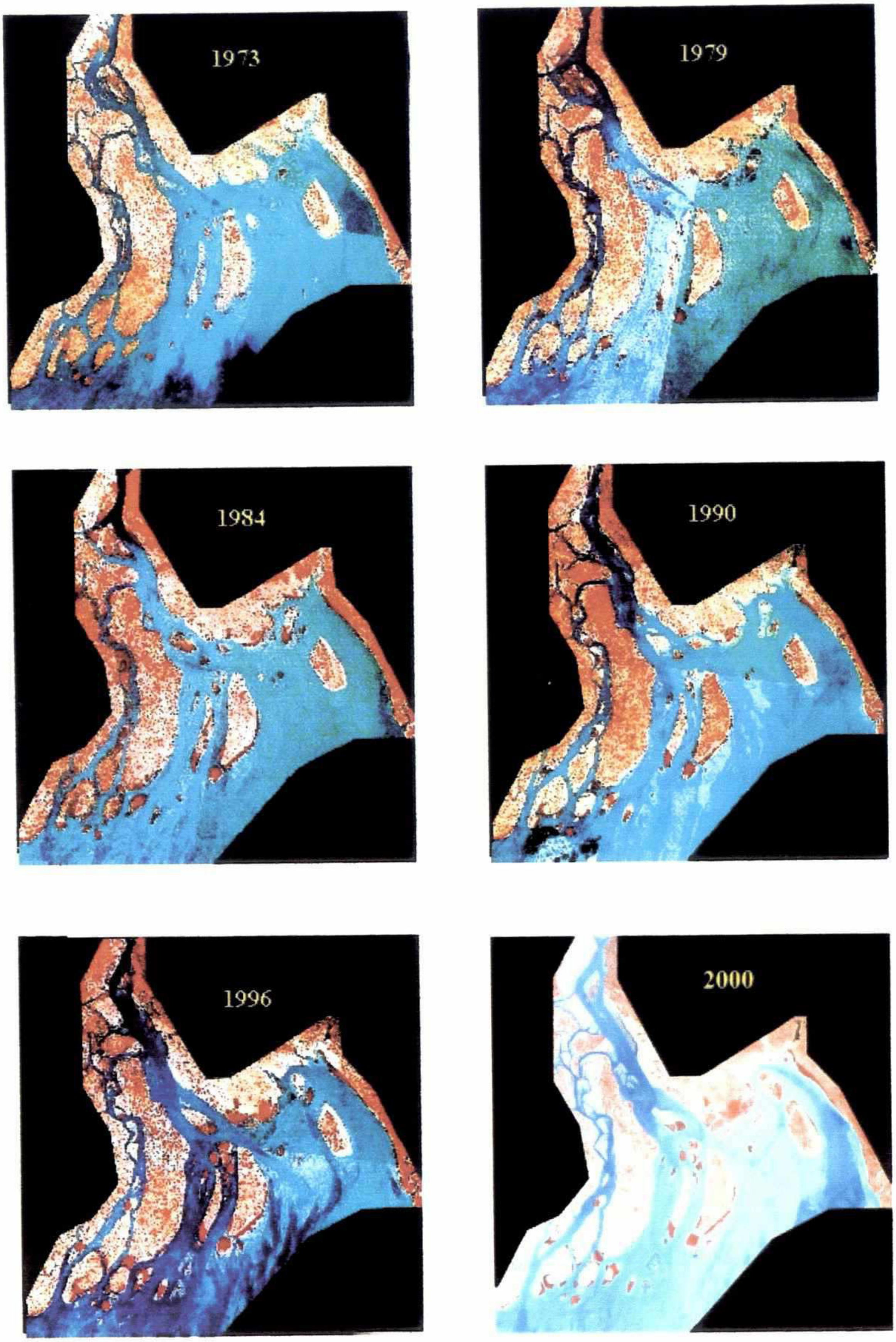
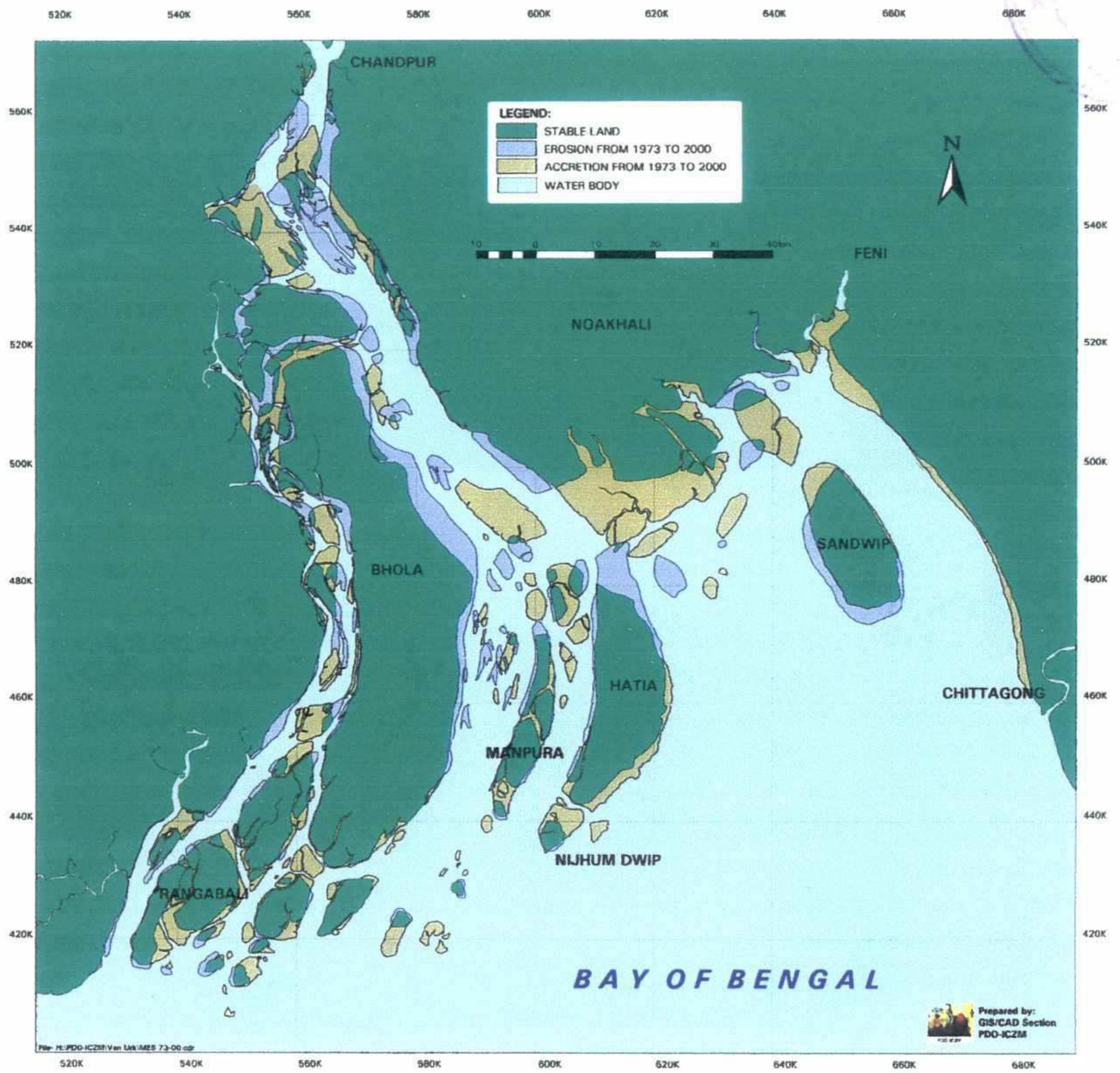


Figure 7 Changes of the shoreline in the period 1973-2000



Indicative morphological development

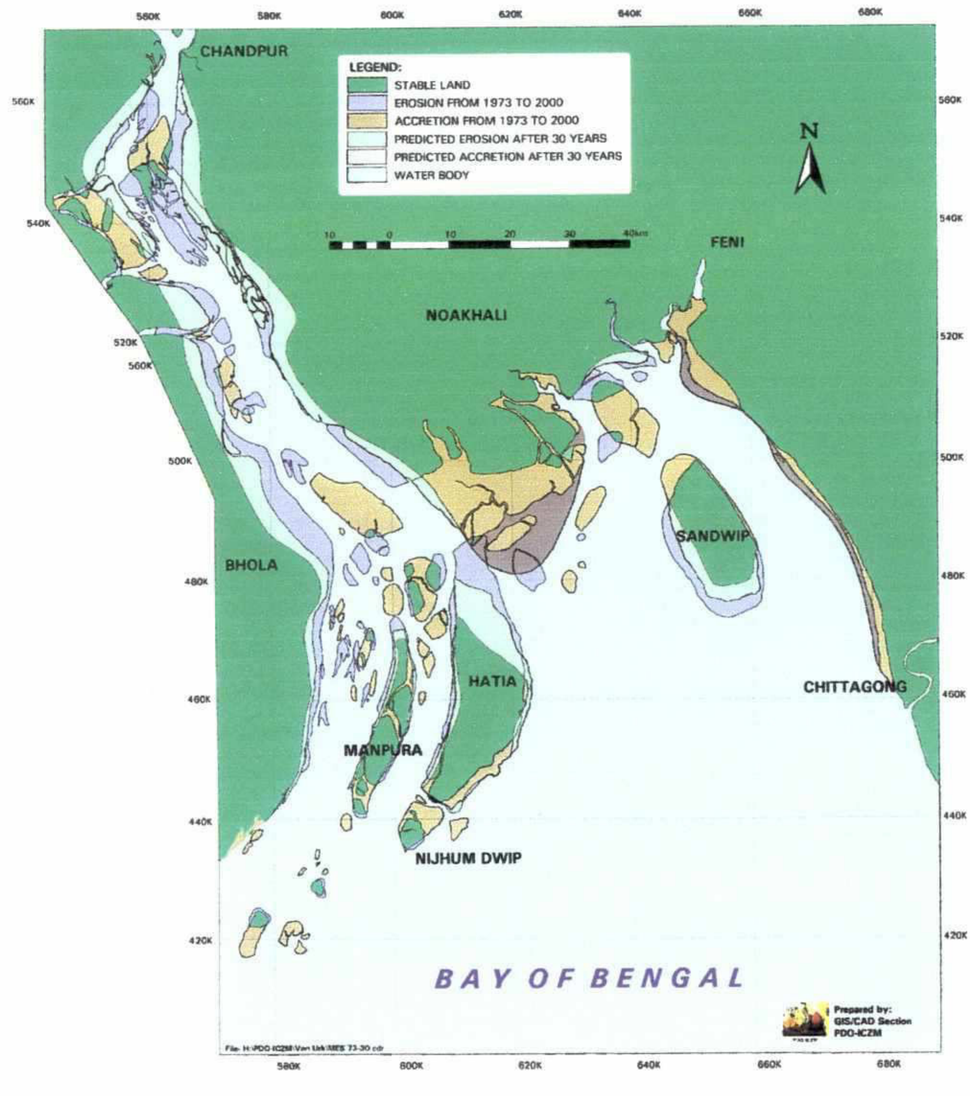
In this study, the expected evolution of the dry land and chars in the Meghna Estuary on a long-term (30 years) time scale has been obtained by extrapolation of existing trends and patterns in the geo-morphological development over the last decades. Catastrophic events, which might trigger a shift in morphological development and patterns, are not taken into account. *Furthermore, it has to be noted that outcome of this analysis should serve purely as an indication of the possible development of the shorelines.*

Indicative changes to the shoreline are given in Figure 8. According to the performed analysis, large shoreline movements are expected in the following areas:

- West bank of Lower Meghna near Gosairhat (opposite Haimchar on the east bank, in the northern part of the project area), which will continue to erode severely. This is related to the migration of channel to the west and the development of a large char in the middle of the river;

- East bank of Lower Meghna near Haimchar, which will continue to erode. This movement is related to the migration of the main conveyance channel towards the east bank;
- West bank downstream of Khorki to North Bhola and east bank downstream of Haimchar which will continue to erode due to migration of channels towards west and east respectively, resulting in widening of the river;
- Area Char Bouye – Noakhali mainland: the massive accretion in this area will continue, causing southward migration of the Hatia Channel;
- The northern head of Hatia which will continue to erode excessively due to above mentioned movement of the Hatia Channel to the south;
- Mouth of Feni which will continue to accrete;
- East, west and south banks of Sandwip where some erosion is expected.

Figure 8 Accretion and Erosion : past and indication of future changes



It is noted, that the prediction method is based on a data series of at maximum 44 years (27 years in most of the cases). This data series is used for extrapolation 30 years ahead. This causes a significant uncertainty. It is assumed that areas, which were eroding during the last decades, would continue to erode in the future, and that the areas with a high rate of change would not become more stable. The results of extrapolation have been checked against observed trends and recent changes, and corrected whenever necessary.

5 RECOMMENDATIONS

A substantial insight has been acquired in the knowledge of the hydro-morphological dynamics of the Meghna estuary. This insight is an essential basis for the development of the estuarine region, whether this will be accompanied by physical interventions to protect life and property or not. It should be stressed that keeping up the knowledge is a continuous effort, which should have a high priority. Therefore, the following is strongly recommended with regard to morphological studies and surveys in the field:

Morphological studies:
It is essential to continue with morphological studies as the knowledge is still limited and can easily fade away when no attention is paid to it. For the development of the estuary, a continuous updating of the insight is urgently needed. Studies should encompass the following topics:

- Large-scale morphological developments from yearly bathymetric surveys and satellite images.
- Changes to the channel system (migration of channels and chars, changes to cross-sections, etc.).
- Morphological behaviour of areas close to the main bifurcation points.
- Predictions of bank erosion for spatial planning purposes.
- Detailed study of areas where pilot interventions might be planned and implemented.
- Impact of climate change related phenomena as accelerated sea level rise and others, on the development of the estuary.

Surveys:
The need for a continuous survey operation has to be stressed to provide the necessary field data for the support of nearby or future decisions. Survey operations should encompass the following elements:

- Bathymetric surveys at regular time intervals depending on the rate of change.
- Discharge, velocities and water level measurements in various locations.
- Sediment concentration measurements along with bed sampling.
- Measurements of salinities, waves and water quality.

To realise this, a smooth operating survey unit should be available on a long term basis along with proper data processing, analysing and storage facilities in a supporting office. In that office, also attention has to be paid, amongst others, to numerical modelling, remote sensing and morphological predictions.