Government of the People's Republic of Bangladesh
Ministry of Water Resources
Water Resources Planning Orgnization (WARPO)

INTEGRATED COASTAL ZONE MANAGEMENT PLAN PROJECT

Knowledge Portal on Estuary Development (KPED)

Working Paper

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Preface

The Knowledge Portal on Estuary Development (KPED) has been developed by the Center for Environmental and Geographic Information Services (CEGIS) on request and in support of the Program Development Office (PDO) for an Integrated Coastal Zone Management Plan (ICZMP).

The 1999 GoB Policy Note on ICZM and subsequent PDO-ICZMP project documents emphasize the need to improve the understanding of coastal zone processes and to establish a system for collection of data and synthesizing information that will directly serve decision making processes. Accordingly, the development of a knowledge base has become an important output (Output 6) of the PDO-ICZMP project.

One of the purposes of this component of the PDO-ICZMP project (Feb. 2002 – Jan. 2005) is to gather, assimilate and make available data and knowledge on the coastal zone and the livelihood of coastal area dwellers for all stakeholders involved in developing and implementing ICZM. A critical consideration in any knowledge management approach is to ensure that information represents the state of the art and is easily accessible for any type of user. It was recognized that the most effective means for access and dissemination of knowledge is a well-constructed and maintained Web site. Such a Web site as a *"portal to knowledge"* could include -- in the form of overviews or downloadable information:

- ◊ introductions on relevant topics in a well-structured context;
- ◊ national and international literature and library databases;
- ◊ relevant publications, news letters;
- ◊ Web sites of relevant institutes;
- ◊ contents of databases (metadata); and
- ◊ data themselves and maps.

This working paper reports on a pilot project carried out between October 2002 and February 2003. It focuses on the physical processes of the Meghna Estuary. The main purpose was to reach an assessment of the suitability and feasibility of knowledge portals as tool for knowledge management. The study focuses on technical aspects and as such could be considered to represent the state of the art of: (i) what technically is possible in terms of Web-based technology; and (ii) the physical processes of the Meghna Estuary.

The knowledge portal will be made available through the project's Web site: www.iczmpbangladesh.org, but is also included on a CD in this report.

The PDO-ICZMP project and CEGIS would appreciate to receive comments and/or suggestions on this KPED that lead to a better knowledge portal and further enhance its utilization.

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Acknowledgement

The Knowledge Portal on Estuary Development (KPED) covers only the physical aspects of the Meghna Estuary. Developing the KPED is a pilot scheme, which would support the formulation of a knowledge management strategy for ICZM and eventually may lead to the development of more comprehensive knowledge portals, covering other parts of the coast and other than physical aspects.

The PDO-ICZM project has contracted CEGIS to develop the KPED, using project funds that were allocated by DfID for the purpose of knowledge management. The contribution of DfID is kindly acknowledged.

At the beginning, a 10 days long work session was held to design and develop the structure of KPED, and compile the available knowledge on the estuary development. The participants of the workshop were the national and international experts on the coastal hydraulics, geology, morphology and soil resources. Rob Koudstaal and Timothy C. Martin are acknowledged for providing the useful advice in developing the KPED structure. The Survey and Study Division (SSD) of Bangladesh Water Development Board (BWDB) is acknowledged to provide the facilities of office space, computers, MES project data and library for the work session. During the work supports from PDO-ICZMP and WARPO are also duly acknowledged.

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List of abbreviations

ASP	Active Server Pages
BIWTA	Bangladesh Inland Water Transport Authority
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CDSP	Char Development and Settlement Project
CEGIS	Center for Environmental and Geographic Information System Services
CERP	Coastal Embankment Rehabilitation Project
DfID	Department for International Development
DoE	Department of Environment
DoF	Department of Fisheries
GIS	Geographic Information System
GSB	Geological Survey of Bangladesh
HTML	Hyper Text Markup Language
IIS	Internet Information Services
IT	Information Technology
IWFM	Institute of Water and Flood Management
IWM	Institute of Water Modelling
KPED	Knowledge Portal for Estuary Development
LGED	Local Government Engineering Department
MES	Meghna Estuary Study
PDO-ICZMP	Program Development Office – Integrated Coastal Zone Management Plan
RDMS	Relational Database Management System
RHD	Roads and Highways Department
SRDI	Soil Resources Development Institute
SSD	Survey and Study Division

1. Introduction

In 1940, HG Wells wrote *'An immense and ever-increasing wealth of knowledge is scattered about the world today; knowledge that would probably suffice to solve all the mighty difficulties of our age, but it is dispersed and unorganised. We need a sort of mental clearing house for the mind: a depot where knowledge and ideas are received, sorted, summarised, digested, clarified and compared.'* Today, with the development of the web based communication network (world wide web), which is an easy and widely used mass communication and message transmission media, scientific and research knowledge is stored in a common place called a "knowledge portal" so that a wide range of people may benefit from it.

One of the main components of the PDO-ICZM (Program Development Office – Integrated Coastal Zone Managment) is the creation of a knowledge base which contains the identification of indicators for the ICZM process, an inventory of available data and knowledge and corresponding gaps, and the formulation of an information plan as part of the Coastal Development Strategy. The knowledge base is to be easily available to the project staff and relevant government agencies, consultants, students, researchers and in general, to the public at large. To achieve this goal, it was assumed that a web-based knowledge portal would be the most suitable tool.

During the last few years, extensive data collection and analysis activities have been carried out on the Meghna Estuary, and some of the activities are still on-going. Given the importance of the development processes of the estuary and the availability of updated information, the development of a web-based Knowledge Portal for Estuary Development (KPED) was initiated by the PDO-ICZM as a pilot activity for which DfID provided the necessary funds.

The Center for Environmental and Geographic Information Services (CEGIS) was contracted to accomplish the task. A 10 day work-session was therefore organized by CEGIS in October 2002 to develop the structure of the KPED and to compile the existing knowledge on estuary development. National and international experts in different disciplines like geology, morphology, soil resources, and coastal hydraulics participated in the work session. The outcome has been the basis of the web-based knowledge portal. The compiled knowledge on the physical processes of the development of the Meghna Estuary has been incorporated in the knowledge portal in an easily accessible form as presented in Annex 1.

The KPED thus concentrates mainly on the physical processes of the Meghna Estuary. The logical sequence of the processes of estuary development starts from *forces and inputs* (geology, climate, hydrological cycle, tide, fresh water input, sediment input, natural calamities, human interventions), goes through *resulting processes* (e.g., salinity processes, wind-storm-waves and sea-level changes), a nd combines these processes to the *patterns of water circulations and sediment and salinity distribution*. All of these determine the physical environment of the estuary (flooding and drainage, soil resources, fresh water resources, erosion and accretion and channel development). The KPED provides the relationships between different physical factors and their impacts on the different key issues influencing the lives and livelihoods of the people living in the estuary. It also provides information about the agencies/institutes that are working in the estuary along with the ongoing projects there.

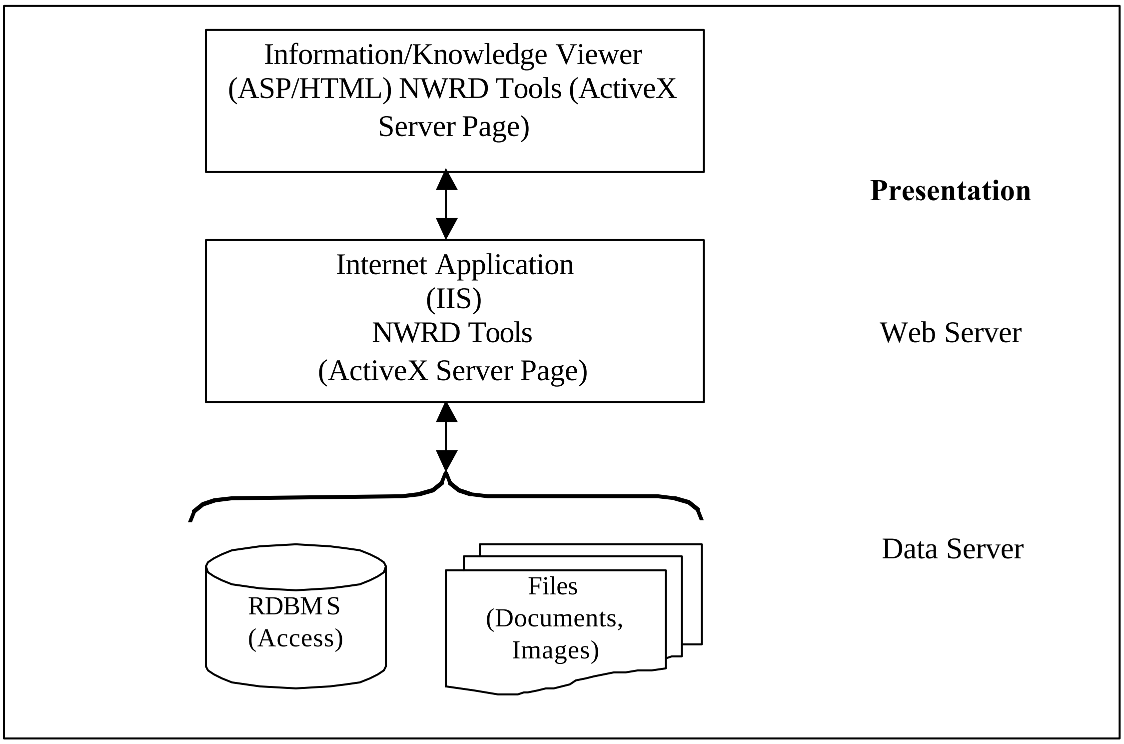
2. Objectives

The main objective of the knowledge portal is to compile and disseminate knowledge and information to policy makers, stakeholders and the public at large. The primary objective is to develop a knowledge portal for estuary development on a pilot basis to assess the suitability of disseminating knowledge through such a medium. The decision to develop the portal was taken at a workshop organized by CEGIS and ICZMP on February 6, 2003 (Annex 2).

The specific objectives of this report are to

- Provide the design aspects,
- Show the way to navigate through the portal and
- Assess the suitability and future possibility of the KPED

3. Design



Notes:

ASP: Active Server Pages

HTML: Hypertext Markup Language

IIS: Internet Information Server

RDBMS: Relational Database Management System

The Web enabled KPED is designed and developed using a 3-tier architecture. It consists of the following layers.

- Presentation
- Web Server
- Data Server

3.1 Presentation

The presentation layer is the user-interface to interact with the portal. It is developed using Active Server Pages, HTML pages and the Java script. The layer utilizes frames to promote a multi-tiered, user-friendly navigation system for accessing and viewing different documents, maps, figures, reports, references and animation related to different physical aspects and key issues of estuary development; addresses of relevant government and non-government agencies/institutes in Bangladesh working in the Meghna Estuary area; and a list of relevant on-going projects. The user can navigate through different physical aspects and key issues by using the tree structure or logical model provided in the portal. There is also a pop up menu for this purpose.

3.2 Web server

The main component for a web enabled application is the web server. It is a program that manages and delivers web pages and allows users to communicate with the server that pass data through the internet or intranet. The KPED web server is configured using IIS 5.0.

3.3 Data server

The data server contains documents, maps, figures, reports, references and other relevant information. An access database is used to maintain the relationships between the different physical aspects of estuary development and the location of relevant knowledge base documents.

4. Interface

In order to retrieve data from the KPED, the user must send a request through the Active Server Pages (ASP), which would pass on the request to the Data server. The server retrieves the location of the HTML pages containing relevant information and sends it back to the Web server. Finally, the Web server sends the pages to the end-user. The portal uses the following ASP and HTML pages.

Start.*html* is the main frameset of the portal. There are two frames in the frameset; namely "top1" and "bottom1".

Top1.html is the page that loads initially in the "top1" frame found at the top of the screen. This is the only frame where no other page is ever loaded.

Index.asp loads in the "bottom1" frame found at the bottom of the screen. The page divides the "bottom1" frame into two sub frames: "top" and "bottom".

Top.asp is the page that loads in the "top" frame found at the top of the "bottom1" frameset. Initially, this frame contains no icons. Depending on the page loaded in the "bottom" frame, Top.asp can contain 3/4 icons: search, back, forward and home. It also contains a checkbox to hide/unhide the tree loaded in the "bottom" frame.

Home.htm is initially loaded in the "bottom" frame found at the bottom of the "bottom1" frameset. This frame contains 8 navigation links: Introduction, Model, Acknowledgment, Reports, Projects, Agencies/Institutes, Current Events and Overview. These are the main navigation links for the portal interface.

Introduction.htm loads in the "bottom" frame when the "Introduction" link is clicked in the home page. this page provides a brief introduction to the KPED.

Acknowledgement.htm loads in the “bottom” frame when the “Acknowledgment” link is clicked in the home page.

MESpublications.htm loads in the “bottom” frame when the “Reports” link is clicked in the home page. The page gives ready access to the relevant reports of the Meghna Estuary Study (MES).

Projectlist.htm loads in the “bottom” frame when the “Projects” link is clicked in the home page. This page gives a list of the relevant on-going projects.

Institutions.htm loads in the “bottom” frame when the “Agencies/Institutes” link is clicked in the home page. It provides the addresses of relevant government and non-government agencies/institutes in Bangladesh working in the Meghna Estuary area.

Overview.htm loads in the “bottom” frame when the “Overview” link is clicked in the home page. The page provides a brief overview of the main physical processes in the estuary to help understand their complexity. A brief description of the most relevant aspects/issues is presented here. Clicking on the link corresponding to *issues* will facilitate navigation through the portal.

SearchReasult.asp loads in the “bottom” frame when the “Search” icon is clicked. This icon appears in the “top” frame when *Overview.htm* loads in the “bottom” frame. *SearchReasult.asp* provides keyword search facilities between the physical aspects of the processes of estuary development. With the search results the user can navigate through corresponding physical aspects.

Issues.asp loads in the “bottom” frame when the navigation link for key aspects/issues is clicked in the overview page. It divides the bottom frame into two sub frames: “main” and “contents”.

Model.html loads in the “bottom” frame when the navigation link “Model” is clicked in the home page. It divides the bottom frame into two sub frames: “main” and “contents”.

Struc.htm loads in the right frame named “main” found at the “bottom” frameset when the navigation link “Model” is clicked in the home page. This page shows a comprehensive logical model of relationships between different physical factors and their impacts on the estuary.

Tree.asp loads in the left frame named “contents” found at the “bottom” frameset. It loads the relationships between different physical factors and their impacts on the estuary in a tree structure in order to make the navigation easier. Clicking on any of the physical aspects in the tree will display the relevant knowledge base information document at the right frame of the bottom frameset. The tree can be expanded or collapsed by clicking on the ‘+’ or ’-‘ sign that appears on the left of each of the physical aspects.

SubIndex.asp loads in the right frame named “main” found at the “bottom” frameset. It divides the right frame into 2 sub frames. The left frame is called “labels”. The right frame is further divided into two sub frames: “subtop” and “sub”.

OtherLinks.asp loads in the left frame named “labels” found in the “main” frameset. This frame contains 4 image buttons in the following order: Literature and Reports, Related Social Issues, Contact, Figures and Tables. Only two buttons are currently active. “Literature and Reports” displays corresponding literature and reports in the right frame of the “main” frameset. “Figures and Tables” shows related figures and tables. The buttons “Related Social Issues” and “Contact” will be activated when information on social issues and addresses of contact persons relevant to the corresponding physical aspects become available.

ParentNodes.asp loads at the top of the right frame named “subtop” found in the “main” frameset. The logical sequence of the processes of estuary development starts from *forces and inputs* (geology, climate, hydrological cycle, tide, fresh water input, sediment input, natural calamities, human interventions), goes through *resulting processes* (e.g., salinity processes, wind-storm-waves and sea-level changes), and combines these processes with the *patterns of water circulations and sediment and salinity distribution*. This frame contains 4 navigation nodes. The image at the right of each node shows the current level of navigation. Each node has a small pop up menu that appears above the node when the user moves the mouse over the node. The pop up menu lists the sub topics of the corresponding physical aspect.

Menus.css contains a ”cascading style sheet” for the pop up menu.

Menus.js contains required java script functions for the pop up menu.

default.html loads a blank page.

All the files above are found under the root directory. The following files are found under each sub directory.

References.htm loads corresponding literature and reports in the right frame named “subtop” found in the “main” frameset. It loads when the “Literature and Reports” image button, found in the left frame named “labels” of the “main” frameset, is clicked.

Maps.htm loads in the frame named “subtop” when the “Figures and Tables” image button found in the “labels” frame is clicked. It lists the name of figures and tables related to the corresponding physical aspect.

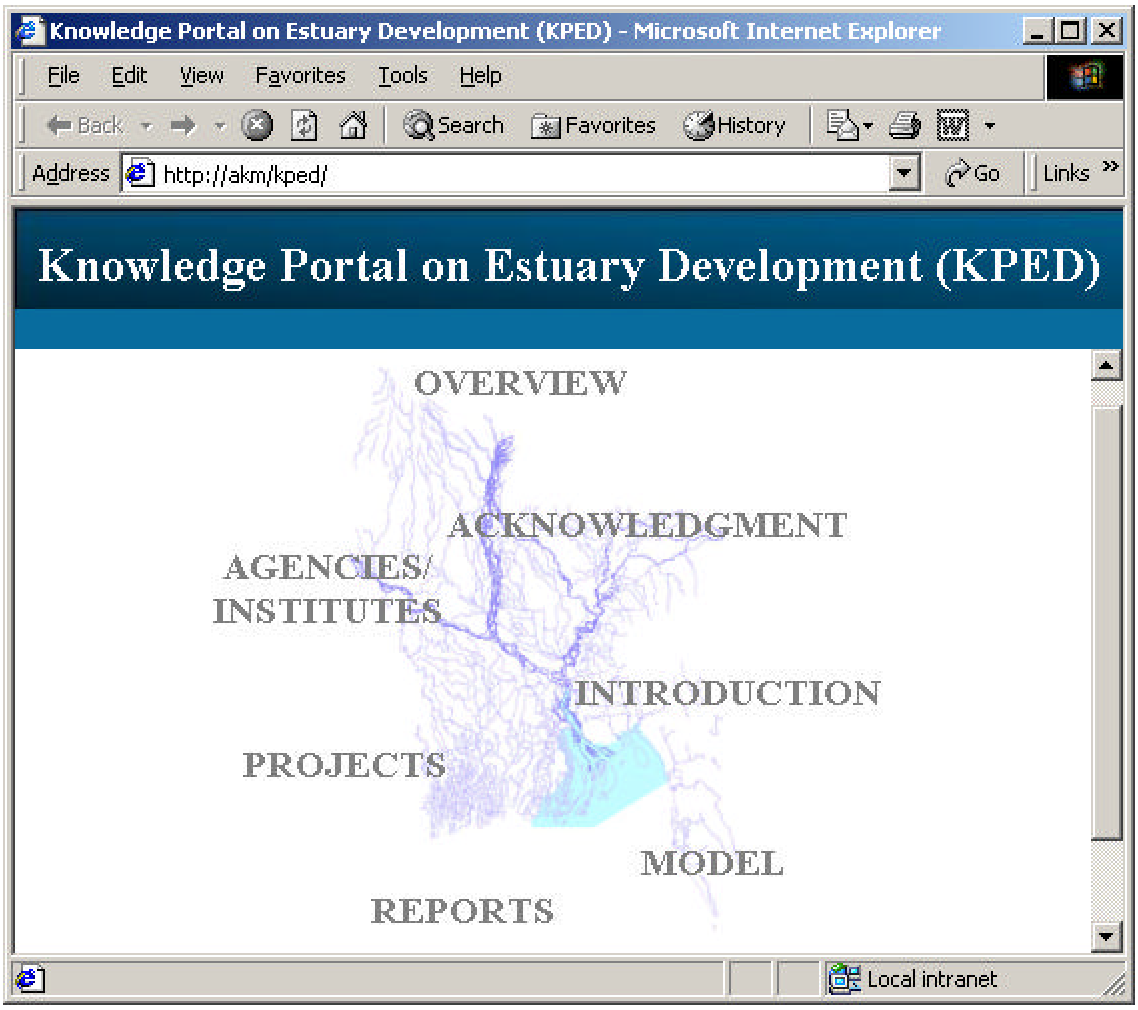
ViewMaps.asp shows the corresponding figures and tables in the “subtop” frame.

The knowledge base information related to each physical aspect is saved as an html file under the respective sub directory. They load in the right frame named “subtop” found in the “main” frameset.

An Activex Dll named “obout_ASPTreeView.dll” is used to create the tree.

5. Navigation

The home page of this portal contains 8 navigation links: Introduction, Model, Acknowledgment, Reports, Projects, Agencies/Institutes, Current Events and Overview. These are the main navigation links of the portal's interface.



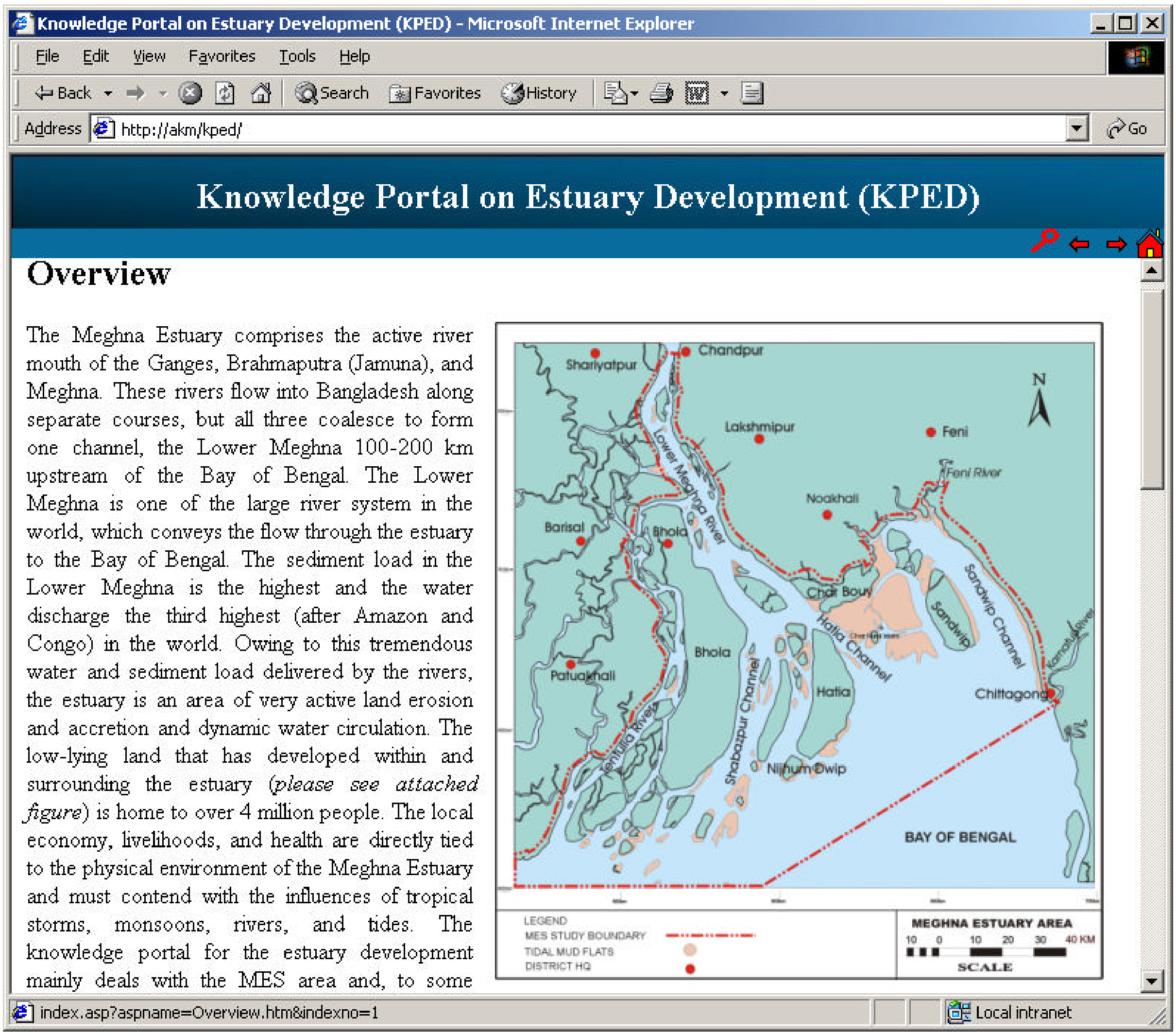
Introduction provides a brief introduction to the KPED.

Reports gives ready access to the relevant reports of the MES.

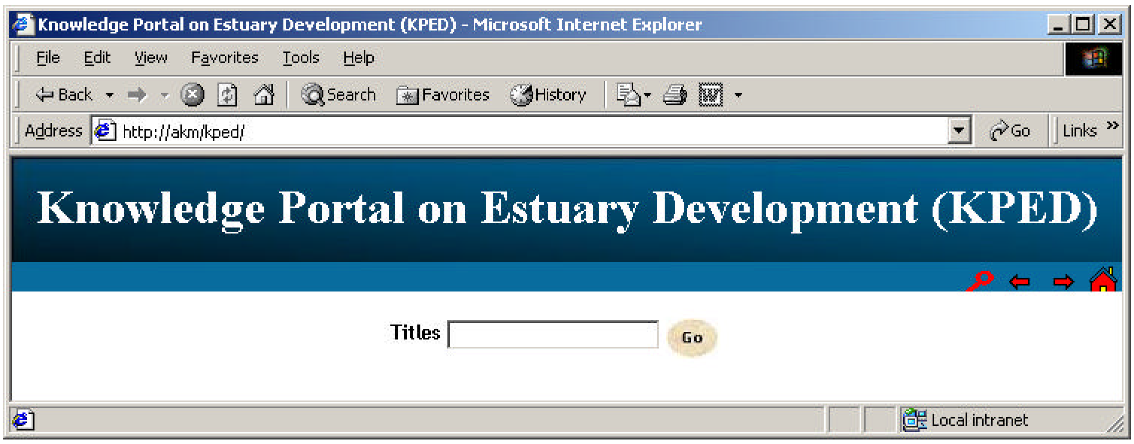
Projects gives a list of relevant on-going projects.

Agencies/Institutes provides the addresses of relevant government and non-government agencies/institutes in Bangladesh working in the Meghna Estuary area.

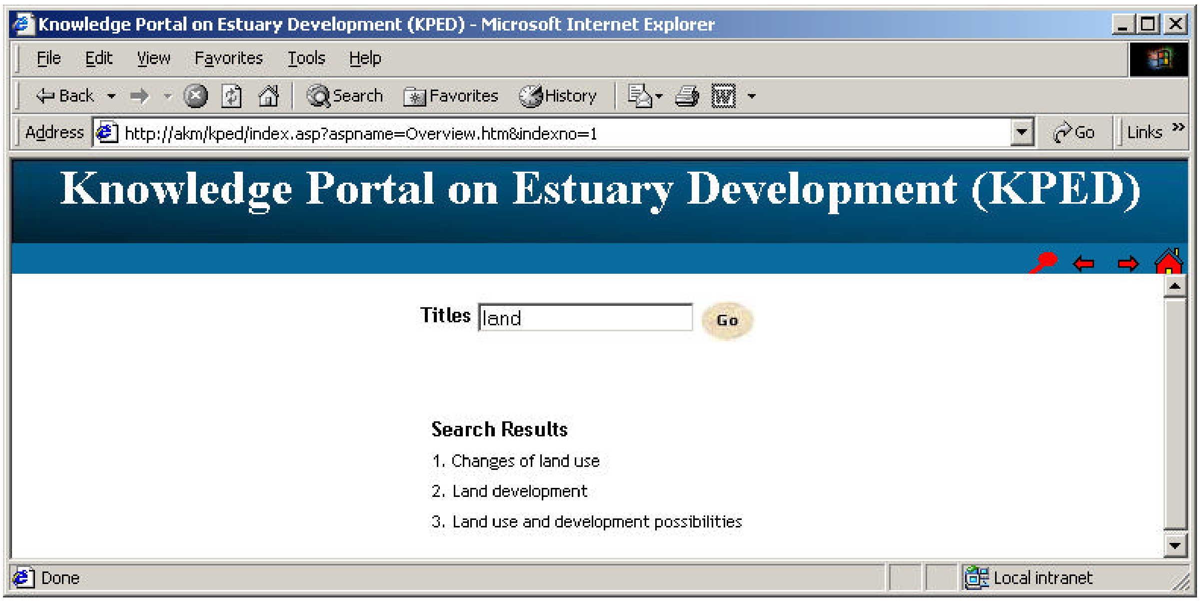
Overview provides a brief overview of the main physical processes in the estuary to help understand the complexity of the processes.



A brief description of the most relevant aspects/issues is presented here. Clicking on the links corresponding to *issues* will facilitate navigation through the portal. Four icons are available at the top of the page in the following order: Search, Back, Forward and Home. The “Search” icon provides the keyword or title search facilities between the physical aspects/issues of the processes of estuary development by loading the following page.

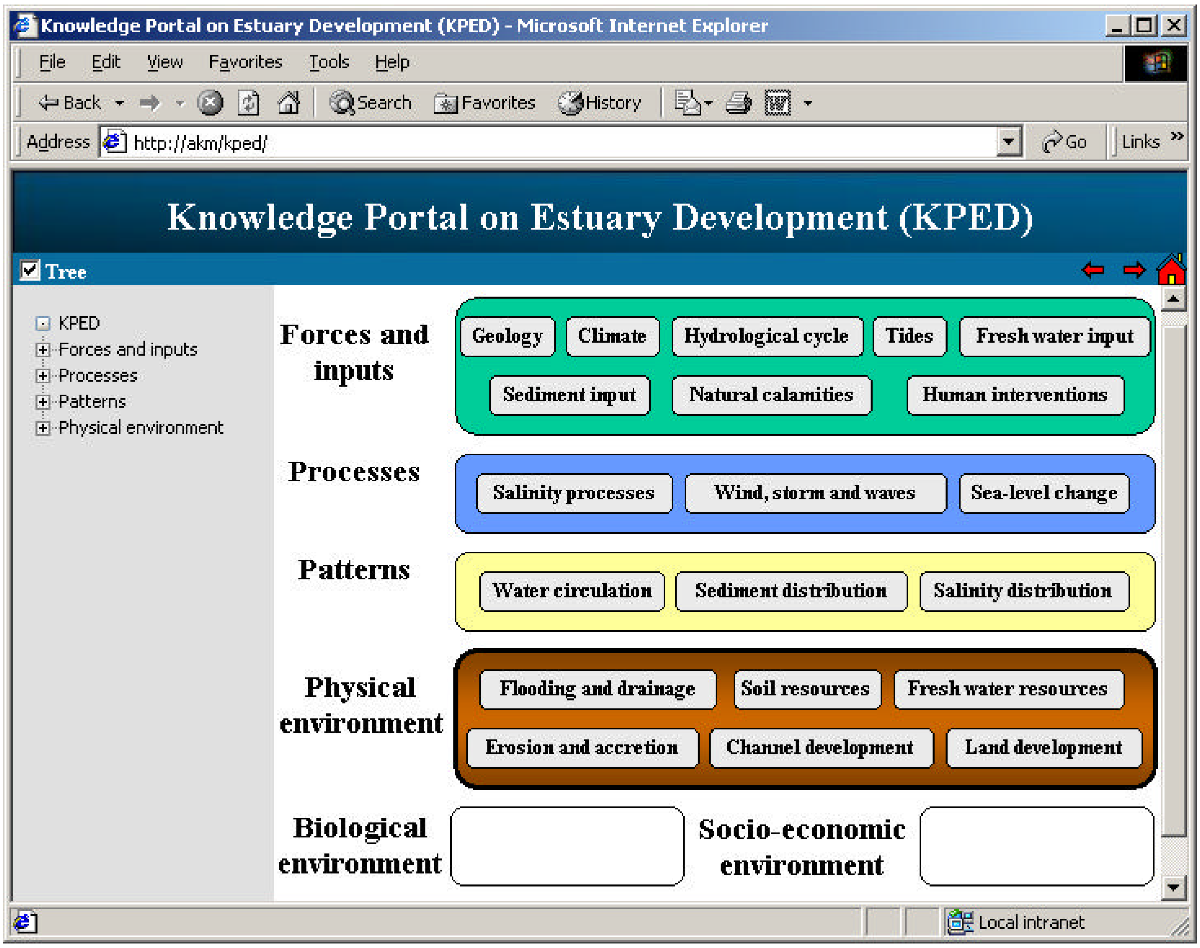


Typing the desired word(s) and clicking on the 'Go' button will display the titles of the physical aspects/issues containing the word(s). Clicking on each physical aspect/issue appearing as "Search Result" will load the corresponding knowledge base documents.

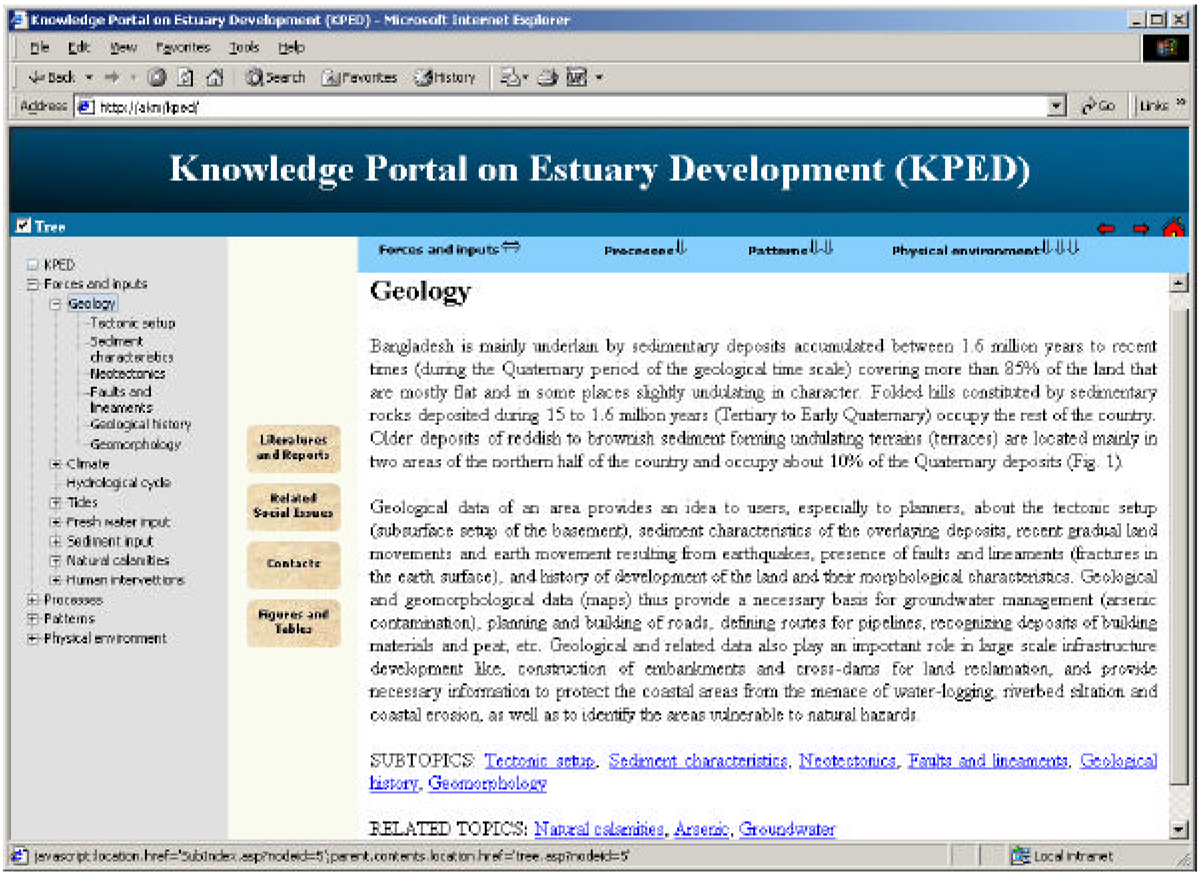


The "Back" and "Forward" icons will be used to go backward or forwards in the portal interface. The "Home" icon will load the home page.

Model loads the relationships between different physical factors and their role in the processes of estuary development as a tree structure and a comprehensive logical model in the left and right frame respectively at the bottom frameset.



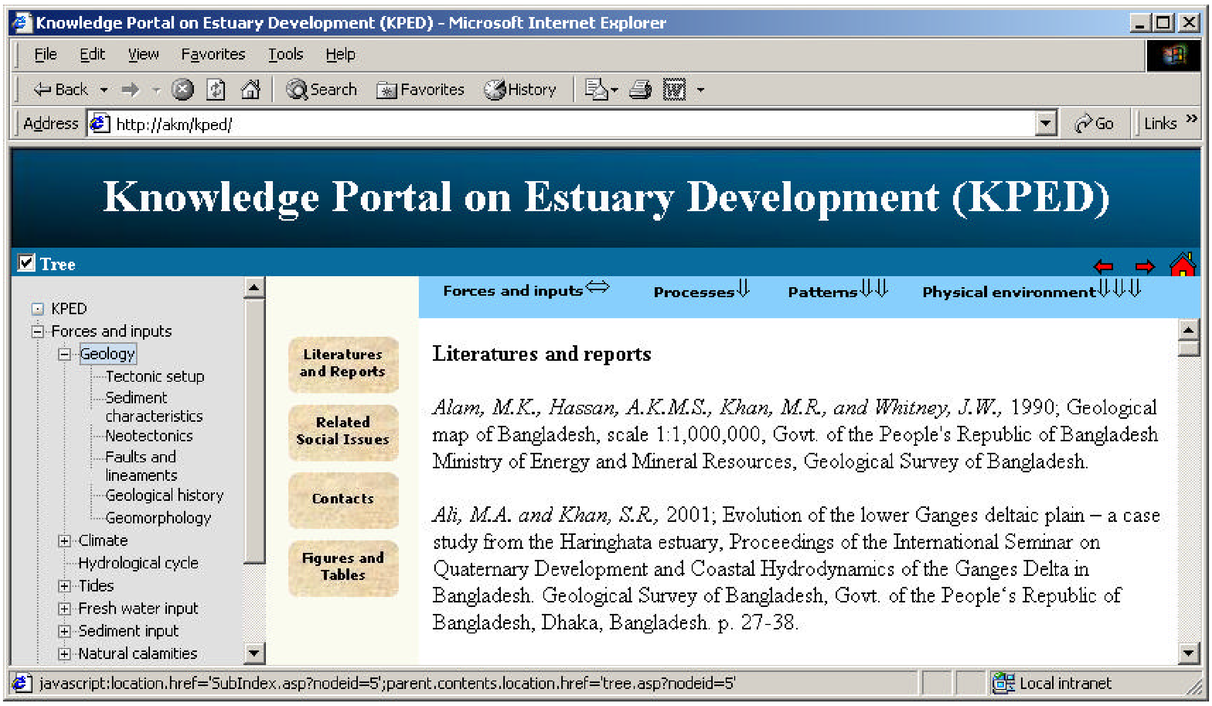
Clicking on a physical aspect in the model will load the related knowledge base documents. It will also expand the tree and highlight the selected physical aspect.



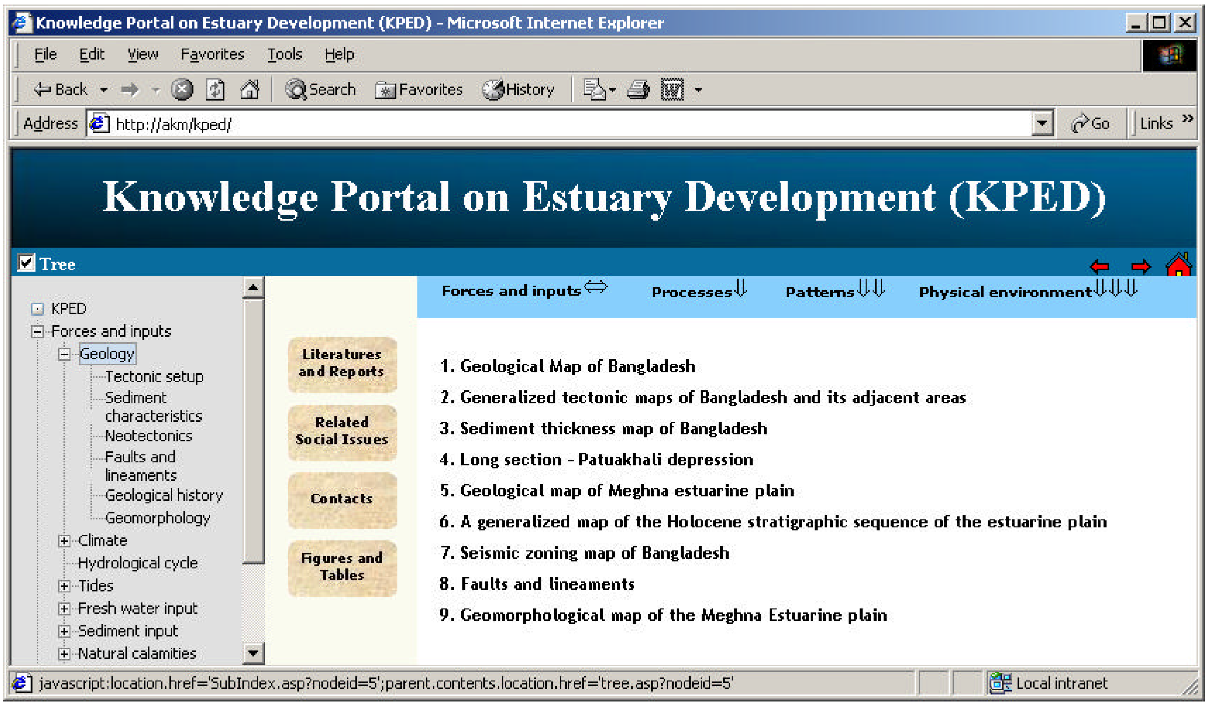
Links for corresponding subtopics and related topics are available at the end of each knowledge base document. Clicking on a topic will load the corresponding document and highlight the topic in the tree.

The tree can also be used for the purpose of navigation. It can be expanded or collapsed by clicking on the '+' or '-' sign that appears on the left of each physical aspect. The tree can be hidden or unhidden by clicking on the checkbox named "Tree" appearing at the top left corner of the page.

The "Literature and Reports" button will load the corresponding literature and reports.

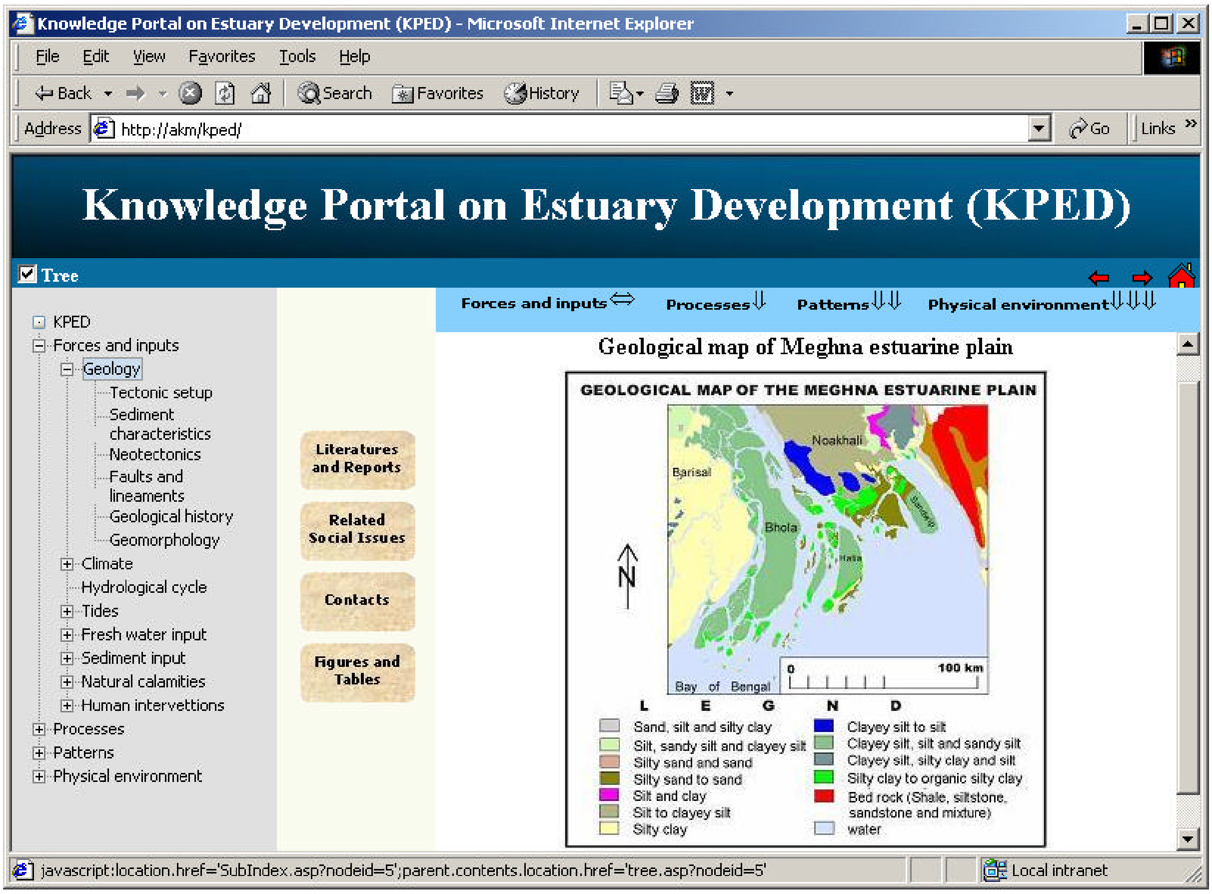


“Figures and Tables” gives ready access to the related figures and tables.



Clicking on each title will load the corresponding figure.

The buttons “Related Social Issues” and “Contact” will be activated when information on social issues and addresses of contact persons relevant to the corresponding physical aspects become available.



Four navigation nodes load at the top of the right frame of the "main" frameset. They represent the logical sequence of the processes of estuary development. The image at the right of each node shows the current level of navigation in the portal interface. "⇔" means the knowledge base document currently viewed belongs to the current sequence. Each "⇓ " means the corresponding sequence is one level below the current sequence. Each node has a small pop up menu that appears above the node when users move the mouse over it. The pop up menu lists the subtopics of the corresponding physical aspect. Clicking on each item in the pop up menu will load the corresponding documents and highlight the selected physical aspect in the tree. These pop up menus will be helpful for navigation when the tree is hidden by deselecting the checkbox "Tree".

6. Limitations

Browsing of this portal is most suitable on Internet Explorer 4.0 (or higher) with a screen resolution higher than 640*480 on the windows platform (95/98/2000/NT). Pop up menus do not work with the Netscape Navigator. The portal is designed and developed only for the Windows platform. An NT/2000 server and IIS 5.0 are needed to host the portal. This is not applicable for other operating systems.

7. Future provisions

The portal can be modified and tested so that it can be browsed with any browser on any platform. It can be browsed on the Netscape Navigator only by changing the code related to pop up menus. The physical aspects related to the biological and socio-economic environment could be incorporated into the portal. Social issues and contact person's addresses related to corresponding physical aspects could be included in the system. In the future, a link to the National Water Resources Database (NWRD) could be provided, allowing access to online data from this database.

8. Suitability and future prospects

The suitability and future prospects of the knowledge portal were assessed at the workshop organized by CEGIS and ICZMP on February 6, 2003 (for details please see Annex 2). About 45 participants from different organizations attended the workshop. The objectives of the KPED and the method for its development were presented at the workshop. A CD-version of the KPED was demonstrated there, following a discussion session on its use. The participants expressed their opinion with regard to the usability, suitability and future prospects of the knowledge portal and were of the opinion that it would be an effective tool for disseminating knowledge.

It was unanimously agreed at the workshop that the knowledge portal should be extended to include the socio-economic and ecological aspects of the estuary. The participants also expressed their hope that in the near future the portal will be developed further to cover the whole water sector. The main questions raised at the workshop were:

- who will host the portal; and
- who will update and incorporate the knowledge in the portal.

The questions will have to be resolved eventually. For the time being, ICZMP is going to take the responsibility to host it.

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Annex 1
Information and knowledge compiled in KPED

Overview

Introduction

Model

Projects

Agencies/Institutes

National and international experts participating in the 10 days working sessions in October 2002 to outline the KPED and compile the available knowledge.

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Overview

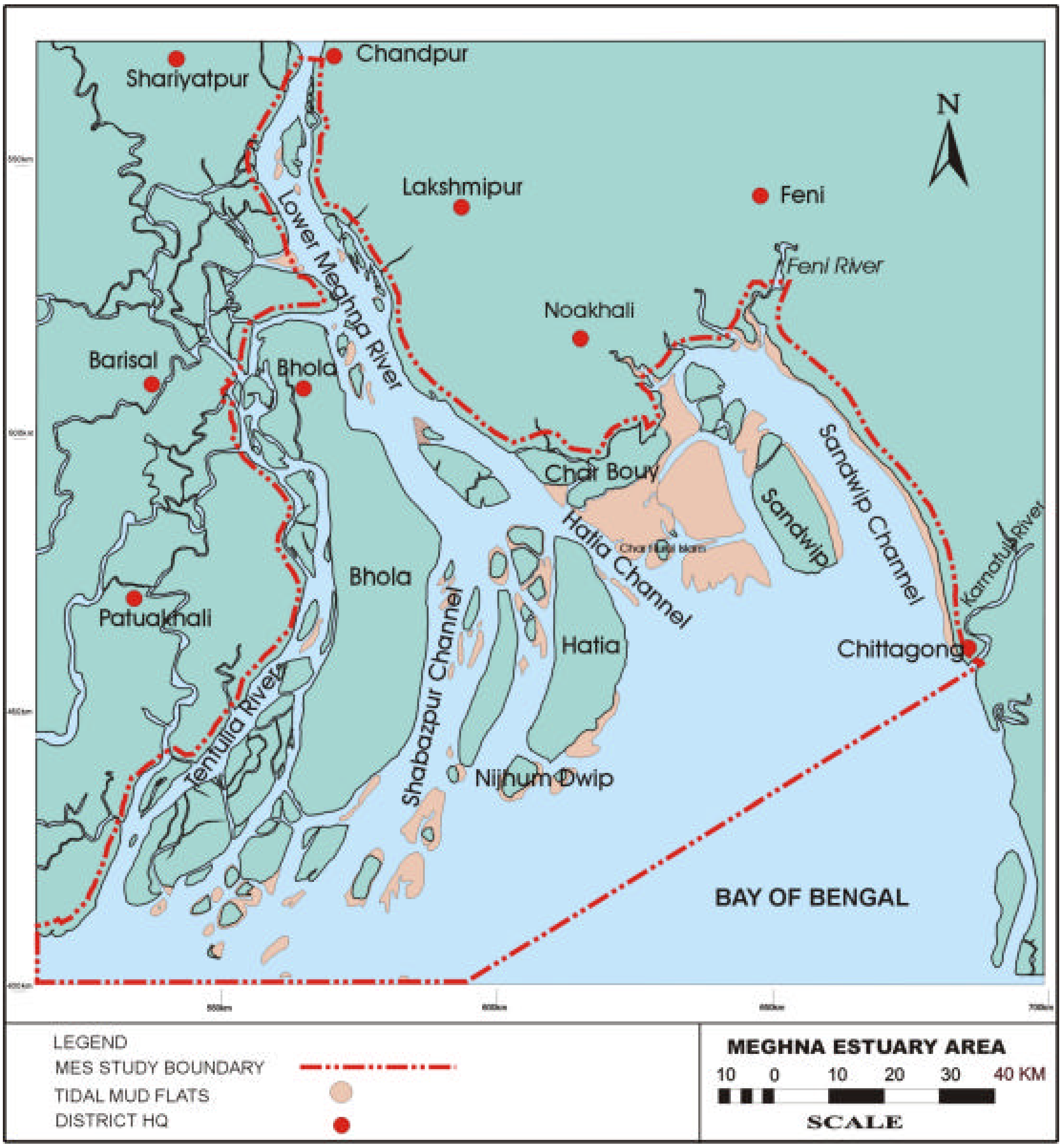
Overview

The Meghna Estuary comprises the active river mouth of the Ganges, Brahmaputra (Jamuna), and Meghna. These rivers flow into Bangladesh along separate courses, but all three coalesce to form one channel, the Lower Meghna 100-200 km upstream of the Bay of Bengal. The Lower Meghna is one of the large river system in the world, which conveys the flow through the estuary to the Bay of Bengal. The sediment load in the Lower Meghna is the highest and the water discharge the third highest (after Amazon and Congo) in the world. Owing to this tremendous water and sediment load delivered by the rivers, the estuary is an area of very active land erosion and accretion and dynamic water circulation. The low-lying land that has developed within and surrounding the estuary (*please see attached figure*) is home to over 4 million people. The local economy, livelihoods, and health are directly tied to the physical environment of the Meghna Estuary and must contend with the influences of tropical storms, monsoons, rivers, and tides. The knowledge portal for the estuary development mainly deals with the MES area and, to some extent, its surroundings.

The main physical processes in the estuary are related to the dynamics of water and sediment. During the wet season (June-October), rivers bring huge amounts of sediment to the estuary. These sediment are partly deposited in the estuary and partly flushed into the Bay of Bengal. Strong water flows cause erosion of riverbanks and contributes to the flooding of un-poldered lands. At the beginning and end of the wet season, tropical storms and cyclones are likely to occur. These can have devastating impacts on the low-lying areas in the estuary, often taking lives and destroying properties and infrastructure. During the dry season, the sediment are re-arranged and mainly deposited near the coast and new land is thus formed. A net accretion rate of about 19 km^2/year has been observed for the last 50 years, which is nearly 2.5 times higher than the long-term (150-200 years) accretion rate. This land, however, is not a replacement of the fertile land lost to erosion. The soils are muddy, salty, and lack nutrients. It takes many years before they can be used for the cultivation of crops. Low fresh water flow during the dry season (November-May) in the Lower Meghna is unable to stop the upstream intrusion of saline water, which can enter the river mouth with the tide.

Both human interventions and climate changes are likely to change the prevailing processes in the estuary. Upstream water withdrawal may contribute to further landward salinity intrusion. The construction of cross-dams will influence the water circulation, locally promote accretion, but may increase erosion in other places. Depending on the scale of the intervention, the tides may be influenced, resulting in higher water levels. These can have negative impacts on the safety of people living behind embankments and cause problems with drainage from land. Sea-level rise will have an impact on the floodplains, which will probably build out towards the sea. Higher sea levels will change the tidal motion in the estuary, especially during the dry season. This will have an impact on the sedimentation and erosion processes. Landward salinity intrusion during dry periods may increase.

There are several physical factors which largely influences the lives and livelihoods of the people in the Meghna Estuary. A brief description of the most relevant aspects/issues is given below.



Erosion and accretion: The very dynamic physical processes of the Meghna Estuary are causing erosion and accretion in the scale of hundred sq. kilometres per year and cause several thousands of people to become landless and homeless every year. Although the net balance is towards accretion, loss of old fertile land is considered to be national loss.

Soil resources: The Meghna Estuary is a very dynamic area – erosion and accretion are continuously changing the landform. Old and mature soils erode away and new land comprising immature soils accrete. Mature soils are suitable for year round cultivation, while new soils are poorly fertile. Salt contents are also high in this soil. The soil takes several years to mature, but poldering expedites the process of soil formation.

Land development: The Meghna Estuary is an active delta building estuary. The rate of net land development is about 19 km^2/year. The newly created land provides much needed space to this densely populated country.

Channel development: There are several channels within the estuary, which pour and distribute fresh water and sediment over the Meghna Estuary with the help of tidal flow. These channels are responsible for the erosion and accretion processes and play an important role in navigation.

Salinity distribution: An estuary is the mixing place of fresh and salt water. The Meghna Estuary is a well-mixed estuary i.e., the salinity does not vary with the water depth. The location of the saline water front varies with the fresh water input, which on the other hand greatly varies from dry to wet season. During the dry season, the saline water front progresses landward, while during the wet season it is pushed out to the bay. Salinity has an impact on agriculture, fisheries and other different areas of water use.

Fresh water resource: The Meghna Estuary area is surrounded by water, though the availability of fresh water for irrigation, household uses and drinking purposes is a major constraint. This constraint both in surface and ground water is relatively acute in the estuary compared to the mainland of Bangladesh.

Flooding and drainage: Flooding due to high upstream flow is not a common phenomena in the Meghna Estuary. Rather, floods in this area are related to storm surges. High tide during monsoon also causes floods in un-poldered areas. On the other hand, drainage congestion in the Noakhali and Lakhmipur areas are worsening mainly due to human interventions and the southward progression of the delta. Both floods and drainage congestions have adverse effects on agricultural productions.

Storms: The Bay of Bengal is a breeding sea for cyclonic storms. Most of the devastating cyclones in human history formed here, such as the ones in 1970 and 1991, which took the lives of hundreds of thousands of people in the coastal region of Bangladesh. In the coastal region, the Meghna Estuary area is most vulnerable to cyclonic storms.

Introduction

Introduction

One of the aims of the PDO-ICZM is the creation of a knowledge base that would support planning, implementation and monitoring of the ICZM process. Such a knowledge base should be fully and easily available to the project staff, government agencies, consultants, students and researchers, and even to the public at large. The web is the most efficient tool to disseminate knowledge. Knowledge portals provide a flexible web-based interface that structures access to many different kind of information for different purposes, varying from specialized data for design to information on experts available in Bangladesh.

During the last few years, extensive data collection and analysis activities have been carried out on the Meghna Estuary, and some of the activities are still on-going. Given the importance of the development processes of the estuary and the availability of updated information, developing a web-based Knowledge Portal for Estuary Development (KPED) was initiated by the PDO-ICZM as a pilot activity.

The portal will be integrated in a ICZM web-site, which is under development by the PDO-ICZM project. The KPED provides an overview of the physical processes of the Meghna Estuary and information on literatures and reports, and agencies/institutes. It gives ready access to the relevant reports of the Meghna Estuary Study (MES).

There are several ways to navigate through the portal:

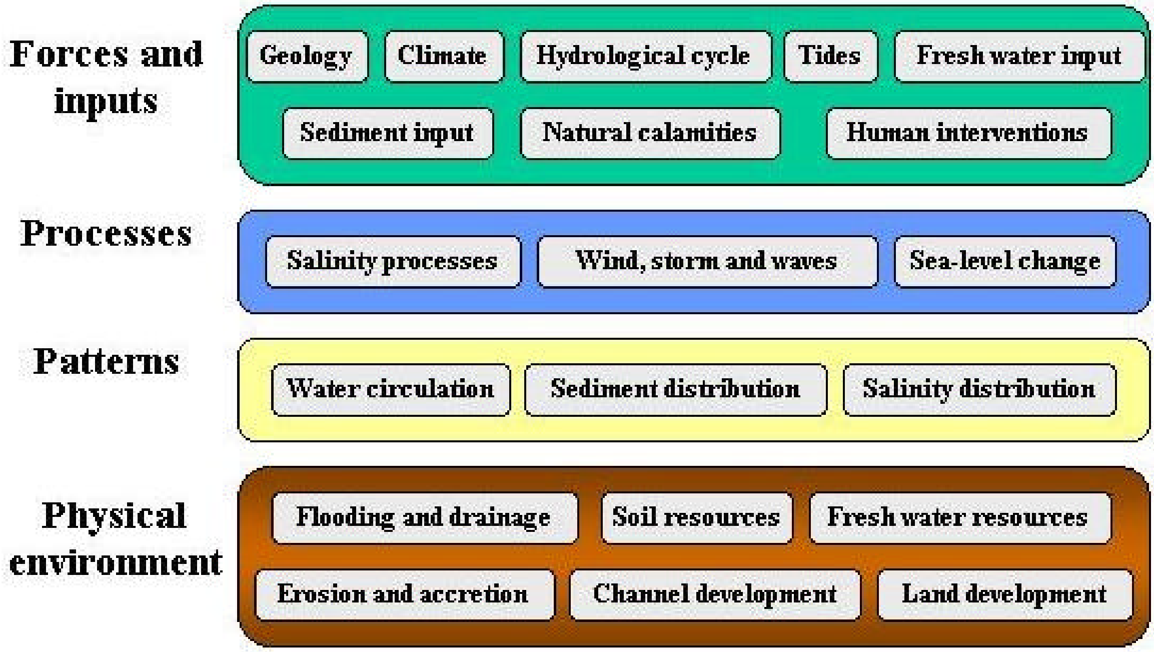
- A brief overview of the main physical processes in the estuary is provided to help understand the complexity of the estuary development. A brief description of the most relevant aspects/issues are presented. Clicking on the *issues* button will facilitate the navigation through the portal.

- A comprehensive logical model of relationships between different physical factors and their impacts on the estuary is available to guide the KPED-visitor. It starts from *forces and inputs* (geology, climate, hydrological cycle, tide, fresh water input, sediment input, natural calamities, human interventions), goes through *resulting processes* (e.g., salinity processes, wind-storm-waves and sea-level changes), and combines these processes to the *patterns of water circulations and sediment and salinity distribution*. All of these determine the physical environment (flooding and drainage, soil resources, fresh water resources, erosion and accretion and channel development) for the people living and working in the estuary. From here it could link to other information on the ecology and the socio-economic system of the area.

The KPED has the potential to link to existing database for downloading concrete data. It is hoped that in the near future such a link can be established with the National Water Resources Database (NWRD) housed at WARPO as well.

Model

Model


Forces and inputs
Geology
Climate
Hydrological cycle
Tides
Fresh water input
Sediment input
Natural calamities
Human interventions
Processes
Salinity processes
Wind, storm and waves
Sea-level change
Patterns
Water circulation
Sediment distribution
Salinity distribution
Physical environment
Flooding and drainage
Soil resources
Fresh water resources
Erosion and accretion
Channel development
Land development

1. Forces and inputs

1.1 Geology

Bangladesh is mainly underlain by sedimentary deposits accumulated between 1.6 million years to recent times (during the Quaternary period of the geological time scale) covering more than 85% of the land that are mostly flat and in some places slightly undulating in character. Folded hills constituted by sedimentary rocks deposited during 15 to 1.6 million years (Tertiary to Early Quaternary) occupy the rest of the country. Older deposits of reddish to brownish sediment forming undulating terrains (terraces) are located mainly in two areas of the northern half of the country and occupy about 10% of the Quaternary deposits (Fig. 1).

Geological data of an area provides an idea to users, especially to planners, about the tectonic setup (subsurface setup of the basement), sediment characteristics of the overlaying deposits, recent gradual land movements and earth movement resulting from earthquakes, presence of faults and lineaments (fractures in the earth surface), and history of development of the land and their morphological characteristics. Geological and geomorphological data (maps) thus provide a necessary basis for groundwater management (arsenic contamination), planning and building of roads, defining routes for pipelines, recognizing deposits of building materials and peat, etc. Geological and related data also play an important role in large scale infrastructure development like, construction of embankments and cross-dams for land reclamation, and provide necessary information to protect the coastal areas from the menace of water-logging, riverbed siltation and coastal erosion, as well as to identify the areas vulnerable to natural hazards.

Related topics: Natural calamities, Arsenic, Groundwater

1.1.1 Tectonic setup

Tectonic setup provides an idea as to how and whether the basement rocks or the parent rocks exposed or situated at depths are structured. Different parts of the basement behave differently due to regional or local tectonism resulting from plate movements (collision), isostatic balance (subsidence and upliftment) and earthquakes. The mechanism for land reclamation, coastal erosion and deposition is depended on the tectonic behavior of an area. Bangladesh is divided into different tectonic elements on the basis of basement behavior and fault characteristics.

Regional Tectonic Setup

Bangladesh constitutes the major parts of the Bengal Basin, a structurally complex area due to the presence of an active Himalayan folded belt (thrust belt) in the north and Indo-Burman fold belt in the east. The Bengal Basin is surrounded by the Archean (3.8 to 2.6 billion years old) Indian Platform (Shield) in the west, Tertiary (time range between 65 to 1.6 million years) and, in part, Mesozoic (225 to 65 million years) metamorphic Indo-Burman ranges in the east (Shamsuddin and Abdullah, 1997), and the Archean basement of the Shillong Plateau in the north. The Bengal Basin is open to the Bay of Bengal in the south (map).

Aeromagnetic and gravity anomaly information indicates that the basement arches floor the plain and platforms, in association with a diverse assemble of faults or flexture zones. The tectonic elements are Sub-Himalayan Foredeep, Rangpur Saddle, Bogra Shelf, and Bengal Foredeep, including three troughs namely the Faridpur trough, the Sylhet trough and the Hatia trough or Patuakhali depression, and one gravity high or the Barisal gravity high as well as the eastern folded belts (map). The basement rock is only a few hundred meters below the surface at the northwestern part of the country whereas it is at a depth of more than 20 km in the Hatia trough or Patuakhali depression (Shamsuddin and Abdullah, 97).

Local

The Meghna Estuary lies on the southern part (Patuakhali depression) of the Bengal Foredeep tectonic unit of the Bengal Basin. The Patuakhali depression is bound by the Barisal gravity high (an uplift) in all directions except for the eastern folded belts which bind the eastern part (Shamsuddin and Abdullah, 97). The Patuakhali depression is formed by relative subsidence of the basement complex along deep-seated faults, with a deep flank at the western zone.

Mostly sedimentary rocks from Carboniferous to recent ages (345 million years to present) overlie the basement rock in the investigated area and are unfolded in character. The thickness of the sedimentary rocks above the basement increases in two directions from west to east and from north to south with a general trend in the southeast direction keeping the trend of the basement topography.

Related topics: Natural calamities, Long-term sediment budget, Drainage

1.1.2 Sediment characteristics

Surficial sediment

The Meghna Estuary is situated in the lower deltaic plain of the Ganges-Brahmaputra-Meghna (GBM) delta system. A Meso- to Macro-tidal environment, having a tidal height ranging from 2 to > 4 meters, prevails in the area and contributes significant intertidal deposits. Sand, silt, clay and their mixtures constitute the surface layers in the different environments of deposition (map). All the sediments of the area have been deposited under a fluvio-tidal environment.

Subsurface

Holocene (last 10 thousand years) grey to olive-grey sediment in the Meghna Estuary are 55 to 70m thick resting on Pleistocene (older than 10 thousand years) brownish- to reddish-stiff clay in some places and clean comparatively well-sorted fine to medium sand in others. The generalized Holocene stratigraphic sequence of the estuarine plain (Fig) shows that a 35 to 40-m-thick sandy mud to muddy sand deposit overlies the Pleistocene deposit followed by a deposit of alternating silt and sand. The thickness of the latter unit varies between 15 and 20m. The surface layer consists of mostly silt or silty loam with mud in some places of a 3 to 5-m-thickness. The upper layer generally lacks preserved organics (wood, or shells), although peat layers do alternate with the mud deposits in local basins.

Related topics: Erosion and accretion, Soil resources

1.1.3 Neotectonics (Recent Tectonics)

Data on recent local earth movement (neotectonics) is very important as it is directly related to the shaping of the area (in this case, the Meghna Estuary) and sea level variation due to global and local factors. Subsidence, upliftment and earthquakes are the factors controlling the recent tectonic activities in the Meghna Estuary. The tectonic movements affect sediment dispersal and redistribution.

Subsidence

An interpretation of radiocarbon dates shows different rates of subsidence in the different parts of the lower delta plain. Adjustment of isostatic balance and neotectonic activities due to the presence of a reasonable number of subsurface faults and lineaments might be the reason behind the differential subsidence rates.

The subsidence rate in the northern part of the Meghna Estuary is about 2-3 mm/yr, whereas it is about 4-6 mm/yr in the southern part. The high sedimentation rate in the Patuakhali coastal part indicates a higher rate of subsidence of the Patuakhali tectonic depression (a tectonic low) in comparison with adjacent tectonic elements.

Upliftment

Most parts of the Chittagong coastal belt fringing the Tertiary hills have been undergoing upliftment as a combined result of the sub-plate convergence and also due to the isostatic balance. A huge pile of sediment that have been depositing just west of the belt is continuously subsiding in order to accommodate more sediment in the basin and thus resulting into an upward pushing of the eastern part to maintain the isostatic balance. The rate of upliftment is yet to be determined but the estimation is at the range of 1 to 1.5 mm/yr.

Earthquakes

Earthquakes are the detectable shaking of the earth's surface resulting from seismic waves generated by a sudden release of energy from inside the earth. Recent earthquake data indicate that Bangladesh is not really an earthquake prone country; however, some large earthquakes have occurred in the past in and around the country. Earthquakes of smaller intensities (<4.0 MB in Richter scale) have been regularly shaking the Chittagong coast for the past couple of years although no remarkable damage has been reported.

Considering the past earthquake records and the geological setting of the country, Bangladesh has been divided into three seismic zones with respect to the ranges of seismic co-efficient. So far, the map is very popular among the users of earthquake information. The area falls within the smallest earthquake potential region (Zone-I) in Bangladesh (map) where the maximum probable earthquake shock would be VII on the Modified Mercali Scale or 6 to 6.5 on the Richter Scale (Bangladesh National Building Code, 1992). The basic seismic coefficient for Zone-1 is 0.08 whereas the peak ground acceleration could be $3.50M/S^2$. Earthquakes of this intensity are severe and could damage buildings.

Related topics: Natural calamities, Flooding and drainage, Floodplain sedimentation

1.1.4 Faults and lineaments

Faults are displacements of some parts of the earth crust where the displacements can take place in any direction (vertical, oblique and transverse or sideways). Faults can extend from the surface up to a couple of kilometers below the surface and may be present in the subsurface covered by younger sediment. The surface faults are detectable in the field as well as on the images. Any linear features detectable on images are usually termed as lineament and these could be either the signature of subsurface faults or natural or man-made features like roads, canals, etc. Detection of faults and lineaments is important as these are the areas of weakness of the earth crust requiring special attention as they are susceptible to damage in the event earthquakes occur. Therefore, special attention or design is required to avoid future disasters.

In Bangladesh and adjoining areas, there are a number of regional faults and lineaments along with smaller faults. The prominent ones are the Tista lineament, Bogra fault, Padma lineament, Kolkata-Mymensingh lineament, Tangail fault, Bagerhat-Brahmanbaria lineament, Bhola-Feni lineament, etc.

Related topic: Natural calamities

1.1.5 Geological history

History of the formation of Bangladesh

Bangladesh, a major part of the Bengal Basin, was formed during the Tertiary (about 55 million years BP) as the Indian Plate broke away from Gondwanaland in the Late Cretaceous (70 to 65 million years BP) and moved toward a collision course with the Eurasian plate (Tapponier, et al., 1986) and continued to be subducted beneath the Eurasian and Burmese plates. The deposition of sediment into the basin accelerated after the Himalayan ranges began to rise (20-17 million years BP), resulting in the formation of the present submarine Bengal Fan and Ganges-Brahmaputra delta.

The eastern part of the Bengal Basin was folded into the broad Tripura-Chittagong Fold Belt in the Late Pliocene to Late Pleistocene (3,000,000 - 10,000 years BP), in response to the eastward subduction and strike-slip movement of the Indian plate beneath the Burmese plate. The anticlinal structures died out rapidly to the west and the western Bengal Basin acquired the characteristics of mostly gentle depositional gradients and low-relief features. The shelf, hinge and trough form a monocline that was maintained by more or less continual subsidence during the Tertiary. At present times, the Indian plate is still moving in the northeasterly direction subducting beneath the Eurasian and Burmese plates. It is most likely that deep-seated faults or zones of weakness affecting recent geology and the recent tilting of some surfaces and subsidence indicate that some isostatic adjustment is taking place. These tectonic elements are likely to contribute to the changes in drainage pattern, sedimentation, and coastal configuration.

History of the formation of the present Meghna Estuary

The paleosurface of the present Meghna Estuary was undulating in character covered by reddish- to brownish- stiff clay and was exposed for a long time (about 20 thousand years) during the last glacial period starting from about 30 thousand years ago. Channels of the former Brahmaputra-Meghna river system were deeply incised into the paleosurface as the sea level dropped up to 120m 18 thousand years ago (BP). Most of the sediment at that time were delivered to the deep sea through the 'Swatch of No Ground' (SONG), presently a submarine canyon, till about 9,000 cal yr BP (Weber et al., 1997). The present delta started to form around the 9,000 to 8,500 calender year BP with an annual sea level rise of about 1 cm (Blanchon and Shaw, 1995) only when the sea level was high enough (-50 to -55 m than the present level) to inundate a considerable part of the paleosurface (Pleistocene surface) and the channels were so back filled that they were no longer able to carry sediment to the deep sea through the 'SONG'. The combined flow of the old Brahmaputra and Meghna rivers used to flow through this estuary from the very beginning of the present delta formation and used to carry sediments to the SONG from the east, while the course of the Ganges River shifted several times from the west to east. The Ganges carried sediment to the SONG from the west at the earlier stage and from the east at later stages about a couple of hundred years ago. The sea transgressed deep into the land about 7,000 years BP when the Brahmaputra River, the major sediment feeder to the delta, changed its course to the inland Sylhet basin and seriously starved the delta followed by gradual land subsidence. The coastline migrated about 80 km north from the present coastline in the western part and about 140 km north in the eastern part of the delta. The modern Ganges Delta together with the Meghna Estuary began to take shape from that time and took its current shape about 3000 years ago when the sea regressed to its present position as the Brahmaputra River again changed its course and flowed to the sea around 5500 to 6000 yr BP, causing seaward progradation of the delta.

Related topics: Fresh water input, Sediment input

1.1.6 Geomorphology

The geomorphology of the coastal areas plays a very important role in storm surge propagation from the coastline towards inland. Storm surges travel longer distances on the plain land with low surface slopes compared to plain land with moderate to steeper slopes. Coastal flooding from the surges is directly influenced by the variation in elevation and surface form. Therefore, there is a clear relation between geomorphology and surge propagation or, in other words, between geomorphology and storm surge height. The higher the elevation of the surface form and steeper the slope, the lower the penetration of surge waters inland and vice versa.

The coastal morphology of Bangladesh is dominated by:

(a) a vast network of rivers, (b) an enormous discharge of river water heavily laden with sediment, both suspended and saltation load, (c) a large number of off-shore islands and sand bars, (d) the Swatch of No-Ground running NE-SW partially across the continental shelf about 24 km south of the Bangladesh coast, (e) a funnel shaped, shallow and wide estuary, (f) a gently sloping wide continental shelf, (f) a narrow strip of coastal landforms fronting hill ranges, (g) strong tidal actions, and (h) frequent landfall of tropical cyclones.

Geomorphological units

The geomorphic units of Bangladesh are grouped into the morphogenetic headings of fluvial, fluvio-denudational, fluvio-marine, marine and coastal, and structural-denudational origins where the landforms of the Meghna estuarine area are mainly fluvio-marine in origin (map).

The geomorphological units of the Meghna Estuary are fluvio-marine in origin and flat in character. The units are mangrove swamps, estuarine mudflats, estuarine plains, tidal floodplains, back swamps/depressions, channel bars, and coastal mud and fan complexes. Sediment coming from upstream through the Bharamaputra-Ganges-Meghna rivers and their distributaries, and sediment redistributed by tides form these landforms. The coastal areas of the fluvio-marine landforms are very susceptible to coastal flooding from storm surges, as these landforms are only elevated 3 to 6 metres above msl and have an almost level topography, criss-crossed by numerous tidal creeks and channels. The sediment are of mixed Ganges and Brahmaputra origin and are therefore slightly calcareous. The relief is mainly smooth and predominantly silty in composition. Estuarine mudflats are almost level recent bars composed of predominantly silty, stratified, and slightly calcareous materials.

Related topics: Water circulation, Short-term sediment budget, Long-term sediment budget, Erosion and accretion

1.2 Climate

Climate has an overarching control on the natural processes and human livelihoods. At the very heart of this region is the delta of the Ganges and Brahmaputra rivers, which is a direct consequence of South Asia's wet monsoon season and which erodes the Himalayas and delivers sediment to Bangladesh. This same climate also seasonally transforms the low-lying country from land to inland sea through intense local rainfall and bank overflow of the rivers. Weather conditions are generally calm during the wet and dry periods, but strong tropical storms punctuate the climate during spring and fall transitions. Beyond regional climate patterns, though, global climate change and variability also have important impacts upon Bangladesh. Major flood years tend to track El Niño oscillations, and it is likely that global warming will increase temperatures, rainfall, and storm activity. The consequences of future climate change are not well known at present, but given the important role of climate in this region, they are conceivably quite significant.

Related topics: Freshwater input, Sea-level change, Storms

1.2.1 South Asian Monsoons

Monsoons are seasonally prevailing winds that are driven between areas of high and low pressure. During the summer when more sunlight hits areas north of the equator, the warming air masses rise and draw winds from the south to form the southwest (SW) monsoon. As the seasons change and the sun strikes areas south of the equator more directly, the patterns reverse and the monsoon winds flow from the north to form the northeast (NE) monsoon. The striking difference between the climates of the SW and NE monsoons, however, is a result of air temperature and humidity. During the SW monsoon, air drawn off the Indian Ocean toward Tibet is warm and moist. This moisture is released as intense rainfall as the winds approach South Asia and the Himalayas. In contrast, air drawn off Tibet and the Himalays during the winter is cool and dry, contributing to the arid, cloudless weather of the NE monsoon. Of course in any given year, the strength of the SW or NE monsoons can vary significantly. These variations generally track global climate phenomena such as El Niño or La Niña, but a complete understanding of these relationships has not been achieved yet. In general though, El Niño events appear to drive a stronger SW monsoon and elevated regional rainfall.

Related topics: Freshwater input, Wind and waves.

1.2.2 Global warming

Global temperatures are increasing and have been doing so for several thousand years since the last glacial period. What remains uncertain is how this trend will continue in coming decades. Although extensive research has improved our assessments of climate change, current estimates vary significantly. The prevailing evidence suggests that humans are enhancing, or perhaps even causing, global warming through the release of greenhouse gases to the atmosphere. The dominant contributions to this are carbon dioxide (CO_2) from fossil fuel usage and deforestation and methane (CH_4) from paddy cultivation and cattle farming. The warming caused by CO_2 and methane is also enhanced because it increases water vapor in the atmosphere. Water vapor traps much more heat than other greenhouse gases. In the foreseeable future, global temperatures are almost certain to continue increasing. The major questions for Bangladesh then becomes (1) how warming will affect the regional climate and (2) what will be the impacts of these changes on natural systems. Ideas on these issues are discussed more under the heading of *Climate Chang*.

Related topics: Global patterns, Sea-level change

1.2.3 Climate change

Extensive research has been conducted on global warming and its role in future climate change. Beyond just understanding why the world is undergoing a warming process, it is important to know how climate and weather patterns are likely to change. Described below are the general changes that are expected and some of their potential consequences. It should be noted, though, that changes are expected to be gradual over the next century, and that deviations from current climate patterns may only be 5% or 10%. Thus, these changes should be considered quite serious but are not meant to be a cause for alarm.

Temperature: Perhaps the most certain trend is that temperatures will increase, but the degree is uncertain. Current best estimates suggest about 2°C in the next century, although the increase at lower latitudes will likely be less. One of the direct consequences of this warming will be a shift in the range of many plant and animal species. Species that are presently constrained by temperature will likely shift their ranges in response to warming. This may have broad and possibly significant consequences. For example, the abundance of cholera disease in Bangladesh is directly linked with higher temperatures in the Indian Ocean through the abundance of its plankton host. Other possible consequences of warming include the spread of some insects, such as disease-carrying species and agricultural pests.

Precipitation: Rainfall patterns are also expected to change in South Asia, with higher temperatures favoring stronger monsoon circulation. This enhanced atmospheric circulation is expected to force wetter wet seasons and drier dry seasons. Potential consequences of this change include more frequent and extensive flooding of Bangladesh. Dry season consequences may be reduced water availability and increased pressure on available water resources. Like temperature, changes in precipitation may also impact the range of plant and animal species that are sensitive to levels of rainfall or aridity. This could have important consequences for cultivation and forestry.

Cyclones: Storm development is also predicted to increase as a result of global warming. Higher temperatures increase the amount of moisture in the atmosphere, which is a primary source of energy for tropical cyclones. This is expected to increase the intensity of storms and thus the frequency of high category events. Also, enhanced temperature gradients between the South Asian landmass and Indian Ocean are likely to increase atmospheric instabilities that lead to storm formation. The expected result is a greater number of storms developing each year, which could mean more frequent and strong storms affecting coastal Bangladesh.

Related topics: Sea-level change, Cyclones

1.2.4 Local rainfall and wind

Rainfall

The climate of Bangladesh is tropical, with a hot, humid summer (March to June), a rainy monsoon (June to September) with predominantly south-westerly monsoon winds, and a dry, relatively cool winter (September to June) with predominantly north-westerly monsoon winds. The annual average rainfall in Bangladesh varies from 1500 to 4,600 mm, most of which falls during the monsoon months. The average rainfall in the Meghna Estuary area is about 2000-3600 mm/year

Wind

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 62.5 m/s, corresponding to 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.

Related Topics: Surface water

1.3 Hydrological cycle

Water exists in a space called the hydrosphere which extends about 15 km up into the atmosphere and about 1 km down into the lithosphere, which is the earth crust. Water circulates in the hydrosphere through paths known as the hydrological cycle, which is schematically presented in the following figure. The cycle has no beginning and no end, and its many processes occur continuously. This cycle is the driving force that brings fresh water and sediment from the land surface to the sea through rivers. The mixing processes of fresh water and sediment with the saline water of the sea form the estuaries and deltas.

In total, there is about $1.39 * 10^{18}$ m^3 of water – implying that it could cover the whole earth surface by more than 2.7 km of depth. About 96.5% of earth's water is in the oceans. Of the remainder, 1.7% is in the polar ice, 1.7% in the ground water and only 0.1% in the surface and atmospheric water systems. It implies that a very small fraction of earth's water is given consideration while dealing with estuary development.

In South Asia, precipitation in the form of rainfall mainly occurs due to the southwest monsoon during June to October. The rivers collect water mostly as surface runoff from the catchments nearly 11 times higher than the area of Bangladesh and deliver to the Bay of Bengal through the Meghna Estuary as surface outflow. Nearly 85% of the total outflow through the Meghna Estuary occurs during the monsoon (5 months).

Related topics: Fresh water input, Sediment input.

1.4 Tide

Tide is the movement of water in the seas and oceans of earth caused by the attraction force of the moon and the sun. The tidal wave observed along the coast of Bangladesh originates in the Indian Ocean. It travels across the deep Bay of Bengal and approaches the coast from the south, arriving at Hiran Point and at Cox's Bazar at about the same time. The vertical water movement of the sea face of the Meghna Estuary causes a tidal wave that propagates throughout the estuary. The tidal ranges vary from one location to the other. Moreover, there is a seasonal variation of the mean tide level in the bay due to the variation of pressure and wind. During the winter, the mean sea level stands about 0.5 m below than the summer.

The tidal wave is one of the major forces driving the water movement in the estuary, and its influence reaches as far as the Padma and Upper Meghna. In combination with the river flow from the Lower Meghna, tidal flows are the cause of the erosion and accretion processes that shape the estuary. The rising flows usually flood large areas of land (floodplains).

Related topics: Water circulation, Sediment distribution, Erosion and accretion

1.4.1 Tidal water levels

The tide in the Meghna Estuary is of the semi-diurnal type, with 2 high and 2 low water levels occurring daily. The period of the tide is approximately 12 hours 25 minutes.

The tidal range (difference between high and low water level) varies with time. The tide with the highest range is referred to as spring tide, occurring every 14 days. The tide with the lowest range is referred to as neap tide, occurring midway between two spring tides. In the Meghna Estuary, the variation from neap to spring tide is approximately 0.6 to 1.4 of the average range. There is a large spatial variation of the average tidal range in the estuary, from approximately 1.5 m in the west to over 4 m in the Sandwip Channel. At spring tide, the tidal range can be close to 6 m near Sandwip and Urir Char.

The Meghna estuary can be divided into 3 zones:

- Tetulia River – Chandpur: *Micro-tidal zone*: tidal range 0 – 2 m,
- South Bhola – Hatia North: *Meso-tidal zone*: tidal range 2 – 4 m,
- East Hatia - Sandwip: *Macro-tidal zone*: tidal range > 4 m.

Tidal waves travelling upstream of the estuary undergo deformation due to the bed resistance and difference in the propagation speed at different water depths (wave travels faster at greater depths). The duration of the trough is much longer than at the top, as during low water the propagation speed is lower than during high water. The most extreme form of this deformation is a so-called tidal bore, where due to the difference in the propagation speed between the top and the trough of the tidal wave, the top travels so much faster that it actually overtakes the trough. The result is a breaking tidal wave, a nearly vertical front of water moving upstream with a roaring sound. Tidal bores are frequently observed south of Urir Char. They present extreme danger to fishing boats.

Also the form of the estuary influences the waves. The Sandwip Channel has a funnel shape, which causes a significant amplification of the tidal wave towards the upper end of the channel.

Related Topics: Sediment distribution, Land development

1.4.2 Tidal flow

A tidal wave travelling through the estuary causes gradients (spatial differences in surface level) in the water surface. As water always flows to the lowest point, these gradients are the cause of tidal flows observed in the estuary. Just like the tidal wave, this flow is periodical and changes from flood when the flow is directed upstream to ebb when the flow is directed back towards the sea. The maximum current velocities in the Meghna Estuary can reach more than 3.5 m/s in the main tidal channels and 0.5 m/s in the shallow areas. The neap tide velocities are generally lower than the spring tide velocities. Sediment distribution in the estuary mainly governed by the magnitude and net flow direction of the tidal flow. Erosion and accretion along the banks and shorelines of the Estuary are very much related to the flow velocities dominated by the tidal flow.

Related topics: Water circulation, Salinity distribution, Sediment distribution

1.5 Fresh water input

Nearly a trillion (10^{12}) m^3 of water pours into the estuary annually from the Ganges, Brahmaputra/Jamuna and Upper Meghna rivers. These rivers drain a basin of about 1,650,000 km^2 of area which is 11 times larger than that of Bangladesh. The Padma River- which is the combined flow of the Ganges and Brahmaputra/Jamuna - has the main contribution in fresh water input in the estuary, i.e., about 90%. The water input in the estuary varies greatly over the year, from 5,000 m^3/s in February/March to 100,000 m^3/s in July to September. The annual variations in peak flow are substantial, being within the range of 70,000 to 130,000 m^3/s. The strong seasonality of the fresh water input has an impact on the water circulation, sediment distribution and salinity intrusion in the estuary. The high input of fresh water also accelerates bank erosion along the Lower Meghna and Shahbazpur Channel. The expected climate change may increase the monsoon flow and decrease the dry season flow of all the rivers.

Related topics: Human interventions. Engineering structures, Impact of human interventions, Climate change, Salinity distribution, Water circulation, Sediment distribution

1.5.1 Brahmaputra/Jamuna River

This river drains the northern and a part of the southern slope of the Himalayas. Its basin area is nearly 570,000 km^2, and it is the highest contributor of fresh water into the estuary – more than 60% annually. Compared to the Ganges River, human interventions are insignificant in the Brahmaputra/Jamuna basin. The flow hydrograph for the Jamuna shows that the average peak (70,000 m^3/s) of the river occurs in July/August and the average minimum flow (4,200 m^3/s) occurs in February/March.

Long-term observation of discharges suggests an apparent (although not significant) trend of increase in the flow volume. Since the seventies, very high variability has been apparent in the annual peak discharges, though the reasons for this trend are not yet clear. This has an impact on the Meghna Estuary, especially in terms of increasing fresh water flows during the wet season.

Related topics: Human interventions. Engineering structures, Impact of human interventions, Climate change, Salinity intrusion, Sediment distribution

1.5.2 Ganges River

This river mainly drains the southern slope of the Himalayas. The area of this basin is about 1,000,000 km^2, the highest among the other major rivers in Bangladesh. It supplies about 30% of fresh water into the estuary. Human interventions in the Ganges basin are very pronounced compared to the other rivers. Several dams and barrages are placed for hydropower generation and diversion of fresh water for irrigation and other purposes. Moreover, intensive cultivation and deforestation have changed the flow regime of the Ganges.

The daily averaged flow hydrograph of the Ganges River shows that peak flow occurs in August/September with the minimum flow occurring in March/April. Long-term observation of discharges suggests no changes in the annual flow volume or in peak discharges. Due to the withdrawal of fresh water upstream for irrigation and diversion of fresh water through the Bagirahti River by the Farakka Barrage, the dry season flow through the river diminishes considerably.

The dry season flow in the Ganges depends mainly on the operation of the Farakka Barrage, which, in turn, depends on the existence of the water sharing treaty between Bangladesh and India. Before Farakka came into operation, the average minimum flow through the Ganges was 2,000 m^3/s, which dropped in 1995 to a minimum of 150 m^3/s at the Hardinge Bridge. The reduction of dry season flow in the Ganges is contributing to the increase in salinity intrusion.

Related topics: Human interventions. Engineering structures, Impact of human interventions, Climate change, Salinity intrusion, Sediment distribution

1.5.3 Padma River

This river is the combined flow of the Brahmaputra/Jamuna and Ganges rivers. Therefore, any change in the flow regimes of these rivers would have an impact on that of the Padma River. A part of the wet season discharge of the Ganges River flows into the Bay of Bengal through the Gorai River downstream of the gauging station at the Hardinge Bridge. During the last decades, the distributaries of the Ganges and Brahmaputra such as the Gorai, Old Brahmputra and Dhaleshwari have been declining. In addition to an apparent trend of increase in the annual flow volume and peak discharges of the Jamuna River at Bahadurabad, the declining distributaries indicate the trend of increase in the annual flow volume and peak discharges of the Padma River. The decline in the dry season flow of the Ganges also contributes to a decline in the dry season flow of the Padma River. Besides, the impact of human interventions and declining of the distributaries, and expected climate change may enhance the present trend of increase in the monsoon flow and decrease in the dry season flow.

A major distributary of the Padma River is the Arial Khan River. This river diverts a part of the fresh water to the west of the Meghna Estuary, which can be considered insignificant if compared to the contribution of the Padma River.

Related topics: Human interventions. Engineering structures, Impact of human interventions, Climate change, Salinity distribution, Sediment distribution

1.5.4 Upper Meghna River

The river drains the Manipura and Meghalaya hills of India. The total basin area of this river is 77,000 km^2, which is much lower than that of the Brahmaputra/Jamuna and Ganges rivers. There is a barrage on the Barak River- at the upstream reach of the Upper Meghna River in India, which partly regulates the flow and sediment regimes of the Upper Meghna River. The river contributes nearly 10% of the fresh water flow to the estuary. During the dry season, the contribution of this river is very insignificant. Long-term observation of the discharges does not indicate any changes in the average or peak flows.

Related topics: Human interventions. Engineering structures, Impact of human interventions, Climate change, Salinity distribution

1.6 Sediment Input

In an estuary, sediment input can occur from the upstream rivers as well as through long shore sediment transport. Little is known about the latter source of sediment input in the Meghna Estuary which is generally assumed to be small compared to the large volume of upstream input. Nearly a billion tons of sediment enters through the Brahmaputra/Jamuna, Ganges and Upper Meghna rivers. Compare to other two rivers sediment input in the estuary is negligible through the Upper Meghna River. According to recent studies, amount of floodplain sedimentations is about 1/3 of the sediment that is carried by the major two rivers. The rest, 660 Mtons, enters the Meghna Estuary through the Lower Meghna River. A part of the sediment forms new land in the estuary, another sets off lateral and vertical accretion of the shelf area, and the rest is lost forever through the canyons in the ocean floor.

Related topics: Sediment characteristics, Geological history, Impact of human interventions

1.6.1 Brahmaputra/Jamuna River

The Brahmaputra/Jamuna is the largest source of sediment in the Meghna Estuary. The Bhadurabad station, situated about 240 km upstream of Chandpur in the northern limit of the Meghna Estuary, is the only sediment gauging station in the Brahmaputra/Jamuna River in Bangladesh. Time-series (although not continuous) sediment measurements since 1964 are available at this gauging station.

The bed materials in the Brahmaputra/Jamuna River comprise fine sand of an average grain size of 0.20 mm, which become gradually finer downstream. The suspended mode of sediment transport is the dominant process in the river. 1/3 of this sediment consists of fine sand and the rest silt and clay. Nearly 500 to 600 Mtons of sediment input is found at Bahadurabad. It has been found that the sand fraction of the sediment has decreased considerably over time, which indicates that there is variation in sediment input in the estuary with time. This is assumed to be the result of the Assam Earthquake in 1950, during which a huge amount of sediment was produced and transported to the estuary through the Brahmaputra/Jamuna River. The high accretion rate in the Meghna Estuary during the last 50 years is probably related to the extra sediment produced by the earthquake.

Related issues: Earthquakes, Geomorphology,

1.6.2 The Ganges River

Although the contribution of Ganges is in supplying the water to the estuary is nearly half of the Brahmaputra/Jamuna River, the sediment supplied by the Ganges is very close to the Brahmaputra/Jamuma. The Hardinge Bridge, located about 180 km upstream of Chandpur in the northern limit of the Meghna Estuary, is the only the sediment gauging station on the Ganges River in Bangladesh. Time-series (although not continuous) sediment measurements since 1964 are available at this gauging station.

The average bed material size in the Ganges at Hardinge Bridge is 0.16 mm, which is finer than that of the Brahmaputra/Jamuna River at Bahadurabad. The grain becomes finer downstream. The suspended mode of sediment transport is the dominant process in the river. 1/3 of the sediment consists of fine sand and the rest consists of silt and clay. Nearly 400 to 500 Mm^3 of sediment input is found at Hardinge Bridge. It has been found that the sand fraction of the sediment has decreased considerably over time (although not to extent as in the Brahmaputra/Jamuna River), which indicates that there is variation in sediment input in the estuary with time. The decrease in the sand fraction of sediment in the Ganges in the seventies and eighties was probably the result of the construction of several dams and barrages in the Ganges basin.

Related topics: Sediment characteristics, Geological history, Impact of human interventions.

1.6.3 Floodplain sedimentation

Almost every year, the main rivers of Bangladesh overspill and inundate nearly 20% of the area of the country. The inundation is partly caused by local rainfall. The overspill, occurring along the main rivers and their tributaries and distributaries, brings a huge amount of sediment and causes it to be trapped in the floodplain. Recent studies show that during the last 10,000 years, about 30% of the river borne sediment has been trapped in the floodplain. A part of the sediment is trapped in the subsiding Sylhet basin and another compensates for the compaction of newly deposited sediment. Although it reduces input in the estuary, sedimentation is maintaining the floodplain by matching the pace of subsidence and compaction.

Related topics: Sediment characteristics, Newtectonics

1.7 Natural calamities

Natural calamities, including earthquakes, floods, droughts, and storms, are frequent phenomena in South Asia. Among these, earthquakes that occurs far from the estuary have long-term effects. On the other hand the cyclones are very frequent in the Meghna estuary and have both short and long term significant effect on physical and socioeconomic impacts.

Some historic earthquakes in India have led to increased sediment delivery to Bangladesh, causing coastal accretion, river course switching, and channel bank erosion. These phenomena have both positive and negative consequences.

The tropical cyclone is another calamity that originates outside the country, typically developing in the southern Bay of Bengal. Several severe events in the recent past rank among the world's worst natural disasters.

In the recent years, the arsenic contamination of the ground water appears to be a disastrous natural hazards. These three natural calamities and hazards are addressed under this section.

Related Topics: Geology, Neotectonics, Climate

1.7.1 Earthquakes

Pressure along fault zones caused by the Indian-Asian collision generates frequent earthquakes in South Asia. Although most of these pressures are weak, occasionally heavy ones build up and cause powerful earthquakes when released. Several such catastrophic events have affected Bangladesh and the surrounding areas in historical times, including two major earthquakes in northeast India (1897, 1950) and two in northwestern and east-central Bangladesh (1885, 1918). Among the direct impacts of these events are building collapse and the destruction of roads, bridges, and flood-control structures (e.g., embankments, polders). In the latter cases, shaking of the ground can cause earthen structures to collapse. Earthquakes can also have more indirect influences, such as inducing river course changes, local sedimentation, and altering channel morphology. The 1885 earthquake is believed to be responsible for the Teesta switching course and draining into the Brahamputra. This greatly increased the Brahmaputra's sand load and induced downstream sedimentation. The subsequent earthquake of 1897 led to the Brahmaputra shifting its course 150 km west to the Jamuna channel. In these instances, changes in the upstream basin likely affected the coastal plain as a result of the altered sediment inputs. An example of this process occurred when the 1950 Assam earthquake introduced a massive pulse of sediment into the Brahmaputra. This pulse is believed to have caused a rapid land accretion in the Noakhali region, a process that was enhanced by the construction of a cross-dam in 1957.

Related topics: Tectonic setup, Land development, Sediment budgets, Cross-dams

1.7.2 Cyclones

Tropical cyclones are responsible for some of the most devastating disasters in Bangladesh, and any strategy for coastal management should anticipate possible impacts of future disasters. Damages from storms are caused by a variety of factors, including high winds, heavy rainfall, and coastal surges. The impacts are even more diverse, affecting agriculture, water supply, sanitation, livestock, wildlife, fisheries, infrastructure, housing, and health. Of course there is also loss of life, as for instance, nearly one million people were killed during two severe storms in 1970 and 1991. One of the least understood impacts, though, is how storms contribute to land formation and coastal dynamics. Tremendous amounts of sediment are redistributed by large storms, with much of it being deposited on the land surface, thus aiding accretion. In the channels too, sediment is moved contributing to major shifts in circulation patterns that do not follow earlier trends. It is for this reason that predictions of channel migration and land accretion cannot be made for more than a year or two into the future. However, the baseline studies by MES and MES-II will allow the impacts of future storm events to be better understood, and thus contribute to improved development plans for the coastal zone.

The frequency of storms varies significantly, possibly following decadal climate patterns related to El Niño and La Niña. For example, of the 35 major storms affecting Bangladesh from 1960 to 1991, 25 events occurred in the first half of this period. Thus, the frequency of storms dropped more than 50%, from 1.6 per year to 0.6 per year. In the coming decades climate change is expected to increase the number and intensity of storms, but that it will lead to greater impacts in Bangladesh is uncertain.

Related topics: Flooding, Climate change

1.7.3 Arsenic

Arsenic-contaminated groundwaters have emerged as a catastrophic problem across much of Bangladesh. The general source of arsenic appears to be iron-oxide coatings on the deltaplain sediments, although these levels are not higher than many areas of the world. In this mineral phase, the arsenic does not pose a human health threath. However, the release of just a small fraction of this arsenic into the groundwater produces the unsafe levels that widely reported in Bangladesh. Across the deltaplain, the distribution of groundwater arsenic is closely correlated with local sediment geology and hydrology, which both control chemical changes in the groundwater and the presence of dissolved arsenic. Specifically in the Meghna estuary region, arsenic in tubewell water ranges from very clean to some of the highest known concentrations. The generally safe wells are located along the western rivermouth (Patuakhali, Barguna) and rivermouth islands (Hatia, Bola), where most tubewells are drilled to great depths to avoid saline groundwater. These deep groundwaters appear to largely free of arsenic. However, it is not known if the shallow groundwaters (< 100 m) of this area are also arsenic free, because there are very few wells at these depths. In contrast, areas along the lower Meghna (Chandpur, Sariatpur, Barisal) generally have high tube well arsenic and some of the highest levels recorded. This contrast with the largely clean wells of the river mouth area is probably related to the depth of tube well installation, which in the lower Meghna area is generally more shallow where most of the high arsenic levels are found. These differences in arsenic distribution present one of the most difficult challenges for comprehensive mitigation of the arsenic poisoning. Certainly any integrated coastal-zone management plan must consider arsenic and hydrology as a key factor for future population growth and groundwater development in the Meghna estuary region.

Related topics: Geology, Ground water.

1.8 Human interventions

Human interventions occur both at the upstream basin area and along the Meghna Estuary. The types and impacts of these interventions on the estuary vary. The impact of human interventions at the upstream basin area is mainly limited to fresh water and sediment input in the estuary, which ultimately influences the patterns in estuary development. Human interventions within the estuary have a direct impact on the patterns such as on water circulation, sediment distribution and salinity intrusion, which in turn have an influence on the flooding, drainage, erosion and accretion.

Related topics: Water circulation, Sediment distribution, Salinity distribution, Flooding, Drainage

1.8.1 Human interventions in the upstream basin area

The Ganges-Brahmaputra-Meghna basin, comprising an area of 1.6 million km^2 in India, China, Nepal, Bhutan and Bangladesh, drains into the Bay of Bengal through the Meghna Estuary. During the last century, different types of interventions were undertaken in the basin like dams, barrages, water diversion canals, etc., in order to exploit the water resources there. Flood control and bank protection also became major issues in the basin during this period, and therefore, embankments and bank protection structures were constructed along the different rivers. As a result of the population growth and technological development in the last century, land use pattern in the basin has changed dramatically. The high population growth has also significantly reduced the forest area.

Although the upstream interventions were set up far away (hundreds to thousands of kilometers) from the Meghna estuary, they have had far reaching impacts. These interventions have changed the water flow and sediment regimes in the Ganges, Brahmaputra and Upper Meghna rivers, and consequently, in the estuary. The impact of each type of intervention may differ from one another.

Related topics: Fresh water input, Sediment input, Erosion and accretion

1.8.1.1 Engineering structures

Engineering structures include dams, barrages, and embankments and bank protections structures.

Dams and barrages

Human interventions are very intensive in the Ganges basin compared to other basins. The interventions include dams and barrages constructed on the tributaries of the Ganges, Brhamaputra and Upper Meghna (GBM) system. The largest intervention in the system is the Farakka Barrage, which was constructed along the main course of the Ganges River.

Dams generally trap sediment except for fine fractions such as silt and clay. Therefore, these dams reduce the input of sand in the estuary, and have little contribution in the net flow therein. But they alter the flow pattern, for example, at the end of the dry season these dams generally stand at their minimum; beginning of the monsoon filling up the lake upstream of the dam delays the monsoon flow in the rivers and thus in the estuary.

The Farakka Barrage on the Ganges River is 18 km away from the Bangladesh border. This barrage became operational in 1975, and since then has been diverting water during the dry season through the Hoogly River. Its impact on the distributaries of the Ganges, like the Gorai River, is in terms of causing a decline in their flow. As less monsoon flow is conveyed through the Gorai River, more water is delivered by the Ganges to the Meghna estuary. But diversion of water at the Farakka barrage leads to a decrease in dry season fresh water input in the estuary causing an increase in salinity intrusion.

Embankments and bank protections structures

In Bangladesh, many embankments were constructed in the 60s and 70s for flood protection along the banks of the main rivers upstream of the estuary. No information is available on the Indian part of the rivers. These embankments prevent water and sediment flow into the floodplain, thus increasing wet season water and sediment input in the estuary.

Bank protection structures were constructed along the banks of the main rivers and its tributaries both Bangladesh and India. Impacts of these structures are likely to be limited within localized scale. Probably bank protection structures along the upstream rivers do not have any impact on the estuary.

Related topics: Erosion and accretion, Salinity distribution

1.8.1.2 Changes of land use

Nearly 45% of the population of India, the total population of Nepal, Bhutan and more than 1 million of Tibet's population, in total near about 500 million people, live in the basin of the Ganges, Brahmaputra and Meghna rivers. Adding the population of Bangladesh makes the estimated population in the region about 600 million. The rate of population growth in this region for the last few decades has been about 2%. Most of the people here live below the poverty line. An intensive use of land in the basin area has been observed since the middle of the last century to meet with the demand for food and shelter for an increasing number of people. At the same time, more and more areas are coming under cultivation and day by day the withdrawal of water for irrigation is increasing.

The changes in land use and withdrawal of water for irrigation are causing more sediment during monsoon and less water during the dry season to enter the estuary.

Related topics: Erosion and accretion, Salinity distribution

1.8.1.3 Deforestation

In India, about 30 million ha of forest lay in the Ganges-Brahmaputra basin, and about 5 million ha is located in Nepal. These estimates of the forest cover were made in the early to mid eighties. Another 2 to 3 million ha of forest can be assumed for Bhutan, but the exact figure is not known.

Due to the high population density and growth rate, forests were converted to agricultural lands all along the basin of the Ganges, Brahmaputra and Upper Meghna River. In India, the annual deforestation rate is estimated to be in the range of hundreds of thousands ha. Deforestation is also intensive in Nepal.

Although scientifically not well studied, it is generally believed that flood intensity increases with increasing deforestation. Deforestation also increases sediment input in the river.

Related topics: Erosion and accretion, Salinity distribution

1.8.1.4 Impacts of upstream interventions

A qualitative diagram of the impacts of upstream human interventions on the flow and sediment input in the estuary is presented in the following table:

Interventions	Water input		Sediment input	
	Dry season	Wet season	Sand	Silt + clay
Dams	0	0	-	0
Barrage	-	+	-	0
Embankments	0	+	+	+
Land use	-	0	0	+
Deforestation	-	+	+	+

Note: '0' stands for no change, '-' stands for decrease and '+' stands for increase

The qualitative assessment indicates that human interventions may cause an increase in wet season flow and a decrease in dry season flow. Furthermore, they may reduce coarse sediment (fine sand) input in the Meghna estuary.

Human interventions are very pronounced in the Ganges basin. The analyses of the discharge and sediment gauging data of the Ganges at the Hardinge Bridge showing the increase of monsoon discharge and decrease of the coarse sediment supports the above assessment.

Related topics: Erosion and accretion, Salinity intrusion, Sediment input

1.8.2 Human interventions within the estuary

People used to protect their lands from salt intrusion by constructing low height dykes. The dykes saved their homestead vegetation and Rabi crops planted in relatively high lands. These types of interventions were made in the estuary over several hundreds of years. But from the 50s and 60s, large-scale human interventions were initiated such as cross-dams for accelerating the land accretion process, embankments for empoldering different land masses to protect the land from tidal flooding and salt intrusion, and construction of bank protection structures. These interventions have largely altered the landform in the estuary area. They have also changed tide induced water circulation, sediment distribution and tidal ranges. As a result, flooding, drainage and salinity intrusion etc., in the estuary have undergone considerable changes.

Related topics: Flooding, drainage, Salinity distribution, Erosion and accretion

1.8.2.1 Cross-dams

Cross-dams are expected to speed up the natural process of silting up of channels, thereby creating new land, which can be used for agriculture or settlement. The effects of cross-dams are generally local. Tidal channels fill up with sediment when their flow is stopped or greatly reduced. A large cross-dam (12 km long) was first constructed in 1957 on the eastern anabranch of the Lower Meghna River connecting the Ramgati Island to the Noakhali mainland. This anabranch had been silting up over a few decades prior to 1957. A second cross-dam was constructed further downstream of the same river bed connecting the Char Jabbar to the mainland in 1964. Within a few years, these cross dams accelerated the net accretion of land (20,000 ha).

Several studies have been conducted on the construction of new cross-dams in tidal channels, and it has been found that the favourable returns of the Noakhali cross-dam are not likely to be achieved through the construction of other such cross-dams. The huge sediment input in the estuary generated by the 1950 Assam earthquake is believed to play the main role in accelerating the sedimentation rate in the Noakhali area.

At this stage of the estuary development, the best effects can be achieved by closing relatively narrow tidal channels with high sediment concentrations. Experiments by MES at Char Montaz and Nijhum Dwip (trial dam) have confirmed this assumption. However, blocking of flow can cause undesired effects. Numerical simulations show that the Sandwip cross-dam, considered in the past, could amplify the tidal wave. An increase in the high water levels could endanger the polder embankments at Sandwip. Higher water levels also mean that more time will be needed for new chars to emerge above the high water and become stable land. If the level of new chars becomes higher than the level of the present stable land, problems with drainage can be expected (e.g., as in the case of the Feni River).

Related topics: Natural hazards, Erosion and accretion, Drainage

1.8.2.2 Polders

Polders are constructed by enclosing a piece of land by embankments. This way the tidal plains are protected from tidal floods and salinity intrusion. In the 60s and 70s most of the land in the Meghna Estuary were brought under the polder system. The embankment of the polder not only protects land from tidal floods, it also protects it from nominal storm surges. The poldering also helps to reduce soil salinity and contributes to the formation of soils.

Newly accreted lands like the Urir Char, Char Bouy, and Char Gajaria have not yet been brought under poldering. The poldering restricts sediment deposit on the tidal plain, and therefore, prevailing rate of subsidence cannot be compensated by the sedimentation. This would have negative long-term effects due to the relative sea-level rise.

Poldering has modified the tidal water circulation and reduced the tidal volume in different tidal channels and creeks, resulting in the reduction of their sizes. The sudden decrease in the size of the tidal channels may enhance the tidal range.

Related topics: Storms, Impact (sea-level change), Neo-tectonics

1.8.2.3 Bank protection works

Bank erosion is a very common phenomena in the estuary area. The annual rate of erosion of both old and new land is about 10,000 ha. This causes enormous suffering to the people. Although accretion is the dominating process in the Meghna Estuary, the value of eroding land cannot be compensated by the newly accreted lands. In that consideration, erosion causes huge national losses every year.

Considering the extent and magnitude of suffering, little was done to protect the land of the estuary. Only recently some test bank protection structures were tried in the Meghna estuary area, especially along the left and right bank of the Lower Meghna River. It is expected that in the near future more bank protection structures will be constructed to protect the old and matured land in the estuary.

Related topics: Erosion and accretion

2. Processes

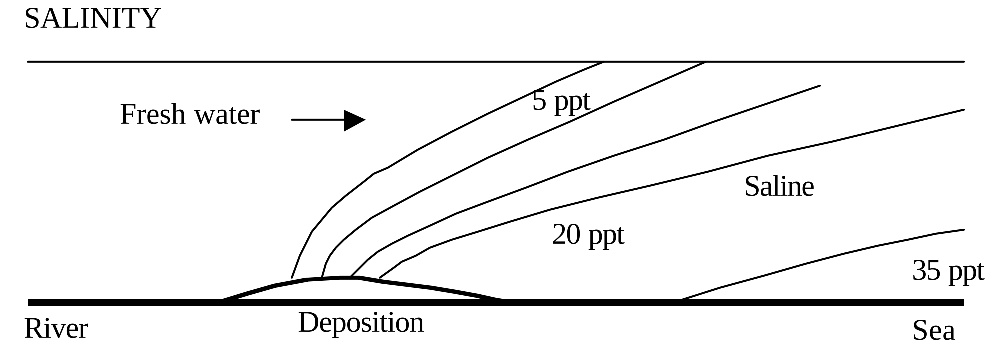
2.1 Salinity processes

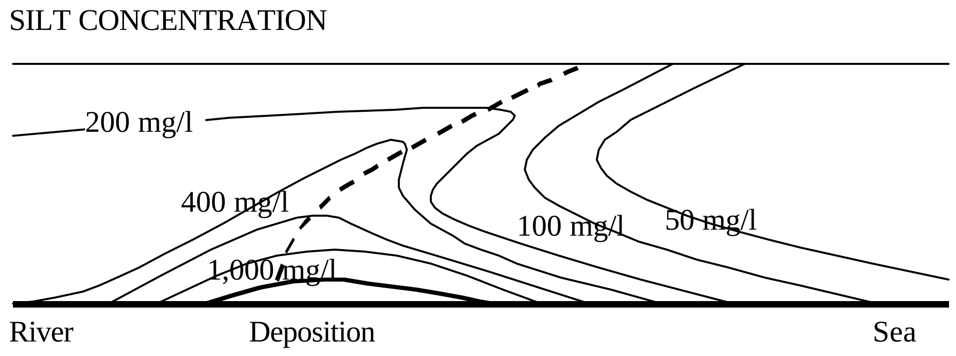
Salinity plays an important role in the delta formation process. The landward intrusion of saline water determines its usability for drinking and irrigation. The spatial distribution and concentrations of salinity in the estuary are important for the deposition of silt and clay. Vertical stratification (vertical variation) of salinity during the wet season may play a role in the seasonal storing of sediment at the outskirts of the estuary.

Related topics: Fresh water input, Sediment input, Sediment distribution

2.1.1 Stratification

The Meghna Estuary is generally a well-mixed estuary where the salinity is constant in a vertical water column. The estuary is too shallow to create stratification of this water column. Measurements by LRP and MES show that during the monsoon, an approximately 100 km long zone (Kutubdia-Sandwip) develops in the south-east end of the estuary where stratification occurs. In this zone, a layer of brackish water moves with the tide over a salt wedge. It is expected that during the monsoon, stratification may also occur at the south and southwest (of Hatia-Bhola) boundaries of the estuary where the shallow waters (10 m contour) end. A large portion of the sediment is transported towards this zone by the fresh water flow. Sedimentation is generally higher (Fig) at the front of the stratified layer. The influence of the stratification in the Meghna Estuary has not been studied well, but it could be assumed that it may significantly contribute to the temporary storage of monsoon sediment in the shallow shelf area outside the estuary. There is a general belief that during the dry season, a part of the sediment is brought back into the estuary through a so-called tidal pumping process and deposited there.





Flow, salinity and silt/clay zone of deposition near the salt wedge in a stratified estuary

Related topics: Fresh water input, Sediment input, Sediment distribution

2.1.2 Influence on sediment

When the fine fractions (silt+clay) of riverine sediment mix with salt water, flocculation occurs. Flocculation increases the fall velocity of fine fractions and thus enhances deposition of sediment. As flocculation increases with increasing salinity, it facilitates the deposition of sediment in favourable conditions of flow velocity and turbulence.

The pattern of sedimentation is different for the stratified and well-mixed areas. In the stratified areas, sedimentation is very pronounced at the front part of the salt wedge (Fig), while in the well-mixed waters sedimentation may occur anywhere, depending on the tidal flow velocities and turbulences. During the monsoon, most of the sedimentation is expected to occur in the stratified areas far away from the coast. This does not imply the there would not be any sedimentation in the estuary, but compared to the total sediment input there, the amount might not be significant. During the dry season, the tidal pumping process brings sediment from the south towards the land. During the period, salinity increases in the estuary and facilitates sediment deposit where favourable environment prevails.

Related Topics: Fresh water input, Sediment input, Sediment distribution

2.2 Wind, Storm and Waves

The wind pattern in the Bay of Bengal, including the Meghna Estuary region, shows a seasonal variation. During the dry season, the wind velocity is very low and it mainly blows towards the offshore direction. During the wet season or monsoon, the wind blows from the south south-east direction with an average velocity varying between 8 m/s and 12 m/s. In the transition between dry and wet season, storms or cyclones may occur mainly during April-May and October-December. Information on wind direction and velocity distribution in the Meghna Estuary region throughout the year (on a daily basis) can be found at *http://12.150.207.161/fileimages/wpac_36.gif*. The wind distribution and low pressure during monsoon produces a monsoon set-up along the coast, which is different from the effect of storms or cyclones. The monsoon wind and low pressure result in a general rise of sea level along the coast, which is termed as monsoon set-up, whereas storms or cyclones mainly cause storm surges. The wind can also produce wind waves and wind induced circulation.

Waves generally play a less important role in the Meghna Estuary. Wave conditions are rather mild, as the energy is dissipated on the shallows of the estuary. However, during heavy storms, and in particular during cyclones, high waves can build up and pose a threat to life and property.

Related topics: Climate, Natural hazards, Tide, Flooding, Sea-level changes, Water circulation.

2.2.1 Wind

When the wind blows over the sea during the wet season or monsoon, the sea level starts rising, particularly near the coast. Although the effective wind stress is the same on deep and shallow water, the funneling shape and shallowness of the bay near the coast causes the sea level to rise more near the coast than at the deep ocean. The effect is more pronounced with the increase of wind speed. The model study shows that as the monsoon winds blow over the sea, water level rises along the

Bangladesh coast including the Meghna Estuary. On average, an expected maximum monsoon wind speed of 12 m/s over the sea can cause a sea level rise of 25 cm above the normal tide along the coast. The resulting backwater effect due to this wind set-up can reduce the conveyance of outgoing flow of the Meghna Estuary by about 30%.

Return Period (Years)	Wind Velocity (m/s)	Significant Wave Heights (meter)
1	**8**	**0.42**
10	**16**	**0.96**
100	**20**	**1.25**

Related topics: Climate, Tide, Flooding and drainage, Sea-level changes, Water circulation.

2.2.2 Storm

General information: The Bay of Bengal is the breeding sea for tropical cyclones. Most of the devastating cyclones in human history formed here with the most severe having occurred in 1876. Cyclones, which affect the Bangladesh coast, originate mainly near and over the South Andaman sea and the South Bay of Bengal. April to May and October to mid December are the periods when westward propagating minor tropical disturbances near and over the South Andaman sea and the South Bay of Bengal develop into cyclones. The nomenclature used to classify this tropical disturbance is:

Wind speed range (km/hr)	Nomenclature
>30	Low pressure area
31 – 50	Depression
51 – 61	Deep depression
62 – 88	Cyclonic storm
89 – 117	Severe cyclonic storm
118 – 220	Very severe cyclonic storm
>221	Super cyclonic storm

Formation: When cold air mass is located above an organized cluster of tropical disturbance, an unstable atmosphere results. This instability leads to strong updrafts that lift the air and moisture upwards, creating an environment favourable for the development of high towering clouds. A tropical disturbance is born when this moving mass maintains its identity for a period of 24 hrs or more. This is the first stage of developing a cyclone. The air cools as it rises and condensation occurs. The condensation of water vapour to liquid water releases the latent heat of condensation into the atmosphere. This heating causes the air to expand, forcing the it to diverge at the upper level. Sine pressure is a measure of the weight of the air above an area. Removal of air at the upper level subsequently reduces pressure at the surface. As long as favourable conditions exist, this process continues to build upon itself. These winds draw thunderclouds around the storm, creating the spiral rain bands that are clearly visible on the satellite image of the storm. The winds spiralling around the central core create the eye of the tropical cyclone. Since the main source of energy for the storm is the heat contained in the warm tropical ocean, if the storm moves over the land, it is cut off from its source of heat and will rapidly dissipate.

Landfall: Satellite images and radar data from land-based stations are used to track the position and probable location of the landfall of a cyclone. Because cyclones are influenced by large-scale air masses, they sometimes move along rather erratic paths. The location of landfall of some major cyclones during 1960 to 1991 along the Bangladesh coast, including the Meghna Estuary region, is shown in *Figure* (map of cyclone landfall). During this period, 25 out of 36 cyclones, which crossed the Bangladesh coast, made a landfall on the Meghna Estuary.

Storm Surge: During 1797 to 1991, this country was hit by 59 severe cyclones, 32 of which were accompanied by storm surges. Cyclonic storm surges form in the deep sea. The surges are in part due to pressure drops and in part due to blowing wind. The surges move toward the coast as long waves. Storm surges are not appreciable in the deep sea until they reach the continental shelf, which is 150 km to 300 km long from the coastline of Bangladesh. The important factor, which causes amplification of the height of a cyclonic storm surge, is the long and shallow continental shelf of the Bay of Bengal. The height of storm surges also depends on the tidal cycle. If a storm approaches the coast during the high tide, the surge will be higher than if it approaches during the low tide. In the Meghna estuary, storm surges propagate deep into the mainland through the river channels and at heights comparatively greater than any in other parts of the coast. The height of storm surges in the Meghna Estuary can be as high as 8 m. The historical record of storm surge height, wind speed and damage assessment along the Bangladesh coast including the Meghna Estuary is shown in the table *(Table for Chronology of major cyclones and storm surges in Bangladesh)*.

Return Period (Years)	Surge Height (meter)
20	4.8 ± 1.0
50	6.5 ± 1.4
100	7.8 ± 1.8

Related topics:Climate change, Cyclone, Human interventions, Tide, Flooding, Sea-level changes.

2.2.3 Waves

No wave heights had been recorded during severe storms until now. Wave measurements over the period December '96 - March '97 indicate that the wave heights in the landward part of the estuary do not exceed 0.4 m due to moderate wind conditions. Wave models indicate that under the prevailing S-SE winds (with an 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 lower than 0.6 m. During the monsoon season, wave heights exceed 2 m.

Higher waves may occur mainly in the pre and post monsoon periods during cyclones. In a study carried out under the Second Coastal Embankment Rehabilitation Project, the following estimates were compiled for the offshore wave heights:

Return Period (years)	Wind Speed (m/s)	Water depth (m)		
		20	15	10
		Wave height (m)		
5	46.6	7.6	6.1	4.5
10	53.2	8.2	6.6	4.9
25	60.9	9.0	7.2	5.3
70	68.5	9.6	7.8	5.7
100	71.0	9.9	7.9	5.9

The maximum wave height is limited by the water depth. The depth of 20m is representative of a deeper part of the continental shelf. In the estuary, depths are generally lower. Taking into account cyclone surges, the water depth in the estuary will be less than 5-10m. Waves higher than 0.6-0.8

times the local water depth will break due to insufficient depth. Still, waves higher than 5m can be expected in the outer part of the estuary during a cyclone.

Waves generally influence sediment transport in the shallow areas. Especially during cyclones, waves have an important role in sediment redistribution in the estuary, although no quantitative data is available. Waves often cause erosion of shorelines, and embankments of polders. In designing any structures along the coast or in the bay, it is necessary to know the wave height and length in order to estimate the design energy load on the structure.

Related topics: Sediment distribution, Poldering and bank protection structures

2.3 Sea-level Change

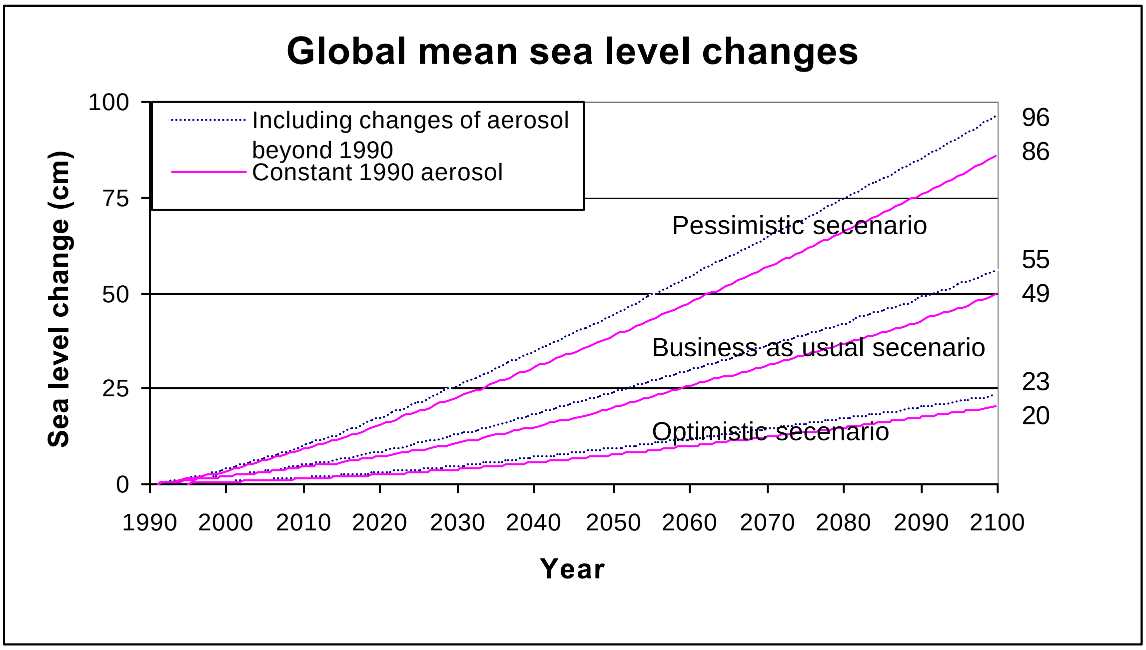
Sea level is a major control of the world's coastlines, particularly for low-lying areas such as Bangladesh. In this region, important coastal-zone responses such as shoreline erosion, coastal flooding, land formation, and salinity intrusion are closely linked with sea-level change. Unfortunately, sea surfaces vary many meters with tides, winds, and storms, and these factors make longer-term sea-level change difficult to detect. Typically, the annual rates of sea-level change are less than a few millimeters. However, there are currently no data records in Bangladesh that are sufficiently accurate to measure these changes. Furthermore, the sea level is controlled by both global and local factors. Global sea-level changes are fairly well known, but local factors in Bangladesh, such as land subsidence and uplift, are quite poorly known. The potential consequences of sea-level change are great in Bangladesh, but future changes and how the delta will respond to them need to be taken well into account.

Related topics: Climate change; Salinity intrusion; Land formation; Flooding

2.3.1 Global Patterns

Historical Trends: The rates of global sea-level change, called *eustacy*, are difficult to determine because of complications from local factors. However, the most current estimates from tide-gauge records and satellite data fall in the range of 1-2 mm/yr. The most useful tide-gauge records extend back roughly one-hundred years, and these suggest that the rates of sea-level rise have nearly doubled in this time. This trend has also been observed from very accurate satellite-altimetry records. These satellite data suggest that the global rates of rise may have increased to more than 2 mm/yr for the past 10 years.

Causes: It is widely agreed that global sea-level rise is a consequence of climate warming. Increasing temperatures contribute to rising sea level through two major responses: (1) thermal expansion of the oceans and (2) melting of land-based ice. The retreat of small mountain glaciers has been widely documented in the past century although it has only contributed slightly to the sea-level rise. In fact, the melting of the massive ice sheets of Greenland and Antarctica is potentially much more significant. At present, scientists are not certain as to how these ice sheets will respond to continued global warming, and recent measurements have not revealed any clear trends. With regard to thermal expansion of the oceans, this process refers to the slight expansion of water as it warms. In the past 50 years, the upper 300 m of the oceans have warmed about 0.5°C on average. Recent studies suggest that rather than ice melt, thermal expansion from ocean warming has been the major contributor to recent sea-level rise.



Predicted sea-level changes under different scenarios

Related topics: Climate change, Salinity distribution, Land development, Flooding

2.3.2 Local causes and rates of change

Causes

At any particular location around the world, the elevation of sea level and the rate of change result from both global and local factors. Together these are called *relative sea level changes*. The local components of sea-level change are mainly a result of vertical land movement, which affects the coastal elevation in relation to the sea level. The major causes of vertical land movement are (1) tectonic activity and (2) compaction of sediment. In Bangladesh, both these processes are important, but their rates and distribution are not well known. Tectonic activity is perhaps the most significant along the southeastern coast due to the land uplifting along the Indo-Burmese mountain belt (i.e., Chittagong Hill Tract region). Such uplift might also extend into the eastern Meghna Estuary, such as the Noakhali area. Along the central Meghna Estuary, tectonic activity may be lowering the coast through subsidence (sinking of land under the weight of thick delta sediment). In southwestern Bangladesh, tectonic activity is not as significant since it is distant from the mountains and since the delta deposits are relatively thin. The second major component of local sea-level change is sediment compaction. Compaction occurs as water between sediment grains is forced out under increasing pressure, resulting in slight consolidation and lowering of the land. This occurs less in sandy deposits and more in mud, clays, and peat. Thus, areas in the central delta where there are extensive beels and basins (e.g., in Gopalganj, Jessore) may be affected by sediment compaction. It should be noted that in many deltas, the extraction of groundwater by humans has induced sediment compaction and lowering of the land. In the Ganges-Brahmaputra delta, however, this consequence is not believed to be significant owing to the dominance of sandy subsurface sediment.

Rate of change

The rates of relative sea-level change in Bangladesh are not well known as the tide gauge records typically used for these calculations are either too brief or of poor quality. Alternatively, a less accurate calculation of relative sea-level change can be made by summing up the estimated global rates with estimated rates of local land movements (i.e., compaction, uplift, or subsidence). So, the average global rate is about 1.5 mm/yr, although this figure will vary slightly due to regional differences in the earth's structure (see *Future Impacts*). Unfortunately, vertical land movements in Bangladesh are poorly known, but these are estimated to be less than 1 mm/yr in the Meghna estuary. Thus, the rates of relative sea-level rise along the eastern delta coastline (Kalapara to Noakhali) are probably 1.5-2.5 mm/yr. These rates reflect the global rise trend and the slow subsidence and compaction of the land surface. Along the southwestern coast (Chittagong to Teknaf), the relative sea level is likely to become stable or even fall due to the tectonic uplift. However, a critical point here is whether this tectonic uplift is slow and continuous or occurs in large, infrequent jumps. The former case would cause a stable or falling sea-level. In contrast, the latter case could ensure that the sea level continues to rise in the coming decades until an uplift event occurs in response to an earthquake. Needless to say, better knowledge on the rates and patterns of relative sea-level change are needed for developing successful coastal management strategies.

Related Topics: Tectonic setup, Neotectonics, Land development, Salinity distribution, Flooding and drainage

2.3.3 Impacts of sea-level changes

The global rate of sea-level rise is almost certainly going to increase over the next century due to climatic warming. However, estimates of the change vary widely, ranging from 2-8 mm/yr in the coming decades. The highest estimates are probably unrealistic, and most studies are converging on the lower values of 2.0-5.0 mm/yr in the next 50 years. Fortunately for Bangladesh, these global rates may be suppressed in the Bengal region. One factor that controls the regional sea level is the strength of gravity. In the Bengal region, the extremely thick sediment deposits (8-20 km) that underlie the region result in a slightly weaker gravitation pull. This reduced gravity is expressed as a slightly lower water elevation in the Bay of Bengal, as compared with other ocean regions. Thus, it is likely that the impacts of sea-level rise will not follow the worst predictions.

Even more important than the actual sea-level rise will be how the Bangladesh coastal system responds to these changes. Given the extremely low elevation of the region, the potential consequences of higher sea level is great. However, the immense sediment load delivered by the Ganges and Brahmaputra rivers tends to balance the effects of sea-level rise and generally favors coastal stability. This response can be seen from historical records that show broad stability (or even accretion) along the Bangladesh coast in the past 150 years (note: local erosion is mostly a result of coastal processes, not sea-level rise). Thus, the impacts of sea-level rise on coastal Bangladesh will be controlled by the supply of riverine sediment and actual changes in water elevation.

There are also several possible consequences of sea-level rise that often remain unforeseen. One is the increased frequency of coastal flooding due to storm surges. The effective height of a storm surge is the sum of both the storm 'wave' and the height of the ocean surface. Thus, coastal areas will be flooded when the height of these factors exceeds that of coastal protection structures. If mean ocean levels increase, then smaller, more frequent storms will be able to overtop flood-control structures in the future. This consequence may be exacerbated by an anticipated increase in the strength and number of storms due to global warming. Another possibly unforeseen impact of sea-level rise is the greater landward intrusion of saltwater during the dry season. This occurs as higher elevation of the sea allows dense saltwater to move farther upstream, contaminating surface freshwater resources and possibly even groundwater. The effect may be further enhanced if dry-season flow continues to be reduced by humans and/or climate induced changes. Sea-level rise should not affect wet-season salinity because of the river dominance at that time.

Related Topics: Climate change, Salinity distribution, Flooding, Storm

3. Patterns

3.1 Water circulation

Water movement in the Meghna Estuary and in the coastal zone of Bangladesh is determined by the influences of fresh water flow from the rivers, tide coming from the Bay of Bengal, and meteorological conditions (low pressure systems, wind, storms and cyclones). Water circulation patterns determine processes of land erosion and accretion, and salinity.

The mean water level varies significantly over the year. The seasonal variation in the mean high water level (from dry to wet season) decreases distinctly along the Lower Meghna Estuary towards the south. The mean water level close to the sea increases by approximately 0.6 m during the monsoon due to the wind set-up and low air pressure, causing an increase in the mean water level in the Bay of Bengal.

Most of the fresh water from the Lower Meghna River is conveyed towards the Bay of Bengal through the western part of the estuary: upper and mid-estuary, Tetulia and the Shahbazpur Channel west of Hatia Island. The eastern part of the estuary is mainly influenced by the tide and much less by the fresh water flow from the river system. A prominent counter-clockwise residual circulation is present around Sandwip. This circulation is strongly dependent on the seasons (monsoon vs. dry). 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.

Waves generally play a less important role in the Meghna Estuary. Wave conditions are rather mild, as the energy is dissipated on the shallows of the estuary. However, during heavy storms, and in particular during cyclones, high waves can build up and pose a threat to life and property.

Related Topics: Salinity intrusion, Sediment distribution, Fresh water input, Wind storm and waves, Tide

3.1.1 Dry season

The dry season is the calm period in the estuary. The wind is weak, and the river discharge is much lower than during the monsoon. Water movement in the estuary is mainly forced by the tide entering from the Bay of Bengal. The influence of fresh water on the water circulation is less pronounced than in the wet season. Fresh water enters the Lower Meghna River and is distributed through the Tetulia and Shabazpur channels.

The tidal water enters the estuary from the south. At the eastern side, the tidal wave travels faster in the deep Sandwip Channel than over the shallows west of Sandwip Island. Both waves meet in the north-west of Urir Char. The tide enters the Lower Meghna River through the East and West Shahbazpur Channel, and through the Hatia Channel. Due to the long travelling periods, large differences in the tidal phases are observed: the flood at the southern edge of the estuary occurs simultaneously with the ebb in the upper estuary. During ebb, water flows towards the south in most part of the estuary, but there is also a significant northerly flow through the Hatia Channel to the Lower Meghna. During the dry season, the flood flow dominates in the Hatia Channel.

The residual flow creates a net transport of water out of the Meghna Estuary, mainly through the West Shahbazpur Channel, and an easterly flow outside the estuary. A prominent counter-clockwise circulation is found around the Sandwip Island, with a northerly current in the Sandwip Channel and southerly current in the southern part of the Hatia Channel. The anti-clockwise circulation is mainly forced by tides, but is also influenced by river discharge. The circulation traps fresh water from the river in the estuary and thus increases the residence time. This may be the reason for the relatively low salinity in the estuary even during the dry season.

Related Topics: Salinity intrusion, Sediment distribution, Fresh water input, Tide

3.1.2 Wet season

The south-westerly monsoon wind is steady, and the river discharge is high. Furthermore, the mean water level is higher than that of the dry season due to the low atmospheric pressure systems in the Bay of Bengal. The Lower Meghna River pours several tens of thousands of discharges into the bay through the Tetulia, Shahbazpur channels and Hatia Channel. These huge volumes of fresh water modify the dry season water circulation mainly induced by tides.

The tidal waters enter the estuary from the south. The flow patterns in the eastern part of the estuary are similar to the patterns observed during the dry period. This area is clearly dominated by the tide. The strong river flow counteracts the flood flow in the East and West Shahbazpur channels, making the period of northerly flow in these channels very short (approx. 2 hours) and weak. Also during monsoon, there are large phase differences in the tide between the upper and lower estuary. During ebb, there is a significant flow towards the Lower Meghna through the Hatia Channel. The river empties itself into the Bay of Bengal through both the Shahbazpur Channel and the Hatia Channel.

The residual counter-clockwise circulation around the Sandwip Island is similar to the circulation during the dry period. The net and maximum flow velocities in the Lower Meghna are higher during neap tide than during spring tide, whereas in the Sandwip Channel, given the tide domination, maximum velocities are higher during spring tide. Due to higher water levels during monsoon, the maximum speeds in the estuary are slightly lower than during the dry period. In the Lower Meghna River, the velocities increase due to increased water flow. Simulations show maximum flow velocities of 1-2 m/s in the Lower Meghna. In June 2000, velocities of more than 3.5 m/s were measured near Hanar Char, south of Chandpur.

Related Topics: Sediment distribution, Fresh water input

3.2 Sediment distribution

The formation of new lands and erosion of existing lands in the Meghna Estuary are very common phenomena. The magnitude of this annual formation and erosion of lands are in the range of hundreds of square kilometers. Sediment distribution together with water circulation in the estuary mainly determines the locations of the formation of new lands and the erosion of existing lands. The main source of the sediment in the estuary is the upstream sediment input from the Ganges, Brahmaputra and Meghna (GBM) System. Sediment composition and seasonal variation of fresh water and sediment in the estuary cause the seasonal variation in sediment distribution. Changes in the planform of the estuary resulting from sediment distribution again cause new patterns of sediment distribution. The changes in sediment distribution patterns have the time range of a few decades.

Related topics: Water circulation, Sediment input, Erosion and accretion, Land development

3.2.1 Characteristics of sediment

Bed materials:

Within the Meghna Estuary, concentrations of suspended sediment are generally high, with particles that are fine, cohesive, prone to flocculate, and richly organic. Bed materials are those found in the river or channel beds. Bed materials in the active or main channels are generally coarser than that of suspended materials. The materials in the main channels consist of sand and silts. The size of the materials varies between 16 and 250 µm. Over 50% of the samples collected by MES have a mean diameter of less than 63 µm (silts).

Sediment concentrations:

Sediment concentration measurements at different heights in the water column show that the concentration near the bottom is only slightly higher than at the surface. This indicates that the major part of the sediment transport comprises vertically well-mixed suspended materials.

The maximum depth-averaged sediment concentrations, measured during the dry season, vary between 0.5 and 9 gr/litre. The highest concentrations have been found in the areas close to Urir Char - Char Balua and Manpura - North Hatia.

The measurements conducted by MES and LRP indicate a variation in sediment concentration over a fortnightly cycle of the spring and neap tides. The variation shows a tendency to increase towards the spring tide. The maximum depth averaged sediment concentration at spring tide is about 2-5 times higher than at neap tide.

During the dry season, sediment input from upstream is negligible. But the sediment concentration in the estuary during the dry season is generally found very high. Salinity measurements conducted by LRP during low river discharge indicate that the high sediment concentration in the estuary coincided approximately with the zone of salinity intrusion. The lower limit lies at approximately the 10-20 m depth contour. The upper limit of the sediment concentration is generally found where the sedimentation occurs. A mud flow is very common around those areas and their surroundings.

Related topics: Sediment input, Tide, Salinity processes.

3.2.2 Conceptual model of dominant sediment distribution processes

Combining the results of bathymetric, hydraulic and morphological analyses with results from numerical modelling allows to define a conceptual model of the sediment distribution processes dominating the development of the coastal area of the Lower Meghna Estuary. In this model, the Meghna Estuary can be divided into three zones where separate driving forces can be distinguished. In these zones the processes can be described as (i) marine-dominated, (ii) mixed-energy, or (iii) river-dominated. All of these zones have their own characteristics concerning sedimentation and erosion.

Dry-season period

During the dry-season, a relatively large part of the estuary can be described as a well-mixed to a partly mixed system. The sediment trapping efficiency of this area is place and time dependent. The turbidity maximum (location of high sediment concentration) moves up and down the estuary along with the tidal intrusion.

The southern part of the estuary can be described as marine-dominated. A relatively important factor in this area is the so-called tidal pumping process that results in a net landward transport of sediment, causing accretion on mud flats.

The interaction between tidal and river currents forms net circulation patterns in the vicinity of the Sandwip area. This net circulation pattern seems to act as a sediment trap. Satellite images taken during the last two decades show a rapid accretion of the mudflats resulting in a shallowing of the near shore waters and growth of new chars at the northern edge of the estuary (south of the Noakhali mainland).

Monsoon period

Most of the sediment input from upstream occurs during the monsoon. In a large part of the Lower Meghna and Shabazpur Channel, the processes during monsoon can be classified as river dominated. The marine dominated zone does not change significantly in size. This results in a compression of the mixed-energy zone and probably in a limitation of the tidal intrusion into the estuary. Energy conditions governing the erosion sedimentation processes differ significantly from those in the dry season. Compression of the mixed-energy zone results in a situation where energy dissipation takes place in a smaller area, resulting in higher energy conditions that lessen the change in permanent sedimentation.

Another effect of the higher river discharge is an enlargement of the net circulation around Sandwip Island. The effect of this enlargement on sedimentation and erosion processes in this area is unclear at this moment. Enlargement of the net circulation could lead to sedimentation in the deeper parts. The higher suspended sediment load of the river discharge could speed up this effect, leaving a surplus of sediment to be deposited on the intertidal flats between Hatia and Sandwip.

Related topics: Water circulation, Tide, Sediment input

3.2.3 Short-term Sediment budget

The approximate overall sediment budget in the Meghna Estuary over the period 1997-2000 indicates that the deposition processes exceed the erosion processes. Net accretion during this 3-year period amounts to approximately 400 million m^3 equivalent to 130 million m^3/year (200 million ton/year). Given an annual sediment input of 1,100 million tons of sediment, and 30% of upstream floodplain sedimentation, it could be assumed that 20% of the sediment that enters Bangladesh is actually deposited within the estuary, while the remaining 50% is flushed through the estuary to be deposited at the continental shelf and into the Bay of Bengal.

Erosion dominates in the northern part of the river system. Erosion in the Lower Meghna from the northern end down to the northern head of Hatia is about 0.1 - 0.2 m/year. A high rate of accretion (approximately 0.2 m/year) is found in the north-east of the estuary between the Noakhali mainland, Urir Char and Sandwip. Also, the area between Bhola and Hatia, and the south-west end of the estuary is accreting at a rate of 0 - 0.1 m/year. In other areas in the estuary, erosive and depositing processes are more or less balanced.

Related Topics: Sediment input, Water circulation, Floodplain sedimentation

3.2.4 Long-term Sediment Budget

The sediment load reaching the Meghna Estuary is perhaps the most important control on the development and stability of this coastal system. High-energy processes from river, tide, and storm influences, as well as sea-level rise, would quickly erode the Bangladesh coast if it were not for the immense sediment load delivered by the Ganges and Brahmaputra rivers. A common misperception, though, is that all of the sediment reaches the coast and is deposited there. In fact, of the 1000-1200 million tons of sediment measured annually at the Harding Bridge and Bahadurabad gauging station, only about 20% is actually deposited in the coastal zone. Roughly one third, or about 350 million tons, is first deposited on the broad riverine floodplains of the middle delta. In terms of coastal management, sediment cannot be considered for diversion to the coast as they are critical for maintaining land elevation and soil fertility in the middle delta. Nevertheless, a huge load of 750 million tons reaches the Meghna Estuary mainly during the wet season. In this complex coastal system, much of the sediment is seasonally stored here. However, during the dry season, high-energy tides, storms, waves, and coastal currents rework much of the wet-season flood deposits and transports them into deeper water offshore (> 10 m deep). Of this material, about 200 million tons reach far offshore to about 50-80 meters water depth, where they are rapidly accumulating in the underwater portion of the Ganges-Brahmaputra delta. Once again, these deposits actually benefit the coastline by forming a buffer against large storm waves that can be highly erosive if they reached the coast. Another 280 million tons of sediment is transported westward along the coast by ocean currents. It is probable that some fraction of the sediment is transported back inland and deposited along the western delta plain (e.g., the Sundarbans). Here, the sediment would help maintain land elevation and limit shoreline erosion, which appears to be perhaps slower than expected. However, by far most of this material enters the Swatch of No Ground canyon system, which reaches within 30 km of the shoreline. Sediment that enter the canyon are ultimately swept to the deep ocean and permanently removed from the delta system. Thus, in total only about 200 million tons of the Ganges and Brahmaputra sediment is actually retained in the Meghna Estuary. In the past few centuries, most of this load appears to have accumulated in the near shore zone, causing overall water depths to shallow. This process of a shallowing coastal ocean is the necessary first step leading to new land formation.

Related topics: Sediment input, Floodplain sedimentation

3.3 Salinity distribution

Upstream intrusion of saline water into the river system limits the usability of water for drinking and irrigation. Changes in the water circulation patterns can increase salinity intrusion during the dry season, causing undesired effects.

Salinity distribution in the estuary is strongly influenced by 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 ppt) but always remains distinctly lower. Penetration of saline water during dry season stops north of Char Gazaria where salinities less than 1 ppt are found.

Upstream, salinity intrusion can increase either due to a decrease of fresh water flow in the Lower Meghna during the dry season, or due to further penetration of tide into the river system. These effects may be caused by human interventions like an upstream withdrawal of water and reducing size of floodplains, or by climate changes like decrease in dry season rainfall and sea level rise.

The horizontal distribution of salinity is strongly influenced by the fresh water flow in the Lower Meghna River. During the wet season, nearly the whole estuary is filled with fresh water (salinity lower than 0.2 ppt). Only in the southeast part of the estuary, south of the Sandwip Channel, higher salinities are found. There, a stratified zone with a width of approximately 100 km develops, with a layer of brackish water moving with the tide over a salt wedge. This zone forms a transition between the fresh water in the estuary and the more saline water coming from the Bay of Bengal with salinity of approximately 20 ppt.

During the dry season (November-May), the flow in the Meghna River gradually decreases, and saline water penetrates into the estuary. The penetration of saline water ends in the river's mouth. North of Char Gazaria, salinities of around 1 are found. The salinities in the main river channels, East and West Shabazpur, are noticeably lower (between 6 ppt and 8 ppt) than in the western part of the estuary where salinities between 10 ppt and 20 ppt are found. Exchange of water with the deeper parts of the Bay of Bengal is clearly insufficient to bring seawater into the estuary. The estuary is well mixed by the strong tidal currents, with velocities of up to 3-4 m/s.

Related topics: Fresh water input, Impact of upstream interventions, Polders, Sea level rise

4. Physical environment

4.1 Flooding and drainage

Most of the lands in the Meghna Estuary are newly accreted. Age of the lands (after the appearance of vegetation) varies from a few years to a few hundred years. The old land masses are part of the Sandwip, Hatia and Bhola islands, the age of which could be in the range of a few hundred years. Most of the lands were embanked to restrict tidal flooding under the Coastal Embankment Project (CEP) in the 60s and 70s. Newly accreted lands are exposed to tidal flooding. Recently, the Char Development and Settlement Project (CDSP) has taken the initiative to bring the newly accreted lands of the estuary under polder embankment. However, except for the un-embanked lands, floods are not common in the Meghna Estuary area. But the main lands in the Noakhali and Feni districts behind the newly accreted lands are suffering from drainage congestion. This drainage congestion is related to the delta development processes over the last decades. But cyclone generated floods often cause damages to life, infrastructure, settlements and crops.

Related topics: Polders, Land development, Erosion and accretion

4.1.1 Flooding

In the embanked polders, rainwater drains through the sluices during low tides into the bay. The difference in the mean tidal level from the dry to the wet season is about 60 cm. River induced floods can raise the average tide level 2.5-3 m at Chandpur at the northern boundary of the Meghna Estuary, which gradually diminishes to the south and nearly equals to 60 cm.

In the estuary, except for the mainland of the Noakhali and Feni districts, the upstream flood carried by the main rivers of Bangladesh does not have any significant impact. In the southernmost part of the estuary, the impact cannot even be felt. The main causes of flood in the estuary is cyclone-generated floods. Before the 60s in the last century, storm surges could easily penetrate into the land. Now after the construction of the embankment, for flooding the surge height should be more than the crest of the embankment. Cyclones and storm surges are frequent in the estuary area. But the surge height often dos not exceed the embankment crest.

The Meghna Estuary was severely affected by the cyclone in 1970. The storm surge washed away the embankment, people, cattle, houses and infrastructures. Nearly 300,000 people were killed by the surge. Later in 1985, another storm surge affected Sandwip and Urrir Char. Urir Char was then un-embanked and the surge washed away thousands of people. The devastating storm surge of 1991 did not have that much effect on the Meghna Estuary area, as the landfall of the storm was on the Chittagong coast.

Subsidence related to the compaction of these newly accreted land of the estuary is substantial: about 4 – 6 mm/year. Vertical accretion was restricted by empoldering. Therefore, to cope with the subsidence only the embankment height should be higher by 20 to 30 cm for the next fifty years to avoid the flooding from normal cyclones or surge. Sea level increase at a rate of 2 – 5 mm/year will require an additional 10 to 25 cm higher embankment. This implies that by 2050, the embankment height in most part of the estuary should be 30 – 55 cm higher than that of the present to protect the land from storm surges of the same magnitude. Climate change might also be associated to the increase of frequency and magnitude of storm-surges, which may further deteriorate the situation.

Human interventions and morphological developments in some locations increase the tidal range, which also increases the risk of increasing the overall surge (tide + surge) height. For example, increase in the tidal range at the Sandwip-Urir char area related (probably) to the construction of the Noakhali cross-dams in 1950s and 60s has increased the risk of the high surge.

Related topics: Wind, Storms, Cyclones, Subsidence, Sea level change, Water circulation, Tide.

4.1.2 Drainage

The Meghna Estuary is an active delta building estuary. Land accretion in the estuary is associated to sediment distribution by tide induced water circulation. On the other hand, vertical accretion is determined by tidal range. During the last five decades, human interventions have accelerated land accretion in the south of Noakhali. Changes in landform have changed the hydraulic and morphologic regime of these areas like increase in the tidal range in the Sandwip-Urir Char areas and increase in salinity at the south of Noakhali after the closing of the eastern anabranch of the Lower Meghna River in the late 50s of the last century.

At present, a large part of the Noakhali, Feni and Lakshmipur districts comprising the catchment area of the Little Feni River, Bamni Khal, Noakhali Khal and Baggar Dona River are suffering from drainage congestions. Early floods, increase in flood extent and slow recession of floods cause damages to crops and decrease yields. The area that is suffering from drainage congestion is about 380,000 ha. Probable causes for the deteriorating drainage situation are: (i) rapid accretion of the mainland to the south increasing the length of drainage channels, (ii) higher accretion level than the elevation of the mainland behind, (iii) human interventions, like the empoldering and regulators cutting down the tidal prism, which reduces the size of the drainage channel and (iv) increase in salinity increasing the rate of sedimentation in the channel downstream of the regulator during the dry season.

The trend of estuary development towards the south will aggravate the present situation. Moreover, the high rate of subsidence of these newly accreted lands, raising of sea level, and the expected increase in monsoon rainfall associated with climate change will further deteriorate the situation in the near future.

Related topics: Climate change, Subsidence, Sea level change, Water circulation, Tide, Human interventions.

4.2 Soil Resources

The soils of Bangladesh constitute major river sediment that are rich in weatherable minerals derived from the crystalline rocks of the Himalayas and smaller rivers in the north and east. The sediment are deposited under piedmont apron, meander floodplain, estuarine and tidal conditions. These soils vary widely in texture, mineralogy, drainage and age.

The charlands or young alluvial lands of the Meghna Estuary, undergoing continuous processes of erosion and accretion, lie in the physiographic unit vis-a-vis the agro-ecological region of the Young Meghna Estuarine Floodplain (physiography). The charlands occupy about 9,000 sq. km., which is about 6 percent of the area of Bangladesh. The soils are developed in the fine floodplain sediment of the Brahmaputra, Ganges and Meghna river sources under the influence of the tidal action at the mouth of the Bay of Bengal. The newly accreted soils of the area are very resourceful with soil nutrients, but the deadly cyclonic storms from the south often wash away the ripened crops of the field along with lives and properties of local inhabitants. Now a days, soil resources are protected in many places by setting up polders. This has reduced soil salinity and helped the farmers to introduce a variety of crops in the field.

Related topic: Sediment input, Geology

4.2.1 Physical status

The estuarine floodplain has a typical flattish topography with less than a metre differences in elevation between low floodplain ridges and shallow basins, usually occupied by silt loams and silty clay loams, respectively. Stratified alluvium is present in the younger soils. The older soils consist of about 5-8cm thick cultivated topsoil; some 5-10cm thick compact ploughpan layer and grey, mottled brown, porous and structured subsoil overlying stratified alluvium in the substratum.

The dynamic processes of soil formation that operate in the alluvial lands of the Meghna Estuary present a unique set of various stages of development. Soil development stages range from almost perennially wet, saline, calcareous, raw and soggy mud to only periodically wet, salt and lime free, structured, porous and firm soils. The physical status changes with the advancement of soil formation stages. The mud in the initial stages are almost regularly tidally inundated (brackish or saline water up to a 1-2 metre depth) with very poorly drained, neutral to mildly alkaline, slightly calcareous, pale brown, and finely stratified un-ripened soggy alluvium with silt to silty clay loam textures (DSS, 1976). The soggy deposit has a very low bearing capacity.

The fairly compact firm and massive alluvium is the immediate product of perennially ripened wet and soggy mud. The soil mass has very fine stratification of alternate layers of highly silty and very fine sandy materials (FAO, 1971), indicating that the sedimentation of these materials took place under varied tidal flows.

The young soils developed from the alluvium are poorly drained with seasonal rainwater inundations up to depths of 30-90cim, which may be controlled by the use of sluice gates. Stratifications in the upper parts of the substratum are partially broken locally with formation of weak structural peds of very coarse prism. The ped interiors are porous and friable to firm in the silt to silt loam soils of the higher sites with silty clay loams occurring in the depressions.

The old soils are mostly poorly drained, seasonally flooded shallowly by rainwater up to a depth of 20-50cm. These highly silty loamy to clayey soils occur in large areas of this floodplain They have a grey plough layer with brown mottles overlying a 5 to 10 cm thick very firm, compact ploughpan. The subsoils are friable to firm with prismatic and blocky structures.

Related topics: Sediment input, Sediment distribution

4.2.2 Chemical and biological status

Soil salinity status

The soil salinity range varies with the stages of soil development. The mudland and young alluvium are slightly to moderately saline in the dry season. They become practically non saline in the wet months of July – October. Locally these areas become highly saline with EC value ranges between 20 to 40. The young soils of this area are mainly non saline to slightly saline. The older soils are mainly non saline. Locally they are very slight to slightly saline

Soil nutrient status

The major sources of plant nutrients in soils are the mineral constituents and organic matter. The mineral constituents mainly include nitrogen, phosphorus, potassium, sulphur, calcium, and magnesium. Soil organic matter as the dominant source supplies some 95 percent of the natural nitrogen. The young estuarine floodplain soils are low to very low in total nitrogen content. Organic matter plays a beneficial role towards the promotion of nutrient availability. It enhances the moisture and nutrient holding capacity of soil and their availability to plants as well. These soils are found to be low to very low in available phosphorus content (SRDI, 1991), which is essential for all plant growth processes, root development and synthesis of protein. Potassium plays a role in photosynthesis and in the synthesis of protoplasm in plants. The soils of the Meghna estuarine land are usually rich in exchangeable potassium contents ranging from optimum to very high levels (SRDI, 1991-2002). However, the general trend in potassium content was high to very high in the younger soils and mud, while it was low to optimum in the older soils. The sulphur was derived from the seawater mostly with alluvial deposition. The sulphur contents of these soils are high to excessive. Sulphur performs an indispensable function in plant metabolism. The estuarine land soils are rich in exchangeable calcium. Lack of calcium restricts the normal growth of root tips and buds and the functioning of cells. Tidal deposits in general are rich in magnesium, which is a constituent of chlorofill that also helps in some enzymetic processes in the plant.

Related topics: Salinity intrusion

4.2.3 Land use and development possibilities

The barren mud banks with pioneer vegetation of uri grass, nona jhau, etc., have planned plantations of mangrove species on sea faces. A single crop of Transplanted Aman is grown on the young salt affected soils, while triple crops of Rabi, chilli, peanut or pulses followed by dibbled Aus and Transplanted Aman are extensively cultivated on older salt-free soils in polder areas.

Development constraints are tidal flooding and dry-season salinity in younger soils and low bearing capacity of mud as well as localized dry-season salinity in older soils. Risks of bank erosion, cyclones and storm surges are common to the whole area in addition to lack of suitable water for irrigation, adequate communication and other infrastructure facilities.

The relatively salt, drought and wind resistant varieties of field crops, fruit and timber trees may be grown on potential suitable sites. Use of green manure crops and organic manure would enhance desalinization of the affected soils. Proper maintenance of embankments and sluice gates would ensure more security to crops, property and lives. Provision of drainage and introduction of deep rooting grass varieties would enhance ripening of the soggy mud land.

Related topics: Tides, Polders

4.3 Fresh water resources

Although the water is abundant, availability of fresh water both in the form of surface and groundwater in the Meghna Estuary area is very crucial. Fresh water is required for drinking, household and irrigation purposes. For the purpose of drinking, the chloride (salt) content should be less than 0.7 ppt (parts per thousand) in the water and for irrigation the salinity should not be more than 2 ppt.

The lands of the estuary are surrounded by rivers or the sea, that bring in fresh or partly fresh water during the monsoon. This, together with the high precipitation during the monsoon creates an abundant volume of fresh water. But in the dry season, water of both rivers and the sea become brackish or saline and the precipitation is also less. The saline water cannot enter the polders, but it enters the land which has not yet been empoldered (attached figure) through tidal channels or creeks. Fresh surface water may be found in ponds and regulated channels in the polders, but availability of such fresh water during the dry season is less in other areas.

Like surface water, groundwater too is abundant in the estuary area, although most of the aquifers contain saline water. Fresh groundwater is scarce with recharge limited in the estuary area.

Related topics: Human interventions, Salinity distribution

4.3.1 Surface water

The source of surface water in the Meghna Estuary is mainly the rain. Rainfall in the area varies from 2500-3000 mm, and the distribution is uniform with a peak in the month of July. The dry season rainfall is very scarce and ranges between 300-400 mm. Other sources of fresh surface water are ponds, canals and khals. Water in the canals and khals desiccate, while water in the khals turns brackish to saline during the dry periods.

Fresh surface water is scarce during the dry periods. Ponds are the major source of water for all users. Ponds located in villages in the polder areas become the source of water during the driest time of the year for people. However, the water in these ponds is generally of poor quality. Canal water is sweet after the monsoon period, but it gradually dries up. Canal water is used for irrigation, cleaning and bathing. During the dry season, many canals become saline and dry up. People generally excavate their ponds to increase storage capacity and around 20% of the households excavate their ponds every year. *Indra* (well at the bottom of a dried up pond) is a popular measure to cope with water crisis during the peak of the dry season.

Related topics: Human interventions, Salinity distribution

4.3.2 Groundwater

Groundwater is an important natural resource of the study area. It has been used in conjunction with surface water. This is the principal source of water for domestic water supply. It is also used for irrigation in the Noakhali and Lakshmipur area. Compared to many other parts of the country, groundwater use in the study area is quite low. The main reason for this is its higher salinity level. Given the limited availability of fresh surface water, fresh groundwater is most crucial in the Meghna Estuary area.

Due to a general southwards fining of the deltaic sediment and particularly due to the thick upper clay layer in many places, together with the salinity condition, the study area is generally less favorable for groundwater development than elsewhere in Bangladesh. The potential annual recharge of groundwater in Bangladesh ranges between 400 to 700 mm. In this particular area, the thick surface clay layer is a constraint to groundwater recharge.

In most of the areas, excepting Lakshmipur and Noakhali, groundwater abstraction for irrigation is extremely low. But in Noakhali and Lashmipur, nearly 20% of the total irrigated area is covered by groundwater. While in Bhola District, the area irrigated by groundwater is only 2 percent of the total irrigated area. But such abstraction needs careful monitoring in order to maintain the sustainability of the fresh groundwater sources for drinking use.

Salinity at different aquifers in same locations varies substantially. In most cases, fresh water is available in the deep aquifers. The Department of Public Health Engineering (DPHE) goes for deep drilling and installs deep hand tube-wells. There is acute shortage of fresh groundwater in shallow aquifers.

Related topics: Human interventions, Salinity distribution, Geology

4.4 Erosion and accretion

The coast of the Meghna Estuary is shaped by the dynamics of water movement (circulation and waves) and sediment movement. These are the driving forces causing the processes of land erosion and accretion, and any change to either of these forces may result in a (desired or undesired) change in the existing trends. Understanding the rates and patterns of these processes is important for longer-term planning, such as for the next several decades.

The topography of the Meghna Estuary undergoes very rapid changes. The main channel of the Lower Meghna River shifts over considerable distances (even hundreds of meters locally per year) causing loss of fertile land and property, and damaging embankments that protect land from flooding. The total loss of stable land in the estuary due to erosion during 1973-2000 was approx. 880 km^2 while the total gain was 1385 km^2. The eroded land has been replaced elsewhere by newly accreted land. Here, the term 'land' refers to vegetated land only. Over the period 1973-2000, a net gain of land was observed of a total of 505 km^2. New extensive shallows emerge in the estuary north and east of Hatia Island. These shallows are inundated during high water, but would become permanently dry in the near future. However, the value of the lost land is generally higher than that of new land yet to be cultivated. Also, the loss of property due to erosion is irreversible.

Related topics: Water circulation, Sediment distribution, Sediment input, Land development

4.4.1 Short-term erosion accretion

Lower Meghna-Tetulia area

Erosion is the dominating process in the upper estuary. This can be seen in the widening of the main river channel south of Chandpur. Between 1973 and 2000, loss of stable land amounted to over 500 km^2, equivalent to 18.5 km^2/y. The rate of erosion and accretion varies significantly in time. In the period 1973-1984, the rate of erosion and accretion was the highest 31.4 km^2/y, but nearly equal in magnitude. From 1984, more land has been lost than recreated. The rate of net loss increased from 5.4

km^2/yr between 1984-1993 to 7.5 km^2/yr between 1993-2000. The largest areas lost to erosion are the riverbank of Bhola from Tetulia offtake to Char Gazaria, and large stretches of the left bank of Lower Meghna, south of Chandpur, and near Char Gazaria.

Erosion and accretion in Lower Meghna – Tetulia Zone (in km^2)				
	1973-2000	1973-1984	1984-1993	1993-2000
Total area of Erosion	500	346	271	247
Total area of Accretion	400	346	222	194
Net Change	-100	0	-49	-53

Note: (-) value stands for net erosion

Rate of change in Lower Meghna - Tetulia Zone (in km^2/yr)				
	1973-2000	1973-1984	1984-1993	1993-2000
Total area of Erosion	18.5	31.4	30.1	35.2
Total area of Accretion	14.7	31.4	24.7	27.8
Net Change	3.8	0	-5.4	-7.5

The net erosion in the period 1997-2000, determined from bathymetric surveys of MES, amounts to 325 million m^3.

Bhola-Hatia

The change maps derived from satellite images by MES indicate that in the period 1973-2000 accretion was the dominating process. The net accretion in this period amounted to 250 km2. The largest accretion occurred in the period 1973-1984 (net gain of 15.3 km^2/yr). The changes in the period 1984-1993 were much slower (net gain of 1.5 km2/yr). Recently, the processes of both erosion and accretion have gained in strength, with a net gain of land of nearly 10 km^2/yr. The greatest changes were observed in the southern outskirts of the estuary, which shows a tendency to extend towards south.

Erosion and accretion in Bhola – Hatia Zone (in km^2)				
	1973-2000	1973-1984	1984-1993	1993-2000
Total area of Erosion	196	121	120	97
Total area of Accretion	447	289	133	166
Net Change	251	168	13	69

Rate of change in Bhola – Hatia Zone (in km^2/yr)				
	1973-2000	1973-1984	1984-1993	1993-2000
Total area of Erosion	7.2	11	13.3	13.8
Total area of Accretion	16.5	26.3	14.8	23.7
Net Change	9.3	15.3	1.5	9.9

The net accretion in the period 1997-2000, determined from bathymetric surveys of MES, amounts to 545 million m^3.

Hatia-Sandwip

In the zone east of Hatia, very high net accretion is observed. Over the period 1973-2000 a net accretion of 251 km^2 occurred. This amounts to nearly 9.3 km^2/year. Between 1973-1984, the net gain of land amounted to 17 km2/year, followed by a period of lower accretion (net change of 5.6 km2/yr) between 1984-1993. Recently, a spectacular increase of accretion is observed, with a net gain of land of nearly 22 km^2/yr. The main accretion areas are the southward extension of the Noakhali mainland, and growth of Urir Char north of Sandwip Island.

Erosion and accretion in Hatia - Sandwip Zone (in km^2)				
	1973-2000	1973-1984	1984-1993	1993-2000
Total area of Erosion	182	118	128	88
Total area of Accretion	537	270	179	241
Net Change	355	152	51	153

Rate of change in Hatia - Sandwip Zone (in km^2/yr)				
	1973-2000	1973-1984	1984-1993	1993-2000
Total area of Erosion	6.7	13.1	14.2	12.6
Total area of Accretion	19.9	30.0	19.9	34.4
Net Change	13.2	16.9	5.7	21.8

The net accretion in the period 1997-2000, determined from bathymetric surveys of MES, amounts to 180 million m^3.

Related topics: Water circulation, Sediment distribution, Sediment input, Land development

4.4.2 Long-term erosion and accretion

Deltas and estuaries are generally known as areas of a net deposition of sediment either carried by the river or supplied from the sea. The growth of the delta and the accretion of land in the estuaries is a continuous and generally a very gradual natural process impacted by the dynamics of the ever-changing courses of their channels.

A comparison of the 1999 satellite image with the 1779 map of J.Rennell shows a completely changed system of channels and river courses but a more or less stable coastline west of the Tetulia River. In the east of the Tetulia River, however, a general tendency of seaward growth of the coastline can be recognised, particularly in the region of Bhola Island - Hatia Island and in Noakhali District.

Different studies have estimated the net change in the Meghna Estuary area using old maps and satellite images. The time range varies from 220 to 27 years from now. The rate shows that the long-term averaged rate of accretion is significantly less than that of the short-term averaged rate. This higher accretion rate is probably attributable to the huge sediment generated by the Assam Earthquake.

Erosion and accretion rates from different studies				
Length of study period (years)	Period of study	Net Change for Period (km^2)	Rate of change (km^2/y)	Reference
220	1776-1996	+2187	9.9	EGIS (1997)
192	1792-1984	+1346	7.0	Allison (1998)
144	1840-1984	+638	4.4	Allison (1998)
23	1940-1963	+279	12.1	Eysink (1983)
27	1973-2000	+508	18.8	MES Study

Although the overall process of accretion is dominant, areas of erosion can be recognised. The erosion is the result of southwest ward migration of the estuary. Sandwip and the coastal area of the Chittagong mainland are also showing a tendency towards erosion. The coastal protection measures have arrested the trend of erosion near the Chittagong mainland.

For the coming decennia, it is expected that the eastward migration of the Lower Meghna River and the building of new land south of Noakhali will continue. The severe erosion of the northern head of Hatia will continue to compensate for the southward extension of the Noakhali mainland. Severe erosion is also expected in the northeast part of Bhola.

Related topics: Water circulation, Sediment distribution, Sediment input, Land development

4.5 Channel development

The main channels in the Meghna Estuary consist of the Lower Meghna River between Chandpur and the northern head of Bhola, the Shahbazpur Channel between Bhola and Hatia, the Tetulia River west of Bhola, and the Hatia Channel north and east of Hatia. The primary functions of these channels consist of conveying water and sediment from upstream and distributing into the estuary. The channels are also very important to navigation as the major route linking the Chittagong seaport to the capital city Dhaka passes though the estuary.

These channels are very dynamic in nature. Frequent natural shifting of these channels and the development of large chars cause erosion of land in the estuary and threaten navigational safety.

The planform of the Lower Meghna River reacts to changes in the upstream input of water and sediment caused by a change in the intensity of erosion and accretion. All the channels in the Meghna Estuary are very dynamic due to the active processes of accretion and erosion of the channel beds and banks. The size and shape of these channels change over time. The processes of delta development tend to change the importance of the channels by gradual closing or widening.

The character of the estuary channels is determined by the combined influence of tidal and river flows. The Lower Meghna River is clearly dominated by fluvial (river) processes, and the East and West Hatia channels are dominated by tides, while the East and West Shahbazpur channels and the downstream reach of the Tetulia are fluvio-tidal channels.

Related topics: Fresh water input, Sediment input, Erosion and accretion

4.5.1 Lower Meghna River

Every year, the Lower Meghna pours 10^{12} m^3 of water and 0.4 to $0.5*10^9$ m^3 of sediment into the estuary. The fresh water and sediment input of the estuary vary over time due to seasonal influences, construction of barrages, dams and flood protection structures, such as embankments. It has been found that during the last few decades, annual flow input has been increasing, while sediment transport, especially the bed material input (particularly sand), has been decreasing. This is causing big changes to the planform of the Lower Meghna River (see *Figure* on time series satellite images). The planform of the river has changed from braiding to straight from the seventies to the eighties and since then to braiding again. These changes have resulted in thousands of hectares of land to be either accreted or eroded. Presently, the river is widening by eroding both its banks. This widening process of the river is generally related both to the changes in planform and enlargement of the flow area of the rivers. Recent MES surveys have shown a net erosion along the Lower Meghna River in the scale of 100 million m^3/year. In recent years, it was observed that the thalweg (deep channel) shifted in several places towards the left bank of the river, causing severe erosion.

Related topics: Fresh water input, Sediment input

4.5.2 Shahbazpur Channel

The Shahbazpur Channel is located between Bhola and Hatia. The large islands, i.e., Char Gazaria and Manpura, bisect the Shabazpur Channel into the West and East Shahbazpur channels. Both channels are dominated by the fluvio-tidal processes (interaction between upstream discharge and tide coming in from the sea). The size and shape of the channels change over time, causing erosion and accretion of the chars in the east and west side of Bhola and Hatia, respectively.

In recent years, the East Shabazpur Channel has been reducing in size. Measurements indicate that in the period 1985-2000, the cross-sectional area in this channel decreased by more than 25%. This is probably related to the development of large chars west of Hatia, near the entrance of this channel which obstruct the river flow. Emergence of these chars presumably reduced the rate of erosion in the west bank of Hatia.

Recent MES surveys indicated that both the Shahbazpur channels have remained relatively stable between 1997 and 2000. In general, only lateral shifts of the conveyance channels have occurred.

Longer-term data for the West Shahbazpur Channel is not available.

Related Topics: Erosion and accretion

4.5.3 Hatia Channel

The Hatia Channel is a tidal channel starting at the north-east of Char Gazaria, crossing between Hatia and the mainland and then following its course east of Hatia. It is the main navigation channel towards Chittagong.

In recent years, a vast area of new land has emerged at the foreshore of the Noakhali mainland and near Char Bouy. This has reduced the depth of the channel which has forced the main water flow towards the northern head of Hatia, causing a massive erosion of the head of the island (up to 400 m/yr). The channel shifts towards Hatia, and changes its form at a spectacular pace. The width of the main conveyance channel (deepest part of the channel) decreased from approximately 5 km (1985-1994) to 2 km in 2000, but the cross-sectional area has remained nearly constant since 1990, as the depth increased in the same period from 15 to 20 m.

Related topics: Erosion and accretion, Water circulation

4.6 Land development (from Sea to Land)

Short-term patterns of erosion, accretion, and channel migration ultimately lead to the formation of stable land and development of the coastal plain. Understanding the rates and patterns of these processes is important for longer-term planning, such as through the next several decades.

The formation of new land from open marine waters is an important process that results from many coastal processes. Recent studies of the Bangladesh coastal plain have recognized a characteristic sequence of steps that lead open-marine habitats to evolve into newly emergent land. Presently, a broad region of the coastal ocean less than 10 m deep reaches about 50 km off the Bangladesh coast. This seafloor surface is swept by strong waves and tides that only allow coarse, sandy sediment discharged by the rivers to accumulate. As this surface slowly builds upward with new sediment, the shallowing water depth greatly reduces wave energy. This causes tidal action to become the dominant control at depths of 3-6 m, and the tide-deposited sediment at these depths develop a characteristic layering of silts and sand. The different layers are generated by the changing strength of the tide over the spring/neap cycle. As this tidal environment slowly shallows because of sediment accumulation, the role of tides decreases and riverine deposition becomes more significant. During the wet monsoon when river discharge is high and the coastal sea is elevated, the shallow tidal flats are draped with fine-grained riverine muds. After some years of accretion, this surface becomes high enough from wet-season accretion for it to remain exposed even during high tide in the dry season. Ultimately, these seasonally exposed land surfaces are stablilized by vegetation and continue to build vertically with river- and storm-delivered sediment. In summary, a sequence of steps from coastal to estuarine to riverine influences are required for new land to develop at the shoreline, and these diverse controls emphasize the need to maintain a broad view for future planning along the coastal zone.

An analysis of recent bathymetric surveys and other information shows that in the Meghna Estuary area, nearly 7 to 9 m of accretion is required to form land. The average bed level of the all channels in the Meghna Estuary are found to be –5 m+PWD. The surface level of the land varies from west to the northeast direction, depending on the tidal ranges. It is nearly 2 m+PWD close to Khepupara, while it is 4 m+PWD near Urir char.

Related Topics: Sediment distribution, Water circulation, Erosion/accretion, Tides

Projects

Projects in the Meghna Estuary area

The ongoing projects in the Meghna Estuary area carrying out by different government and non-government agencies are presented in tables 1 and 2. The list of the projects are selected from an ICZM working paper on Inventory of Projects & Initiatives in the Coastal Zone (2002).

Table 1: List of the GoB projects in the Meghna Estuary

SL	Name of agency and Project	Project Period	Location (District)	Total cost (Project aid)	Sources of Project aid
Bangladesh Water Development Board (BWDB) and Water Resource Planning Organization (WARPO)					
1	Coastal Embankment and Rehabilitation project, Phase -2	1995-96 2002-2003	Cox's Bazar, Chittagong, Feni, Noakhali, Lakshmipur, Patuakhali, Barguna, Bagerhat	4980.30 (3562.70)	IDA, EEC
2	Chandpur Town Protection Project , Second Phase	1997-98 2003-04	Chandpur	1099.10	
3	Polder 59/2 Extention	1998-99 2002-03	Lakshmipur	99.80	
4	Bhulaura River Re-excavation	1998-99 2001-03	Noakhali Lakshmipur	115.02	
5	Noakhali khal Re-excavation	1998-99 2002-03	Noakhali	99.00	
6	Bhola Town Protection	1992-93 2003-04	Bhola	331.71	
7	Char Development and Settelment project -2	1999-00 2003-03	Chittagong, Feni, Noakhali	1367.60 (1033.70)	Netherlands
8	Meghna Estuary Study Phase II and SSSU	1998-99 2001-02	Coastal Area and Lower Meghna River	553.00 (484.5)	Netherlands
9	Integrated Coastal Zone Management	2001-02 2004-05	Coastal Districts	136.6 (122.10)	Netherlands
10	Rehabilitation of Damaged High Risk Polders in Coastal region (72 polders)	2002-03 2006-07		1602.6 (1282.00)	without allocation'
Local Government Engineering Department (LGED)					
1	Construction of Low Cost Bridge /Culvert on Rural road	1995-96 2003-04		2500.00	
2	Rural Development Project - 22: Infrastructure of Noakhali district	1998-99 2002-03	Noakhali	870.66	IDB
3	Costruction of Multi-purpose Cyclone Shelter Centre under Japanese Assistance	1998-99 2002-03	Coastal Districts	1267.10 (993.00)	JICA
4	Rural Development Project - 23: Infrastructure of Laksmipur and Feni district	2000-01 2004-05	Laksmipur, Feni	590.00 (532.00)	DANIDA
5	Cyclone Rehabilitation Project : Entire Coastal Area (2nd Phase)	2001-02 2005-06	Coastal Districts	1800.00 (1350.00)	OPEC
6	Rural Development Project in Greater Noakhali & Chittagong	2001-02 2004-05	Feni, Lakshmipur, Noakhali, Chittagong, Cox's Bazar	1800.00 (1350.00)	
Forest Department (FD)					
1	Coastal Green Belt Project	1995-96 2001-02	Coastal Districts	1300.08	ADB
Department od Environment (DoE) & MoEF					
1	Country case Study on Climate Change Impact and Adaptation Assessment in Bangladesh (Study)	2000-01		12.09 (11.61)	UNEP

Table 1 (contd.)

SL	Name of agency and Project	Project Period	Location (District)	Total cost (Project aid)	Sources of Project aid
Department of Fisheries (DoF)					
1	Greater Noakhali Aquaculture Extention Project	1997-98	Noakhali, Feni,Lakshmipur	358.13 (341.13)	DANIDA
2	Coastal Marine Fishery Management Strengthening Project	1997-98 2001-02	Coastal Districts	70.42	
3	Fourth Fisheries Project	1993-94 2003-04		3003.50 (2395.90)	WB
4	Jhatka (Juvenile Hilsa) Conservation and Management Project	2000-01 2002-03		514.64	
5	Employment of Coastal Fishing Community for Livelihood Security (study)	2000-01 2003-04		316.47 (295.62)	UNDP, FAO
Department of Public Helth Engineering					
1	Water Supply Project in Coastal Area	1998-99 2002-03		915.29 (528.51)	IDB
2	Rural Sanitation Project	1996-97 2001-02		1996	
3	Water Supply, Sanitation, Drainage and Waste Disposal Project in Municipality, Thana and Growth Centre (Noakhali, Feni, Lakshmipur, Patuakhali, and Barguna Districts)	1996-97 2006-07	Noakhali, Feni,Lakshmipur, Patuakhali, Barguna	2529.70 (2106.80)	DANIDA
Roads and Highways Department (R & H)					
1	Ilisha-Bhola-Char Fassion-Charmanika Regional Highway Construction	1991-92 2002-03	Bhola	662.8	
2	Barisal-Bhola-Lakshmipur Road Construction	1994-95 2002-03	Barisal, Bhola, Lakshmipur	726.38	
3	Improvement of Lakshmipur Char Alexander-Sonapur-Maijdi Road into Regional Highway		Noakhali, Lakshmipur	866.14	
Bangladesh Inland Water Transport Authority (BIWTA)					
1	Construction of ferry Terminal and Ferryghat at Harinaghat and Alubazar to provide ferry Service between Chandpur-Shariatpur	1999-00 2003-04	Chandpur and Shariatpur	57.37	
2	Construction of Water craft Landing Facility along with Ghat in three coastal Upzila-1st Phase (Teknaf, Sandwip and Manpura) - Feasibility Study.	2001-02		3.00	
Bangladesh Inland Water Transport Corporation (BIWTC)					
1	Procuremenat of 4 passenger seatruck for communication in coastal area and islands of the country			56.00	Without Allocation
Bangladesh Meteorological Department (BMD)					
1	Shifting and Reconstruction of Class-1 Meteorological observatory of Sandwip	1999-00 2001-02		3.84	
SPARRSO					
1	Observation Procedure for Environment Disaster and Resources	1998-99 2004-05		1566.86	

Table 2: List of NGOs projects in the Meghna Estuary

SL	Name of agency and Project	Project	Location	Total cost	Sources of
1	Development of Sustainable Aquaculture Project (DASP)	2001-02 2004-05	Bhola	0.83	USAID
2	Nutrition, Income and Flood Security (NIFS)	1998-99 2004-05	Bhola, Chittagong, Cox's Bazar	1.97	Norway
3	Promotioning Good Governance Through Interactive Peoples Organization	2000-01 2004-05	Bhola	2.53	Norway
4	Self Sustained Embankment Maintenance group and union parisad (SSEMP)	1996-97 2004-05	Bhola		ADB
CODEC					
1	Socio Economic Development of the Coastal and Riverine Fisherfork Communities, phase III	1996-97 2000-01	Chittagong, Lakshmipur, Patuakhali, Barguna	35.45	DANIDA
2	Community Development Centre	1996-97 2000-01	Chittagong, Lakshmipur, Patuakhali, Barguna	48.2	DANIDA
CARE International Bangladesh					
1	Local Initiative for Farmers Training (LIFT)	1998-99 2002-2003	Noakhali, Feni, Lakshmipur		DANIDA
Mennonite Central Committee (MCC)					
1	MCC Agriculturre Program		Noakhali, Feni, Lakshmipur		
Association for Social Advancement (ASA)					
1	Proverty Alleviation Program in greater Noakhali District	1998-99 2002-03	Noakhali, Feni, Lakshmipur		DANIDA
Mass-line Media Centre (MMC)					
1	Support to Mass - line Media Centre	2000-01 2002-03	Noakhali, Feni, Lakshmipur,Patuakhali, Barguna, Barisal, Bhola, Jhalokhali, Pirojpur		DANIDA

Agencies/Institutes

Institutions/Agencies

Several GoB organizations and NGOs are working to understand the physical processes in order to intervene in the natural system and/or improve the infrastructure and socio-economic environment of the Meghna Estuary area. The name of the organization/agencies and their involvements in the Meghna Estuary area are briefly described. Information presented about the organization include the addresses of the head office, head of the organization, the relevant branch offices and name of relevant officials.

BWDB

Bangladesh Water Development Board (BWDB) is one of the important organizations involved in developing the physical environment of the Meghna Estuary since the late 1950s and early 1960s. BWDB's earliest large intervention in the estuary is the construction of the Noakhali Cross-dams . These dams enhanced the land accretion rate south of Noakhali. Coastal Embankment Project implemented in 1960s and 1970s was also a very large interventions in the estuary area. The construction of the embankments has prevented salt water intrusion and protected the the estuary from flooding.

In the late 1970s, the Land Reclamation Project (LRP) started with the aim of understanding the physical processes of the Meghna Estuary. LRP collected hydro-morphological data in the Meghna Estuary for more than a decade and carried out several studies to better understand the processes.

Meghna Estuary Study (MES) started in the 2nd half of the 1990s and collected hydro-morphological, biological and socio-economic data of the Meghna Estuary. The project submitted draft master plan and draft development plan for the MES area. In the second phase i.e. the MES II project carried out pilot interventions to enhance the sedimentation and protect bank erosion at different locations of the Meghna Estuary.

Another important project of BWDB is the Char Development and Settlement Project (CDSP). This project has been playing a role in reclaiming the newly accreted land in Chaittagang, Feni and Noakhali districts and providing the necessary facilities for human settlement.

In addition to the above mentioned projects, BWDB has a few otherr projects in the area. These are: 'Bhola Town protection', 'Noakhali Khal Re-excavation', 'Chandpur Town Protection' and 'Rehabilitation of Damaged High-risk Polders'.

Head Office: WAPDA Bhaban, Motijheel C/A, Dhaka 1000.

Head of the Organization:

Mr. Mukhlesuzzaman

Director General

WAPDA Bhaban

Motijheel C/A, Dhaka 1000

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Relevant persons and branch offices:

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Project Director, PMU-ESPP, BWDB

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Mr. Humayun Kabir

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Survey and Study Division (SSD), BWDB

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Mr. Md. Sayeedur Rahman

Project Director, CERP II

54 Elite House (8th floor), Motijheel C/A

Dhaka 1000

Phone 9565420

Superintending Engineer

Bhola O&M Circle,

BWDB Bhola

Phone 0491-55595

Superintending Engineer

O&M Circle, BWDB, Feni

Phone 0331-73542

WARPO

Water Resources Planning Organization (WARPO) is responsible for preparing and monitoring the implementation of the National Water Management Plan (NWMP). Presently the Integrated Coastal Zone Management Project (ICZMP) is working under the framework of WARPO. The study area of the ICZMP includes the Meghna Estuary area.

Head office: Saimon Centre, Road 22, House 4/A, Gulshan 1, Dhaka 1212, Bangladesh.

Pabx no. 8814554, 8814556

Head of the Organization:

Mr. H.S. Mozaddad Faruque

Director General

Saimon Centre, Road 22, House 4/A

Gulshan 1, Dhaka 1212

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E-mail: dg_warpo@bangla.net

Relevant persons and branch offices:

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Mr. Md. Shahjahan

Principle Scientific Officer (Econ.)

Saimon Centre, Road 22, House 4/A

Gulshan 1, Dhaka 1212

Phone: 8814554, 8814556, E-mail:

LGED

Local Government Engineering Department (LGED) is carrying out different projects to improve the infrastructures in the rural areas. They have a number of nation-wide projects, which includes the Meghna Estuary area. Examples of projects covering the Meghna Estuary area are 'Construction of Low Cost Bridge/Culvert on Rural Raod', 'Construction of Multi-purpose Cyclone Shelter Center' and 'Rural Development Project in Greater Noakhali and Chittagong'.

Moreover, LGED has some location specific projects mostly covering the MES area. Examples are 'Rural Development 22: Infrastructure of Noakhali Districts' and 'Rural Development 23:Infrastructure of Laksmipur and Feni districts'.

Head office: LGED Bhaban, Agargaon, Dhaka

Pabx no; 8114217-9

Mr. M. Shahidul Hassan

Chief Engineer

LGED Bhaban, Agargaon, Dhaka

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Relevant persons and branch offices:

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Agargaon, Dhaka.

Project Director

Cyclone Rehabilitation Project: Entire Coastal Area

House 4, Road 2/C, Pallabi, Mirpur

Dhaka –1221

Phone 8017216

DPHE

Department of Public Health Engineering (DPHE) has a project mainly targeted to a part of the coastal area including the MES area. The project is Water Supply, Sanitation, Drainage and Waste Disposal Project in Municipality, Thana and Growth Centres. The districts covered are Noakhali, Feni, Lakshmipur, Patuakhali and Barguna. DPHE has other nation-wide and coastal zone wise projects which include the Meghna Estuary area, such as ‘Rural Sanitation Project’ and ‘Water Supply Project in Coastal Area’.

Head Office: DPHE Bhaban, 14 Captain Mansur Ali Sharoni, Dhaka

Pabx no. 9346167-70

Head of the Organization:

Mr. Fareed Uddin Ahmed

Chief Engineer

Kakrail, Dhaka

Phone: 9343358

Fax: 9343375

Relevant persons and branch offices:

Central co-ordination Unit

DPHE-DNIDA Water Supply and Sanitation Components

DPHE Bahaban

14 Captain Mansur Ali Sharoni, Dhaka

Pabx no. 9346167-70

RHD

The Roads and Highways Department (RHD) mainly constructs the roads in the Meghna Estuary area and links them to the regional and national road networks. Presently RHD is working on the projects-Ilsha-Bhola-Char Fassion-Char Manika Regional Highway Construction, Barisal-Bhola-Lakshmipur Road Construction and Improvement of Lakshmipur-Char Alexander-Sonapur-Maijdi Road into Regional Highway.

Head Office: Sharak Bhaban, Ramna, Dhaka

Head of the Organization:

Mr. Md. Fazlul Haque

Chief Engineer

Sharak Bhaban, Ramna

Dhaka

Phone: 9562829, 9560598

Fax: 9562798

Relevant persons and branch offices:

BIWTA

Bangladesh Inland Water Transport Authority (BIWTA) is maintaining the inland navigation routes including the navigation route from Chittagong to Barisal via Sandwip, Hatia and Bhola. BIWTA generally provides the berthing and land facilities at the different passenger and cargo handling *ghats*. They have presently two projects in the Meghna Estuary area: Construction of ferry Terminal and Ferryghat at Harinaghat and Alubazar" to provide ferry service between Chandpur and Shariatpur and "Construction of Water Craft Landing Facility along with Ghat in three Coastal Upazila - 1st Phase (Teknaf, Sandwip and Manpura) – Feasibility Study".

Head Office: BIWTA Bhaban, 141-43 Motijheel C/A, Dhaka 1000.

Pabx no. 9556151-55

Head of the Organization:

Mr. M. Shahidul Islam Chowdhury

Chairman

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Dhaka 1000

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Relevant persons and branch offices:

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Phone 9556151-55, Ext. 1187

Engr. M.A. Mannan

Executive Engineer

BIWTA, Chandpur Division

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Forest Department

The Forest Department is playing an important role in planting the mangroves on the emerging land of the Meghna Estuary. The mangrove forests enhance the vertical accretion and protect the land from denudation. Moreover, they have a project titled “Coastal Greenbelt Project (CGP)” which aims to carry out planting along the embankment, roadsides, in homestead and foreshore areas.

Head Office: Bana Bhaban, Mohakhali, Dhaka

Fax: 9886887

Head of the Organization:

Mr. Anwar Faruque

Chief Conservator of Forest

Bana Bhaban, Mohakhali, Dhaka

Phone: 8828364

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Relevant persons and branch offices:

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Conservator of Forests, Coastal Circle,

Bana Bhaban, Mohakhali, Dhaka

Phone 8826964

Mr. Md. Iklil Mondal

Project Director, Coastal Greenbelt Project,

Bana Bhaban, Mohakhali, Dhaka

Phone: 9886887

DoF

Department of Fisheries (DoF) is working to improve the marine and closed waterbody fisheries in the Meghna. Forimplementing this they have a number of on-going projects. These projects are: Greater Noakhali Aquaculture Extension Project, Coastal Marine Fishery Management Strengthening Project, Fourth Fisheries Project, Jhatka (Juvenile Hilsa) Conservation and Management Project and Employment of Coastal Fishing Community for Livelihood Security Study.

Head Office: Matshaya Bhaban, Ramna, Dhaka

Pabx no:9561355, 9565021-3

Head of the Organization:

Mr. Nasiruddin Ahmed

Director General, DoF

Matshaya Bhaban, Ramna

Dhaka

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Relevant persons and branch offices:

Mr. Wahidunnabi Choudhury

Project Director GNAEP

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Maijde Housing Estate,

Noakhali 3800

Phone 0321-5473

Mr. Md. Rafiqul Islam

Project Co-ordinating Director

Fourth Fisheries Project

Matshaya Bhaban, Ramna

Dhaka

NGOs

COAST

Coastal Association for Social Transformation (COAST) is working to improve the livelihood of the coastal area. Presently their ongoing projects are mainly on the improvement of the household income through aquaculture, poultry and livestock development, etc., and also the self sustained embankment maintenance.

Head Office: COAST Central Office, Village, Kulsumbag, P.S. Charfession, District Bhola

Head of the Organization:

Relevant persons and branch offices:

Mr. Md. Shamsuddoha

Senior Coordinator

COAST Trust,

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Dhaka

Phone: 9129395

E-mail: coasttst@citechco.net

CODEC

Community Development Centre (CODEC) is working to improve the socio-economic environment of the people living in the coastal and riverine areas of Bangladesh. Their main activities include building and development of institutions and providing education and training. They also have savings and credit program.

Head Office: House 62/B, Road 3, Chandgaon R/A, Chittagong. Phone: 031-670663

Head of the Organization:

Dr. Khurshid Alam

Executive Director

House 62/B, Road 3

Chandgaon R/A,

Chittagong

Phone: 031-670663, 031-671405

E-mail: codec@spnetctg.com

IWFM

Institute of Water and Flood Management (IWFM), an institute of Bangladesh University of Engineering and Technology (BUET) has many years of experience in predicting the storm surge height and designing the multipurpose cyclone shelters.

Head Office: IWFM Building, BUET Campus, Dhaka

Pabx: 9665650-80

Head of the Organization:

Prof. Jahir Uddin Choudhury

Director

IWFM Building, BUET Campus

Dhaka

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IWM

Institute of Water Modelling (IWM) has been involved in measuring the hydro-morphological data with the Meghna Estuary Study (MES) project. They are also involved in developing, calibrating, validating and simulating the 2D hydrodynamic (HD) model for alternative options for the Meghna Estuary area. This model was developed under the framework of the MES Project. IWM also simulated 2D HD model for estimating the surge height and depth for 2nd Coastal Embankment Rehabilitation Project (CERP).

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CEGIS

Center for Environmental and Geographic Information Services (CEGIS) supported Meghna Estuary Study (MES) projects by procuring, processing and analyzing satellite images covering the MES area for the period 1997-2002. CEGIS carried out a pilot study to assess the changes in the intertidal and land areas in the Meghna Estuary using satellite images. The Morphologist of CEGIS has prepared a report for Survey and Study Support Unit (SSSU) on Considerations on Morphological Processes in the Meghna Estuary.

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Annex 2

Proceedings of

the workshop on the Knowledge Portal on the Estuary Development

(KPED)

Venue: **WARPO Conference Room**

Date: February 6, 2003

The workshop was organized by CEGIS and PDO-ICZMP. Invitation letters were delivered to different government and private agencies and projects for participating in the workshop. These organizations and projects are: BWDB, WARPO, DoE, DoF, BIWTA, LGED, IWFM – BUET, GSB, IWM, PDO-ICZMP, CEGIS, RNE, DfID, CERP, CDSP. Nearly 45 representatives from all the organizations except DoE, DoF, BIWTA and IWM were participated in the workshop.

The opening session started at 10:30. The session was chaired by H. S. Mozaddad Faruque, Director General, WARPO and Chief Guest was Mr. Mukhlesuzzaman, Director General, BWDB. At the beginning of the session Dr. Riaz Khan delivered the welcome address. Rob Koudstaal presented the Knowledge base of ICZM. He described the aim of the PDO-ICZMP and the role of the project in managing the knowledge of ICZM.

Maminul Haque Sarker presented the Introduction of KPED. He described the method that CEGIS had followed to develop the KPED. A 10 days work session was organized by CEGIS to design the KPED and compile and organize the knowledge of the estuary development processes. Later CEGIS programmers have developed the web-based application of the knowledge portal.

Chief Guest of the opening session, Mr. Mukhlesuzzaman, pointed out that the workshop does not have enough representation from the different water sector organizations. He also stressed that not only the physical aspects, KPED should contains the knowledge and information on the other aspects such as ecological and socio-economic aspects of the Meghna Estuary.

The chair of the session, Mr. H.S. Mozaddad Faruque also stressed on the representation from different organizations in the water sector in such an important workshop. He pointed out that this sort of web-based knowledge portal should be user-friendly. Mr. Faruque expected that in the future the social aspects will be incorporated in the portal. He hoped that in the near future a knowledge portal would be developed covering the all whole water sector. He reminded that if any digital version of reports of any organization is put in the portal, the prior permission should be required from the concerned authority.

The technical session started at 11:45. The session was chaired by Dr. Riaz Khan. Mr. Martin Leach, Senior Rural Livelihoods Advisor, DfID, Bangladesh, was the chief Guest of the session. Mr. Hasan Ali described the design aspects of the KPED. He described the considerations in designing a good knowledge portal. He mentioned after defining the aim, the users of the knowledge portal should be identified and the structure of compilation of knowledge portal should be done accordingly. A.K.M. Hasan demonstrated the CD version of the knowledge portal. After completion of the web-site of PDO-ICZMP, the portal will be linked with the PDO-ICZMP web site.

Mr. Abu M. Kamal Uddin facilitated the discussion on the use of knowledge portal. Mr. Sayeedur Rahman BWDB and Humayun Kabir of BWDB; Dr. Mohiuddin Ahmed and Rob Koudstaal of ICZMP; Sirajul Haque, LGED, Dr. Lindsay Saunders and Ms. Caro Kriger of RNE, Dr. Riaz Khan, Md. Hasan Ali and Maminul Haque Sarker participated in the discussion.

Most of the discussants raised the following key issues:

1. who will be the host organization of the knowledge portal

2. extension of the knowledge portal by including the socio-economic and ecological aspects

3. who and how frequently the portal can be updated and refreshed with updated information

4. how the knowledge can be disseminated to the people with this portal, who do not have the access to internet facilities

5. how the portal can be linked to NWRD or ICRD

However, question was also raised on other issues, whether it would be wise to include the data to the web. In most of the cases, the data capturing authority sells the data to meet the partial cost of data collection. If the data were put in the web, these organizations will be loosened.

Ms. Caro added that in the knowledge portal prevailing policies of the government on different issues, like the policy on the agriculture, industry, environment or on the coastal areas should be incorporated. Inclusion of the policy will make the knowledge portal more acceptable to the planners, consultants and others.

Mr. Sirajul Haque of LGED, suggested that LGED have lot of information on the coastal region, which could be included in the KPED. Dr. Riaz Khan mentioned the design of the KPED is simple and easy to navigate. He also added that during the design of the web-based knowledge portal, the speed of the computers and internet services in Bangladesh should be kept in mind.

Mr. Martin Leach, Chief Guest of the session requested to add the livelihood aspects to the KPED and he also expressed his concern about maintenance and updating of the knowledge portal.

During delivering the speech of the chair, Dr. Riaz Khan mentioned developing the KPED is a very good initiation in knowledge management. He hoped that in the coming future, knowledge portal will cover the every branches of knowledge.

Mr. Mukhlesuzzaman (left), DG, BWDB attended the workshop on KPED as chief guest and

Mr. H.S. Mozaddad Faruque (right), DG, WARPO chaired the opening session.

List of PDO-ICZM publications