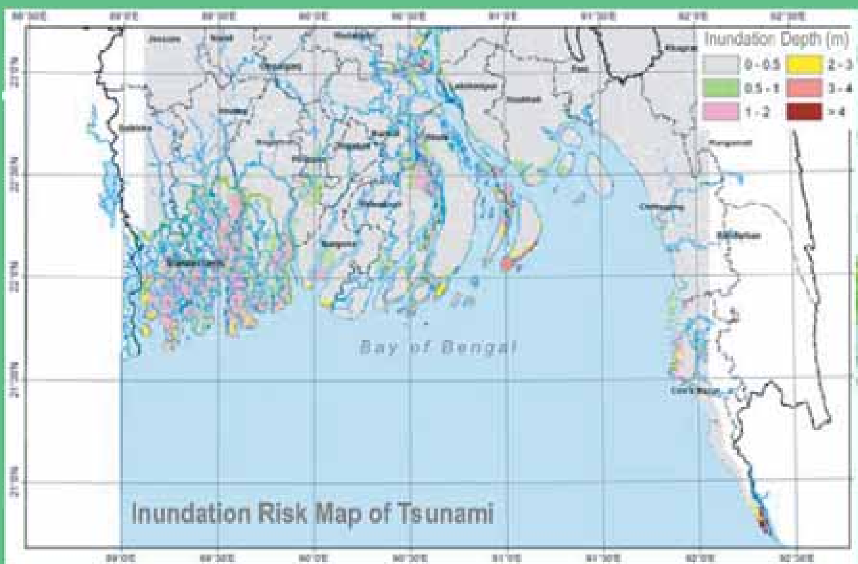
# Use Existing Data on Available Digital Elevation Models to Prepare Useable Tsunami and Storm Surge Inundation Risk Maps for the Entire Coastal Region






## FINAL REPORT
## Volume-II: DEM, Landuse and Geo-morphology Maps

## April 2009

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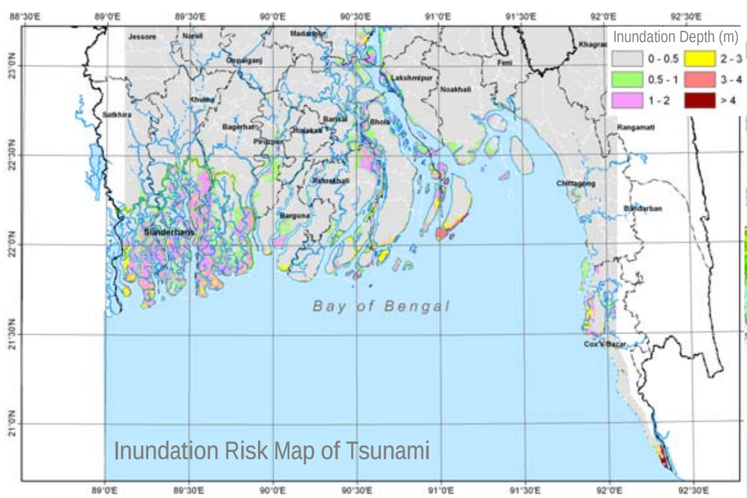


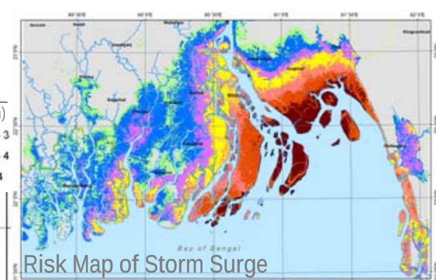


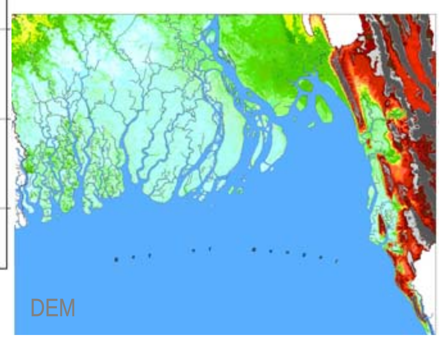


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Institute of Water Modelling, Bangladesh

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April 2009

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FINAL REPORT

Volume-II: DEM, Landuse and Geo-morphological Maps

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BTM | Bangladesh Transverse Mercator |
| BWDB | Bangladesh Water Development Board |
| CDMP | Comprehensive Disaster Management Programme |
| CSPS | Cyclone Shelter Preparatory Study |
| DEM | Digital Elevation Model |
| ETM | Enhanced Thematic Mapper |
| FCC | False Colour Composite |
| FAP | Flood Action Plan |
| GCP | Ground Control Point |
| GPS | Global Positioning System |
| GSB | Geological Survey of Bangladesh |
| IWM | Institute of Water Modelling |
| KJDRP | Khulna Jessore Drainage Rehabilitation Project |
| LCC | Lambert Conformal Conic |
| LGED | Local Government Engineering Department |
| LISS | Linear Imaging Self-scanning Sensor |
| MPO | Master Planning Organization |
| MSS | Multi-Spectral Scanner |
| MSL | Mean Sea Level |
| PWD | Public Works Department |
| RBV | Return Beam Vidicon |
| SoB | Survey of Bangladesh |
| SRF | Sundarban Reserved Forest |
| TM | Thematic Mapper |
| WiFS | Wide Field Sensor |

# 1. INTRODUCTION

This is the volume-II of the Final Report of the study titled *"Use existing data on available digital elevation models to prepare useable tsunami and storm surge inundation risk maps for the entire coastal region"*. This report contains the Digital Elevation Model (DEM) of the entire coastal region, landuse and geomorphological maps of Bangladesh. It describes the methods and material used for the preparation of DEM, landuse map and geomorphological map. Soft copies of the DEM, landuse and geomorphological maps have been provided in a CD along with this report, which may be considered as a part of the report.

Comprehensive Disaster Management Programme (CDMP) commissioned Institute of Water Modelling (IWM) to carry out this study n December 2007.

# 2. DEVELOPMENT OF DIGITAL ELEVATION MODEL

## 2.1 General

A Digital Elevation Model (DEM) is a computerized representation of a continuous surface, usually that of the Earth. More, specifically, it is an array of digitally stored numbers representation of the elevation of discrete points on a surface.

In the following, the digital elevation model is simply referred to as the DEM.

## 2.2 Available DEM

Since early eighties efforts have been made to produce regional & national DEM in Bangladesh. The earlier development works are described in the following section;.

**a)** During the 1980, the MPO (Master Planning Organization ) digitized a national level grid of elevation points having 1 km (1000 m) horizontal spacing (Not a DEM) using contour maps of BWDB elevation points Those digitization has done from BWDB topographic map data. The low horizontal resolution limits its usefulness in quantitative terrain analysis.

**b)** In 1993, FAP-19 prepared several DEMs based on the BWDB topographic data. Those were **i).** DEM of North Central region, **ii).** DEM of Tangail Area, **iii).** Bangladesh National DEM. These DEMs include high resolution regional DEM constructed from the original spot elevation points of BWDB maps and MPO’s interpreted 1 km grid of elevation points.

**c)** In October, 1994, FAP-19 produced a medium resolution or Semi-detail DEM (500 m X 500 m) based on generalized BWDB spot elevation points. This generalization has done manually by super imposing a transparent 500 m grid template on the source maps and recording the elevation point nearest each grid intersection.(A detailed procedure is found in the FAP 19 Technical report *“Medium Resolution DEM of Bangladesh”*). Finally the pixel size of the DEM was chosen as 300 m X 300 m. However, the input data resolution was from the 500 m template grid. The accuracy of this DEM is largely depends on the original data density

**d)** In 1997, an attempt has been initiated to prepare a updated DEM for entire Coastal belt of Bangladesh under the project entitled “*Cyclone Shelter Preparatory Study (CSPS)”*. The DEM covers the lower part of Bangladesh up to Chandpur with the resolution of 600 X 600 m considering interest of the project.

In view of the above, development of a fine resolution DEM for the coastal area has become essential considering available recent data set. This chapter describes the data used and the preprocessing involved in generating a Digital Elevation Model (DEM) of the lower part of Bangladesh in connection with the *CDMP, Risk Management project*.

## 2.3 Methodology of Development of DEM

### 2.3.1 Specification of the Coastal DEM

The main concern of use of the DEM is to enhance the flood inundation result in a realistic manner. In this way the Flood model's requirement also has considered for Generated DEM. Following are the Specifications:

| | |
|---|---|
| **Projection** | BTM |
| **Datum** | PWD |
| **Western boundary** | 380913.9807 |
| **Eastern boundary** | 747313.9807 |
| **Southern boundary** | 275305.7448 |
| **Northern boundary** | 568605.7448 |
| **Cell Size (m)** | 50 |
| **Dimension** | 7328X5866 |
| **Orientation (grid N)** | 0 |
| **Digital format** | ASCII, ArcView GRID |

Basically, the DEM covers the lower part of Bangladesh up to Chandpur. Grid boundaries has been determined so that the DEM immediately matches with the MIKE21 fine grid model.

### 2.3.2 Data Processing

The data processing involved in making the DEM has been divided into three steps:

1. Generating a Partial Coastline.
2. Preparing Input Data.
3. Generating the DEM.

These steps are described in the following.

### 2.3.3 Generation of Coastline

We need an estimate of a coastline primarily to remove outdated data, i.e. FINNMAP or others data measured where there is no water. However, the coastline estimate can also be useful in the interpolation and for display purposes. The coastline is based on available recent satellite images and shoreline survey data

| Images | Origin | Area Covered |
|---|---|---|
| Landsat TM | Jan, 2007 | Coast of Ramgati to Situkunda including Sandwip, upper part of Monpura and Hatia. |
| Image from Google Earth | 2006-07 | Most coastlines in Sundarban Reserved Forest |
| Landsat TM | Feb, 2006 | Kuakata to Lower part of Bhola, Lower part of Hatia & Monpura |
| IRS LISS3 | 2005 | From Sitakunda coast to upper part of Moheshkhali Island. |
| IRS LISS3<br>Shoreline survey | Dec, 2004, 2005 | Upper part of Bhola to Laksmipur Coast including adjoining area of Chandpur |
| Landsat ETM | 2003 | From Baleswar river to Kuakata Coast & Moheshkhali Coast |
| | | |

Prior to identifying the recent coastline, the images (raw and archives in IWM data sources) has been geo-corrected in respect of available ground control point (GCP) by surveyed topographic information. Image processing software ERDAS Imagine & Image Analyst extension of the Arcview GIS have been used for geo-rectification in this regard. After geo-correction, an on-screen digitization procedure has performed to capture the coastline.

### 2.3.4 Input Data

The following data has been used in creating the DEM.

| Data Source | Origin | Area Covered |
|---|---|---|
| BWDB (Khulna Jessore Drainage Rehabilitation Project (KJDRP) data, Surveyed by IWM) | 1997 | Khulna Jessore Area |
| BWDB Beel Kapalia, Surveyed by IWM | March, 2008 | Beel Kapalia (Inside KJDRP) |
| BWD Beel Khuksia, Surveyed by IWM | Feb, 2004 | Beel Kuksia (Inside KJDRP) |
| FINNMAP Land Survey | 1991 | All over the coastal areas. |
| FAP19 – National DEM | 1952-64 | Excluding KJDRP & FINNMAP Surveyed Area |

Figure 2.1 shows the different sources of data and its coverage that are used for the generation of the DEM.

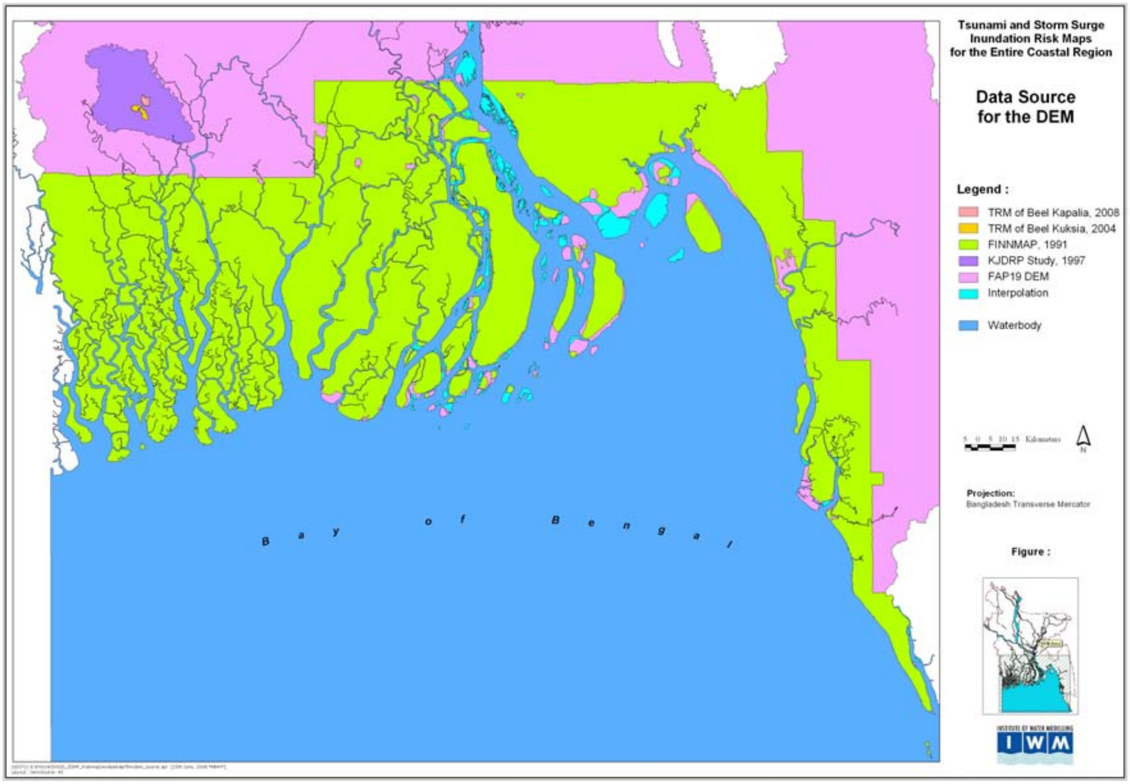


Figure 2.1: Data sources for the Digital Elevation Model (DEM)

The FINNMAP data does not overlap with the BWDB data at Jessore and Khulna area. However, the FAP19 DEM data do overlap and these are old data set. Mainly FINMAP and BWDB data were used and FAP 19 data are used only where these data are not available.

During CSPS-II project in 1997-98, about 500 sheets of FINNMAP topographic map were digitized and used for generated DEM. Under the present study, another 570 sheets of FINNMAP topographic map have been digitized for capturing the spot heights. Having determined the *extent* of land (where possible), the next step is to merge data in order to get the information of land level.

The following describes the process of merging these three different data types into one theme, which has been used for the final generation of the DEM.

#### 2.3.5 Processing of FINNMAP and BWDB data

The first step was to generate a theme containing both FINNMAP and BWDB data.

- Spot heights which are on the embankments or elevated road has not been considered during interpolation. But spot heights which are on the homestead, has been used in interpolation process;

- Merging the available FINNMAP data in BTM projection and PWD datum. Original elevation is in SOB datum, which is in MSL. MSL value has been transferred to PWD datum by adding 0.459m;
- Conversion of FINNMAP data into ArcView shapefile;
- Removal of obsolete FINNMAP points by using the recent coastline by clipping;
- Conversion of BWDB data into ArcView shapefile in BTM and PWD; and
- The BWDB data and the FINNMAP data have been merged into one shapefile.

#### 2.3.6 FAP19 National DEM data

Next the relevant FAP19 National DEM data was extracted and converted into point data.

- Obtained as Arc/Info integer grid format (300 m) in BTM and PWD in millimetres;
- A mask has been generated covering the areas of the FAP19 DEM where no other data are available (i.e. FINNMAP or BWDB data). Specifically this mask is the area covered by the FAP19 DEM excluding areas covered by FINNMAP and BWDB data;
- The relevant parts of the FAP19 DEM data has been extracted using the mask previously generated;
- The generated grid is then converted into a point theme, where each point corresponds to a grid center point; and
- Some of these points are clearly irrelevant as they are outside the land boundary. These points have been deleted.

#### 2.3.7 Merging of data

Finally, the three types of data were combined. The FINNMAP and BWDB data are then merged with the FAP19 DEM data. The result of this operation is a set of points, which will be used in the final interpolation generating the DEM.

#### 2.3.8 Field verification of FINNMAP data

IWM had performed a evaluation survey work during a project “Sundarban Biodiversity Conservation Project” in 2003 for consideration of using FINNMAP’s elevation data for throughout the Sundarban Reserved Forest (SRF), The project has used this data source because land level from aerial survey of FINNMAP was the only secondary source available. IWM surveyed 4 sample areas at Jongra and Katka (2km X 2km) and smaller area at Kaikhali and Patkusta in SRF. The positions of spot levels were recorded by using hand GPS. Land levels of the three pilot areas were compared with the level obtained from FINNMAP aerial survey. A reasonable match was found between IWM survey and FINNMAP survey for some points. However, most of the FINNMAP spot levels vary with those of IWM survey.

## 2.4 Generation of DEM

In generating the actual DEM it is necessary to specify the area to be covered by the interpolation by generating a mask covering land. As it is obvious the interpolation will not generate reasonable values for non-land. The land mask is generated on the basis of the coastline and the availability of data. The generated coastline has simply been converted into grid format. This is the mask that will determine which areas are covered by the interpolation of land data.

Generating the DEM by interpolation has been an iterative process. Several interpolation routines has been tried and it has proved necessary to add supporting points where the interpolation otherwise gives unreasonable results. The process involved in generation of DEM is as follows:

- Supporting points has been created in order to help the interpolation routine on its way. These points are of two types:

    1. Points to stop the interpolation going wild. The level values for these points has either been estimated from the closest surrounding values or from the values that it has been assumed that these points would have (e.g. in the highlands).

    2. Points to help the interpolation where there is no data at all. This situation arises for several of the smaller island in the estuary (e.g. the islands north of Sandwip, south of Hatia etc.). The level values for these points has been set to spring tide + 0.5 meter, where the spring tide value has been taken from the closest station where this information is measured.

- The previously generated points and the supporting points has been merged into one theme containing all points for the interpolation.

- The points have been interpolated generating the DEM. The DEM covers the same area as the land mask described in the previous section (i.e. not water). Spline, The interpolation method has been used for generated final DEM. This surface fitting method is the simplest and most appropriate method (within Spatial Analyst) for topographic interpolation. It has the advantages of being able to generate ridges and valleys, while at the same time ensuring that the surface goes through the points used in the interpolation.

- Finally, the DEM has been smoothed by applying a 3x3 averaging window on all cells. The result is what will be considered the final DEM.

Digital Elevation Model (DEM) of the coastal region of Bangladesh is shown in Figure 2.2.

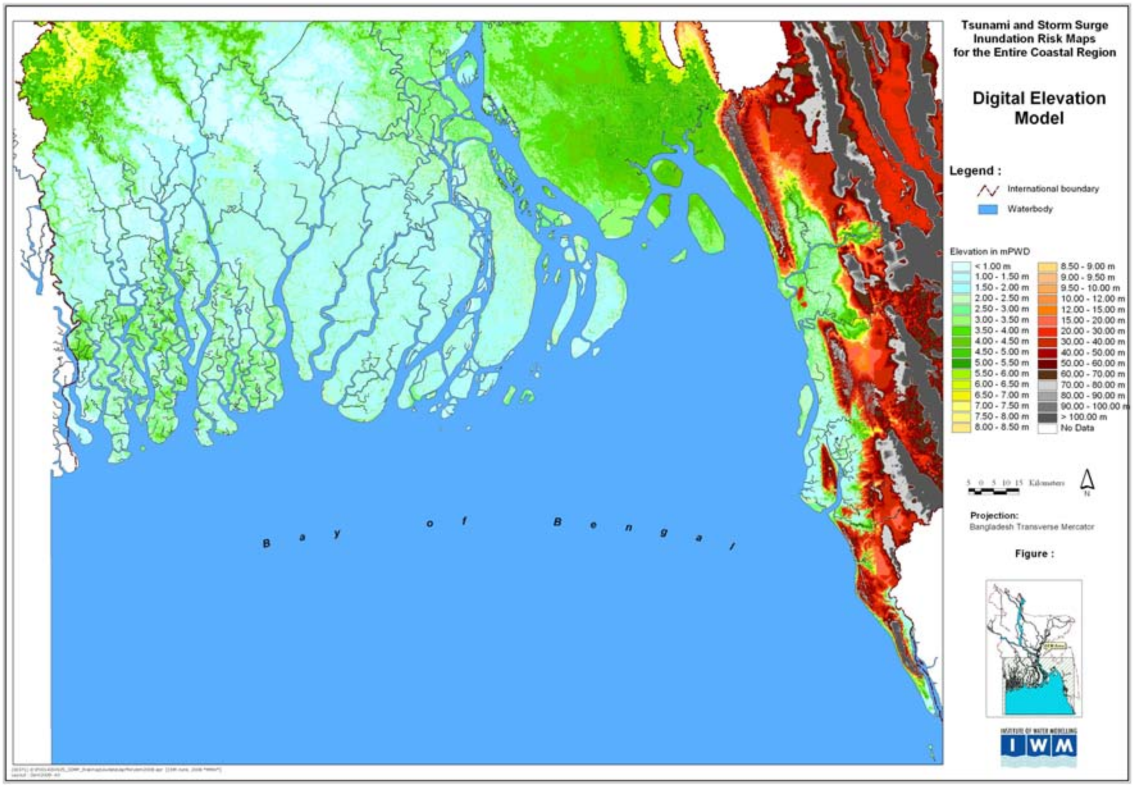


Figure 2.2: Digital Elevation model of coastal region of Bangladesh

# 3. PREPARATION OF LAND USE MAP

## 3.1 General

Land use map is required to know the current land use pattern, which is the main basis of computing the decay factor for tsunami waves. The SRDI maps and LGED upazila maps at a scale of 1: 50000 and field survey data are the primary basis of preparing land use map for upazilas of the coastal areas. A large part of the coastal area is used as settlement areas and crop cultivation. Settlement areas are usually surrounded by trees of varying heights. The beels/depressions are usually used for pisciculture during the rainy season (monsoon) and for rice cultivation during the dry season (winter). Only a small part of the deltaic area is occupied by a mangrove forest with an aerial extent of 571,508 ha. situated in the south western part of Bangladesh.

Land use of the coastal region of Bangladesh has been categorized into five different uses such as (i) Settlement and social forest, (ii) reserved forest, (iii) agriculture, (iv) swamp and inundated area, and (v) river. Different land uses have been delineated from different sources. The whole procedure of delineating different land uses has been elaborated in the following section.

Settlement and social forest are combined into one category because these two cannot be differentiated from high resolution (24m and 30m ground resolution) available multi-spectral satellite images. Two sources of settlement and social forest are existing LGED Upazila Base Maps and recent satellite imagery (Landsat 5 TM of year 2006-07, Landsat 7 ETM of year 2003, IRS LISS III of year 2004-05). The bands used to extract different land use types for Landsat 5 TM of 13 February 2006 and 22 January 2007, Landsat 7 ETM of year 2003 (made mosaic of 17-19 January 2003 for the whole coastal area of Bangladesh) are 2, 3 and 4 as false colour composite (FCC). The bands used for IRS LISS III imagery of 29 December 2004 and 16 March 2005 are 1, 2 and 3 as FCC. All these imagery were purchased for different previous studies conducted by IWM. The specifications of satellite imagery that have been used in this study, and the method applied for preparing landuse map are summarized in this chapter (Infoterra, 2007).

## 3.2 Specifications of Satellite Imagery

### 3.2.1 Landsat

The Landsat series of American satellites has provided high quality multi-spectral data since 1972. Over the years, millions of scenes have been acquired to form a world-wide archive of Earth observation data.

Landsat 7 was launched successfully on 15th April 1999 and has enhanced features, including a 15 metre panchromatic band (Table 3.1). It is an ideal, multi-purpose, cost-effective tool for a huge range of applications.

Landsat 1 - 3 carried a MSS (multi-spectral scanner) sensor and a RBV (return beam vidicon).

Landsat 4 and 5, launched in 1982 and 1984 respectively, have a MSS and TM (thematic mapper) sensor on board.

The satellite orbits at an altitude of 705Km. A full size Landsat MSS or TM scene covers an area of approximately 185Km by 175Km. The swathe of the sensor restricts the maximum width, and the contiguous orbit data is then divided up into nominal scenes. Digital products include raw and system corrected data.

*3.2.1.1 Landsat 7 ETM+ Data*

The ETM+ sensor on Landsat 7 has a number of enhanced features, including:

- New panchromatic band with 15 metre spatial resolution, co-registered with the multi-spectral bands;
- Thermal infra-red band 6 has increased resolution from 120m to 60m, and now has two gain settings;
- Worldwide data - the solid state tape recorder can collect 100 images per day from anywhere in the world;

Table 3.1: A summary of the band information is contained in the table below.

| | Band Width | Spatial Resolution |
|---|---|---|
| Band 1 | 0.45 - 0.52µm (blue) | 30 metres |
| Band 2 | 0.52 - 0.60µm (green) | 30 metres |
| Band 3 | 0.63 - 0.69µm (red) | 30 metres |
| Band 4 | 0.75 - 0.90µm (near infra-red) | 30 metres |
| Band 5 | 1.55 - 1.75µm (infra-red) | 30 metres |
| Band 6 | 10.4 - 12.50µm (thermal infra-red) | 60 metres |
| Band 7 | 2.08 - 2.35µm (near infra-red) | 30 metres |
| Band 8 | 0.52 - 0.90µm (green - near infra-red) | 15 metres |

*3.2.1.2 Landsat 4 & 5 TM*

Landsat 4 and Landsat 5 data are essentially similar to the 30 metre spectral bands of Landsat 7 ETM+ data. Band 6 has a resolution of 120 metres. Landsat 4/5 data is typically more noisy than ETM+ data. Source: (Infoterra, 2007)

### 3.2.2 Indian Remote Sensing Satellite (IRS)

IRS-1D is the latest in a series of Indian satellites and was launched on the 29th September 1997, and carries an identical payload to the IRS-1C satellite, launched on the 28th December 1995. Both satellites carry three sensors:

- Linear Imaging Self-scanning Sensor (LISS III)
- Panchromatic (Pan)

- Wide Field Sensor (WiFS)

The IRS satellites orbit at an altitude of 817Km. IRS Pan scene sizes are typically 70Km by 70Km (vertical viewing) and LISS scenes are 140Km by 140Km. Pan sub-scenes are also available (23Km by 23Km).

*3.2.2.1 IRS Panchromatic*

IRS Pan data is acquired over the visible green to near infra-red portion of the spectrum, and has 5.8 metre spatial resolution. However, compared to SPOT 1-4 10 metre Pan data, which has 256 grey levels, IRS Pan has only 64 grey levels. Therefore, the increased spatial resolution of the IRS imagery has to be balanced against the better depth of SPOT 1-4 data. Generally, IRS data is of higher quality in lower latitudes compared to higher latitudes due to a better sun angle.

*3.2.2.2 IRS LISS III data*

The LISS III sensor has similar bands to SPOT XI. However, it does have a limitation regarding the reduced resolution of band 4 (Landsat equivalent band 5) which reduces the potential number of applications for this sensor (Table 3.2).

Table 3.2: A summary of the band information is contained in the table below.

| | Band Width | Spatial Resolution |
|---|---|---|
| Band 1 | 0.52 - 0.59µm (green) | 23 metres |
| Band 2 | 0.62 - 0.68µm (red) | 23 metres |
| Band 3 | 0.77 - 0.86µm (near infra-red) | 23 metres |
| Band 4 | 1.55 - 1.70µm (mid infra-red) | 70 metres |

Source: (Infoterra, 2007)

## 3.3 Methodology

Landuse map for the entire coastal region of Bangladesh has been prepared based on the Local Government Engineering Department (LGED) data, recent satellite imagery and field survey data. Preparation of landuse map has been described below:

### 3.3.1 LGED data

LGED prepared Upazila Base Maps in 1:50000 scale compiling data from following sources (LGED, 2005).

- Topographical maps from Survey of Bangladesh (SoB) published in 1962.
- Old Thana (Upazila) and District Maps from Department of Land Record (DLR) published in 1941.
- Aerial photograph from SoB of the year 1980.

- Satellite imagery (SPOT image of year 1988-90)

LGED digital data have been collected in ArcInfo coverage format. The LGED digital data (PC ArcInfo coverages) of settlement and social forest have been found for 65 upazilas of the study area (total 82 upazilas). These data were projected in Lambert Conformal Conic (LCC) projection system. LGED settlement coverages have been merged all together first to make a single coverage or a shape file (ArcView's native file format). The LCC projected shape file was then projected to Bangladesh Tranverse Mercator (BTM) projection system because all other GIS data in IWM are projected into BTM. The combined shape file was then compared to the latest high resolution multi-spectral satellite images and updated accordingly. The updating of old LGED settlement data (1980-90) has been taken place mainly where there are big changes such as settlement shifting for river bank erosion or char area shifting mainly in Bhola island and both banks of wide rivers, increase of settlement area mainly in Noakhali, Feni and Lalxmipur District. The same procedure has also been applied to the coverages of location names in each upazila.

### 3.3.2 Satellite Imagery Data

All other land use type and the rest of settlement and social forest have been digitized from latest collected satellite imagery (Table 3.3 and Figure 3.1). The individual shape files of different land use types were then combined together to make one polygon shape file. All these jobs have been conducted using ESRI® ArcGIS™ 9.1 (ESRI, 2005).

Table 3.3: Satellite imagery as sources of land use data extraction

| Images | Origin | Area Covered |
|---|---|---|
| Image from Google Earth | 2006-07 | Most coastlines in Sundarban Reserved Forest |
| Landsat ETM | 17-19 Jan 2003 | From Baleswar river to Kuakata Coast & Moheshkhali Coast |
| Landsat TM | 13 Feb, 2006 | Kuakata to Lower part of Bhola, Lower part of Hatia & Monpura |
| IRS LISS3 | 29 Dec, 2004 | Upper part of Bhola to Laksmipur Coast including adjoining area of Chandpur |
| Landsat TM | 22 Jan, 2007 | Coast of Ramgati to Situkunda including Shandwip, upper part of Monpura and Hatia. |
| IRS LISS3 | 16 Mar, 2005 | From Sitakunda coast to upper part of Moheshkhali Island. |
| Landsat TM | 1997 | Cox's Bazar to Saint Martin's Island |

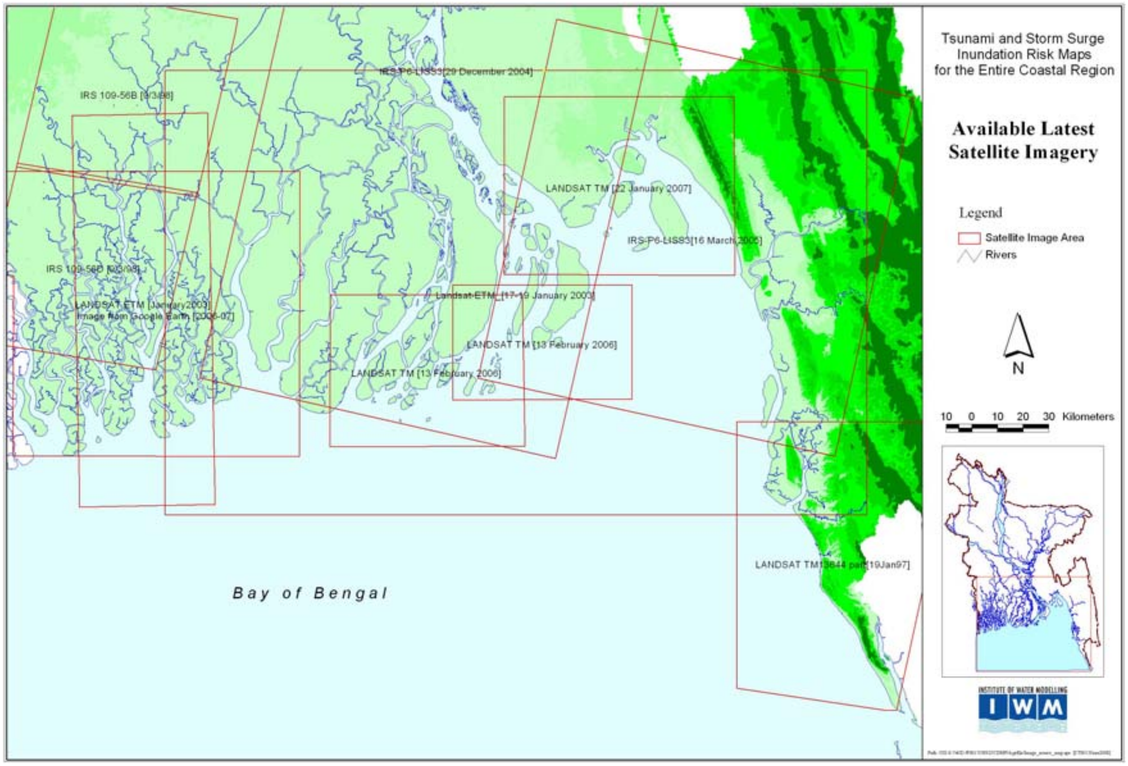


Figure 3.1: Available latest satellite imagery of coastal region of Bangladesh

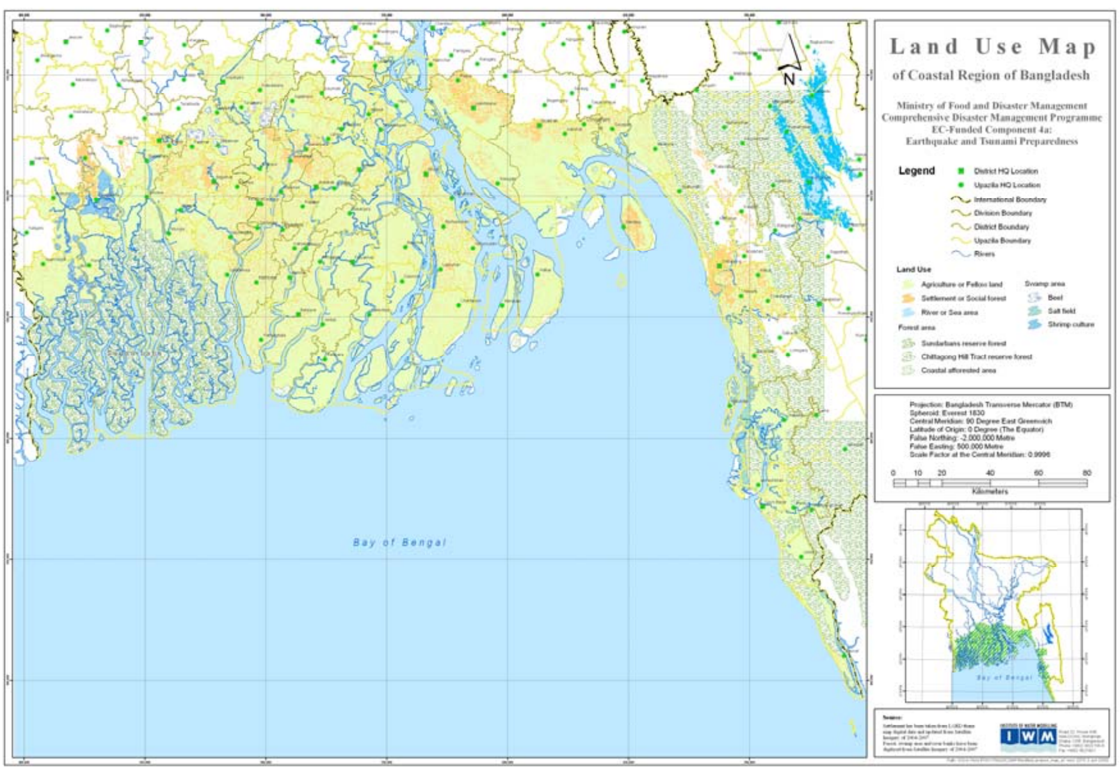


Figure 3.2: Land use map of coastal region of Bangladesh

### 3.4 References

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Infoterra. (2007). Infoterra: an EADS Astrium company. Retrieved May 22, 2008, from http://www.infoterra.co.uk

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# 4. GEOMORPHOLOGY OF THE CENTRAL COASTAL PLAINS OF BANGLADESH

## 4.1 General

Bangladesh lies between 20°34' and 23°38' north latitude and 88°01' and 92°41' east longitude. Coastline of Bangladesh, about 710 km in long (Fig. 4.1), extends along the Bay of Bengal from the mouth of the Naaf river in the south-east to the mouth of the Raimongal river in the south-west.

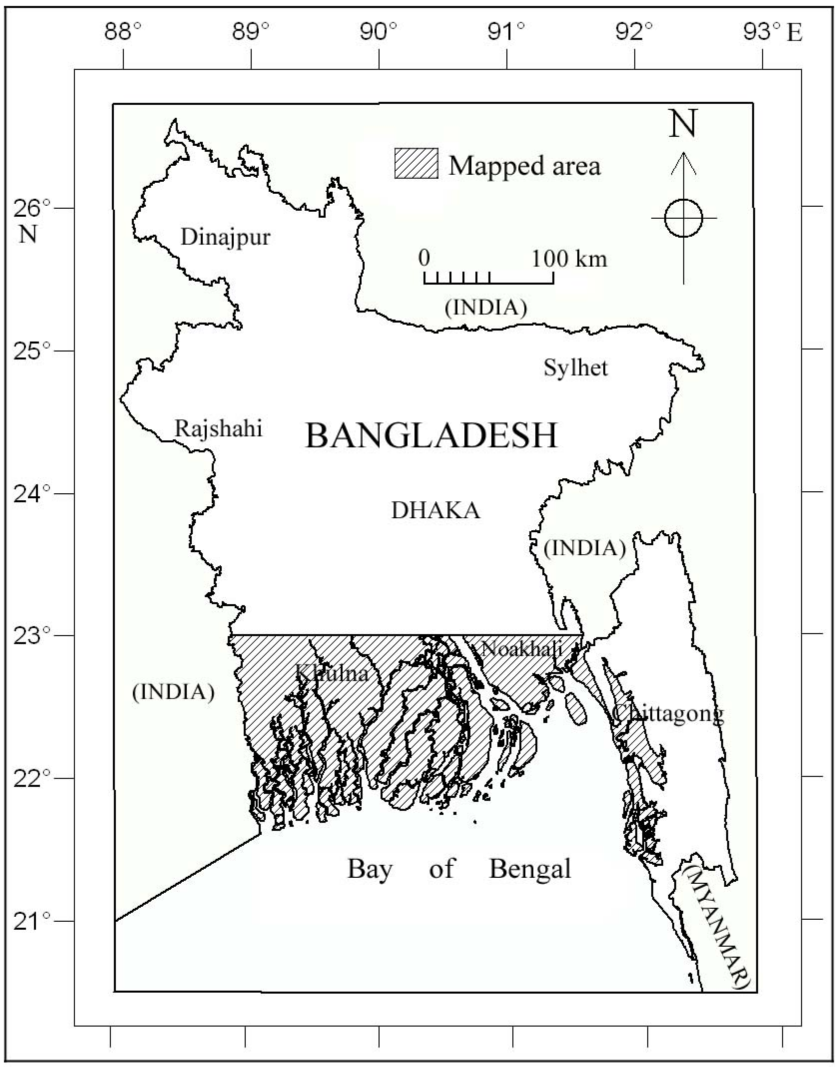


Figure 4.1. Location map of the mapped area.

Geomorphologically, the entire coastal plain of Bangladesh can be broadly classified into two major zones. These are the Ganges-Brahmaputra delta of the Satkhira-Noakhali area, which includes the Meghna estuary as its main component and the inter-deltaic coastal belt of the Chittagong-Cox's Bazar area. The deltaic coastal plain stretches in the east-west direction and meets with the Chiitagong-Cox’s Bazar coastal belt with an angle almost at perpendicular direction near the mouth of Meghna estuary. Alluvial deposits carried by the three mighty river systems, the Ganges, the Brahmaputra, and the Meghna have gradually built up the Ganges delta including the Meghna estuary. The major estuarine parts are constituted by a large number of small and large islands and mouth bars criss-crossed by tidal and distributary channels and rivers. Most of the land surface in the deltaic coastal plain of Ganges-Brahmaputra delta is situated only 3 meters above mean sea level. Major parts of the area are susceptible to flooding by high tide water as because the average tidal amplitude in the area is also 3 meters. The coastal plains along the Chittagong-Cox’s Bazar stretch almost north-south direction and occupy a few kilometers of area between the sea and the hill ranges. The land surface in this belt is situated 3.5 meters above mean sea level and is susceptible to flooding by high tide water as because the average tidal amplitude in the area is also 4 meters.

Large rivers like the Feni, Meghna, Bishkhali, Buriswar, Baleswar or Haringhata, Sibsa, Raimangal, etc control the drainage system in the deltaic part. The eastern rivers carry water and sediments from the upstream whereas the western rivers are mainly tidal rivers as their upper parts have become silted up in recent past. The major tidal channels in the deltaic plain act as distributaries as well as tributaries of the aforesaid large rivers. In addition to these, a network of inter-connected minor tidal channels and creeks has formed the drainage system. Major rivers of the area enter the plain from the north and flow southward more or less parallel to one another towards the Bay of Bengal. Rivers like Karnaphuli, Sangu, Matamuhuri and Naaf control the drainage system in the Chittagong-Cox’s Bazar coastal belt. All the rivers in this belt come from the east and flow westward to the Bay of Bengal.

Major parts of the coastal plains of Bangladesh are being used as settlement areas and cultivated land. Rice is the main crop for cultivation in those areas. Settlement areas are usually surrounded by trees of varying heights. Only a small part of the deltaic area is occupied by a mangrove forest with an aerial extent of 571,508 ha in 1994, situated in the south western part of Bangladesh. Hilly areas are mainly forested with scattered small settlements.

## 4.2 Geomorphology

### 4.2.1 Methodology

Geomorphological mapping of the mapped area was based on the qualitative and quantitative interpretation of data and information, i.e. the interpretation of satellite images, field survey, previous works as well as related documents.

The fieldwork was centred at the verification of the geomorphological map already prepared at Geological Survey of Bangladesh (GSB), and other researchers for their M.Sc. and PhD dissertations.

### 4.2.2 Data sources

Preparation of the geomorphological map was done by the interpretation of the following remote sensing data at regional scale:

> Colour composite of Landsat Enhanced Thematic Mapper (ETM) imageries (soft copies), which include the bands of 3,4, and 5 taken on the dry season (January-March) of 2003, 2004 and 2005 for the entire mapped area (path/row: 135/46, 136/44, 136/45, 136/46, 137/44, 137/45, 138/45, and 138/44).

> Panchromatic SPOT imageries (hard copies) covering the coastal area in 1: 50,000 scale taken on January and February 1989-90 (dry season).

### 4.2.3 Regional setting

The coastal plains of Bangladesh comprise of broad deltaic plains in the west and narrow strip of non-deltaic or coastal plains in the east.

The Ganges-Brahmaputra (GB) delta is one of the largest deltas of the world. The mighty rivers like Ganges and Brahmaputra flow from the northwest and the north respectively and empty in the northern tip of Bay of Bengal through lower Meghna estuary. The Holocene delta is surrounded by Pleistocene uplands and alluvial lowlands in the north, sub-Recent relatively higher land in the east and opens to the Bay of Bengal in the south. The western part of the delta extends beyond the international boundary to the West Bengal, India. Elevation of the delta from the mean sea level (msl) is about 15 m in the northwest and 1-2 m in the south. On the basis of morphogenetic criteria, the GB deltaic part in Bangladesh can be divided into two broad geomorphic super domains viz. fluvial or Upper Deltaic Plain and fluvio-tidal or Lower Deltaic Plain.

The Upper Deltaic Plain of fluvial origin is formed by the deposition of present and past meandering rivers. The units in the upper deltaic plain are floodplains, beel/depressions, active and abandoned channels. These areas are drained by the major distributaries and sub-distributaries of the Ganges, namely, Madhumati, Betna, and Bha. Fluvial landforms can be subdivided into two parts on the basis of dimension of their natural levees and flood basins. The northwestern part of the fluvial delta has broad and low natural levees whereas the central part has large natural levees and broad flood basins.

The Lower Deltaic Plain of fluvio-tidal origin is formed by the deposition of fluvial rivers and tides. The major units of the plain are interdistributary tidal plain, mangrove swamp, mudflat and estuarine plain. The delta plain are drained by the lower part of the major distributaries and sub-distributaries of the Ganges, namely, Haringhata, Burishwar, Bishkhali, Tetulia, Pusur, Shibsa, and Hariabhanga. The estuarine plain situated around the mouth of the Meghna (mouth of GB) is a very dynamic area where landforms are unstable due to frequent thalweg migration during the time of summer monsoon (time of high discharge).

The narrow strip of coastal land in the non-deltaic coastal part is formed by the deposition of fluvial rivers, fans and tides in the northern upper part whereas the southern lower part is formed by marine processes.

The mapped area includes a smaller part of the Upper Delta Plain, the entire part of the Lower Delta plain and the narrow strip of non-deltaic plains.

#### 4.2.4 General soil characteristics of the study area

The agricultural soil of the mapped area is developed mainly on the sediments derived from the accumulation of the fluvial and tidal processes and is the major resources of the area. Non-calcareous gray flood plain soil (Statistical Yearbook of Bangladesh, 1989), is recognized on the basis of grain size, clay content, organic material, acidity, and soil structure.

Non-calcareous gray flood plain soil is characterized by gray colour fine brown mottling and prismatic to blocky structure. It is seasonally flooded and has seasonally acid topsoil and nearly neutral subsoil.

#### 4.2.5 Geomorphological units

The coastal morphology of Bangladesh is characterized by:

- a vast network of rivers,
- an enormous discharge of river water heavily laden with sediments, both suspended

and saltation load,
- a large numbers of off-shore islands and sand bars,
- the Swatch of No-Ground (a submarine canyon) running NE-SW partially across the continental shelf about 24 km south of Bangladesh coast,
- a funnel shaped, shallow and wide estuary,
- a gently sloping wide continental shelf,
- a narrow strip of coastal landforms fronting hill ranges,
- strong tidal actions, and
- frequent landfall of tropical cyclones.

The coastal plain under study can broadly be divided into six geomorphological domains on the basis of origin. These are plains of fluvial, fluvio-tidal, tidal, marine & coastal, fluvio-denudational and structural-denudational (Plate 4.1). The landforms under river floodplains are Levee or Levee complex, Beels or Depressions and abandoned distributary fill. Interdistributary tidal plains, Mangrove swamp, estuarine plains, bars and mudflats constitute the landforms of the fluvio-tidal plain domain. Tidal landforms are constituted by lower, upper and supra-tidal flats. The landforms constituting the marine and coastal plain are beach, old beach-dune complex, beach ridge complex. The landforms under fluvio-denudational domain are fluvio-colluvial plain, alluvial fan complex and coastal mud-fan complex. Hills and plateaus fall under structural-denudational landform. Figure 4.2 shows the major geomorphic landforms of the mapped area. Minor landforms can not be shown due to scale factor.

#### *4.2.5.1 Fluvial Landforms*

Fluvial landforms are formed by the deposition of present and past meandering rivers. The units of fluvial origin are levee or levee complex, beels/depressions, and abandoned distributary fill plain, mainly composed of recent to subrecent alluvium. These areas are drained by the major distributaries and sub-distributaries of the Ganges, namely, Madhumoti, Betna, Bha. Fluvial landforms are not susceptible to coastal flooding by surges as these landforms are located far away from the coastline.

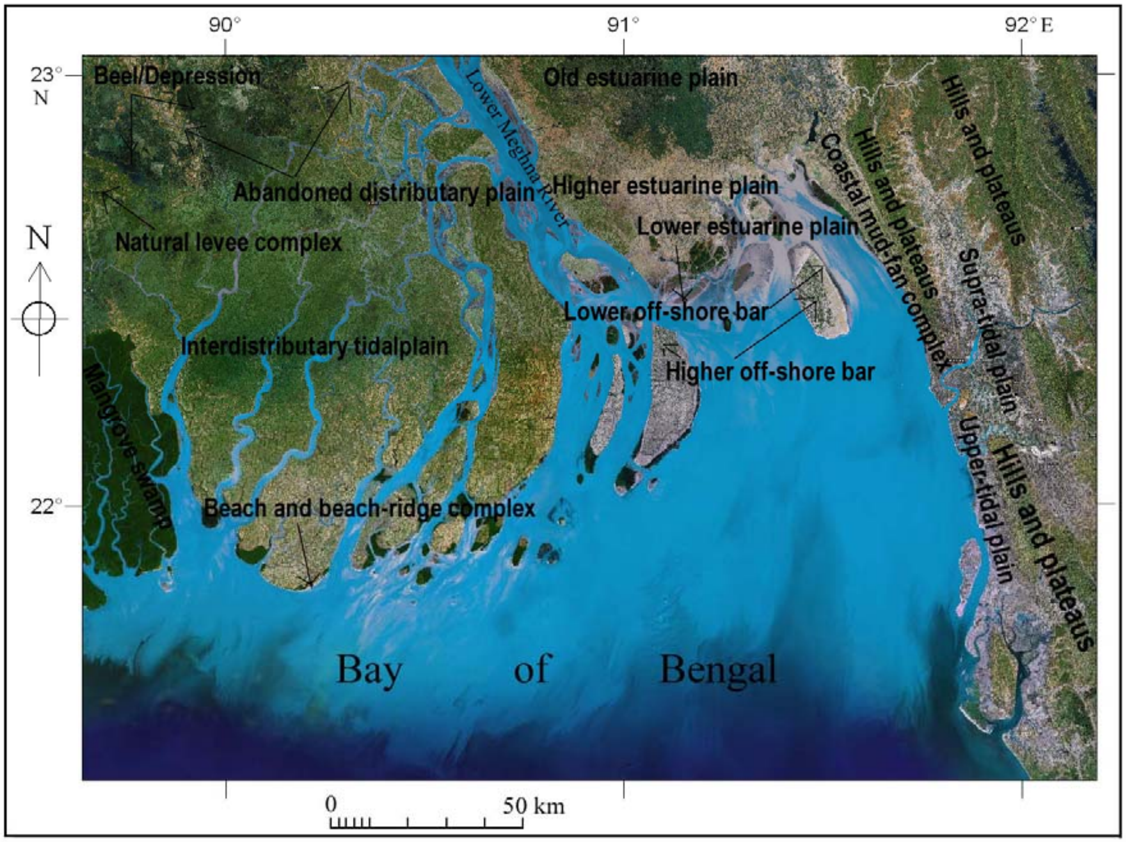


Plate 4.1: Geomorphological units are shown on the TM image in natural colour taken in January, 2003.

Linear, sometime irregular and dissected ridge-like accumulation of vertically accreted sediments along the stream immediately adjacent to channels has given rise to natural levee deposits. The deposits are thickest at the channel bank and pinch out towards the contact of the levee and other unit boundaries. Trees and human settlements in the area are on the relatively older levees whereas younger levees are covered by grass. In most cases the natural levees have been artificially raised and broadened to protect the settlement and cultivated land from semi-diurnal tide. The levees or levee complexes in the upper reaches of the mapped area are very prominent and conspicuous and the elevation is generally 50 cm to 1.5 m higher than the surrounding units. This unit can be easily identified in the imageries and aerial photographs. Most of the settlements are located on the levees.

The beels/depressions have sloping surfaces towards the centre and remain under water only during the rainy season. Materials washed out from the adjacent plains underlain these depressions. These units are depositional places for sediments during the rainy season and are suitable places for abundant vegetation growth. Most of the beels/depressions are peat basins where central parts remain under water round the year. Local farmers cultivate rice in the marginal parts of these basins during the dry season. The beels or depressions are poorly drained and most of them are perennial. The elevation of the beels ranges between sea level and 1 m above mean sea level. The marginal parts of the larger beels and most parts of other beels are cultivated once a year. Recently, psiciculture and shrimp cultures are extensively practiced in those beels.

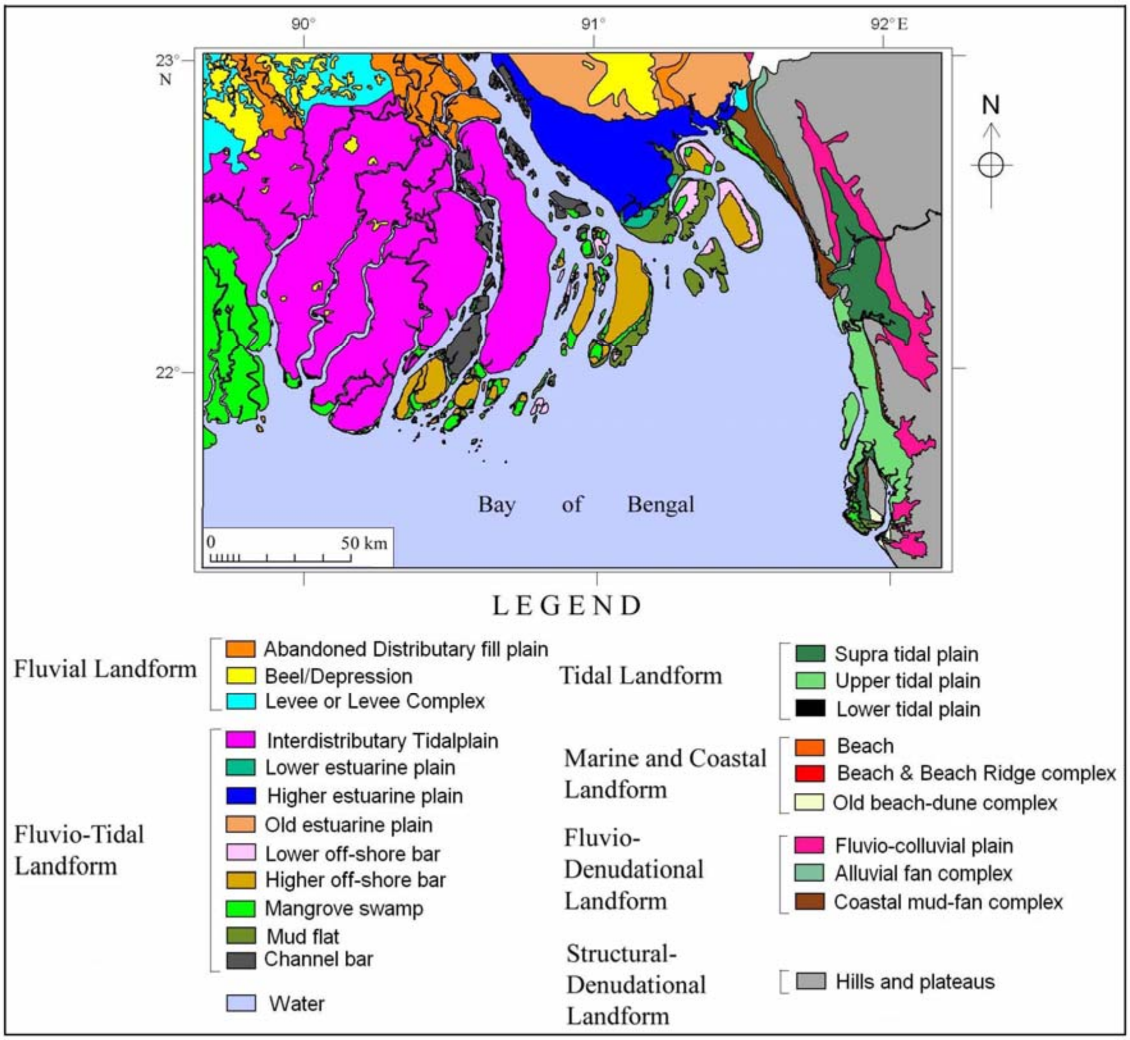


Figure 4.2. Geomorphological map of the mapped area.

The abandoned distributary fill unit of fluvial origin is the paleochannel of the Ganges, Brahmaputra, Meghna and their combination rivers. During sub-recent times the aforesaid rivers used to follow these courses to the Bay of Bengal. Then the Ganges-Brahmaputra river shifted their courses to the east and the Meghna to the west to join and form the present unified course. The elevation of the unit ranges between sea level and 2.5 m above mean sea level. The unit is characterised by cut-off meander channels, ox-bow lakes, numerous point bars, and crevasse splays. Most of the rivers in this unit are only active during the rainy season due to heavy siltation in the river beds. Dominant is silt on ridges and the substratum and with a clay mantle over most of the area. The sediments are calcareous and rich in feldspar and biotite.

#### *4.2.5.2 Fluvio-Tidal Landforms*

The geomorphological units of fluvio-tidal origin include mangrove swamps, estuarine mudflats, lower and higher estuarine plains, old estuarine plain, lower and upper tidal floodplains, and channel bar. Sediments coming from upstream through those aforesaid rivers and their distributaries and sediments redistributed by tides are forming these landforms. The coastal areas of the fluvio-tidal landforms are very susceptible to coastal flooding by storm surge, as these landforms are only elevated 3 to 6 m above msl and have an almost level topography, criss-crossed by numerous tidal creeks and channels.

The lower deltaic floodplain differs from the Upper deltaic floodplain in that it has a lower relief and is criss-crossed by innumerable tidal creeks and rivers. The average elevation of this plain is such that (2 to 3 m above mean sea level) spring tide is capable of inundating the area. The sediments are mainly non-calcareous clays and silty clays, but become siltier in the east and have a buried peat layer in the west.

The fluvio-tidal plain is tidal lowland with numerous creeks and anastomosed tidal channels. The south-central part of the lower delta is being used as ideal place for shrimp cultivation due to easy availability of brackish water and better drainage system. The mangrove swamp (Sunderbans) occupies areas subject to tidal flooding with brackish or saline water. The landscape is almost level with innumerable tidal rivers and creeks criss-crossing the area. The tidal plains in the coastal areas are very susceptible to coastal flooding by storm surge, as these landforms are only elevated 3 m above msl.

The interdistributary tidal floodplain differs from the fluvial floodplain in that it has a lower relief and is criss-crossed by innumerable tidal creeks and channels. The average elevation of this plain (2 to 3 m above mean sea level) is such that spring tide is capable of inundating the area. Constant changing of the river flow does not allow developing natural levee along the sides of the channels in this unit.

Estuarine plains are divided into subunits on the basis of relative elevations and age. These plains are elevated only 2 to 4 m from the mean sea level are slightly calcareous. Old estuarine plain is little higher in elevation than the adjacent estuarine plains and the central part is depressed which keeps water almost round the year due to bad drainage system. The relief of the estuarine plains are mainly smooth and predominantly silty in composition. Estuarine mudflats are almost level recent bars composed of predominantly silty, stratified, and slightly calcareous materials.

Like estuarine plains the off-shore bars are also divided into subunits on the basis of relative elevations and age. These plains are elevated only 2 to 4 m from the mean sea level are 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.

*4.2.5.3 Tidal Landforms*

The tidal plains present in the south-eastern part of the coastal plain are nearly a level topography with less tidal channel and creeks than the deltaic interdistributary tidal plains. These plains are elevated 2.5 to 4 m from the mean sea level. The upper tidal plain is inundated in every 15 days during spring tides whereas the suprtidal plains go under water during the time of cyclone.

The lower intertidal flat is characterized by mud flats which are very gently sloping ($1^o$ to $3^o$) towards the coast. Semi-diurnal flood tides periodically inundated these flats. The underlying sediments are mostly light grey sand. These intertidal zones of the area are dissected by a series of creeks which are feeder channels to the flats and also drain the area. Most of the creeks have no fresh water source. Creeks are denser in the lower tidal flats than the upper tidal flats. The top layer up to the depth of 2 m is composed of soft gray clayey silt. The flat is likely to be flooded by surges of any intensity.

The upper intertidal flats are broad and nearly horizontal, occupying the interdistributary area dissected by tidal channels with relatively few tidal creeks. These areas are usually elevated; 2 to 3 m above mean sea level and inundated by brackish water only during the time of spring tide and very gently sloping towards the coast. The elevation is lower than the adjacent plains. This unit is not flooded by tide water because of the embankment constructed along the coast; otherwise a good extent of this unit would have been inundated during high tide. So, deposition on these flats only takes place during the storm or cyclone when wind pushes the water over the embankments. Deposit of the Upper intertidal flats is silty clay which is olive grey colour. Scattered very fine sand lenses are found near the channels and creeks. This flat is susceptible to storm surge inundation by surges of moderate to high intensity cyclones.

Supratidal flats are broad to elongated horizontal plains and are elevated 3.5 m above msl. The average elevation of this plain is higher than the adjacent upper intertidal flats and slopes very gently towards the surrounding plains. Deposit of the supratidal flat is silty clay which is olive grey to light grey in colour. The surface is characterised by the presence of a very fewer number of tidal channels and almost absence of tidal creeks.

#### *4.2.5.4 Marine and Coastal Landforms*

Landforms like beach, old beach-dune complex, and beach ridge complex fall under this category which has a specific marine origin and no fluvial influence. The sediment load from the Andermanik, Meghna, Karnaphuli, Sangu, and Matamuhuri rivers which empty into the bay through the narrow coastal belt is redistributed by waves and tides forming beach and beach ridge complex. Herbaceous plants and small trees in some places cover them but most parts are bare. These landforms are equally susceptible to storm surge flooding, like the other landforms, for their lower elevation (sea level to 6 m above msl) and a very close presence from the coastline

The intertidal areas along the coastline fringing usually by beach ridges and extending up to the mean low-tide lines have been mapped as beach. The beach gently slopes ranging from $3^o$ to $4^o$ towards the sea. The beach is flat to undulated, very gently dipping into the bay, dissected by irregular narrow runnels and ridges. Most part of the beach goes under water during every flood tide and the entire beach inundates by tidal water in every 15 days during spring tide.

Beach-ridge topography in the investigated area consists of a series of subparallel ridges and swales mostly situated immediately inland from the present beach. Each ridge represents the subaerial portion of a beach profile which has been stranded upon coastal progradation. Beach ridge systems develop in association with delta distributary mouths. Near the active channels, coastal sedimentation produces progradation and leads to the development of beach ridges. However, as distributary sites change, areas of coastal progradation also shift. Abandonment of a distributary or less sediment supply commonly results in marine erosion of the adjoining beach and truncation of the flaring ridge pattern at the river mouth. A ridge is depositional and formed when storm waves erode parts of the foreshore (beach) zone and deposit some sediment within the landward portion of wave uprush. Washover deposits later transform a berm into a beach ridge. Winter wind conditions subsequently widen the beach and form dunes on the relatively recent ridges. Ridges attain height of 0.1 to 6 m above the swales, and spacing of the crests commonly varies from 25 to 100 m. Owing to it's relatively high elevation the beach ridge act as natural barrier against coastal flooding by low to moderate cyclone surges.

The old beach and dune complex fronting the hill ranges of Moheskhali has a undulating topography consisting of ridges and swales. The unit has an average elevation of 3 to 5 m above msl and only inundates during tidal surges.

#### *4.2.5.5 Fluvio-Denudational Landforms*

Landforms of fluvio-denudational origin include the fluvio-colluvial plain, coastal mud-fan complex and the alluvial fan complex. These landforms are not susceptible to coastal flooding by surges because of their elevations (6 to 9 m above msl) and distances from the coastline.

The fluvio-colluvial plains comprises smooth and very gently sloping alluvial fans which are underlain by recent mixed alluvial and colluvial sediments with scattered presence of very low hills. The hills have an average elevation of 12 m above the adjoining plains.

The coastal mud and fan complex plain (alluvial-colluvial) occupies a narrow strip between the hill ranges and the coastline of Chittagong and Cox's Bazar. It comprises a smooth, nearly level, tidal floodplain traversed by a number of tidal creeks. Sediments of Alluvial fans overlie the tidal deposits along the foot of the hill ranges and along some streams coming out from the hills.

The alluvial fan complex or piedmont alluvial plain is a generally narrow, gently sloping plain bordering the hills of Comilla and the area north of Chittagong. The sediments are sandy near the hills but become clayey downslope. The landforms underlain by clay deposits are often subject to deep flooding.

#### *4.2.5.6 Structural-Denudational Landforms*

The hill areas include the Chittagong Hill Tracts and parts of Chittagong and Noakhali Districts. These areas are underlain by Tertiary and Quaternary sediments which have been folded, faulted, and uplifted, then deeply dissected by rivers and streams. Along the coastal front the hills are only 30 to 70 m in height. The structural-denudational landforms are completely free from storm surge flooding because of their elevation above the sea level.

## 4.3 References

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