Guideline
for
Hazard Analysis and Risk Assessment for Local Disaster Risk Reduction Action Plan

April, 2025

The Project for Capacity Enhancement on Formulation and Implementation of Local Disaster Risk Reduction Plan (LDRRP)

Table of Contents

Acronyms

ADP	Annual Development Programme
BDRCS	Bangladesh Red Crescent Society
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Meteorological Department
BNBC	Bangladesh National Building Code
BWDB	Bangladesh Water Development Board
CPP	Cyclone Preparedness Programme
CRA method	Community Risk Assessment
DAE	Department of Agricultural Extension
DDM	Department of Disaster Management
DDMC	District Disaster Management Committee
DEM	Digital Elevation Model
DMC	Disaster Management Committee
DPHE	Department of Public Health Engineering
DPP	Development Project Proposal
DRMP	Disaster Risk Management Plan
DRR	Disaster risk reduction
ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
ERCC	Emergency Response Coordination Centre
FSCD	Fire Service and Civil Defense
GIS	Geographic Information System
ID	Identity Document
INGO	International non-governmental organization
JICA	Japan International Cooperation Agency
LDRRP	Local Disaster Risk Reduction Plan
LGED	Local Government Engineering Department
MoDMR	Ministry of Disaster Management and Relief
MoE	Ministry of Education
NGO	Non-governmental Organization
PGA	Peak Ground Acceleration
PIO	Project Implementation Officer
PWD	Public Works Department
PWDB	Bangladesh Water Development Board
RRAP	Risk Reduction Action Plan
SFDRR	Sendai Framework for Disaster Risk Reduction
SOB	Survey of Bangladesh
SOD	Standing Orders on Disaster 2019
SOP	Standard Operation Procedure
TSC	Technical Sub-Committee
UDD	Urban Development Directorate
UNO	Upazila Nirbahi Officer
UPs	Union Parishad
UzDRRPs	Upazila Disaster Risk Reduction Plans
UzSC	Upazila Disaster Risk Reduction Plans Sub-Committee

1. Introduction

1.1 Purpose of the Guideline

This guideline focuses on feasible methods and those analytic procedures for Upazila-level hazard analysis and risk assessment conducted in a part of formulation of the Upazila Disaster Risk Reduction Action Plan (UzDRRAP). As features of the UzDRRAP, every Upazila Disaster Management Committee (UzDMC) sets the DRR target for that how disaster risks have to be reduced stepwise in their own area and clarifies needed structural and non-structural measures that should be implemented to achieve the said target as a priority action. For this purpose, UzDMC needs to understand the potential of local hazards spatially as a map, and grasp how much damage by various hazard is expected objectively and quantitatively in own area. In consideration for providing the technical guidance for local hazard mapping and simplified risk assessment to not only an analyst like a GIS engineer but a user of those result in the planning process, this guideline explains how to illustrate the spatial distribution of potential hazards on the premise of utilizing digital elevation data and spatial data available in Bangladesh and estimate quantitatively damages and losses based on hazard maps.

1.2 Scope of the Guideline

The output of Upazila-level hazard analysis and risk assessment based on this guideline is intended to visualize in an objective and quantitative manner what disaster risks exist near their vicinity, and to be used as one of the objective foundations for considering the necessity and priority of countermeasures. For simplicity and versatility of analysis and evaluation, it is assumed that simplified GIS-based analytic methods regardless of the skill of a analyst are adopted with input data which can be collected relatively easily, such as free Digital Elevation Model (DEM), Census statistics and others. Therefore, due to the limited accuracy of the analysis and evaluation, the outputs are to be used only for the formulation of the UzDRRAP, and it is recommended that a more accurate analysis method should be applied separately when implementing the Feasibility Study (F/S) and other detailed evaluation for structural countermeasures.

The UzDRRAP will cover all disaster types. However, due to the limitations of available data and analytical methods, it is not possible to spatially assess the Upazila-wise hazard potential for all disaster types. In addition, depending on the type of disasters, it is not possible to identify local hazard characteristics other than the record of actual disasters. In consideration of such actual status and the geographical characteristics of Bangladesh, the 'Flood', 'Coastal Disasters', 'Sediment Disasters' and 'Earthquakes' were chosen as the initial targets in this guideline. The type of disasters targeted for hazard analysis and risk assessment will be increased as necessary.

2. Hazard Analysis and Risk Assessment

2.1 Flood (Seasonal Flood, Flash Flood, River Erosion)

2.1.1. Current Status of Flood Hazard in Bangladesh

The surface water system of Bangladesh is made up out of a vast network of major and minor rivers. There are 405 rivers crisscrossing the country, of which 57 are trans-boundary. Out of them, the Padma, Jamuna and Meghna are the most significant. These three major river systems cover five countries, including India (62.9%), China (19.1%), Nepal (8%), Bangladesh (7.4%) and Bhutan (2.6%). All of their flow drains to the Bay of Bengal through Bangladesh. The river system of the delta has evolved through various changes in the last several hundred years. The rivers abandoned their courses and subsequently occupied other new courses. Avulsion of major rivers has triggered major hydrological changes over the years.

Bangladesh is prone to several types of floods as shown below:

Seasonal flood (Monsoon flood) is a phenomenon caused by overflows from embankments in major rivers in Bangladesh. River floods from major rivers generally rise and fall slowly over a period of 10 to 20 days or more. Of the total flow, around 80% occurs during the 5 months of monsoon from June to October. Bangladesh suffers from abundance of water in monsoon, frequently resulting into floods and water scarcity in other parts of the year, developing drought conditions. Climatologically, the discharge into Bangladesh from upper catchments occurs at different time of the monsoon. In the Jamuna, maximum discharge usually occurs in early monsoon in June and July whereas in the Padma, maximum discharge tends to occur in August and September. Synchronization of the peaks of these rivers results in devastating floods. Such incidents are not uncommon in Bangladesh. The rivers of Bangladesh drain about 1.76 million km^2 area of which approximately 93% lies outside its territory in India, Nepal, Bhutan and China.

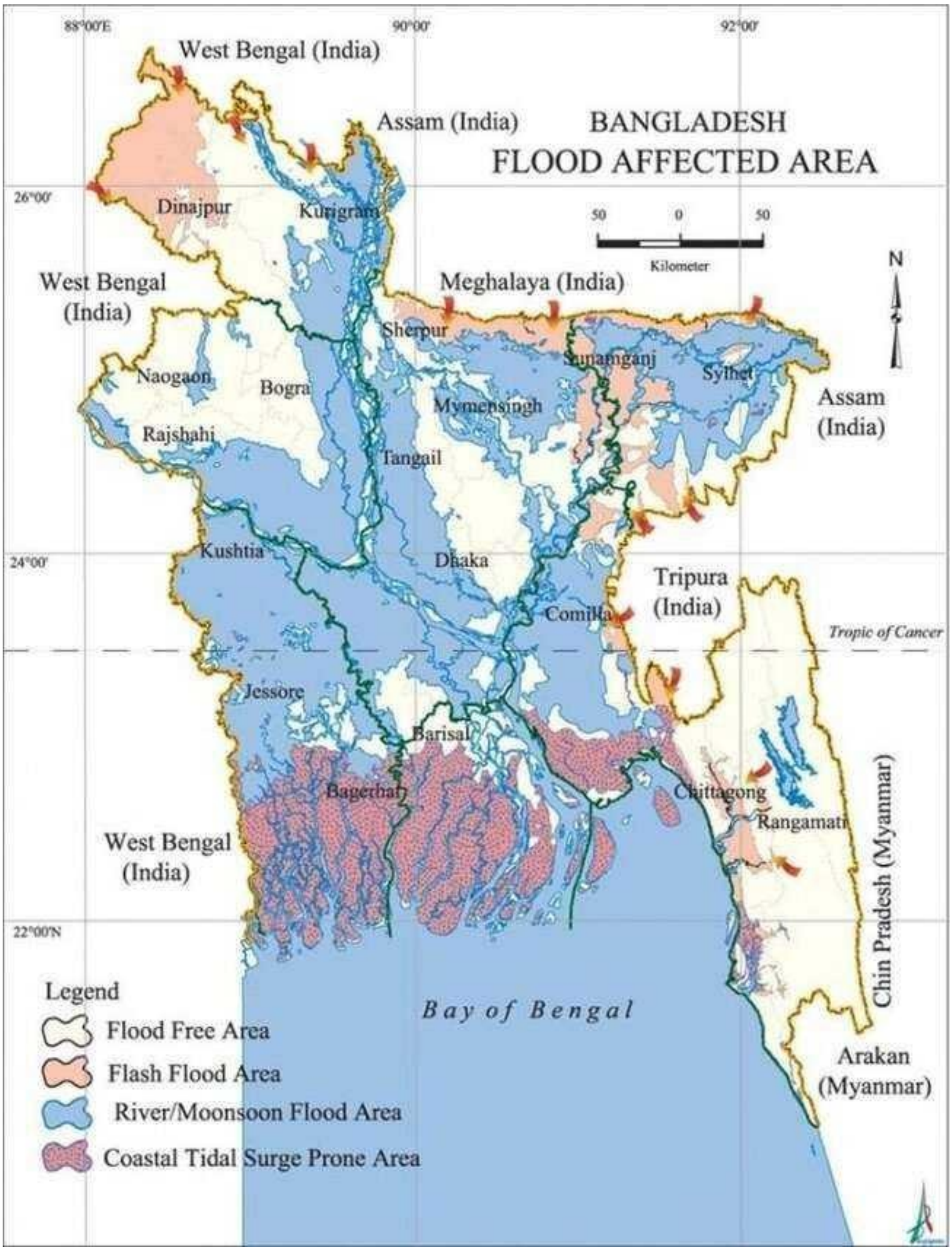
Flash flood is caused by overflowing of hilly rivers in eastern and northern Bangladesh in April-May and September-November. Flash flood prone areas of the Bangladesh are at the foothills and Haor basin. Intense local and short-lived rainfall is the primary cause of flash floods. Compared to normal river flood, flash flood is characterized by a sharp rise followed by a relatively rapid recession, and can occur within a few hours. In the months of April and May flash floods affect the winter rice crop at the harvesting stage in the districts of Northeast and Southeast regions of the country.

Inland flood generally occurs in many parts of the country. This kind of flood occurs in the flood plains where natural drainage systems have been disturbed either due to human interferences e.g.

construction of unplanned rural roads and encroachment of river courses etc. or due to gradual decay of the natural drainage system. When intense rainfall takes place in those areas, the natural drainage system cannot carry the run-off generated by the rainfall and causes temporary inundation in many localities. This kind of rain-fed flood is increasing in the south-western part and major urban areas.

In addition to flood, river erosion in Bangladesh is no less dangerous and problematic compared to other types of disaster. Rivers in Bangladesh are morphologically highly dynamic. Major rivers are braided and form islands or chars between the braiding channels. Erosion processes are highly unpredictable and not compensated by accretion. These processes also have dramatic consequences on the lives of people living in those areas.

Riverbank erosion depends to various factors such as quantity of rainfall, river morphology, soil properties and bank material, flow regime and water level variations, near bank flow velocities, sediment supply into the river due to large earthquakes or sudden river mergers that cause rapid sediment inflows, stability of reticulated channels, topography of river floodplain, socio-economic condition of riparian communities, large-scale intervention in upstream. The increase in riverine area due to riverbank erosion means a reduction in agricultural land area, especially in Bangladesh, which is an impediment to the country's development.



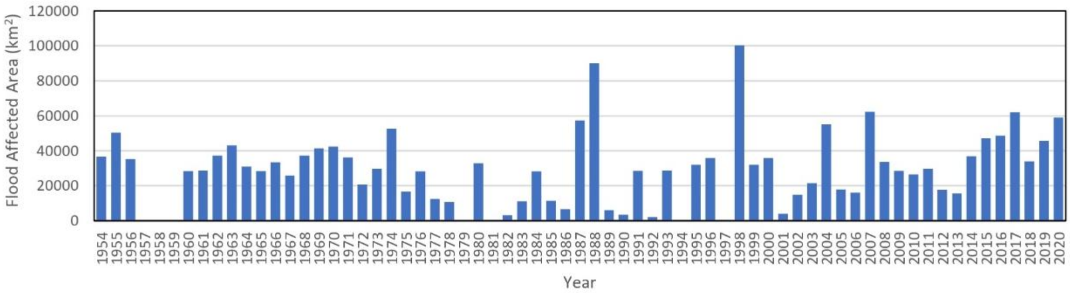
Source: National Encyclopedia of Bangladesh (https://en.banglapedia.org/index.php?title=Natural_Hazard)

Figure 2.1.1 Flood Characteristics of Bangladesh

Table 2.1.1 Past Major Flood Event Since 1980

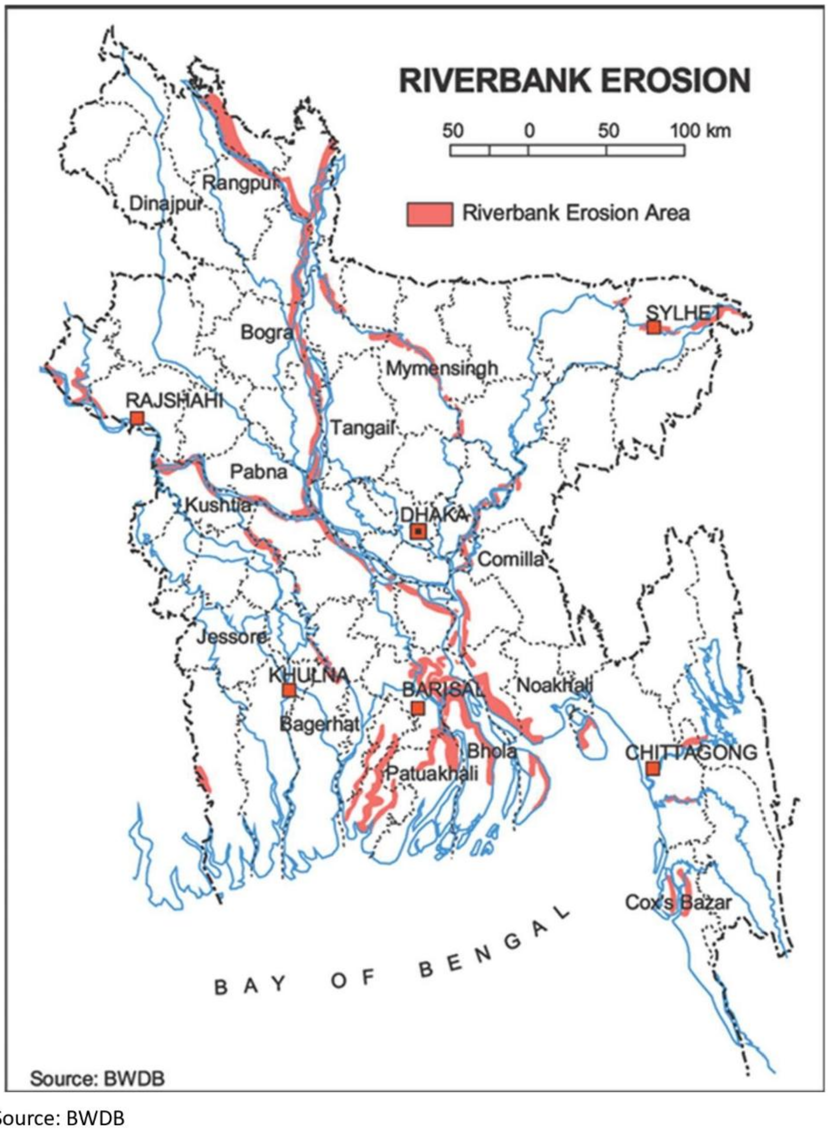
No.	Flood	Outline
1	1987 flood	✓ Inundation area: more than 57,000 km^2 (39% of the country) ✓ Number of deaths: 2,055 ✓ Total Damage Amount: US$ 1.0 billion (The World Bank, 2002)
2	1988 flood	✓ Inundation area: 90,000 km^2 (61% of the country) ✓ Number of deaths: 2,300 ✓ Affected population: approx. 4,500,000 ✓ Total Damage Amount: US$ 1.2 billion (The World Bank, 2002)
3	1998 flood	✓ Inundation area: 100,250 km^2 (68% of the country) ✓ Number of deaths: more than 1,100 ✓ Affected population: approx. 3,100,000 ✓ Damage: houses 500,000, road 23,500 km, embankment 4,500 km, cropland 500,000 ha ✓ Total Damage Amount: US$ 2.8 billion (The World Bank, 2002)
4	2004 flood	✓ Inundation area: more than 56,000 km^2 (38% of the country) ✓ Number of deaths: 750 ✓ Affected population: approx. 36,000,000 ✓ Damage: road 58,000 km, embankment 3,100 km, crops 1.3 million ha ✓ Total Damage Amount: US$ 2.2 billion (ADB-World Bank, 2004)
5	2007 flood	✓ Inundation area: more than 63,000 km^2 (43% of the country) ✓ Number of deaths: 831 ✓ Affected population: approx. 13,300,000 ✓ Damage: completely destroyed houses 81,000, partly destroyed houses 1 million, crops 8.9 million ha, livelihood thousands of deaths, completely destroyed road 3,619 km, partly destroyed road 25,104 km, embankment flowing out 88 km, partly destroyed embankment 1,002 km, bridges/culverts 1,770, education facilities destroyed 557, education facilities partly destroyed 7,592, flood shelter 1,673 ✓ Total Damage Amount: US$ 1.8 billion (DMIC SitRep, 22 September 2007)
6	2017 flood	✓ Inundation area: more than 62,000 km^2 (42% of the country) ✓ Number of deaths: 144 ✓ Affected population: approx. 8,000,000 ✓ Damage: completely destroyed houses 103,516, partly destroyed houses 618,516, destroyed crops 102,808 ha, partly damaged crops 504,147 ha ✓ Total Damage Amount: US$ 5.0 billion (Shelter Cluster, EM-DAT)
7	2019 flood	✓ Inundation area: 46,000 km^2 (31% of the country) ✓ Number of deaths: 114 ✓ Affected population: approx. 7,600,000 ✓ Damage: completely destroyed houses 34,731, partly destroyed houses 548,671, road 6,641 km, embankment 1,515 km, bridges and culvert 1,275, crops 137,798 ha ✓ Total Damage Amount: US$ 0.75 billion (NDRCC, 2019)
8	2022 flood (May - June in Northeast and North)	✓ Inundation area: more than 5,000 km^2 (60% of Sylhet District and 80% of Sunamganj District) ✓ Number of deaths: 40 ✓ Affected population: approx. 4,300,000 ✓ Damage: agricultural land 266,137 ha, 38 embankments, 600 km of roads, 28 culverts, 600 educational facilities, 11,640 tubewells, 6.5 km of water supply pipes ✓ Total Damage Amount: approx. 1,100 crore taka (Sylhet District and Sylhet City Corporation)
9	2024 flood	✓ Number of deaths: 71 ✓ Affected population: approx. 5,820,000 ✓ Damage: 153,738 partially damaged houses and 53,581 fully damaged houses in 11 districts ✓ A total of 296,852 hectares of crops have been affected by the flood. ✓ Over 7,000 schools are closed due to flooding, affecting 1,750,000 primary students across the affected districts ✓ Total Damage Amount: US$ 1.2 billion (OCHA, 2024)

Source: 1) DDM, 2) UN OCHA,
3) Data Collection Survey for Disaster Risk Reduction and Prevention In Bangladesh, 2022, JICA



Source: Data Collection Survey for Disaster Risk Reduction and Prevention In Bangladesh, 2022, JICA, with Original Data from FFWC

Figure 2.1.2 Change of Flood-Affected Areas in Bangladesh



Source: BWDB

Figure 2.1.3 BWDB Riverbank Erosion Map of Bangladesh

2.1.2. Recommended Methods of Flood Analysis for UzDRRAP

2.1.2.1. Concept of Flood Analysis

The purpose of flood analysis is to understand the flood hazard in the targeted upazila and surrounding areas by estimating possible flooding extent and depth.

There are some existing studies on flood analysis conducted by the Government of Bangladesh (GoB) and other relevant organizations, such as the Institution of Water Modeling (IWM), the Centre for Environmental and Geographic Information Services (CEGIS), academic institutions, or others developed in cooperation with international development partners. From the perspective of fully utilizing existing available resources, these study results should be collected and referred to as the first source for understanding of flood hazard. If these study results are not enough in terms of their accuracy and coverage area, flood analyses shown hereafter should be performed.

2.1.2.2. Types of Analysis

There are two types of flood analyses proposed in this guideline. The first is a relatively simple analysis utilizing existing flood hazard map or water level information. These information will be updated based on the latest and/or more accurate digital elevation model (DEM) using GIS software to improve their reliability. The other is hydrological and hydraulic analysis using Rainfall-Runoff-Inundation (RRI) model and GIS software combined with rainfall, DEM and some other input data.

The general features of these analyses are described in the following table. The choice of which method to be used depends on the technical levels of the operator and availability of hydrological, topographical and other input data.

Table 2.1.2 Features of the Flood Hazard Analysis

	1. Compilation of existing flood Information (simple method)	2. Hydrological and hydraulic analysis (advanced method)
Concept	Updating the existing hazard map or water level information based on the latest ground elevation model to reflect the recent topographical conditions.	Conducting the hydrological and hydraulic analysis to estimate the extent and depth of flooding under a given rainfall condition.
Applicable area	Areas where the hydrological observation network is developed to some extent. River basins which are huge and difficult to develop hydrological/hydraulic model. (Major river basins)	Areas where no reliable flood hazard information. River basins where hydrological observation network is not fully developed. River basins whose size are not so large. (Peripheral areas, south-eastern areas, flash flood areas)
Methodology	The water surface map is derived from existing flood hazard map or water level information.	Conduct hydrological and hydraulic analysis with RRI model in one or several river basins which cover target area(s). The computed

	1. Compilation of existing flood Information (simple method)	2. Hydrological and hydraulic analysis (advanced method)
	Without changing the water surface elevation, update the ground elevation using the latest topographic data (DEM) in GIS software, to produce updated flood depth distribution map (flood hazard map).	flood area and depth are further compiled into hazard maps in GIS software.
Data Requirement for the Analysis	(Required) Existing flood hazard map or water level distribution information (to be collected from gauging stations, on-site investigation and/or interview survey from local residents.) Ground elevation data applied in existing flood hazard map Latest digital elevation data (DEM) (Not required but preferable to collect and use) Road, embankment and other local elevation data	(Required) Rainfall data or rainfall intensity formula Digital elevation data (DEM) (Not required but preferable to collect and use) Land cover data Water level data at river mouth River channel data (width and depth) Road, embankment and other local elevation data
Note	When using the existing flood hazard map or water level information, it should be confirmed whether the peak situation of water level rising or maximum water level during flood is captured in those information. It also should be confirmed if the occurrence probability (or return period) of the water level is known. In case there are no such information, the UzDRRAP will have a quantitative uncertainty of target safety level.	Although RRI model is relatively simple and easy to handle, conducting flood analysis with RRI model requires a certain technical level in software operation as well as knowledge in hydrology and hydraulics. Training of the operation of the software would be required.

The flows of each analysis are shown as follows.

1) Compilation of existing flood Information (simple method)

The following figure shows the procedure for compilation of existing flood information. For more detailed procedure, please refer to Annex (technical manual).

1. Data Collection

- Preparation of water surface map before update
  - Existing flood hazard map with ground elevation info

  or
  - Inter/extrapolation of gauged water level
- Collection of new DEM such as AW3D or MERIT-DEM (provided by the University of Tokyo, Japan).

2. Update of the ground elevation

- Update the ground elevation (Replacement of old elevation data with new one)
  - With new DEM
  - Adding information of the newly developed areas, roads, and embankments (if necessary)

3. Create new flood hazard map

- Calculate new flood depth

  (Flood depth (m)

  = Flood surface level - Ground elevation)
- Create new flood hazard map with GIS software

Figure 2.1.4 Flow of Compilation of existing flood Information

2) Hydrological and hydraulic analysis (advanced method)

The following figure shows the procedure of hydrological and hydraulic analysis. For more detailed procedure, please refer to Annex (technical manual).

1. Data Collection

- Rainfall data (hourly, daily, formula)
  - Collection of rainfall data, or
  - Collection of rainfall intensity formula
- Water level at river mouth (if necessary)
- New DEM information covering target area, such as AW3D or MERIT-Hydro.
- Adding local elevations at newly developed areas, roads, and embankments (if necessary)

2. Preparation of the hydrological and hydraulic analysis

- Preparation of the model rainfall wave form
  - Calculation of probable rainfall
  - Application of rainfall intensity formula (if available)
- Setting of water level at river mouth (if necessary)
- Preparation of the ground elevation data
  - DEM to the elevations for each grid of the model
  - Incorporating the elevation and location of the newly developed areas, roads, and embankments to the elevations in each grid (if necessary)

3. Conduct the hydrological and hydraulic analysis

- Computation of flooding areas and depths with RRI model simulation

4. Create flood hazard map

- Processing of RRI model output file(s) with GIS software to create flood hazard map

Figure 2.1.5 Flow of the Hydrological and Hydraulic Analysis

2.1.2.3. Required Data

In each analysis mentioned above, some hydrological data and terrain elevation data are required. Those are summarized in the following table.

Table 2.1.3 Required Data for the Flood Hazard Analysis

	1. Compilation of existing flood Information (simple method)	2. Hydrological and hydraulic analysis (advanced method)
Data	1. Preparation of water surface map before update ・ Existing flood hazard map, or ・ Gauged water level information covering target area 2. Ground elevation ・ Ground elevation data used in the existing flood hazard map ・ New DEM covering target area such as AW3D, or MERIT-DEM	1. Rainfall data (hourly, daily, formula) ・ Rainfall data, or ・ Rainfall intensity formula 2. Ground elevation ・ New DEM covering target area such as AW3D, or MERIT-HYDRO ・ Information of the newly developed areas, roads, embankments (if necessary)

Table 2.1.4 Major Sources of Required Data

	Data Type	Data Sources
1	Existing Flood Hazard Maps	-Multi Hazard Risk and Vulnerability Assessment, Modeling and Mapping (MRVAM) http://www.ddm.gov.bd/site/page/c2d881ae-fcfd-45bd-9f03-81b33d080aab/Multi-Hazard-Risk-and-Vulnerability-Assessment-Modeling-and-Mapping-- -IWM's Flood Map (BANGLADESH DELTA PLAN 2100 Baseline Studies: Volume 1 Water Resources Management, Figure3.13) http://www.plancomm.gov.bd/site/files/0adcee77-2db8-41bf-b36b-657b5ee1efb9/Bangladesh-Delta-Plan-2100 *These maps are not raw data files but processed Image files. Users cannot extract raw data from these data sources. To utilize these image files, GIS-based data processing is necessary.
2	Water Level Data	-Danger Level and Highest Water Level http://www.ffwc.gov.bd/ (FFWC) http://geo.iwmbd.com:4003/ (Flash Flood Early Warning System) -Probable Water Level with Return Period for North-East Region https://oldweb.lged.gov.bd/UploadedDocument/ProjectLibraryGallery/1393/Final%20Report.pdf -More detailed Information It should be requested to FFWC.
3	Rainfall Data	-Rainfall Data (Daily) It should be requested to BMD or FFWC. -Rainfall Intensity Formula in Cox's Bazar https://www.jica.go.jp/english/our_work/social_environmental/id/asia/

	Data Type	Data Sources
		south/bangladesh/c8h0vm0000bikdzb-att/c8h0vm0000dqx3ly.pdf Preparatory Survey on Matarbari Port Development Project, JICA, 2019 -Rainfall Intensity Formula in Dhaka https://dwasa.portal.gov.bd/sites/default/files/files/dwasa.portal.gov.bd/page/071726be_2cac_41f0_9412_be8936c47d2c/Drainage%20master%20Plan.pdf Updating/Preparation of the Storm water Drainage Master Plan for Dhaka City, 2016
4	Digital Elevation Model	-AW3D (NTT DATA Corporation and RESTEC) https://www.aw3d.jp/en/products/ -MERIT (University of Tokyo) (MERIT-DEM) http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/ (MERIT-HYDRO) http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/ -GMTED2010 (U.S. Geological Survey) https://www.usgs.gov/coastal-changes-and-impacts/gmted2010 (Download) https://earthexplorer.usgs.gov/ -FABDEM (University of Bristol) https://data.bris.ac.uk/data/dataset/25wfy0f9ukoge2gs7a5mqpq2j7

2.1.3. Sample Output of Flood Analysis

2.1.3.1. General

The legend shown in the sample figures is set by reference to standard flood depth classification in Bangladesh. However, it can be changed for the convenience of users depending on the purpose of output flood hazard map.

Depth (m)	
<= 0.30	F0: Not considered as flooded with less than 30 cm water depth
0.30 - 0.90	F1: The flood depth is 30 to 90 cm
0.90 - 1.80	F2: The flood depth is 90 to 180 cm
1.80 - 3.60	F3: The flood depth is 180 to 360 cm
> 3.60	F4: The flood depth is more than 360 cm

In general, areas with following topographic characteristics are prone to flooding:

- Low-lying areas
- Topographically depressed areas
- River channel sections with small storage capacity (narrower or shallower

sections)

- Confluence of rivers
- Riverside
- Insufficient drainage outlet

For the sample analysis results based on 1) Compilation of existing flood Information are shown in the 2.1.3.2.

For the sample results based on 2) Hydrological and hydraulic analysis are shown in the 2.1.3.3.

In case of 2), by using RRI model, changes of flooding situation after the implementation of some structural countermeasures can be simulated. By doing such simulations, users can compare the flooding situation with and without countermeasures and understand their effectiveness. For detailed procedure to consider structural countermeasures in RRI model, please refer to Annex (technical manual).

2.1.3.2. Sample Output of Flood Analysis based on 'Compilation of existing flood Information'

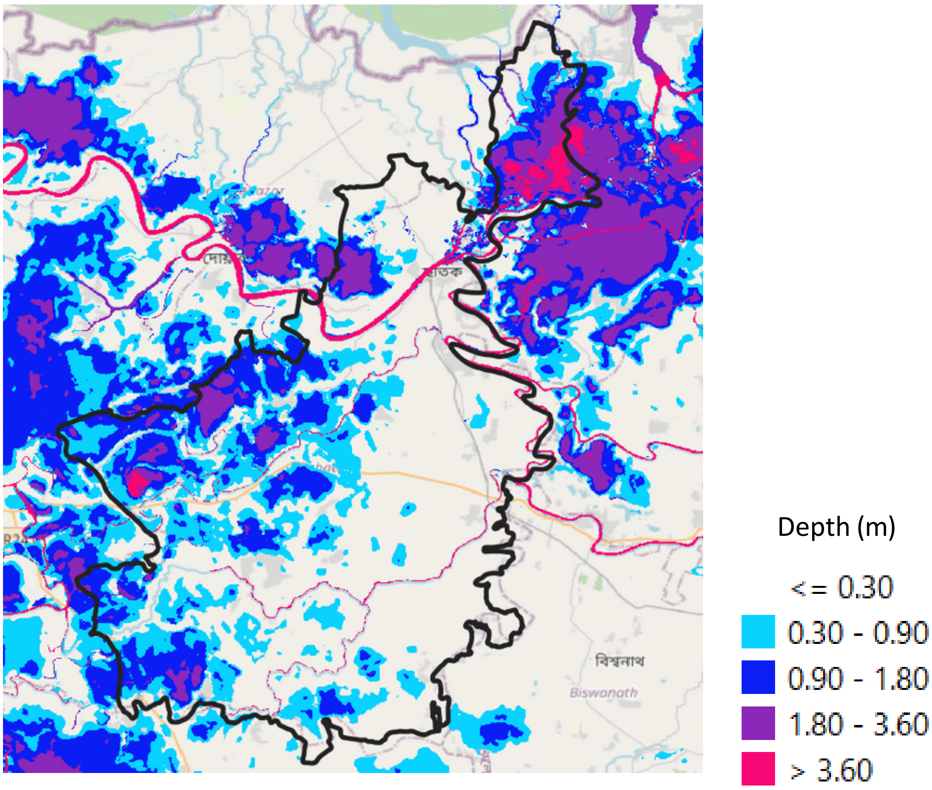


Figure 2.1.6 Sample Output of Flood Analysis (Chhatak Upazila)

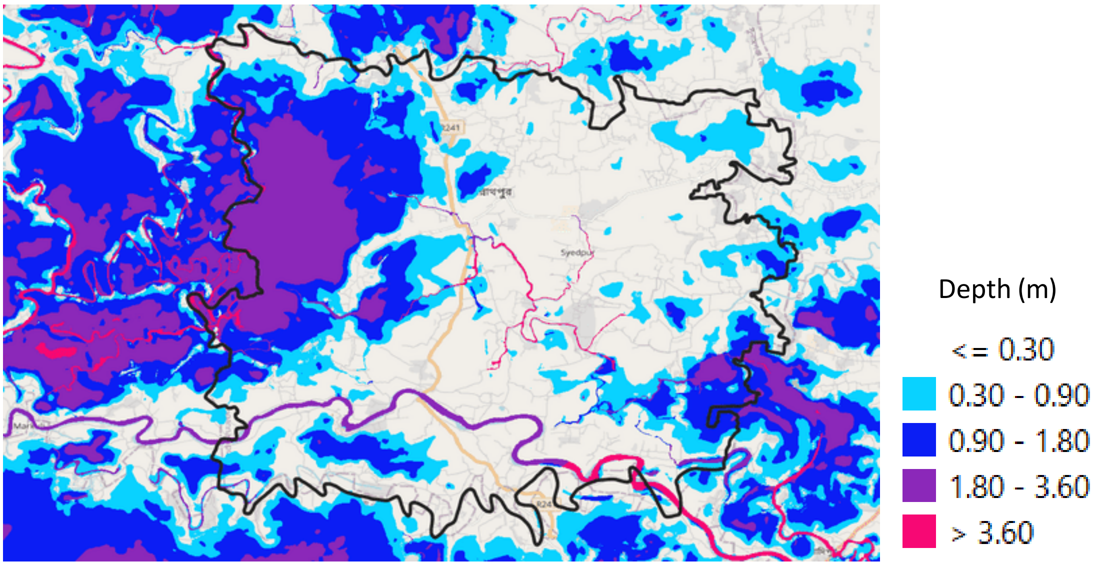


Figure 2.1.7 Sample Output of Flood Analysis (Jagannathpur Upazila)

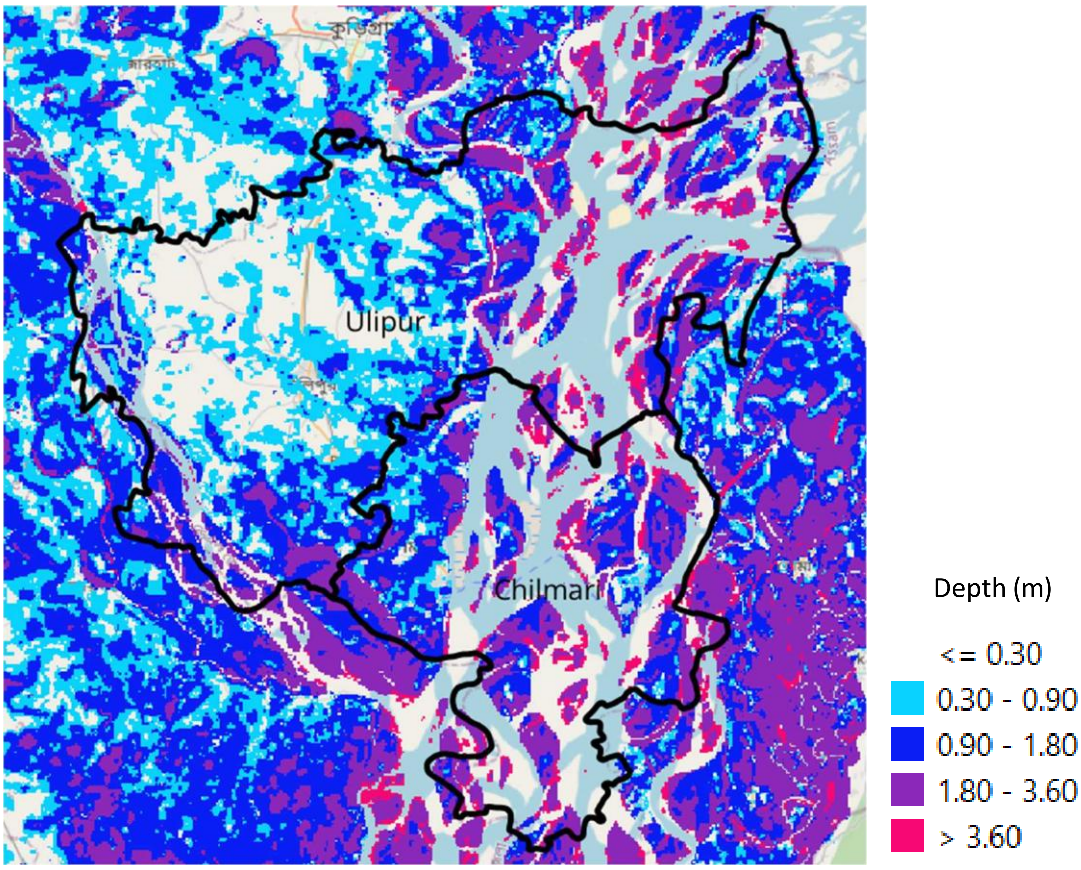


Figure 2.1.8 Sample Output of Flood Analysis (Ulipur and Chilmari)

2.1.3.3. Sample Output of Flood Analysis based on 'Hydrological and hydraulic analysis'

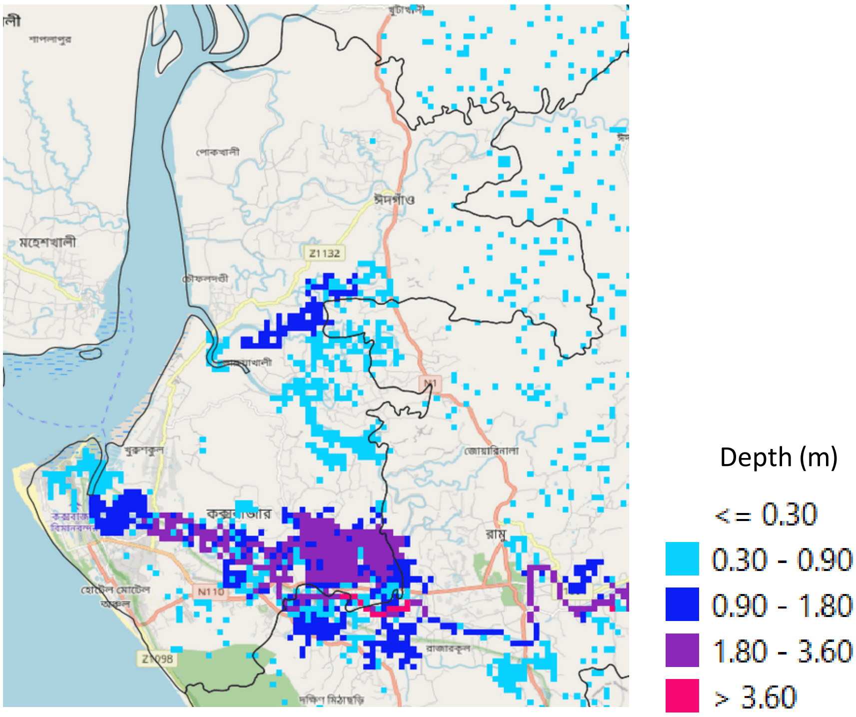


Figure 2.1.9 Sample Output of Flood Analysis (Cox's Bazar Sadar Upazila)

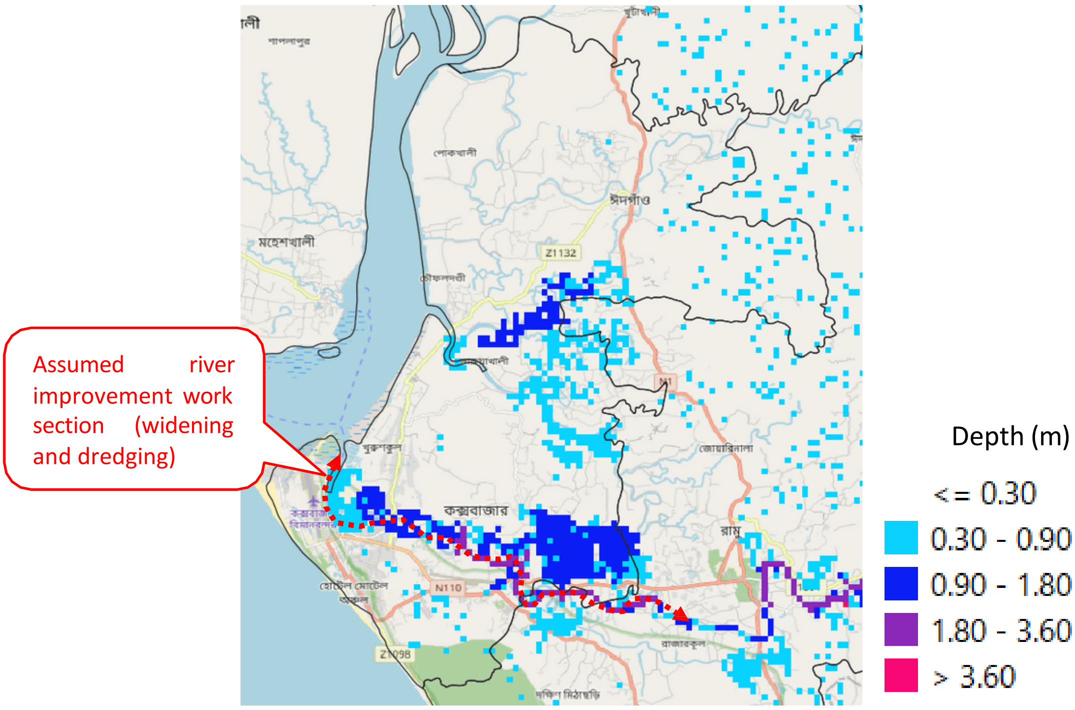


Figure 2.1.10 Sample Output of Flood Analysis in Case of Rive Improvement Works (Cox's Bazar Sadar)

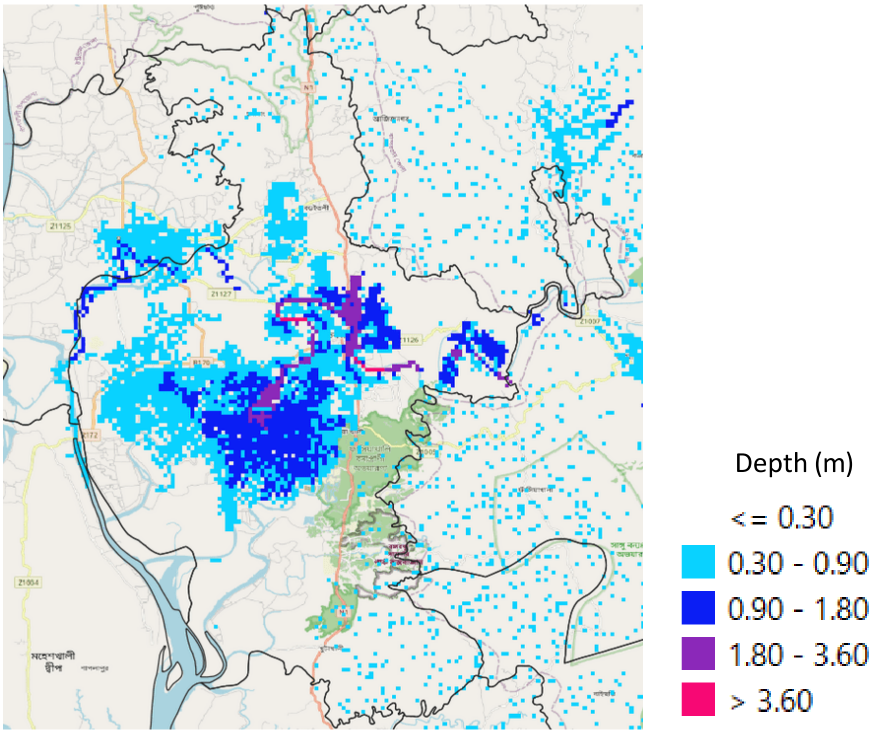


Figure 2.1.11 Sample Output of Flood Analysis (Chakaria Upazila)

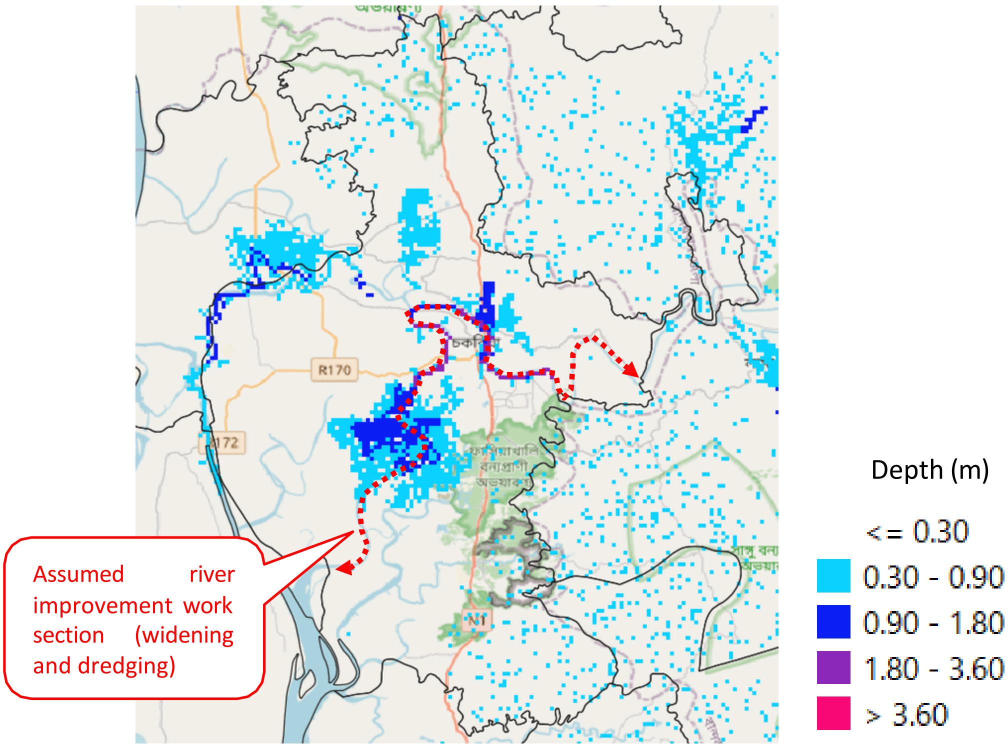


Figure 2.1.12 Sample Output of Flood Analysis in Case of Rive Improvement Works (Chakaria Upazila)

2.1.4. Recommended methods of Riverbank Erosion Analysis for UzDRRAP

2.1.4.1. Concept of Riverbank Erosion Analysis

The purpose of riverbank erosion analysis is to understand the tendency of river channel movement and identify the High-hazard area with river erosion.

There are a few existing studies on riverbank erosion conducted by the Government of Bangladesh (GoB) and other relevant organizations, such as BWDB with the Centre for Environmental and Geographic Information Services (CEGIS), others developed in cooperation with international development partners. From the perspective of fully utilizing existing available resources, these study results should be collected and referred to as the first source for understanding the riverbank erosion hazard. However, those data are not open for public sometimes, so that comprehensible analysis methods is expected.

2.1.4.2. Types of Analysis

There are two types of riverbank erosion analyses proposed in this guideline. The first is for the rivers with one or two significant main streams, focusing on the movement of the main streams in the last 10 to 15 years with free satellite images. The other is for the braided river channels showing unpredictable stream movements, such as channels going through the Char areas, focusing on the movements in the last couple of years. These analyses results are expected to be updated annually, based on the latest satellite photos using GIS software to update and reflect the latest geological conditions.

The general features of these analyses are described in the following table. The choice of which method to be used depends on the river scale and trends of the river movement.

Table 2.1.5 Features of the Riverbank Erosion Hazard Analysis

	1. For rivers with one or two significant main streams	2. For braided river channels
Concept	Recognizing the tendencies of the movement of the main streams in the last 10 to 15 years, predict the coming movement of the main streams and identify the high-hazardous area	Find the High-hazard areas for the coming couple of years with the last three-year-movement of braided river streams.
Applicable area	Large-scale rivers such as Padma River, Jamuna River, Meghna River, Karnaphuli River, Teesta River, Buriganga River, Turag River, Balu River, and Sitalakhya River	Areas with braided river channels such as the Char areas
Methodology	Firstly, satellite photos (Landsat 7, 8, and/or 9) for the past 10 to 15 years are collected to create the colored photo and to find water body areas by calculation with GIS software.	Firstly, satellite photos (Landsat 8, or 9) for the past 4 years are collected to find water body areas by calculation with GIS software.

	1. For rivers with one or two significant main streams	2. For braided river channels
	Secondary, those water bodies are overlayed and tendencies of the movement of the main streams are identified. Thirdly, the areas where the main streams are approaching to the land area are selected as the High-hazard areas.	Secondary, those water bodies are overlayed, annual eroded areas are found and tendencies of erosion are recognized. Thirdly, the areas where the annual erosion is continuously developed are selected as the High-hazard areas.
Data Requirement for the Analysis	(Required) Satellite photos (Landsat 7, 8, and/or 9) for the past 10 to 15 years (Not required but preferable to collect and use) Road, embankment and other structures which will protect river banks against erosion	(Required) Satellite photos (Landsat 8, or 9) for the past 4 years (Not required but preferable to collect and use) Road, embankment and other structures which will protect river banks against erosion
Note	It is best if the risks against riverbank erosion has been studied and such information is available in public. Those information should be referred first to plan the local disaster risk reduction management. The information about historical erosion damages and movement of the main streams should be always utilized for identifying the High-hazard areas.	The risks against riverbank erosion has been seldom studied for the braided rivers. However, if there is and if such information is available in public, those information should be referred first to plan the local disaster risk reduction management.

The flows of each analysis are shown as follows.

2.1.4.3. For rivers with one or two significant main streams

The following figure shows the procedure to identify the High-hazard areas at the areas with one or two significant main streams.

For more detailed procedure, please refer to Annex (technical manual).

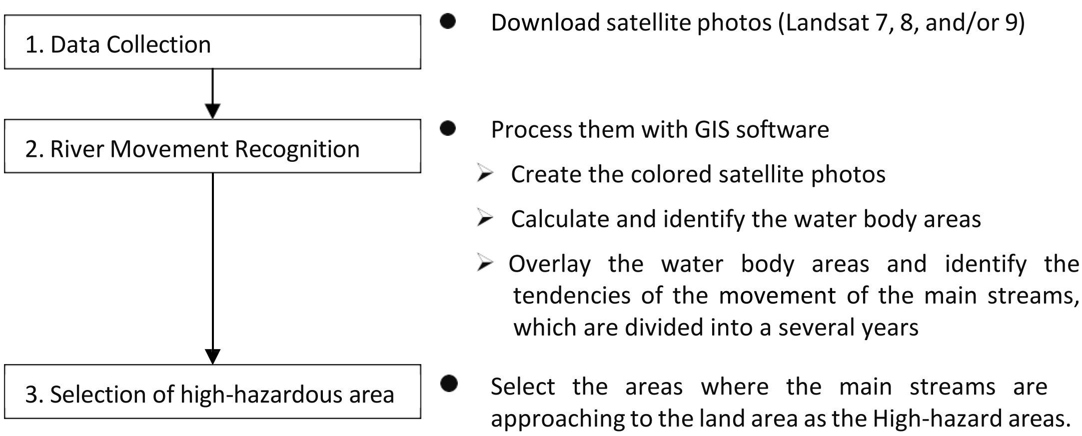


Figure 2.1.13 Flow of the Riverbank Erosion Analysis (Areas with One or Two Significant Main Streams)

2.1.4.4. For braided river channels

The following figure shows the procedure to identify the High-hazard areas at the areas with braided river channels.

For more detailed procedure, please refer to Annex (technical manual).

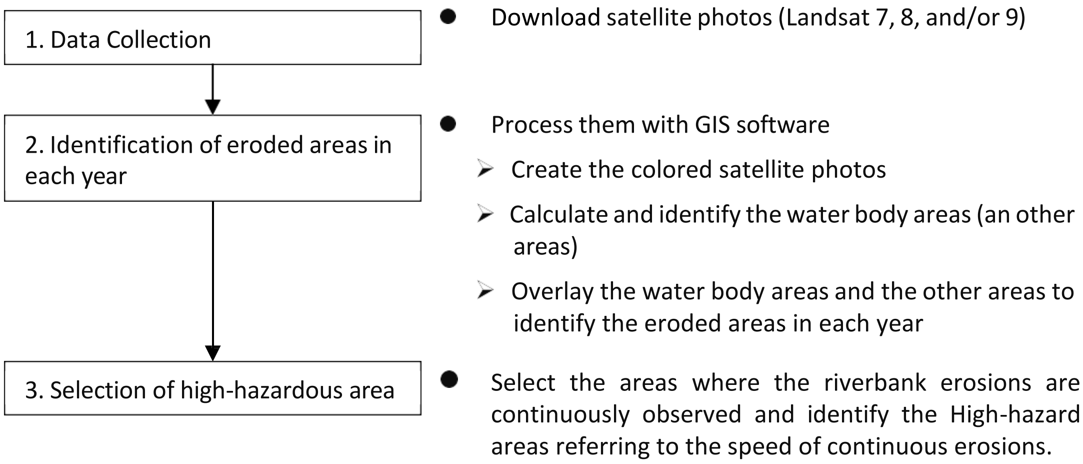


Figure 2.1.14 Flow of the Riverbank Erosion Analysis (Areas with Braided River Channels)

2.1.4.5. Required Data

In each analysis mentioned above, some hydrological data are required. Those are summarized in the following table.

Table 2.1.6 Required Data for the Riverbank Erosion Hazard Analysis

	1. For rivers with one or two significant main streams	2. For braided river channels
Data	Satellite photo (Landsat 7, 8 and/or 9) in collection 2, level 2 ・ Band range (B1-B4) for Landsat (7) and band range (B2-B5) for Landsat 8 and 9	Satellite photo (Landsat 8 and/or 9) in collection 2, level 2 ・ Band range (B2-B5) for Landsat 8 and 9

Note: These satellite photos are free to download. The detailed steps to download those files are explained in the Annex.

2.1.5. Sample Output of Riverbank Erosion Analysis

As examples of the colored satellite photo generated from the Landsat data, extraction of water body, tendency of movement of Teesta River are shown in the following figures.

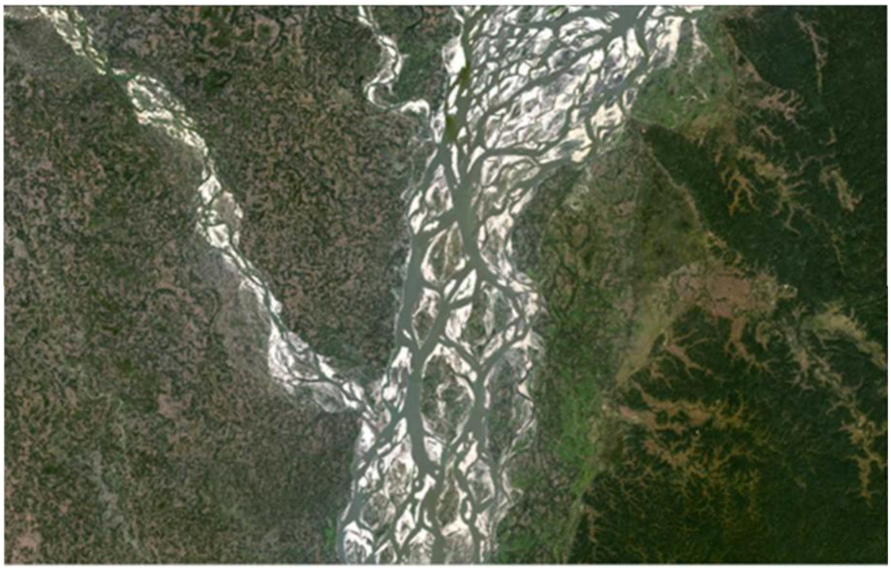


Figure 2.1.15 Colored Satellite Photo Generated from the Landsat Data

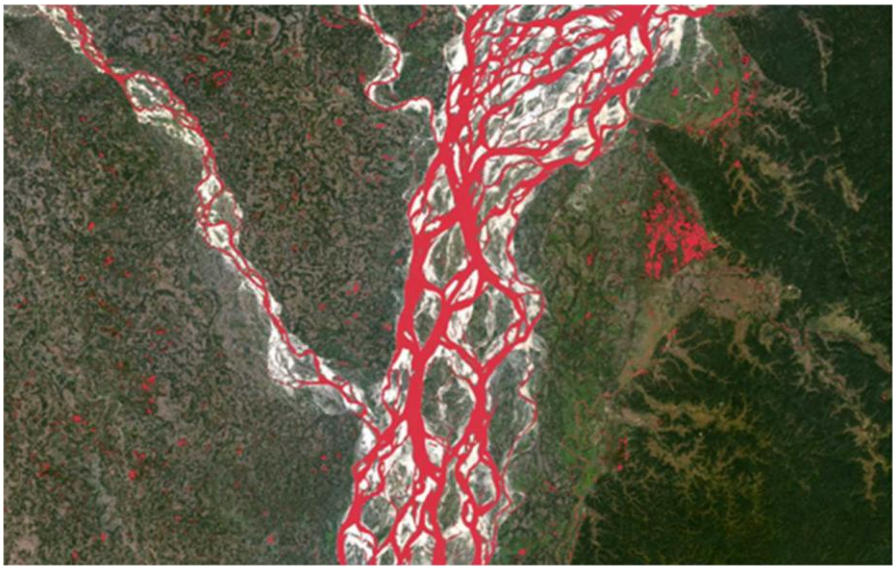


Figure 2.1.16 Extracted Water Body (shown in red)

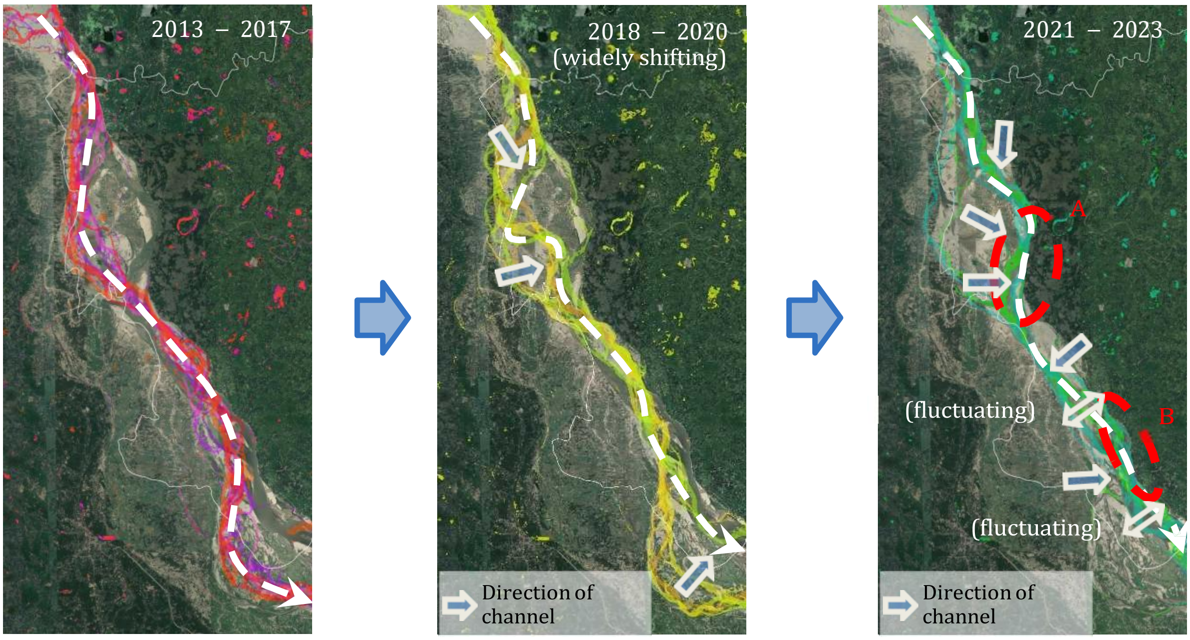


Figure 2.1.17 Tendency of Movement of Teesta River along Ulipur Upazila in Large Scale

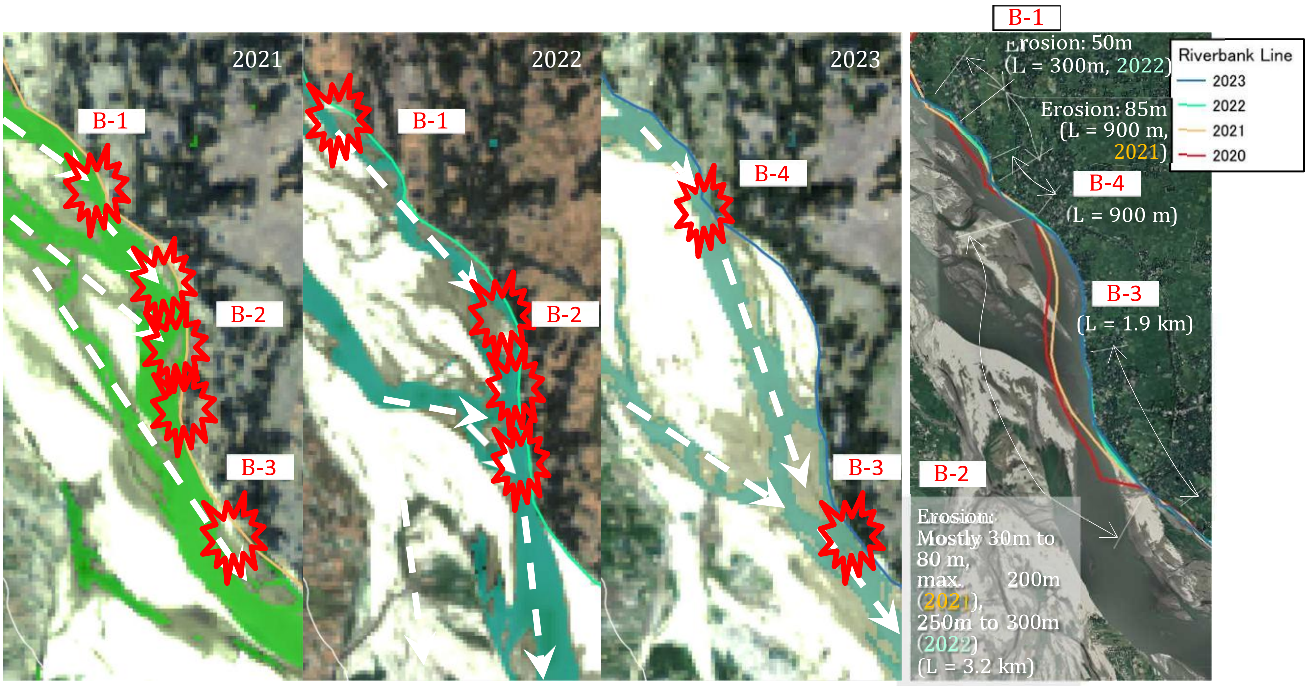


Figure 2.1.18 Tendency of Movement of Teesta River along Ulipur Upazila in Local Scale

Figure 2.1.19 Selected High-hazard Area for Riverbank Erosion along Ulipur Upazila (for 2024)

As the example of analysis for the braided river channels, the calculated distribution of the annual riverbank erosion in the Char area and the selected high-hazard for riverbank erosion in the Char area are shown in Figure 2.1.20.

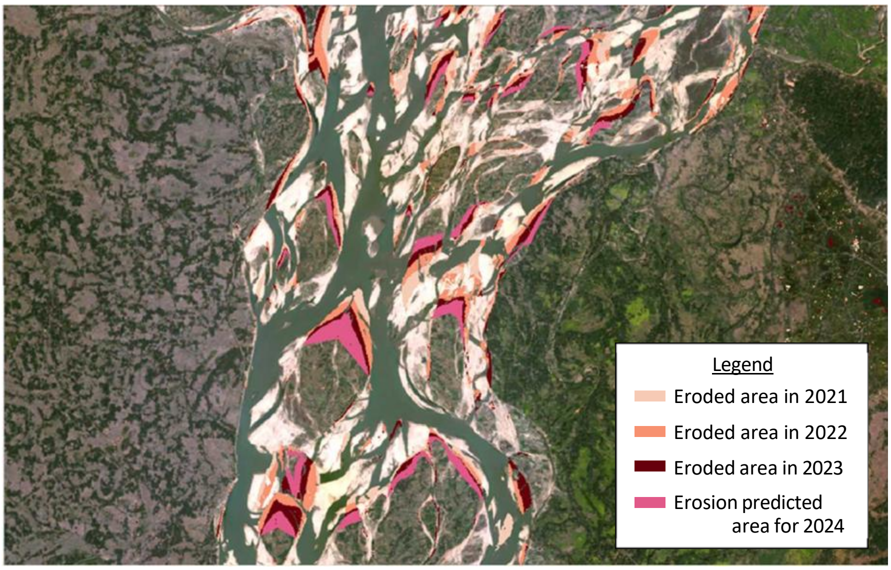


Figure 2.1.20 Selected High-hazard Area for Riverbank Erosion in Char Area (for 2024)

2.1.6. Risk Assessment on Flood

2.1.6.1. Concept of Risk Assessment on Flood

The risk assessment on flood aims to comprehend the exposure, vulnerability and capacity against flood hazard in the upazila. The goal of the assessment is to obtain the distribution of quantitative data showing how much the areas are affected by the flood hazard.

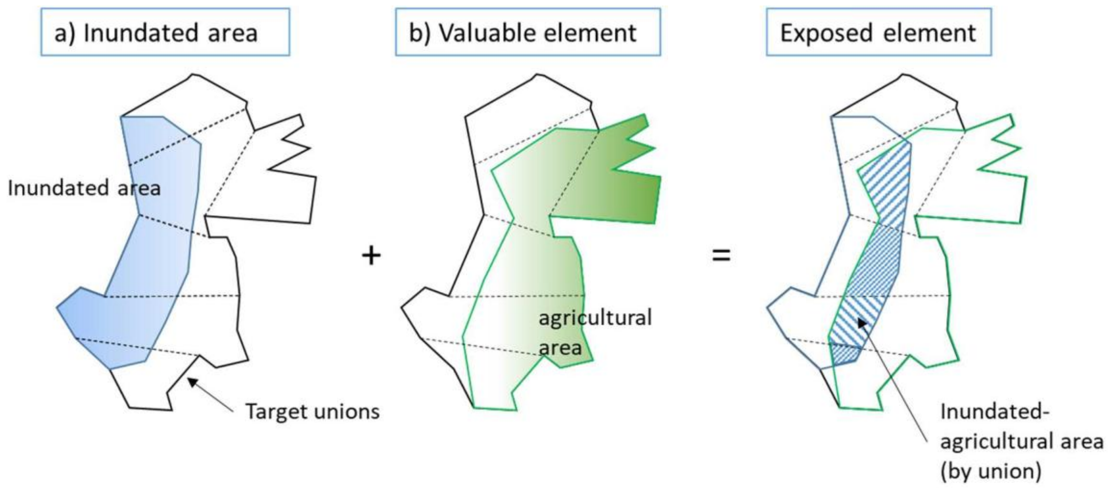
As the hazard analysis on flood, there might be some existing flood hazard analysis and flood risk assessment results conducted by some organizations Hence, those study results should be collected at first and utilized to compile the UzDRRAP. If those results could not be found, or are not enough, the risk assessment is required.

2.1.6.2. Risk Assessment Flow

The following figure shows the flow of the risk assessment on flood. The concept of the procedure is also shown in Figure 2.1.22and Figure 2.1.23.

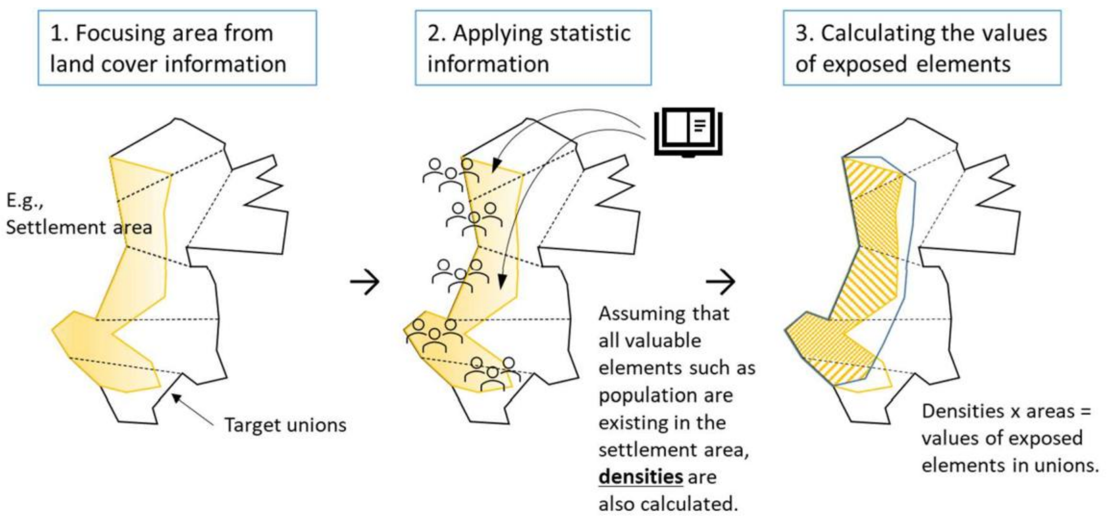
1. Data Collection	● Existing hazard analysis results and risk assessment results ● Statistic data (e.g., population, agricultural production, number of buildings, etc.) ● Land cover (e.g., settlement area, agricultural area, paddy field, etc.) ➢ Those can be extracted from the satellite photo manually.
2. Finding the indexes for the assessment under assumptions	● Assumption: ➢ E.g., “All buildings and populations exit in the settlement area.”, etc., ● Indexes for exposure: ➢ E.g., inundated agricultural land area, paddy production loss, inundated settlement area, number of inundated buildings, damage costs on the buildings
3. Obtain exposure data under flood hazard by union	● Over laying the hazard map on the land cover map, to calculate the values (e.g., settlement area, agricultural area, etc.) under the inundation area

Figure 2.1.21 Flow of the risk assessment on flood



Source: JICA Expert Team

Figure 2.1.22 Concept of the risk assessment on flood for agriculture

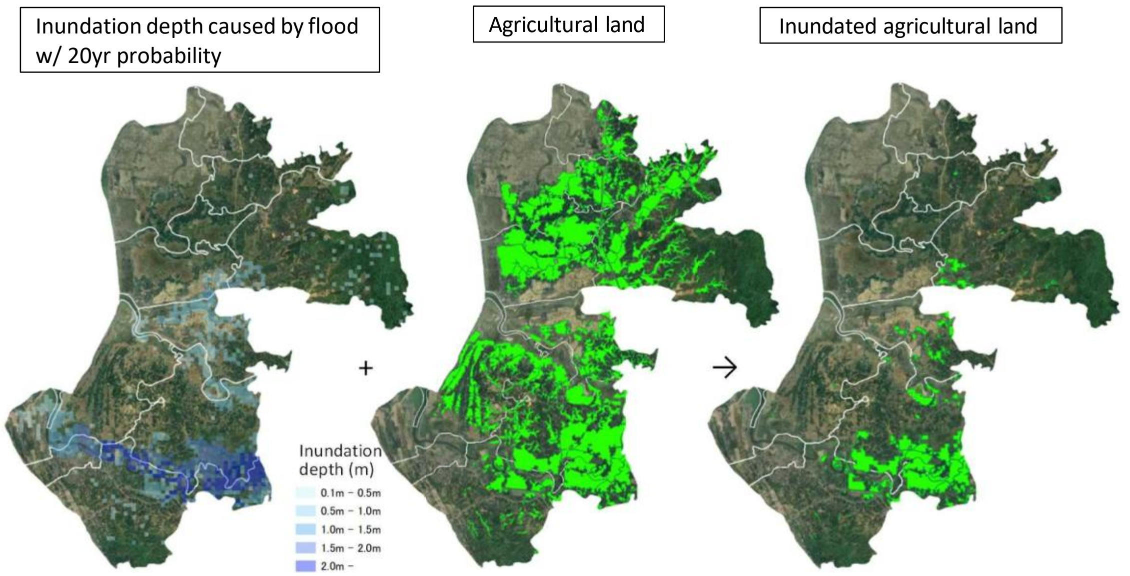


Source: JICA Expert Team

Figure 2.1.23 Concept of the risk assessment on flood for building and facility

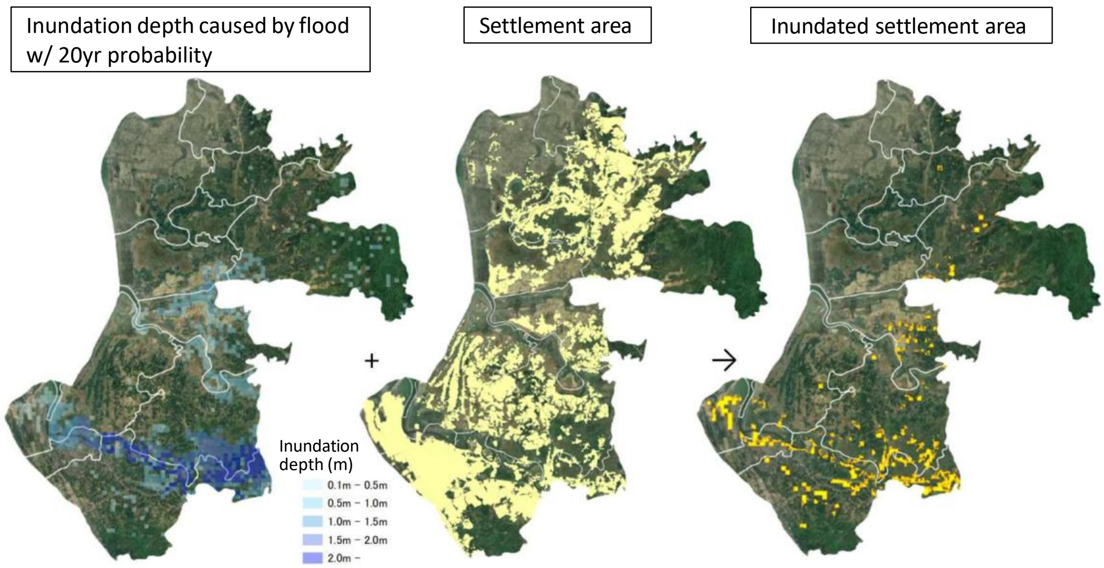
2.1.6.3. Examples of the Risk Assessment on Flood

As examples, the process and the results of the assessment in the Cox's Bazar Upazila is shown in the following figures. As indexes of the risk assessment, inundated agricultural land area, inundated settlement area and affected (inundated) population were selected. Furthermore, assuming the all of the population is distributed only in the settlement area evenly, affected (inundated) population can be roughly proposed.



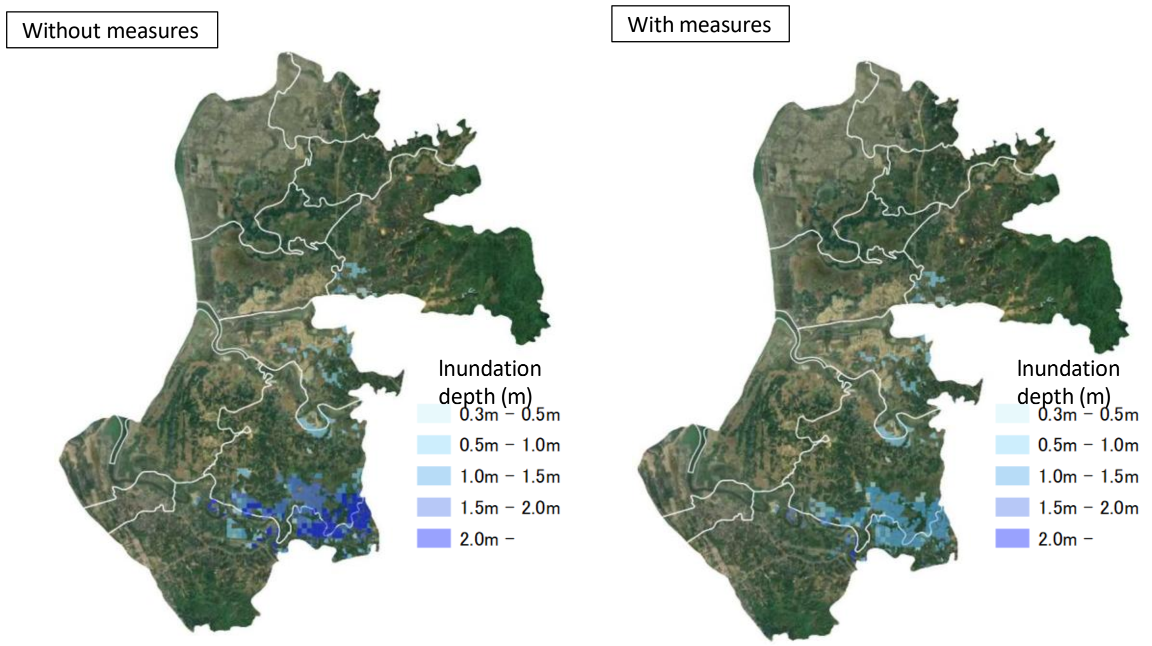
Source: JICA Expert Team

Figure 2.1.24 Risk assessment on flood for agricultural land area in Cox's Bazar Sadar Upazila



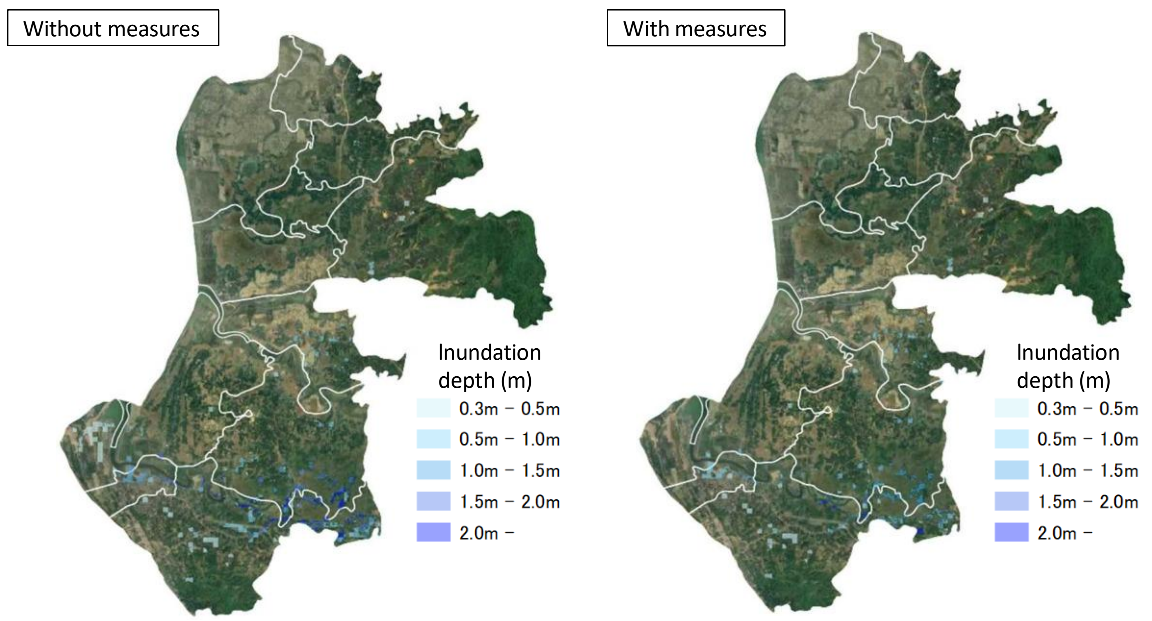
Source: JICA Expert Team

Figure 2.1.25 Risk assessment on flood for settlement area in Cox's Bazar Sadar Upazila



Source: JICA Expert Team

Figure 2.1.26 Example of affected agricultural land area with and without measures against flood in Cox's Bazar Sadar Upazila



Source: JICA Expert Team

Figure 2.1.27 Example of affected settlement area with and without measures against flood in Cox's Bazar Sadar Upazila

Table 2.1.7 Example of affected agricultural land area with and without measures against flood in Cox's Bazar Sadar Upazila

(unit: ha)

	Measure	0.3m≦x<0.5m	0.5m≦ x<1m	1m≦ x<1.5m	1.5m≦ x<2m	2m≦x	Total
Bharuakhali	Without	2.1	114.3	0.0	0.0	0.0	**116.4**
	With	3.8	112.5	0.0	0.0	0.0	**116.4**
Chaufaldandi	Without	0.0	0.3	0.1	0.0	0.0	**0.3**
	With	0.0	0.3	0.1	0.0	0.0	**0.3**
Cox's Bazar Paurashava	Without	0.0	0.0	0.0	0.0	0.0	**0.0**
	With	0.0	0.0	0.0	0.0	0.0	**0.0**
Idgaon	Without	34.2	29.3	10.4	0.0	0.0	**73.9**
	With	34.2	29.3	10.4	0.0	0.0	**73.9**
Islamabad	Without	2.2	0.0	0.0	0.0	0.0	**2.2**
	With	2.2	0.0	0.0	0.0	0.0	**2.2**
Islampur	Without	0.4	0.0	0.0	0.0	0.0	**0.4**
	With	0.4	0.0	0.0	0.0	0.0	**0.4**
Jalalabad	Without	0.0	0.0	0.0	0.0	0.0	**0.0**
	With	0.0	0.0	0.0	0.0	0.0	**0.0**
Jhilwanja	Without	38.2	62.7	31.5	77.6	178.9	**389.0**
	With	14.5	51.1	187.6	20.1	13.0	**286.4**
Khurushkul	Without	0.8	0.7	0.0	0.0	0.0	**1.5**
	With	1.5	0.0	0.0	0.0	0.0	**1.5**
Patali Machhuakhali	Without	16.6	86.8	58.5	214.4	115.8	**492.2**
	With	45.9	100.3	271.0	12.8	0.0	**430.0**
Pokkhali	Without	0.0	0.0	0.0	0.0	0.0	**0.0**
	With	0.0	0.0	0.0	0.0	0.0	**0.0**

Source: JICA Expert Team

Table 2.1.8 Example of affected settlement area with and without measures against flood in Cox's Bazar Sadar Upazila

(unit: ha)

	Measure	0.3m≦x<0.5m	0.5m≦ x<1m	1m≦ x<1.5m	1.5m≦ x<2m	2m≦x	Total
Bharuakhali	Without	298	2,572	0	0	0	**2,870**
	With	298	2,572	0	0	0	**5**
Chaufaldandi	Without	0	1	4	0	0	**5**
	With	0	1	4	0	0	**23,794**
Cox's Bazar Paurashava	Without	391	2,491	15,335	5,577	0	**23,359**
	With	2,447	16,014	4,898	0	0	**1,356**
Idgaon	Without	956	363	37	0	0	**1,356**
	With	956	363	37	0	0	**109**
Islamabad	Without	109	0	0	0	0	**109**
	With	109	0	0	0	0	**33**
Islampur	Without	33	0	0	0	0	**33**
	With	33	0	0	0	0	**0**
Jalalabad	Without	0	0	0	0	0	**0**
	With	0	0	0	0	0	**7,682**
Jhilwanja	Without	2,324	2,124	748	1,398	1,088	**4,987**
	With	2,080	1,184	1,052	296	375	**3,789**
Khurushkul	Without	3,121	161	388	115	4	**822**
	With	315	503	4	0	0	**5,991**
Patali Machhuakhali	Without	804	1,300	747	1,852	1,288	**4,530**
	With	694	1,195	2,174	283	184	**0**
Pokkhali	Without	0	0	0	0	0	**0**
	With	0	0	0	0	0	**0**

Source: JICA Expert Team

Table 2.1.9 Example of affected population with and without measures against flood in Cox's Bazar Sadar Upazila

(unit: pp)

	Measure	0.3m≦x<0.5m	0.5m≦ x<1m	1m≦ x<1.5m	1.5m≦ x<2m	2m≦x	Total
Bharuakhali	Without	4.0	34.7	0.0	0.0	0.0	**38.8**
	With	4.0	34.7	0.0	0.0	0.0	**38.8**
Chaufaldandi	Without	0.0	0.0	0.0	0.0	0.0	**0.1**
	With	0.0	0.0	0.0	0.0	0.0	**0.1**
Cox's Bazar Paurashava	Without	0.6	3.8	23.7	8.6	0.0	**36.7**
	With	3.8	24.7	7.6	0.0	0.0	**36.0**
Idgaon	Without	18.4	7.0	0.7	0.0	0.0	**26.1**
	With	18.4	7.0	0.7	0.0	0.0	**26.1**
Islamabad	Without	1.8	0.0	0.0	0.0	0.0	**1.8**
	With	1.8	0.0	0.0	0.0	0.0	**1.8**
Islampur	Without	0.3	0.0	0.0	0.0	0.0	**0.3**
	With	0.3	0.0	0.0	0.0	0.0	**0.3**
Jalalabad	Without	0.0	0.0	0.0	0.0	0.0	**0.0**
	With	0.0	0.0	0.0	0.0	0.0	**0.0**
Jhilwanja	Without	76.1	69.6	24.5	45.8	35.6	**251.7**
	With	68.1	38.8	34.5	9.7	12.3	**163.4**
Khurushkul	Without	74.4	3.8	9.2	2.7	0.1	**90.3**
	With	7.5	12.0	0.1	0.0	0.0	**19.6**
Patali Machhuakhali	Without	16.9	27.3	15.7	38.9	27.1	**125.9**
	With	14.6	25.1	45.7	6.0	3.9	**95.2**
Pokkhali	Without	0.0	0.0	0.0	0.0	0.0	**0.0**
	With	0.0	0.0	0.0	0.0	0.0	**0.0**

Source: JICA Expert Team

2.2. Costal Disasters (Storm Surge, Tsunami)

2.2.1. Current Status of Costal Disasters in Bangladesh

Coastal disasters are damage that happens at coastal area, mainly water related disaster. For example, tropical cyclone induces storm surge if it passes through coastal area and strong wind causes high wave, resulting in overtopping at coast. High wave also causes coastal erosion and sedimentation at coastal and river mouth. Not only meteorological phenomena, geological one (e.g., earthquake, land slide and eruption) can cause tsunami, which induce coastal inundation at coastal area.

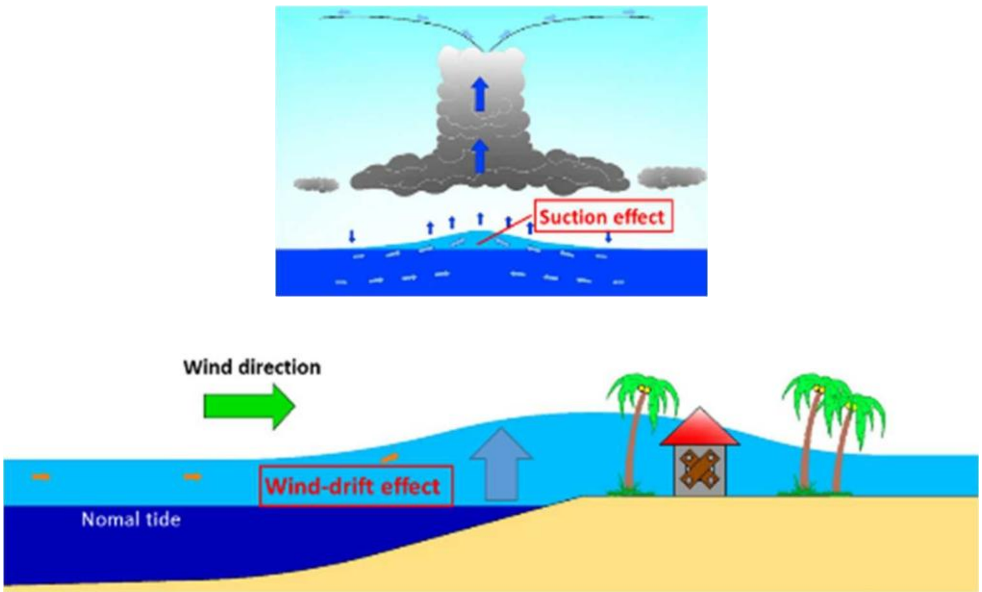
The following sections will explain the coastal disasters in Bangladesh, referencing the existing technical reports and papers. Although the detailed description is shown later, the main points of this guideline will focus on coastal disasters related to cyclone (i.e., storm surge, storm wave, erosion).

2.2.1.1. Storm Surge

According to NOAA's expression, storm surge is the abnormal rise in seawater level during a storm, measured as the height of the water above the normal predicted astronomical tide.

The surge is caused by the following primary 2 factors which mechanism is shown in Figure 2.2.1.

1. Wind drift effect: a storm's winds push water onshore.
2. Suction effect: sea surface is risen by the atmospheric pressure depression



Source: JICA Expert Team

Figure 2.2.1 Mechanism of storm surge (top: suction effect, bottom: wind-drift effect)

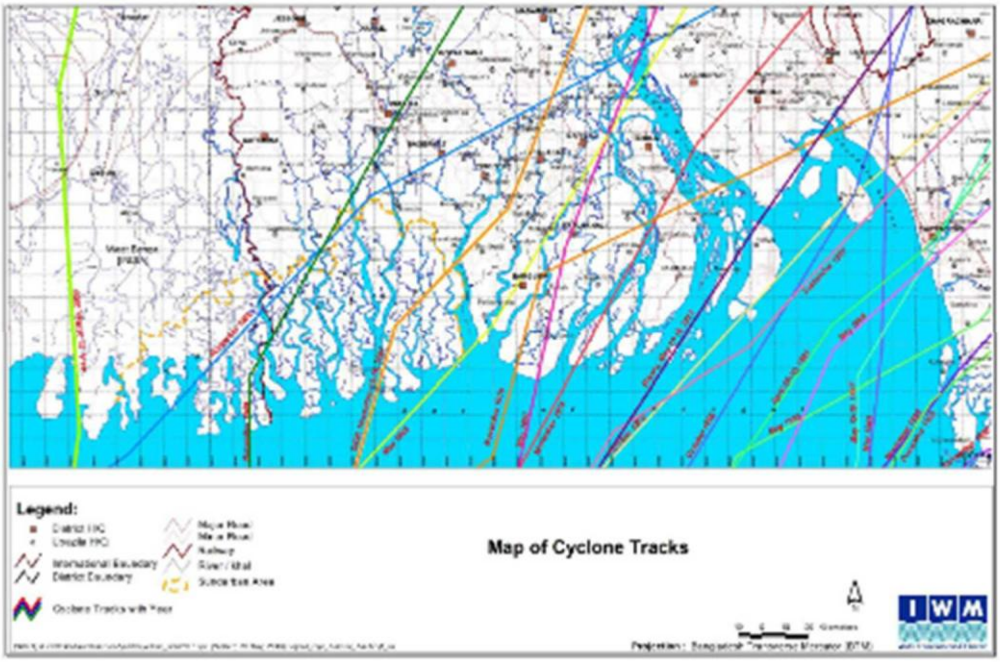
In Bangladesh, there are several existing studies related to storm surge (shown in Table 2.2.1). DDM conducted multi hazard, risk and vulnerability assessment including storm surge, tsunami, flood and so on. BUET has several related projects like SATREPS and others. JICA conducted the data collection survey for Matarbari port development and storm surge survey was done in the study for setting the design condition of tide and wave. The climate change effect should be included for considering the coastal disaster because coastal area is the one of the most affected area by climate change (e.g. Sea Level Rise, intensity of tropical cyclone). One of the recent research in Bangladesh is the report by DoE/ MoEF. The following part will show some results of these studies.

Table 2.2.1 List of existing study regarding storm surge

No.	Existing Study Name	Agency	Outline
1	Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh	DDM (IWM etc.)	Storm Surge, Tsunami, Flood, and so on
2	The Project for Research on Disaster Prevention/Mitigation Measures Against Floods and Storm Surges in Bangladesh	BUET/ DPRI, KU	SATREPS Bangladesh Coastal Model (BCM)/ Bangladesh Delta Model (BDM)
3	Data Collection Survey on the Matarbari Port Development in People's Republic of Bangladesh	JICA	Storm surge analysis as setting design condition for port facilities
4	Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis	DoE/ MoEF	SLR summary in Bangladesh

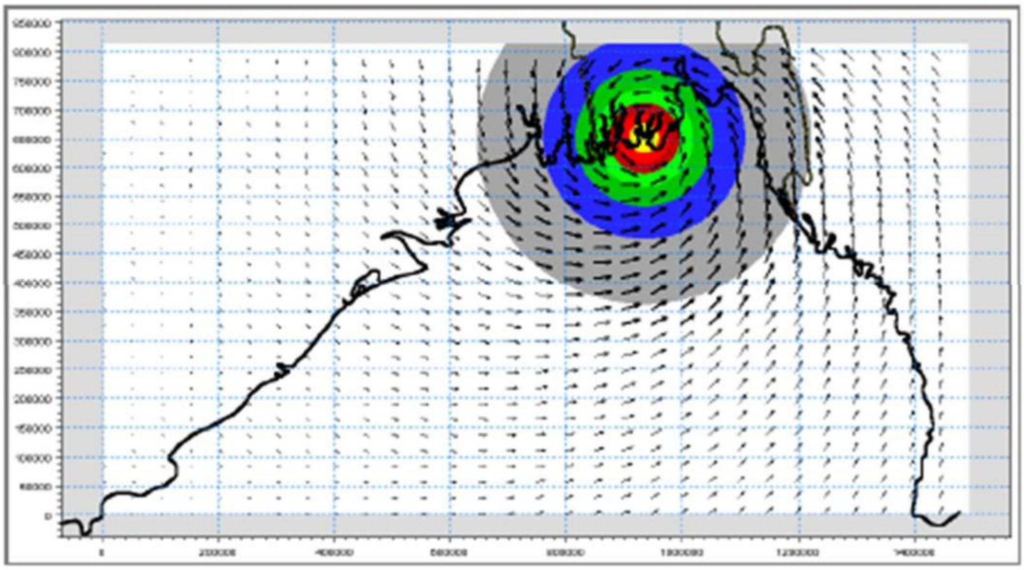
1) Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh

IWM and other companies conducted the technical analysis of this project funded by DDM. In the project, they conducted a series of numerical simulations by using the actual cyclone tracks which passed through Bangladesh's coast in the past. Figure 2.2.2 shows the cyclone tracks used in the project and Figure 2.2.3 indicates a image of pressure and wind field in the numerical simulation. The reports showed inundation map due to storm surge with several return periods of tide. Several results are shown in Figure 2.2.4.



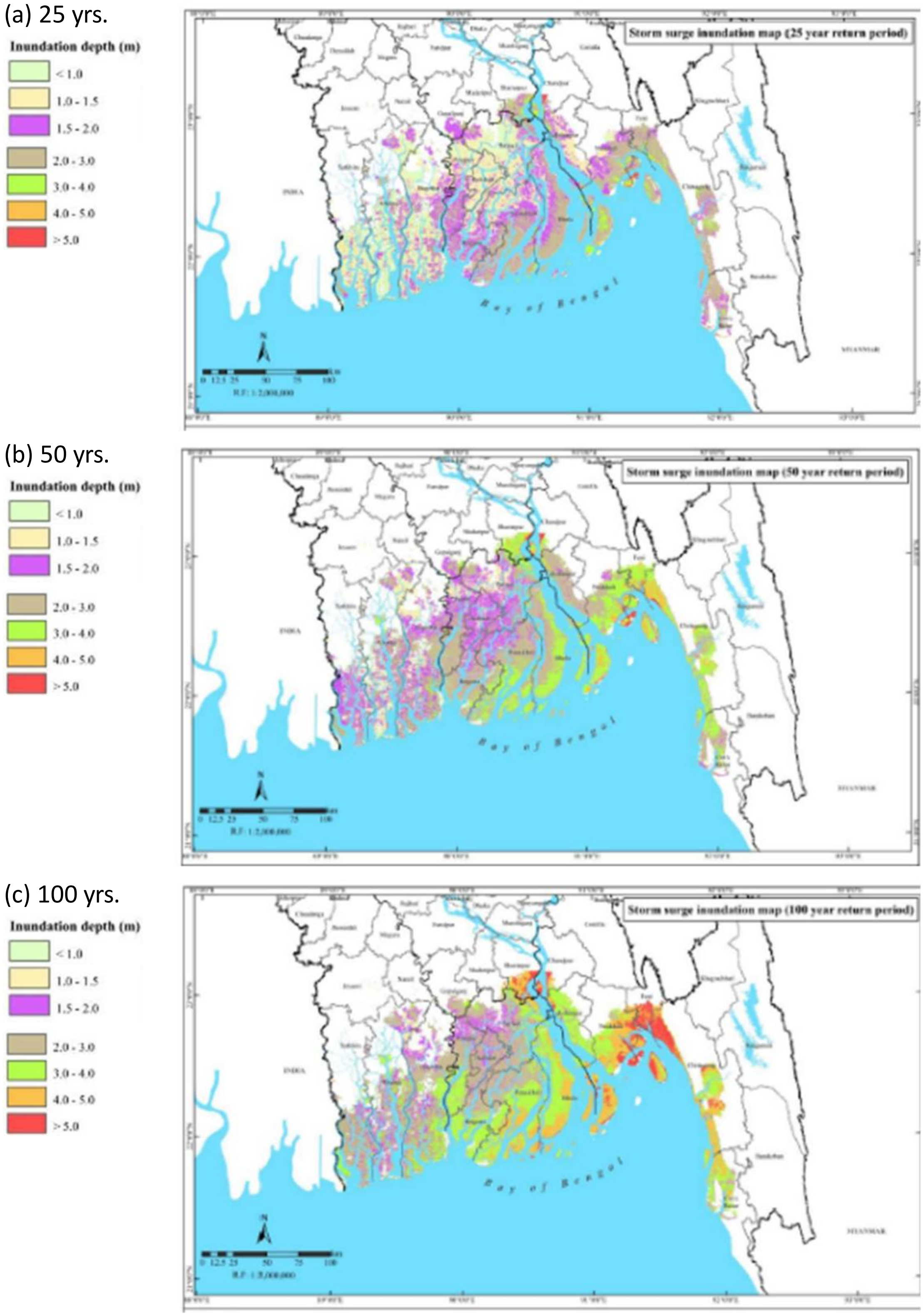
Source: Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh

Figure 2.2.2 Historical Cyclone Track Map of Bangladesh



Source: Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh

Figure 2.2.3 Simulated pressure and wind field in case of cyclone SIDR



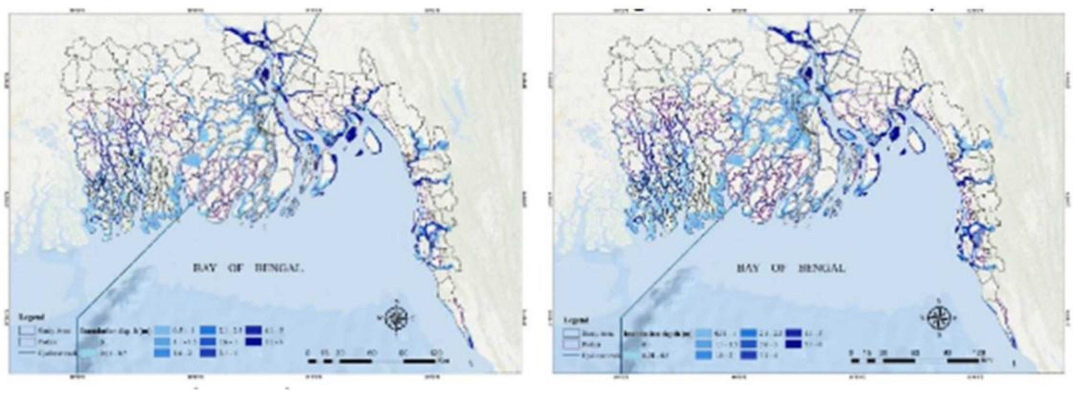
Source: Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh

Figure 2.2.4 Storm surge inundation map of entire coastal area for 25-, 50-, 100-year return period

2) **The Project for Research on Disaster Prevention/Mitigation Measures Against Floods and Storm Surges in Bangladesh**

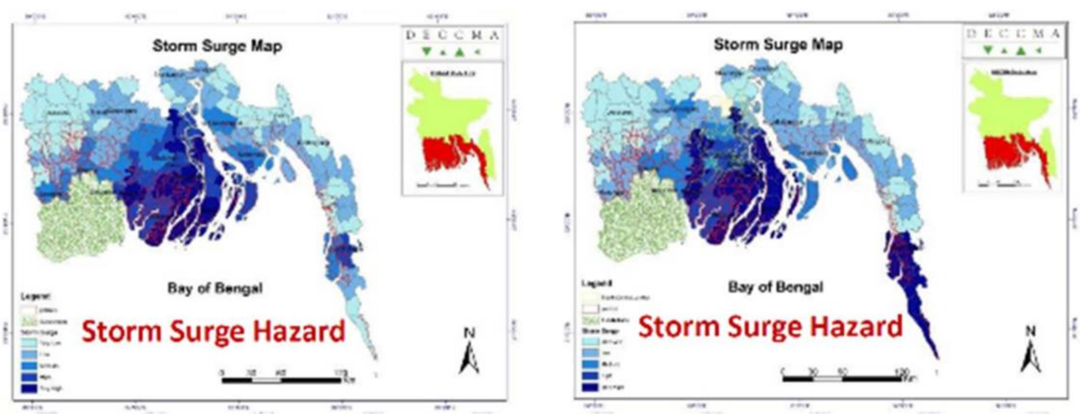
BUET is one of the most advanced research organizations in Bangladesh and has main 2 coastal models related to storm surge: BCM (Bangladesh Coastal Model) and BDM (Bangladesh Delta Model).

They utilized BCM for inundation simulation against Cyclone Sidr for whole Bangladesh's coast with and without climate change effect shown in Figure 2.2.5. The mesh is about from 300 to 500 m for whole coastal area. BDM is a integrated model by considering not only storm surge but also riverine flood and sediment transport. One of the results in BUET studies is storm surge risk map with and without climate change for whole country shown in Figure 2.2.6.



Source: BUET

Figure 2.2.5 Storm surge inundation map at cyclone SIDR with present climate (L) and future climate (R)

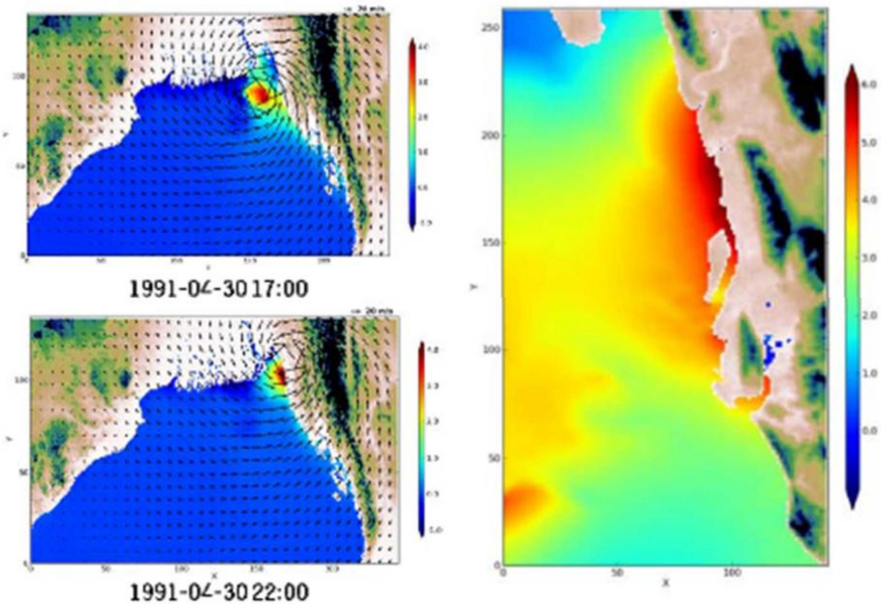


Source: BUET

Figure 2.2.6 Storm surge risk map with present climate (L) and future climate (R)

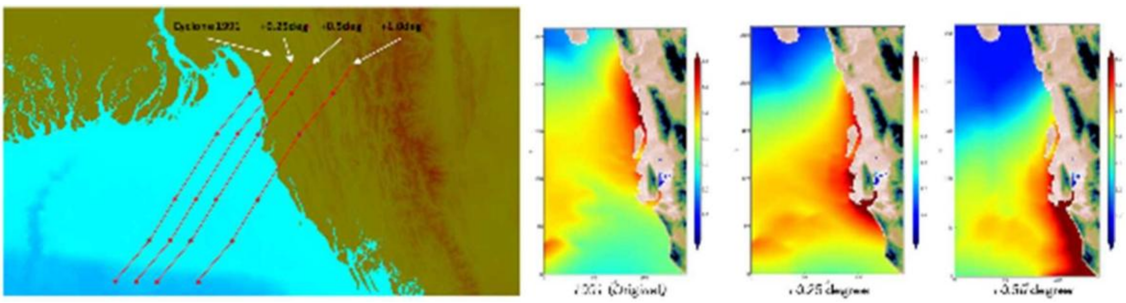
3) Data Collection Survey on the Matarbari Port Development in People's Republic of Bangladesh

JICA conducted the data collection survey for the Matarbari port development. This report included several storm surge analysis for setting design condition of port facilities. They conducted a series of numerical simulations by using actual and virtual tropical cyclones and analyzed the worst-case scenario for the Matarbari port. The 1991 cyclone hit this area and caused severe storm surge damage there. Figure 2.2.7 shows the results of the simulation. They also assumed several virtual cyclone tracks shifted to 1991 cyclone and conducted storm surge analysis to understand the worst track for the Matarbari port as shown in Figure 2.2.8.



Source: Data Collection Survey on the Matarbari Port Development in People's Republic of Bangladesh, JICA

Figure 2.2.7 Snapshots of Wind Velocity and Storm Surge Height Distribution (L) and Maximum Storm Surge Height Distribution (R) of 1991 Cyclone



Source: Data Collection Survey on the Matarbari Port Development in People's Republic of Bangladesh, JICA

Figure 2.2.8 Original Cyclone Track and Virtual Tracks (Top) and Maximum storm surge height distribution (Bottom)

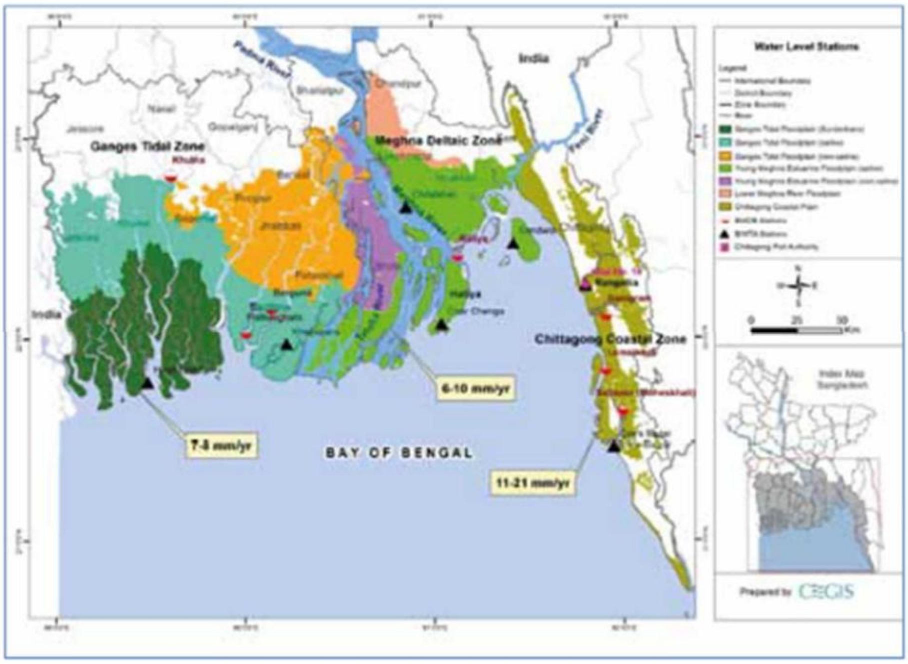
4) Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis

DoE assessed the sea level rise for whole Bangladesh coast by using observed tide data and reanalysis data. They conducted the trend analysis for last 30 years for six divided regions shown in Table 2.2.2 and Figure 2.2.9.

Table 2.2.2 Significant trends derived of the selected water level stations in the coastal region of Bangladesh based on the data of last 30 years

Source	Location	Subzone	Analysis Period	Trend based on Regression Slope (mm/year)	Trend based on Sen's Slope (mm/year)	Significance level
BIWTA	Hiron Point	Ganges tidal floodplain (saline)	1981-2013	8	7	significant at 99%
BIWTA	Char Chenga	Meghna estuarine floodplain (charland)	1980-2012	6	6	significant at 99%
BIWTA	Sandwip	Meghna estuarine floodplain (charland)	1977-2012	10	10	significant at 99%
BIWTA	Khal No. 10	Chittagong coastal plain	1983-2012	15	20	significant at 99%
BIWTA	Cox's Bazar	Chittagong coastal plain	1980-2012	11	13	significant at 99%
BWDB	Lemiskhali	Chittagong coastal plain	1981-88, 1990-2012	21	18	significant at 99%

Source: Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis, DoE

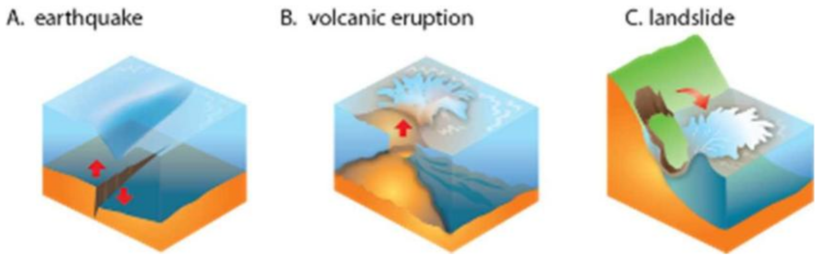


Source: Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis, DoE

Figure 2.2.9 Water level trends for the Ganges, Meghna and Chittagong coastal sub zone of Bangladesh based on the data of last 30 years

2.2.1.2. Tsunami

Tsunami is a large-scale wave propagation phenomenon in the ocean caused by sudden changes in seabed and coastal topography, and its main factors are earthquakes, landslides (sector collapse), volcanic activities, etc. as shown in Figure 2.2.10.

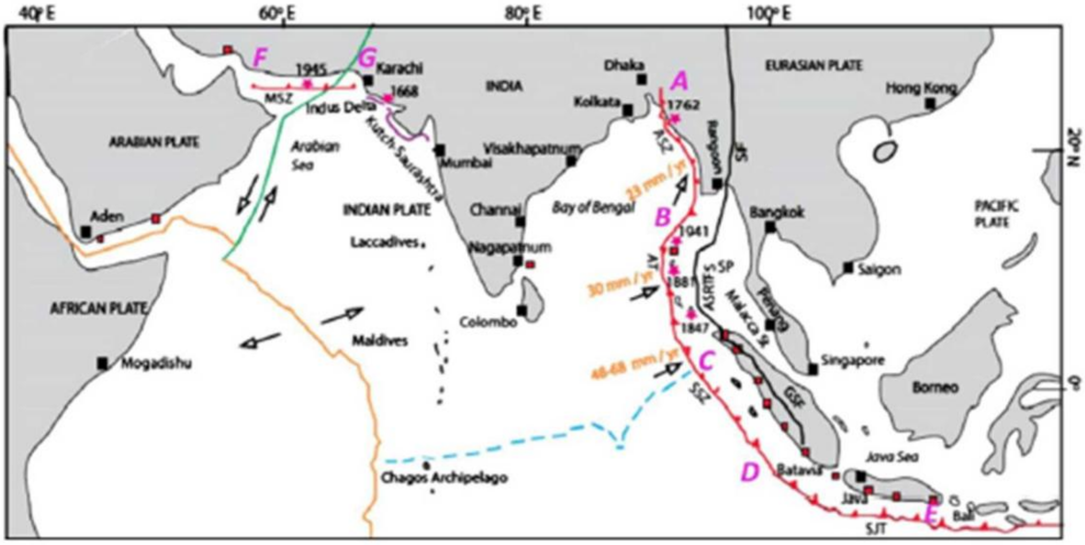


Source: D University of Hawaii website

Figure 2.2.10 Sources of tsunami

DDM conducted the project: Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh. The project included tsunami as one of the target hazards. IWM and other companies conducted the technical analysis of this project funded by DDM. In the project, they conducted a series of numerical simulations by using the subduction zones which are assumed for earthquake occurrence shown in Figure 2.2.11. They set several return periods (50, 100, 200, 500, 1000-year) of tsunami sources for numerical simulations combined with the assumed tsunamigenic source. The magnitude and the source parameters of seismic events are summarized in Table 2.2.3.

The reports showed inundation map due to tsunami with several return periods as shown in Figure 2.2.12. Figure 2.2.12 (a) shows the inundation area due to 50-year return period of tsunami and the very limited area is inundated. Comparing the storm surge inundation area with 50-year return period (see Figure 2.2.4), it is found that inundation area due to storm surge is significantly larger than that of tsunami. It should be noted that 1000-year return period of tsunami causes rather large area of inundation although that is a very rare event. Considering the target hazard level, tsunami is much rare rather than storm surge and the main countermeasures against tsunami is principally the same as those of storm surge. Therefore, this guideline focuses on the storm surge disaster as a primary coastal disaster.



Source: Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh

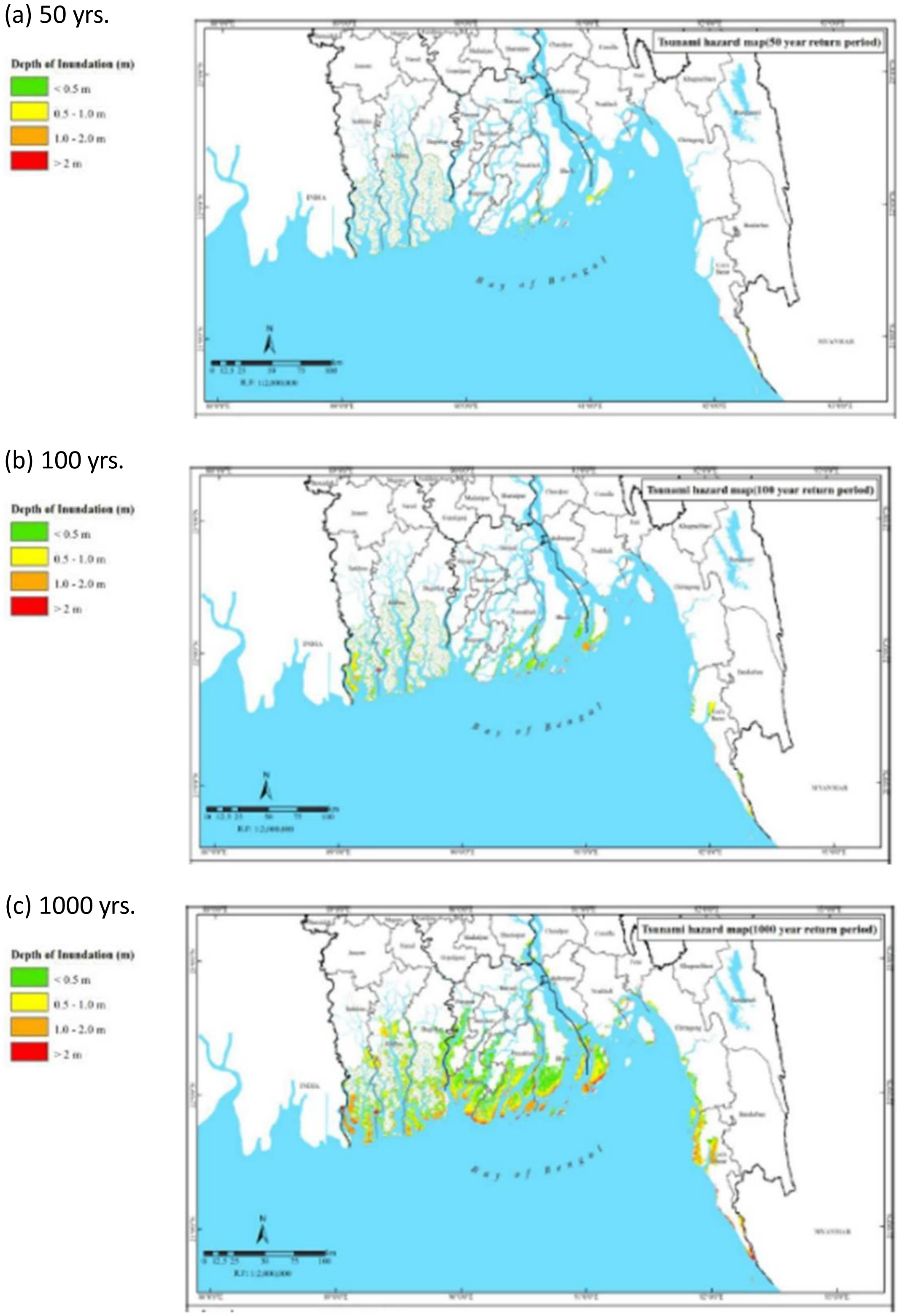
Figure 2.2.11 Sub-duction zones in the Indian Ocean Basin

Table 2.2.3 The magnitude and the source parameters of seismic events corresponding to different recurrence intervals

Seismic scenario	Return period (years)	Seismic zone	Mw	M0 (Nm)	Source parameters						
					Φ (deg)	δ (deg)	λ (deg)	L (km)	W (km)	H (km)	Δu (m)
1	25	Andaman	7.4	1.2x1020	10	12	90	50	40	25	2.1
2	50	Andaman	7.7	4.0x1020	10	12	90	70	45	25	4.3
3	100	Andaman	8.1	1.5x1021	10	12	90	150	65	25	5.5
4	200	Andaman	8.4	4.5x1021	10	12	90	250	85	25	7.0
5	500	Andaman	8.7	1.5x1022	10	12	90	500	95	25	10.5
6	>1000	Arakan	8.6	7.9x1021	324	20	124	470	100	25	6.5
7		Arakan	8.8	1.6x1022	20	15	90	470	175	25	7.0
8		Andaman	9.1	4.5x1022	Multi-segment source model of Ji (2005), reported in Ammon et al. (2005)						

Note: Seismic zones - Arakan (AB) and Andaman (BC) in Fig. 1.20.

Source: Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh



Source: Multi-Hazard, Risk and Vulnerability Assessment, Modelling and Mapping in Bangladesh

Figure 2.2.12 Tsunami inundation map of entire coastal area for 50-, 100-, 1000-year return period

2.2.2. Recommended methods of Costal Disasters Analysis for UzDRRAP

2.2.2.1. Outline of recommended methods

The following part explains the recommended methods for coastal disaster analysis for UzDRRAP. The methods have several options which can choose based on the data availability, technical skills (outsourcing or existing reports) and local conditions.

Main options are as follows.

1) Setting target storm surge
2) Inundation Analysis for Storm Surge

1) Setting Target Storm Surge

At first, we have to determine the target storm surge as a target disaster for UzDRRAP. There are 2 main options for setting the target storm surge. Both options consider whether climate change effect should be included or not. The difference between the 2 methods is summarized in Table 2.2.4.

a) Target Storm Surge = Historical maximum tide w/wo Climate change effect
b) Target Storm Surge = XX-year probability water level w/wo Climate change effect

Table 2.2.4 Comparison of historical observations and numerical analysis methods

Method	(a) Historical observations	(b) Storm surge numerical analysis
Items can be assessed	➢ Storm surges at coasts (historical events)	➢ Storm surges at coasts ➢ Time-series of storm surges
Major Necessary Data	➢ Tide level observation data	➢ Bathymetry ➢ Time series of typhoon information (location, central pressure) ➢ Calculation program
Characteristics (●Pros, ×Cons)	● Hazard assessment based on observed scientific approach is possible. ● The accuracy is expected to be improved in conjunction	● The accuracy is high because weather information such as typhoons is input, and storm surges are directly calculated at the target disturbance. ● Hazard assessment based on scientific basis × Take time to calculate × Experience is required in acquiring numerical calculation × Depend on the accuracy of topographic data

Method	(a) Historical observations	(b) Storm surge numerical analysis
	with the method of past events. × The result is restricted to a certain location that has observation equipment. × The specific event must be within the observation period × Not accommodate a variety of storm surges	

Source: JICA Expert Team

2) Inundation Analysis for Storm Surge

In order to analyze inundation area due to storm surge, inundation analysis is necessary. There are 2 main options for inundation analysis of UzDRRAP. The difference between the 2 methods is summarized in Table 2.2.5.

a) Fill level method: Relatively simpler method by using digital elevation model and target storm surge level
b) Flood simulation: Highly sophisticated method by using numerical simulation with many input data

Table 2.2.5 Comparison of fill level method and flood simulation

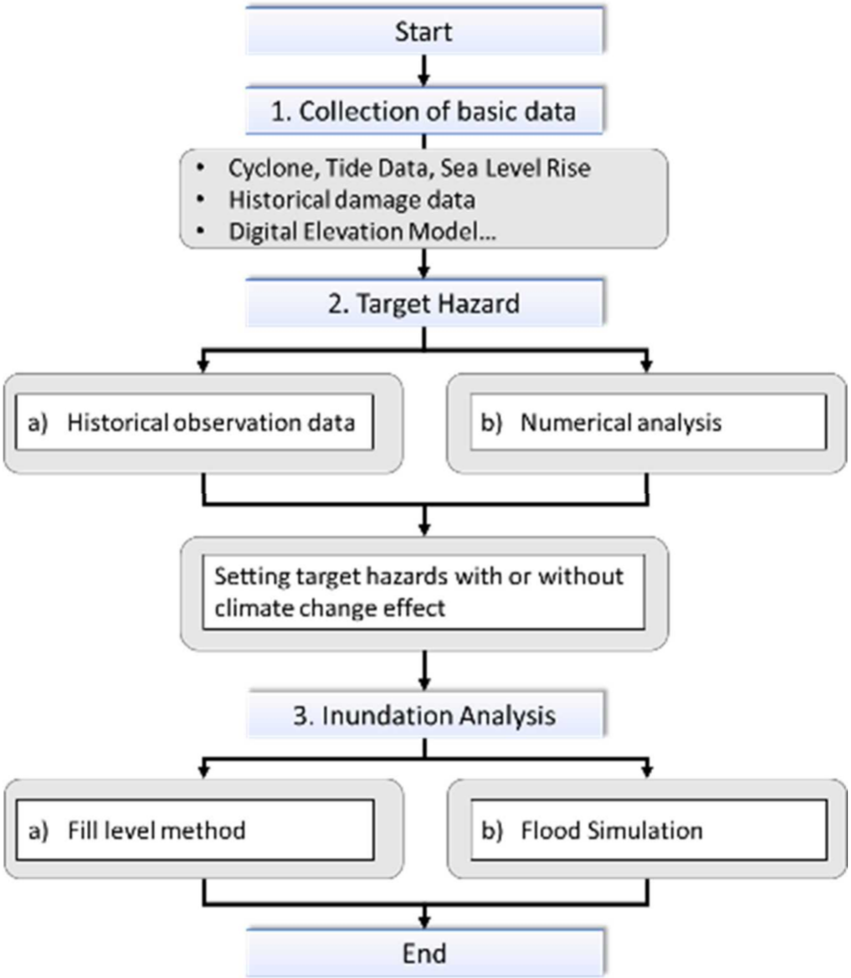
Method	(a) Fill level method (FLM)	(b) Flood simulation
Items can be assessed	➢ Inundated area ➢ Inundation depth	➢ Inundated area ➢ Inundation depth ➢ Flow velocity and flow direction ➢ Arrival time ➢ Duration of inundation
Major Necessary Data	➢ Sea-side storm surge level ➢ DEM	➢ DEM ➢ Land use data ➢ Structure data
Characteristics (●Pros, ×Cons)	● If there is a water level between DEM and the sea side, it can be easily evaluated. ● The inundation depth in each mesh of DEM can be evaluated. × The effect of detailed topography, etc. cannot be considered. × Influences caused by structures cannot be considered.	● Ground data, land use data and structure data can be reflected. ● Reduction of inundation range by structural measures can be evaluated. × Detailed ground data, etc. are required. × Computationally long time is necessary. × Acquisition requires skill and time.

Source: JICA Expert Team

2.2.2.2. Analysis procedures

The procedures of the recommended methods are described in Figure 2.2.13. The method consists of the following 3 parts where are several options as mentioned above.

1. Collection of basic data
2. Target Hazard
    a. Historical observation data
    b. Numerical analysis
3. Inundation Analysis
    a. Fill Level Method
    b. Flood Analysis



Source: JICA Expert Team

Figure 2.2.13 Flow chart of hazard assessment for storm surge

1) Collection of Basic Data

The necessary data for the recommended analysis of storm surge is listed in Table 2.2.6. The options of the methods determine the necessary data based on their characteristics.

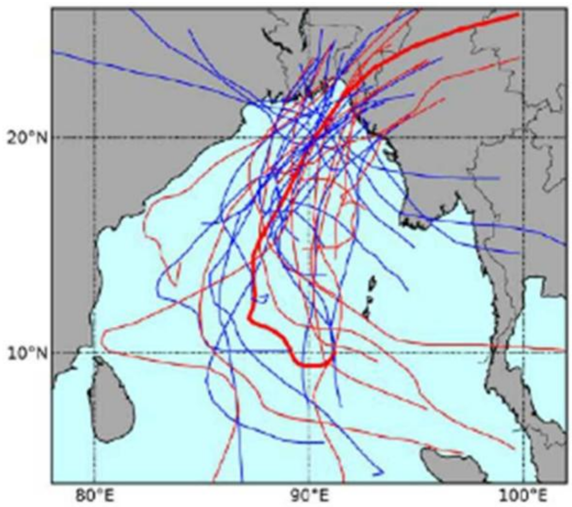
Table 2.2.6 List of necessary data for storm surge analysis

No.	Items	i. Target Hazard		ii. Inundation Analysis	
		a) Obs.	b) Sim.	a) FLM	b) Sim.
1	Cyclone data	✓	✓		
2	Tide observation data	✓	✓		
3	Climate change data	✓	✓		
4	Historical damage data	✓	✓	✓	✓
5	Digital Elevation Model			✓	✓
6	Bathymetry		✓		
7	Structural data				✓

Source: JICA Expert Team

a) Cyclone data

Sample of cyclone data is shown in Figure 2.2.14. The data can be obtained through web site (e.g., https://www.ncdc.noaa.gov/ibtracs/).

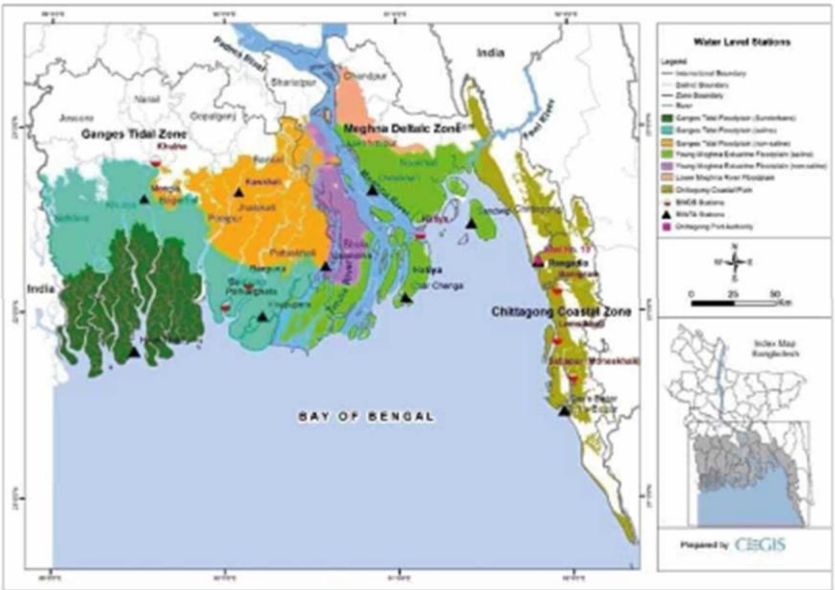


Source: Data Collection Survey on the Matarbari Port Development in People's Republic of Bangladesh, JICA

Figure 2.2.14 Cyclone tracks passed around Matarbari

b) Tide observation data

Tide observation in Bangladesh has been operated several points in coastal area by the governmental agencies (e.g., BIWTA and BWDB). DoE has selected the representative tide observation sites for 6 regions in whole country shown in Figure 2.2.15.



Source: Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis, DoE

Figure 2.2.15 Locations of water level stations for whole coastal area in Bangladesh

2) Setting Target Storm Surge

There are 2 main options for setting target storm surge in the recommended method. The procedure of each option is described in the following part.

a) Target Storm Surge = Historical Maximum Tide w/wo Climate change effect

b) Target Storm Surge = XX-year probability water level w/wo Climate change effect

a) Historical observations

The simpler method for evaluating storm surge hazards is based on past observation data. This is to estimate the scale of storm surges using tide level observation records of remarkable storm surge events that have occurred in the past in the subject area. The necessary data are tide level observation data and astronomical tide level data at the time of the event in the past, and it is a method to estimate the deviation (storm surge deviation) caused by typhoons, etc. by subtracting the astronomical tide level at that time from the observed tide level. This method is a primitive method for estimating the magnitude of storm surges from the results of actual disturbances and disasters, but it has been adopted in areas with tide observation stations in Japan in the past. And this method is applicable only for storm surge events which actually occurred, and the object range is limited.

b) Storm surge numerical analysis

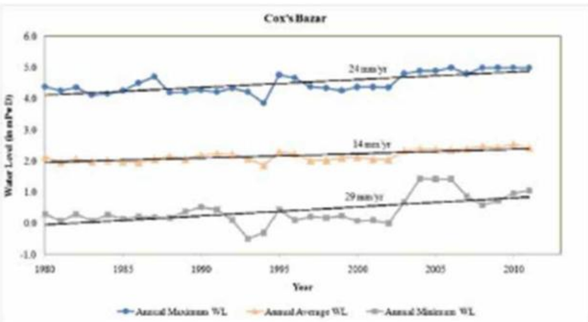
The detailed storm surge hazard evaluation method is to carry out storm surge simulation. This method is shown in the "Guide to Creation of Inundation Assumed Areas for Storm Surge" of Japan, and it is carried out by the attached procedure in the case of storm surges caused by typhoons. The influences of waves, etc. may be considered as necessary.

Since this method can calculate storm surge deviations corresponding to any paths and parameters (e.g., central pressure) such as typhoons in time series, virtual typhoons that shift the paths north and south or rotate the moving direction can also be considered as objects. Therefore, it can also be used for the study of assumed disasters targeting those other than actual typhoons, etc., and it has been adopted for the study of hazard maps, etc. targeting the assumed largest-scale storm surges. Taking advantage of its characteristics, it also responds to analyses considering the intensification of typhoons due to climate change.

This method is adopted in Japan's "Guide to Creation of Inundation Assumed Areas for Storm Surge" and is utilized in the preparation of storm surge hazard maps nationwide. It is the most detailed evaluation method at present. It is also utilized in JICA technical cooperation projects outside of Japan.

c) Setting target storm surge considering climate change effect

Both options a and b consider whether climate change effect should be included or not for target storm surge in the target area. As mentioned above, DoE has prepared the SLR trend for 6 regions of coastal area in Bangladesh. Figure 2.2.16 shows the sample result of the trend analysis in Cox's Bazar. The SLR value can be estimated by using the liner equation according the target year. Therefore, the target year should also be discussed when SLR is considered for setting target storm surge.



Source: Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis, DoE

Figure 2.2.16 Observed trend of tidal water level at Cox's Bazar based on the linear regression analysis over the last 30 years

3) Inundation Analysis for Storm Surge

There are 2 main options for inundation analysis of storm surge in the recommended method. The procedure of each option is described in the following part.

a) Fill level method (FLM)
b) Flood Analysis

a) Fill level method (FLM)

This is a method for evaluating the extent of inundation by assuming that the storm surge level is inundated to land at the same level after setting the target water level. The data required by this method are DEM in addition to the storm surge level at the coast. Since this method is a level flooding method, and the flooded water level is fixed and the flooded area is evaluated without considering the water level change as the flooded water is inundated to the land area. It is a method that can evaluate only the largest flooded area. However, it can consider the difference in inundation depth at each grid of DEM by using the detailed DEM. In addition to this, there is an advantage that the inundation range can be displayed instantaneously when the water level is set because the calculation time is unnecessary. It is impossible to evaluate the inundation situation in time series and the inundation time, and it is also impossible to evaluate the extent of inundation with structural measures because structural data cannot be considered. Since this method is very simple, it is still used in the cost benefit analysis of coastal projects in Japan at present (see "Cost benefit analysis guideline for coastal projects [revised edition] July, 2004"). Since the method does not directly calculate inundation area and consider the influences of topography, it is inferior to the method described later in terms of scientific basis, but it is judged that a certain degree of accuracy can be expected.

b) Flood Analysis

The detailed method of storm surge inundation is to carry out inundation calculation. This method is shown in Japan's "Guide to Creation of Inundation Assumed Areas for Storm Surge". The required data include topographic data, land use data, and structural data. Considering the existence of the structure and its height, this method can consider the start of flooding, and can evaluate the time-series development of flooding. Therefore, the change of inundation range and inundation depth considering types, location, heights, etc. of structural countermeasures can be evaluated. This method is considered to be superior in scientific reliability and grounds to the other method. Since direct numerical analysis is carried out, analytical modeling and verification of this method require high-level engineers and reliable data.

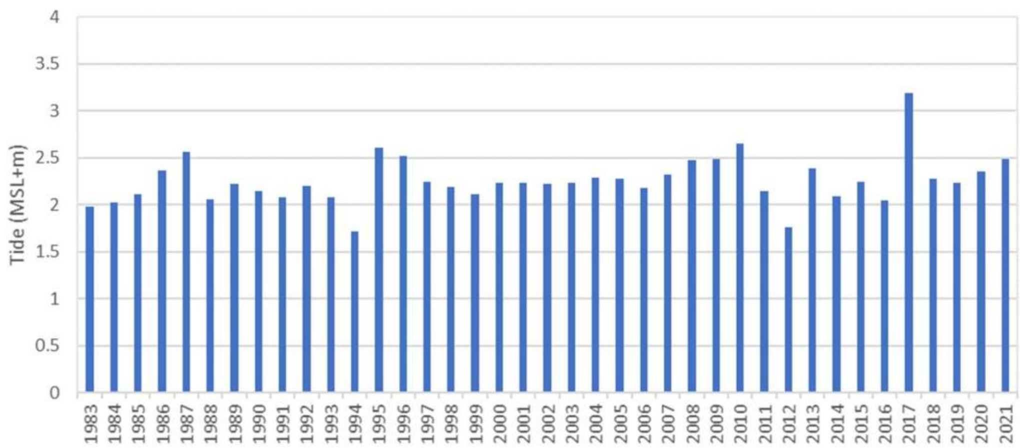
2.2.3. Sample Output of Costal Disasters Analysis

The following section explains the sample output of coastal disaster analysis at Cox's Bazar, especially Cox' Bazar Sadar and Chakaria Upazilas.

2.2.3.1. Collection of Basic Data & Setting Target Storm Surge

1) Tide Observation Data

The tide observation data was obtained from the related organizations at Cox's Bazar. The annual maximum tide in Cox's Bazar was selected as shown in Figure 2.2.17.



Source: JICA Expert Team

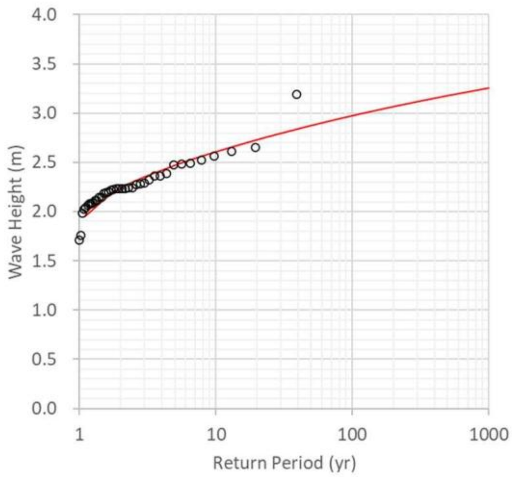
Figure 2.2.17 Annual maximum tide in Cox's Bazar

Based on <u>the series of annual maximum tide from historical observations</u>, the probabilistic analysis based on was conducted. The results shown in Table 2.2.7 and Figure 2.2.18. As the target level of storm surge, the 20 year return period of tide is selected.

Table 2.2.7 Results of probability analysis of the historical tide observation data in Cox's Bazar

No.	Case		Water Level (M.S.L.+m)	
1	Historical maximum tide		3.193	3.2
2	Provability water level	10-yr	2.61	2.6
3	Provability water level	20-yr	2.73	2.7
4	Provability water level	25-yr	2.77	2.8
5	Provability water level	30yr	2.80	2.8
6	Provability water level	50-yr	2.87	2.9
7	Provability water level	100-yr	2.97	3.0

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2.2.18 Probability Analysis of Annual Maximum Tide in Cox's Bazar

<Reference of the result of the Matarbari port project >

The Matarbari port project conducted storm surge numerical analysis for getting storm surge height which can be used for storm surge analysis in Cox's Bazar district shown in Table 2.2.8.

Table 2.2.8 List of historical storm surge in the past for the Matarbari port area

Year	Category	Duration	Maximum Height in Matarbari (m)
1991	5	1991/04/24 18:00 ~ 1991/04/30 18:00	5.9062
1994	2	1994/04/29 0:00 ~ 1994/05/02 18:00	0.3096
1995	8	1995/11/21 12:00 ~ 1995/11/25 9:00	0.1944
1997	7	1997/09/23 3:00 ~ 1997/09/27 12:00	1.0546
1997	1	1997/05/15 6:00 ~ 1997/05/19 12:00	0.9787
2002	3	2002/11/09 18:00 ~ 2002/11/12 12:00	0.1438
2003	1	2003/05/08 12:00 ~ 2003/05/19 18:00	0.0054
2004	2	2004/05/14 18:00 ~ 2004/05/19 18:00	0.0313
2005	3	2005/10/01 6:00 ~ 2005/10/03 6:00	0.0549
2007	6	2007/11/10 6:00 ~ 2007/11/16 0:00	1.2689
2009	1	2009/04/14 0:00 ~ 2009/04/18 0:00	0.5589
2009	2	2009/05/22 18:00 ~ 2009/05/26 6:00	0.1353
2009	3	2009/09/03 18:00 ~ 2009/09/07 0:00	0.0373
2011	2	2011/10/17 0:00 ~ 2011/10/19 18:00	0.1191
2013	1	2013/05/09 18:00 ~ 2013/05/16 12:00	0.6666

Source: Data Collection Survey on the Matarbari Port Development in People's Republic of Bangladesh, JICA

Table 2.2.9 summarized the probability water level with from 10-year to 100-year and historical maximum tide in Matarbari. Total water level can be estimated by probability water level of surge height with H.W.L.

In order to consider the climate change effect, SLR will be added to the probability water levels. Based on the result of Figure 2.2.17, the annual maximum water level in Cox's Bazar is increasing as 24 mm/yr. If the target year is applied as 25 years, each water level should be added to 0.6 m (= 24 mm/yr. * 25 years). Table 2.2.9 also shows the probability water levels and historical maximum tide with 25-year SLR.

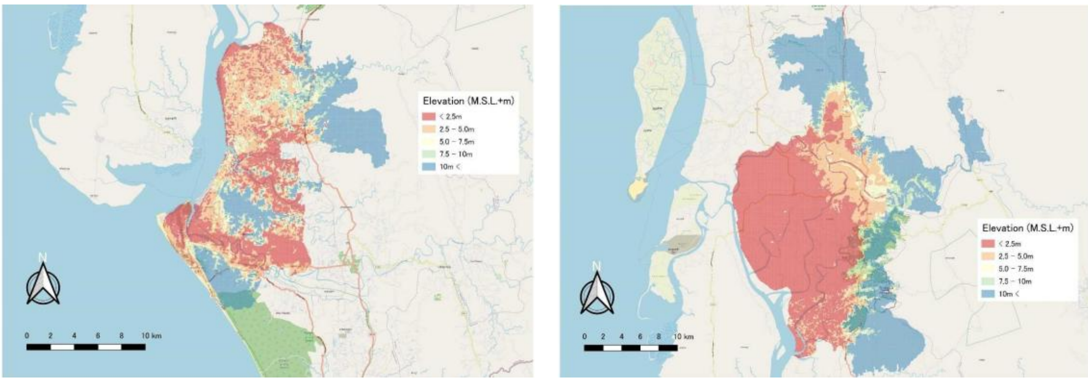
Table 2.2.9 List of Target Storm Surge with historical maximum tide and several probability water level with considering 25-year SLR

No.	Case		Surge height (m)	H.W.L. (M.S.L.+m)	Wave set-up (m)	SLR (m)	Total (M.S.L.+m)
1	Historical maximum tide		5.9062	2.2	0.5	0.6	9.2
2	Provability water level	10-yr	1.58	2.2	0.5	0.6	4.9
3	Provability water level	20-yr	2.59	2.2	0.5	0.6	5.9
4	Provability water level	25-yr	2.98	2.2	0.5	0.6	6.3
5	Provability water level	30yr	3.32	2.2	0.5	0.6	6.6
6	Provability water level	50-yr	4.41	2.2	0.5	0.6	7.7
7	Provability water level	100-yr	6.29	2.2	0.5	0.6	9.6

Source: Data Collection Survey on the Matarbari Port Development in People's Republic of Bangladesh, JICA

2) Digital Elevation Model

Digital Elevation Model (DEM) is shown in Figure 2.2.19 for Cox's Bazar Sadar and Chakaria Upazilas, respectively.

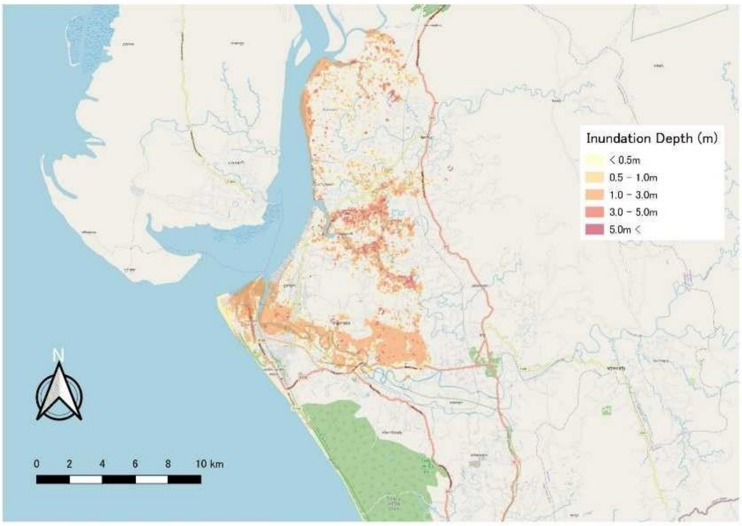


Source: JICA Expert Team

Figure 2.2.19 Digital Elevation Model in Cox's Bazar Sadar & Chakaria

a. **Cox's Bazar Sadar**

Using fill level method, the storm surge inundation area is estimated in Cox's Bazar Sadar. The 20-year probability water level case is shown in Figure 2.2.20 as a sample. Other cases of inundation area are described in Figure 2.2.22 including the historical maximum tide case.



Source: JICA Expert Team

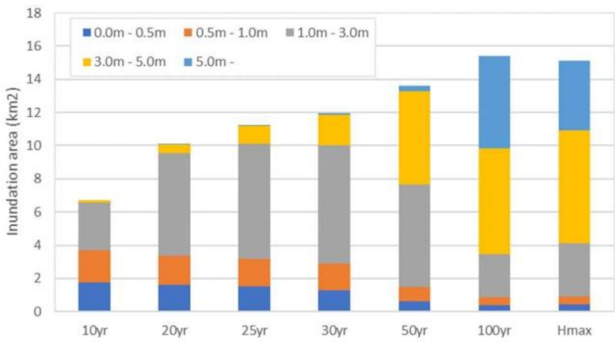
Figure 2.2.20 Inundation depth distribution map with 20-year probability water level in Cox's Bazar Sadar

Inundation area for each probability water level is estimated by using the results of inundation map. Table 2.2.10 and Figure 2.2.21 show the inundation area with inundation depths.

Table 2.2.10 Inundation area with probability water levels by inundation depths

Inundation depth	Inundation area (km2)						
	10yr	20yr	25yr	30yr	50yr	100yr	Hmax
0.0m - 0.5m	1.78	1.62	1.52	1.29	0.65	0.40	0.43
0.5m - 1.0m	1.90	1.74	1.63	1.58	0.83	0.44	0.50
1.0m - 3.0m	2.89	6.20	6.97	7.13	6.18	2.63	3.21
3.0m - 5.0m	0.13	0.49	1.09	1.87	5.61	6.36	6.79
5.0m -	-	0.00	0.04	0.08	0.36	5.58	4.18
Total	6.70	10.06	11.24	11.95	13.62	15.41	15.11

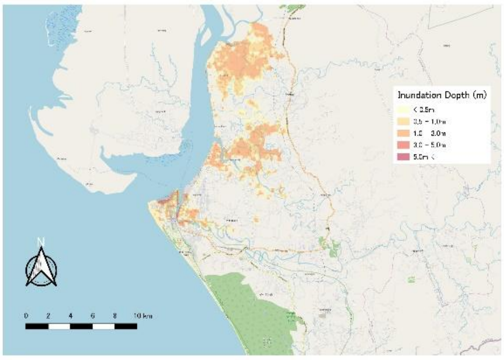
Source: JICA Expert Team



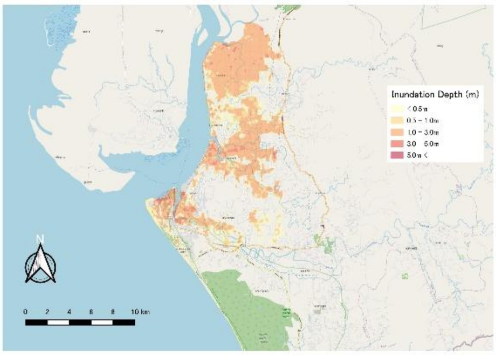
Source: JICA Expert Team

Figure 2.2.21 Inundation area in Cox's Bazar Sadar with different probability water level.

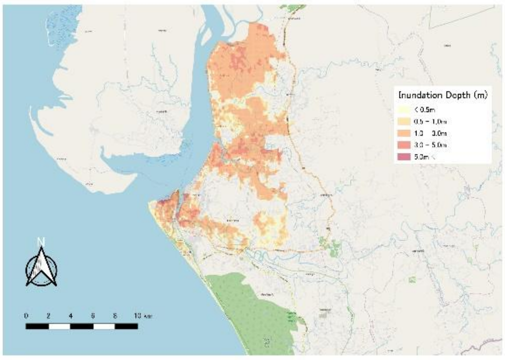
(a) 10 yrs.



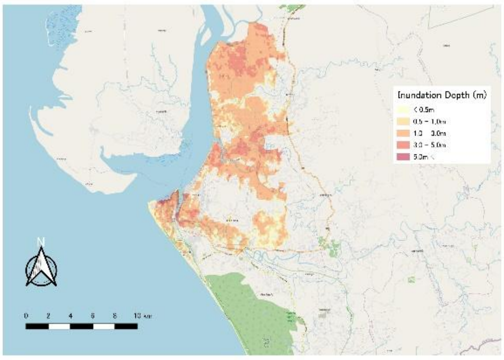
(b) 20 yrs.



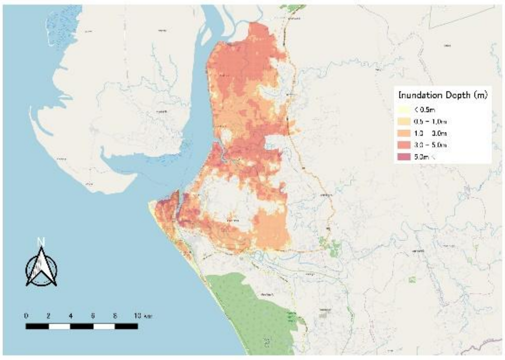
(c) 25 yrs.



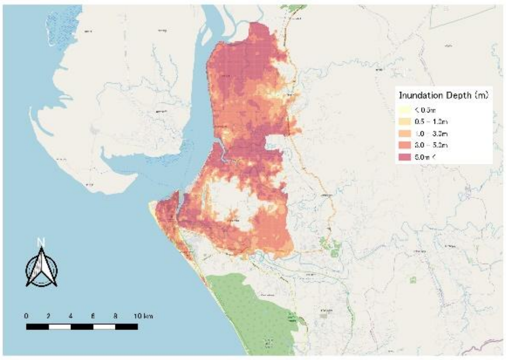
(d) 30 yrs.



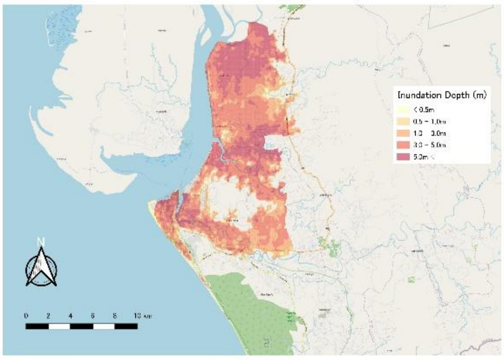
(e) 50 yrs.



(f) 100 yrs.



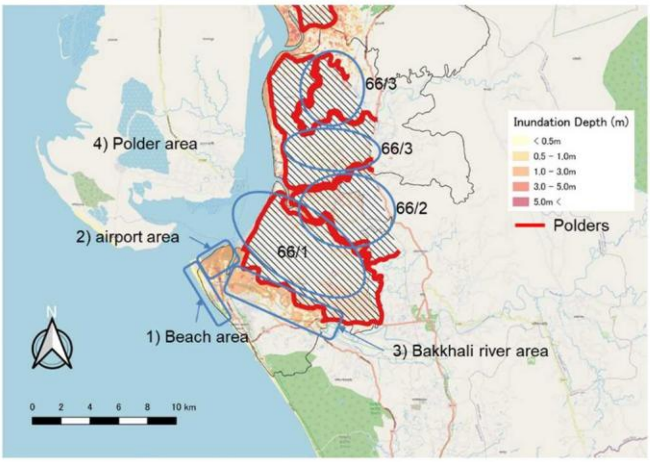
(g) Historical Maximum



Source: JICA Expert Team

Figure 2.2.22 Inundation depth distribution maps with several probability water levels in Cox's Bazar Sadar

This area has several polders as shown in Figure 2.2.23, although the inundation area does not consider the effect of polders. Under the circumstances, the next mitigation measures should be considered in Local DRR plan in this area.



Source: JICA Expert Team

Figure 2.2.23 Polders and possible countermeasures in Cox's Bazar Sadar

There is a project which is under study by BWDB shown in Table 2.2.11. Based on the inundation map, only the project is not enough for prevention of inundation in Cox's Bazar. Therefore, the additional possible countermeasures should be considered such as countermeasures shown in Table 2.2.12.

Table 2.2.11 Countermeasures under study in Cox's Bazar

No	Example of Countermeasures	Implementing agency	Remarks/Concerns
1	Beach Protection for storm surge and coastal erosion (8.72 km = 2.0km + 3.11km + 2.49km + 1.12km)	BWDB	It is small Collaboration with Tourism

Source: JICA Expert Team

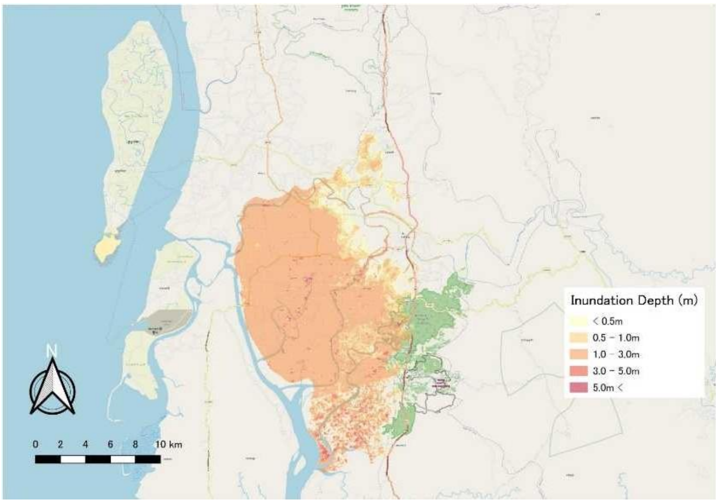
Table 2.2.12 Possible Countermeasures in Cox's Bazar

No	Area	Possible Countermeasures	Remarks/Concerns
1	Beach Area	Beach Protection for storm surge and coastal erosion	Collaboration with Tourism
2	Airport Area	Alt.-1: Protection (ex. Dike, revetment, seawall…)	Consultation with Fishery activities?
		Alt.-2: Protection with the airport expansion plan	Relocation?
		Alt.-3: Evacuation measures (ex. Shelters, drills…)	No structural measures
3	Bakkhali River Left Bank Area	Protection (ex. River dike or flood wall…)	Consideration of River flood measures
4	Polder Area	Maintenance or Enhancement of polders	

Source: JICA Expert Team

b. **Chakaria**

Using fill level method, the storm surge inundation area is estimated in Chakaria. The 20-year probability water level case is shown in Figure 2.2.24 as a sample. Other cases of inundation area are described in Figure 2.2.26 including the historical maximum tide case.



Source: JICA Expert Team

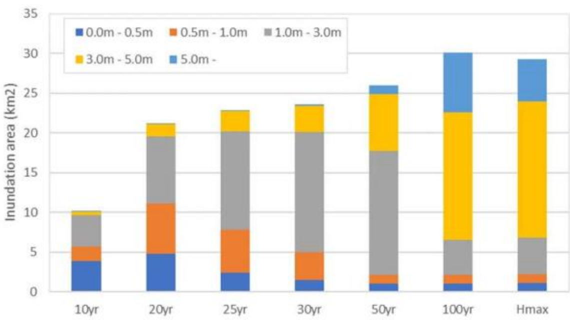
Figure 2.2.24 Inundation depth distribution map with 20-year probability water level in Chakaria

Inundation area for each probability water level is estimated by using the results of inundation map. Table 2.2.13 and Figure 2.2.25 show the inundation area with inundation depths.

Table 2.2.13 Inundation area with probability water levels by inundation depths

Inundation depth	Inundation area (km2)						
	10yr	20yr	25yr	30yr	50yr	100yr	Hmax
0.0m - 0.5m	3.82	4.79	2.37	1.45	0.96	1.03	1.06
0.5m - 1.0m	1.91	6.28	5.46	3.50	1.18	1.08	1.15
1.0m - 3.0m	3.95	8.53	12.39	15.15	15.62	4.36	4.54
3.0m - 5.0m	0.38	1.49	2.52	3.28	7.08	16.12	17.17
5.0m -	0.02	0.06	0.11	0.23	1.14	7.50	5.37
Total	10.08	21.15	22.85	23.62	25.99	30.09	29.29

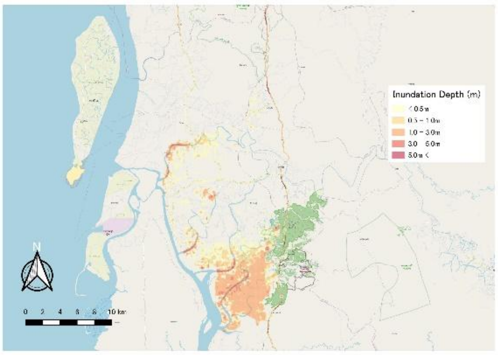
Source: JICA Expert Team



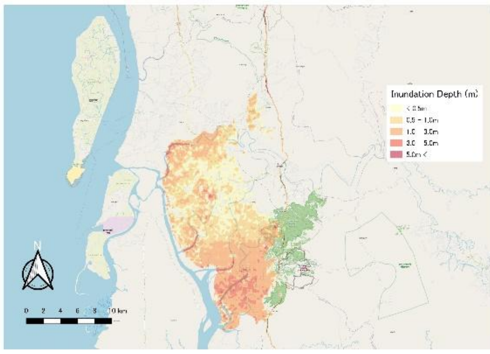
Source: JICA Expert Team

Figure 2.2.25 Inundation area in Chakaria with different probability water level.

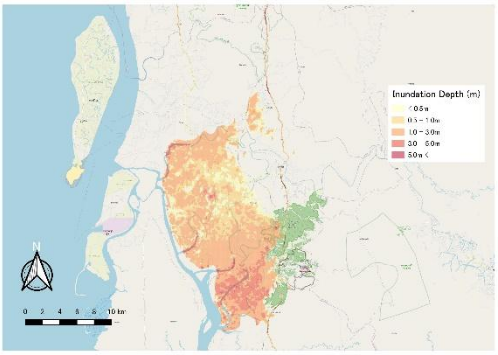
(a) 10 yrs.



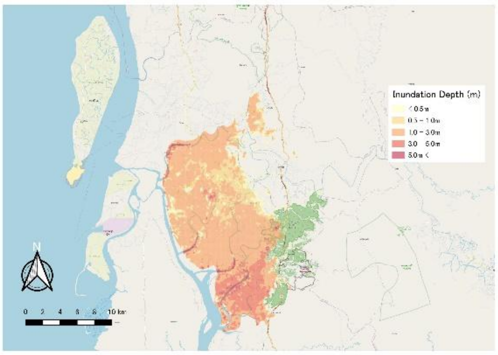
(b) 20 yrs.



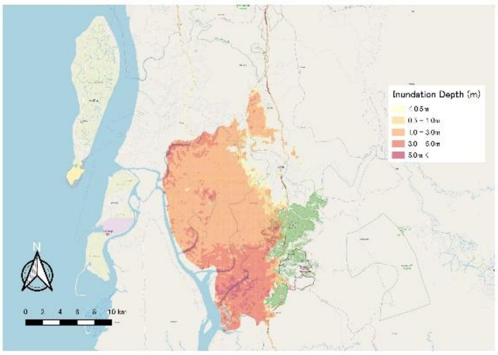
(c) 25 yrs.



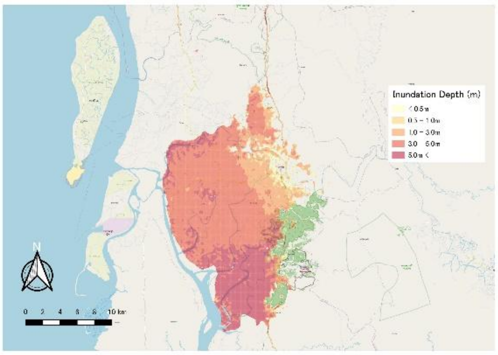
(d) 30 yrs.



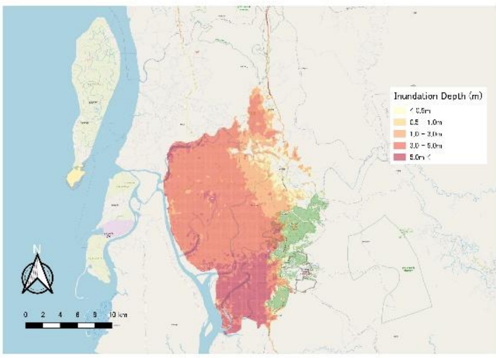
(e) 50 yrs.



(f) 100 yrs.



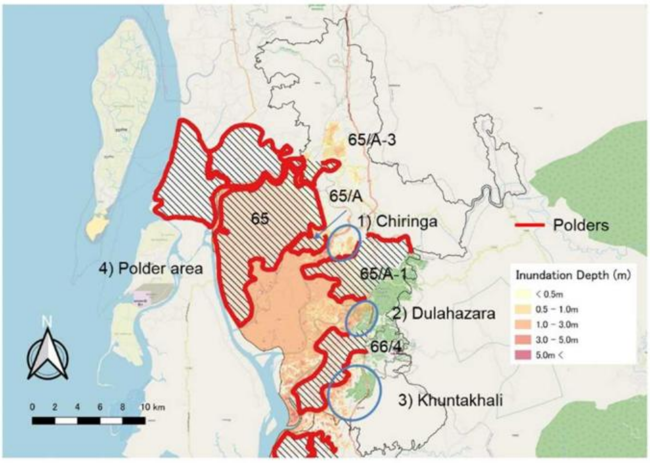
(g) Historical Maximum



Source: JICA Expert Team

Figure 2.2.26 Inundation depth distribution map with several probability water levels in Chakaria

This area has several polders as shown in Figure 2.2.27, although the inundation area does not consider the effect of polders. Under the circumstances, the next mitigation measures should be considered in Local DRR plan in this area.



Source: JICA Expert Team

Figure 2.2.27 Polders and possible countermeasures in Chakaria

At the moment, there is no project studied by BWDB. Based on the inundation map, the additional possible countermeasures should be considered such as countermeasures shown in Table 2.2.12 in order to prevent inundation due to storm surge.

Table 2.2.14 Possible Countermeasures in Cox's Bazar

No	Area	Possible Countermeasures	Remarks/Concerns
1	Chiringa	Protection (ex. dike…)	Connection to Railway basement
2	Dulahazara	Protection (ex. dike…)	Connection to Railway basement
3	Khuntakhali	Protection (ex. dike…)	Connection to Railway basement
4	Polder Area	Maintenance or Enhancement of polders	

Source: JICA Expert Team

2.2.4. Risk Assessment on Coastal Disasters

2.2.4.1. Concept of Risk Assessment on Coastal Disasters

The risk assessment on coastal disasters aims to comprehend the exposure, vulnerability and capacity against coastal hazard in the upazila. The goal of the assessment is to obtain the distribution of quantitative data showing how much the areas are affected by the coastal hazard.

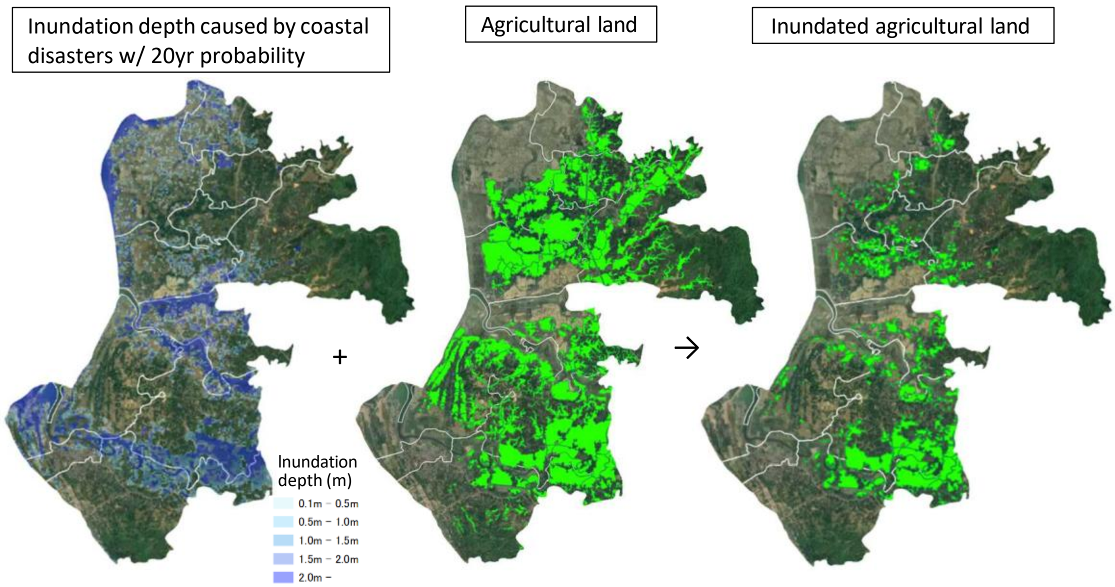
Similar to the risk assessment on the flood, there might be some existing coastal disaster hazard analysis and coastal disaster risk assessment results conducted by some organizations Hence, those study results should be collected at first and utilized to compile the UzDRRAP. If those results could not be found, or are not enough, the risk assessment is required.

2.2.4.2. Risk Assessment Flow

Basically, the same flow is utilized for the risk assessment on the coastal disasters with the one on flood.

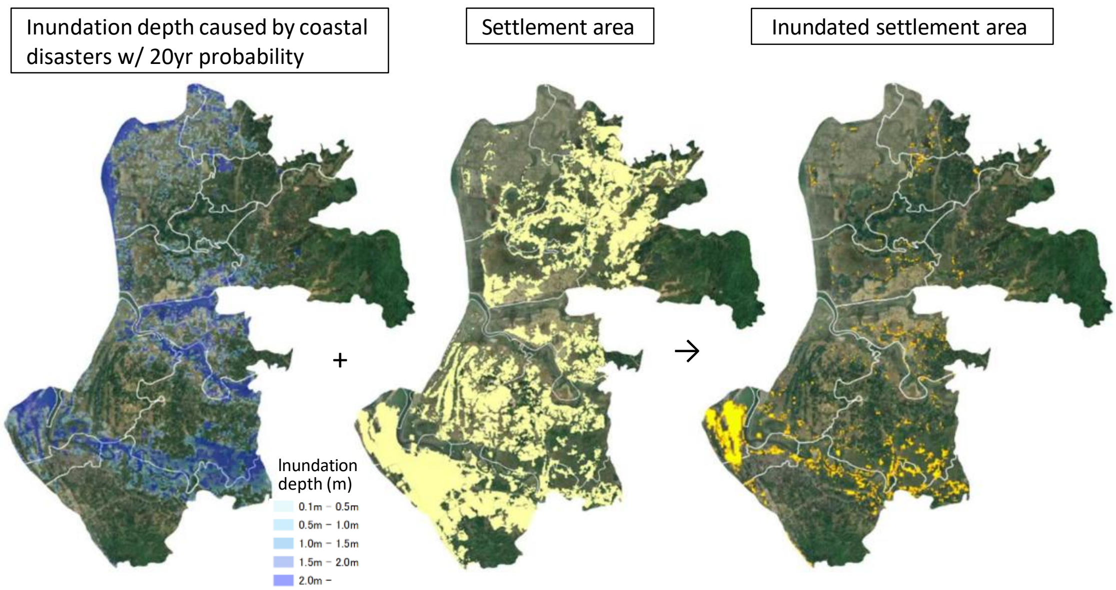
2.2.4.3. Examples of the Risk Assessment on Coastal Disasters

As examples, the process and the results of the assessment in the Cox's Bazar Upazila is shown in the following figures. As indexes of the risk assessment, inundated agricultural land area, inundated settlement area and affected (inundated) population were selected.



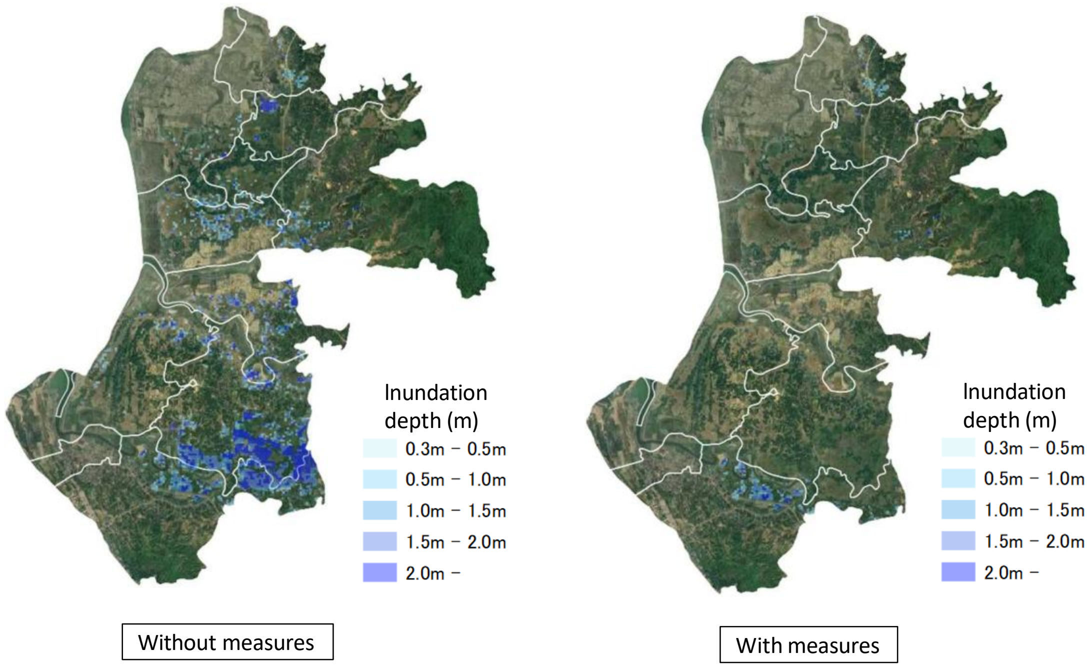
Source: JICA Expert Team

Figure 2.2.28 Risk assessment on coastal disasters for agricultural land area in Cox's Bazar Sadar Upazila



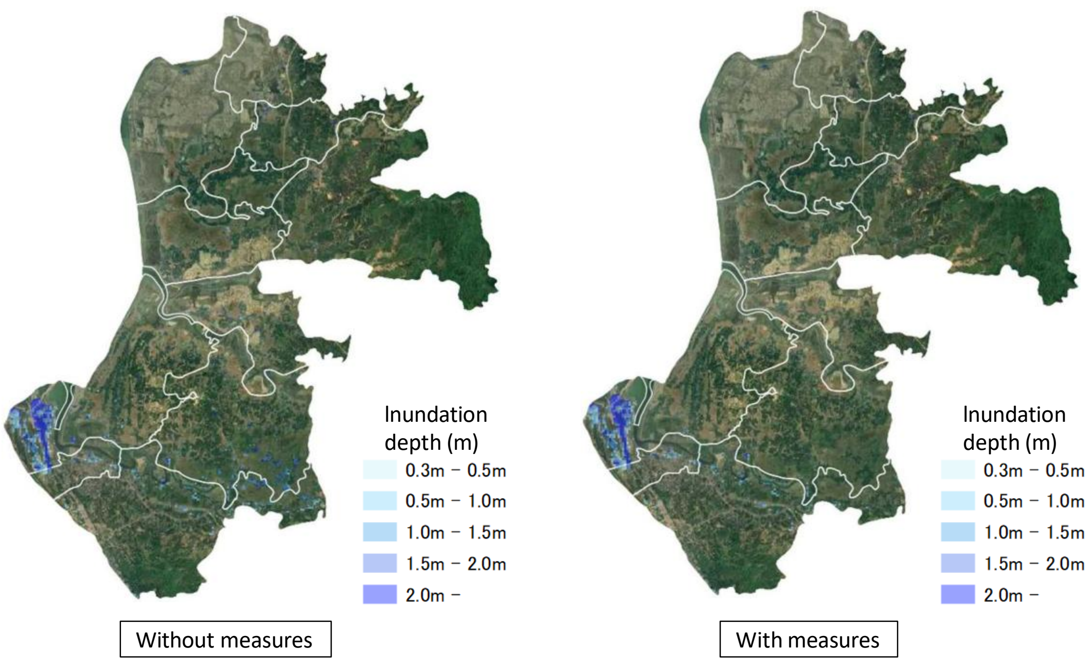
Source: JICA Expert Team

Figure 2.2.29 Risk assessment on flood for settlement area and population in Cox's Bazar Sadar Upazila



Source: JICA Expert Team

Figure 2.2.30 Example of affected agricultural land area with and without measures against coastal disasters in Cox's Bazar Sadar Upazila



Source: JICA Expert Team

Figure 2.2.31 Example of affected settlement area with and without measures against coastal disasters in Cox's Bazar Sadar Upazila

Table 2.2.15 Example of affected agricultural land area with and without measures against coastal disasters in Cox's Bazar Sadar Upazila

(unit: ha)

	Measure	0.3m≦x <0.5m	0.5m≦ x<1m	1m≦ x<1.5m	1.5m≦ x<2m	2m≦ x<5m	5≦x	Total
Bharuakhali	Without	18.7	41.6	44.1	35.5	53.6	1.0	**194.4**
	With	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Chaufaldandi	Without	35.1	68.8	38.8	16.2	11.6	0.0	**170.5**
	With	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Cox's Bazar Paurashava	Without	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	With	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Idgaon	Without	16.2	26.7	24.8	13.3	9.0	2.4	**92.4**
	With	5.1	3.1	4.3	1.4	3.0	2.8	**19.6**
Islamabad	Without	2.4	1.7	2.5	4.0	12.3	16.2	**39.0**
	With	0.0	0.6	0.3	0.0	1.0	1.5	**3.5**
Islampur	Without	10.5	15.2	6.8	2.9	0.8	0.0	**36.1**
	With	5.8	10.5	15.2	6.8	2.9	0.8	**41.9**
Jalalabad	Without	9.1	11.7	3.6	0.7	1.9	0.2	**27.1**
	With	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Jhilwanja	Without	24.5	63.9	91.4	117.9	102.9	4.4	**405.1**
	With	13.3	15.6	46.0	44.8	31.1	21.5	**172.4**
Khurushkul	Without	21.0	31.2	21.1	10.8	14.4	0.0	**98.5**
	With	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Patali Machhuakhali	Without	0.0	0.0	0.0	156.0	266.1	15.8	**437.9**
	With	0.1	0.0	1.3	1.3	0.7	0.2	**3.8**
Pokkhali	Without	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
	With	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**

Note: Assuming all of the polder are maintained well.

Source: JICA Expert Team

Table 2.2.16 Example of affected settlement area with and without measures against coastal disasters in Cox's Bazar Sadar Upazila

(unit: ha)

	Measure	0.3m≦x <0.5m	0.5m≦ x<1m	1m≦ x<1.5m	1.5m≦ x<2m	2m≦ x<5m	5≦x	Total
Bharuakhali	Without	3.6	5.0	5.7	2.6	3.3	0.0	**20.2**
	With	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Chaufaldandi	Without	1.0	3.6	0.8	0.8	1.0	0.0	**7.1**
	With	0.0	0.3	0.1	0.0	0.0	0.0	**0.3**
Cox's Bazar Paurashava	Without	5.4	10.0	7.2	4.6	2.7	0.0	**30.0**
	With	5.4	10.0	7.2	4.6	2.7	0.0	**30.0**
Idgaon	Without	0.6	1.8	1.0	0.0	0.7	0.0	**4.2**
	With	0.1	0.5	0.3	0.0	0.6	0.0	**1.5**
Islamabad	Without	0.5	1.1	0.1	0.7	2.3	2.8	**7.6**
	With	0.0	0.1	0.0	0.0	0.6	0.5	**1.2**
Islampur	Without	1.1	2.0	1.0	0.4	0.7	0.2	**5.4**
	With	1.0	1.9	0.2	0.4	0.7	0.1	**4.3**
Jalalabad	Without	0.4	0.1	0.0	0.0	0.0	0.0	**0.5**
	With	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Jhilwanja	Without	22.4	36.4	29.0	19.2	5.4	0.8	**113.1**
	With	14.6	25.6	14.2	7.5	3.8	0.3	**66.0**
Khurushkul	Without	21.8	43.9	52.1	51.6	93.9	0.7	**264.1**
	With	17.4	39.6	49.1	50.0	88.5	0.0	**244.7**
Patali Machhuakhali	Without	6.1	15.2	22.6	24.2	16.3	0.9	**85.3**
	With	0.7	2.4	1.3	0.8	2.2	0.0	**7.4**
Pokkhali	Without	1.0	0.9	1.0	0.3	1.9	0.1	**5.3**
	With	0.0	0.0	0.0	0.0	1.2	0.0	**1.2**

Note: Assuming all of the polder are maintained well.

Source: JICA Expert Team

Table 2.2.17 Example of affected population with and without measures against coastal disasters in Cox's Bazar Sadar Upazila

(unit: pp)

	Measure	0.3m≦x <0.5m	0.5m≦ x<1m	1m≦ x<1.5m	1.5m≦ x<2m	2m≦ x<5m	5≦x	Total
Bharuakhali	Without	266	368	423	189	245	3	**1,494**
	With	0	0	0	0	0	0	**0**
Chaufaldandi	Without	90	335	77	73	92	0	**667**
	With	0	24	6	0	2	0	**32**
Cox's Bazar Paurashava	Without	3,507	6,491	4,680	2,979	1,783	0	**19,440**
	With	3507	6486	4680	2979	1783	0	**19,435**
Idgaon	Without	34	96	53	0	35	0	**218**
	With	5	26	16	0	32	0	**79**
Islamabad	Without	29	70	4	46	145	176	**470**
	With	0	5	0	0	35	33	**73**
Islampur	Without	121	212	104	40	71	21	**569**
	With	110	204	17	40	71	14	**456**
Jalalabad	Without	35	7	0	0	0	0	**42**
	With	0	0	0	0	0	0	**0**
Jhilwanja	Without	682	1,111	884	587	163	25	**3,452**
	With	445.0	780.0	434.0	229.0	117.0	9.0	**2,014**
Khurushkul	Without	916	1,841	2,188	2,166	3,939	30	**11,080**
	With	730.0	1,662.0	2,062.0	2,098.0	3,715.0	1.0	**10,268**
Patali Machhuakhali	Without	291	726	1,075	1,151	774	44	**4,061**
	With	32.0	116.0	63.0	39.0	103.0	0.0	**353**
Pokkhali	Without	108	99	110	35	206	8	**566**
	With	0.0	0.0	3.0	0.0	125.0	1.0	**129**

Note: Assuming all of the polder are maintained well.

Source: JICA Expert Team

2.3. Sediment Disasters (Slope Failure)

Sediment disasters are defined as the phenomena that cause direct or indirect damage to the lives and properties of people, inconvenience to the life of people, and/or the deterioration of the environment, through a large-scale movement of soil and rock.

Damage due to these disasters occurs in several forms: 1) the ground on which buildings and farmland are situated are lost due to a landslide or an erosion; 2) houses are ruined by the destructive force of soil and rock during their movement; 3) houses and farmland are buried underground by a large-scale accumulation of discharged sediment; and 4) aggradation of a riverbed and burial of a reservoir are caused by sediment discharge along a river system, which may invoke flooding, disorder of water use functions, and deterioration of the environment.

Sediment disasters are roughly categorized into two types: 1) Direct Type Sediment Disasters: cause direct damage as a result of sediment movement; 2) Indirect Type Sediment Disasters: cause a flood or an inundation through the aggradation of a riverbed or blocking of a river course.

Indirect type sedimented disasters are not the subject of the present guideline. And phenomena that cause direct type sediment disasters include debris flows, slope failures, and landslides.

Table 2.3.1 shows the direct type sediment disasters. And sedimented disaster subject of the guideline is **<u>slope failure.</u>**

Table 2.3.1 Phenomena that cause direct type sediment disasters

Debris flow	Slope failure	Landslide
Phenomenon in which soil and rock on the hillside or in the riverbed are carried downward at a dash under the influence of a continuous rain or a torrential rain. Although the flow velocity differs by the scale of debris flow, it sometimes reaches 20-40 km/hr., thereby destroying houses and farmland in an instant.	Phenomenon in which slope abruptly collapses when the soil that has already been weakened by moisture in the ground loses its self-retain ability under the influence of a rain or an earthquake. Because of collapse, many people fail to escape from it if it occurs near a residential area, thus leading to a higher rate of fatalities.	Phenomenon in which a part of or all the soil on a slope moves downward slowly under the influence of groundwater and gravity. Since a large amount of soil mass usually moves, a serious damage can occur. If a slide has been started, it is extremely difficult to stop it.
		

2.3.1. Current Status of Sediment Disasters in Bangladesh

Landslides have become a recent phenomenon due to rapid hill cutting in the south-eastern part of the country. In most of the cases, these landslides are rain inductive and cause damage to life and property in its vicinity.

Table 2.3.2 Past major landslide events

Date	Location	
July 1997*[1]	Charaipada of Bandarban	Affected area: 90,000m^2
11/Aug/1999*[1]	Bandarban	Total no. of deaths: 7
13/Aug/1999*[1]	Chattogram	Total no. of deaths: 10
11/Jun/2007*[1]	Chattogram	Total no. of deaths: over 120 Total no. of families affected: 1,962 Direct losses: USD 13.2 million (SAARC, 2007)
16/Aug/2008*[2]	Chattogram city	Total no. of deaths: 13 Total no. of affected: 50
15/Jun/2010*[2]	Cox's Bazar and Bandarban districts	Total no. of deaths: 66 Total no. of affected: 55,230
4/Jul/2011*[2]	Chattogram city	Total no. of deaths: 17
June 2012*[1]	Chattogram, Cox's Bazar and Bandarban districts	Total no of deaths: 122 (Chattogram: 37, Cox's Bazar: 47 and Bandarban: 38)
18/Jul/2015*[2]	Lalkhan Bazar area	Total no. of deaths: 3 Total no of affected: 1,003
14/Jun/2017*[2]	Chattogram (Teknaf, Rangunia, Chandanaish), Rangamati, Bandarban, Cox's Bazar, Khagrachari	Total no. of deaths: 160 Total no of affected: 80,187
8/Jul/2019*[2]	Cox's Bazar	Total no. of deaths: 2 Total no of affected: 18,016

*1: Multi-Hazard Risk and Vulnerability Assessments, Modeling and Mapping in Bangladesh (MRVAM), DDM, 2016

*2: EM-DAT

Landslides are a complex-disaster phenomenon that can be caused by earthquakes, volcanic eruptions, heavy rainfall (typhoons, hurricanes), sustained rainfall, heavy snowmelt, unregulated anthropogenic developments, mining, and other factors. In Bangladesh, landslides are mostly triggered by heavy rainfall. However, underlying causes of landslides include deforestation, hill cutting, unregulated development work, etc. Moreover, poverty and landlessness force poor people to live on the risky hill-slopes.

2.3.2. Recommended methods of Sediment Disasters Analysis for UzDRRAP

1) Concept of the Recommended Sediment Disaster Analysis

A nationwide landslide hazard assessment maps was developed in 2016 by Department of Disaster Management (DDM) through the Multi Hazard Risk and Vulnerability Assessment, Modeling and Mapping in Bangladesh Project (MRVAM). However, this guideline proposes a simple method for hazard zoning calculated based only on the topographic information, facilitating Upazila planning officers to analyze the site-specific susceptibility of slope failure and help development planning of the correspondent Upazila.

2) Overall Calculation Methods for Calculation of Slope Failure Hazard Levels

The overall flow for calculation of hazard levels based only on the topographical information is shown in Figure 2.3.1.

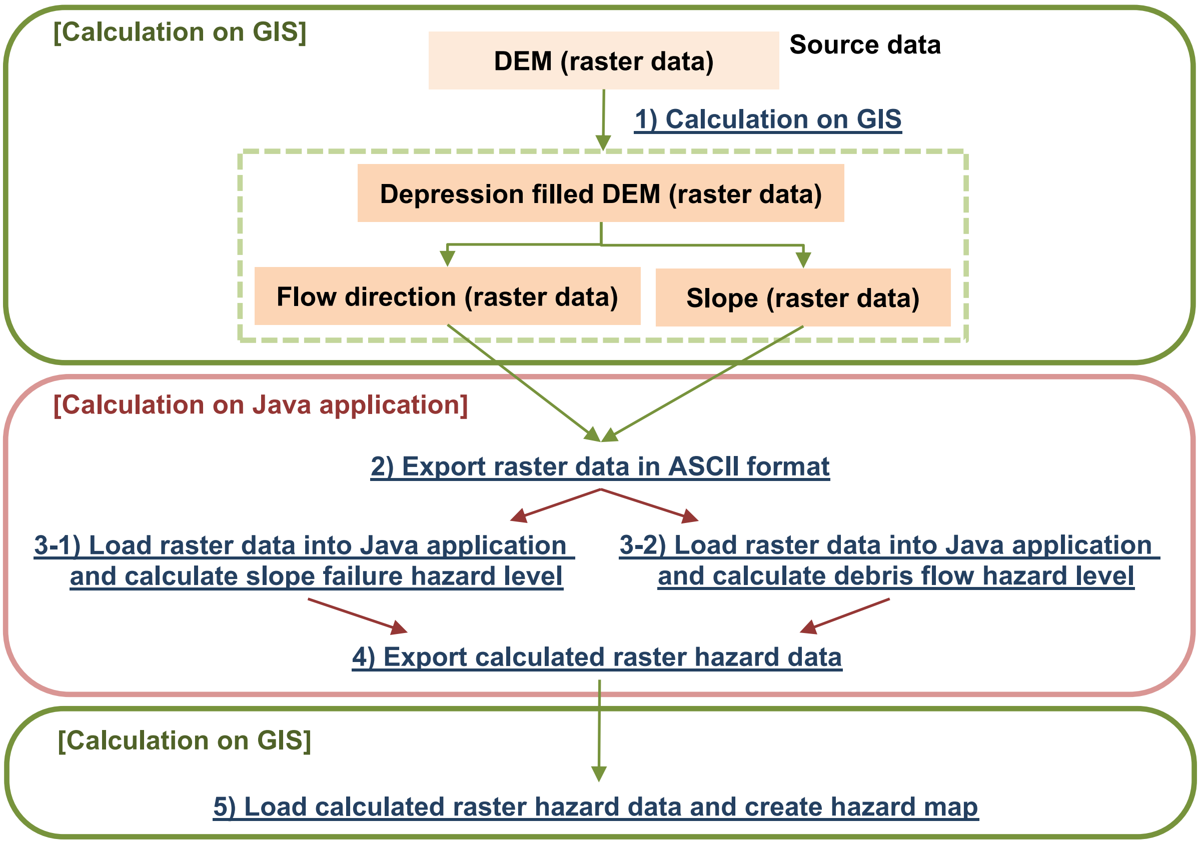


Figure 2.3.1 Overall flow of hazard level calculation

3) Required Data

- Elevation data: Digital elevation model (DEM) of the target area such as SRTM, AW3D, etc.
- Base map data: 1:25,000 topographic map (Survey of Bangladesh), Google Map,

OpenStreetMap, etc.

4) Software

- GIS software (ArcGIS or Qgis)
- JAVA application (developed to calculate hazard zoning)

5) Algorithm

The algorithm for slope failure hazard zoning is based on the concept of "yellow zone" and "red zone", adopted in Japan.

<Hazard Yellow Zone>

Area susceptible to slope failure, called as "Yellow Zone" for brevity. The resistance capacity of normal buildings in Yellow Zone is expected to be larger than force acting on buildings due to the moving debris and earth of landslides.

<Hazard Red Zone>

Area where there is a high risk of damage to buildings and threat to people due to landslide and called as "Red Zone" for brevity. The force acting on buildings due to the moving debris and earth of landslides in Red Zone is expected to be larger than the resistance capacity of normal buildings. Therefore, normal buildings in the Red Zone would be completely destroyed by the moving debris and earth of landslides.

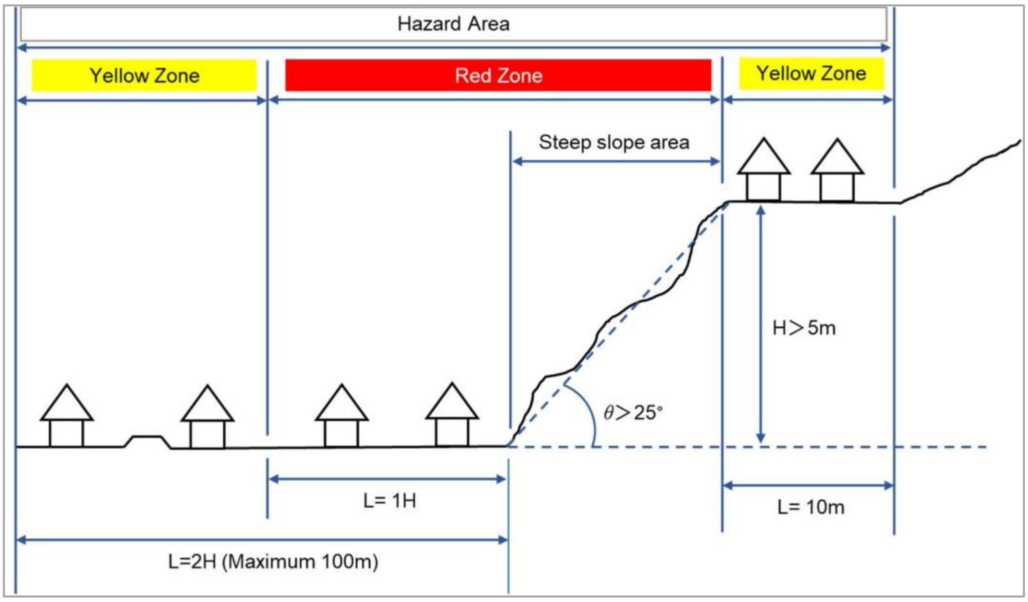


Figure 2.3.2 Concept of slope failure hazard zoning

2.3.3. Sample Output of Sediment Disasters Analysis

Figure 2.3.3 shows the DEM for Chakaria Upazila and Cox's Bazar Sadar created by processing elevation data (e.g. SpotP and ContourL shapefile data) of the 1/25,000 digital topographic map of SOB. For convenience, hilly area was utilized.

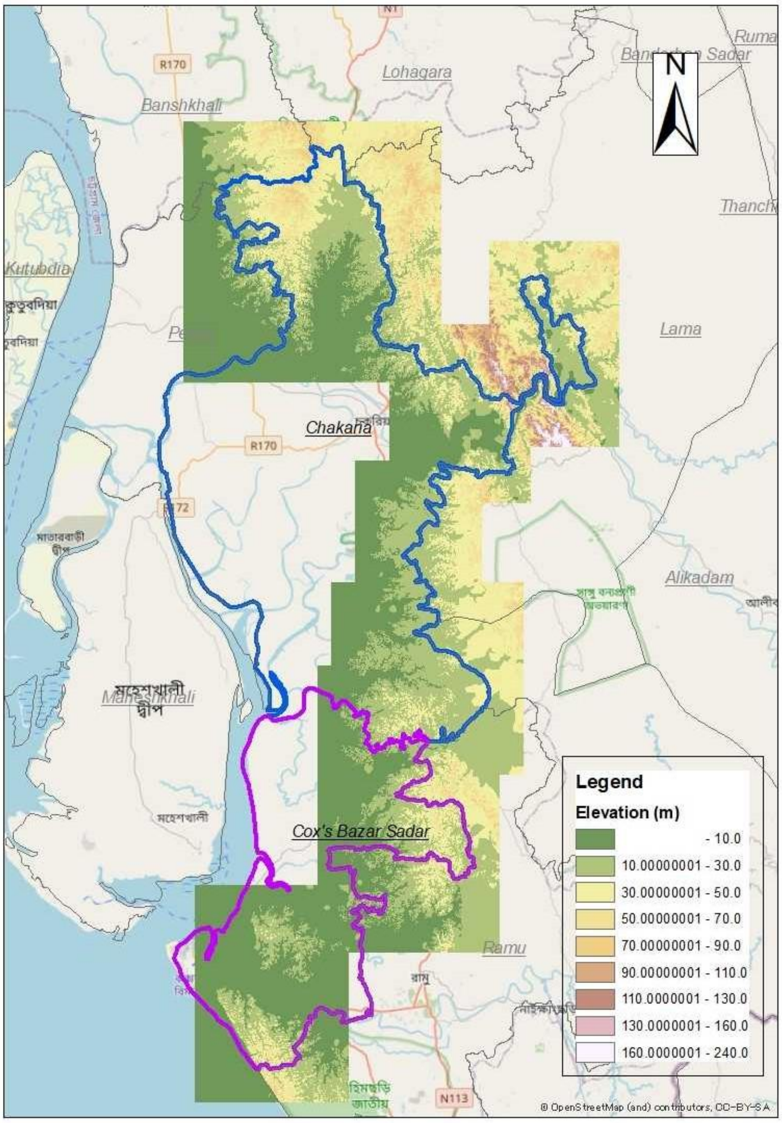


Figure 2.3.3 DEM utilized for calculation of hazard zoning

1) Slope failure hazard zoning

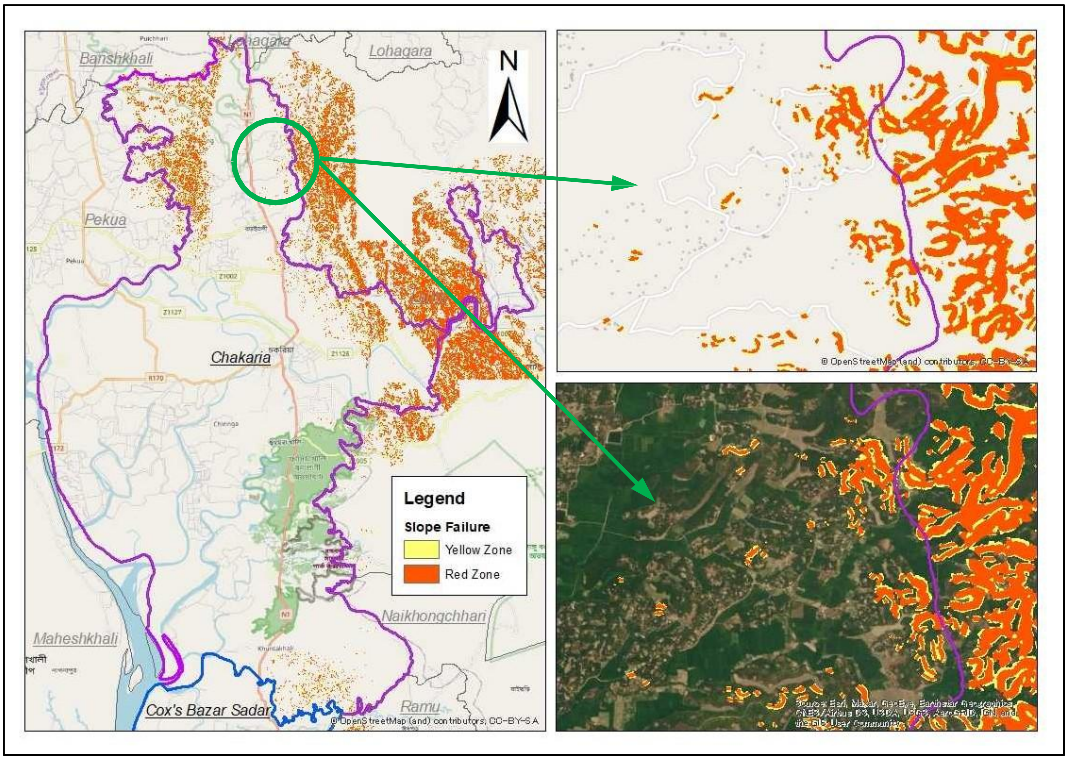


Figure 2.3.4 Result of Slope Failure Hazard Zoning of Chakaria Upazila

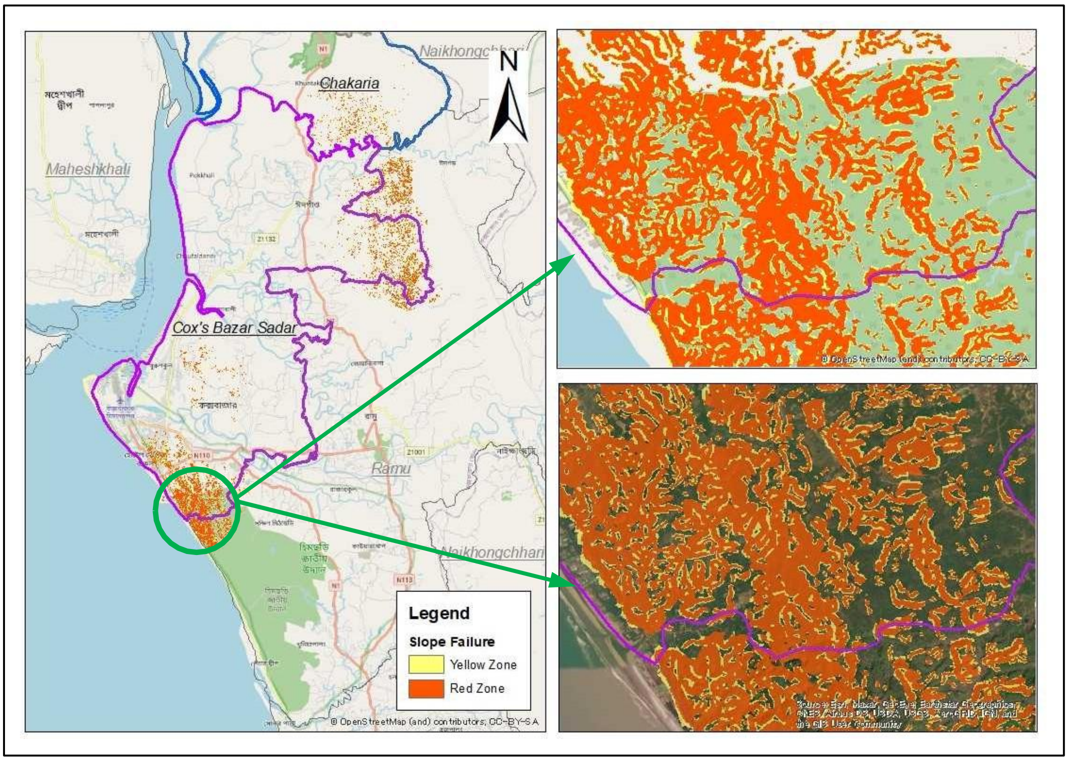


Figure 2.3.5 Result of Slope Failure Hazard Zoning of Cox's Bazar Sadar Upazila

2.3.4. Risk Assessment on Sediment Disasters

2.3.4.1. Concept of Risk Assessment on Sediment Disasters

The risk assessment on sediment disasters aims to comprehend the exposure, vulnerability and capacity against sediment hazard in the upazila. The goal of the assessment is to obtain the distribution of quantitative data showing how much the areas are affected by the sediment hazard.

Similar to the risk assessment on the flood, there might be some existing coastal disaster hazard analysis and sediment disaster risk assessment results conducted by some organizations Hence, those study results should be collected at first and utilized to compile the UzDRRAP. If those results could not be found, or are not enough, the risk assessment is required.

2.3.4.2. Risk Assessment Flow

Basically, the same flow is utilized for the risk assessment on the sediment disasters with the one on flood.

2.3.4.3. Examples of the Risk Assessment on Sediment Disasters

As examples, the process and the results of the assessment in the Cox's Bazar Upazila is shown in the following figures. As indexes of the risk assessment, affected settlement area and affected population were selected per union.

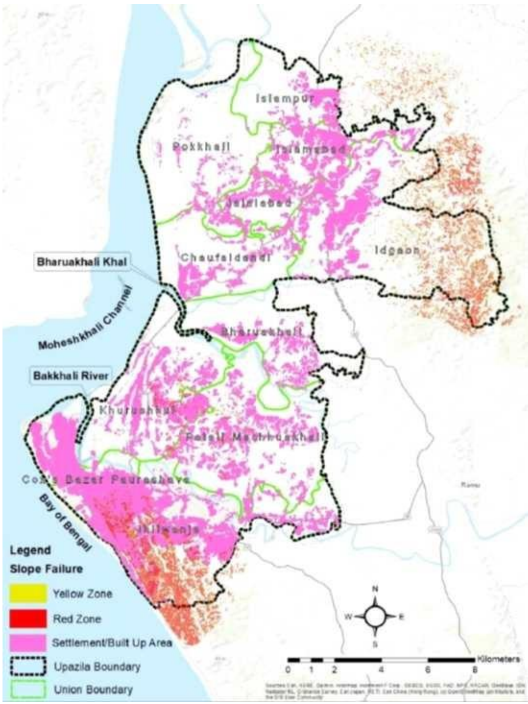


Figure 2.3.6 Affected Settlement by Slope Failure of Cox's Bazar Sadar Upazila

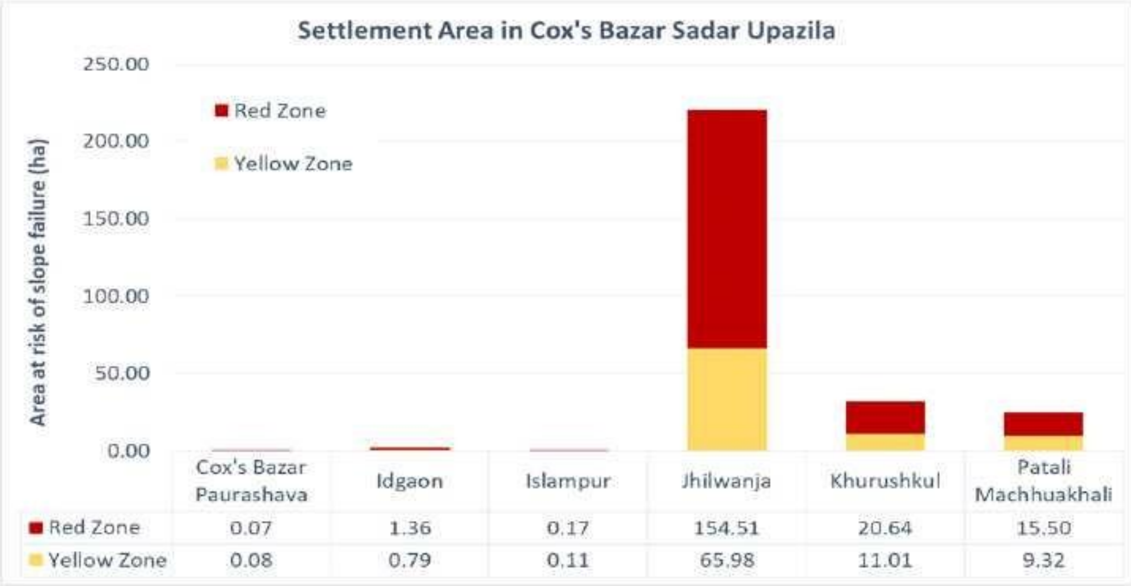


Figure 2.3.7 Settlement Area Affected by Slope Failure in Cox's Bazar Sadar

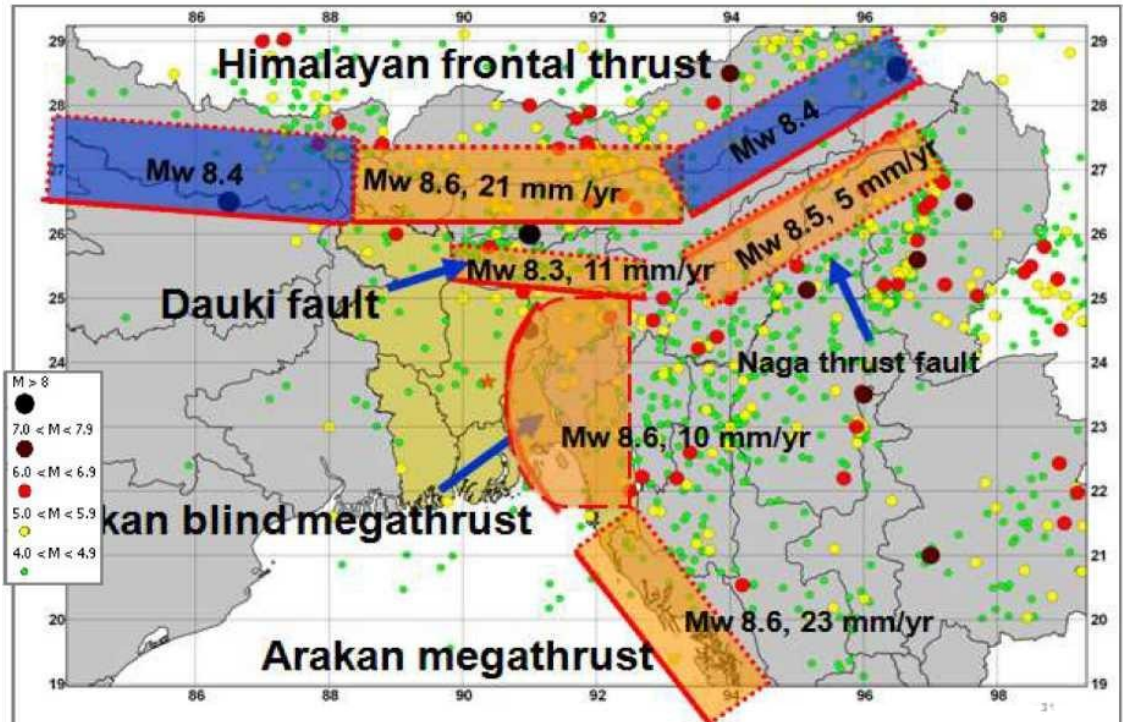
Table 2.3.3 Damaged by Slope Failure in Cox's Bazar Sadar

Union	Potential Area (Red+Yellow) [ha]	Ratio (Potential Area / Settlement Area)	Estimated Affected Population
Bharuakhali	0.00	0.0%	0
Chaufaldandi	0.00	0.0%	0
Cox's Bazar Paurashava	0.14	0.1%	109
Idgaon	2.15	0.3%	144
Islamabad	0.00	0.0%	0
Islampur	0.28	0.2%	41
Jalalabad	0.00	0.0%	0
Jhilwanja	**220.49**	**15.9%**	**9,481**
Khurushkul	31.64	3.2%	1,772
Patali Machhuakhali	24.81	3.2%	1,489
Pokkhali	0.00	0.0%	0

2.4. Earthquake

2.4.1. Current Status of Earthquake in Bangladesh

Bangladesh is located nearby the one of most active crustal movement area in the world, which consists of the Indian Plate, the Eurasian Plate, and the Burmese Plate. Many number of earthquakes have occurred in and surrounding area of Bangladesh.



Source: CDMP-II, MoDMR, 2014

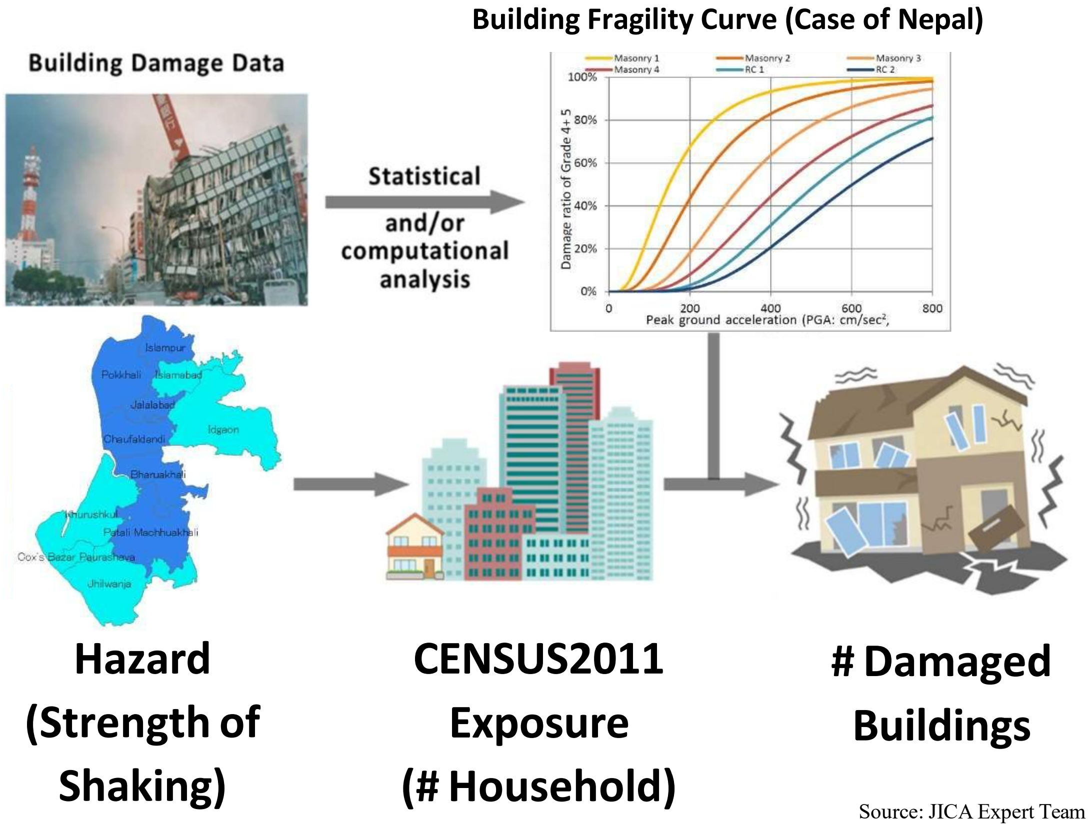
Figure 2.4.1 Mega thrust seismic sources and historical earthquake phenomena in and around Bangladesh

Besides, the thick sediment that came from major rivers such as the Ganges/Padma River, Brahmaputra/Jamuna River, and Meghna River, covers a large area of the national territory. This soft surface layer possibly increases the impact of seismic wave to the buildings, roads/bridges, or river banks and other vital lifelines including electricity, gas pipeline, water supply, sewage, and information and communication networks.

The devastating earthquakes are low-frequency mega-disasters. Once it occurs, the damage would simultaneously spread over a wide area. It means that the emergency response by the central government should be limited at the initial stage. That is why the on-site preparation in advance by each Upazila or other local community is essential to protect people and property from the future earthquakes.

2.4.2. Recommended methods of Earthquake Shaking Analysis for UzDRRAP

The figure below illustrates an overview of the recommended methods of earthquake analysis for UzDRRAP. Details of the methods are explained in the following sub-sections.



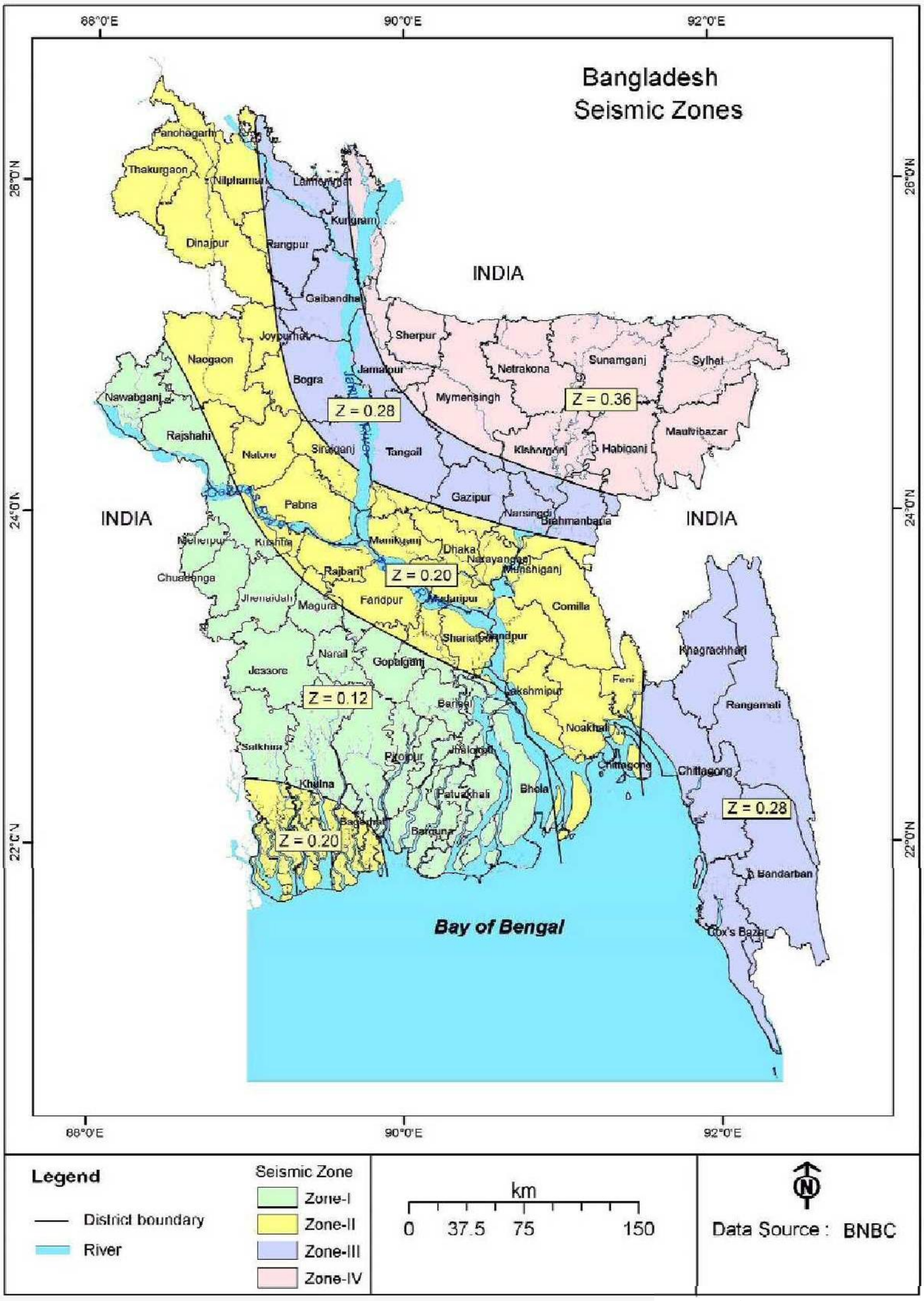
Source: JICA Expert Team

Figure 2.4.2 Method of earthquake analysis for UzDRRAP

2.4.2.1. Estimation of the Strength of Earthquake Shaking

We use the estimated Peak Ground Acceleration (PGA) as the indicator of the on-site strength of earthquake shaking. There are several steps to estimate the PGA described below.

The Government of Bangladesh issued the Bangladesh National Building Code 2020 (BNBC 2020) with the seismic zoning coefficient map (see the following figure).



Source: Figure 6.2.24, BNBC 2020

Figure 2.4.3 Seismic zoning map and the seismic zoning coefficient

The seismic zoning coefficient (Z) for the target area is identified from the map on the BNBC 2020. (For GIS processing, the JICA Expert Team has digitized and georeferenced the seismic zoning map from the PDF file of BNBC 2020.) Then, the Peak Ground Acceleration on very stiff soil/rock (PGAr) is calculated:

$$PGAr = Z \times g$$

PGAr: the maximum considered Peak Ground Acceleration on very stiff soil/rock

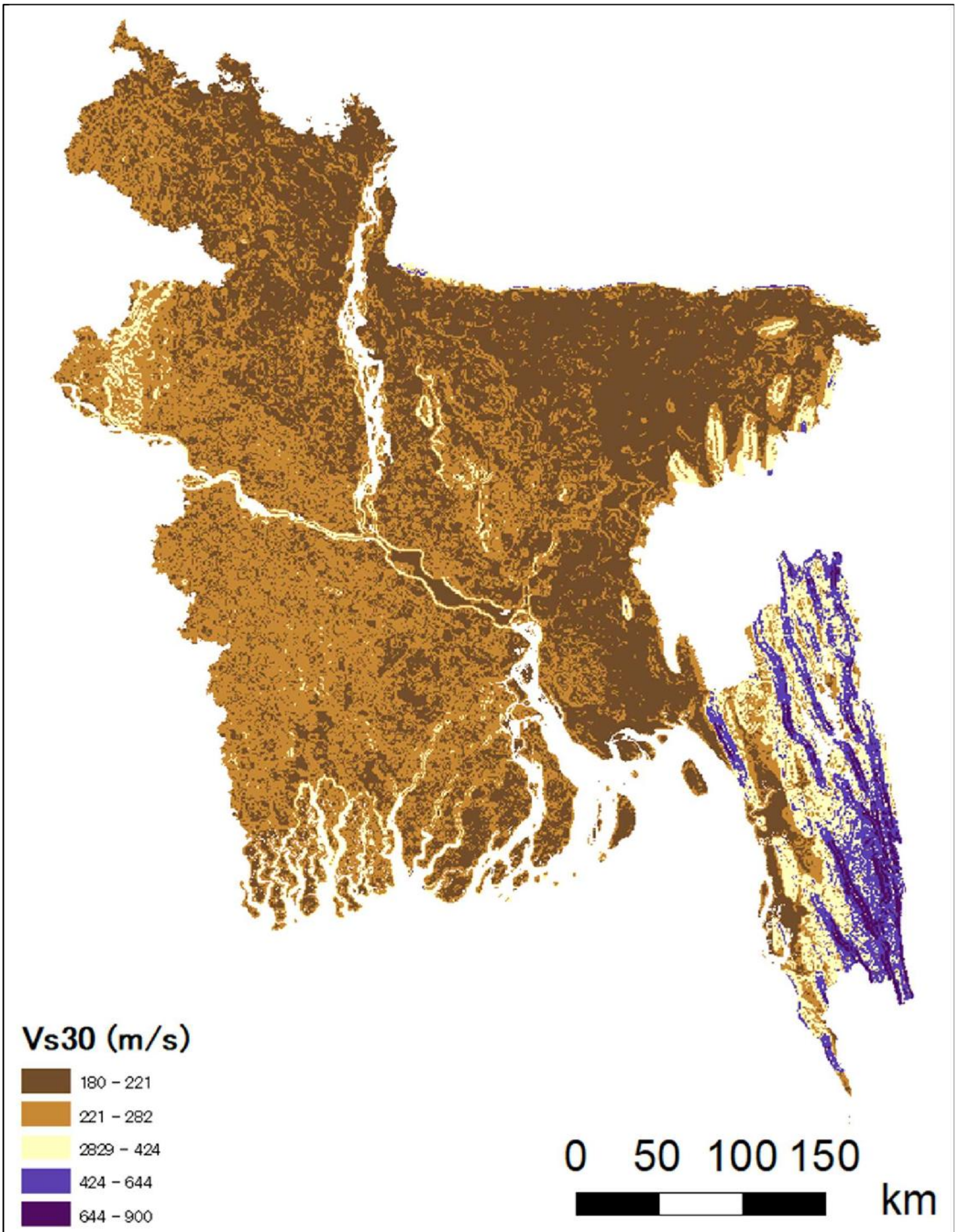
Z: seismic zoning coefficient

g: acceleration due to gravity, 9.8m/s2

In order to consider the effect of the surface layer, this project apply the Vs30 Model compiled by the United States Geographic Survey (USGS). The Vs30 Model is a global model of the time-averaged earthquake shear-wave velocity to 30 m depth. It is based on the topographic data as a proxy for seismic site conditions and amplification.

The resolution of the Vs30 Model is 30 arcsecond-grid. It means around 925 m (North-South) x 860 m (East-West) near Cox’s Bazar Sadar Upazila in Cox’s Bazar District.

The Vs30 Model extracted for the national land territory in Bangladesh (except water body) is shown in the figure below.



Source: USGS, <https://earthquake.usgs.gov/data/vs30/>

Figure 2.4.4 Vs30 Model in Bangladesh (30 arc-second grid)

For calculation of PGA in each 30 arcsecond-grid, we convert this Vs 30 model value to the amplification factor (G) of PGAr based on the research result of Midorikawa et al. (1994).

$$PGA = G \times PGAr = G \times Z \times g \qquad \text{(Midorikawa et al. (1994))}$$

PGA:	Peak Ground Acceleration on surface
PGAr:	the maximum considered Peak Ground Acceleration on very stiff soil/rock
G:	Amplification Factor of PGAr (converted from the Vs30 Model)
Z:	seismic zoning coefficient (Figure 6.2.24, BNBC 2020)
g:	acceleration due to gravity = 9.8 m/s2

Using the PGA in each 30 arc-second grid within each Union, the averaged PGA value in each Union in Bangladesh is calculated. We use these PGA in Unions as strength of earthquake shaking for estimating building damage.

The next two figures show PGA in each 30 arc-second grid and average PGA in each Union for whole Bangladesh territory.

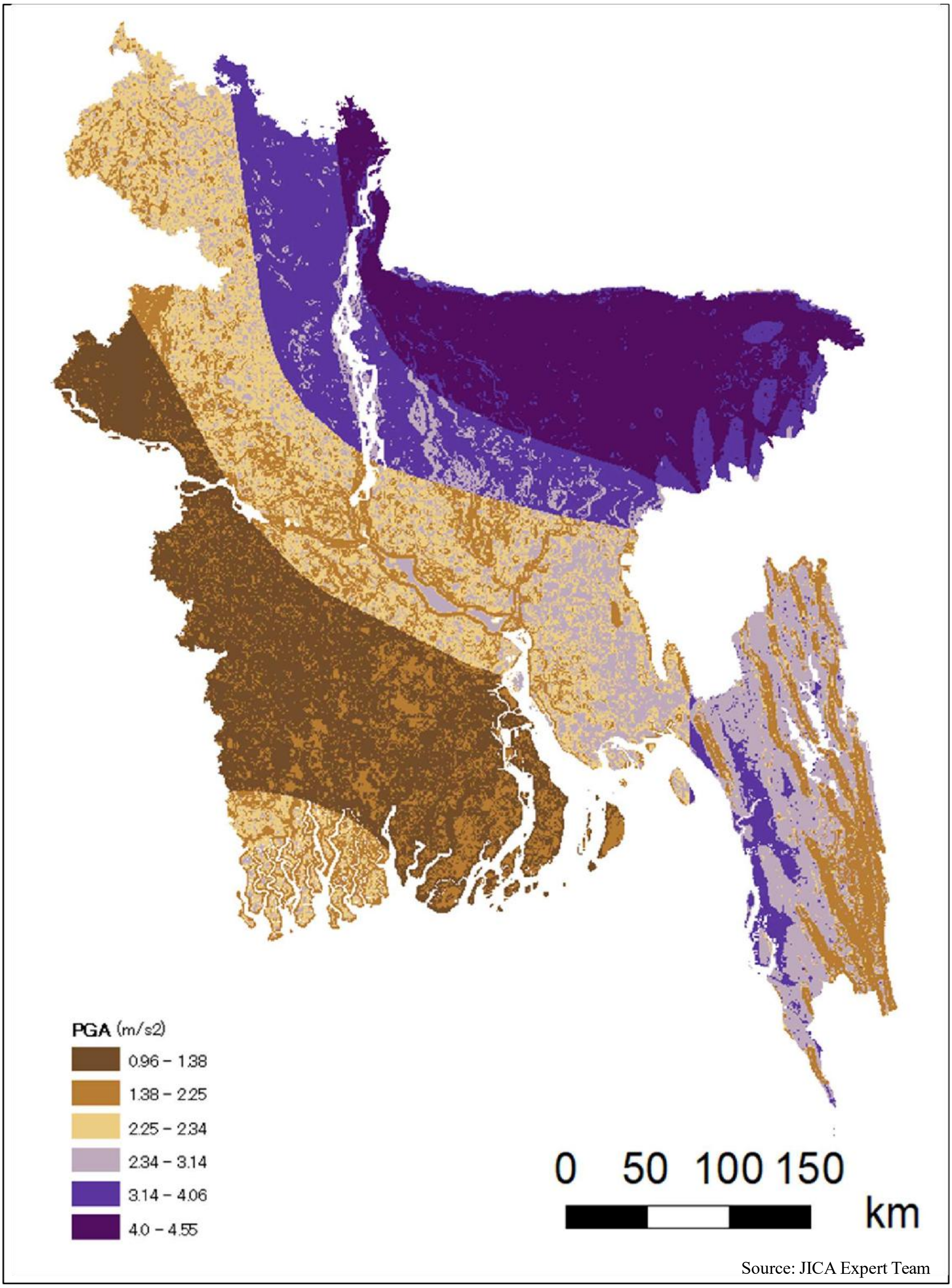
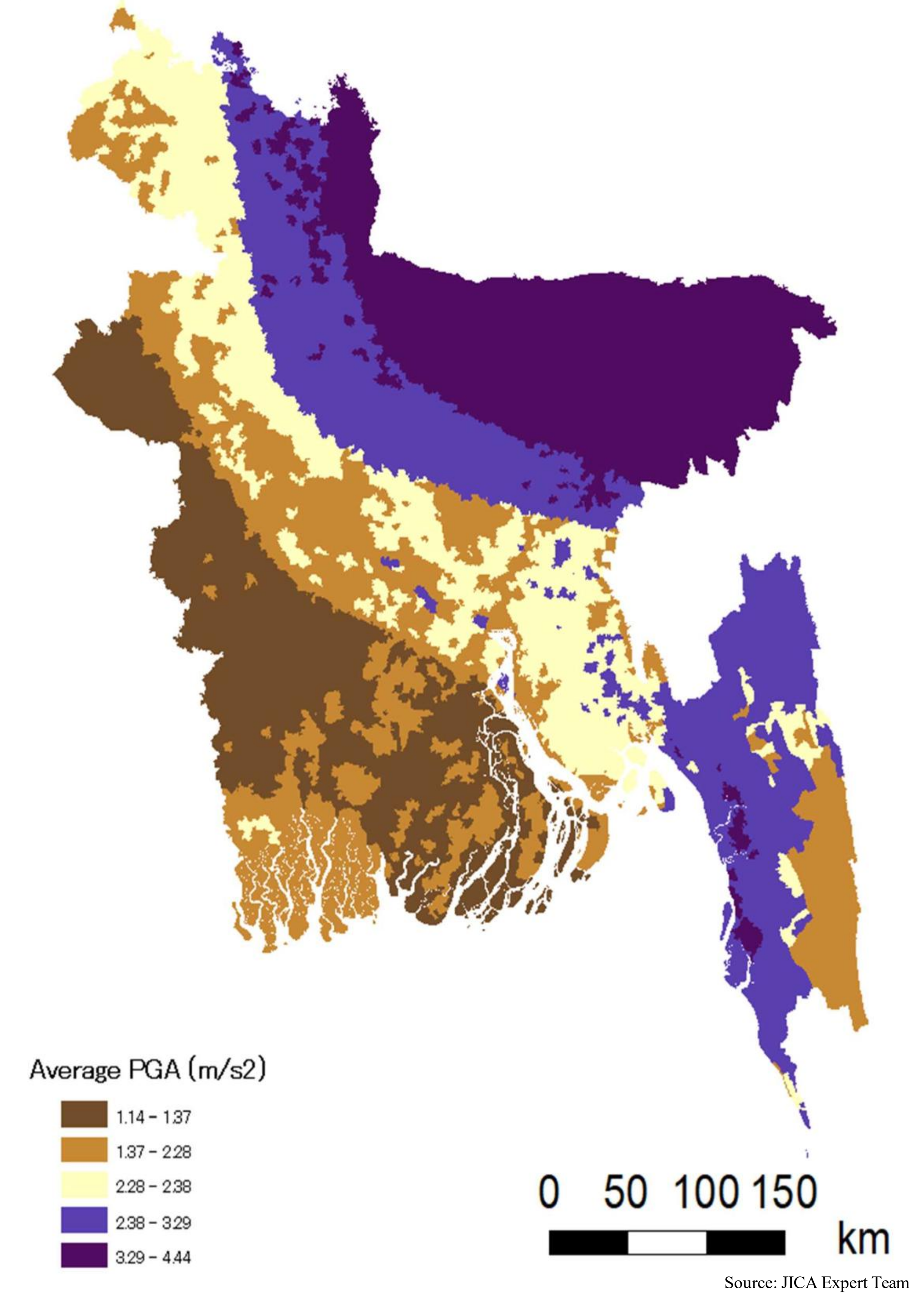


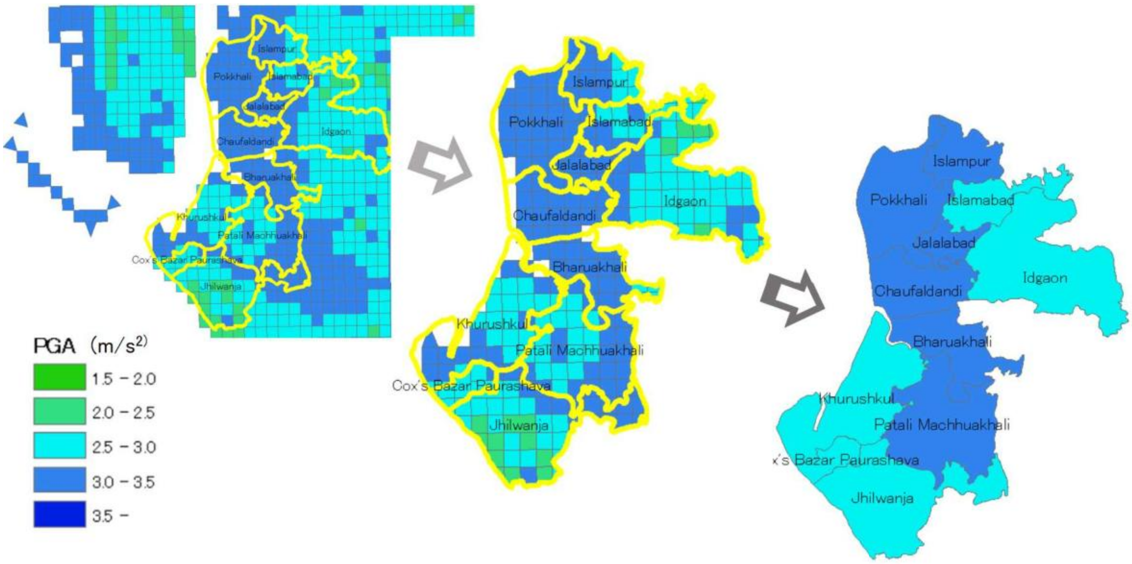
Figure 2.4.5 PGA in Bangladesh



Source: JICA Expert Team

Figure 2.4.6 Average PGA in Unions

Regarding the above process for averaging PGA in each Unions, a schematic flow for Upazila-wise is shown in the figure below. The example is a case for Cox's Bazar Sadar Upazila in Cox's Bazar District:

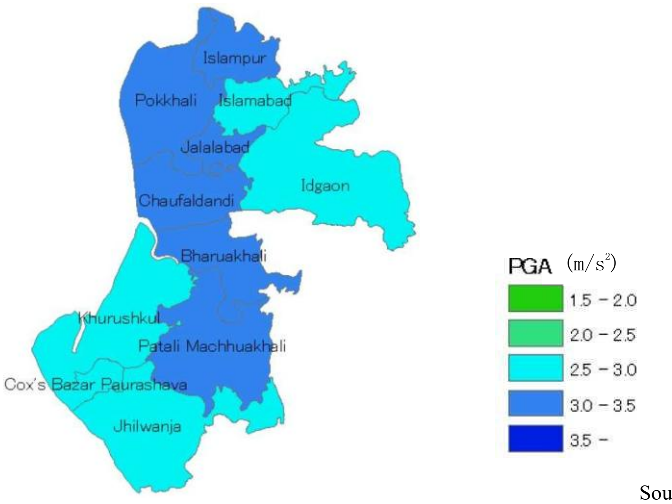


Source: JICA Expert Team

Figure 2.4.7 Averaging PGA in Unions in Cox's Bazar Sadar Upazila

2.4.3. Sample Output of Earthquake Shaking Analysis

For sample output, the figure and table below show the estimated PGA for each Union in Cox's Bazar Sadar Upazila.



Source: JICA Expert Team

Figure 2.4.8 Estimated PGA for the Unions in Cox's Bazar Sadar Upazila

Table 2.4.1 Estimated PGA for the Unions in Cox's Bazar Sadar Upazila

Union Name	Averaged PGA(m/s^2)
Bharuakhali	3.15
Chaufaldandi	3.23
Idgaon	2.84
Islampur	3.14
Islamabad	2.89
Jalalabad	3.24
Jhilwanja	2.85
Khurushkul	2.99
Patali Machhuakhali	3.08
Pokkhali	3.29
Cox's Bazar Paurashava	2.92

Source: JICA Expert Team

2.4.4 Risk Assessment on Earthquake Shaking

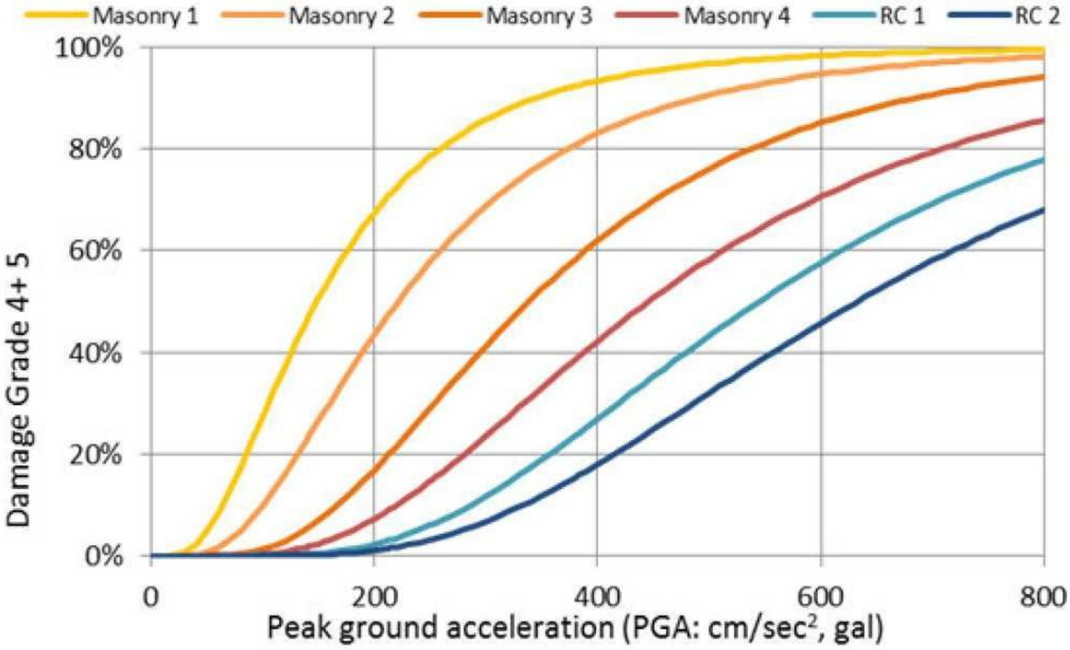
We assess the risk of building damage by PGA, earthquake shaking, using the building fragility curve for the 2015 Nepal Earthquake, because of the lack of Bangladesh case. We assign the building structure type in Bangladesh into the ones in Nepal as the following table.

Table 2.4.2 Grouping of Building Structure Types in Nepal and Bangladesh

Nepal		Bangladesh
Structure Type	Definition	Structure Type
Masonry 1	1. Adobe	Jhupri
Masonry 2	2. Stone with mud 4_1. Brick with mud, flex roof & 20 years and more	Kutcha
Masonry 3	4_2.Brick with mud, rigid roof & flex roof with 1-20 years	-
Masonry 4	3. Stone with cement mortar 5. Brick masonry with cement mortar 8. Others	Semi-pucca
RC 1	6. RC non-engineered	Pucca
RC 2	7. RC engineered with low to mid-rise	-

Source: JICA Expert Team

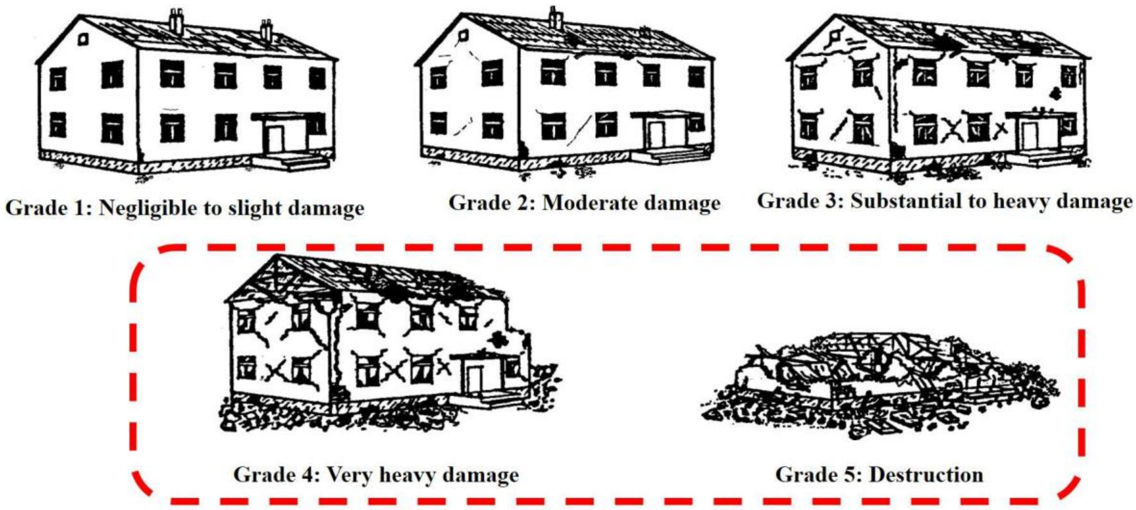
The damage ratios of structure types at the average PGA are extracted from the building fragility curve of the 2015 Nepal Earthquake (Gorkha earthquake).



Source: "The Project for Assessment of Earthquake Disaster Risk for the Kathmandu Valley in Nepal", JICA, OCG and OYO, 2018)

Figure 2.4.9 Building Fragility Curve of the 2015 Nepal Earthquake

In order to estimate maximum risk, we are targeting the Damage Grade 4 and 5 defined as European Macroseismic Scale (EMS).



Source: <https://emergency.copernicus.eu/mapping/book/export/html/138313>

Figure 2.4.10 Damage Grade by European Macroseismic Scale (EMS)

For grasping the number of buildings in each union, we use the results of CENSUS 2011 by Bangladesh Bureau of Statistics. CENSUS 2011 shows the "Number of Households" and "Percentage of Type of Structure" in each union. The structure types have four categories: Pucca, Semi-pucca, Kutcha, and Jhupri.

Table 2.4.3 "Number of Households" and "Percentage of Type of Structure" (partially extracted for Unions in Cox Bazar Sadar Upazila)

Table C-14: Percentage distribution of general household by type of structure, toilet facility, residence and

Administrative Unit Residence Community	RMO	Number of Households	Percentage of Type of Structure				Percentage of Toilet Facility			
			Pucca	Semi-pucca	Kutcha	Jhupri	Sanitary (With Water Seal)	Sanitary (No Water Seal)	Non-Sanitary	None
1	2	3	4	5	6	7	8	9	10	11
Bharuakhali Union Total		3939	6.9	10.6	76.2	6.4	8.9	64.9	24	2.2
Chaufaldandi Union Total		5195	5.2	13.7	78.8	2.3	23.6	42	19.7	14.7
Idgaon Union Total		5984	8.5	24.6	58.1	8.8	7.8	55.5	30.3	6.4
Islampur Union Total		3626	5.3	8.6	73.6	12.5	17	31.1	42.5	9.5
Islamabad Union Total		5275	5.8	16	76.2	2	7.5	34.3	51.8	6.4
Jalalabad Union Total		3048	11.4	21	60.6	7	20.8	26.3	50.2	2.8
Jhilwanja Union Total		7352	9.1	20.5	56.3	14.1	26.7	36.9	27.9	8.5
Khurushkul Union Total		6807	3.6	10.2	78.3	7.9	39.4	32.5	15.1	13
Patali Machhuakhali Union Total		6103	5.9	21.9	68.1	4.1	7.3	51	28.6	13.1
Pokkhali Union Total		3820	7.6	16	69.6	6.8	11	28.5	56.5	4
Cox's Bazar Paurashava		30374	20.4	26.6	39.6	13.3	25.8	41.1	30	3

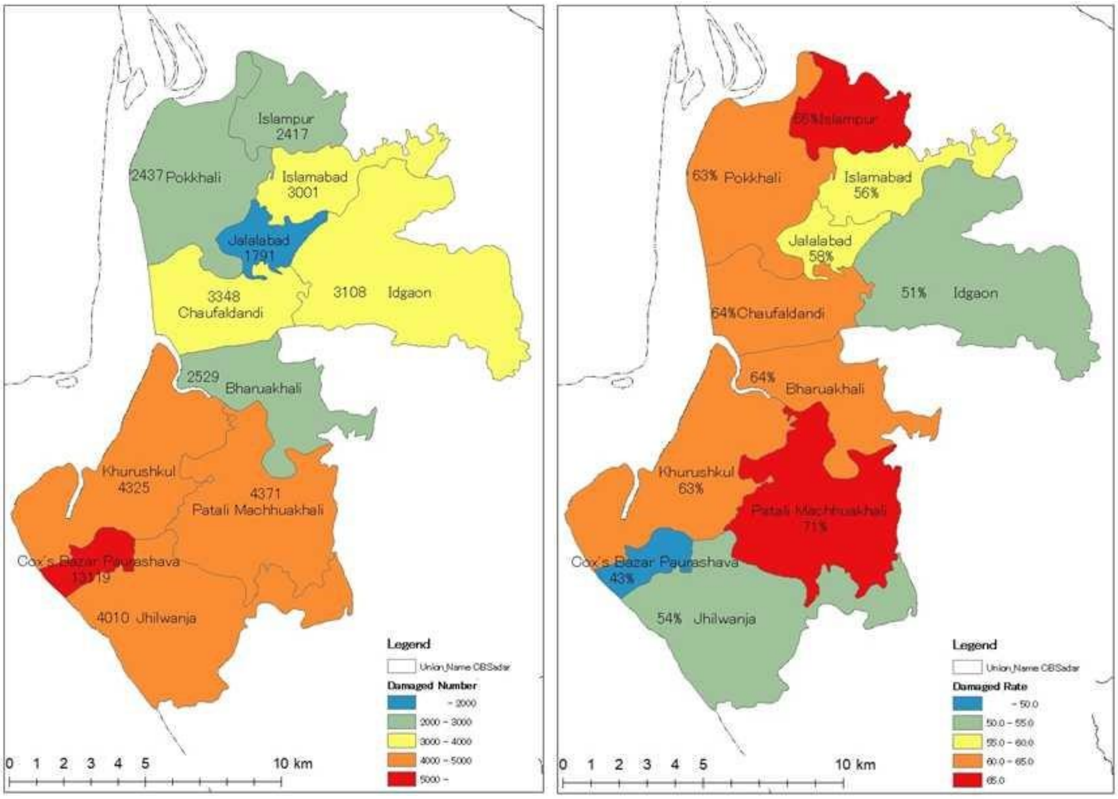
Source: CENSUS 2011

Here we introduce an assumption that one household uses one building. Through the integration of above information, we can assess the possible number of damaged buildings in each Union at the estimated earthquake shaking in BNBC 2020.

[Number of Damaged Building] = [Number of Building] x [Building Damage Ratio]

[Number of Building]: [Number of Households] x [Percentage of Type of Structure] (referred from CENSUS 2011)

[Building Damage Ratio]: derived from Building Fragility Curve at the PGA and Structure Type



Source: JICA Expert Team

Figure 2.4.11 Estimated Number and Ratio of Damaged Buildings in Cox's Bazar Sadar

Not only the "Number of Damaged Buildings", but also the "Ratio of Number of Damaged Buildings / Total Number of Buildings" may show the characteristic difference between structure types in urban area and rural area. For example, even though the number of damaged buildings is not so large, the ratio could be high because the total number of buildings is small. High ratio may still mean that the area could be severely affected overall.

ANNEX 1: Consideration for Climate Change Impact

(Updated April. 2025)

Table of Contents

1. Hazard Analysis

1.1. Consideration for Climate Change Impact

In this section, the recommended methods for considering future climate change impacts and reflect them into hazard analysis is described. The section is compiled based on the information from “National Adaptation Plan of Bangladesh (2023-2050)”.

1.1.1 General Situation

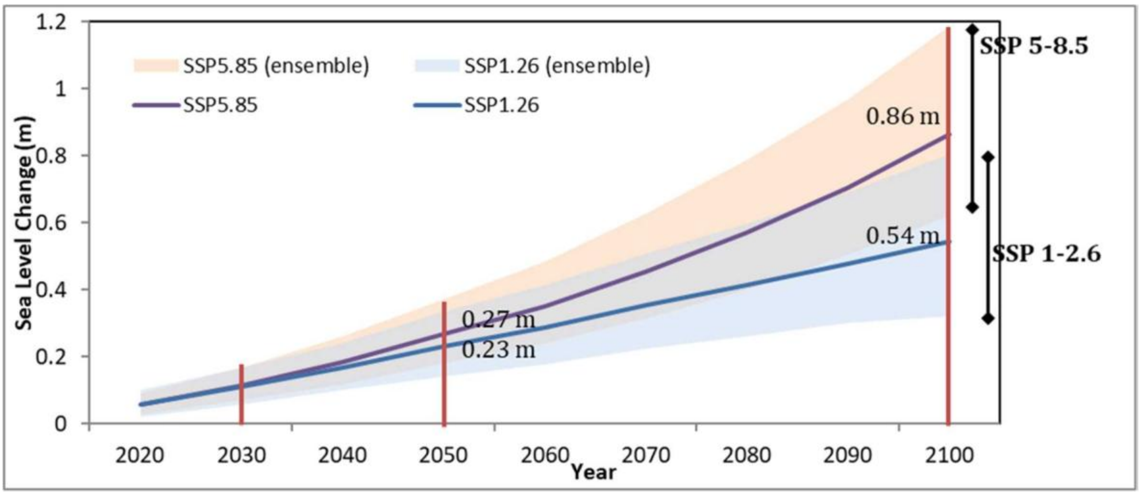
Bangladesh is a subtropical country in South Asia with a warm and humid climate. The average temperature ranges between 15°C and 34°C around the year. Mean annual rainfall is about 2,400 mm; about 70 percent of rainfall occurs during monsoon (June to September). Rainfall varies significantly across the country, with the arid western regions receiving as little as 1,400 mm and the north-eastern region and eastern hills receiving over 4,300 mm. Bangladesh has been experiencing higher temperatures, erratic rainfall and extreme rainfall events in recent decades due to climate change. It also is highly vulnerable to climate change impacts due to its low-lying terrain (13 percent of its territory lies within two meters above the mean sea level), high population density, and location at the confluence of the Ganges, Brahmaputra and Meghna River basins. Observed climate trends, hazards, future projections, ensuing stresses and resultant risks will be elaborated further based different regions of the country that reflect hydrological and topographical variations.

1.1.2 Climate Change Impact on Sea Level

Relevant Hazard Type and Method:

- ✓ Storm Surge: Simplified Full Level Method
- ✓ Storm Surge: Numerical Simulation
- ✓ River Flood: Hydraulic Simulation with RRI Model

Global warming is causing sea-level rise and increasing the vulnerability of low-lying coastal areas of Bangladesh. Future sea-level rise is projected to be between 0.11-0.12 m in the near term, 0.23-0.27 m in the mid-term and 0.54-0.86 metres in the long term (IPCC, 2021). There is, however, substantial uncertainty in the long-term projections near the Bangladesh coast, according to the IPCC. Some global models estimate an increase of up to 1.75 m.



Source: National Adaptation Plan of Bangladesh (2023-2050)

Figure 1 Sea Level Rise Projections near the Bangladesh Coast in the Bay of Bengal

Based on the above future prediction, it is recommended to consider sea level increase under the climate change impact as follows:

Table 1 Recommended Setup of Sea Level Increase Considering Climate Change Impact

Setup Condition	Basis of the Setup
0.25m Increase	Average of 0.23m – 0.27m increase in 2050

Table 2 Application Procedure of Sea Level Increase Considering Climate Change Impact

No.	Hazard Type	Method	Application Procedure
1	Storm Surge	Simplified Full Level Method	Add 0.25m to estimated target storm surge level
2		Numerical Simulation	Add 0.25m to estimated target storm surge level
3	River Flood	Hydraulic Simulation with RRI Model	Add 0.25m to downstream boundary condition of hydraulic simulation

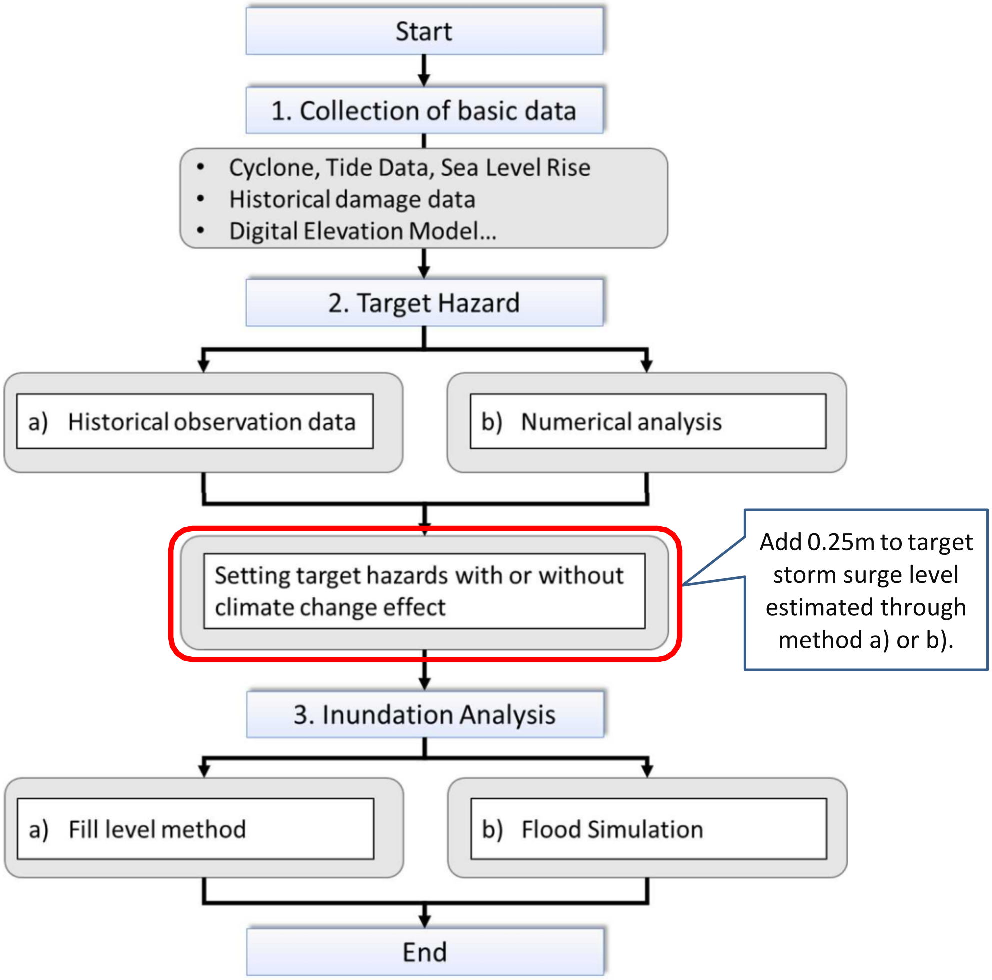


Figure 2 Flow of the Storm Surge Analysis Considering Climate Change

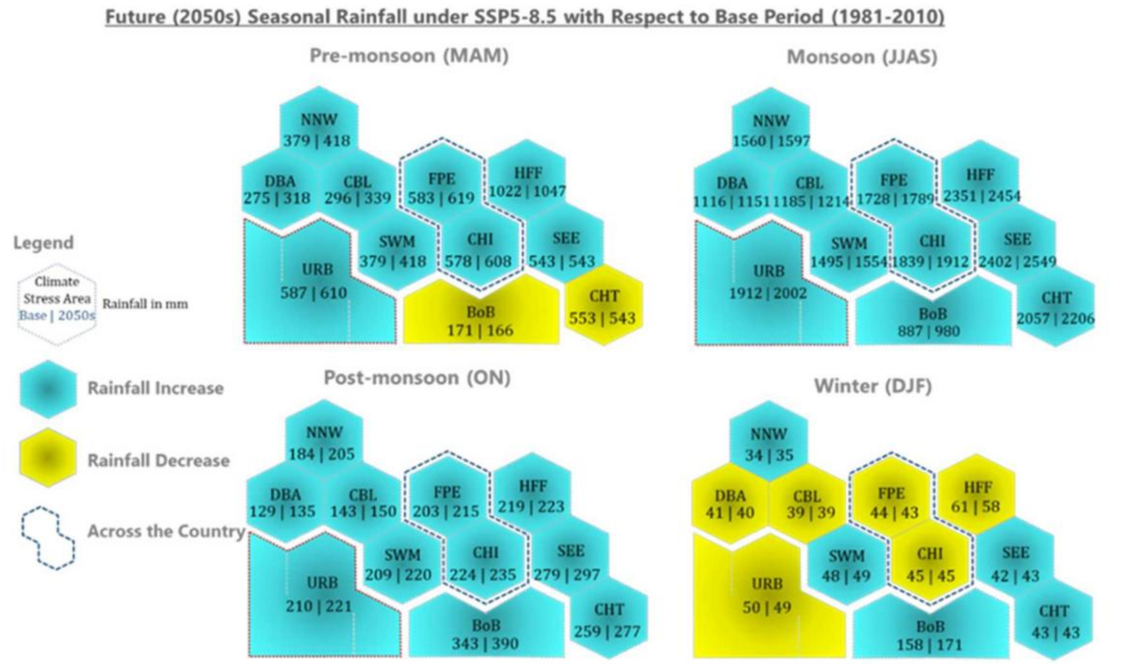
1.1.3 Climate Change Impact on Rainfall Intensity

Relevant Hazard Type and Method:
✓ River Flood: Hydraulic Simulation with RRI Model

Rainfall variation due to future climate change for Bangladesh ranges between 0.1-1.4 percent in the 2030s and 2.4-3.5 percent in 2050s. The northeastern and eastern hills regions will receive higher rainfall, while the western part will see lower levels. Future annual rainfall will be slightly higher or similar in the 2030s across the country.

In the 2050s, rainfall will increase all over the country. A higher amount of change is expected in coastal areas and the Chattogram Hill Tracts. Future projections indicate that winter rainfall is decreasing for most of the country except in the coastal and Chattogram Hill Tracts regions. In contrast, pre-monsoon rainfall will decrease in the Chattogram Hill Tracts and Bay of Bengal.

Rainfall in the rest of the country will increase during this season. Monsoon and post-monsoon rainfall all over the country will increase. The frequency of heavy rainfall events is projected to rise while that of light rainfall events will fall, inferring a shift towards a lower number of wet days with an increase in the intensity of rainfall on days with rain, entailing an increased risk of flash floods.



Source: National Adaptation Plan of Bangladesh (2023-2050)

Figure 3 Seasonal Rainfall under SSP5-8.5 Scenario with Respect to Base Period (1981-2010)

Based on the above future prediction, it is recommended to consider rainfall increase under the climate change impact as follows. The increase ratio would be selected in accordance with the target areas and target flood phenomenon (Pre-monsoon flood or Monsoon flood).

Table 3 Recommended Setup of Rainfall Increase Considering Climate Change Impact (For Pre-Monsoon Flood)

No.	Areas	Setup Conditions	Basis of the Setup	
			Base Period (1981-2010): mm	Future (2050s): mm
1	NNW	10.3%	379	418
2	DBA	15.6%	275	318
3	CBL	14.5%	296	339
4	FPE	6.2%	583	619
5	HFF	2.4%	1022	1047
6	SWM	10.3%	379	418
7	CHI	5.2%	578	608
8	SEE	No Increase	543	543
9	URB	3.9%	587	610
10	BoB	No Increase	171	166
11	CHT	No Increase	553	543

Table 4 Recommended Setup of Rainfall Increase Considering Climate Change Impact (For Monsoon Flood)

No.	Areas	Setup Conditions	Basis of the Setup	
			Base Period (1981-2010): mm	Future (2050s): mm
1	NNW	2.4%	1560	1597
2	DBA	3.1%	1116	1151
3	CBL	2.4%	1185	1214
4	FPE	3.5%	1728	1789
5	HFF	4.4%	2351	2454
6	SWM	3.9%	1495	1554
7	CHI	4.0%	1839	1912
8	SEE	6.0%	2402	2545
9	URB	4.7%	1912	2002
10	BoB	10.5%	887	980
11	CHT	7.2%	2057	2206

Table 5 Application Procedure of Rainfall Increase Considering Climate Change Impact

No.	Hazard Type	Method	Appliation Procedure
1	River Flood	Hydraulic Simulation with RRI Model	Increase input rainfall intensity in accordance with the ratio selected from **Table 3** or **Table 4**

The following figure shows the procedure of the RRI model simulation.

A) Preparation for the Use of RRI Model
↓
B) Topographic Data
↓
C) Rainfall Data
↓
D) Parameter Settings
↓
E) Other Settings
↓
F) Running RRI
↓
G) Result Viewing

- Installation of Tools
  - RRI Model and Attached Tools
  - QGIS
- Preparation and Processing of Topographic Data
  - Selection of DEM
  - Modification/Adjustment of DEM
  - Preparation of Flow Direction
  - Preparation of Flow Accumulation
  - Clip-out of Target Area
  - Upscaling of Topographic Data (Optional)
- Setting of Rainfall Intensity and Its Temporary Variation
  - Setting of Rainfall Intensity and Duration
  - Setting of Temporal Rainfall Distribution
  - Rainfall Increase Considering Climate Change Impact
- Parameter Settings
  - River Channel Parameters
  - Soil Infiltration Parameters
  - Numerical Analysis Parameters
- Other Settings (Optional)
  - Tidal Conditions
  - Tidal Level Increase Considering Climate Change Impact
  - Evapotranspiration
  - Embankment Setting
- Running RRI
  - Execution of RRI Model Simulation
  - Consideration of Flood Countermeasures
- Result Viewing
  - Output of Hourly Flood Depth
  - Creation of Maximum Flood Depth

Figure 4 Flow of the RRI Model Simulation Considering Climate Change

1.1.4 Climate Change Impact on River Flood Level

Relevant Hazard Type and Method:
✓ River Flood: Compilation of Existing Water Level Information (Simplified Method)

River flooding is a recurrent phenomenon in Bangladesh, occurring almost every other year. It generally takes place during the monsoon and inundates low-lying floodplain areas. Major floods happened in 1987, 1988, 1998, 2004, 2007 and 2017. The area inundated during the 1987, 1988, 1998 and 2007 floods comprised 39 percent, 61 percent, 69 percent and 42 percent of the country, respectively. During the 1988 floods, embankments of 1,990 km (17.5 percent of the total), irrigation canals/drainage channels of 283 km (5.3 percent of the total), 1,465 structures (10 percent of the total) and protection works of 265 km (24.8 percent of the total) of the Bangladesh Water Development Board (BWDB) were partially or fully damaged. The 1998 flood caused the death of 1,100 people and damaged 4,500 km of embankments and 575,000 hectares of crop. During the 2004 floods, embankments of 3,158 km (27.7 percent of the total) and protection works of 178 km (16.6 percent of the total) were partially or fully damaged. The 2007 flood caused 405 deaths. The flood of 2020 was an alarming event. Around 5 million people were affected; 41 people lost their lives. Estimated damages due to the flood events of 1988, 1998, 2004, 2007 and 2017 were $1.2 billion, $2.8 billion, $6.6 billion, $1 billion and $900 million, respectively. While flood-related fatalities are decreasing, economic losses have been increasing over the years. Due to climate change, the mean annual flow of the Ganges, Brahmaputra and Meghan river basins will increase by 17-28 percent, 2-5 percent and 1-4 percent, respectively, under the SSP5-8.5 scenario in the 2050s (CEGIS, 2021). The seasonal flow distribution in the 2050s will also increase substantially during the pre-monsoon in all three basins. The flow will increase significantly (18-30 percent) in the Ganges basin, while a smaller increase might occur in the Brahmaputra and Meghan basins. The higher increase in the Ganges basin is most probably attributed to additional flow from melting Himalayan glaciers. This will increase the flooding probability in the country. Winter flows will decrease in the Brahmaputra and Meghan basins under SSP5-8.5.

Based on the above future prediction, it is recommended to consider flood water level increase under the climate change impact as follows:

Table 6 Recommended Setup of Flood Water Level Increase Considering Climate Change Impact

No.	Areas	Setup Conditions	Basis of the Setup
1	Padma River Basin	23 % Increase of estimated water depth	Average of 17-28 % increase
2	Brahmaputra River Basin	4 % Increase of estimated water depth	Average of 2-5 % increase
3	Meghna River Basin	3 % Increase of estimated water depth	Average of 1-4 % increase
4	Other Areas (South-East)	3 % Increase of estimated water depth	Assumed Same as Meghna River Basin

Table 7 Application Procedure of Flood Water Level Increase Considering Climate Change Impact

No.	Hazard Type	Method	Application Procedure
1	River Flood	Compilation of Existing Water Level Information (Simplified Method)	Increase estimated flood water depth in accordance with the ratio selected from **Table 6**

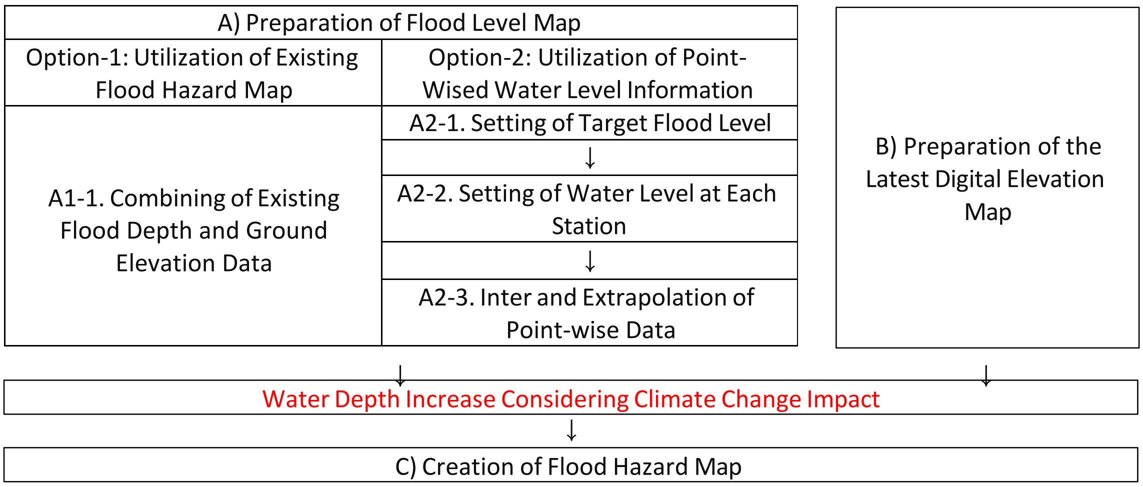


Figure 5 Flow of Simplified Flood Hazard Mapping Considering Climate Change

ANNEX 2: Technical Manual for Flood Analysis

(Updated April. 2025)

Table of Contents

1. Introduction

The purpose of flood analysis is to understand the flood hazard in the targeted upazila and surrounding areas by estimating possible flooding extent and depth.

There are some existing studies on flood analysis conducted by the Government of Bangladesh (GoB) and other relevant organizations, such as the Institution of Water Modeling (IWM), the Centre for Environmental and Geographic Information Services (CEGIS), academic institutions, or others developed in cooperation with international development partners. From the perspective of fully utilizing existing available resources, these study results should be collected and referred to as the first source for understanding of flood hazard. If these study results are not enough in terms of their accuracy and coverage area, flood analyses shown hereafter should be performed.

There are two types of flood analyses proposed in this guideline. The first is a relatively simple analysis utilizing existing flood hazard map or water level information. This information will be updated based on the latest digital elevation model (DEM) using GIS software to improve their reliability. The other is hydrological and hydraulic analysis using Rainfall-Runoff-Inundation (RRI) model and GIS software combined with rainfall, DEM and some other input data. The general features of these analyses are described in the following table. As to which method to be used depends on the technical levels of the operator and availability of hydrological, topographical and other input data.

For “Compilation of existing flood Information (simple method)”, it will be explained in Chapter 2 in this technical manual.

For “Hydrological and hydraulic analysis (advanced method)”, it will be explained in Chapter 3 in this technical manual.

Table 1 Features of the Flood Hazard Analysis

	1. Compilation of existing flood Information (simple method)	2. Hydrological and hydraulic analysis (advanced method)
Concept	Updating the existing hazard map or water level information based on the latest ground elevation model to reflect the recent topographical conditions.	Conducting the hydrological and hydraulic analysis to estimate the extent and depth of flooding under a given rainfall condition.
Applicable area	Areas where the hydrological observation network is developed to some extent. River basins which are huge and difficult to develop hydrological/hydraulic model. (Major river basins)	Areas where no reliable flood hazard information. River basins where hydrological observation network is not fully developed. River basins whose size are not so large. (Peripheral areas, south-eastern areas, flash flood areas)
Methodology	The water surface map is derived from existing flood hazard map or water level information. Without changing the water surface elevation, update the ground elevation using the latest topographic data (DEM) in GIS software, to create updated flood depth distribution map (flood hazard map).	Conduct hydrological and hydraulic analysis with RRI model in one or several river basins which cover target area(s). The computed flood area and depth are further compiled into hazard maps in GIS software.
Data Requirement for the Analysis	(Required) Existing flood hazard map or water level distribution information (to be collected from gauging stations, on-site investigation and/or interview survey from local residents.) Ground elevation data applied in existing flood hazard map Latest digital elevation data (DEM) (Not required but preferable to collect and use) Road, embankment and other local elevation data	(Required) Rainfall data or rainfall intensity formula Digital elevation data (DEM) (Not required but preferable to collect and use) Land cover data Water level data at river mouth River channel data (width and depth) Road, embankment and other local elevation data
Note	When using the existing flood hazard map or water level information, it should be confirmed whether the peak situation of water level rising or maximum water level during flood is captured in those information. It also should be confirmed if the occurrence probability (or return period) of the water level is known. In case there are no such information, the UzDRRP will have a quantitative uncertainty of target safety level.	Although RRI model is relatively simple and easy to handle, conducting flood analysis with RRI model requires a certain technical level in software operation as well as knowledge in hydrology and hydraulics. Training of the operation of the software would be required.

2. Compilation of Existing Flood Information (Simple Method)

2.1. Overview

In this chapter, a methodology for creating flood hazard map by superimposing water surface map with topographic data will be presented. The water surface map would be prepared based on either existing flood hazard map or gauged water level data.

This method is recommended for application in the areas with following characteristics:

- ✓ The topography is unique and complex, making it difficult to reproduce flood conditions through hydraulic simulation.
- ✓ The area is largely affected by hydrological conditions outside the territory of Bangladesh, while it is difficult to collect and confirm such information.
- ✓ The gauged water level data around the target area is well established. Or, the results of statistical analysis of water level data conducted by relevant organizations can be utilized.

In general, this method puts emphasis on simplicity over accuracy. It should be noted, therefore, the obtained flood hazard map needs to be verified through on-site inspection. Particularly, when estimating the water level in the land areas by interpolation or extrapolation of water level within river channel, the analysis results might be different from actual flood situation.

2.2. Procedure Flow

The following figure shows the procedure of the preparation for flood hazard map.

<table>
<tr><td colspan="2">A) Preparation of Flood Level Map</td><td rowspan="7">B) Preparation of the Latest Digital Elevation Map</td></tr>
<tr><td>Option-1: Utilization of Existing Flood Hazard Map</td><td>Option-2: Utilization of Point-Wised Water Level Information</td></tr>
<tr><td rowspan="5">A1-1. Combining of Existing Flood Depth and Ground Elevation Data</td><td>A2-1. Setting of Target Flood Level</td></tr>
<tr><td>↓</td></tr>
<tr><td>A2-2. Setting of Water Level at Each Station</td></tr>
<tr><td>↓</td></tr>
<tr><td>A2-3. Inter and Extrapolation of Point-wise Data</td></tr>
<tr><td colspan="2">↓</td><td>↓</td></tr>
<tr><td colspan="3">C) Creation of Flood Hazard Map</td></tr>
</table>

Figure 1 Flow of Simplified Flood Hazard Mapping

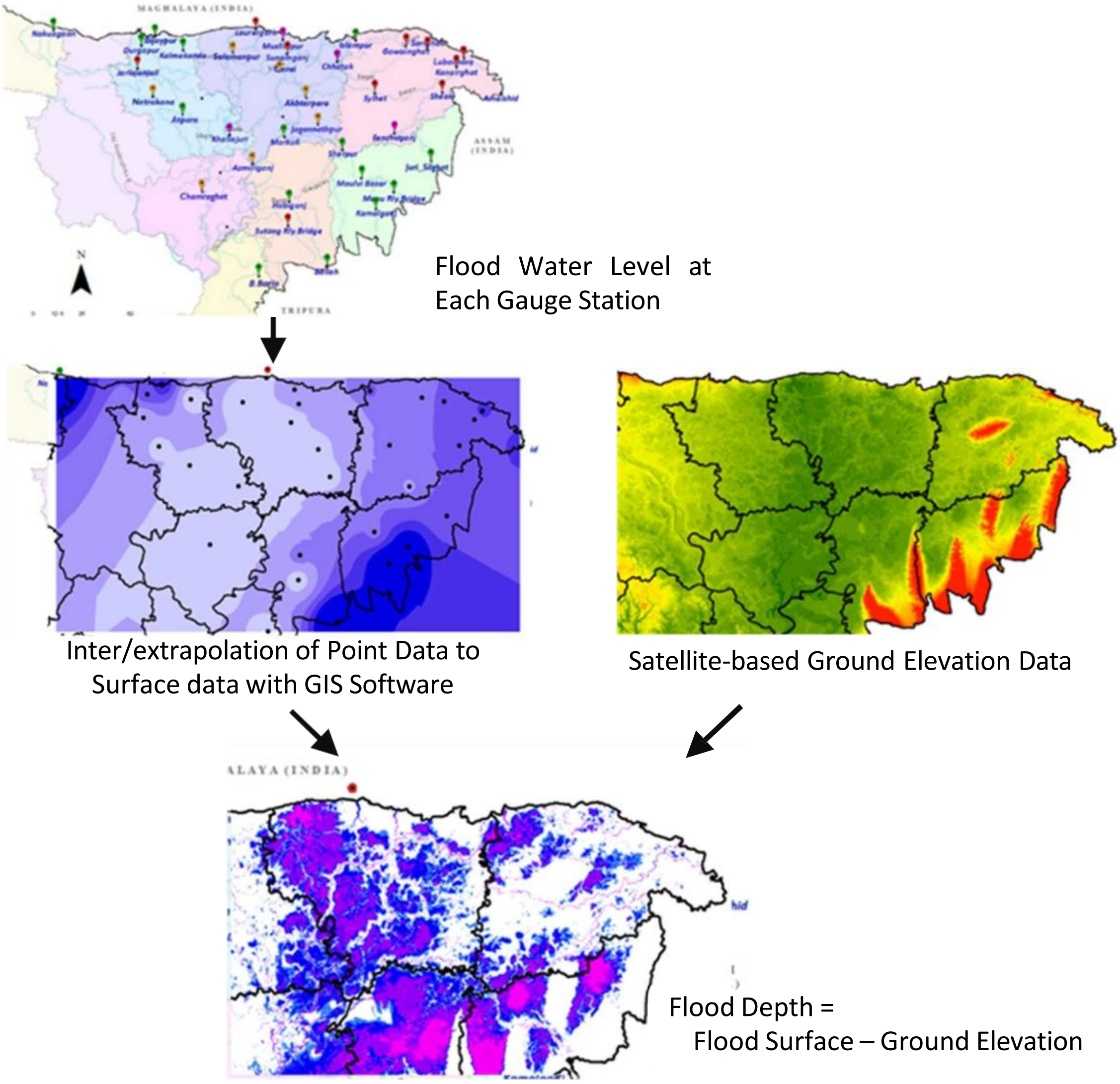


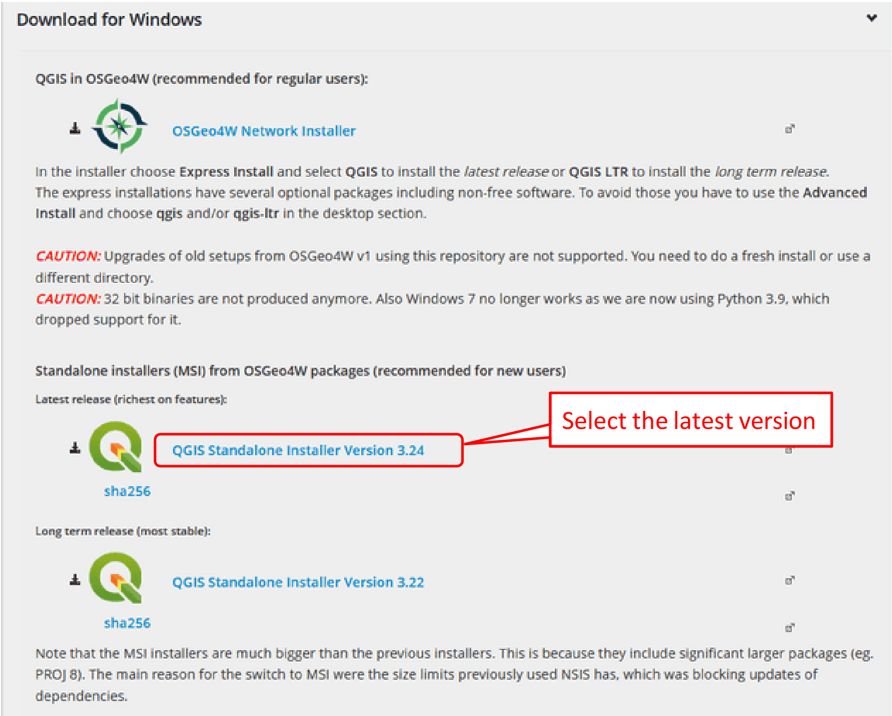
Figure 2 Image of the Preparation of Flood Hazard Map

2.3. Installation of QGIS

Users are required to install QGIS.

Download Site:

https://www.qgis.org/en/site/forusers/download.html



2.4. Preparation of Flood Level Map

2.4.1. Option-1: Utilization of Existing Flood Hazard Map

If the existing flood hazard map is available and to be used, it should be converted to water surface map by combining water depth (existing flood hazard map) and ground elevation which has been used in the analysis of existing flood hazard mapping.

Flood Surface Level = Flood Depth + Ground Level

QGIS Command: Raster Calculator

2.4.2. Option-2: Utilization of Point-Wised Water Level Information

2.4.2.1. Setting of Target Flood Level

There are some options for setting the target water level.

Table 2 Target Water Level

Options for Target Water Level	Remarks
Pre-monsoon Danger Level	Defined by BWDB-FFWC. Danger level at a river location is the level above which it is likely that the flood may cause damages to nearby crops and homesteads. In a river having no embankment, danger level is about annual average flood level. In an embanked river, danger level is fixed slightly below design flood level of the embankment. In pre-monsoon time, flash flood often hits the North-East Region and causes severe damage although in most cases, water level doesn't even touch the danger level or close to it. To represent the severity of flash flood relative to realistic danger level, BWDB reviewed pre-monsoon danger level for the selected flash flood forecast stations in North East Region. These pre-monsoon danger levels will only applicable up to May 15 and then usual danger levels will be followed.
Monsoon Danger Level	Defined by BWDB-FFWC. Danger level at a river location is the level above which it is likely that the flood may cause damages to nearby crops and homesteads. In a river having no embankment, danger level is about annual average flood level. In an embanked river, danger level is fixed slightly below design flood level of the embankment.
10-yr Return Period Flood Level	It is considered standard water level for submergible embankment design according to BWDB standard design manual 1996. However, it has been reviewed in the report on "Flash Flood Early Warning System for North Eastern Part of Bangladesh" in 2019.
20-yr Return Period Flood Level	It is considered standard water level for full embankment design where agricultural damage is predominant, according to BWDB standard design manual 1996.
100-yr Return Period Flood Level	It is considered standard water level for full embankment design where loss of human lives, properties and installations are predominating, according to BWDB standard design manual 1996. In general, embankment along Jamuna, Padma and Meghna rivers shall be designed with this return period.
Other Return Period Flood Level	Other return period water levels such as 5-yr, 50-yr, etc. depending on the target safety level. To determinate water levels corresponding to each occurrence probability, it is necessary to collect annual maximum water levels for approximately 10 years to several decades, and carry out hydrological statistical analysis. The target return period should be selected in accordance with the situation of target areas.
Others	Recorded maximum water level, water level corresponding to past specific flood event, etc.

2.4.2.2. Flood Level Setting at Each Station

For flood level setting at each station, the either of the following approaches is taken:

- Reference to the FFWC website (http://www.ffwc.gov.bd/), Flash Flood Early Warning System website (http://geo.iwmbd.com:4003/) or report on “Flash Flood Early Warning System for North Eastern Part of Bangladesh” 2019.
- Collect raw data from BWDB then conduct statistical analysis to calculate probable water levels.

For the monsoon flood water levels corresponding to several occurrence probabilities are calculated by the JICA Expert Team at 18 water level stations nationwide.

No.	Station ID	Station Name	River Name	No.	Station ID	Station Name	River Name
1	SW18	Barisal	Tangon	10	SW175.5	Sherpur-Sylet	Kirtonkhola
2	SW45.5	Chilmari	Jamuna	11	SW228.5	Mymensingh	Surma
3	SW49A	Kazipur	Jamuna	12	SW241	Khulna	Surma
4	SW72	KhaliaJuri	Turag	13	SW267	Sylhet	Kushiyara
5	SW88	Rajshahi	Atrai	14	SW269	Sunamganj	Dhanu
6	SW91.9R	Goalondo	Ganges	15	SW274	Narsingdi	Old_Brahmaptra
7	SW101	Kamarkhali	Ganges	16	SW277	Chandpur	Khowai
8	SW147	Atrai	Gorai	17	SW285	Thakurugaon	Meghna
9	SW159	Habiganj	Rupsa	18	SW301	Kaliakoir	Lower-Meghna

Source: Flash Flood Early Warning System website (http://geo.iwmbd.com:4003/)

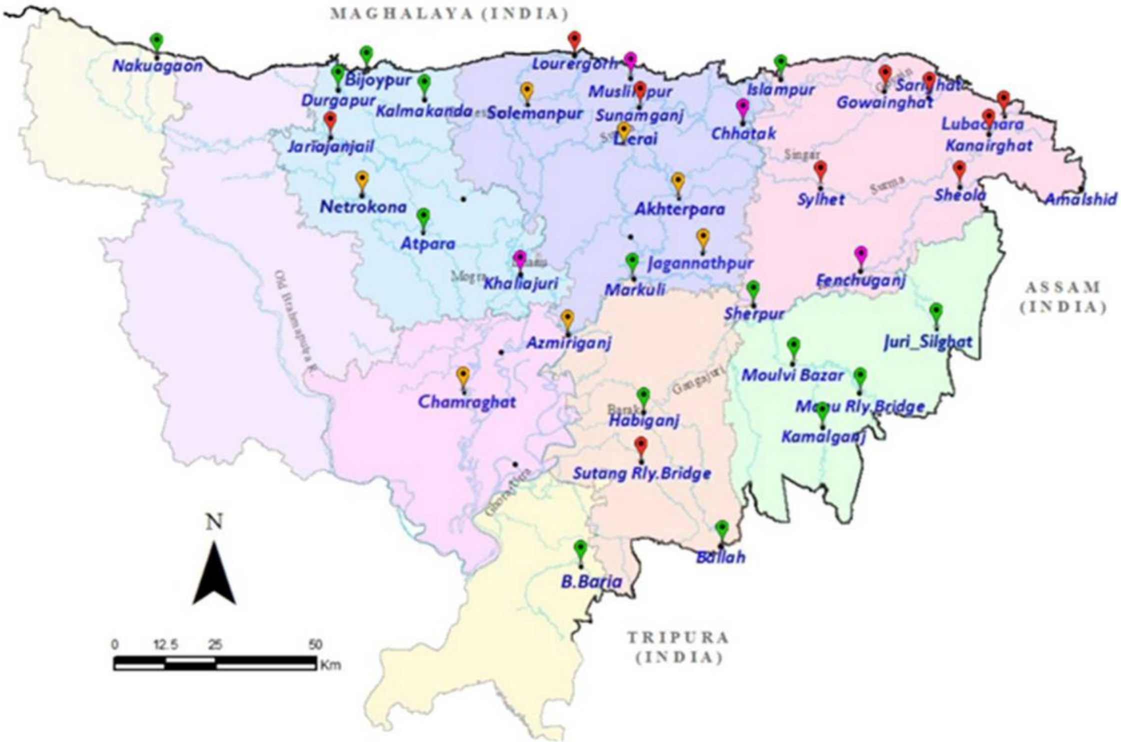
Figure 3 Location of 18 Water Level Stations

Table 3 **Flood Water Levels by Probability Scale**

Station ID	Station Name	Water Level (MSL)					
		Danger Level	5-year	10-year	20-year	50-year	100-year
SW18	Barisal	2.10	2.30	2.42	2.52	2.64	2.72
SW45.5	Chilmari	23.25	23.99	24.21	24.38	24.57	24.69
SW49A	Kazipur	14.80	15.54	15.72	15.83	15.91	15.95
SW72	KhaliaJuri	6.55	6.77	7.16	7.53	8.01	8.37
SW88	Rajshahi	18.05	18.03	18.43	18.77	19.17	19.43
SW91.9R	Goalondo	8.20	8.78	9.03	9.24	9.48	9.64
SW101	Kamarkhali	7.75	7.79	7.98	8.14	8.32	8.45
SW147	Atrai	13.25	13.69	13.84	13.93	14.00	14.04
SW159	Habiganj	9.05	10.38	10.75	11.03	11.33	11.50
SW175.5	Sherpur-Sylet	8.55	8.47	8.66	8.82	9.02	9.15
SW228.5	Mymensingh	12.05	11.56	11.97	12.24	12.49	12.61
SW241	Khulna	2.60	2.74	2.84	2.93	3.03	3.10
SW267	Sylhet	10.80	10.80	11.03	11.24	11.50	11.68
SW269	Sunamganj	7.80	8.31	8.48	8.61	8.77	8.87
SW274	Narsingdi	5.25	5.20	5.55	5.89	6.33	6.66
SW277	Chandpur	3.55	4.44	4.70	4.95	5.27	5.51
SW285	Thakurugaon	49.95	50.07	50.31	50.50	50.69	50.81
SW301	Kaliakoir	7.95	7.51	8.10	8.65	9.37	9.91

Source: Calculated by JICA Expert Team Based on the Information from FFWC

In case of Pre-monsoon Danger Levels at each water level station, they can be obtained from Flash Flood Early Warning System website as follows:



Source: Flash Flood Early Warning System website (http://geo.iwmbd.com:4003/)

Figure 4 Location of Water Level Stations in North-East Region

Station	Pre-monsoon Danger Level (MSL)	Station	Pre-monsoon Danger Level (MSL)
Lourergorh	5.95	Kalmakanda	4.90
Ballah	21.20	Jariajanjail	6.35
Sutang_RB	4.95	Durgapur	10.80
Azmiriganj	4.55	Nakuagaon	20.80
Khaliajuri	4.15	Habiganj	8.65
Markuli	5.95	Lubachara	12.45
Sherpur	7.80	Gowainghat	8.65
Kamalganj	19.05	Juri_Silgbat	10.35
Moulvi-Bazar	9.55	Chhatak	7.40
Manu-RB	16.45	Derai	5.50
Fenchuganj	7.75	Solemanpur	5.40
Sylhet	8.30	Jagannathpur	5.40
Sheola	10.70	Akhterpara	5.40
Kanaighat	10.90	B-Baria	5.05
Muslimpur	6.45	Chamraghat	2.50
Sarighat	10.70	Atpara	5.80
Islampur	10.25	Netrokona	5.50
Sunamganj	6.05	Bijoypur	14.30

Table 4 Pre-monsoon Danger Levels in North-East Region

Source: Flash Flood Early Warning System website (http://geo.iwmbd.com:4003/)

2.4.2.3. Inter and Extrapolation of Point-wise Data

The point-wise water level data will be converted into surface data. It will be processed with GIS software.

QGIS Command: IDW interpolation

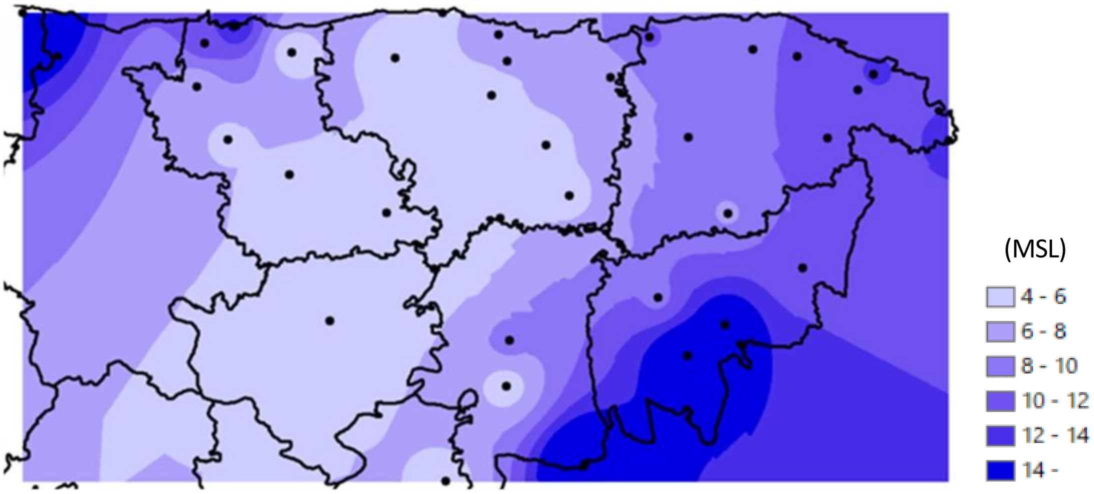


Figure 5 Example of Surface Flood Level Map

2.5. Topographic Conditions

2.5.1. DEM Acquisition

There are some options of satellite-based digital topographic elevation models (DEMs). The thing to note is that these products are basically a result of acquisition of earth surface profile, which includes forest, vegetation and buildings. Hence it doesn't often coincide with the profile of ground surface elevation.

Recently, there have been some improved products by removing or reducing the effect of vegetation's and buildings as well as other intrinsic errors, using advanced technologies like machine learning. In this guideline, the following satellite-based DEMs are recommended to use for analysis.

Table 5 Available DEM Data

Product Name	Item	Description
AW3D	Publisher	NTT DATA Corporation and RESTEC
	Resolution	0.5m – 2.5m (High Resolution Products) Approx. 30m (Published Products)
	Data Source	https://www.aw3d.jp/en/products/
	Remarks	To use high resolution products, users need to purchase data. Although the published products are freely available, removal of vegetation and buildings are not considered in the free products.
MERIT	Publisher	University of Tokyo
	Resolution	Approx. 90m
	Data Source	(MERIT-DEM) http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/ (MERIT-HYDRO) http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/
	Remarks	(MERIT-DEM) It was developed by removing multiple error components (absolute bias, stripe noise, speckle noise, and tree height bias) from the existing spaceborne DEMs (SRTM and AW3D). (MERIT-HYDRO) It was developed based on the MERIT DEM and multiple inland water maps. It contains flow direction, flow accumulation (number of upstream drainage cells), and hydrologically adjusted elevations. Not only elevation file, flow direction and flow accumulation files are also available.
GMTED2010	Publisher	U.S. Geological Survey
	Resolution	Users can select products with 30-, 15-, and 7.5-arc-second spatial resolutions. (Approx. 900m, 450m and 220m, respectively.)
	Data Source	https://www.usgs.gov/coastal-changes-and-impacts/gmted2010 (Download) https://earthexplorer.usgs.gov/
	Remarks	The products are comprised of several layers: minimum elevation, maximum elevation, mean elevation and some others. In this guideline, in the light of avoiding the influence of building, infrastructure and vegetation above ground level, usage of minimum elevation is generally recommended.
FABDEM	Publisher	University of Bristol
	Resolution	Approx. 30m
	Data Source	https://data.bris.ac.uk/data/dataset/25wfy0f9ukoge2gs7a5mqpq2j7
	Remarks	-
SoB Topographic Data	Publisher	Survey of Bangladesh
	Resolution	Approx. 500m
	Data Source	-
	Remarks	The recent topographic characteristics are not reflected into the products because It has been prepared several decades ago. However, it is still helpful to know actual ground elevation and check the accuracy of other DEM products.

- After downloading the DEM data from data source, open the file with QGIS.
- The original DEM data usually contains much extensive information more than those needed for analysis. Therefore, it is recommended that the areas necessary for the analysis be clipped out for efficient data processing in the subsequent steps.

- QGIS Desktop with GRASS → Clip raster by mask layer

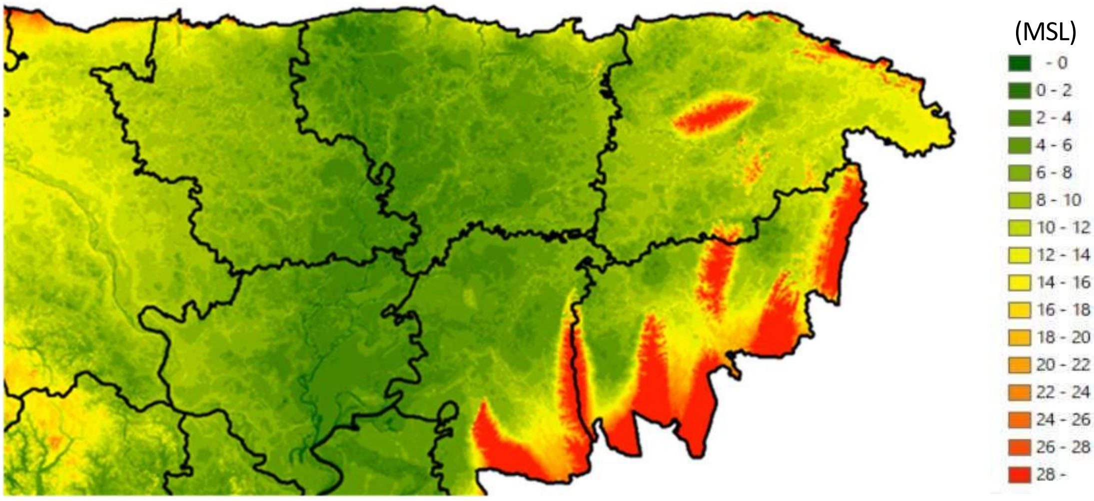


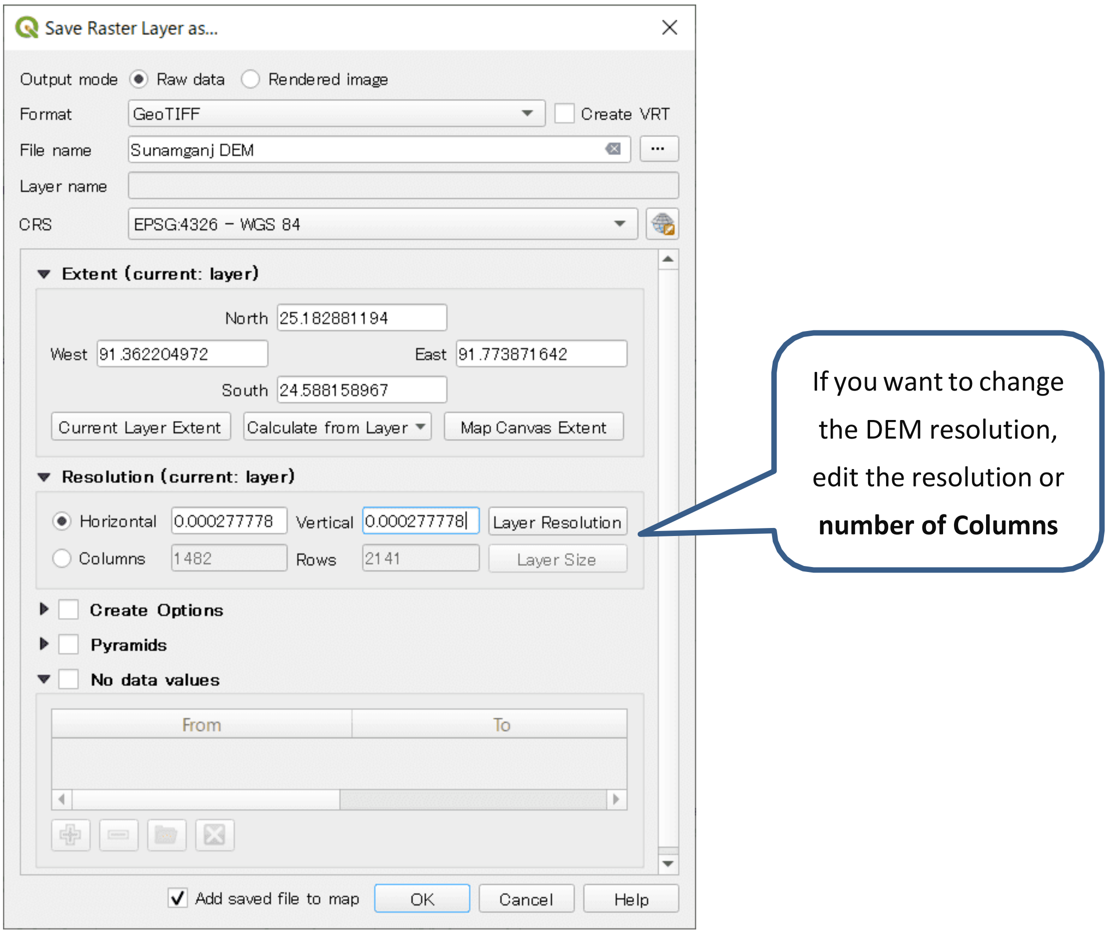
Figure 6 Example of DEM (FABDEM: North Eastern Region)

2.5.2 Upscaling of DEM

The resolution of the original DEMs is often 30 m (1 acres) or less, reflecting the river channel geometry and floodplain elevation distribution in detail. On the other hand, depending on the size of the area to be analyzed, it is often not practical to perform analysis under detailed topographic conditions due to the limitation of computation time and machine storage.

Therefore, the resolution of terrain data should be lowered to the extent that computation can be practically performed. It should be noted, however, that there is a trade-off between the lowering resolution and the sophistication of topographic information. The detailed topographic information that the original DEMs possessed may be lost due to smoothing as a result of lowering resolution.

QGIS Command: Select Target DEM Raster → Export → Save Raster Layer as…



2.6. Creation of Flood Hazard Map

2.6.1. Flood Situation without Countermeasures

Based on the flood level map explained in the section 2.4 and digital elevation map explained in the section 2.5, flood hazard map will be prepared by overlapping them and calculating the level difference of these two maps. It will be processed with GIS software.

Flood Depth = Flood Surface Level – Ground Level

QGIS Command: Raster Calculator

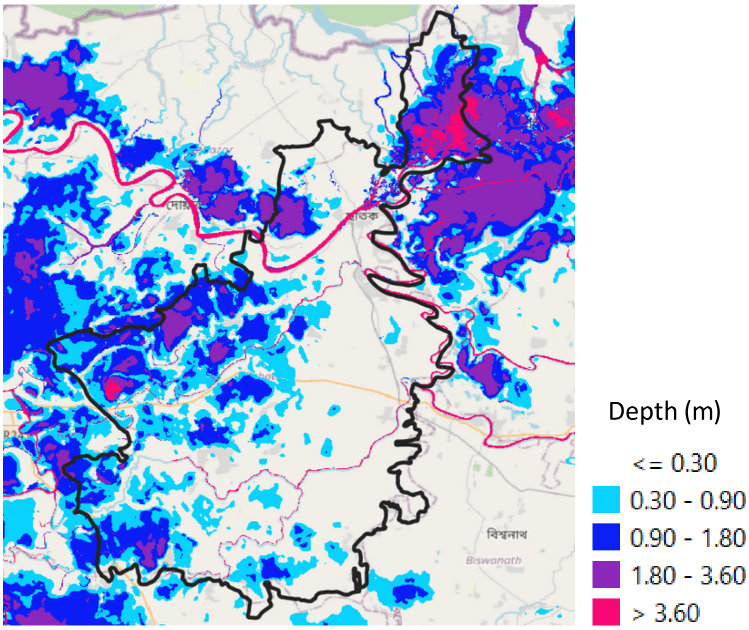


Figure Example of Flood Hazard Map (Chhatak)

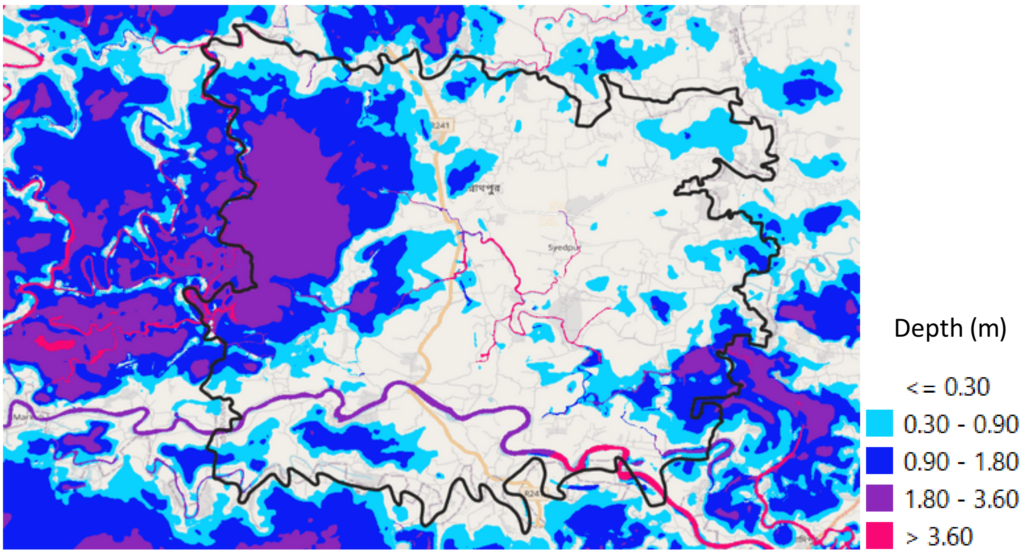


Figure 8 Example of Flood Hazard Map (Chhatak)

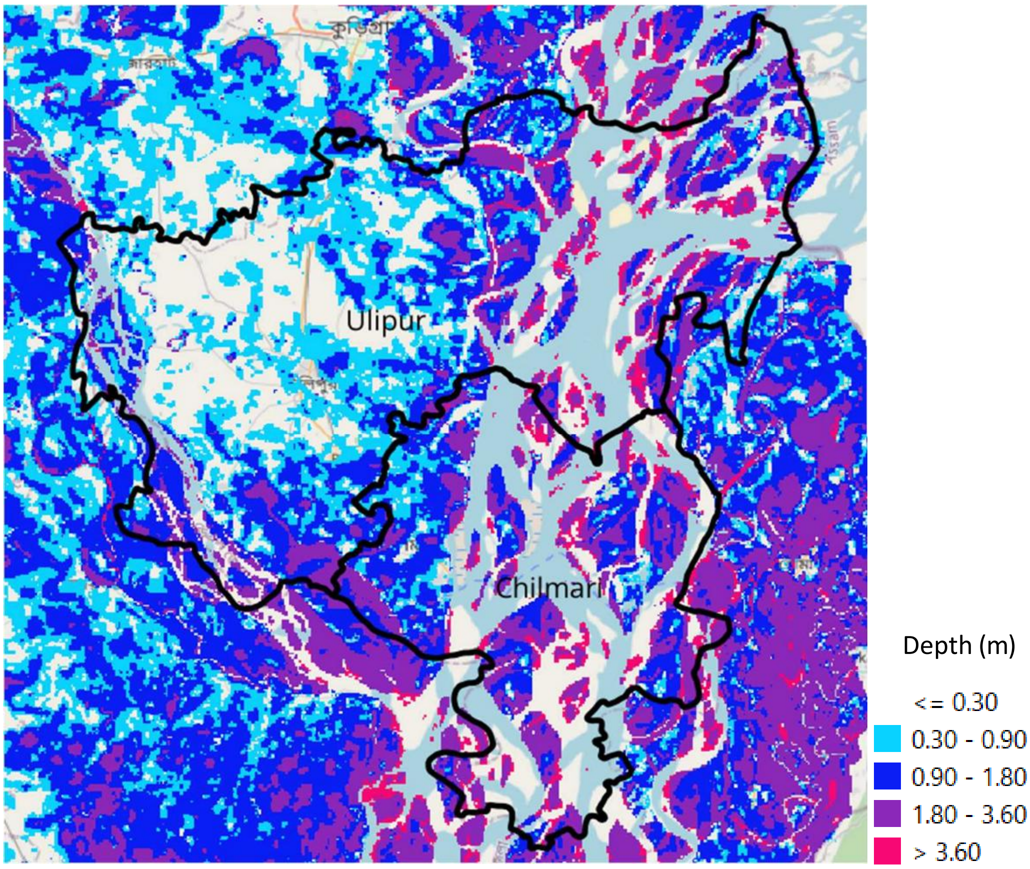


Figure 9 Example of Flood Hazard Map (Ulipur and Chilmari)

2.6.2. Flood Situation with Countermeasures

Users can prepare flood hazard maps in consideration with countermeasures under some assumptions. One of the approach is to assume that the areas 15 explanation by embankments/polders would be not inundated. We can visualize such situation by simple GIS software operation after preparing GIS Polygon files which cover the areas assumed to be non-flooding.

However, it should be noted that the detailed water movement and locations of infrastructure are not considered in the simplified method. Therefore, the maps produced by the method might not fully represent actual flood situation. If the difference is not negligible, users can consider to modify produced flood hazard maps by clipping out (masking) some locally flood areas where they are actually non-flooded areas verified through site investigation.

QGIS Command: Clip Raster by Mask Layer

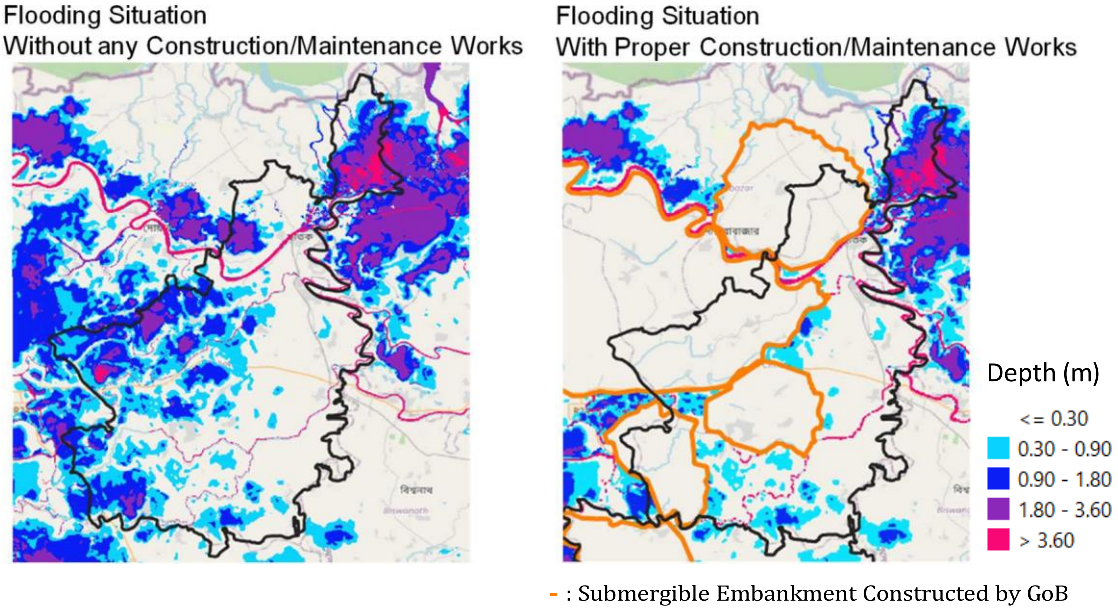


Figure 10 Comparison of Flood Hazard Map (Chhatak)

3. Hydrological and Hydraulic Analysis (Advanced Method)

In this chapter, a methodology for creating flood hazard map by conducting hydrological and hydraulic analysis is outlined. The explanation in this chapter is compiled with reference to the "Rainfall-Runoff-Inundation Model User's Manual ver. 1.4.2.5", published by the International Center for Water Hazard and Risk Management (ICHARM).

This manual focuses on providing key consideration in the collection and preparation of hydrological and topographic data necessary for RRI simulation with the aim of making hazard mapping as simple as possible for DRR personnel at the Upazila level, taking into account data availability in Bangladesh. If users need more detailed and comprehensive 17xplanation, see the RRI Model User's Manual mentioned above.

3.1. Overview

Rainfall-Runoff-Inundation (RRI) model is a hydrological model to simulate the rainfall-runoff process and flood inundation simultaneously to estimate flooding area and its depth. The model covers plain flow and river channel flow.

In the RRI model, the target area is discretized into grid cells based on the digital elevation model (DEM) used as input data of the analysis. Each grid cell is recognized as slope cell. However, at a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell.

Model Features
1) RRI is a model simulating for rainfall-runoff and flood inundation simultaneously.
2) It simulates river channel flow and flood plain flow with their interactions at a river basin scale.
3) It simulates lateral subsurface flow in mountainous areas and vertical infiltration in flat areas.

(More detailed 17xplanation)

The flow on the slope grid cells is calculated with the two-dimensional (2D) diffusive wave hydraulic model, while the channel flow is calculated with the one-dimensional (1D) diffusive wave hydraulic model. For better representations of rainfall-runoff-inundation processes, the RRI model simulates lateral subsurface flow and vertical infiltration flow in addition to surface flow. The lateral subsurface flow, which is typically more important in mountainous regions, is treated in terms of the discharge-hydraulic gradient relationship, which takes into account both saturated subsurface and surface flows. On the other hand, the vertical infiltration flow is estimated by using the Green-Ampt model.

The flow interaction between the river channel and slope is estimated based on overflowing formulae, depending on water-level and levee-height conditions.

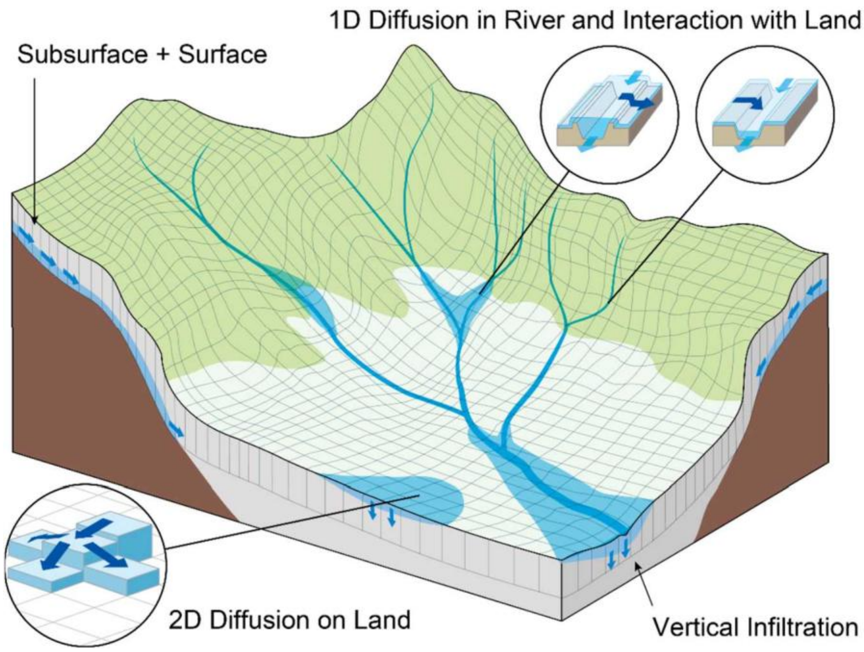


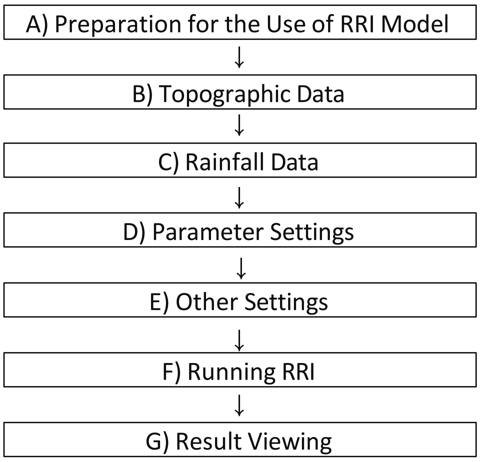
Figure 11 Schematic Diagram of RRI Model

3.2. Points to Note in RRI Model Simulation

The RRI model emphasizes the use of limited hydrologic and topographic data to reproduce and predict inundation events more easily than other conventional hydraulic analyses. Therefore, it should be noted that the analysis is based on several assumptions, for example, the channel shape is assumed to be rectangular.

3.3. Procedure Flow

The following figure shows the procedure of the RRI model simulation.



A) Installation of Tools
- RRI Model and Attached Tools
- QGIS

B) Preparation and Processing of Topographic Data
- Selection of DEM
- Modification/Adjustment of DEM
- Preparation of Flow Direction
- Preparation of Flow Accumulation
- Clip-out of Target Area
- Upscaling of Topographic Data (Optional)

C) Setting of Rainfall Intensity and Its Temporary Variation
- Setting of Rainfall Intensity and Duration
- Setting of Temporal Rainfall Distribution

D) Parameter Settings
- River Channel Parameters
- Soil Infiltration Parameters
- Numerical Analysis Parameters

E) Other Settings (Optional)
- Tidal Conditions
- Evapotranspiration
- Embankment Setting

F) Running RRI
- Execution of RRI Model Simulation
- Consideration of Flood Countermeasures

G) Result Viewing
- Output of Hourly Flood Depth
- Creation of Maximum Flood Depth

Figure 12 Flow of the RRI Model Simulation

3.4. Preparation for the Use of RRI Model

To conduct RRI simulation, users are required to install the following tools:

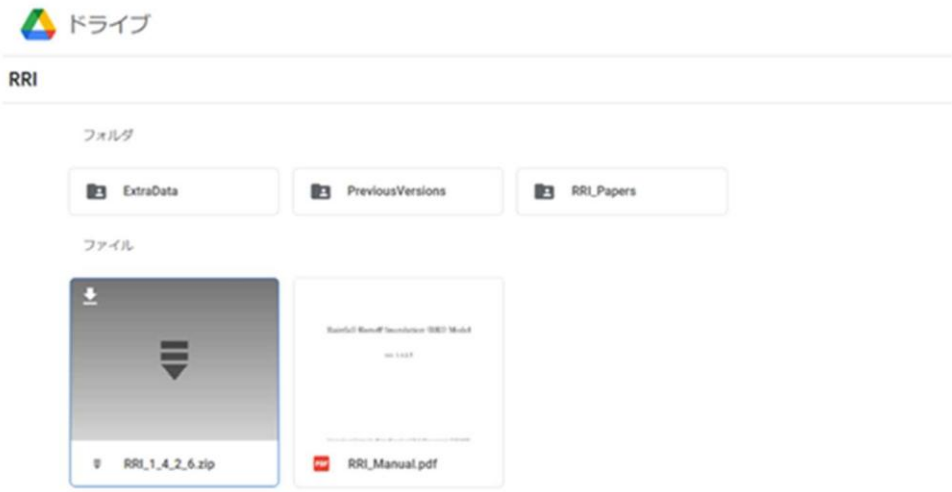
- RRI model and attached processing tools
- QGIS

3.4.1. Installation of RRI Model

RRI model and attached processing tools can be downloaded from ICHARM website below:

https://www.pwri.go.jp/icharm/research/rri/rri_top.html

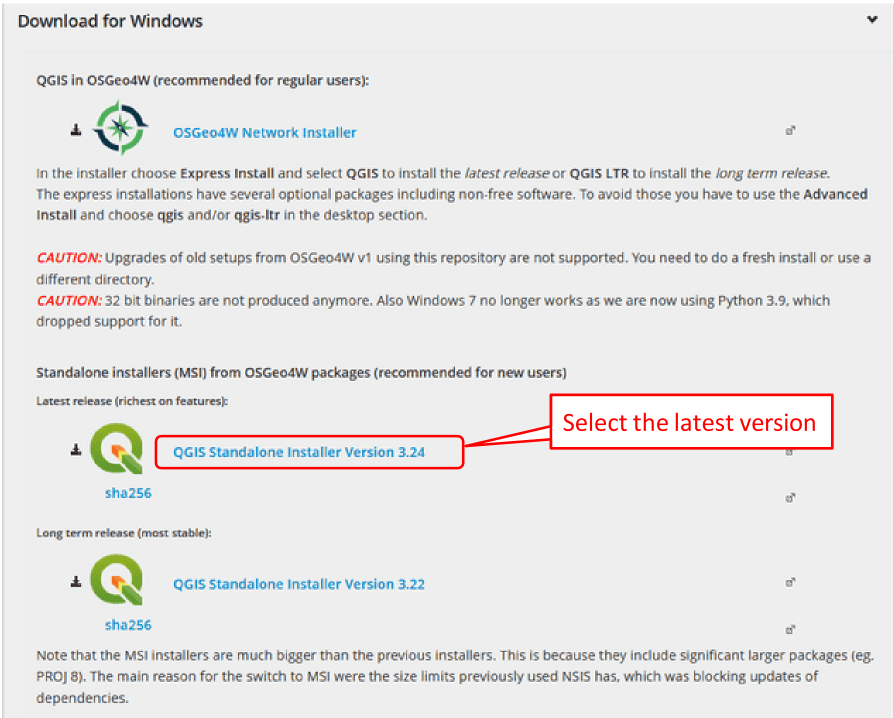
Before proceeding download, users are required to check and agree with “Terms of Use Agreement”.



3.4.2. Installation of QGIS

Download Site:

https://www.qgis.org/en/site/forusers/download.html



3.5. RRI Model Construction

3.5.1. Topographic Conditions

3.5.1.1. DEM Selection

There are some available products of satellite-based digital topographic elevation models (DEMs). The thing note is that these products are basically a result of acquisition of earth surface profile, which includes forest, vegetation and buildings. Therefore, it doesn't often coincide with the profile of ground surface elevation.

Recently, there have been some improved products by removing or reducing the influence of vegetation's and buildings as well as other intrinsic errors, using advanced technologies like machine learning. In this guideline, the following satellite-based DEMs are recommended to be used for RRI simulation.

Table 6 Available DEM Data

Product Name	Item	Description
AW3D	Publisher	NTT DATA Corporation and RESTEC
	Resolution	0.5m – 2.5m (High Resolution Products) Approx. 30m (Published Products)
	Data Source	https://www.aw3d.jp/en/products/
	Remarks	To use high resolution products, users need to purchase data. Although the published products are freely available, removal of vegetation and buildings are not considered in the free products.
MERIT	Publisher	University of Tokyo
	Resolution	Approx. 90m
	Data Source	(MERIT-DEM) http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/ (MERIT-HYDRO) http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/
	Remarks	(MERIT-DEM) It was developed by removing multiple error components (absolute bias, stripe noise, speckle noise, and tree height bias) from the existing spaceborne DEMs (SRTM and AW3D). (MERIT-HYDRO) It was developed based on the MERIT DEM and multiple inland water maps. It contains flow direction, flow accumulation (number of upstream drainage cells), and hydrologically adjusted elevations. Not only elevation file, flow direction and flow accumulation files are also available.
GMTED2010	Publisher	U.S. Geological Survey
	Resolution	Users can select products with 30-, 15-, and 7.5-arc-second spatial resolutions. (Approx. 900m, 450m and 220m, respectively.)
	Data Source	https://www.usgs.gov/coastal-changes-and-impacts/gmted2010 (Download) https://earthexplorer.usgs.gov/
	Remarks	The products are comprised of several layers: minimum elevation, maximum elevation, mean elevation and some others. In this guideline, in the light of avoiding the influence of building, infrastructure and vegetation above ground level, usage of minimum elevation is generally recommended.
FABDEM	Publisher	University of Bristol
	Resolution	Approx. 30m
	Data Source	https://data.bris.ac.uk/data/dataset/25wfy0f9ukoge2gs7a5mqpq2j7
	Remarks	-
SoB Topographic Data	Publisher	Survey of Bangladesh
	Resolution	Approx. 500m
	Data Source	-
	Remarks	The recent topographic characteristics are not reflected into the products because It has been prepared several decades ago. However, it is still helpful to know actual ground elevation and check the accuracy of other DEM products.

- After downloading the DEM data from data source, open the file with QGIS.
- The original DEM data usually contains much extensive information than those needed for analysis. Therefore, it is recommended that the areas necessary for the analysis be roughly clipped out for efficient data processing in the subsequent steps.
- At this stage, a rough clip-out of the area is enough, since the detailed area extraction will be carried out at the succeeding step based on the topographic watershed boundary of target river basin(s).

- QGIS Desktop with GRASS → Clip raster by mask layer

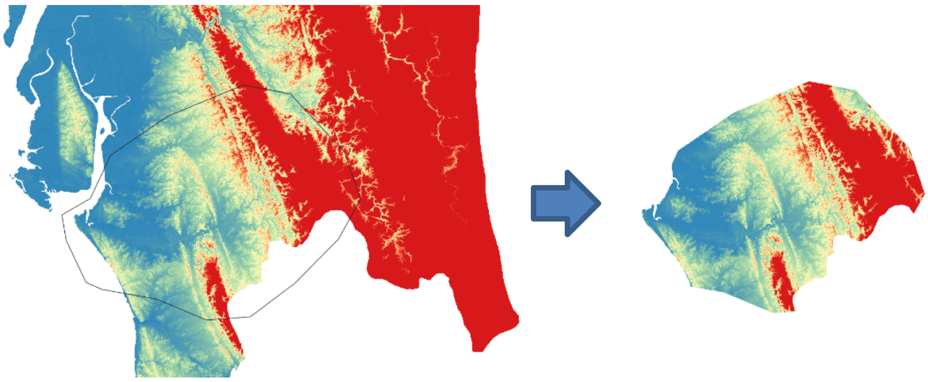


Figure 13 Rough Clip-out of DEM

3.5.1.2. DEM Adjustment

There are some hollows/sinks in the original elevation data. Some of them represent actual topographic features, while some of them are caused due to the intrinsic characteristics of DEM. For example, deep and narrow valley, in which a river flows, may be blocked by surrounding topography because of the DEM resolution. In that case, the water depths simulated with the original DEM are unrealistic.

Therefore, the following DEM adjustment is always recommended to avoid the unrealistic hollows in the original DEM.

- QGIS Desktop with GRASS → r.fill.dir

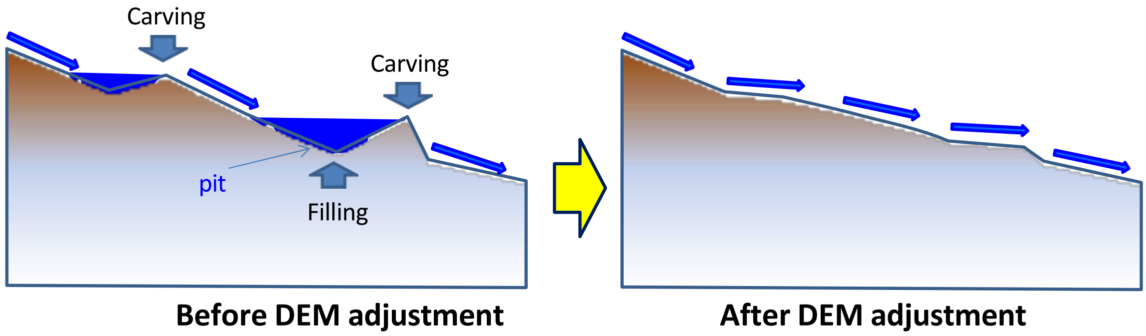


Figure 14 Concept of DEM Adjustment

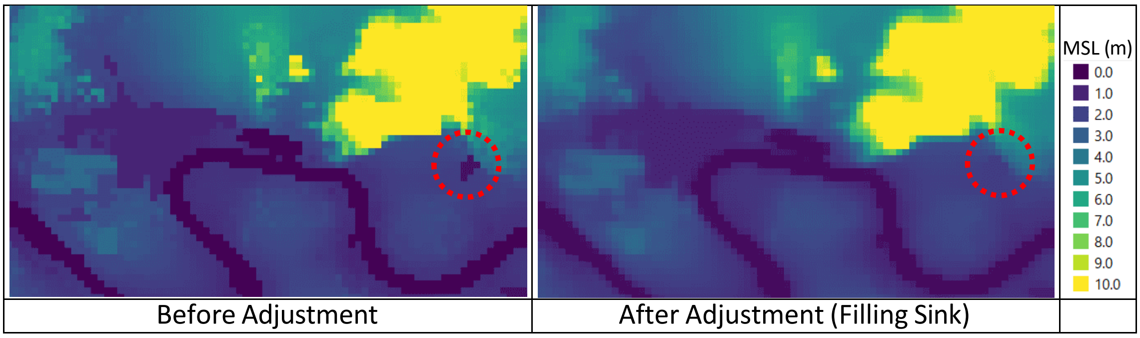


Figure 15 Example of DEM Adjustment

3.5.1.3. Flow Direction

Flow direction and flow accumulation are, as well as elevation data (DEM), the important topography data for the RRI simulation.

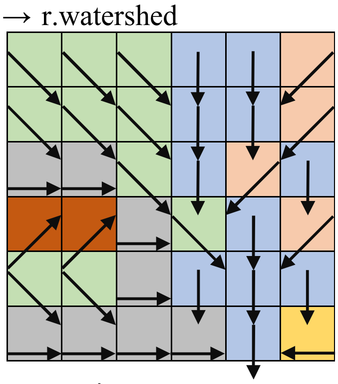
Flow direction value for each pixel means the direction in which water is flowing over that pixel as it makes its way downstream.

■ QGIS Desktop with GRASS → r.watershed

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Elevation

→



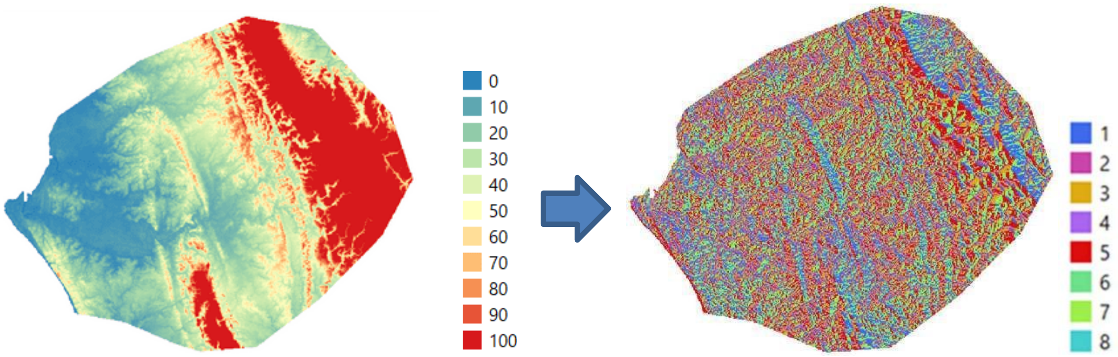
Flow Direction

→

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

Flow Direction Coding*

Figure 16 Image of Flow Direction

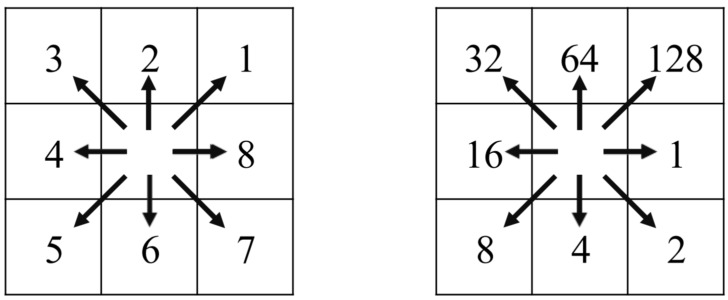


Elevation (DEM) Flow Direction

Figure 17 Preparation of Flow Direction

The flow direction code assigned in QGIS is 1 to 8, while in RRI model the flow directions are recognized as 1,2,4,8,16,32,64 and 128. Therefore, the conversion processing with QGIS is needed.

- QGIS Desktop with GRASS → Raster Calculator



Flow Direction Code as the result of "r.watershed" command in QGIS*

Flow Direction applicable to RRI Model

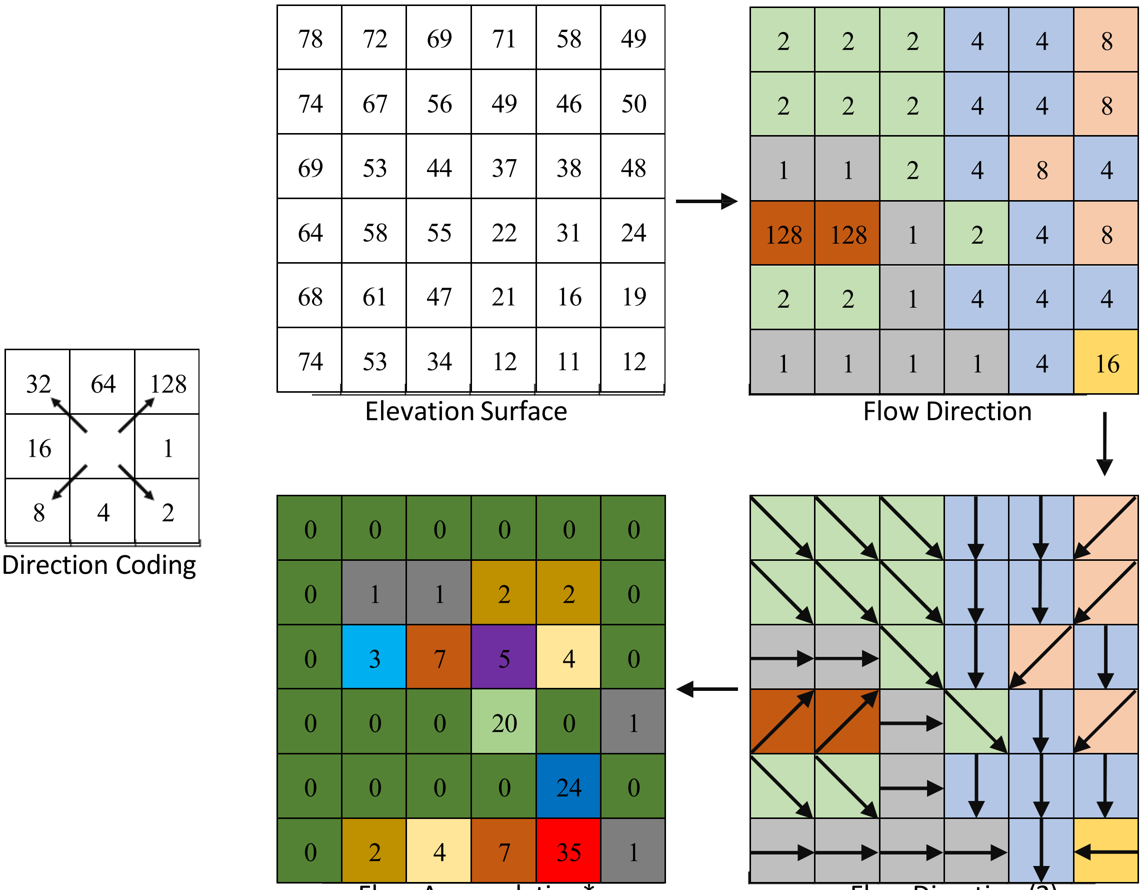
* In QGIS "r.watershed" command, negative values are sometimes accidentally assigned as flow direction code. To correct such situation, please convert them to positive values with "Raster Calculator" command. (Ex; conversion from "-5" to "5").

Figure 18 Difference of Direction Code

3.5.1.4. Flow Accumulation

Flow accumulation value for each pixel means the sum of all flows from upstream of that pixel, that is the accumulated value, indicating the magnitude of the stream that flows over that pixel.

- QGIS Desktop with GRASS → r.watershed (Same as "Flow Direction")



* In QGIS “r.watershed” command, negative values are sometimes accidentally assigned as flow accumulation number. To correct such situation, please convert them to positive values with “Raster Calculator” command. (Ex; conversion from “-500” to “500”).

Figure 19 Image of Flow Accumulation

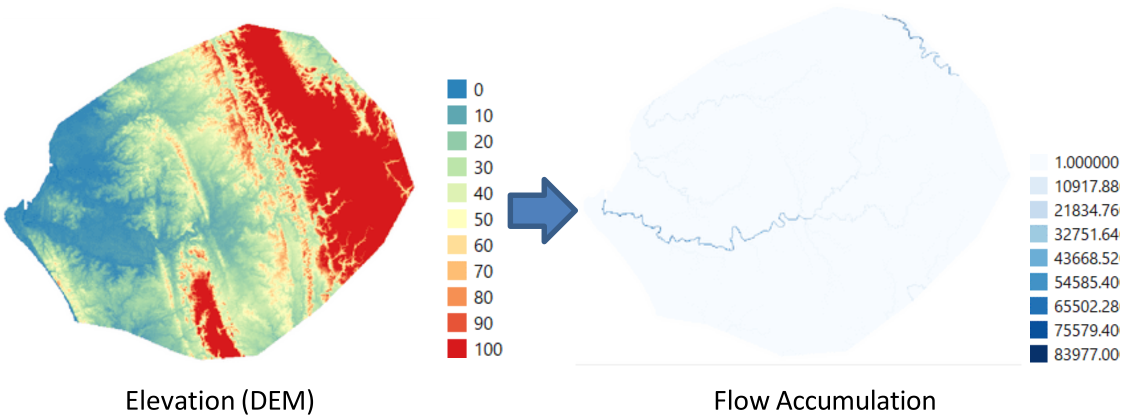


Figure 20 Preparation of Flow Accumulation

3.5.1.5. Clip-out of Target River Basins

Clip out the target river basins by using the basin shape data produced with QGIS.

- QGIS Desktop with GRASS → r.water.outlet
- QGIS Desktop with GRASS → Merge (Should be merged if target river basins are more than two)
- QGIS Desktop with GRASS → r.to.vect
- QGIS Desktop with GRASS → Clip raster by mask layer

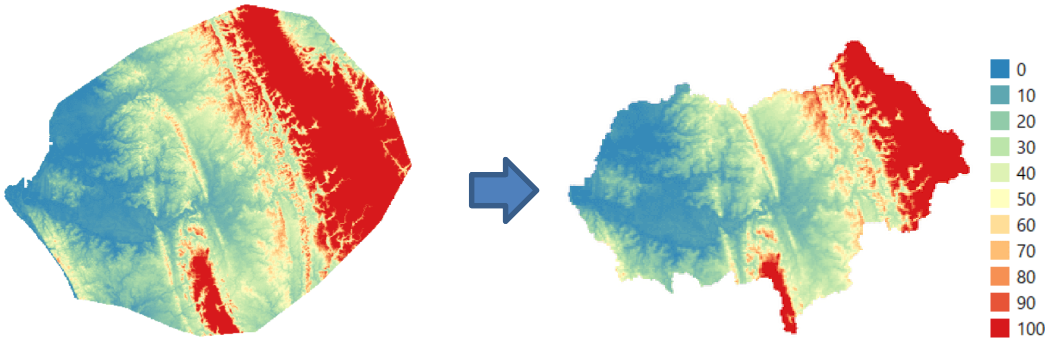


Figure 21 Clip Out of Target River Basins

3.5.1.6. Upscaling of DEM, DIR and ACC

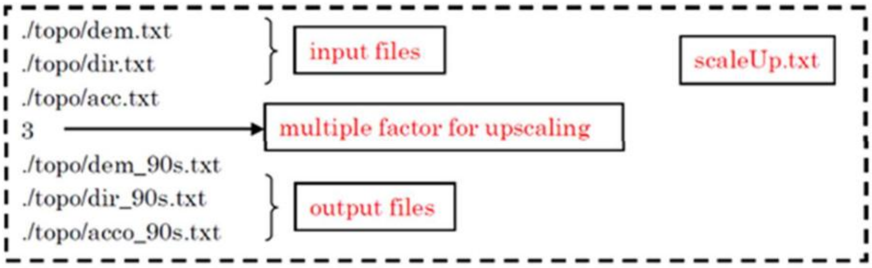
The resolution of the original DEMs is often 30 m (1 arcsec) or less, reflecting the river channel geometry and floodplain elevation distribution in detail. On the other hand, depending on the size of the area to be analyzed, it is often not practical to perform hydraulic analysis under detailed topographic conditions due to the increase of computation time.

Therefore, the resolution of terrain data should be decreased to the extent that calculations can be practical. It should be noted, however, that there is a trade-off between the resolution reduction and the sophistication of topographic information. The detailed topographic information that the original DEMs has had may be lost due to smoothing as a result of resolution reduction.

If users need to lower the resolutions of the topography files (Upscaling), users can use a program called "scaleUp.exe", one of the toolset prepared by ICHARM. By specifying a multiple factor for upscaling the resolution, the program outputs new dem, dir and acc based on the original topography files. For example, if the spatial resolutions of the topography files are 30 sec and the specified multiple factor is 3, the program creates the topography files having 90 sec (30s x 3). The following shows the procedure to use the program.

- Upscaling of DEM, DIR and ACC → scaleUp.exe (One of the toolset provided by ICHARM, which is downloadable along with RRI model)

① Copy "scaleUp.txt" file from "RRI-CUI/etc/scaleUp/" and save it under your project folder (e.g. RRI-CUI/Project/solo30s/)



② Type in "scaleUp.exe" and return to execute scaleUp.exe program and find the created three sets of the topographic data indicated in L5, L6 and L7 in scaleUp.txt

3.5.1.7. Export as RRI Input Format

The DEM, Dir, ACC raster files should be converted to ASCII format as RRI input files.

- QGIS Command: Raster > Conversion > Translate (Convert Format) (Select *.asc as an output data type)

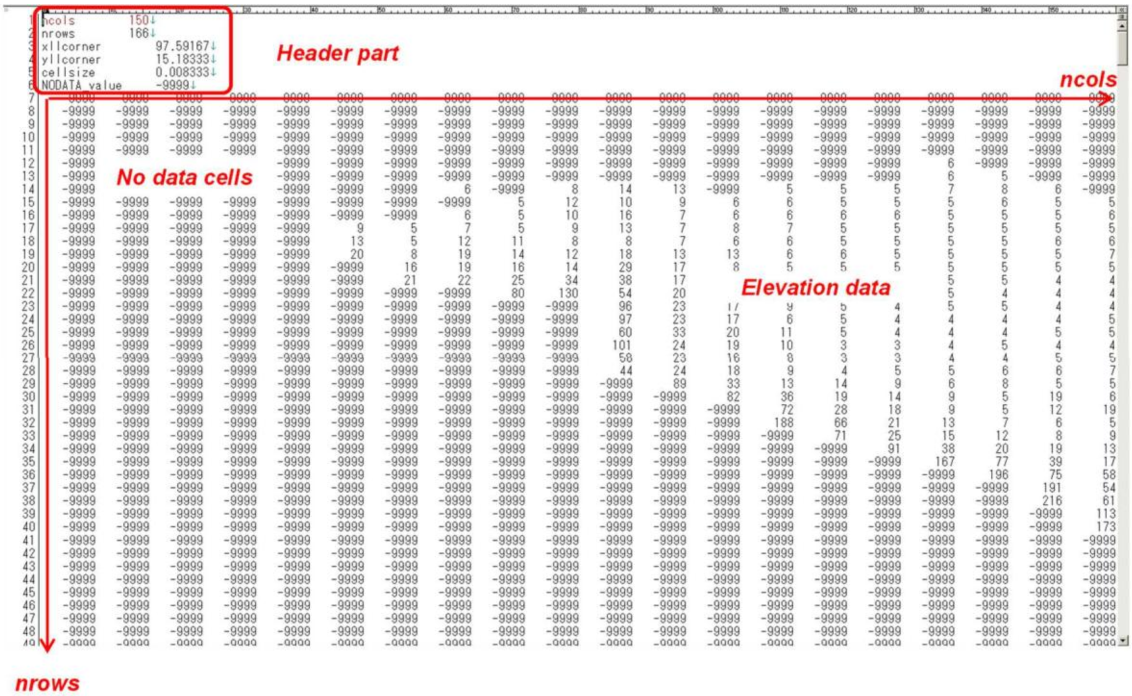


Figure 22 Ascii File Format

3.5.2. Rainfall Conditions

In RRI model simulation, users need to prepare rainfall data set with temporal and special variasion based on the gauged rainfall, rainfall intensity formula proposed in existing hydrological study, or satellite based rainfall such as GSMaP and 3B42RT, as far as it follows a specified data format.

3.5.2.1. Rainfall Occurrence Probability

For the purpose of simulating a flooding situation in case of an intensive rare flood event, it is recommended to set a certain occurrence probabilities of rainfall. In BWDB design guideline, it is instructed that target flood probability be defined in accordance with Table 7. Therefore, in principle, target rainfall occurrence probability should be decided based on the criteria shown in Table 7. However, it can be adjusted and different criteria may be applied taking into account the status of social and economical development in the target area.

Table 7 Criteria for Establishing Target Flood Probability (BWDB)

- 1:20 year’s floods where agricultural damage is predominant;
- 1:100 years, flood where loss of human lives, properties and installations are predominate: In general, embankment along Jamuna, Padma and Meghna rivers shall be designed with this return period.

Source: BWDB Design Guideline 1995

3.5.2.2. Rainfall Duration

For the duration of rainfall considered as an input condition in RRI model, usually it should be decided based on the scale of catchment areas covered in the simulation as well as the recorded actual rainfall events which represents a typical rainfall characteristic of target area. In case there are no reliable information, in this manual, the rainfall duration can be set as Table 8 below, which is considered with reference to the river basin management planning practices in Japan. However, it should be noted that the rainfall characteristic in Japan is different from that in Bangladesh. Therefore, other rainfall conditions which better represent actual rainfall characteristic may be applied.

Table 8 Assumed Rainfall Duration for RRI Model Simulation

Size of River Basins	Assumed Rainfall Duration
Less than 500 km^2	24 hours
500 km^2 to 5,000 km^2	48 hours
5,000 km^2 to 10,000 km^2	72 hours
More than 10,000 km^2	Need to be Studied Based on the Rainfall – Runoff Characteristics of the Target Basins.

3.5.2.3. Rainfall Amount

Total rainfall amount corresponding to occurrence probability and duration should be set up. The most recommended approach is to refer to the rainfall intensity formula prepared by the existing hydrological study reports. For the simulation in Cox’s Bazar, for example, rainfall intensity formula studied by the "Preparatory Survey on the Matarbari Port Development (JICA, 2018)" is applicable. For other regions, "Preparatory Survey on the Cross-Border Road Network Improvement Project (JICA, 2016)" is one of the available sources to obtain rainfall intensity formula.

Another approach is to calculate the amount of rainfall corresponding to the probability set at 3.5.2.1 based on the ground observed rainfall. In this approach, the gauged rainfall data should be collected BMD, BWDB or existing hydrological study reports. With the collected data, users need to conduct statistical analysis to estimate probable rainfall corresponding to the target probability and duration set at 3.5.2.1 and 3.5.2.2 respectively.

3.5.2.4. Hyetograph (Creation of Temporal Variation of Rainfall)

The RRI model simulation requires the input rainfall with temporal variation. It significantly affects the temporal changes of water level and river discharge. In general context in Bangladesh, most of river basins are large in their catchment areas. And their temporal variation in water level and discharge are gradual. In that case, rainfall input data with daily-based temporal variation is enough to simulate the change of water level and discharge in RRI model. On the other hand, in the smaller-scale river basins located mainly in south-eastern regions, hydraulic condition changes more rapidly, so it is required to consider hourly-based rainfall variation.

In this manual, it is recommended that either of the following methods be used:

1) Specific rainfall pattern that actually occurred and observed in the past
2) Assumed centralized rainfall pattern

In the case of 1), the observed rainfall information should be collected from BMD, BWDB or existing hydrological study reports. Then users need to prepare the array of daily or hourly rainfall intensity values with location information of rainfall stations to make it fit to the specific format for RRI simulation (Figure 23). However, it is not common to observe rainfall with hourly- basis in Bangladesh.

In addition to ground gauged rainfall, RRI model has a function to download and import satellite-based rainfall. See RRI Model User's Manual for detailed information. The use of satellite rainfall is advantageous in that it can complement spatial and temporal data deficiencies, but technical issues arise in the evaluation and correction of its accuracy. For this reason, this manual is basically intended to use ground-based rainfall data.

In the case of 2), one of the applicable examples is SCS 24-hour rainfall in "Urban Hydrology for Small Watersheds" (https://nationalstormwater.com/urban-hydrology-for-small-watersheds-tr-

55/). The sample rainfall pattern is prepared based on the SCS 24-hour rainfall distribution Type III as shown in Table 9. Users can set up hyetograph by distributing total rainfall amount calculated in 3.5.2.3 according to the percentages shown in Table 9.

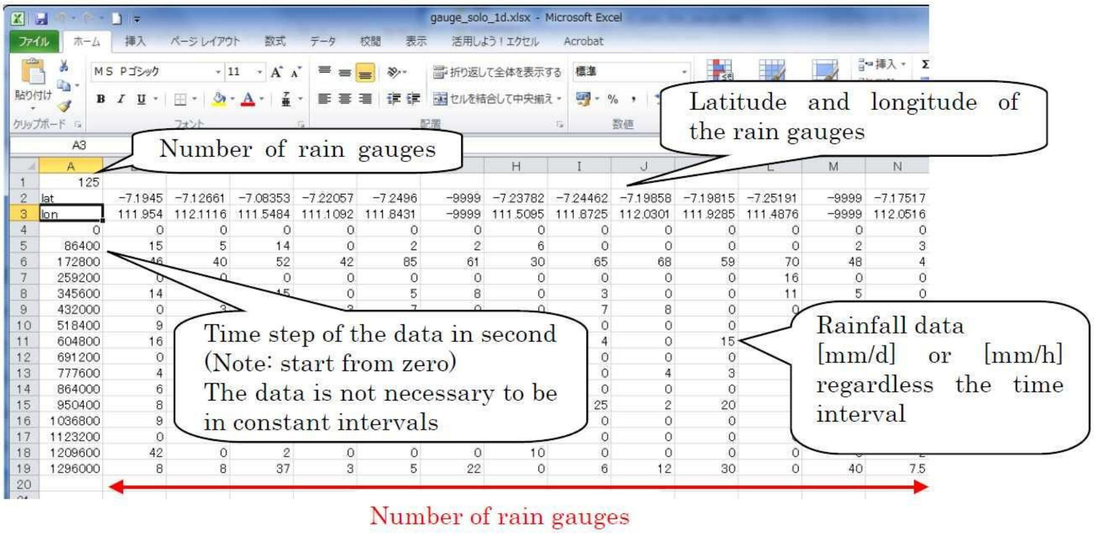


Figure 23 Setting of Rainfall Intensity

Table 9 Example of Centralized Rainfall Pattern (24hours)

hr.	% of Hourly Rainfall Intensity to Total Rainfall (mm/hr.)	hr.	% of Hourly Rainfall Intensity to Total Rainfall (mm/hr.)
1	1.000%	13	15.100%
2	1.000%	14	6.000%
3	1.150%	15	3.750%
4	1.150%	16	3.750%
5	1.450%	17	1.775%
6	1.450%	18	1.775%
7	1.700%	19	1.775%
8	2.600%	20	1.775%
9	3.300%	21	1.075%
10	4.100%	22	1.075%
11	6.100%	23	1.075%
12	35.000%	24	1.075%
Total			100 %

Source: Prepared by JET Based on "Urban Hydrology for Small Watersheds"

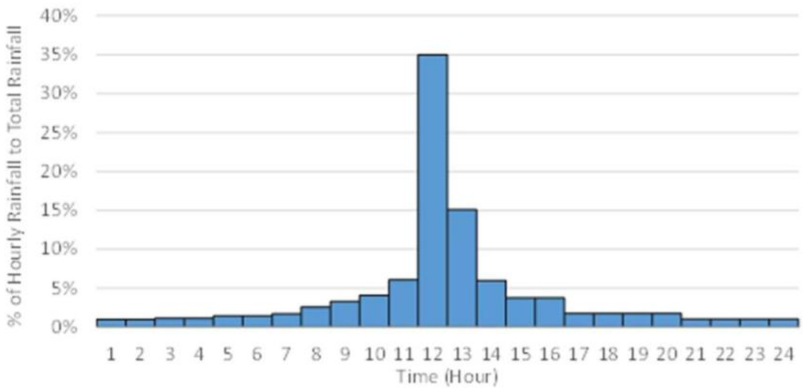


Figure 24 Example of Centralized Rainfall Pattern (24hours)

3.5.3. Parameter Settings

3.5.3.1. River Channel

In RRI model, the river channel geometry is assumed to be rectangle, whose shapes are defined by width W, depth D and embankment height where necessary. When detailed geometry information is not available, the width and depth are approximated by the following function of upstream catchment area A [km2].

$W = C_W A^{S_W}$

$D = C_D A^{S_D}$

where CW, SW, CD and SD are geometry parameters. Here the units of W and D are meters.
The following parameters are used as default settings for river channel widths and depths.
If there are available river channel data like bathymetric survey result, users can adjust the parameters to match the actual river channel geometry.

Table 10 River Channel Parameters

Geometry Parameters	Default Values
C_w	5.0
S_w	0.35
C_d	0.95
S_d	0.20
h	0

3.5.3.2. Roughness

Roughness is a common parameter in river hydraulics to represent the effect of resistance force against flow produced by river bed or floodplain conditions.
It should be decided based on the actual conditions of river channel and land areas. If there are no available information, users can set the following parameter values.

Table 11 Example of Roughness Parameter Values and Their Recommended Ranges

Parameters	Example of Parameter Values and Their Recommended Ranges
River Channel ($m^{-1/3}s$)	0.030 (0.015 – 0.040)
Land Area ($m^{-1/3}s$)	0.30 (0.15 – 1.0)

3.5.3.3. Soil Infiltration

In RRI model, there are three types of soil infiltration conditions. For each land cover class, decide (A), (B) or (C) in the following figure depending on infiltration and subsurface processes, so that the number of calibration parameters will be limited.

For case (A), where only overland flow without infiltration or subsurface flow process are considered, set both Kv and Ka equal to 0.
It is the simplest way and can be applied when users prefer to conduct rough flood estimation without much detailed model construction.

For case (B), where vertical infiltration and infiltration excess overland flow are considered.
In this case, the hydraulic conductivity for the lateral subsurface flow (parameter Ka) is set as zero, while those for vertical infiltration (parameters Kv, Sf and porosity) are set based on the available geological information.

For case (C), where saturated subsurface and saturation excess overland flow are considered. In this case, the hydraulic conductivity for vertical infiltration (parameters Kv) is set as zero, while that for lateral subsurface flow (parameters Ka) is set based on the available geological information.

- Example for Soil Conditions Setting in Bangladesh

https://en.banglapedia.org/index.php/Bangladesh_Soil

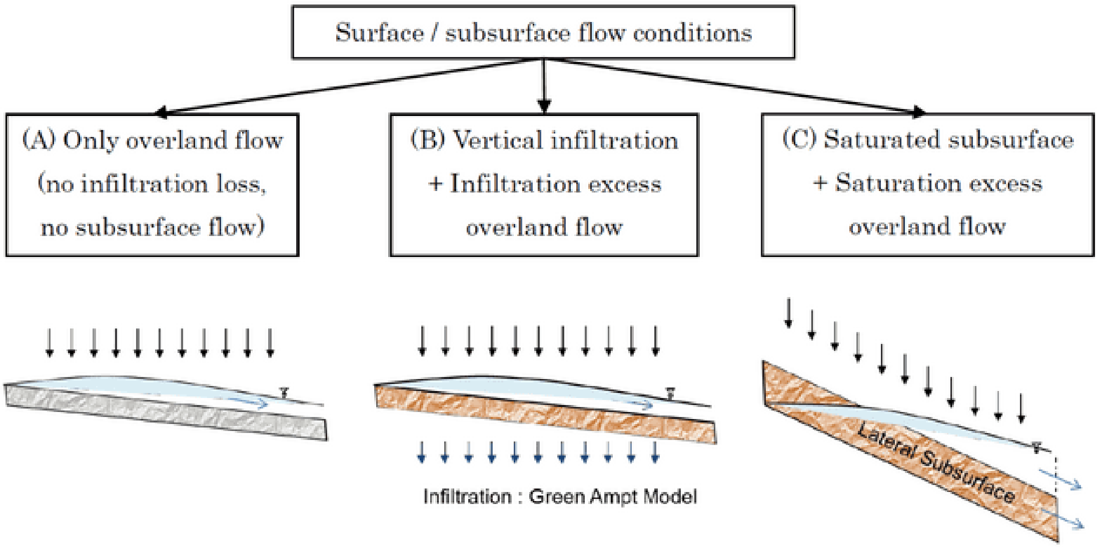


Figure 25 Options on Surface/Subsurface Flow Conditions

Table 12 Vertical Infiltration Parameters for Different Soil Texture

Reference Table : Green-Ampt Infiltration Parameters for different soil texture

Soil texture class	k_v (m/s)	ϕ [gammaa]	S_f (m)
Sand	6.54E-05	0.437	0.0495
Loamy sand	1.66E-05	0.437	0.0613
Sandy loam	6.06E-06	0.453	0.1101
Loam	3.67E-06	0.463	0.0889
Silt loam	1.89E-06	0.501	0.1668
Sandy clay loam	8.33E-07	0.398	0.2185
Clay loam	5.56E-07	0.464	0.2088
Silty clay loam	5.56E-07	0.471	0.273
Sandy clay	3.33E-07	0.43	0.239
Silty clay	2.78E-07	0.479	0.2922
Clay	1.67E-07	0.475	0.3163

It should be decided based on the actual conditions of river channel and land areas. If there are no available information, users can set the following parameter values, although they are just one example values (approximate ranges).

Table 13 Example of Soil Infiltration Parameter Values and Their Recommended Ranges

Parameters	Example of Parameter Values and Their Recommended Ranges
Soil Depth (m)	1.0 (0.5 – 2.0)
Porosity (No dimension)	0.471 (0.3 – 0.5)
K_v (m/s)	5.56 x 10^{-7}
S_f	0.273
K_a (m/s)	0.10 (0.01 – 0.30)

3.5.4. Other Settings

3.5.4.1. Tidal Conditions

Tidal influences can have a significant impact on flooding conditions, especially near the river mouth. Although setting tidal levels at river mouths is not requirement for simulation, it is recommended in low-lying areas where tidal influences are significant.

1) Find locations to provide the boundary conditions.

2) Prepare a boundary condition file with the following format.

Users need to set the value of tidal water level by referring to observed data, astronomical tide levels, or probabilistically evaluated predicted high tide levels.

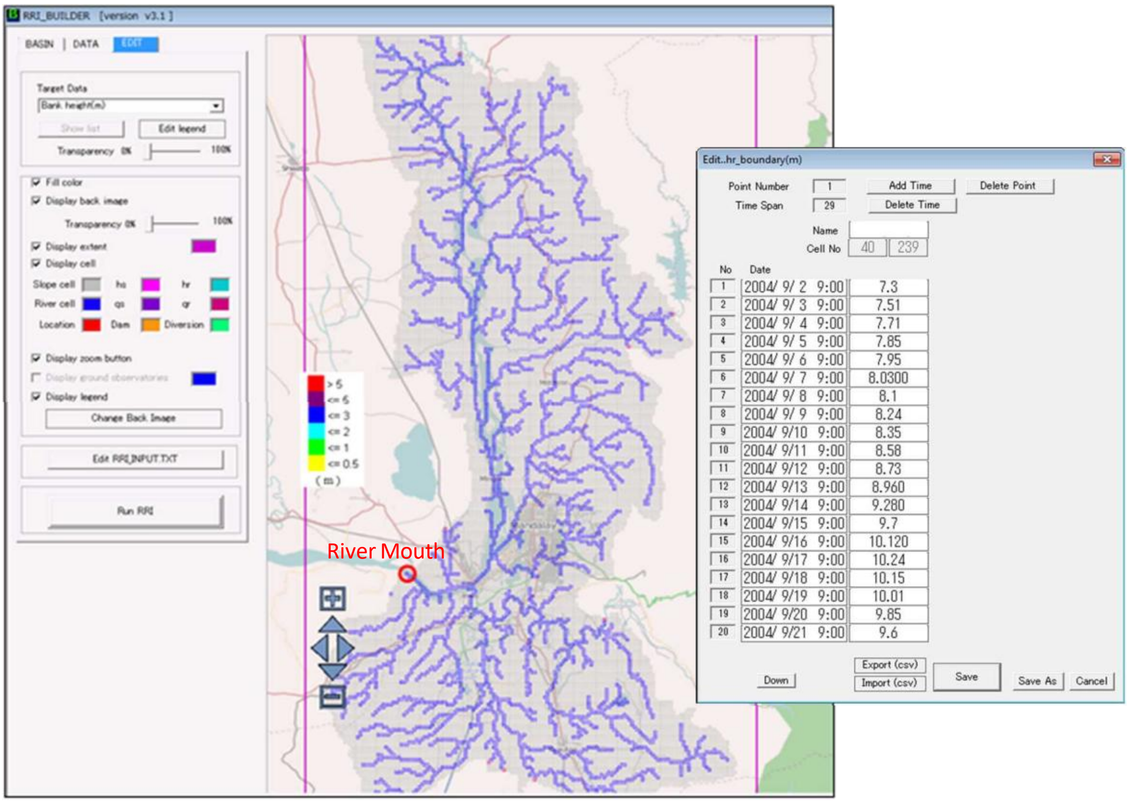


Figure 26 Preparation of Boundary Condition File

3.5.4.2. Evapotranspiration

In general, the effect of evapotranspiration is small and can be ignored when analyzing short-term flooding events of a few days, but when analyzing runoff and inundation events with large watersheds and long periods of time, it is important to reflect the effect of evapotranspiration in the model.

Current version of RRI Model does not have a function to estimate evapotranspiration from climate variables. However, by giving evapotranspiration rate as one of the input files, the model takes the equivalent amount of water from surface and subsurface storages.

The format of the evapotranspiration input is the same as rainfall. Hence the grid cell size and time step of evapotranspiration file can be arbitrary set. For example, to set the constant rate of evapotranspiration, one can prepare the following input file (e.g. evp_4mm.txt), in which the value of 0.166667 mm/h corresponds to 4 mm/d of evapotranspiration.

3.5.4.3. Embankment Setting

There are two kinds of embankment settings in RRI simulation.

A) Embankment along rivers

B) Embankment on slope grid cells

A) The first type of embankment is set as a river channel parameter. The effect of embankment is considered during the interaction of water between river and slope. To set up the first type of embankment in the simulation model, the height value (height > 0) must be set on river grid cells (width > 0). Because of the RRI Model basic structure, a river is set as a centerline of a slope grid, it is not possible to apply different embankment height for different side of the river for this option.

B) The second type of embankment represents roads, railways or other structures that prevent water to across. The spatial information of embankment was converted to raster data on QGIS with having the same resolution with topographic data. The above mentioned "height" file specified in RRI_Input.txt can contain the height information (and therefore the embankment spatial information) on slope grid cells.

Note that even if users intend to set a continuous embankment apart from a main river, if a tributary join into the river and if the "height" value is set on a river grid cell where width >0, the embankment would be regarded as the embankment of Type A. As a result, the set embankment will be discontinuous at the location.

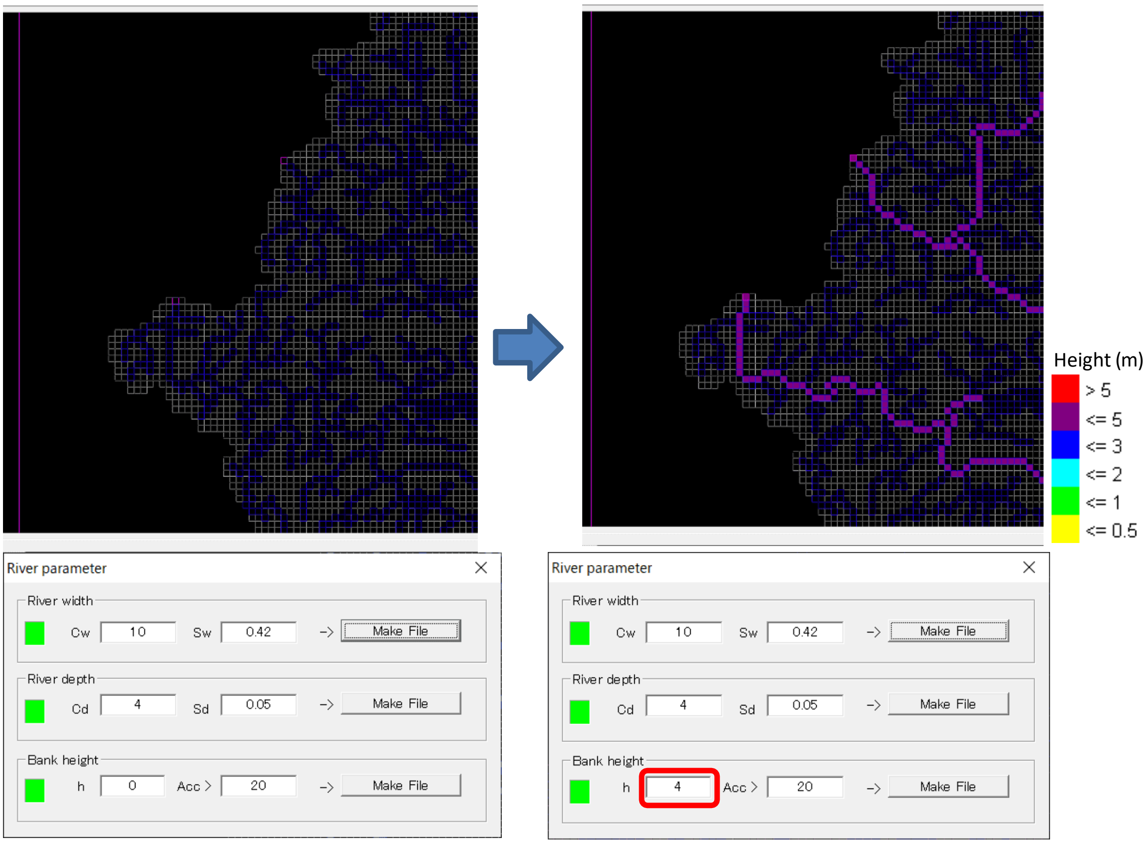


Figure 27 Example of Embankment Setting along Rivers

3.6. RRI Model Simulation

3.6.1. Execution of RRI Model Simulation

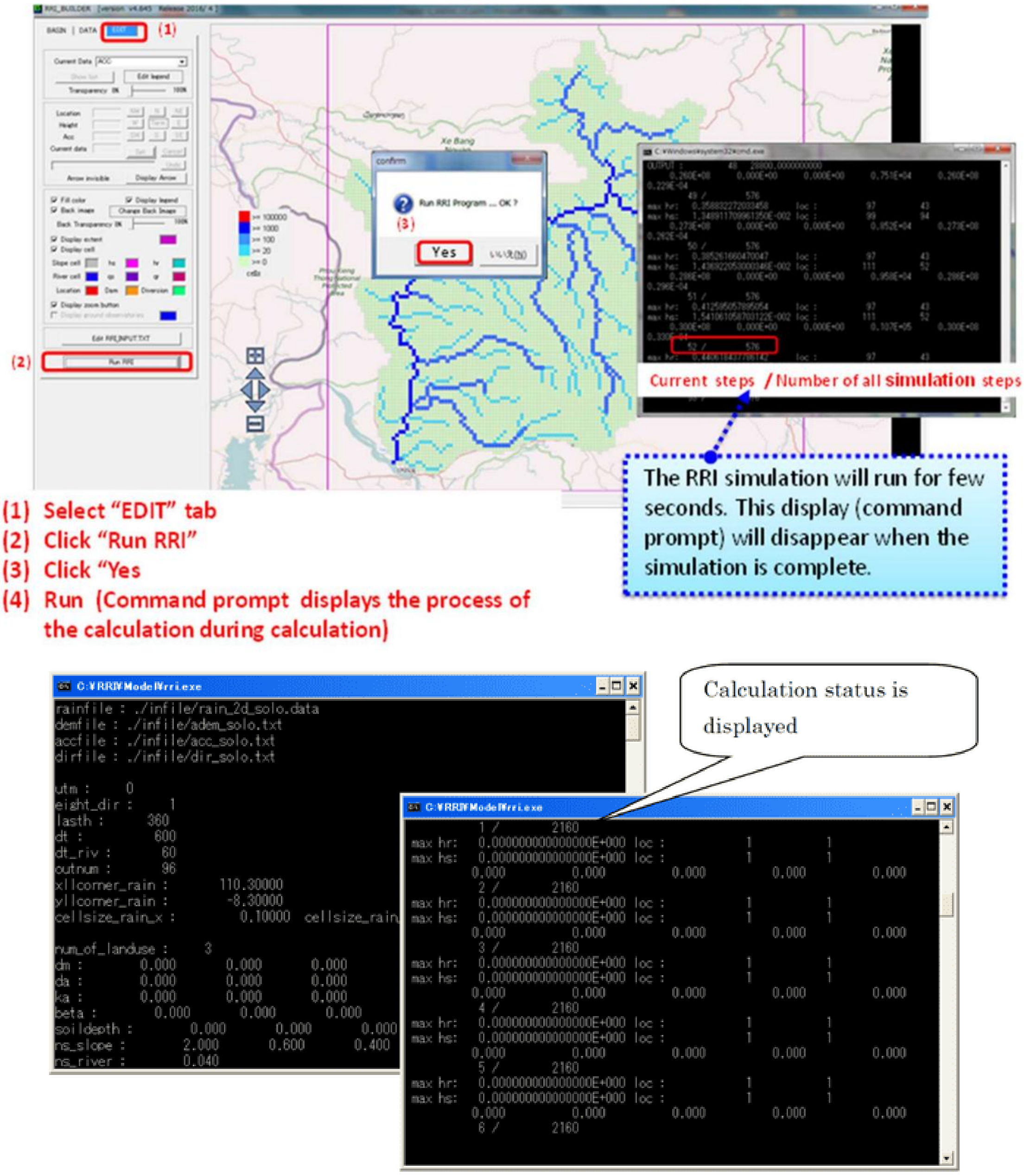


Figure 28 Sample Display of RRI Model Execution

3.6.2. Consideration of Flood Countermeasures

There are several options of flood countermeasures. In order to reflect these countermeasures in the simulation, users need to change input files which are corresponding to each countermeasure. After setting up modified input files, users will conduct the new case(s) of simulation.

Table 14 Options for Countermeasures

Countermeasures	How to Reflect in the Model
River Channel/Drainage Widening	Change the parameter of river channel
River Channel/Drainage Excavation	Change the parameter of river channel
Embankment	Change the parameter of river channel
Enhancement of Rainfall Storage Functions (Advanced)	Change the parameter of soil infiltration
Establishment of Flood Retention Area (Advanced)	Edit the DEM to make Artificial storage space

The example of river channel modification is shown in Figure 29. As described in 3.5.3.1, in RRI model, the value of river width W and depth D at each location is given as the function of upstream catchment area A. By changing the parameter of CW, SW, CD or SD, users can change the distribution of W and D within target area. If there are available river channel data like design drawings of future river widening or dredging project, users can adjust the parameters to match the planned river channel geometries.

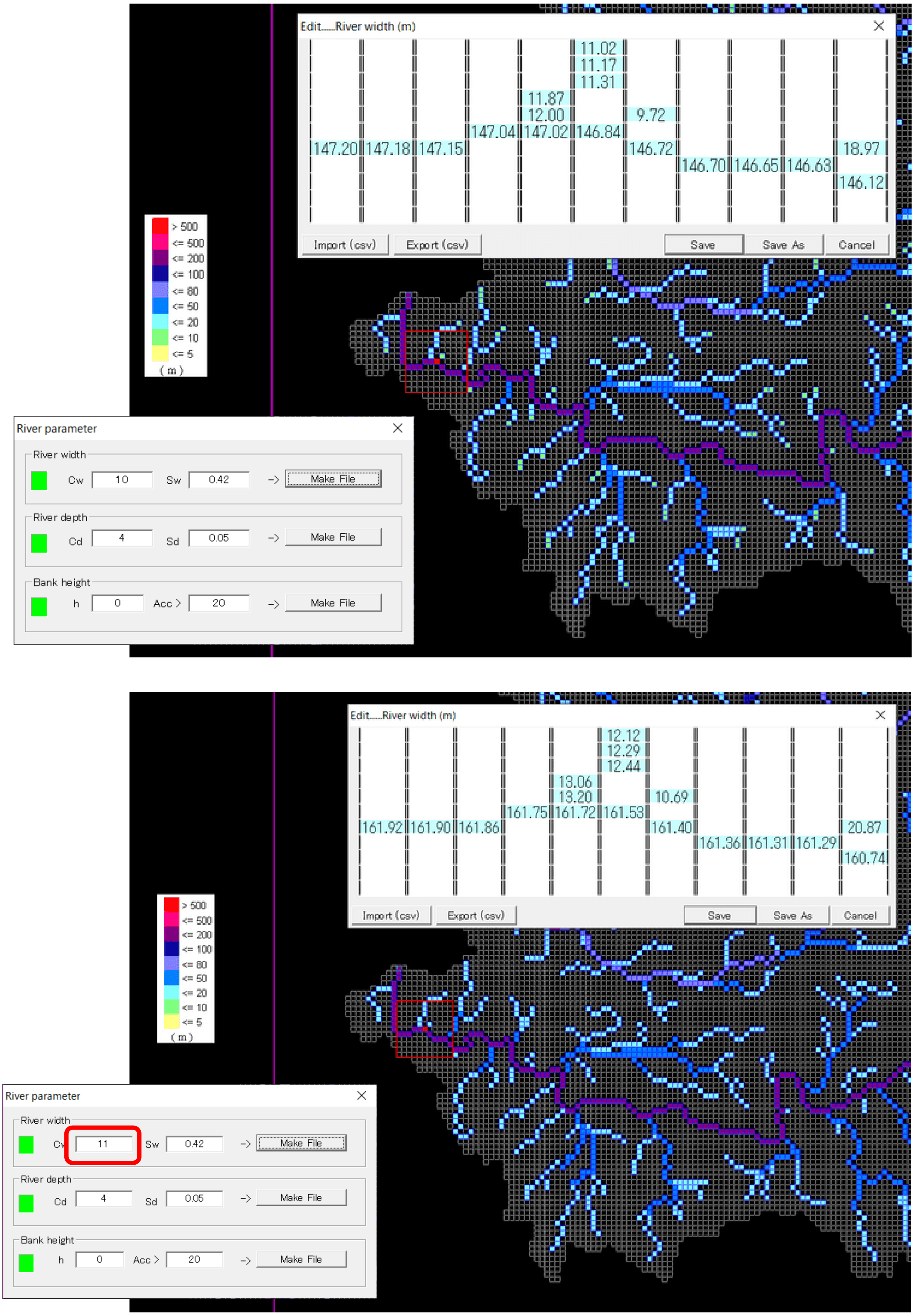


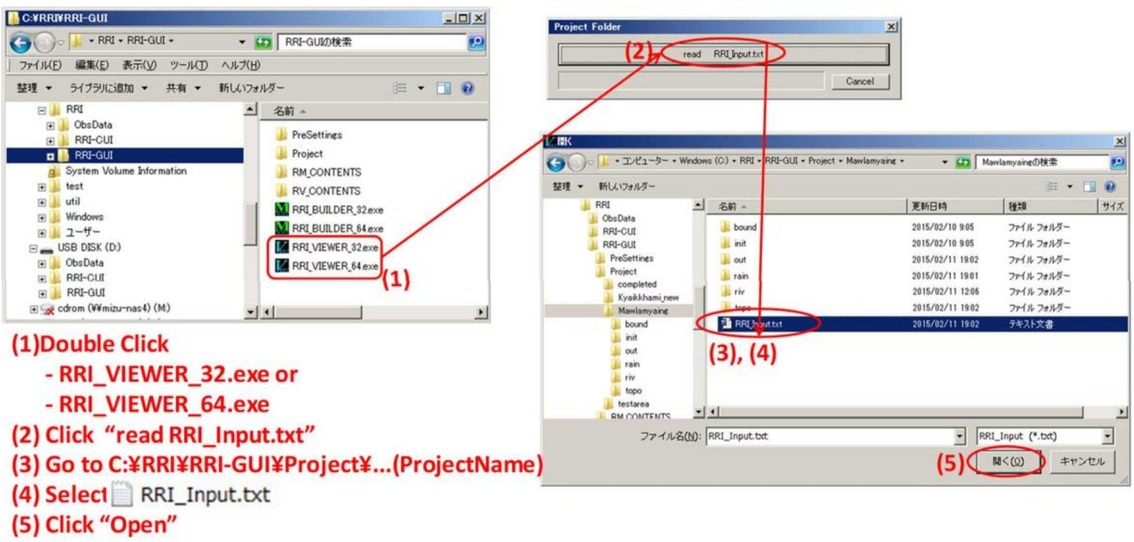
Figure 29 Example of Setting of Flood Countermeasures (River Channel Widening)

3.7. Visualization of RRI Model Results

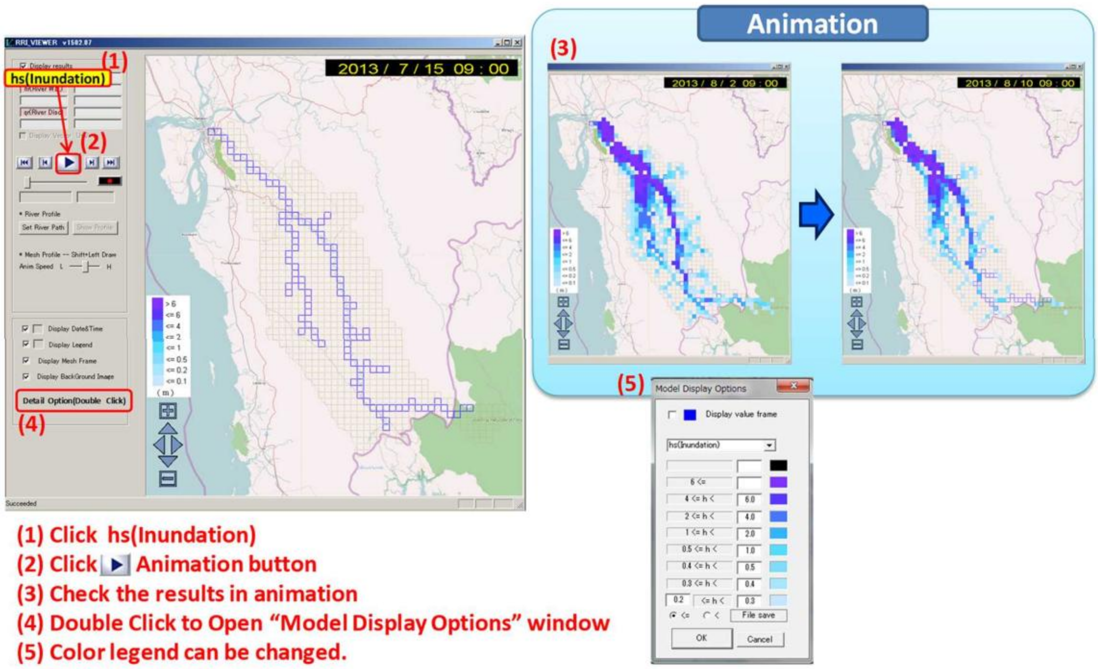
3.7.1. Processing of Output Files

The output file is visualized with RRI_VEIWER.

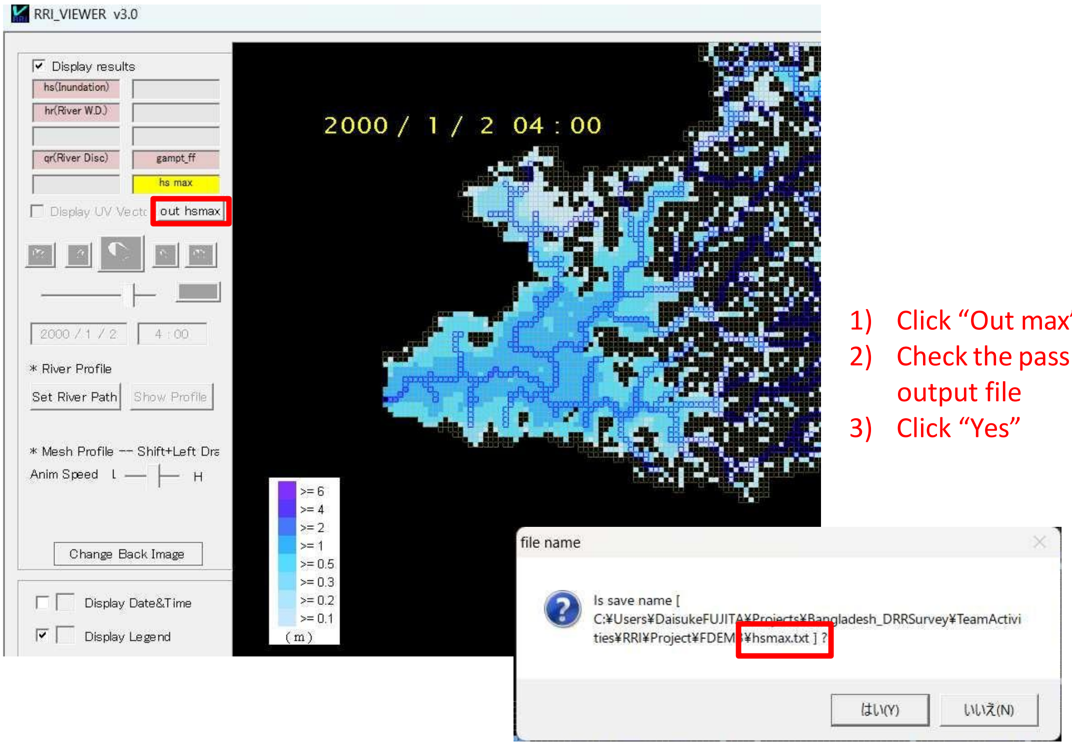
3.7.1.1. Start RRI VIEWER



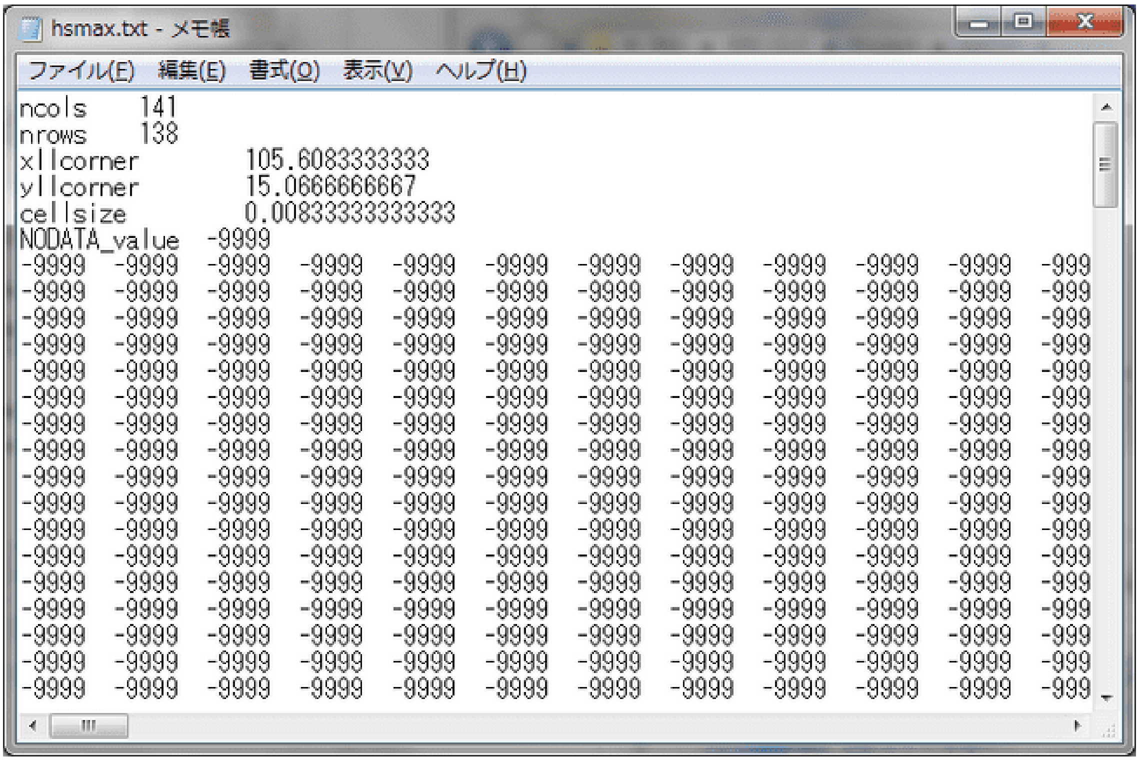
3.7.1.2. Flood Depth Animation



3.7.1.3. Output Maximum Flood Depth



1) Click "Out max"
2) Check the pass of output file
3) Click "Yes"


hsmax.txt - メモ帳

ファイル(F) 編集(E) 書式(O) 表示(V) ヘルプ(H)

```
ncols     141
nrows     138
xllcorner        105.6083333333
yllcorner        15.0666666667
cellsize         0.00833333333333
NODATA_value  -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -999
```

3.7.2. Visualization of Output Files in QGIS

Read the processed file "hsmax.txt" in QGIS.

3.7.2.1. Cox's Bazar Sadar

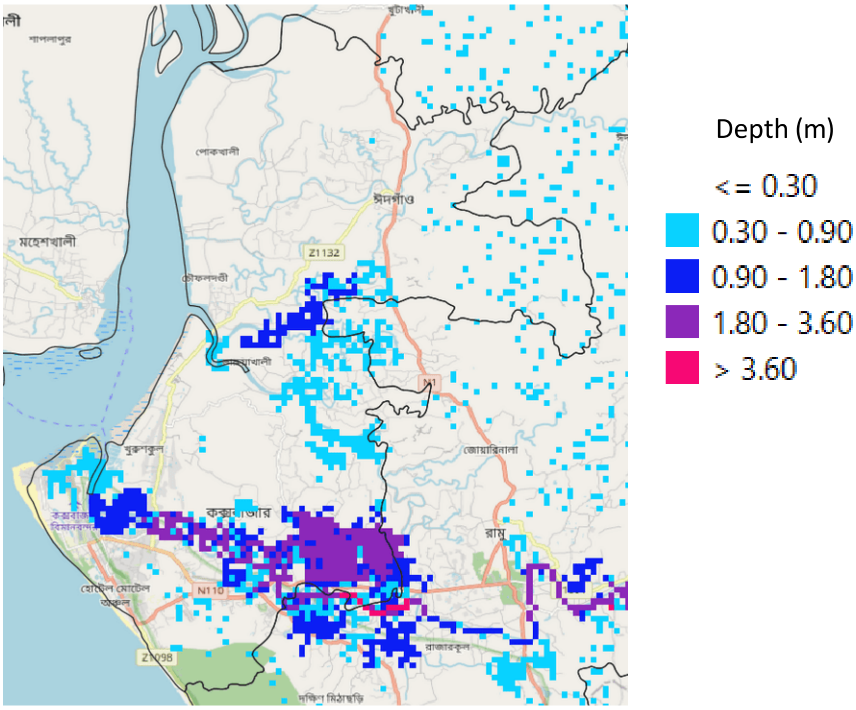


Figure 30 Sample Output of Flood Analysis (Cox's Bazar Sadar)

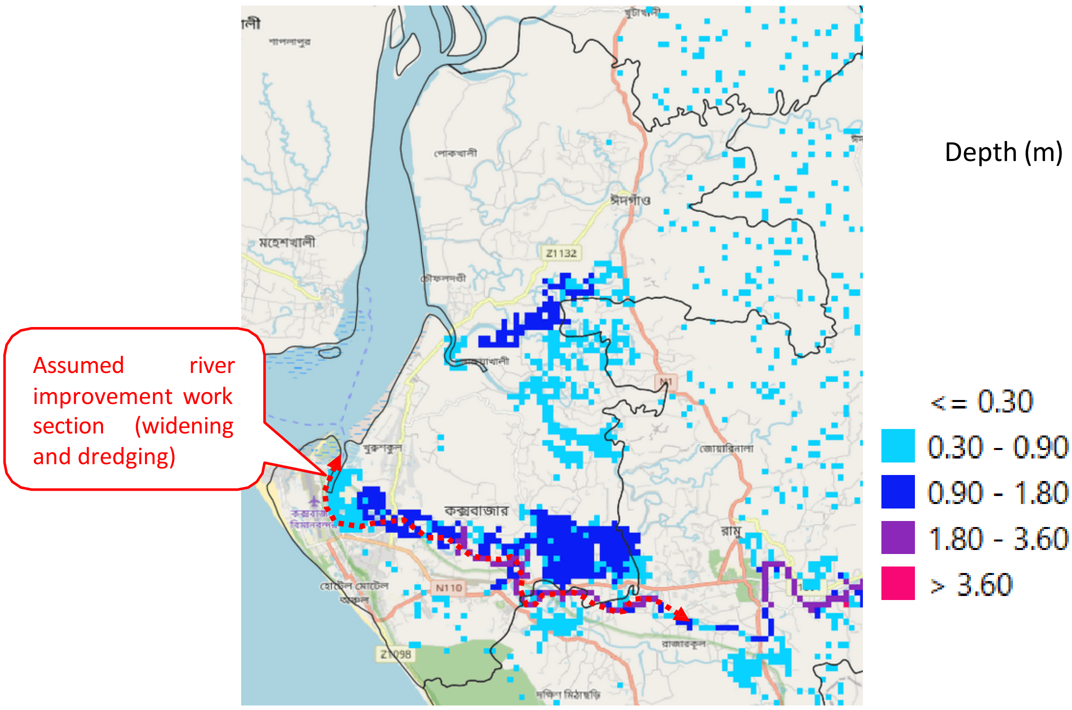


Figure 31 Sample Output of Flood Analysis in Case of Rive Improvement Works (Cox's Bazar Sadar)

3.7.2.2. Chakaria

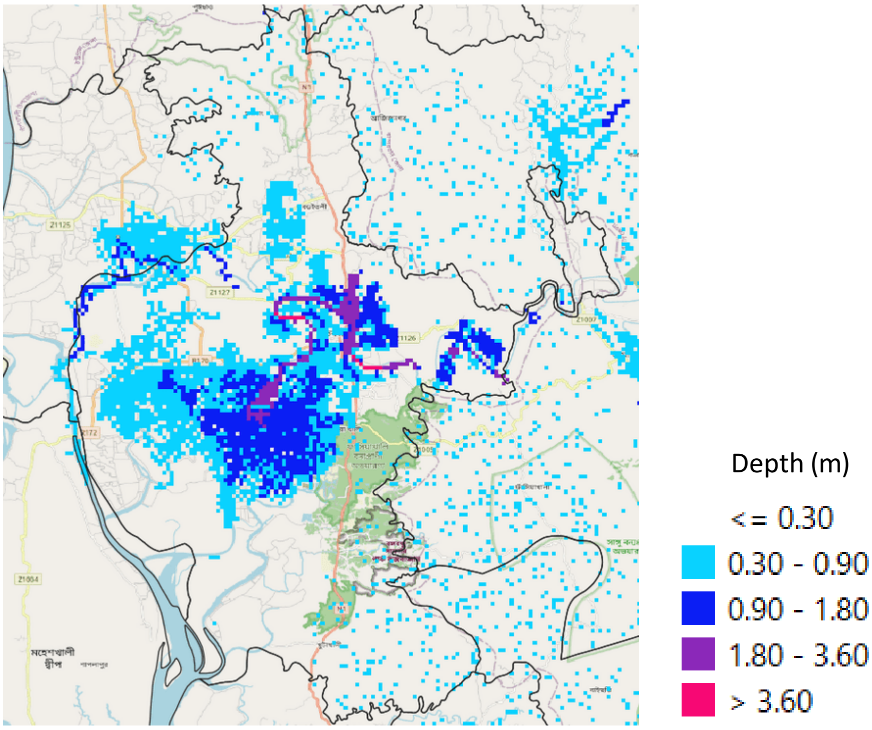


Figure 32 Sample Output of Flood Analysis (Chakaria)

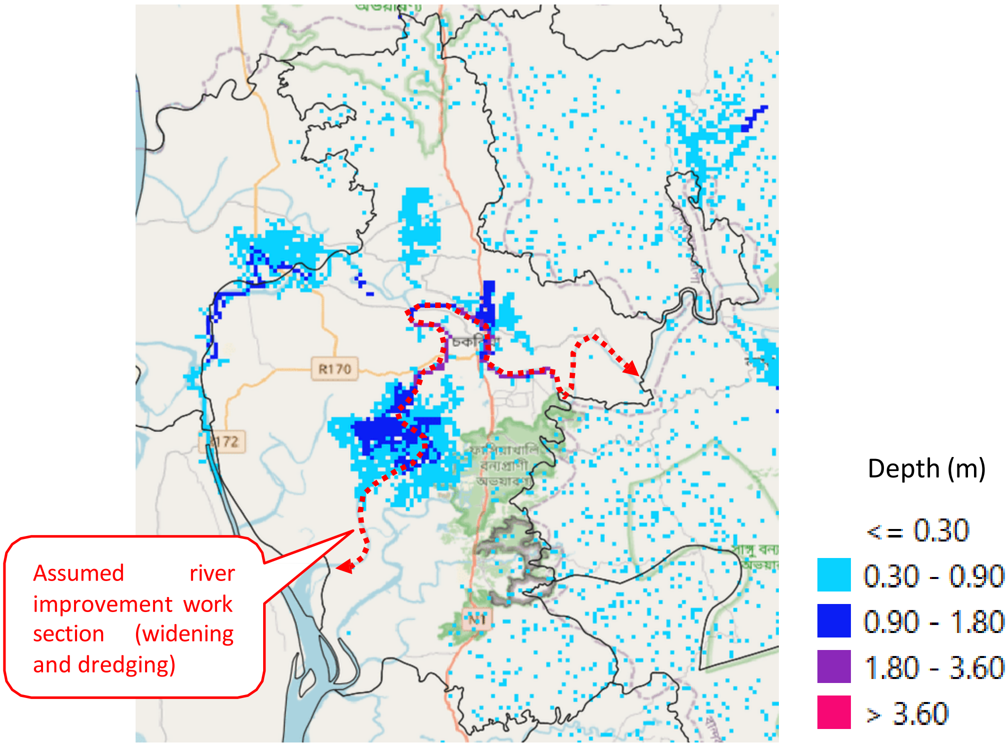


Figure 33 Sample Output of Flood Analysis in Case of Rive Improvement Works (Chakaria)

ANNEX 3: Technical Manual for Riverbank Erosion Analysis

(Updated April. 2025)

Table of Contents

1. Installation of QGIS

To install QGIS, follow these steps based on your operating system:

Windows:

I. **Download the Installer**:
   - Go to the official QGIS website: https://qgis.org
   - Click on **"Download Now"**
   - Choose **QGIS Standalone Installer (Latest Version, 64-bit)**

II. **Run the Installer**:
   - Double-click the downloaded .exe file
   - Follow the installation wizard (default options are fine)

III. **Finish & Launch**:
   - After installation, open QGIS from the Start menu

Mac (macOS):

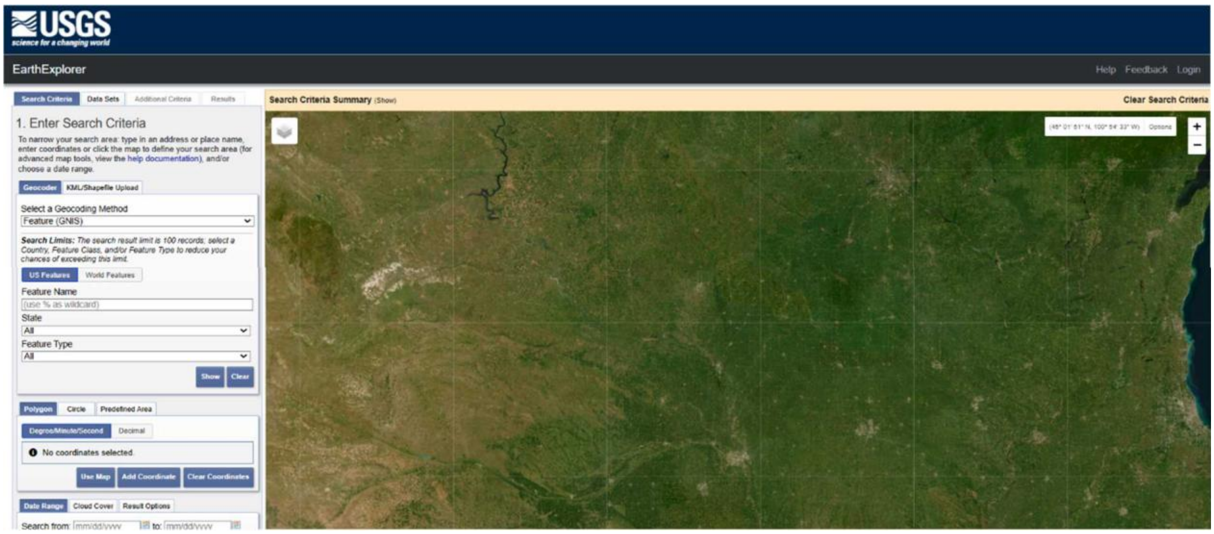
1. **Download the Mac Installer**:
   - Go to https://qgis.org
   - Download **QGIS macOS Installer**
2. **Install QGIS**:
   - Open the .dmg file
   - Drag **QGIS.app** to the **Applications** folder
3. **Run QGIS**:
   - Open **QGIS.app** from Applications

---

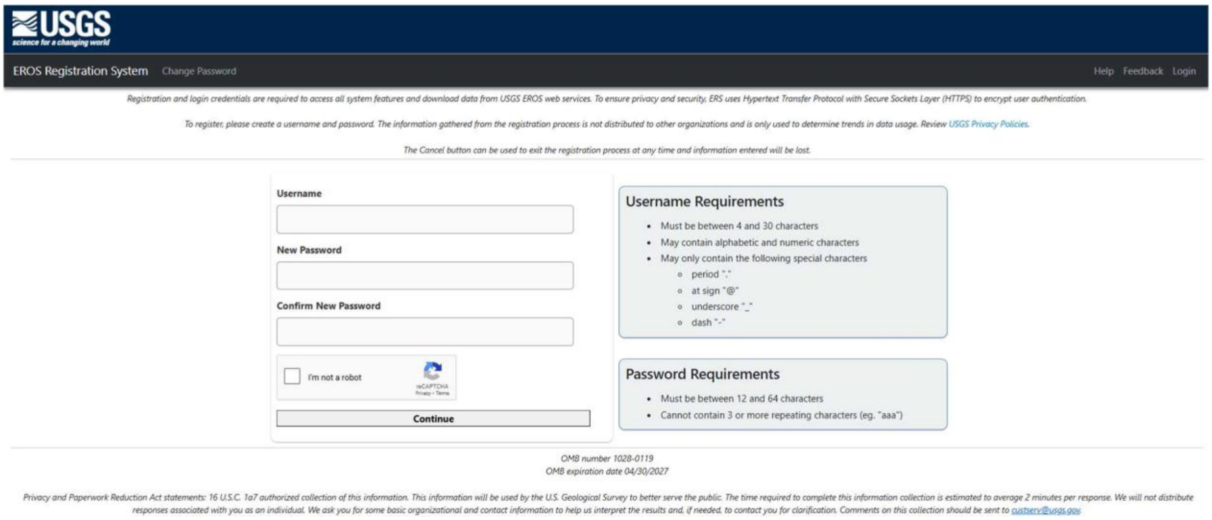
2. Downloading satellite images from USGS Earth Explorer and creating colored satellite images involve a few steps. Here's a step-by-step guide:

Step 1: Create an Account

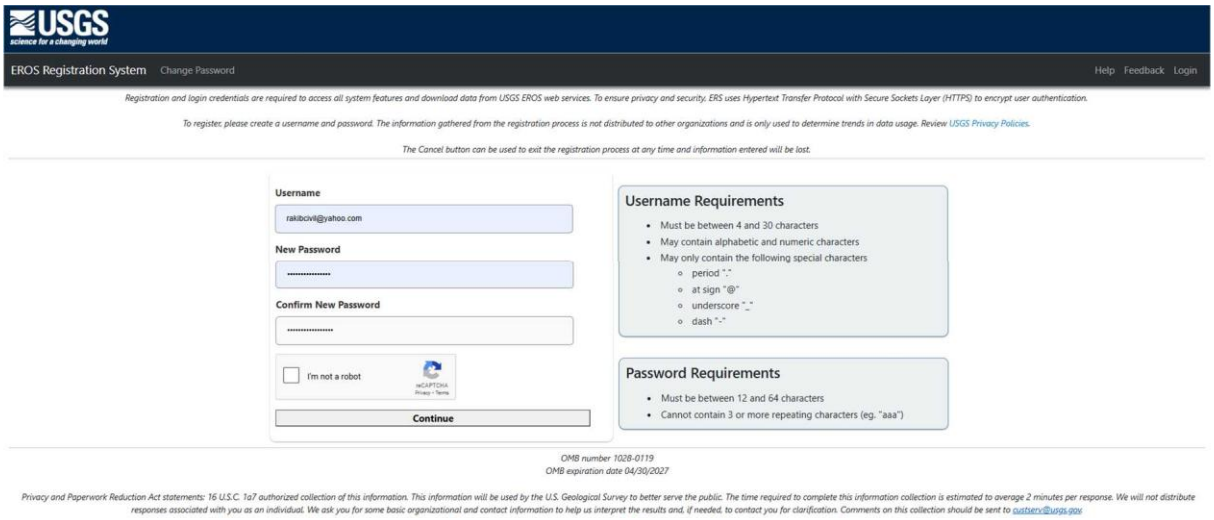
I. Go to **[USGS Earth Explorer]** with Google Chrome or Microsoft Edge at https://earthexplorer.usgs.gov/ (Firefox is not compatible to this system).

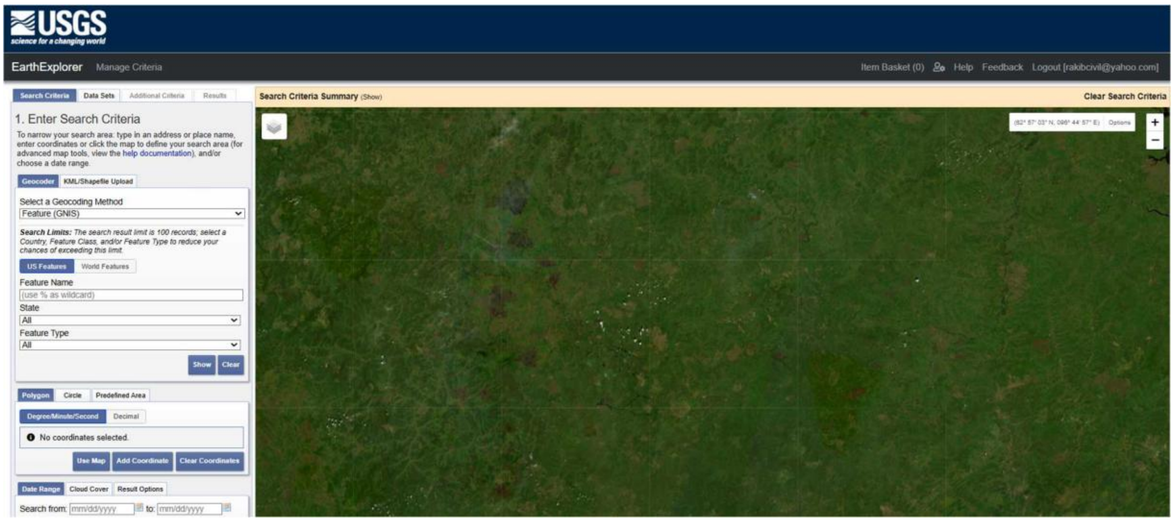


II. Click "**Login**" (top right) and click "Create New Account" to create a free account.



III. Verify your email and log in.

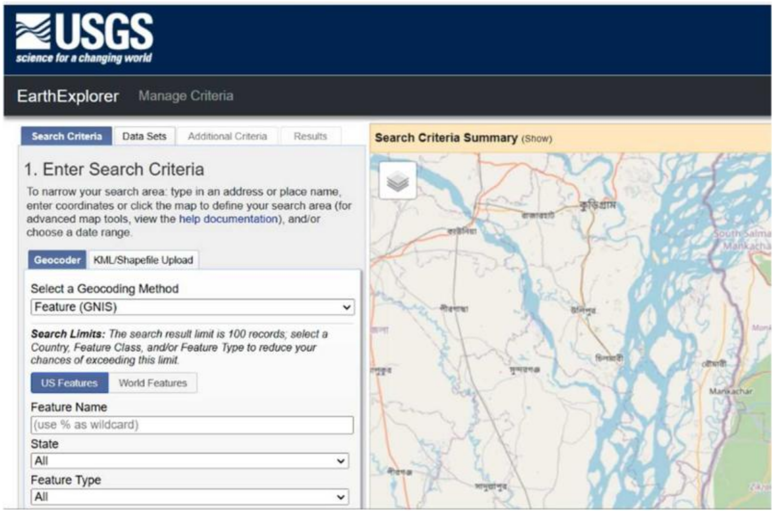




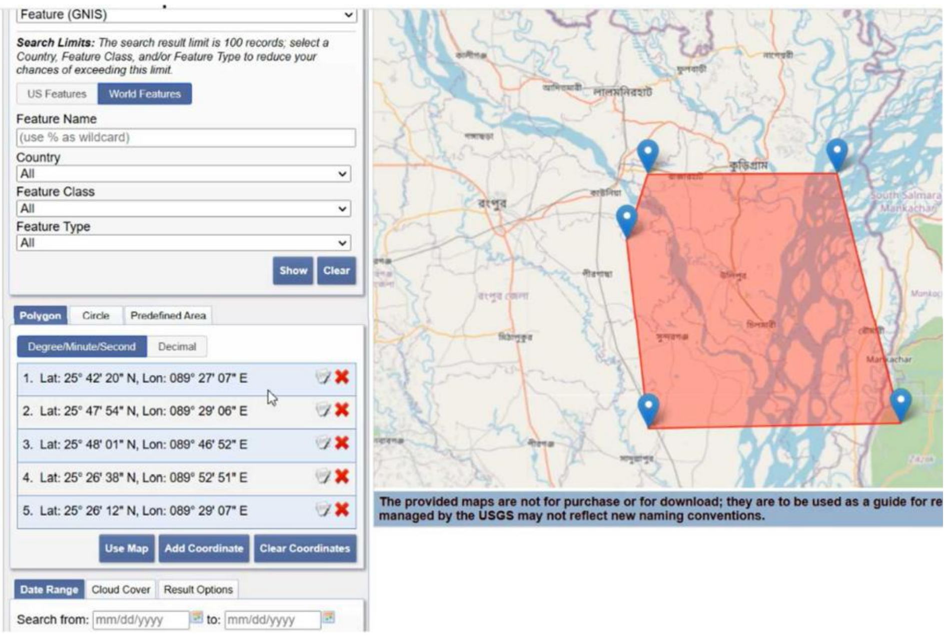
Step 2: Search for a Location

I. Use the "**Search Criteria**" tab to enter:

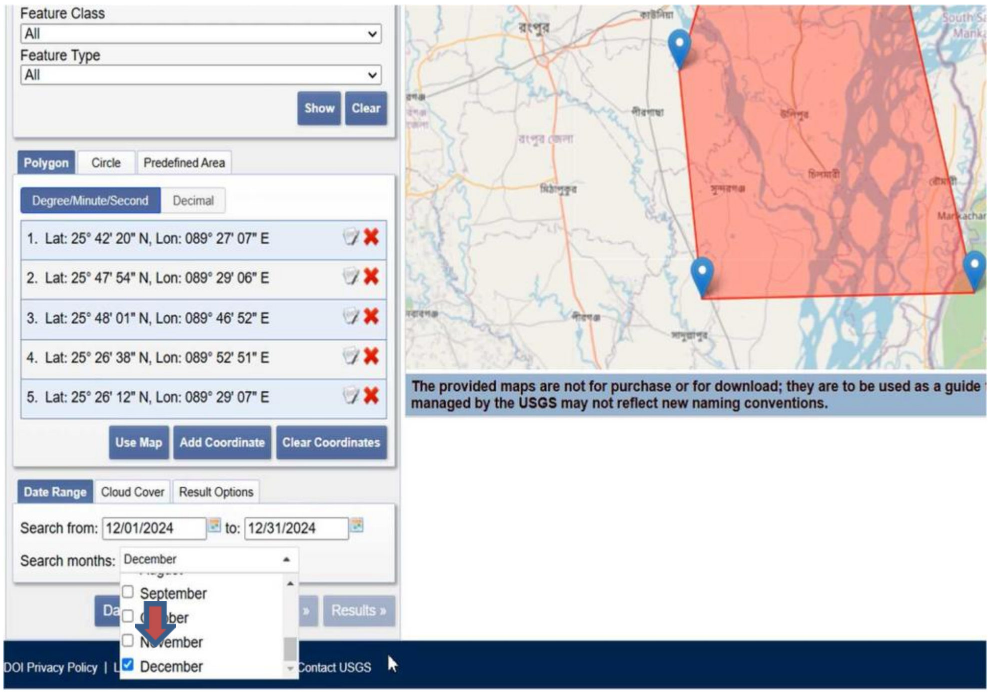
- Find the project location on the maps (e.g. Chilmari Upazila)



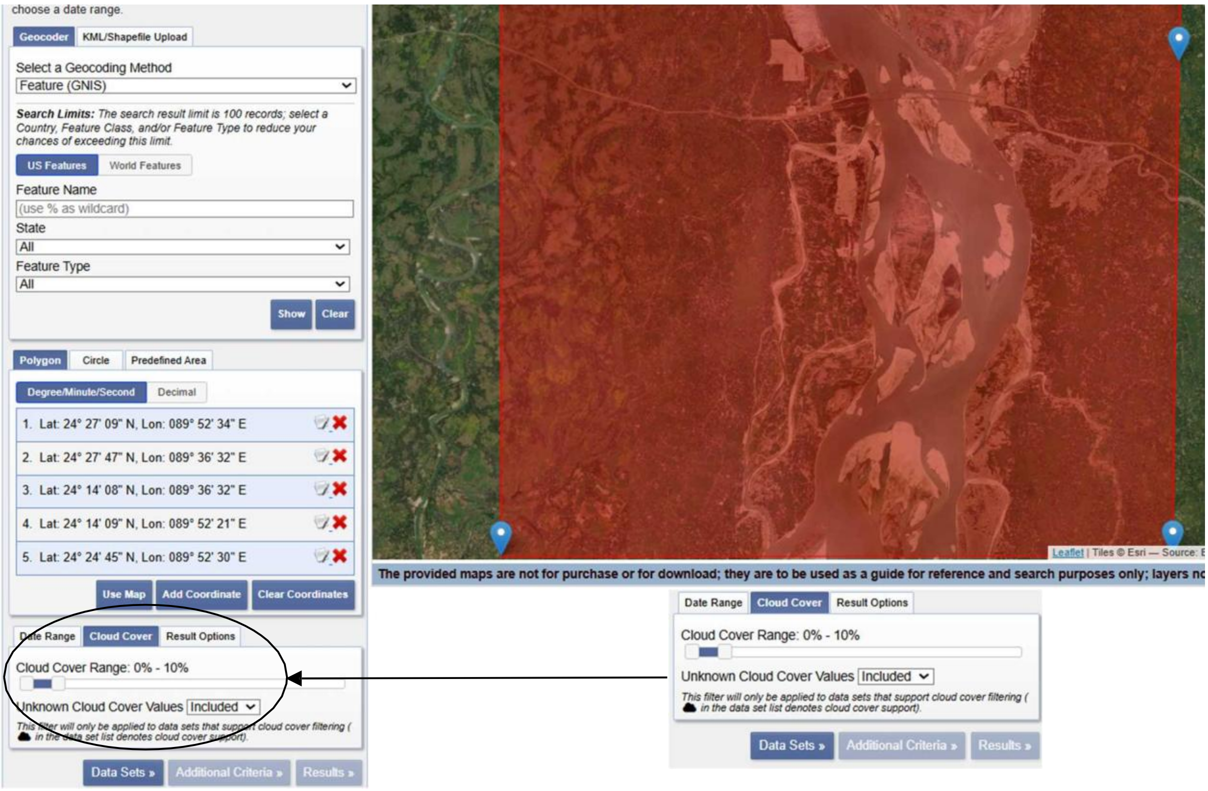
- Specify the area on the map by clicking several points on the map.



- Select the “**Date Range**” (for the riverbank erosion, we should consider the end of rainy season e.g. November–January)



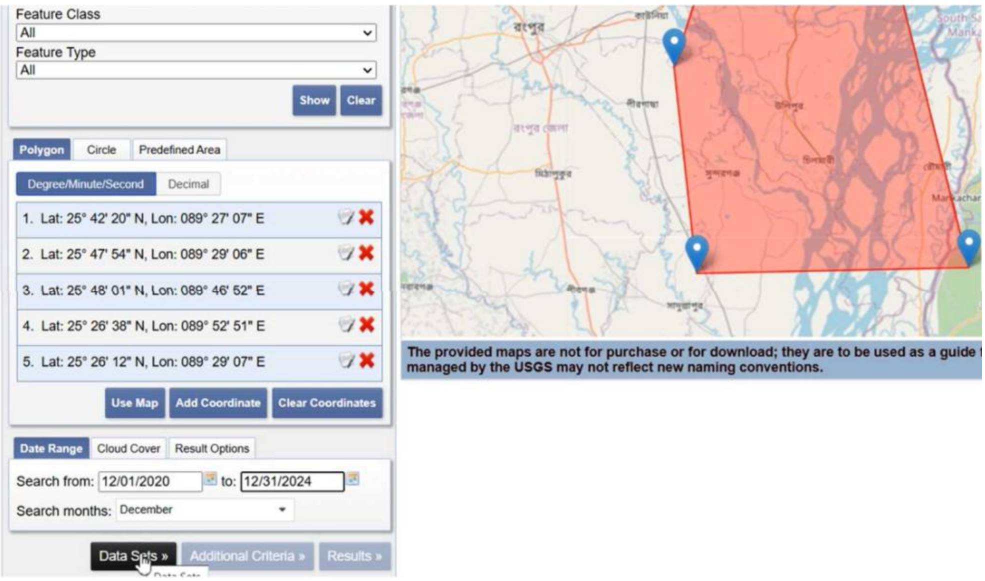
- The “**Cloud Cover**” range should be less (e.g. 0 to 10%) for the better image.



Notes: If we do not find enough images, we have to come back to the “Cloud Cover” and widen the cloud coverage range and search again.

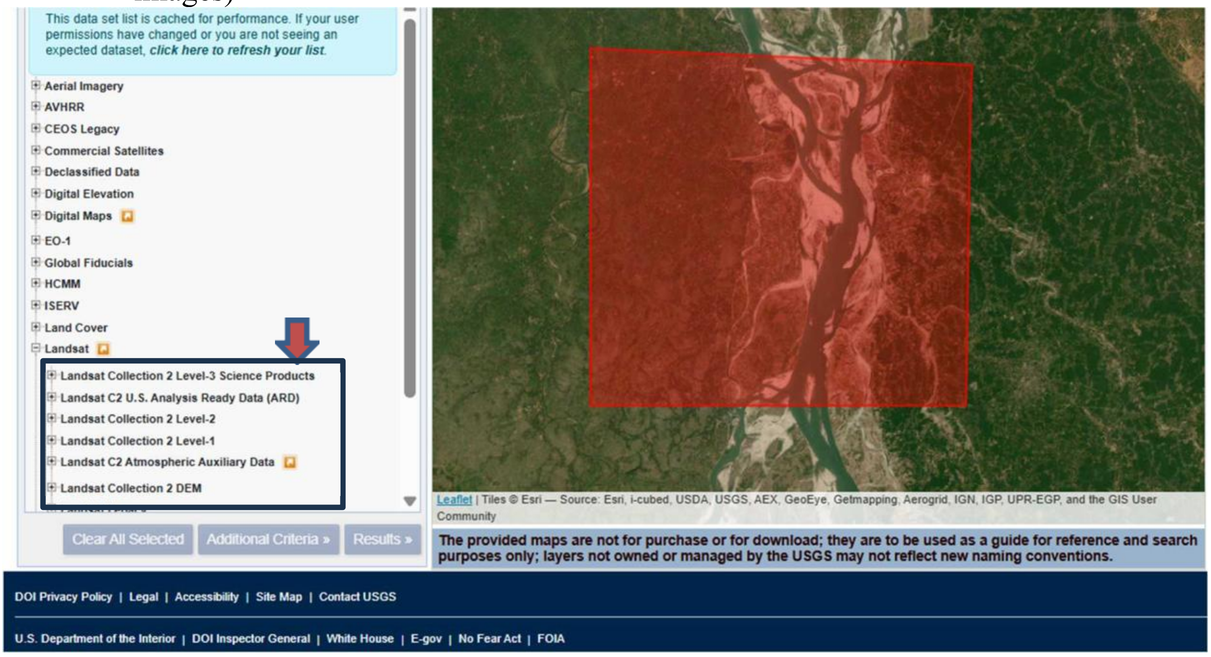
Step 3: Select a Dataset

I. Click on the "**Data Sets**" tab.

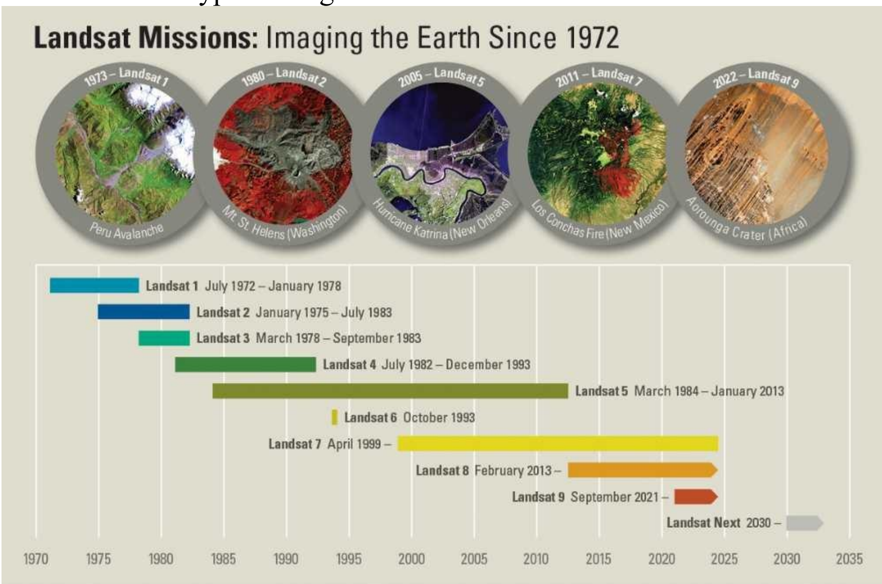


II. Choose the satellite images you need:

- **Landsat** collection 2 Level 2 (e.g., Landsat 8, 9 OLI/TIRS C2 L2 for recent satellite images and Landsat 7 ETM+ C2 L2 for old satellite images)

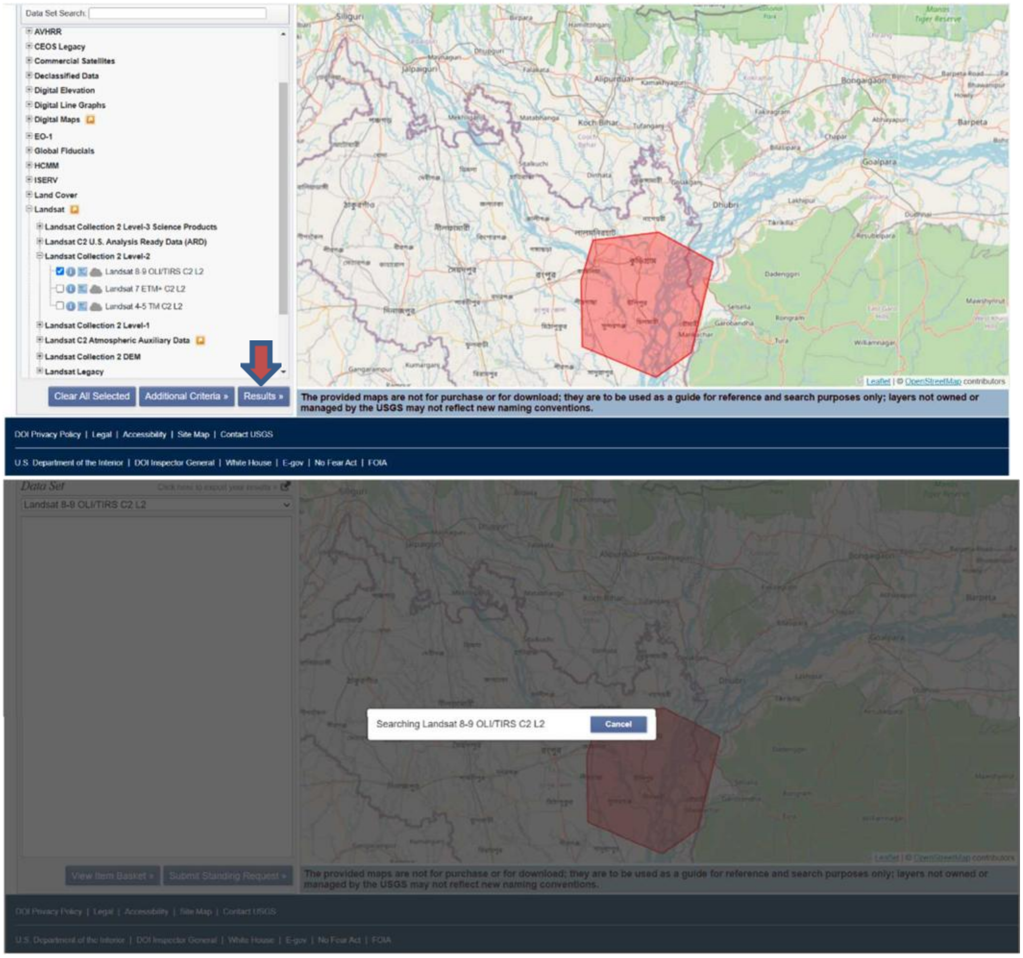


Reference: Available Landsat types and ages



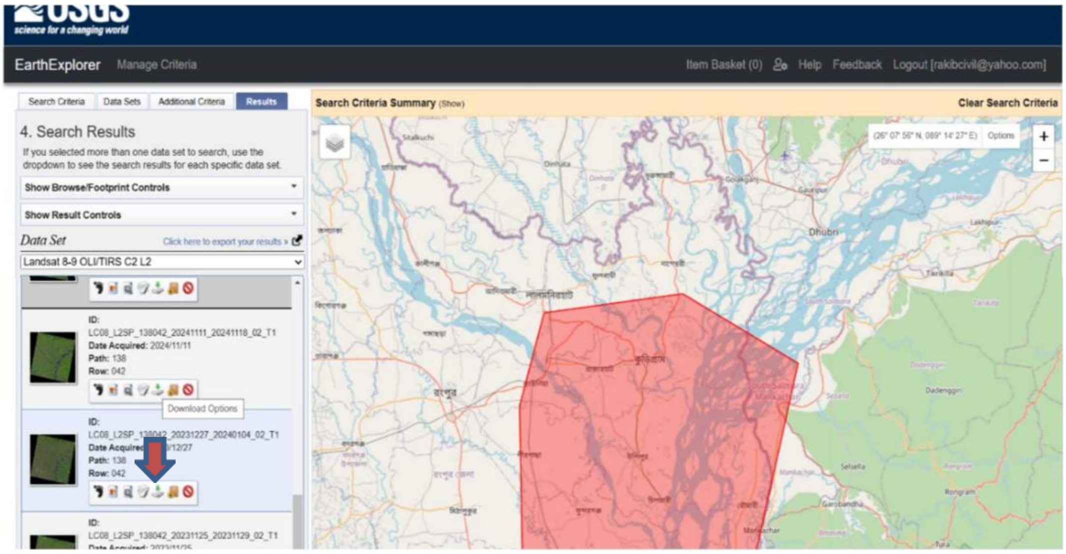
Source: USGS (https://www.usgs.gov/media/images/landsat-missions-timeline)

III. Click "**Results**" to see available images.



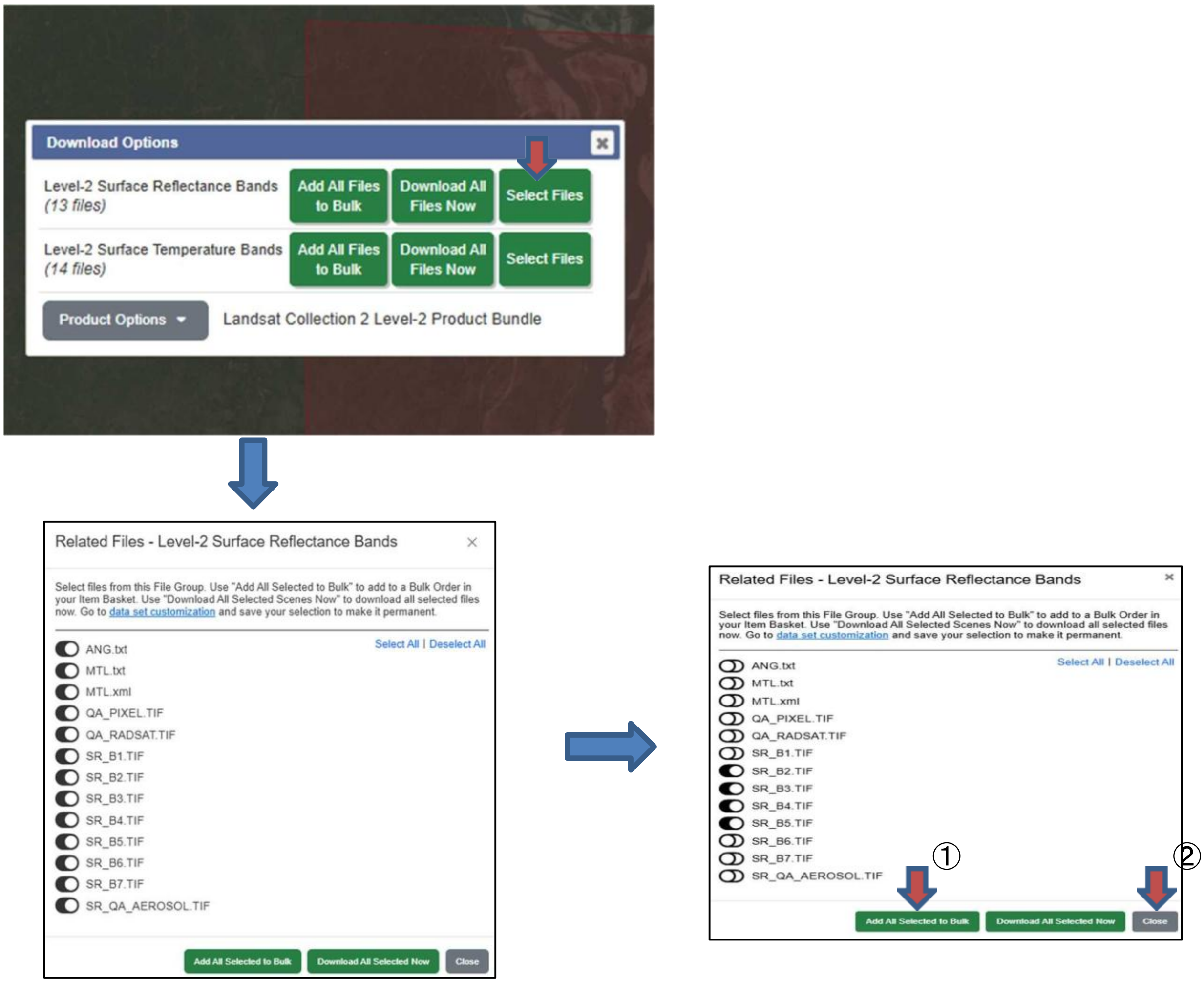
Step 4: Download Image

I. Click the Download Icon next to the image you want.



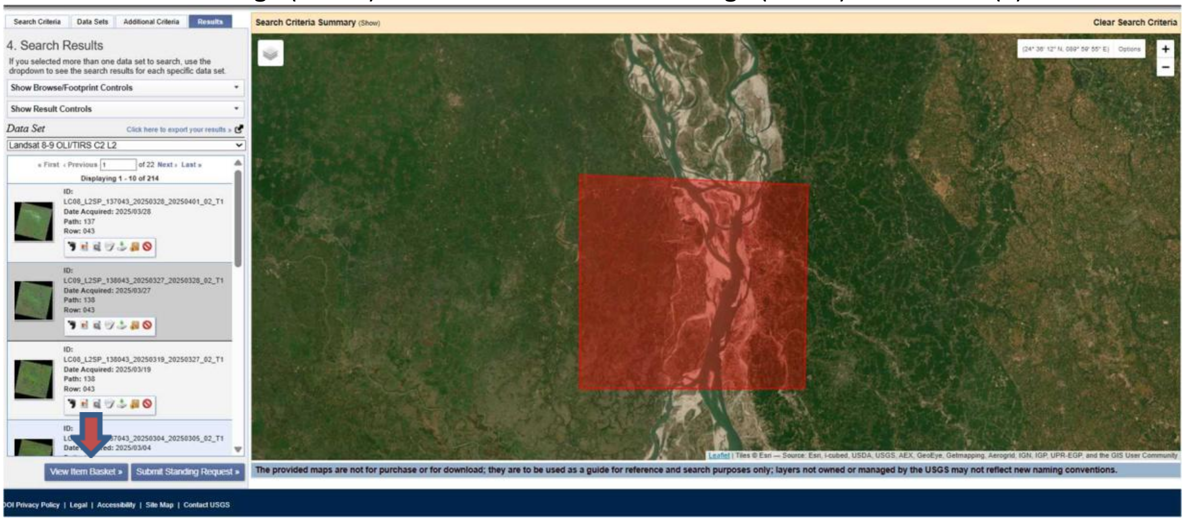
II. Select the file type:

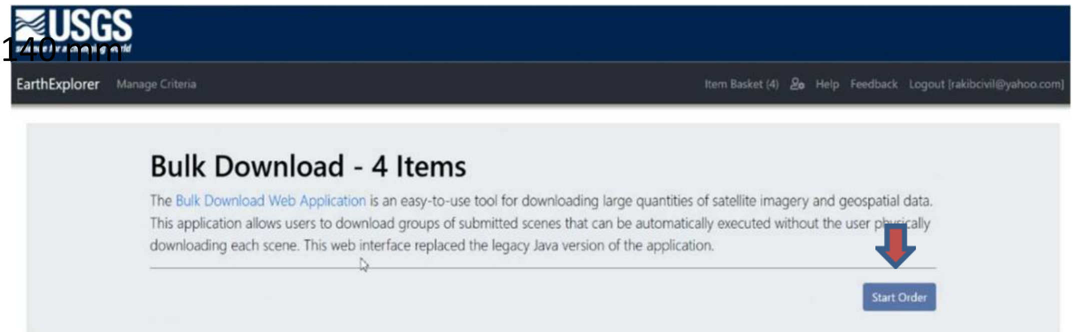
- Level-2 GeoTIFF (for processing in QGIS/ArcGIS)
- Select target 4 bands, ①"**Add All Selected to Bulk**", ② choose "**Close**" then close the "**Download Options**" window.

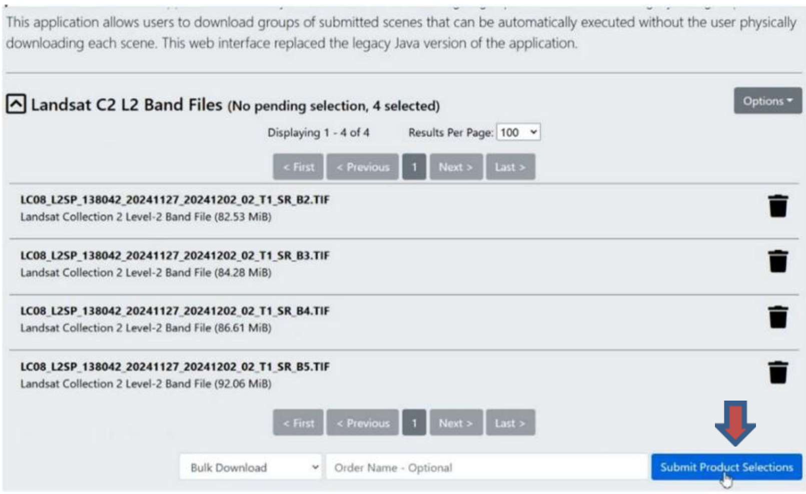


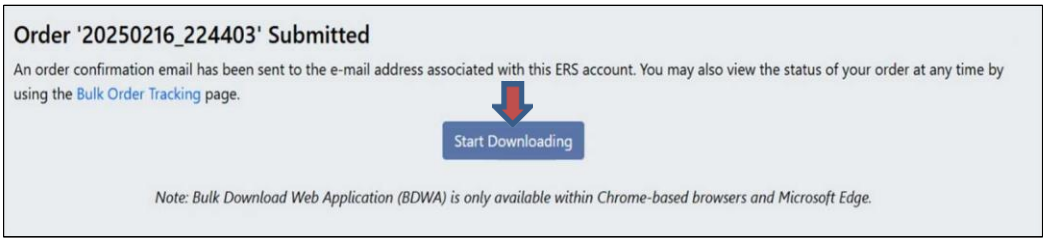
<u><detailed downloading steps></u> (some datasets require login).

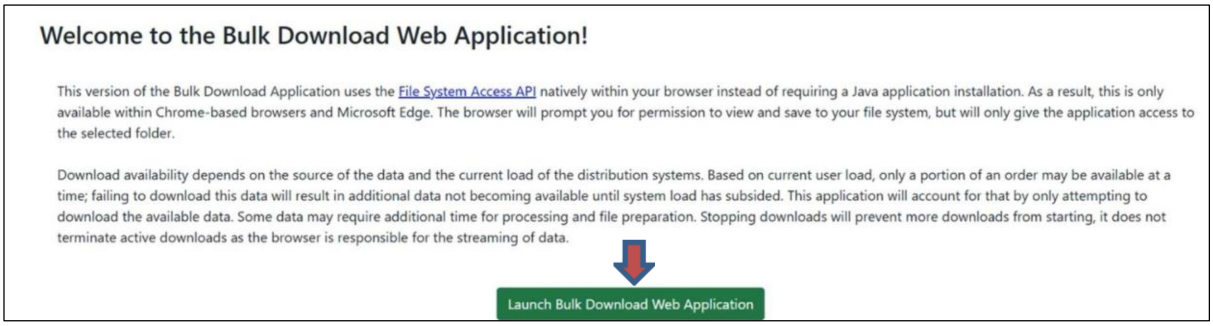
Note: band range (B2-B5) for Landsat 8-9 and band range (B1-B4) for Landsat (7)

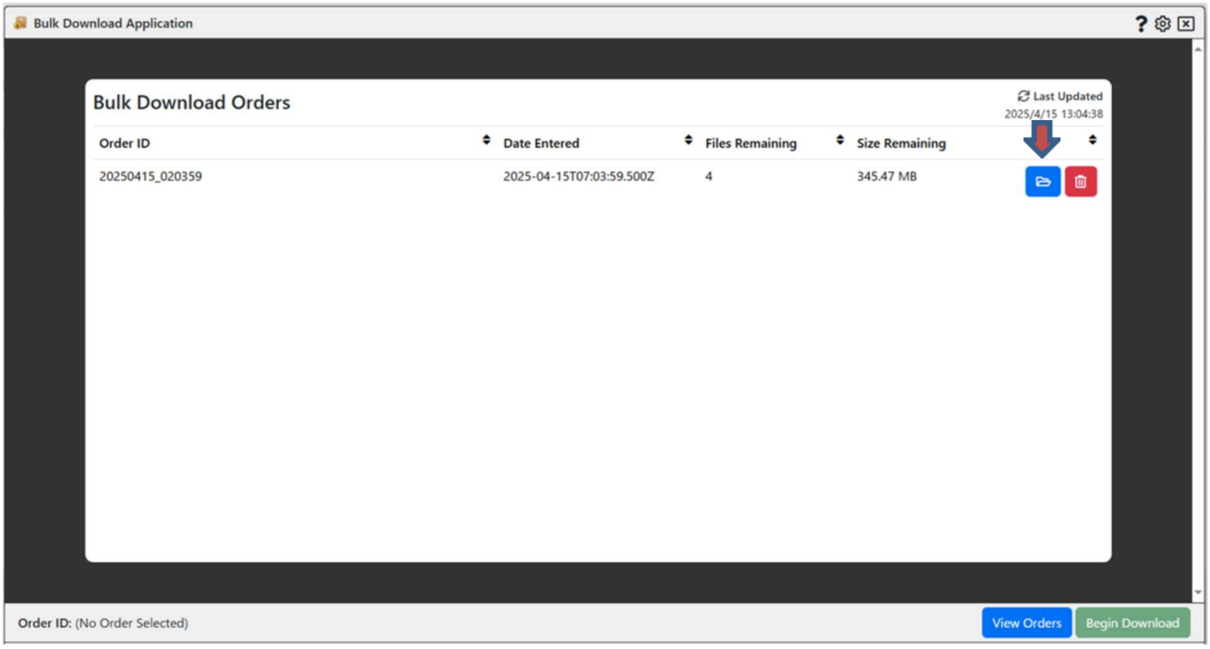


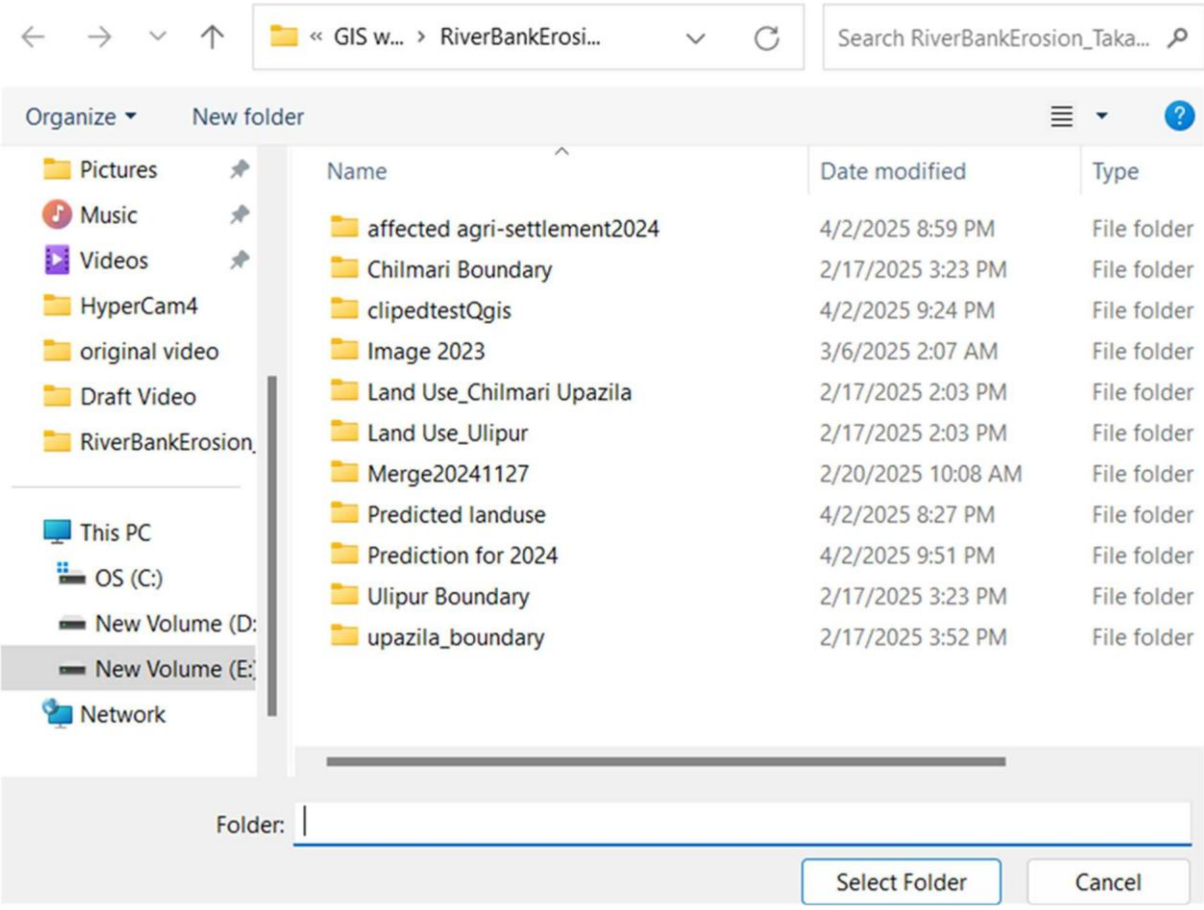




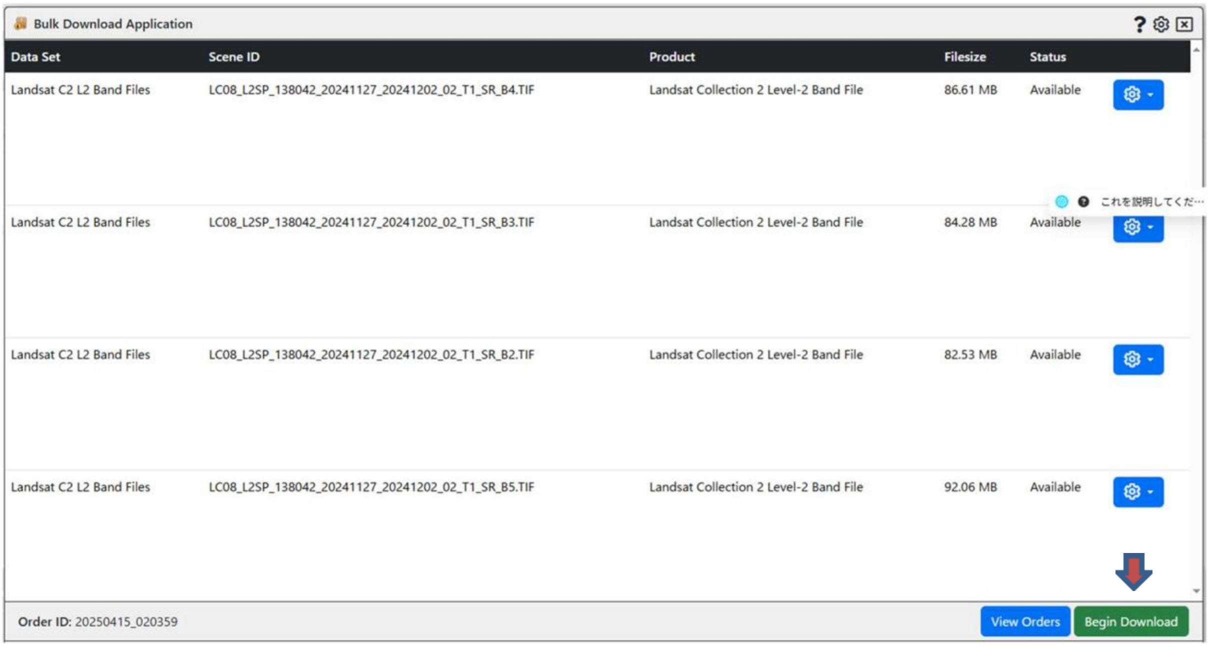

Order '20250216_224403' Submitted
An order confirmation email has been sent to the e-mail address associated with this ERS account. You may also view the status of your order at any time by using the Bulk Order Tracking page.
Start Downloading
Note: Bulk Download Web Application (BDWA) is only available within Chrome-based browsers and Microsoft Edge.


Welcome to the Bulk Download Web Application!
This version of the Bulk Download Application uses the File System Access API natively within your browser instead of requiring a Java application installation. As a result, this is only available within Chrome-based browsers and Microsoft Edge. The browser will prompt you for permission to view and save to your file system, but will only give the application access to the selected folder.
Download availability depends on the source of the data and the current load of the distribution systems. Based on current user load, only a portion of an order may be available at a time; failing to download this data will result in additional data not becoming available until system load has subsided. This application will account for that by only attempting to download the available data. Some data may require additional time for processing and file preparation. Stopping downloads will prevent more downloads from starting, it does not terminate active downloads as the browser is responsible for the streaming of data.
Launch Bulk Download Web Application

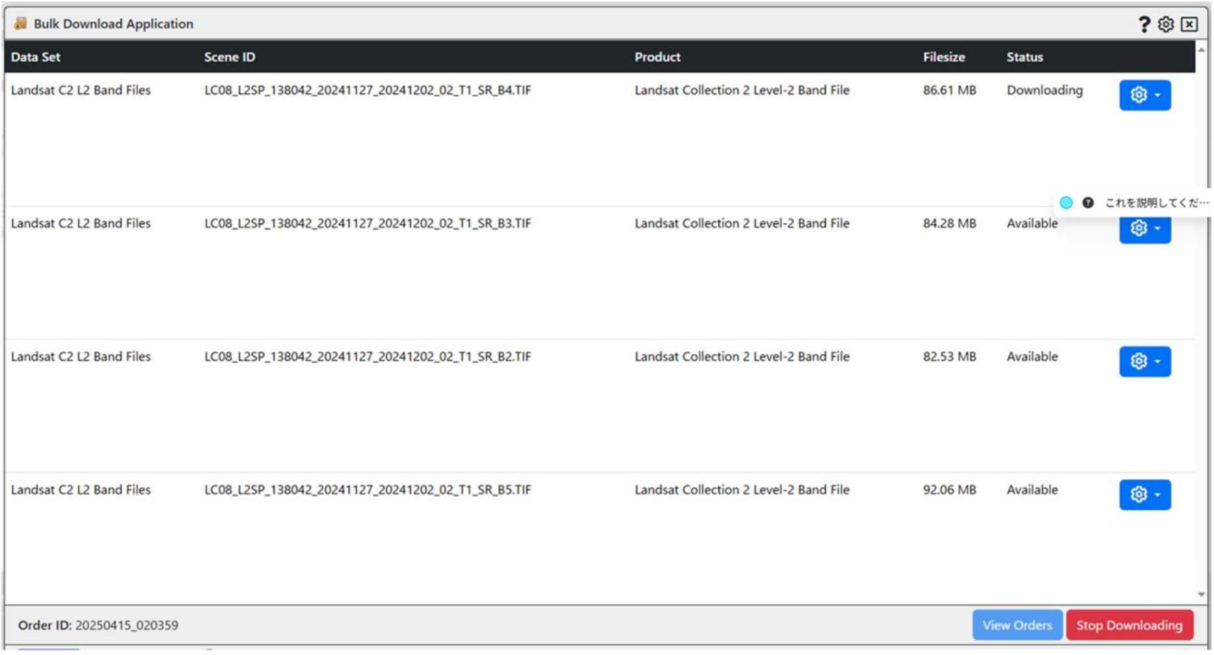

Bulk Download Application
Bulk Download Orders
Last Updated
2025/4/15 13:04:38
Order ID
Date Entered
Files Remaining
Size Remaining
20250415_020359
2025-04-15T07:03:59.500Z
4
345.47 MB
Order ID: (No Order Selected)
View Orders
Begin Download

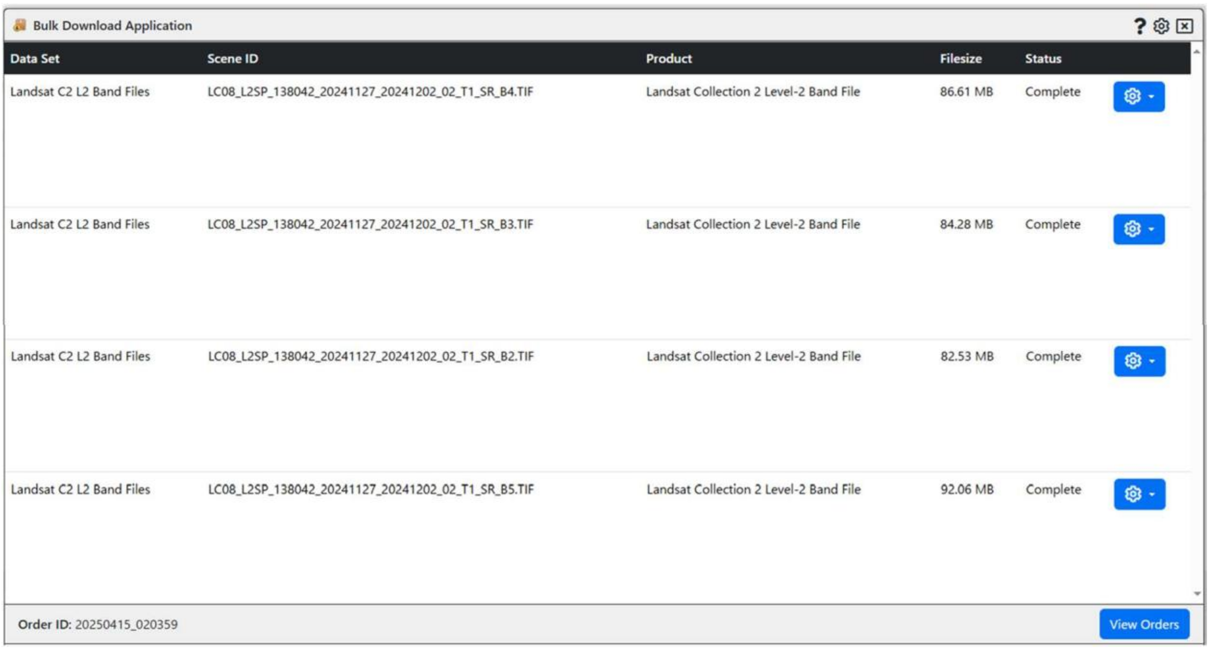


« GIS w... › RiverBankErosi...
Search RiverBankErosion_Taka...
Organize
New folder
Pictures
Music
Videos
HyperCam4
original video
Draft Video
RiverBankErosion_
This PC
OS (C:)
New Volume (D:
New Volume (E:)
Network
Name
Date modified
Type
affected agri-settlement2024 4/2/2025 8:59 PM File folder
Chilmari Boundary 2/17/2025 3:23 PM File folder
clipedtestQgis 4/2/2025 9:24 PM File folder
Image 2023 3/6/2025 2:07 AM File folder
Land Use_Chilmari Upazila 2/17/2025 2:03 PM File folder
Land Use_Ulipur 2/17/2025 2:03 PM File folder
Merge20241127 2/20/2025 10:08 AM File folder
Predicted landuse 4/2/2025 8:27 PM File folder
Prediction for 2024 4/2/2025 9:51 PM File folder
Ulipur Boundary 2/17/2025 3:23 PM File folder
upazila_boundary 2/17/2025 3:52 PM File folder
Folder:
Select Folder
Cancel



Bulk Download Application
Data Set
Scene ID
Product
Filesize
Status
Landsat C2 L2 Band Files LC08_L2SP_138042_20241127_20241202_02_T1_SR_B4.TIF Landsat Collection 2 Level-2 Band File 86.61 MB Available
Landsat C2 L2 Band Files LC08_L2SP_138042_20241127_20241202_02_T1_SR_B3.TIF Landsat Collection 2 Level-2 Band File 84.28 MB Available
Landsat C2 L2 Band Files LC08_L2SP_138042_20241127_20241202_02_T1_SR_B2.TIF Landsat Collection 2 Level-2 Band File 82.53 MB Available
Landsat C2 L2 Band Files LC08_L2SP_138042_20241127_20241202_02_T1_SR_B5.TIF Landsat Collection 2 Level-2 Band File 92.06 MB Available
Order ID: 20250415_020359
View Orders
Begin Download

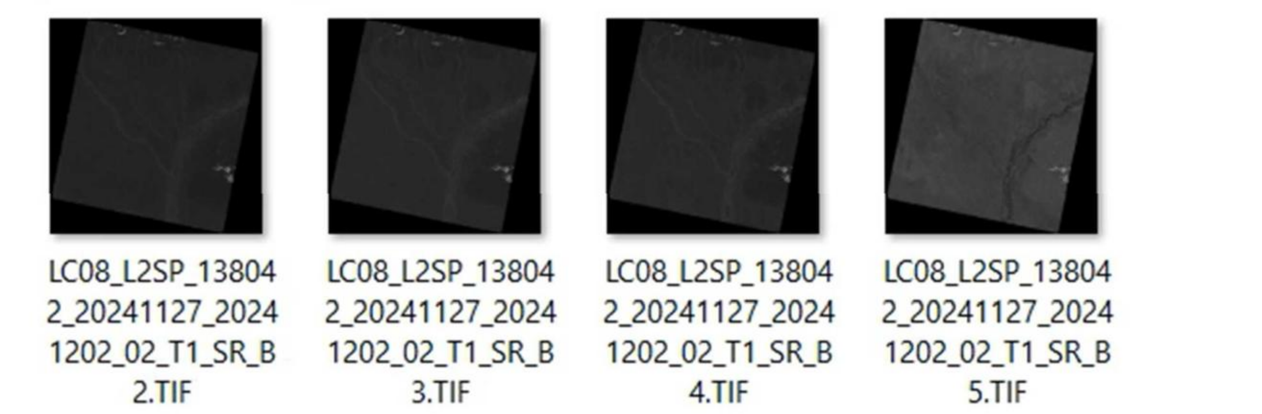




Then, close the window.

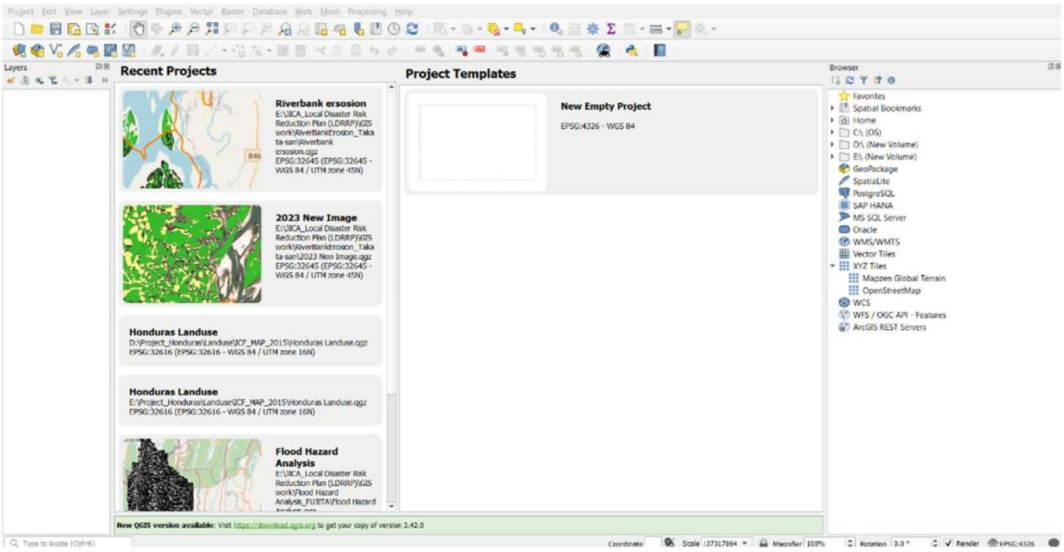
Step 5: Use the Image

- The images are in ".tiff" format.

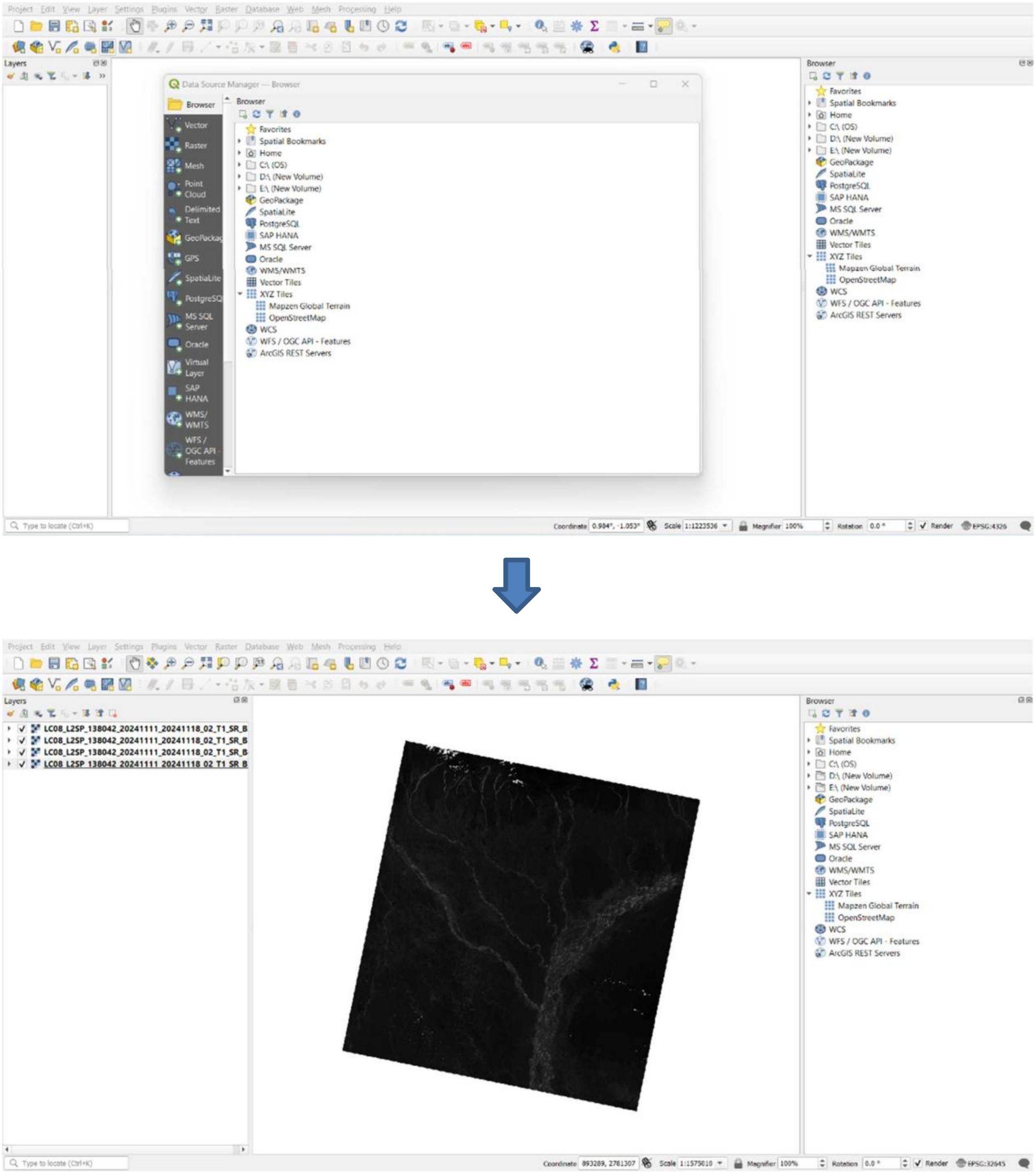


- Extract the files then open them in **QGIS, or ArcGIS**

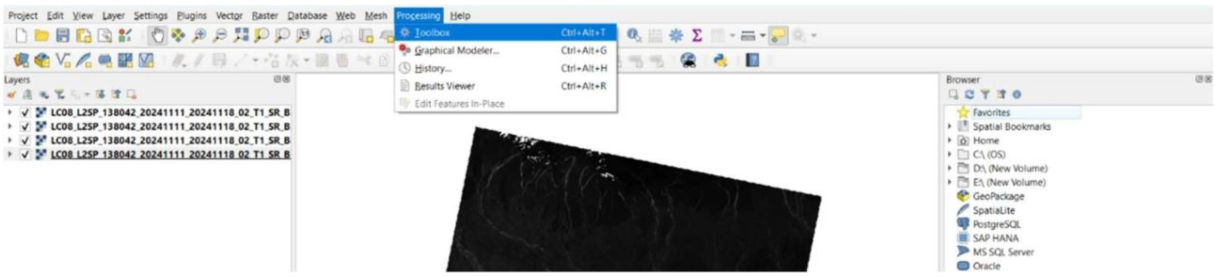
I. Open QGIS: Start by opening QGIS on your computer. Open New Project in QGIS Software



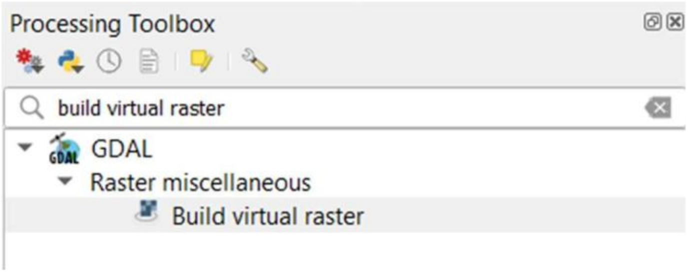
II. Load Raster Layers: Make sure the raster layers you want to merge are loaded into QGIS. You can do this by dragging and dropping them into the QGIS interface or using the Layer > Add Layer > Add Raster Layer... menu option. Open Tiff file through > Data Source Manager-Browser



III. Access the **Processing Toolbox**: Go to Processing in the top menu bar, then select Toolbox. This opens the Processing Toolbox panel.

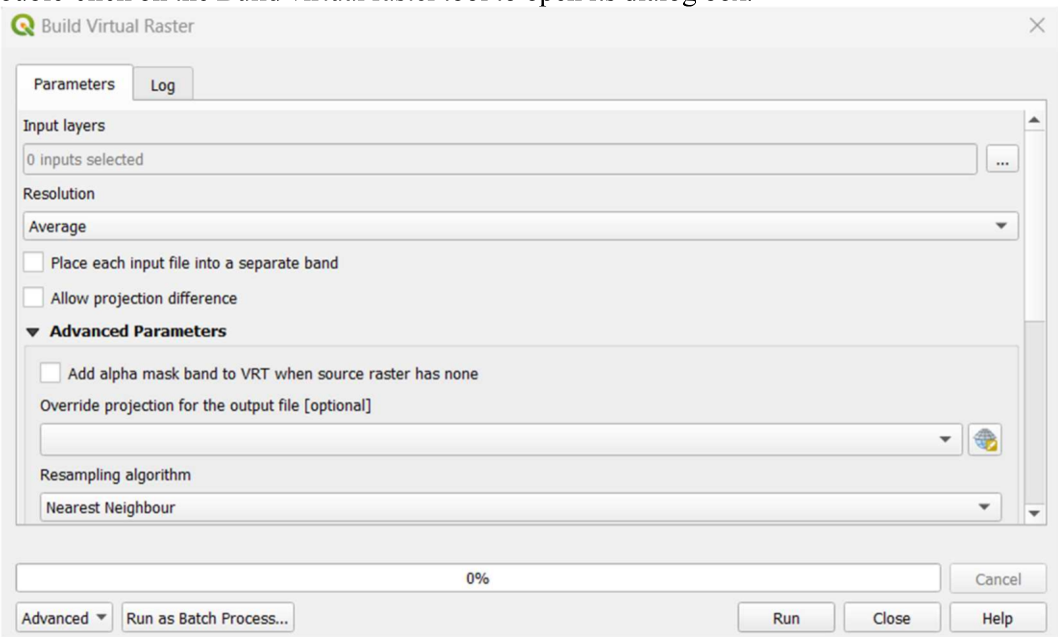


IV. Search for **Build virtual raster Tool**: In the Processing Toolbox panel, type "Build virtual raster" into the search bar.

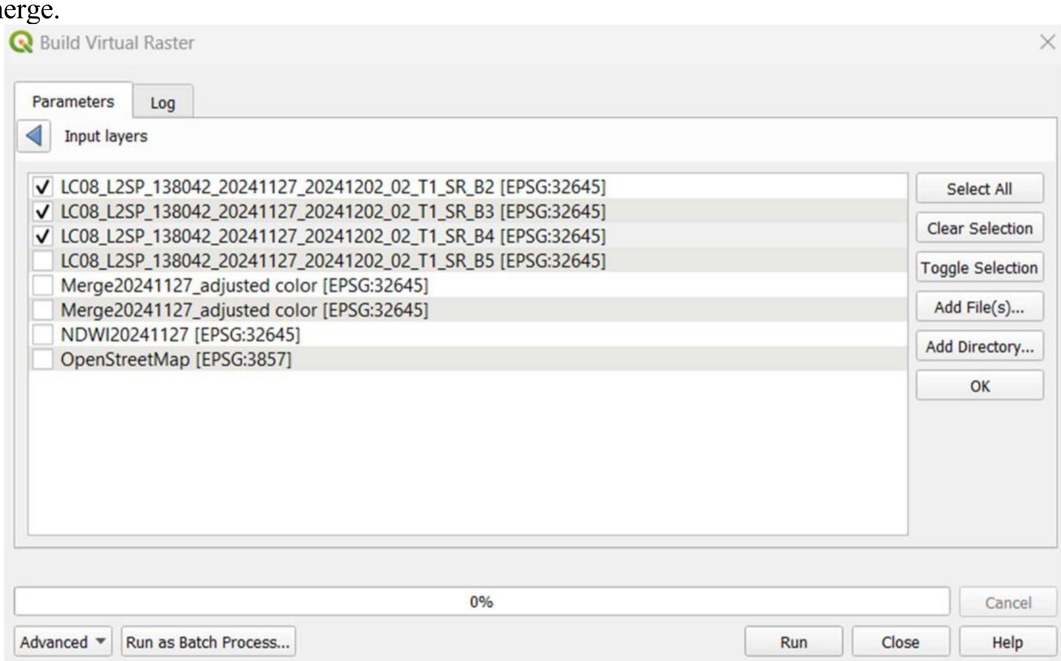


V. Configure **Build virtual raster Tool**:

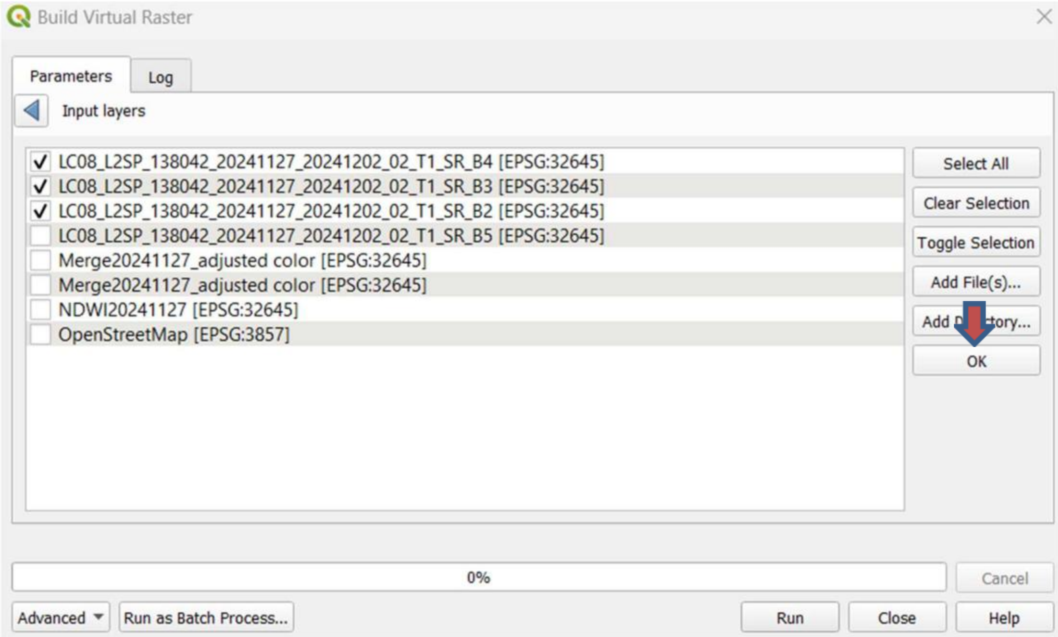
- Double-click on the Build virtual raster tool to open its dialog box.



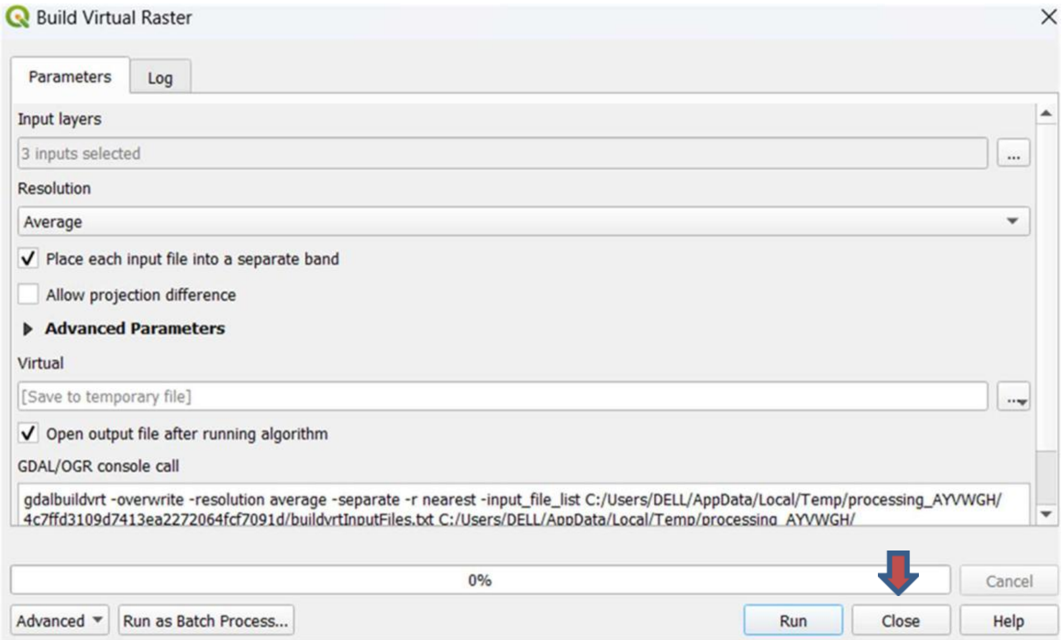
- In the Input layers section, click on **the ellipsis (...) button** to select the raster layers you want to merge.

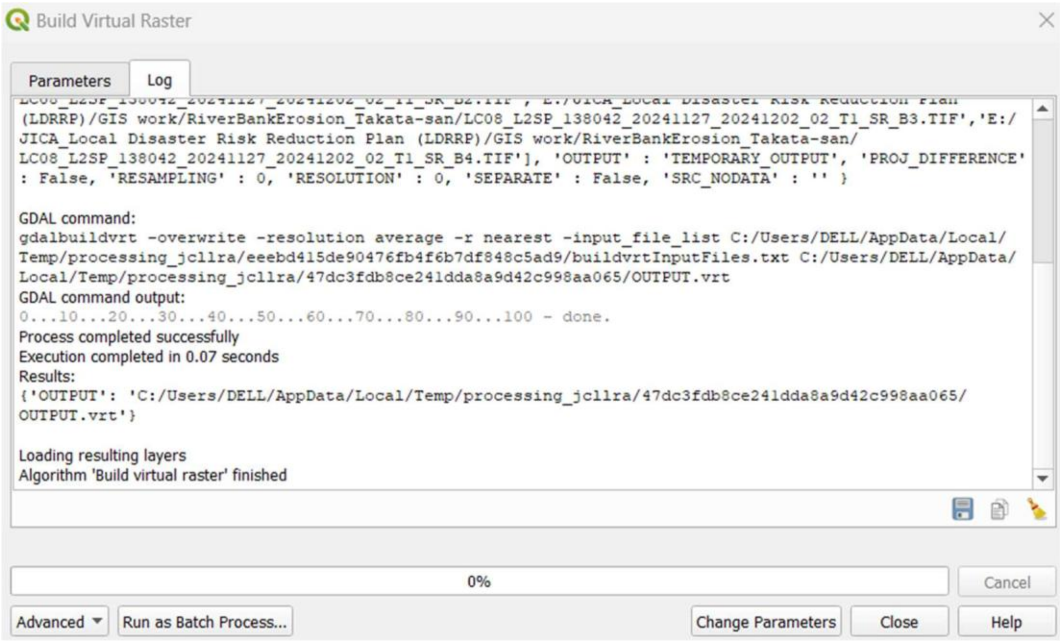


- Change the order of the bands as Band 4, 3, and 2 for Landsat 8 and 9, Band 3, 2 and 1 for Landsat 7 from the top by "click and drag" motion so that those bands are recognized as Red, Green and Blue, respectively.



- Press "**OK**" to go back to the previous window, turn "**place each input file into a separate band**" on and run the **Build virtual raster:** Click "**Run"** to execute the Build virtual raster operation. QGIS will process the raster layers and create a new virtual raster dataset based on your specifications.



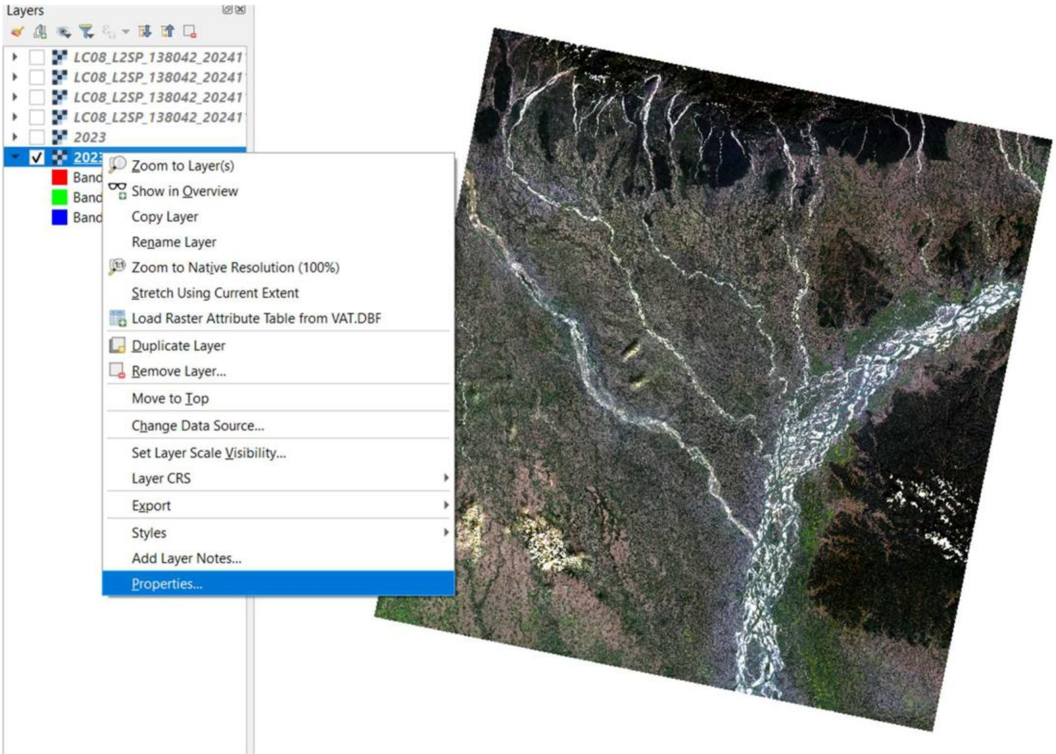


VI. Review the Merged Raster: Once the process is complete, you can add the newly merged raster dataset to QGIS to verify that the merge was successful.

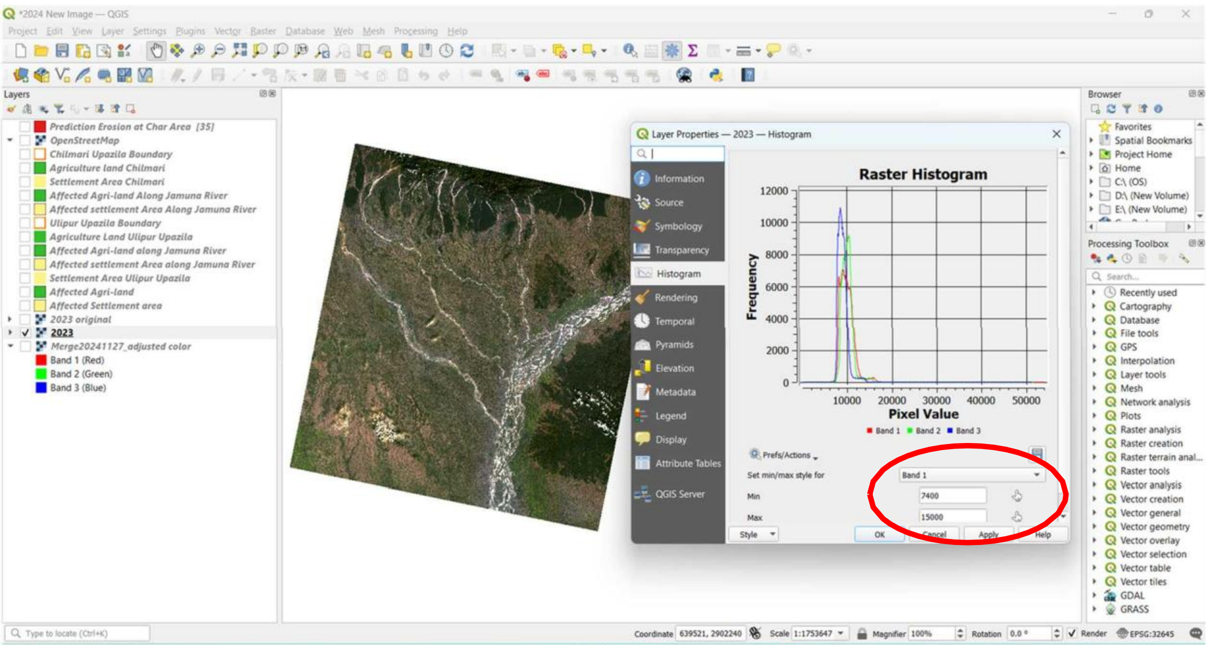
VII. Color adjustment by using specific values. Here are the examples of pixel values for each band.

Band 1: 7400 (min), 15000 (max)
Band 2: 7300 (min), 15500 (max)
Band 3: 7400 (min), 14000 (max)

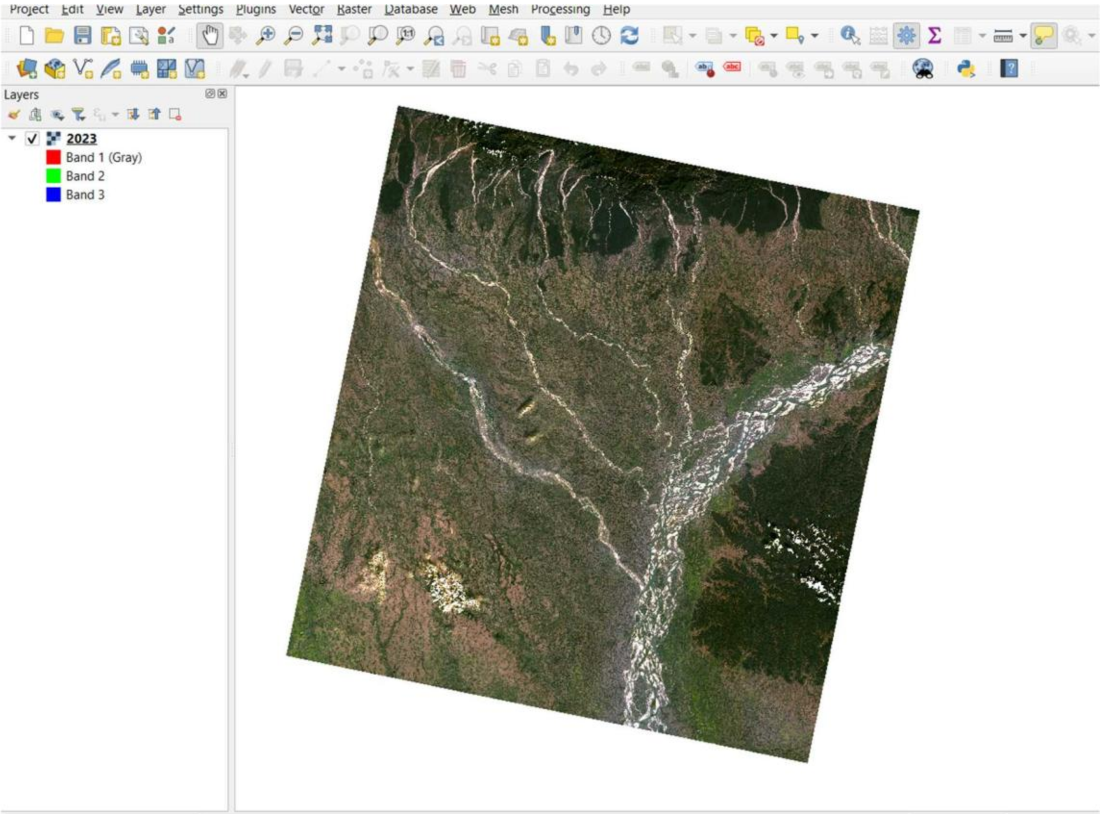
- Right click "**Properties**" of the raster and click "**Histogram**" form the layer properties



- Apply the above-mentioned minimum and maximum values of the Band 1, 2 and 3 for the Pixel Value, or find the better combinations.



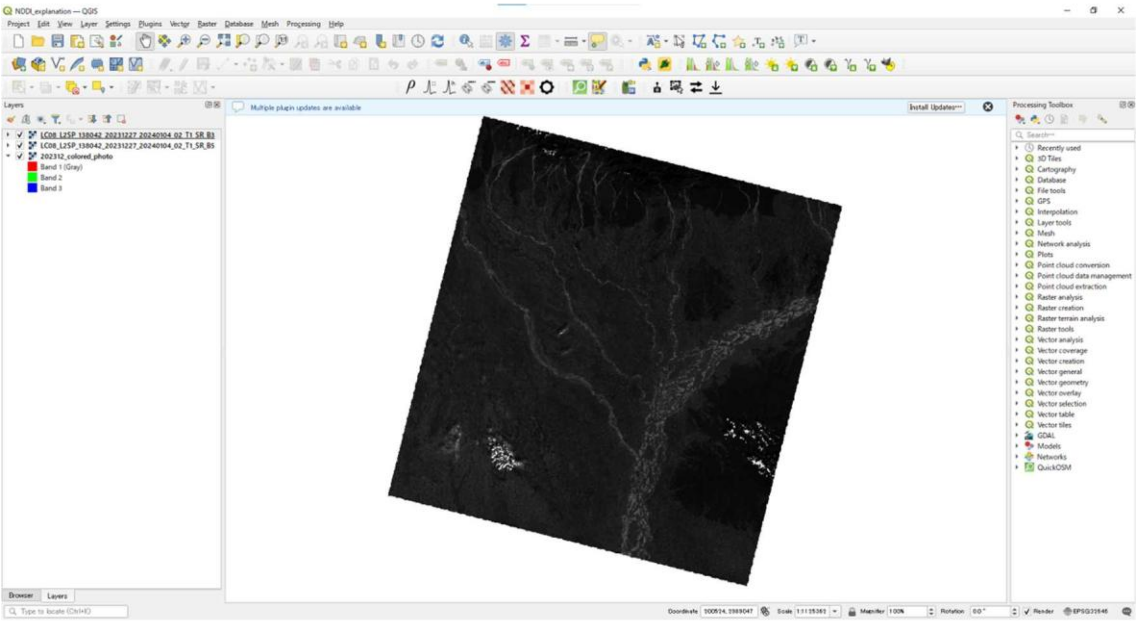
- Then, color adjustment is completed.



3. Defining the water body area with QGIS

Step 1: Open Two Bands.

Open Band 3, and 5 of Landsat 8 and 9, or Band 2 and 4 of Landsat 7 for Green and NIR ("near infrared"), respectively in QGIS, or ArcGIS.



Step 2: Calculate Normalized Difference Water Index (NDWI).

Normalized Difference Water Index (NDWI) is calculated using the following formula:

NDWI = (Green - NIR) / (Green + NIR)

So that

NDWI = (Band 3 – Band 5) / (Band 3 + Band 5) for Landsat 8 and 9, or

NDWI = (Band 2 – Band 4) / (Band 2 + Band 4) for Landsat 7

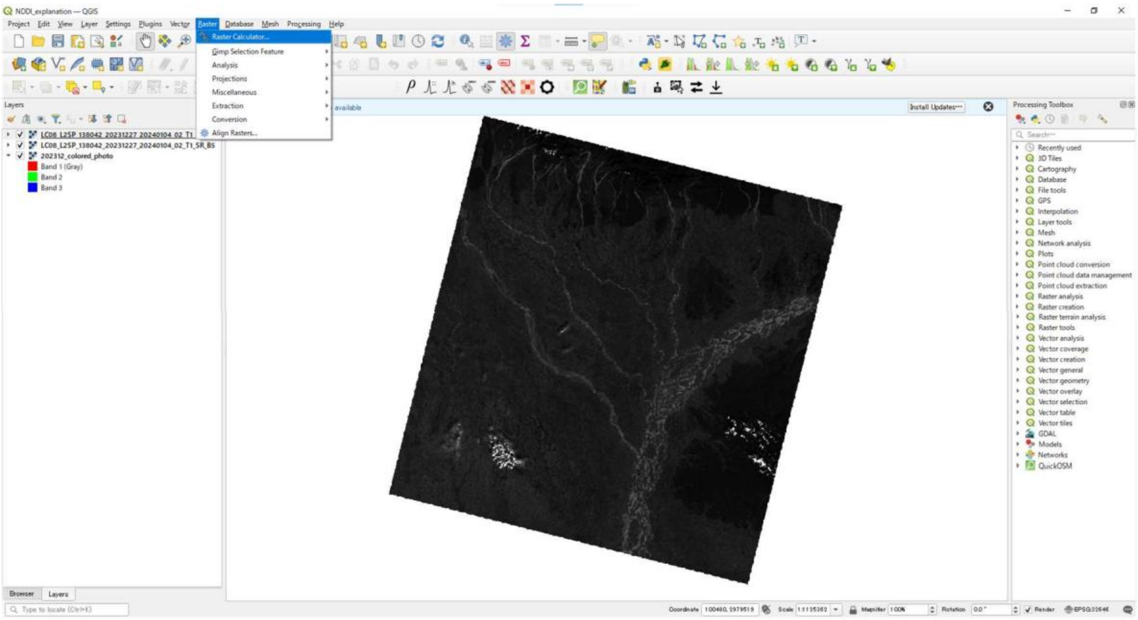
Note:

NDWI values range from -1 to 0: These values generally indicate non-water surfaces such as vegetation, bare soil, or built-up areas.

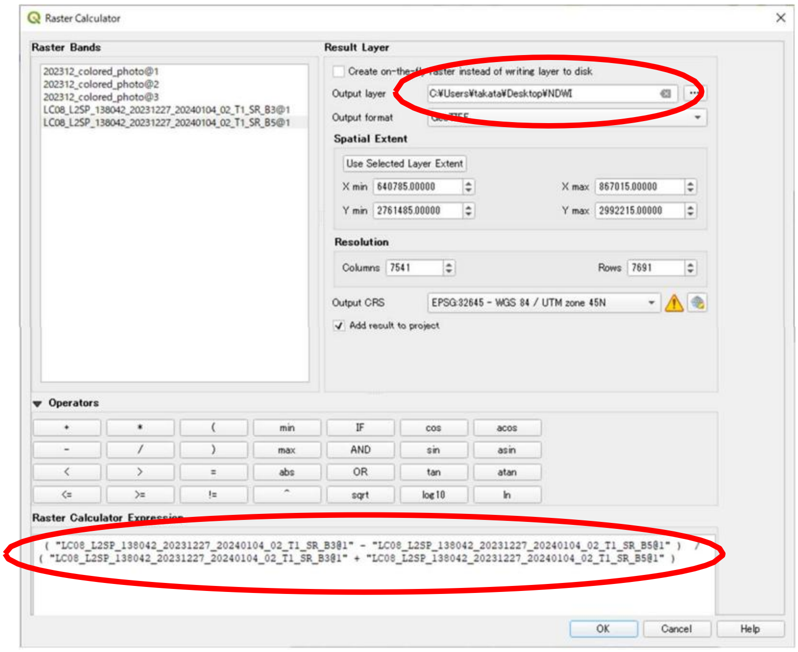
NDWI values range from 0 to +1: These positive values typically represent water bodies or areas with high moisture content.

Here is an example of calculation with QGIS:

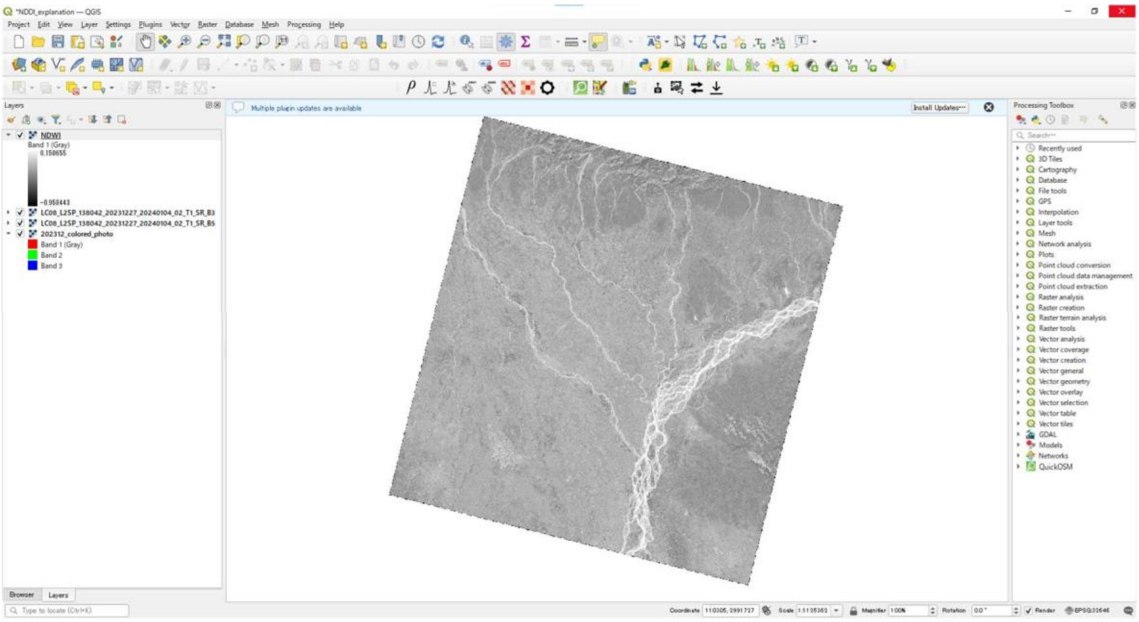
I. After loading the necessary bands, Choose "Raster Calculator" under the "Raster" tab.



II. Define the output layer name and input equation for NDWI, then click "OK".



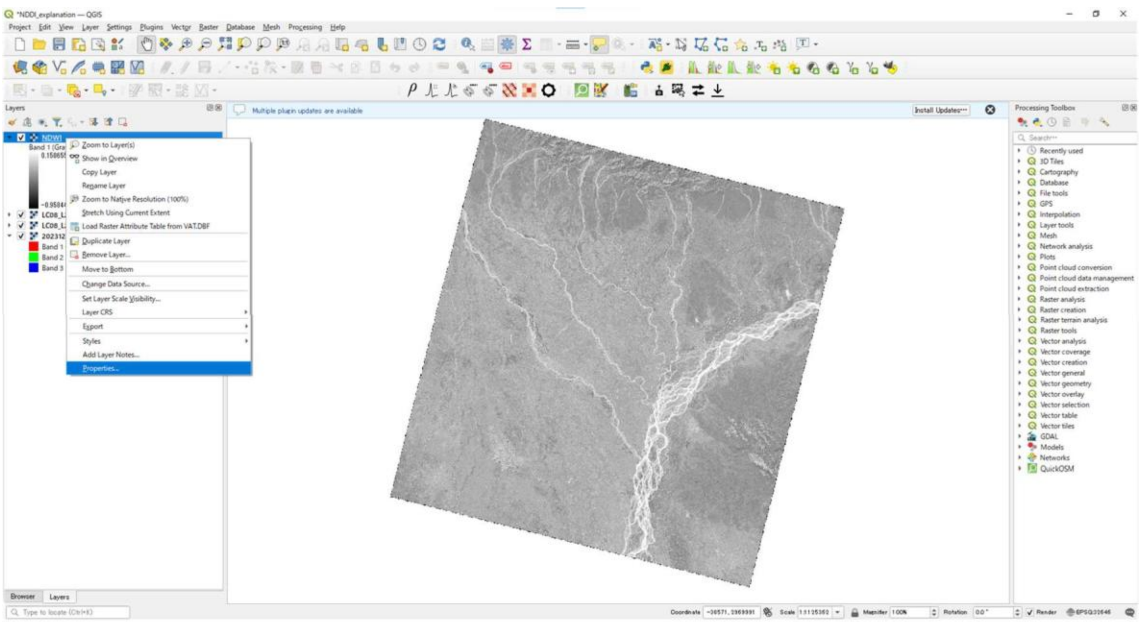
III. NDWI is calculated.



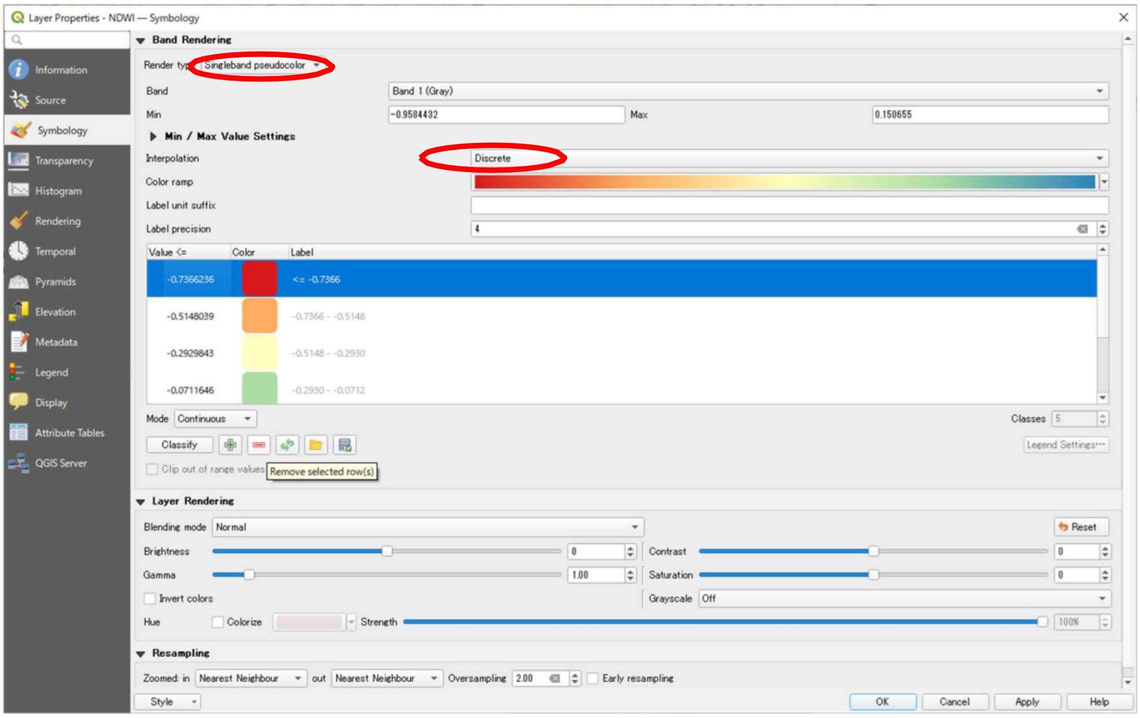
Step 3: Identify the water body with NDWI value.

Here is an example of coloring the areas with positive NDWI value, which means water bodies.

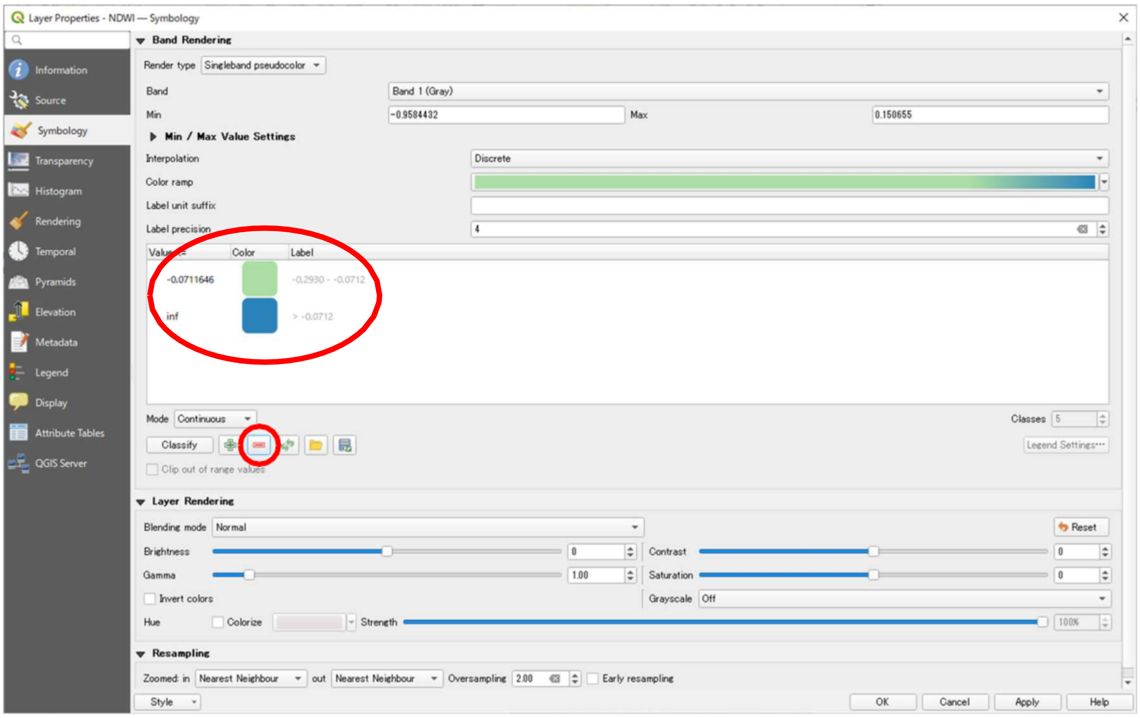
IV. Select “Property” of the newly created layer for NDWI and choose “Symbology”.



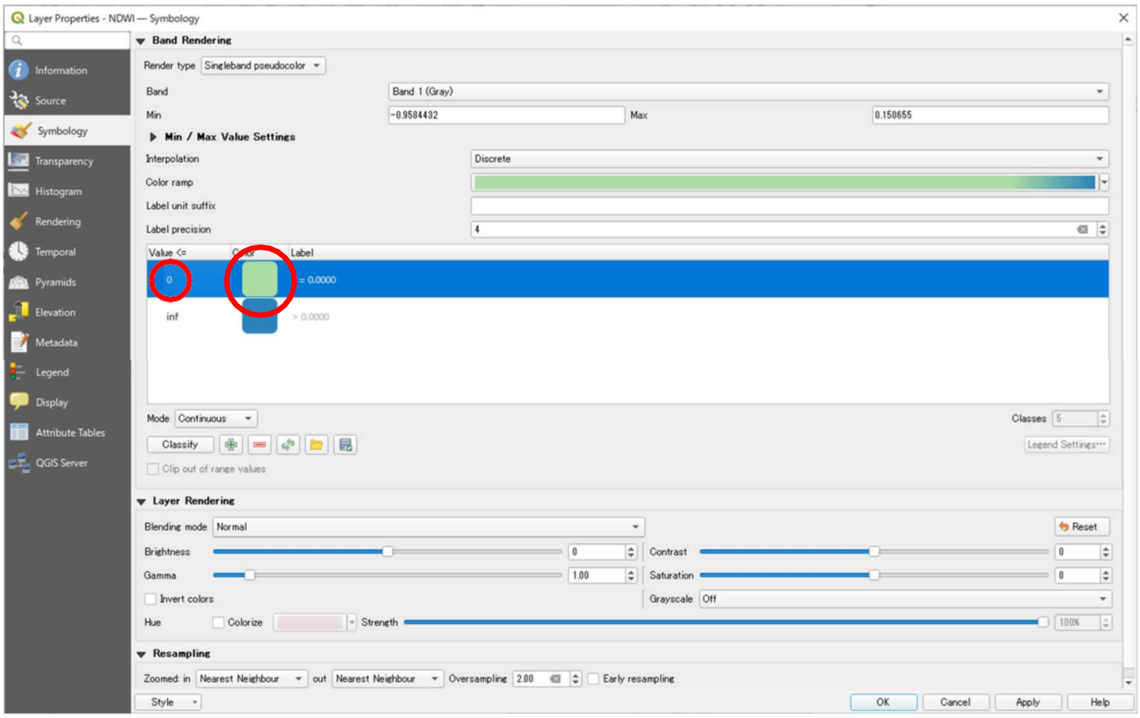
V. Select “Singleband pseudocolor” for “Render type” and “Discrete” for “Interpolation” and select an item in “Label precision”.



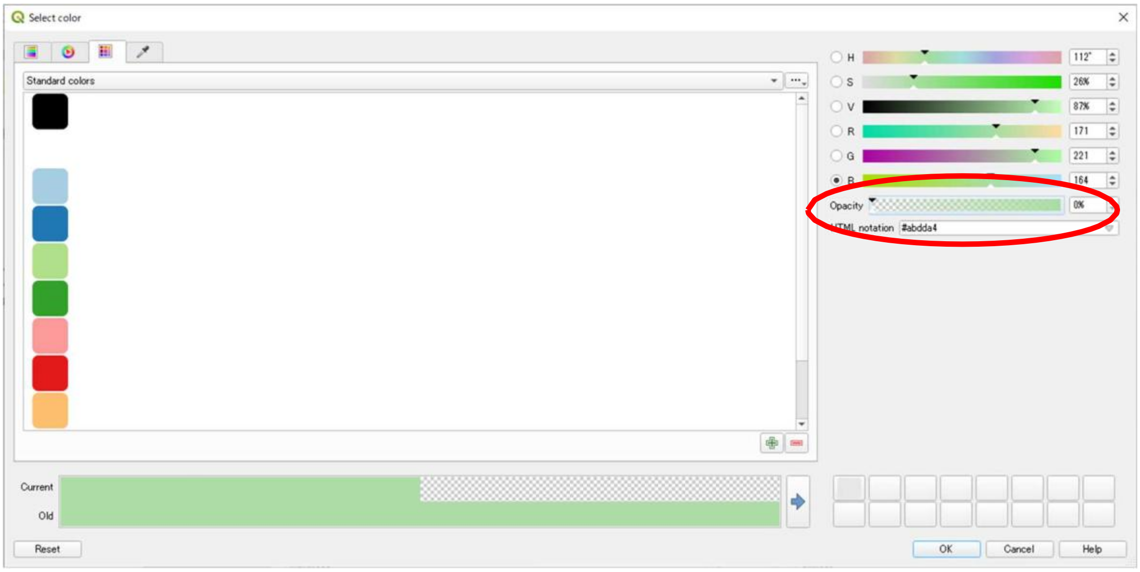
VI. Select an item in "Label precision" and press "-" (minus) symbol to reduce the label until the two labels are left.



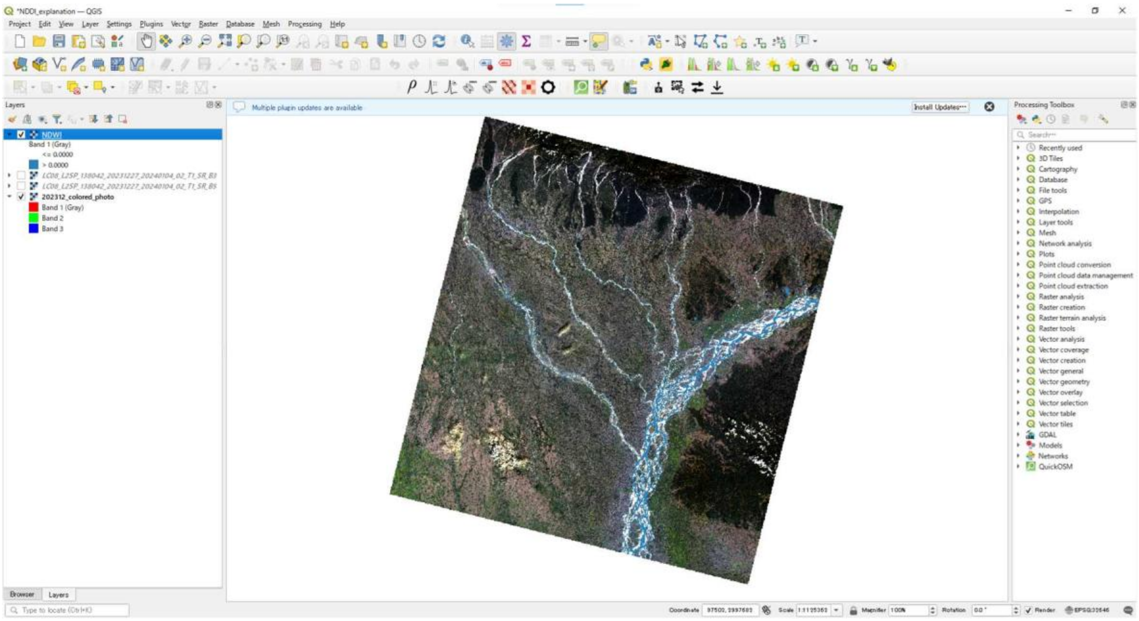
VII. Change the "**Value**" of the first label to 0 (zero) by double-clicking it and type "0", then double-click the color box of the first label.

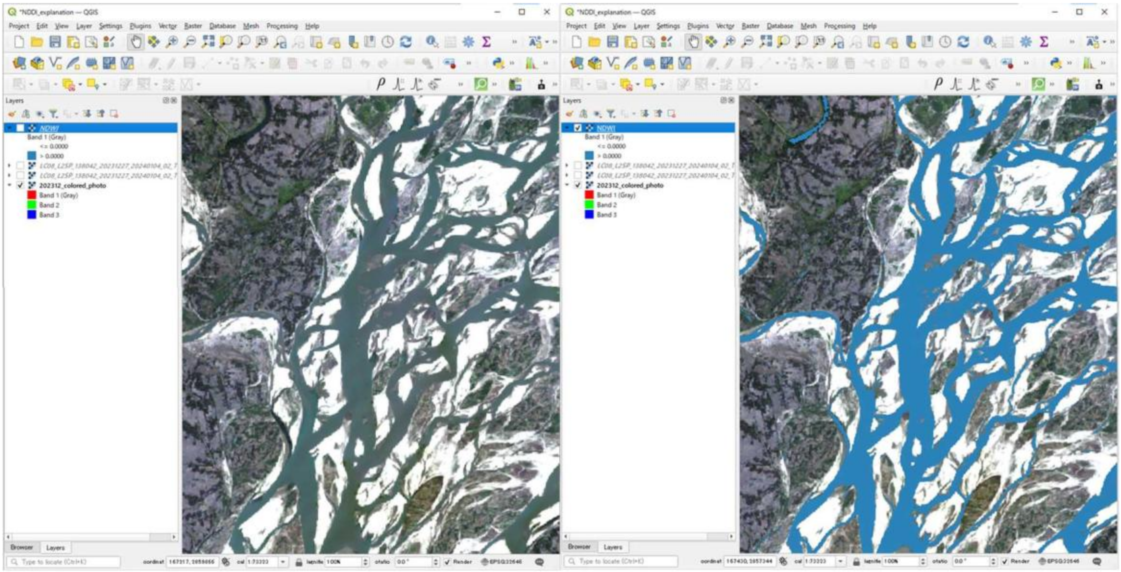


VIII. Slide down the bar "**Opacity**" to 0 to make the color transparent. Then, click "**Ok**".



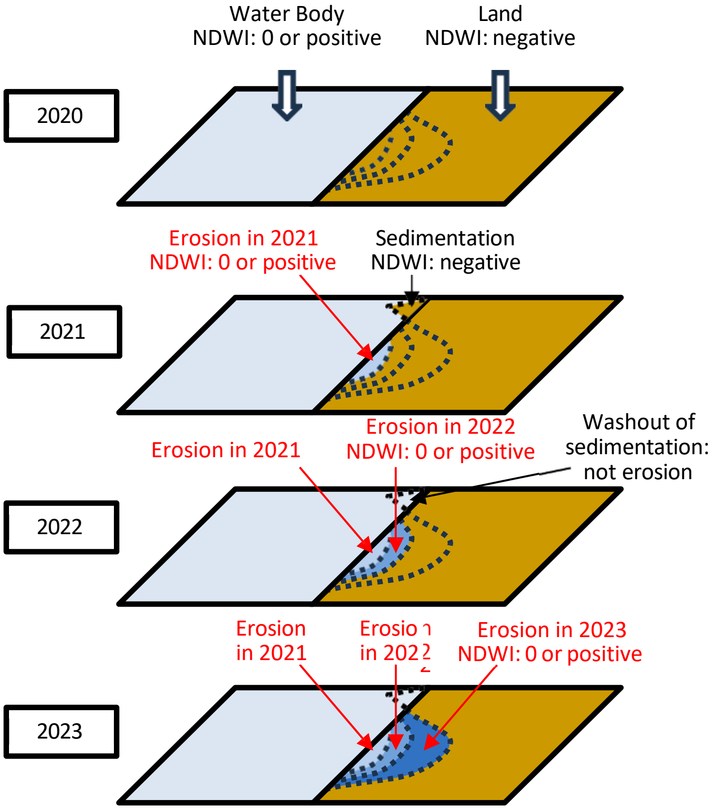
IX. You can get water body area now.





(Left: without water body layer, Right: with water body layer)

4. Concept of the calculations for identifying the eroded areas in each year (e.g., from 2020 to 2023)



The riverbank erosion is identified based on the change of NWDI value. Basically, the area with 0 or positive value representing "water body" and the one with negative value "land". The eroded areas can be expressed as the area whose NDWI value was negative value before, then 0 or positive value later.

Since the purpose of this analysis is to identify the high-risk area for our life, the land areas newly created by sedimentation after the initial year is excluded from this analysis.

Concept Figure of Identification of Eroded Area

Concept Table of Identification of Eroded Area

2020	2021	2022	2023	Erosions to be considered	Adjusted value for GIS computation	Remarks
Land	Land	Land	Land	No	0	
			Water	Erosion in 2023	2023	
		Water	Land	No	0	*1
			Water	Erosion in 2022	2022	
	Water	Land	Land	No	0	*1
			Water	No	0	
		Water	Land	No	0	*1
			Water	Erosion in 2021	2021	
Water	Land	Land	Land	No	0	*1
			Water	No	0	
		Water	Land	No	0	*1
			Water	No	0	
	Water	Land	Land	No	0	*1
			Water	No	0	
		Water	Land	No	0	*1
			Water	No	0	

*1: it is considered that those areas are abandoned areas that are primarily sandy or grassy

Conditions:

If ("NDWI 2020" is 0 or positive (water in 2020), the value is 0,

else (land in 2020)

if ("NDWI 2021" is 0 or positive (water in 2021),

and if ("NDWI 2022" is 0 or positive (water in 2022),

and if ("NDWI 2023" is 0 or positive (water in 2023),

the value is 2021, else 0), else 0),

else if ("NDWI 2022" is 0 or positive (water in 2022),

and if ("NDWI 2023" is 0 or positive (water in 2023),

the value is 2022, else 0),

else if ("NDWI 2023" is 0 or positive (water in

2023), the value is 2023, else 0))))

where: "NDWI ****" shows the name of the raster layer which contains NDWI for the year ****.

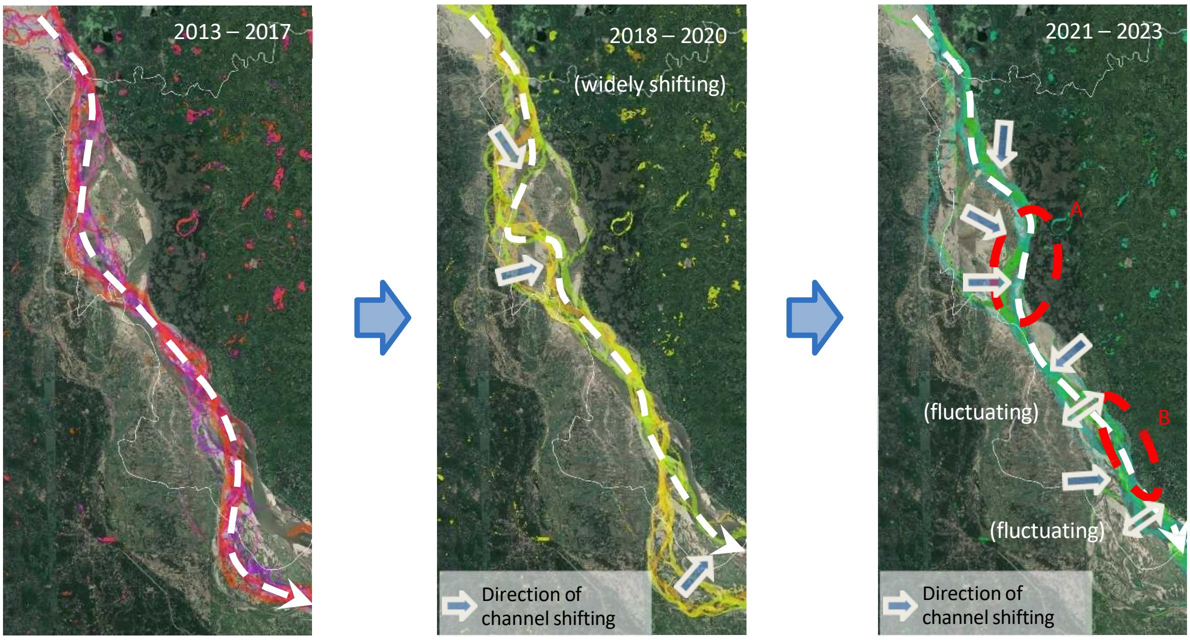
Sample Equation for QGIS:

If ("NDWI 2020" >= 0, 0, if ("NDWI 2021" >= 0, if ("NDWI 2022" >= 0, if ("NDWI 2023" >= 0, 2021, 0), 0), if ("NDWI 2022" >= 0, if ("NDWI 2023" >= 0, 2022, 0), if ("NDWI 2023" >= 0, 2023, 0))))

I. Estimation of High-hazard Area

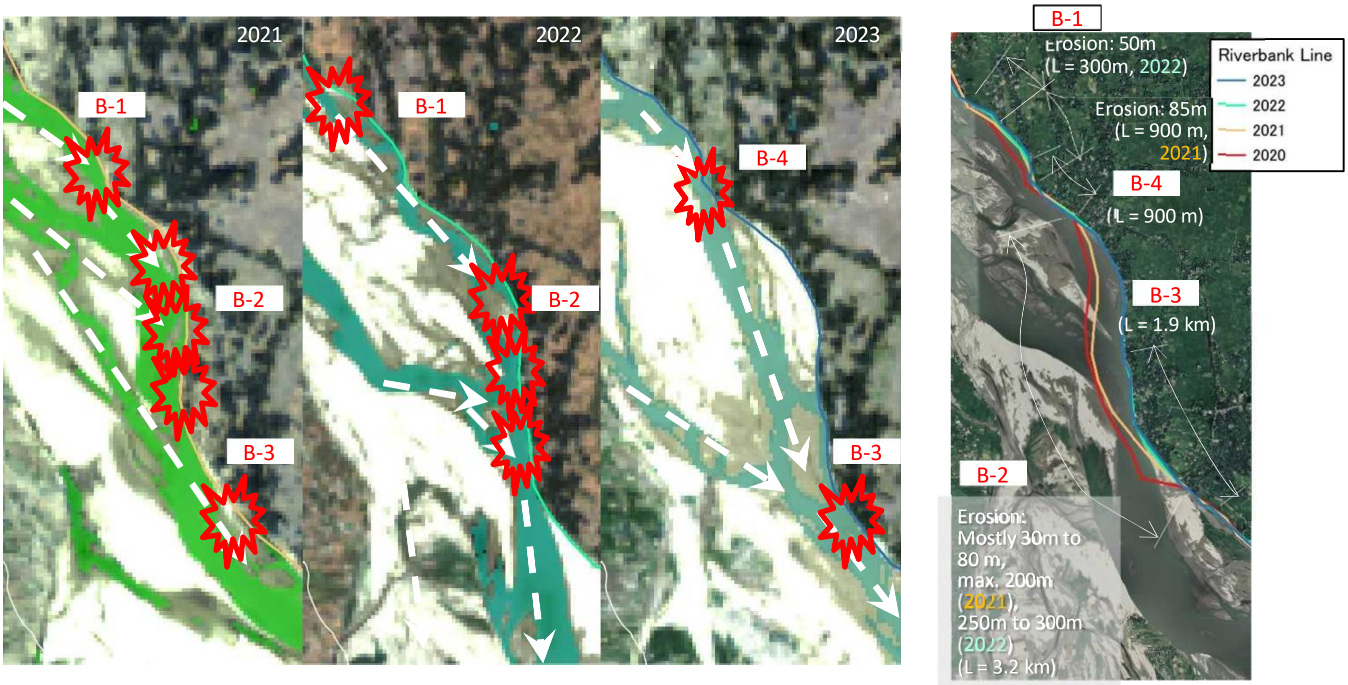
i. For the rivers with one or two significant main streams

For the rivers with one or two significant main streams, the river channel movement is observed referring to the colored satellite images and water body areas in the last 10 to 15 years. Although water body areas can be found by calculations with GIS software, the tendency of the river channel movement will be grasped by people. Recognition of such movement will help you to identify the possible hazard areas (e.g., zone A and zone B in the following figure.)



Tendency of Movement of Teesta River along Ulipur Upazila in Large Scale

After identifying such area, local movement will be studied in the last couple of years, then predict the high-hazard area in the coming couple of years referring to the transition and the geometrical scale of eroded areas.

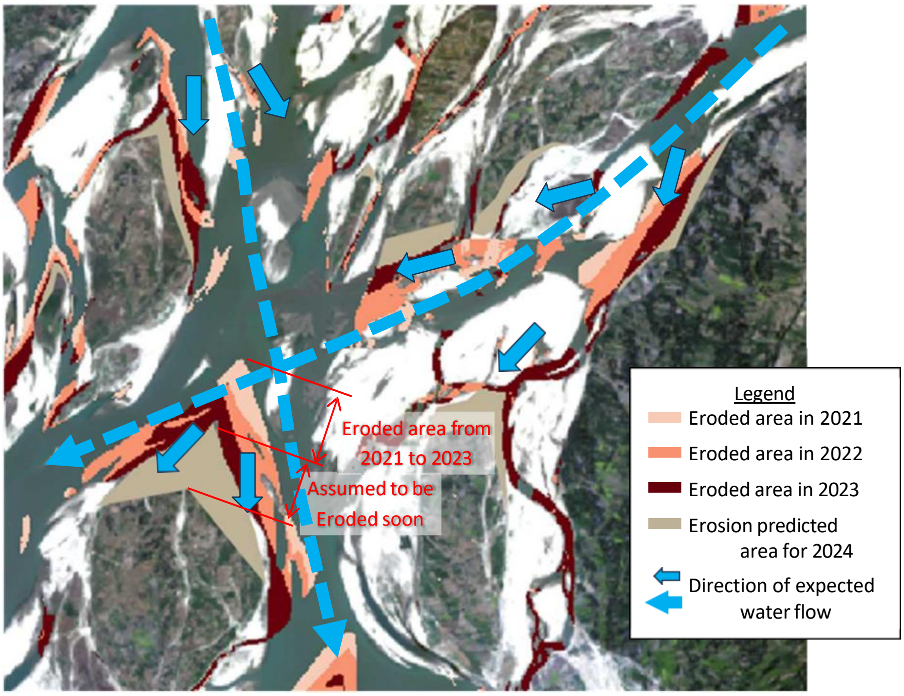


Tendency of Movement of Teesta River along Ulipur Upazila in Local Scale

Selected High-hazard Area for Riverbank Erosion along Ulipur Upazila (for 2024)

ii. For the braided river channels

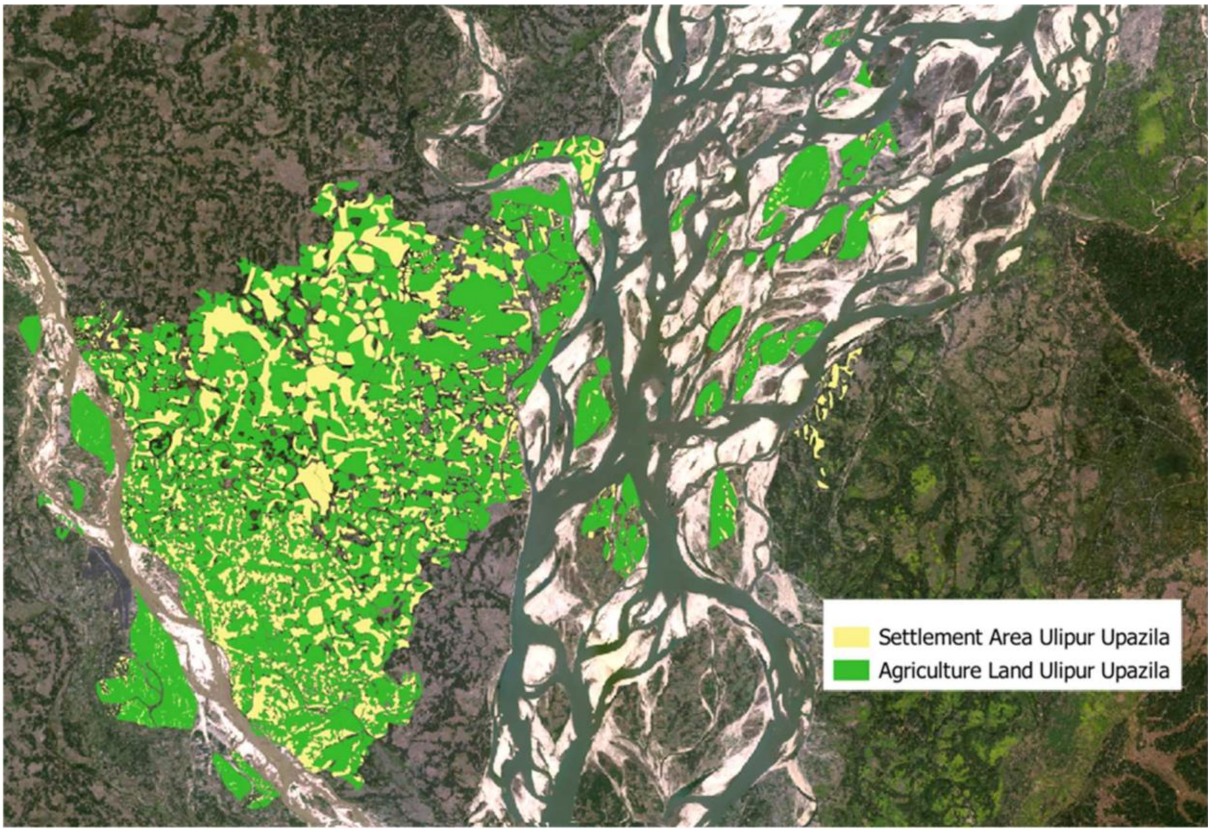
For the braided river channels, referring to the calculated distribution of the annual riverbank erosion in a last couple of years, the high-hazard areas for riverbank erosion will be selected.



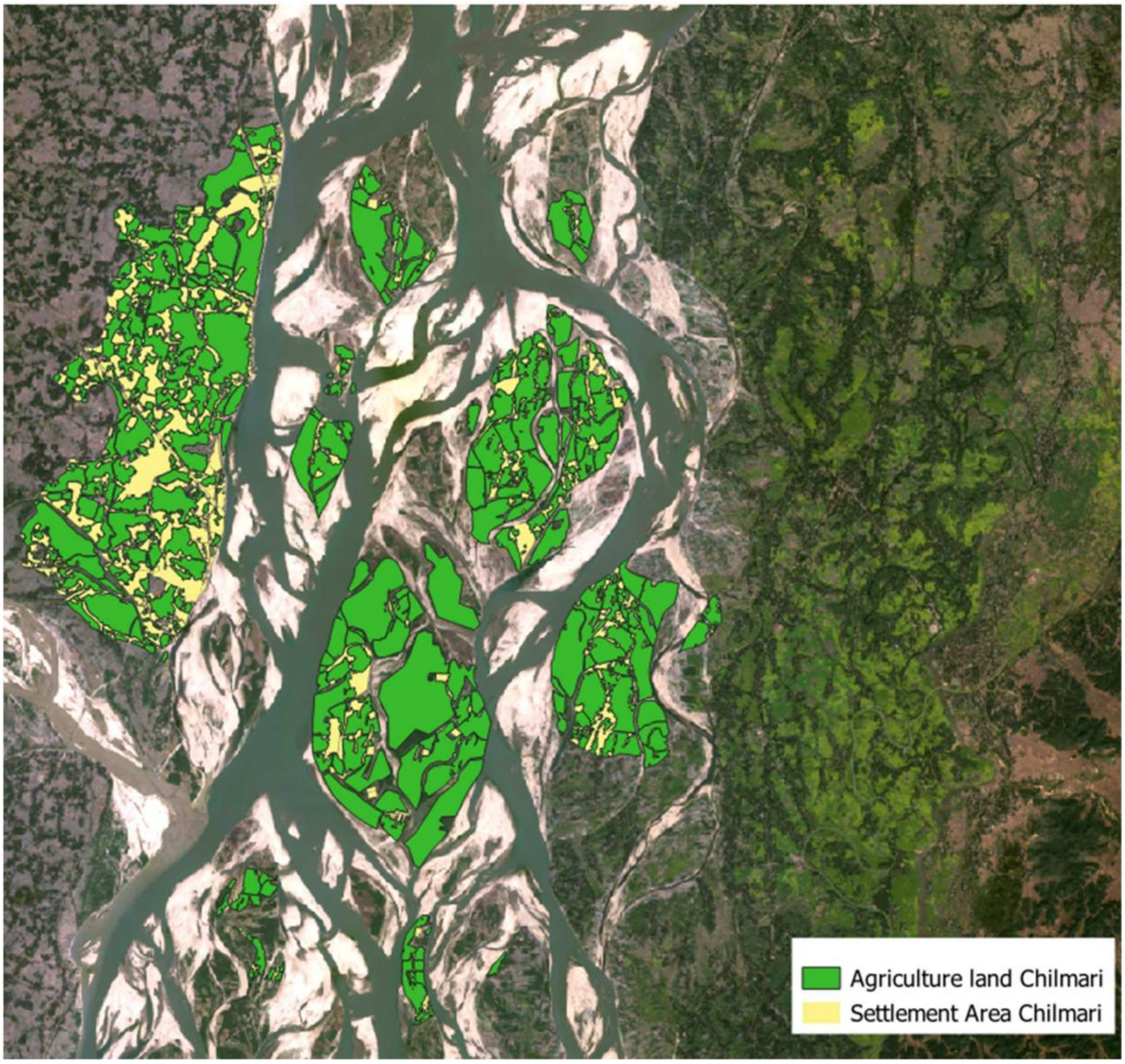
Selected High-hazard Area for Riverbank Erosion in Char Area (for 2024)

5. Estimation of High-risk Area

Basically, the high-risk areas can be selected by overlaying the high-hazard areas and assets. Here, the layers of the settlement areas and agriculture areas (mainly, paddy fields) are generated by creating polygons one by one referring to the satellite photo and are overlayed with the high-risk areas.



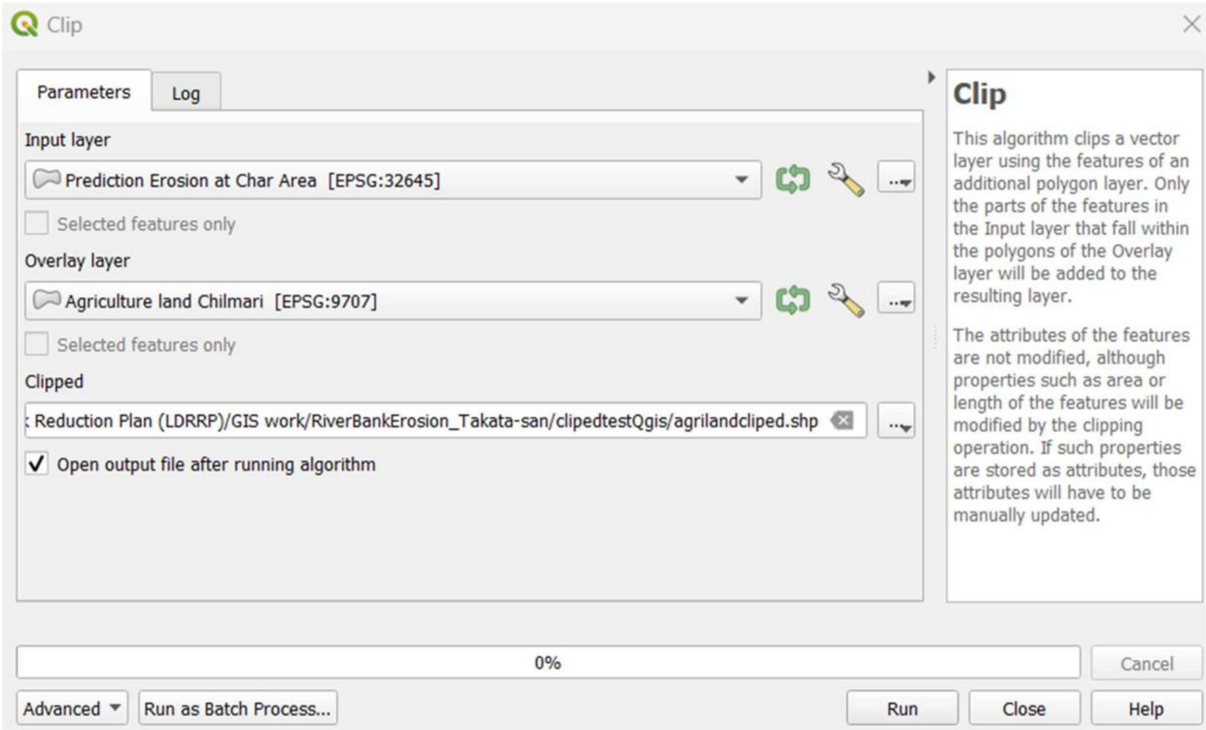
Land-use Map of Ulipur Upazila



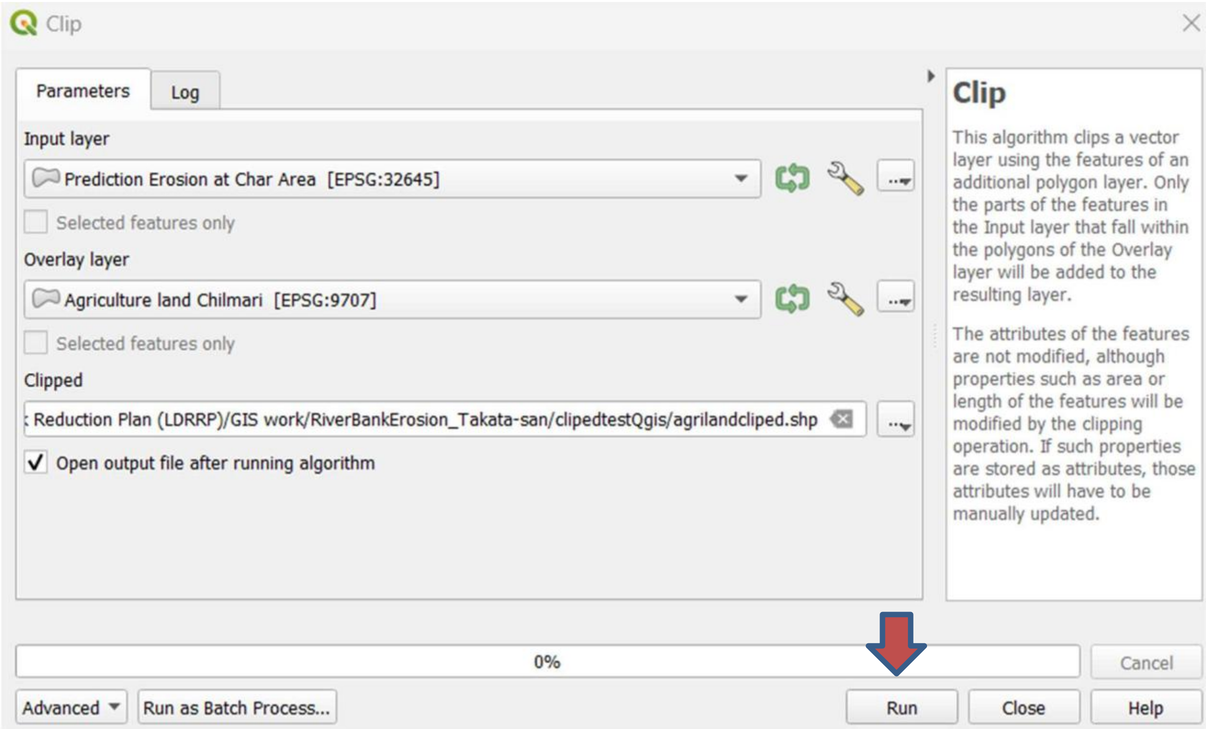
Land-use Map of Chilmari Upazila

<detailed overlaying and trimming steps>

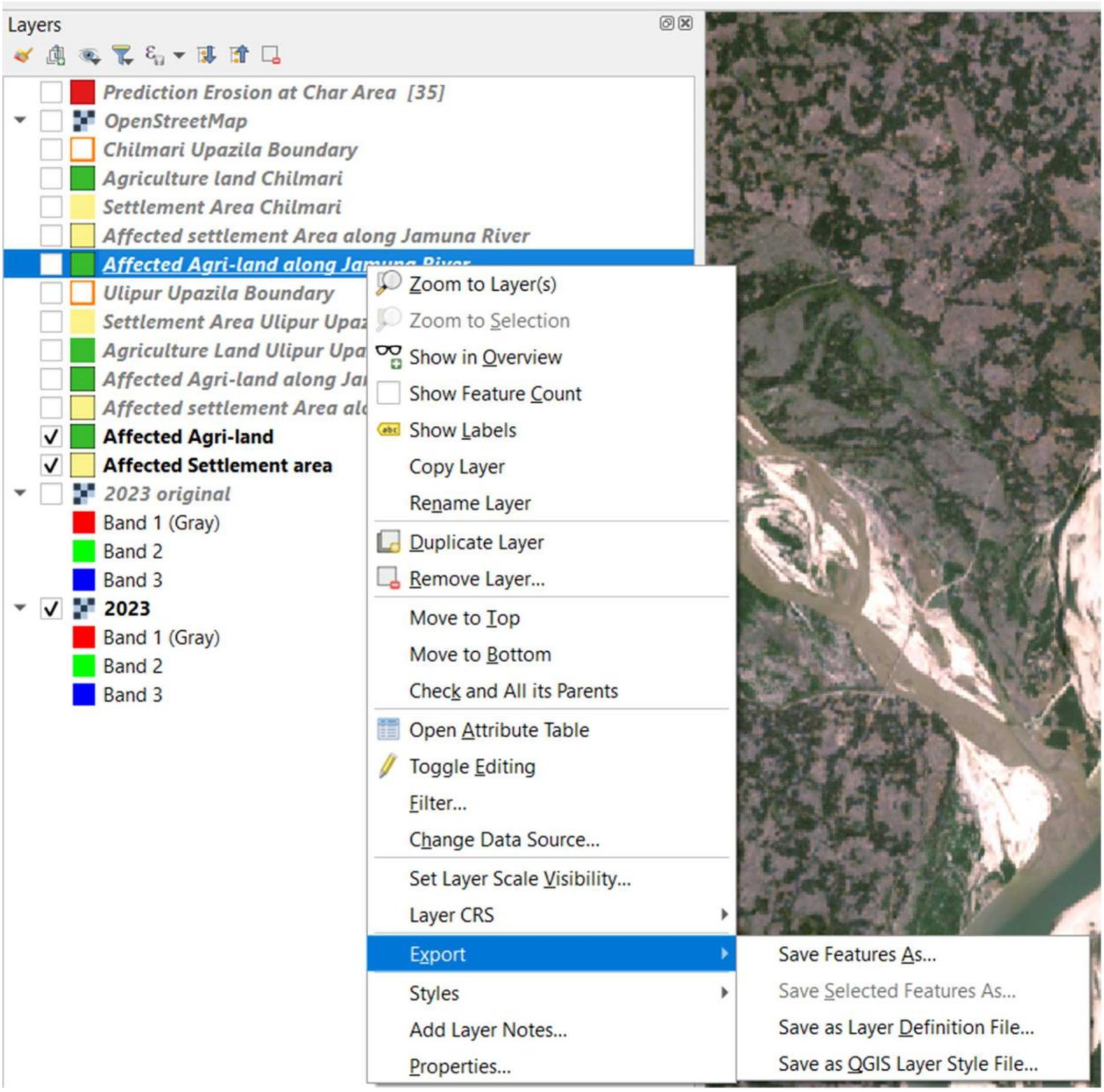
1. Open QGIS: Launch QGIS on your computer.
2. Load Shapefiles: Add both the shapefile you want to clip (the input layer) and the shapefile you will use as the clip boundary (the clip layer) to your project.
3. To add a shapefile: Layer > Add Layer > Add Vector Layer...
4. Ensure CRS Compatibility: Make sure both shapefiles are in the same Coordinate Reference System (CRS). If they are not, you may need to re-project one of the layers to match the other.
5. Right-click on the layer > Properties > Source to check and change CRS if needed.
6. Select Clip Tool: Go to Processing Toolbox (if not visible, View > Panels > Toolbox) and search for the "Clip" tool.
7. Type "Clip" in the search bar to find the tool.
8. Set Input Parameters:
9. Input layer: Select the shapefile you want to clip.
10. Overlay layer: Select the shapefile that will be used to clip the input layer.
11. Clipped: Specify where you want to save the clipped output file.



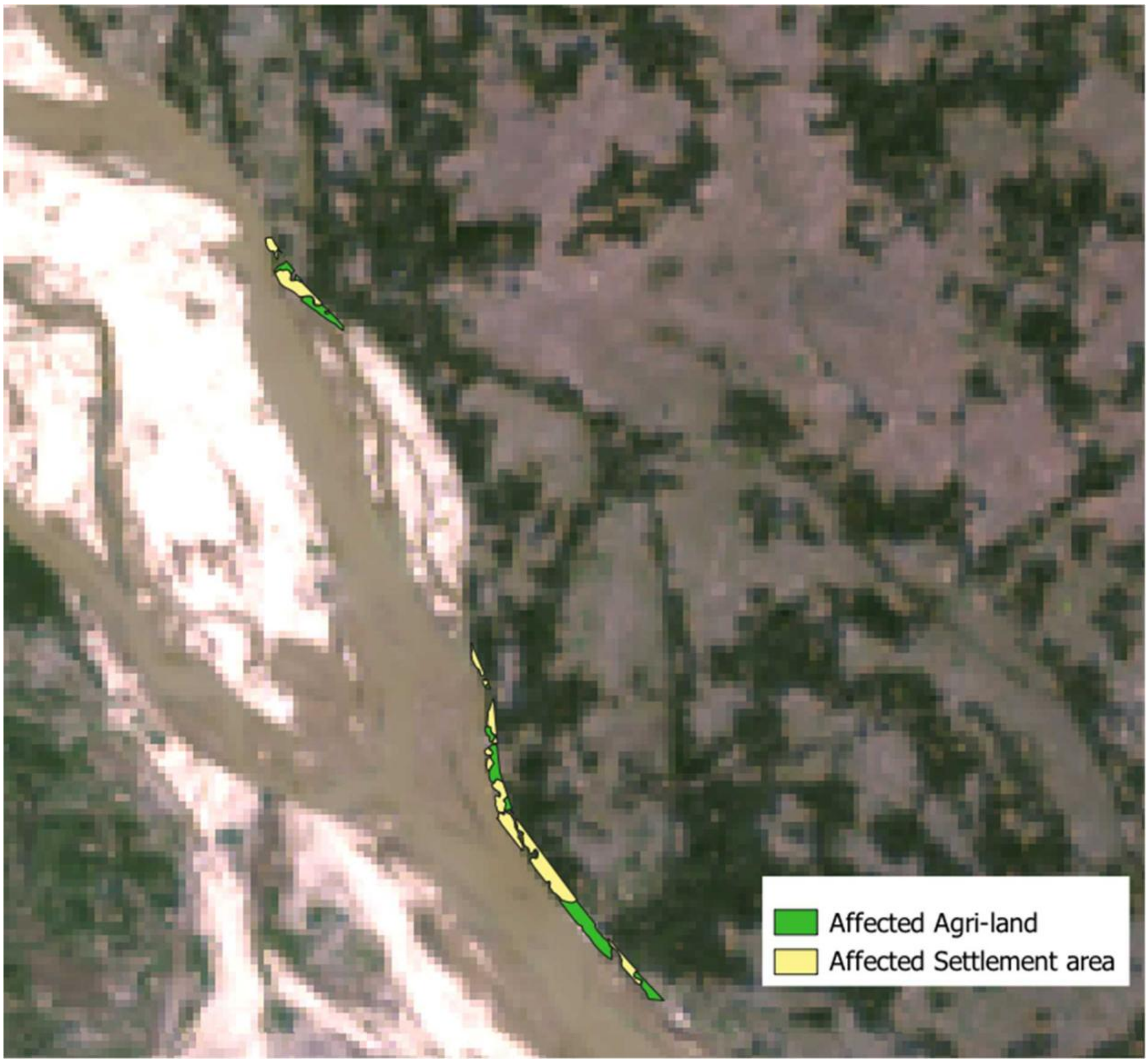
12. Run the Clip Tool: After setting the input parameters, click on the Run button to execute the clip operation.



13. Review the Clipped Output: Once the process completes, you should see a new layer added to your map canvas, which represents the clipped shapefile.
14. Save the Clipped Shapefile: Right-click on the clipped layer in the Layers panel and choose Export > Save Features As... to save the clipped shapefile to your desired location and format.



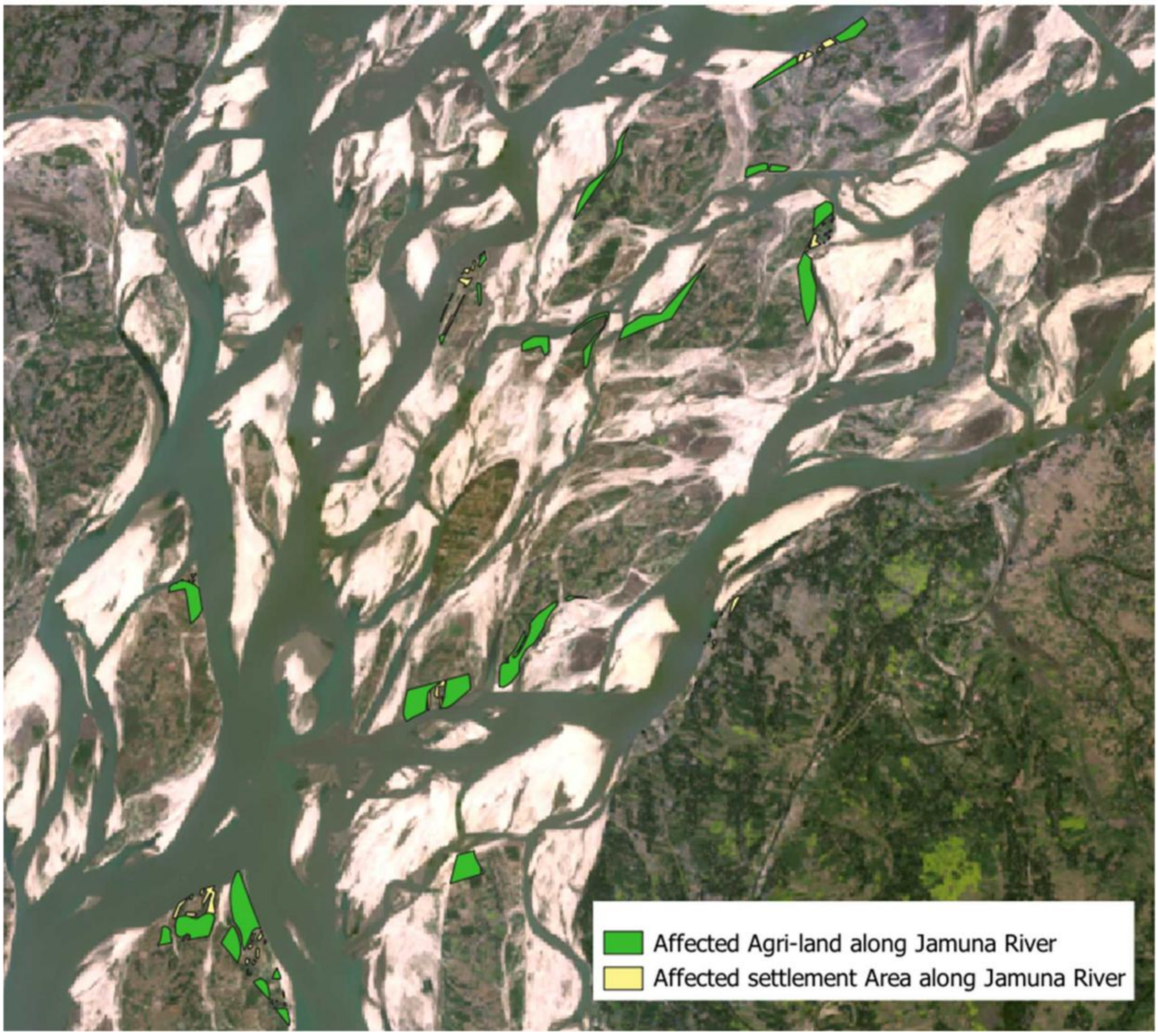
15. **Verify the Clipped Data**: Open the saved clipped shapefile to ensure that it contains only the data that falls within the boundaries of the clip layer.



High-risk area of riverbank erosion along Teesta River (Ulipur Upazila)

High-risk area of riverbank erosion along Teesta River (Ulipur Upazila, unionwise)

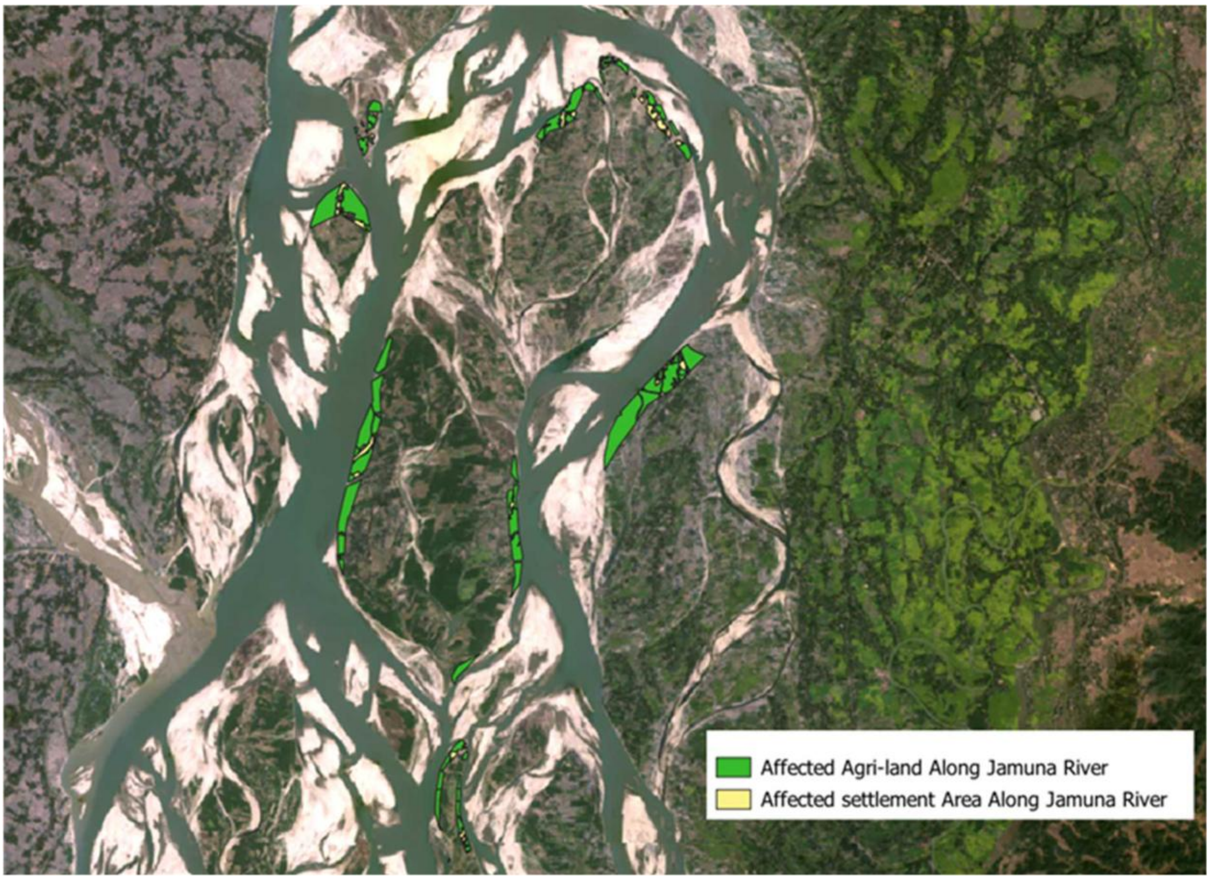
Union	Affected agriculture area (ha)	Affected settlement area (ha)
Bazra	3.7	5.8
Total	3.7	5.8



High-risk area of riverbank erosion at the Char area in Jamuna River (Ulipur Upazila)

High-risk area of riverbank erosion in Jamuna River (Ulipur Upazila, unionwise)

Union	Affected agriculture area (ha)	Affected settlement area (ha)
Begumganj	12.2	4.3
Burabari	0.0	0.7
Hatia	14.4	0.0
Saheber Alga	231.0	30.4
Total	257.6	35.4



High-risk area of riverbank erosion at the Char area in Jamuna River (Chilmari Upazila)

High-risk area of riverbank erosion in Jamuna River (Chilmari Upazila, unionwise)

Union	Affected agriculture area (ha)	Affected settlement area (ha)
Ashtamir Char	192.0	16.8
Chilmari	80.7	8.1
Nayerhat	96.2	23.3
Raniganj	61.0	7.6
Total	429.9	55.8

ANNEX 4: Technical Manual for Costal Disasters Analysis

(Updated April. 2025)

Table of content

1. Detailed Explanation of Tide Analysis in Cox's Bazar

This chapter outlines the calculation method of **Cox's Bazar** below.

1.1. Extracting the data input for analysis

Step 1: To prepare the input data for tide analysis, two methods can be employed based on the observed data. Method 1 involves manually extracting the top yearly highest values from the observed data, which will then be used as input data for the tide analysis. Alternatively, Method 2 requires manually extracting the top three highest yearly values from the same data set, which will be utilized in the subsequent step of the tide analysis process. The extracted data will be arranged accordingly.
Input data for tide analysis from Extraction Method 1 is shown in Table 1-1. (The data we have at Cox's Bazar is annual maximum data, the data from Extraction Method 2 is omitted.)

Table 1-1 Yearly Top Highest Tide Levels (1983-2021)

Year	Max	Year	Max	Year	Max
1983	1.98	1996	2.52	2009	2.48
1984	2.02	1997	2.24	2010	2.65
1985	2.11	1998	2.19	2011	2.14
1986	2.36	1999	2.11	2012	1.76
1987	2.56	2000	2.23	2013	2.38
1988	2.06	2001	2.23	2014	2.09
1989	2.22	2002	2.22	2015	2.24
1990	2.14	2003	2.23	2016	2.04
1991	2.08	2004	2.29	2017	3.19
1992	2.20	2005	2.28	2018	2.27
1993	2.08	2006	2.18	2019	2.23
1994	1.71	2007	2.32	2020	2.36
1995	2.61	2008	2.47	2021	2.49

1.2. Setting Arrangement for Analysis

From the following steps, we will focus on Method 1 based on yearly top highest tide levels as a reference analysis.

Step 2: Transfer the tidal data (excluding the years) from the previous steps into the height (m) column in the Excel sheet(01_arrange_data). Ensure that the first row of the period(s) column is filled with -

999, as period values are not considered to be calculated in this study.

Note: A similar calculation can be performed for Method 2 by using the top three highest values per year.

Step 3: Arrange the values from largest to smallest, as the calculation will begin from the smallest value using a trial-and-error method.

Step 4: Define the valid statistical years as the actual number of observed years. For instance, data for Cox's Bazar spans from 1983 to 2021, totaling 39 years. Exclude any years with missing data from the count of valid years.

Step 5: Perform calculations starting with the smallest values and using trial calculations. Set foot-cutting values and number of sample data accordingly.

Step 6: Then, press the 'Manual Calculation' or 'Automatic Calculation' button until an 'adoption' judgment is reached.

Notes: If an error occurs, adjust the foot-cutting values to the next larger value and modify the sample size accordingly. For example, if calculations fail with the smallest value (e.g., 1.71), increase the cut-off value to the next larger value (e.g., 2.02) and set the sample size to 35. In other words, start with the smallest value, and if issues arise, use the subsequent larger value in the sequence and adjust the sample size based on this new value.

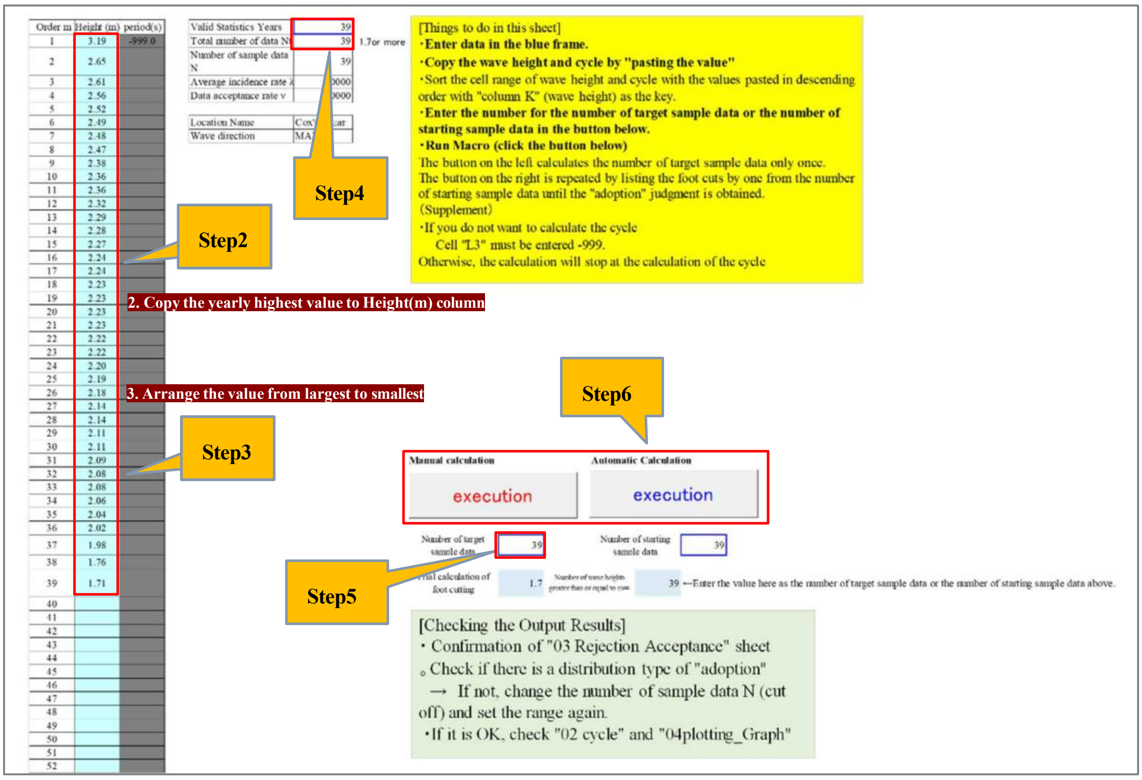


Figure 1-1 Preparation of Input data and Calculation Process

1.3. Analysis Results

Step 7: After completing the calculations, the "03adopt_or_reject" sheet will automatically appear in the Excel file. This sheet will display results from three types of distribution analyses—Extreme Value Type I, Extreme Value Type II, and Weibull—running in the background. The most appropriate distribution will be selected based on these analyses.

Table 1-2 Adoption and Rejection Distribution Type Judgement

valid statisticalyear39year	extreme value type I distribution	Extreme value type II distribution				Weibull distribution			
		k=2.5	k=3.33	k=5.0	k=10.0	k=0.75	k=1.0	k=1.4	k=2.0
Total number of data Nt	39	39	39	39	39	39	39	39	39
Number of sample data N	39	39	39	39	39	39	39	39	39
average incidence λ	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Data acceptance rate v	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Average value X	2.258	2.258	2.258	2.258	2.258	2.258	2.258	2.258	2.258
unbiased standard deviations	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254
REC standard	○	○	○	○	○	×	×	×	×
Downward DOL standard	○	○	○	○	○	○	○	○	○
Upward DOL standard	○	○	○	○	○	[illegible]	[illegible]	[illegible]	×
MIR standard	1.77	1.616	1.368	1.227	1.319	[illegible]	[illegible]	[illegible]	3.531
correlation coefficient r	0.969	0.922	0.949	0.964	0.970	[illegible]	[illegible]	[illegible]	0.954
Parameter A	0.198	0.086	0.116	0.146	0.173	[illegible]	0.250	0.378	0.534
Parameter B	2.146	2.153	2.144	2.140	2.141	[illegible]	2.008	1.914	1.785

Adopted Distribution Function

probability year	EV I wave height(	EV I period ①(s)	EV I period ②(s)	k=2.5 wave height(	k=2.5 period ①(s)	k=2.5 period ②(s)	k=3.33 wave height(	k=3.33 period ①(s)	k=3.33 period ②(s)	k=5.0 wave height(	k=5.0 period ①(s)	k=5.0 period ②(s)	k=10.0 wave height(	k=10.0 period ①(s)	k=10.0 period ②(s)
10year	2.59	0.0	6.0	2.47	0.0	5.8	2.52	0.0	5.9	2.55	0.0	6.0	2.58	0.0	[illegible]
20year	2.73	0.0	6.2	2.65	0.0	6.1	2.70	0.0	6.2	2.73	0.0	6.2	2.74	0.0	6.2
30year	2.82	0.0	6.3	2.77	0.0	6.3	2.82	0.0	6.3	2.84	0.0	6.4	2.84	[illegible]	6.4
50year	2.92	0.0	6.5	2.97	0.0	6.6	3.00	0.0	6.6	3.00	0.0	6.6	[illegible]	0.0	6.6
100year	3.06	0.0	6.7	3.30	0.0	7.0	3.29	0.0	7.0	3.24	0.0	6.9	3.15	0.0	6.8

probability year	k=0.75 wave height(	k=0.75 period ①(s)	k=0.75 period ②(s)	k=1.0 wave height(	k=1.0 period ①(s)	k=1.0 period ②(s)	k=1.4 wave height(	k=1.4 period ①(s)	k=1.4 period ②(s)	k=2.0 wave height(	k=2.0 period(s)	k=2.0 period ②(s)
10year	2.55	0.0	6.0	2.58	0.0	6.0	2.60	0.0	6.0	2.60	0.0	6.0
20year	2.75	0.0	6.2	2.76	0.0	6.3	2.74	0.0	6.2	2.71	0.0	6.2
30year	2.87	0.0	6.4	2.86	0.0	6.4	2.82	0.0	6.3	2.77	0.0	6.3
50year	3.03	0.0	6.6	2.99	0.0	6.6	2.92	0.0	6.5	2.84	0.0	6.4
100year	3.27	0.0	7.0	3.16	0.0	6.8	3.04	0.0	6.6	2.93	0.0	6.5

	extreme value type I distribution	Extreme value type II distribution				Weibull distribution			
		k=2.5	k=3.33	k=5.0	k=10.0	k=0.75	k=1.0	k=1.4	k=2.0
MIR judgment after rejection	1.767	1.616	1.368	1.227	1.319	rejected	rejected	rejected	rejected
Recruitment distribution type				adopt					

Step 8: Review the analysis results on the "04_plotting_Graph" sheet. The graph that shows a trend line closest to the plotted values will indicate the most suitable probabilistic value for the return period.

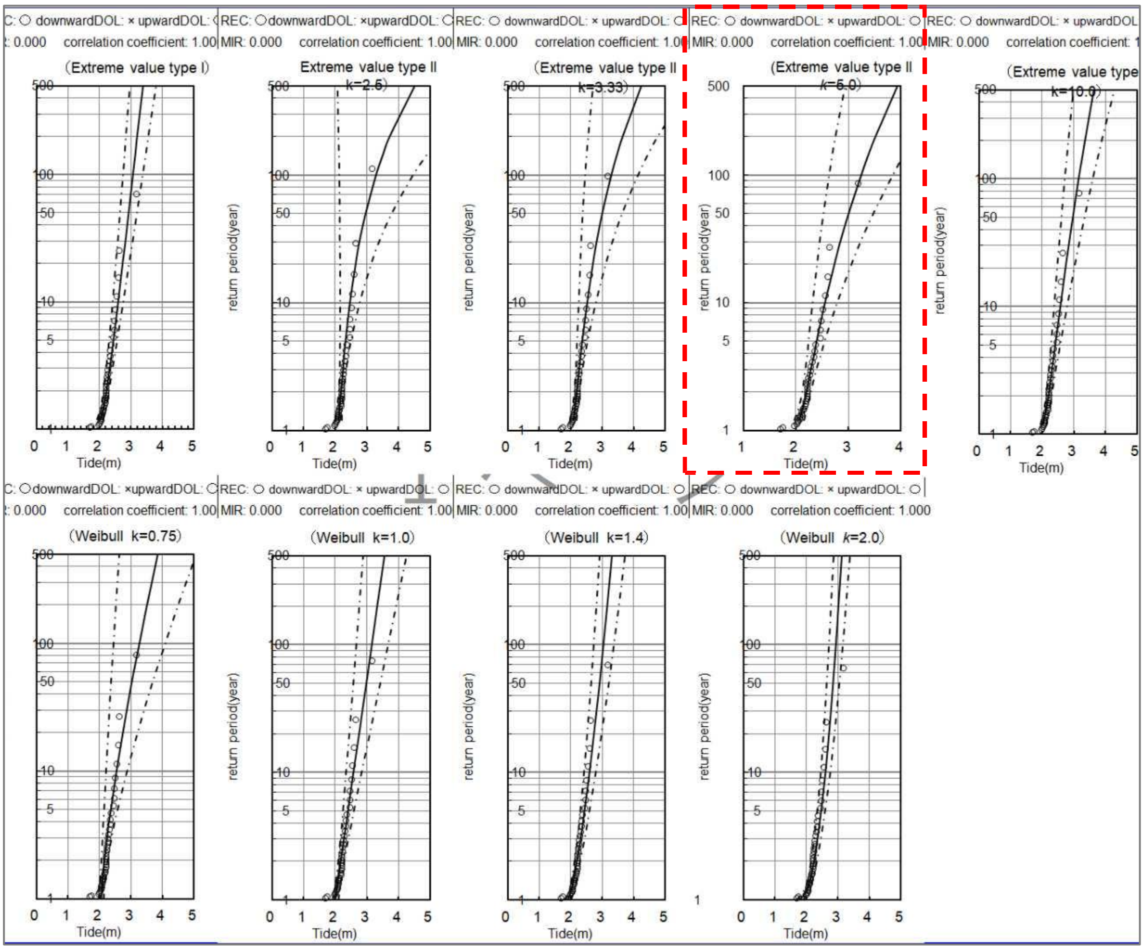
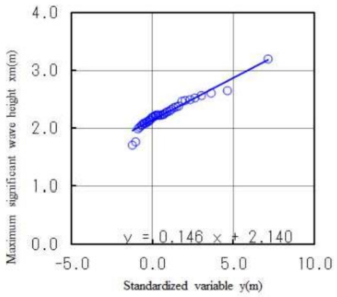


Figure 1-2 Check the Plot Graph with the adopted distribution type (Extreme value type II k=5.0)

Step 9: Once the appropriate distribution is confirmed, check the corresponding sheet for the adopted distribution (e.g., if Extreme value type II with k=5.0 is chosen, review the results on the " Extreme value type II k=5.0" sheet). In the Extreme value type II k=5.0 sheet, resulted probabilistic tide elevations based on the different return periods (10, 15, 20, 25, 30, 50, 100 years) can be checked depending on the project requirements.

■Calculation of probability waves

Extreme Type II(k=5.00)	
Total number of dataNt	39
Number of sample dataN	39
average incidenceλ	1.0000
Data acceptance ratev	1.0000
Average value X	2.258
unbiased standard deviation s	0.2537
REC standard	○
Downward DOL standard	○
Upward DOL standard	○
MIR standard	1.2272
correlation coefficient r	0.9644
Parameter A	0.146
Parameter B	2.140
waveform slope	0.0271



k	α'	β
5.00	0.54	0.10

ξ	Δr
3.68	0.0356

ξ (5%)	a	b	c
2.3330	0.760	0.063	0.100

ξ (95%)	a	b	c
5.1124	0.561	0.473	0.210

Δr(95%)	a	b	c
0.0730	-1.570	-0.220	-0.018

Δr(mean)	a	b	c
0.0290	-2.463	-0.224	-0.019

Source: H30 Port Standards p123-128

Return Period R	Standardized variable yR	Tide Elevation xR(m)	period T(s)
5	1.749	2.39	7.5
10	2.842	2.55	7.8
15	3.535	2.65	7.9
20	4.056	2.73	8.0
25	4.480	2.79	8.1
30	4.838	2.84	8.2
50	5.912	3.00	8.4
100	7.547	3.24	8.8

Result Values of Statistic Analysis

Order m	maximum significant wave height xm(m)	non-exceed probability Fm	Standardized variable y(m)	Reproduction period return period

Figure 1-3 The Probabilistic Values depending on the Reproduction Period

Notes:

1. The calculation excel sheet is initially designed for wave extremes, and results related to the period may be displayed. However, since this study focuses on tide analysis, the period-related results are not necessary for consideration.
2. Results from other sheets can also be reviewed. In some cases, trend lines may not accurately reflect the plotted data points, leading to potentially inappropriate results.

2. Recommended Analysis Procedures for Other Coastal Area

2.1. Recommended Procedures for Other Coastal Area

The method for nationwide hazard analysis requires the applicability to expand the method for all over the nation. There are the 2 main methods for storm surge analysis as follows

1) Simplified Method:
   Historical tide observations and fill level method are used for setting target hazard and inundation analysis, respectively.
2) Detailed Method:
   Storm surge simulation and flood simulation are used for setting target hazard and inundation analysis, respectively.

Table 2-1 Comparison of simplified and detailed methods

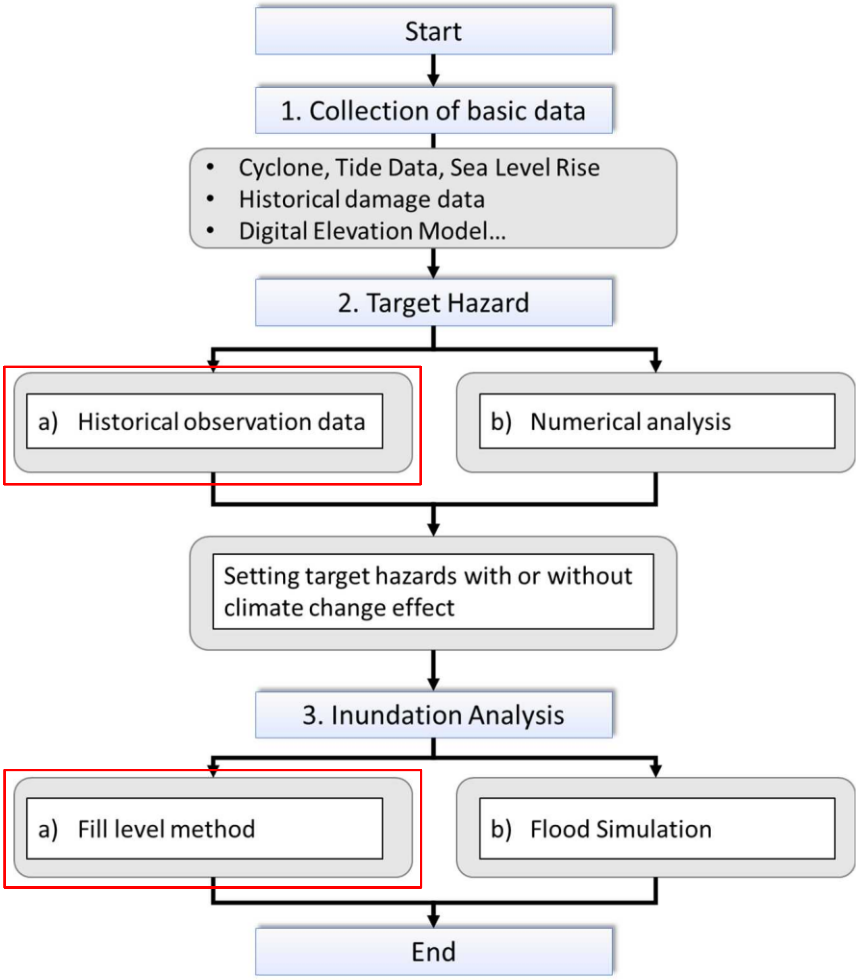
Items	Simplified Method	Detailed Method
Target Hazard	(a) Historical tide observations	(b) Storm surge numerical analysis
Inundation Analysis	(a) Fill level method (FLM)	(b) Flood simulation
Evaluation	Good in short term	Desirable in long term

Source: JICA Expert Team

For applicability to whole nation, the simplified method should be adopted as a basic method unless the results by detailed method or funding for detailed method are available.

The procedures of the recommended methods are described in Figure 2-1. The method consists of the following 3 parts where the simplified methods (i.e., option a) should be selected from these options as mentioned above.

1. Collection of basic data
2. Target Hazard
   a. Historical observation data
   b. Numerical analysis
3. Inundation Analysis
   a. Fill Level Method
   b. Flood Analysis



Source: JICA Expert Team

Figure 2-1 Flow chart of hazard assessment for storm surge

2.2. Necessary Data for Recommended Procedures

The necessary data for the recommended analysis of storm surge is listed in Table 2-2. The options of the methods determine the necessary data based on their characteristics.

Table 2-2 List of necessary data for storm surge analysis

No.	Items	i. Target Hazard		ii. Inundation Analysis	
		a) Obs.	b) Sim.	a) FLM	b) Sim.
1	Cyclone data	✓	✓		
2	Tide observation data	✓	✓		
3	Climate change data	✓	✓		
4	Historical damage data	✓	✓	✓	✓
5	Digital Elevation Model			✓	✓
6	Bathymetry		✓		
7	Structural data				✓

Source: JICA Expert Team

The simplified method for nationwide hazard analysis requires the main 2 necessary data as follows

- Tide Observation Data:
  A series of tide observations have been conducted by BIWTA, BWDB, MPA, and CPA. Such data can be used for this analysis.

- Digital Elevation Model (DEM)
  DEM is necessary to evaluate inundation depth against target hazard level. Although there are some freely available DEMs, more accurate DEM is desirable such as the DEM being developed by SOB.

3. Tide Probability Analysis for Other Coastal Area

3.1. Overall Procedure

The overall methods include the following steps: setting target regions, obtaining observed data, extracting yearly maximum or top three extreme tide elevations, evaluating these extreme tide elevations using extreme value statistical analysis, and determining the target storm surge for each coastal target area and they are shown in following diagram.

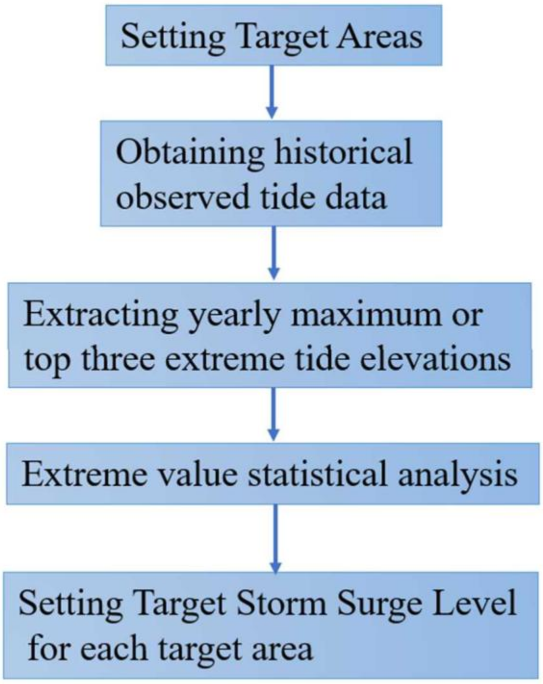


Figure 3-1 Overall method of study

Source: JICA Expert Team

3.2. Setting Target Areas

There are several tide stations which can be observed in the coastal areas of Bangladesh. In this study we have chosen 9 stations as a reference for the analysis and are as follows.

The locations of the nine-tide stations are shown in Figure 3-2.

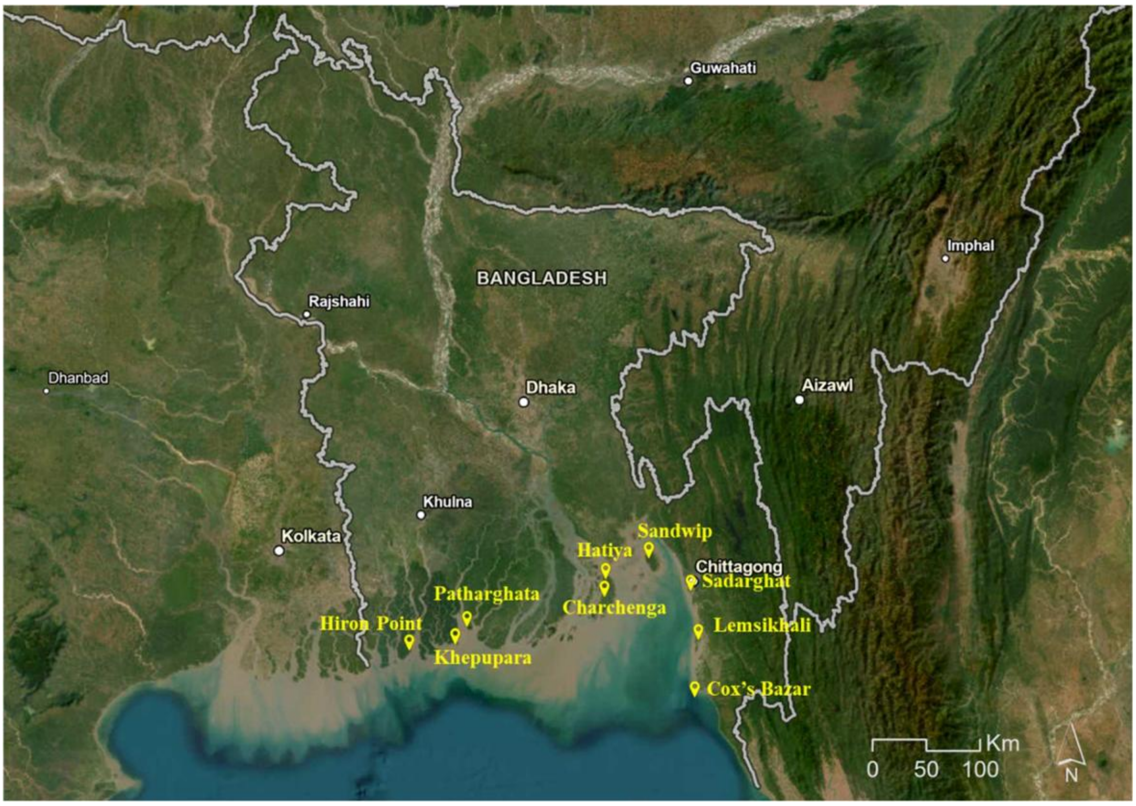


Figure 3-2 Location of Target Areas (Cox's Bazar, Lemsikhali, Sadarghat, Sandwip, Hatiya, Charchenga, Patharghata, Khepupara, Hiron Point)

Source: Earthstar Geographics, Esri, FAO, Garmin, NOAA, TomTom, USGS

3.3. Obtaining the historical observation tide data

The observed tide data consists of historical daily maximum tide levels, monthly maximum tide levels, or annual maximum tide levels from all nine target stations, measured relative to Chart Datum (CD) or Mean Sea Level (MSL). Cox's Bazar data is annual maximum tide levels from 1983 to 2021. Lemsikhali data includes the highest daily tide levels from 1969 to 2022, with no data 1980 and 1989. For Sadarghat, the data span from 1980 to 2022, and for Sandwip, data are available from 1977 to 2022, with some missing values between 1991 and 1995. Hatiya data cover from 1968 to 2024. For Charchenga, data include the monthly highest tide levels from 1980 to 2022, though there are some gaps from 1991 to 1999. Hiron Point data covers monthly highest tide levels from 1991 to 2022.

Patharghata has data from1958 to 2024, except 1966 and 1967. The tide data of Cox's Bazar, Hatiya, and Pathargata are measured relative to MSL, and Sadrghat, Sandiwip, Charchenga, Khepupara, and Hiron Point relative to CD. For Lemsikhali, Datum is PWD/SOB, and SOB is considered MSL, and are following as respectively.

Table 3-1 Target Stations and Observed Years

No.	STATION	RIVER	Observed Year	Missing Years	Datum	Remark
1	Cox's Bazar	Bakkhali	1983~2021		MSL	MSL =CD-2.40449
2	Lemsikhali	Kutubdia	1969~2022	1980, 1989	PWD/ SOB	Before 01/03/2021 SOB=PWD - 0.969m
3	Sadarghat	Karnaphuli	1980~2022		CD	MSL=CD-2.30
4	Sandwip	Satalkhal	1977~2022	1991~1995	CD	MSL=CD-3.514
5	Hatiya	Hatiya	1968~2024		MSL	
6	Charchenga	Shahbazpuri	1980~2022	1991~1999	CD	MSL=CD-2.012
7	Patharghata	Bishkhali	1958~2024	1966, 1967	MSL	
8	Khepupara	Nilganj	1977~2024	2016	CD	MSL =CD - 2.5727
9	Hiron Point	Pussur	1991~2022		CD	MSL=CD-1.859

(1) Cox's Bazar

Table 3-2 Annual Maximum Tide Levels of COX'S BAZAR (1983-2021)

Year	Max
1983	1.98
1984	2.02
1985	2.11
1986	2.36
1987	2.56
1988	2.06
1989	2.22
1990	2.14
1991	2.08
1992	2.20
1993	2.08
1994	1.71
1995	2.61

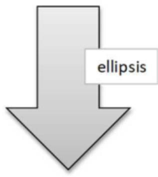
Year	Max
1996	2.52
1997	2.24
1998	2.19
1999	2.11
2000	2.23
2001	2.23
2002	2.22
2003	2.23
2004	2.29
2005	2.28
2006	2.18
2007	2.32
2008	2.47

Year	Max
2009	2.48
2010	2.65
2011	2.14
2012	1.76
2013	2.38
2014	2.09
2015	2.24
2016	2.04
2017	3.19
2018	2.27
2019	2.23
2020	2.36
2021	2.49

(2) Lemsikhali

Table 3-3 Daily Maximum Tide Levels of LEMSIKHALI (1969-2022)

YEAR	MONTH	DAY	HIGHEST
1969	4	1	1.4
1969	4	2	1.77
1969	4	3	2.16
1969	4	4	2.35
1969	4	5	2.01
1969	4	6	1.55
1969	4	7	1.25
1969	4	8	1.1
1969	4	9	0.76
1969	4	10	0.76
1969	4	11	0.64
1969	4	12	0.64
1969	4	13	1.25
1969	4	14	2.01
1969	4	15	2.32
1969	4	16	2.53
1969	4	17	2.13
1969	4	18	1.74
1969	4	19	1.55
1969	4	20	1.55
1969	4	21	1.25
1969	4	22	1.01
1969	4	23	0.7
1969	4	24	0.49
1969	4	25	0.34
1969	4	26	0.3
1969	4	27	0.46
1969	4	28	0.34
1969	4	29	0.82
1969	4	30	1.4
1969	5	1	1.68
1969	5	2	2.16
1969	5	3	2.35
1969	5	4	2.16
1969	5	5	1.83
1969	5	6	1.55
1969	5	7	1.4
1969	5	8	1.1
1969	5	9	0.79
1969	5	10	0.52
1969	5	11	1.04
1969	5	12	1.4
1969	5	13	1.74
1969	5	14	2.07
1969	5	15	2.32
1969	5	16	2.65
1969	5	17	2.32
1969	5	18	2.04
1969	5	19	1.86
1969	5	20	1.71
1969	5	21	1.4
1969	5	22	1.16
1969	5	23	0.85
1969	5	24	0.52
1969	5	25	0.46
1969	5	26	0.55
1969	5	27	0.73
1969	5	28	1.04
1969	5	29	1.4
1969	5	30	1.77
1969	5	31	2.16
1969	6	1	2.35
1969	6	2	2.68
1969	6	3	2.96
1969	6	4	2.68
1969	6	5	2.62
1969	6	6	2.35
1969	6	7	2.16
1969	6	8	1.77
1969	6	9	1.71
1969	6	10	2.13
1969	6	11	2.32
1969	6	12	2.62
1969	6	13	2.93
1969	6	14	3.08
1969	6	15	3.08
1969	6	16	2.93
1969	6	17	2.53
1969	6	18	2.29
1969	6	19	2.01
1969	6	20	1.77
1969	6	21	1.71
1969	6	22	1.4
1969	6	23	1.25
1969	6	24	1.34
1969	6	25	2.26
1969	6	26	2.41
1969	6	27	2.53
1969	6	28	2.74
1969	6	29	3.02
1969	6	30	3.32
1969	7	1	3.47
1969	7	2	3.17
1969	7	3	3.02
1969	7	4	2.71
1969	7	5	2.56
1969	7	6	2.29
1969	7	7	1.8
1969	7	8	1.8
1969	7	9	1.86
1969	7	10	2.29
1969	7	11	2.53
1969	7	12	2.71
1969	7	13	3.08
1969	7	14	3.23
1969	7	15	3.32
1969	7	16	3.47
1969	7	17	3.6
1969	7	18	3.75
1969	7	19	3.41
1969	7	20	3.02
1969	7	21	2.68
1969	7	22	2.26
1969	7	23	2.23
1969	7	24	2.16
1969	7	25	2.38
1969	7	26	2.44
1969	7	27	2.71
1969	7	28	2.8
1969	7	29	3.44
1969	7	30	3.78
1969	7	31	3.47
1969	8	1	2.83
1969	8	2	2.71
1969	8	3	2.41
1969	8	4	2.07
1969	8	5	1.92
1969	8	6	1.95
1969	8	7	2.16
1969	8	8	2.38
1969	8	9	2.47
1969	8	10	2.62
1969	8	11	2.68
1969	8	12	2.83
1969	8	13	3.08
1969	8	14	3.23
1969	8	15	3.08
1969	8	16	2.93
1969	8	17	2.47
1969	8	18	2.56
1969	8	19	2.1
1969	8	20	2.04
1969	8	21	1.8
1969	8	22	1.71
1969	8	23	1.98
1969	8	24	2.1
1969	8	25	2.41
1969	8	26	2.74
1969	8	27	2.93
1969	8	28	3.14
1969	8	29	3.23
1969	8	30	3.14
1969	8	31	2.87
1969	9	1	2.65
1969	9	2	2.41
1969	9	3	2.26
1969	9	4	2.01
1969	9	5	1.92
1969	9	6	2.01
1969	9	7	2.26
1969	9	8	2.5
1969	9	9	2.83
1969	9	10	3.05
1969	9	11	3.29
1969	9	12	3.23
1969	9	13	2.87
1969	9	14	2.77
1969	9	15	2.53
1969	9	16	2.53
1969	9	17	2.47
1969	9	18	2.32
1969	9	19	1.95
1969	9	20	2.16



YEAR	MONTH	DAY	HIGHEST
2022	7	8	2.09
2022	7	9	2.04
2022	7	10	2.14
2022	7	11	2.39
2022	7	12	2.49
2022	7	13	2.59
2022	7	14	2.69
2022	7	15	2.89
2022	7	16	2.79
2022	7	17	2.69
2022	7	18	2.44
2022	7	19	2.19
2022	7	20	1.59
2022	7	21	1.49
2022	7	22	1.64
2022	7	23	1.59
2022	7	24	1.59
2022	7	25	1.69
2022	7	26	1.69
2022	7	27	1.79
2022	7	28	1.89
2022	7	29	2.09
2022	7	30	2.19
2022	7	31	2.29
2022	8	1	1.99
2022	8	2	1.89
2022	8	3	1.89
2022	8	4	1.89
2022	8	5	1.79
2022	8	6	1.59
2022	8	7	1.59
2022	8	8	2.04
2022	8	9	2.34
2022	8	10	2.74
2022	8	11	3.39
2022	8	12	2.69
2022	8	13	3.19
2022	8	14	3.19
2022	8	15	2.64
2022	8	16	2.09
2022	8	17	1.89
2022	8	18	1.64
2022	8	19	1.59
2022	8	20	1.14
2022	8	21	1.29
2022	8	22	1.39
2022	8	23	1.59
2022	8	24	1.69
2022	8	25	2.49
2022	8	26	1.89
2022	8	27	1.99
2022	8	28	2.39
2022	8	29	1.99
2022	8	30	2.09
2022	8	31	1.99
2022	9	1	1.79
2022	9	2	1.69
2022	9	3	1.39
2022	9	4	1.09
2022	9	5	0.79
2022	9	6	1.54
2022	9	7	1.79
2022	9	8	1.99
2022	9	9	2.49
2022	9	10	2.79
2022	9	11	3.04
2022	9	12	2.79
2022	9	13	2.79
2022	9	14	2.29
2022	9	15	2.19
2022	9	16	1.49
2022	9	17	1.34
2022	9	18	0.99
2022	9	19	1.14
2022	9	20	1.19
2022	9	21	1.34
2022	9	22	1.59
2022	9	23	1.79
2022	9	24	1.99
2022	9	25	2.19
2022	9	26	2.24
2022	9	27	2.39
2022	9	28	2.24
2022	9	29	2.09
2022	9	30	1.99
2022	10	1	1.74
2022	10	2	1.44
2022	10	3	1.24
2022	10	4	1.34
2022	10	5	1.69
2022	10	6	1.79
2022	10	7	2.04
2022	10	8	2.19
2022	10	9	2.29
2022	10	10	2.44
2022	10	11	2.34
2022	10	12	2.09
2022	10	13	1.64
2022	10	14	1.39
2022	10	15	1.19
2022	10	16	0.99
2022	10	17	0.89
2022	10	18	0.99
2022	10	19	0.89
2022	10	20	1.14
2022	10	21	1.39
2022	10	22	1.59
2022	10	23	1.79
2022	10	24	2.74
2022	10	25	2.59
2022	10	26	2.19
2022	10	27	2.14
2022	10	28	1.79
2022	10	29	1.49
2022	10	30	1.89
2022	10	31	1.64
2022	11	1	0.84
2022	11	2	0.99
2022	11	3	1.09
2022	11	4	1.19
2022	11	5	1.44
2022	11	6	1.64
2022	11	7	1.64
2022	11	8	1.54
2022	11	9	1.44
2022	11	10	1.39
2022	11	11	1.34
2022	11	12	1.09
2022	11	13	0.84
2022	11	14	0.74
2022	11	15	0.54
2022	11	16	0.59
2022	11	17	0.44
2022	11	18	0.54
2022	11	19	0.74
2022	11	20	1.04
2022	11	21	1.14
2022	11	22	1.29
2022	11	23	1.49
2022	11	24	1.59
2022	11	25	1.64
2022	11	26	1.54
2022	11	27	1.49
2022	11	28	1.19
2022	11	29	0.99
2022	11	30	0.89
2022	12	1	0.89
2022	12	2	0.94
2022	12	3	0.97
2022	12	4	0.99
2022	12	5	1.09
2022	12	6	1.14
2022	12	7	1.19
2022	12	8	1.24
2022	12	9	1.19
2022	12	10	1.19
2022	12	11	1.24
2022	12	12	0.89
2022	12	13	0.79
2022	12	14	0.64
2022	12	15	0.54
2022	12	16	0.54
2022	12	17	0.59
2022	12	18	0.59
2022	12	19	0.64
2022	12	20	0.84
2022	12	21	1.04
2022	12	22	1.29
2022	12	23	1.49
2022	12	24	1.63
2022	12	25	1.69
2022	12	26	1.49
2022	12	27	1.39
2022	12	28	1.24
2022	12	29	0.99
2022	12	30	0.94
2022	12	31	0.74

(3) Sadarghat

Table 3-4 Monthly Maximum Tide Levels of SADARGHAT(1980-2022)

SADARGHAT

YEAR	MONTH	DATE	TIME	HIGHEST
1980	1	2	01:20	3.97
1980	2	18	02:30	4.06
1980	3	18	02:10	4.12
1980	4	16	01:50	4.44
1980	5	11	23:30	4.76
1980	6	30	15:00	4.88
1980	7	30	15:30	5.02
1980	8	28	14:30	5.26
1980	9	26	02:30	4.84
1980	10	25	02:00	5.11
1980	11	23	01:30	4.52
1980	12	10	02:45	4.24
1981	1	8	02:30	4.14
1981	2	8	03:45	3.91
1981	3	8	02:30	4.2
1981	4	6	14:30	4.38
1981	5	5	14:30	4.66
1981	6	5	15:40	4.95
1981	7	4	15:15	4.97
1981	8	2	14:50	5.05
1981	9	26	13:00	5.02
1981	10	16	02:45	4.83
1981	11	12	00:45	4.95
1981	12	11	00:45	4.95
1982	1	11	02:10	4.04
1982	2	9	02:00	3.99
1982	3	29	03:45	4.15
1982	4	24	13:45	4.42
1982	5	7	02:00	4.45
1982	6	21	13:00	5.02
1982	7	23	15:30	4.84
1982	8	19	13:30	5.11
1982	9	17	13:15	4.84
1982	10	2	13:00	4.26
1982	11	4	02:00	4.31
1982	12	2	01:45	4.03
1983	1	30	02:15	4.15
1983	2	28	02:00	4.13
1983	3	16	14:45	4.2
1983	4	30	15:15	4.54
1983	5	14	14:15	4.64
1983	6	26	14:15	4.67
1983	7	11	13:50	4.78
1983	8	9	13:30	5.27
1983	9	7	13:30	4.99
1983	10	8	02:00	4.88
1983	11	5	01:15	4.8
1983	12	4	01:10	4.27
1984	1	20	02:30	4.3
1984	2	19	02:50	4.22
1984	3	18	01:50	4.47
1984	4	18	15:00	4.63
1984	5	15	13:10	4.94
1984	6	3	16:00	4.99
1984	7	31	15:30	5.26
1984	8	1	16:15	5.26
1984	9	27	02:15	4.79
1984	10	14	03:40	5.1
1984	11	24	01:50	4.37
1984	12	12	03:40	3.97
1985	1	8	01:50	3.83
1985	2	7	02:10	4.16
1985	3	8	02:10	4.31
1985	4	9	16:10	4.42
1985	5	25	05:00	5.48
1985	6	2	12:40	5.07
1985	7	3	14:10	5.2
1985	8	1	14:00	5.02
1985	9	15	13:45	4.92
1985	10	17	03:00	5.46
1985	11	13	01:10	4.7
1985	12	13	02:00	4.37

YEAR	MONTH	DATE	TIME	HIGHEST
1986	1	12	02:30	3.99
1986	2	16	06:00	3.98
1986	3	29	15:50	4.14
1986	4	8	01:15	4.7
1986	5	24	13:50	4.61
1986	6	21	12:45	4.86
1986	7	22	14:20	5.29
1986	8	20	14:00	4.95
1986	9	8	04:00	4.62
1986	10	6	02:40	4.7
1986	11	2	01:10	4.53
1986	12	3	02:00	4.29
1987	1	31	02:45	4.04
1987	2	1	03:20	3.99
1987	3	31	14:50	4.04
1987	4	14	13:40	4.4
1987	5	14	14:00	4.43
1987	6	12	13:45	4.82
1987	7	12	14:10	5.24
1987	8	27	14:30	5.67
1987	9	27	03:00	5.44
1987	10	8	01:30	5.14
1987	11	23	02:10	4.82
1987	12	22	02:10	4.67
1988	1	21	02:40	4.42
1988	2	18	01:50	4.64
1988	3	20	15:10	4.52
1988	4	16	13:30	4.9
1988	5	31	13:10	5.02
1988	6	3	15:30	5.22
1988	7	17	15:30	5.52
1988	8	2	16:30	5.43
1988	9	27	01:50	5.36
1988	10	26	01:40	5.06
1988	11	30	04:50	5.11
1988	12	12	02:50	4.62
1989	1	10	02:30	4.44
1989	2	8	02:20	4.58
1989	3	10	15:05	4.51
1989	4	7	14:00	4.68
1989	5	25	16:00	4.9
1989	6	20	13:45	4.9
1989	7	22	15:20	5.39
1989	8	19	14:10	5.18
1989	9	18	02:40	5.06
1989	10	18	03:00	5.46
1989	11	14	01:00	4.69
1989	12	13	01:00	4.22
1990	1	29	02:20	4.04
1990	2	27	02:00	4.17
1990	3	28	14:00	4.18
1990	4	26	13:30	4.56
1990	5	25	13:30	4.8
1990	6	25	14:50	4.92
1990	7	23	13:50	4.98
1990	8	21	13:20	5.14
1990	9	6	13:30	4.68
1990	10	8	02:30	4.91
1990	11	5	01:40	4.68
1990	12	19	02:00	4.38
1991	1	3	02:20	3.48
1991	2	1	02:00	3.3
1991	3	2	01:40	3.35
1991	4	30	14:00	3.88
1991	5	1	02:30	5.04
1991	6	27	14:00	5.08
1991	7	5	08:00	5.1
1991	8	12	14:30	4.69
1991	9	9	13:30	4.64
1991	10	11	03:00	5.19
1991	11	8	02:00	4.44
1991	12	6	01:00	4.14

YEAR	MONTH	DATE	TIME	HIGHEST
1992	1	22	03:00	3.99
1992	2	18	02:00	4.2
1992	3	21	15:00	4.2
1992	4	17	13:30	4.6
1992	5	19	14:30	4.3
1992	6	27	10:30	4.75
1992	7	18	15:00	4.88
1992	8	20	16:30	5.04
1992	9	28	01:30	4.74
1992	10	26	01:10	4.89
1992	11	23	00:30	4.53
1992	12	12	02:20	4.18
1993	1	26	03:10	4.23
1993	2	8	02:10	4.03
1993	3	10	02:30	4.23
1993	4	9	15:10	4.38
1993	5	20	13:00	4.96
1993	6	19	12:40	5.63
1993	7	22	15:20	5.74
1993	8	20	15:00	5.87
1993	9	18	02:35	5.28
1993	10	16	01:30	5.03
1993	11	15	02:10	4.85
1993	12	15	02:30	4.53
1994	1	30	03:10	4.48
1994	2	1	05:00	4.48
1994	3	30	15:25	4.97
1994	4	1	17:00	4.78
1994	5	25	14:05	5.03
1994	6	24	14:10	5.33
1994	7	11	15:40	5.34
1994	8	9	14:30	4.93
1994	9	7	02:00	5.18
1994	10	10	04:35	5.13
1994	11	5	02:05	5.3
1994	12	8	18:30	5.15
1995	1	1	01:05	3.94
1995	2	17	02:30	4.01
1995	3	2	02:00	4.11
1995	4	16	14:00	4.46
1995	5	16	14:00	5.52
1995	6	14	14:15	4.96
1995	7	12	13:05	5.16
1995	8	13	15:00	5.2
1995	9	26	02:00	5.2
1995	10	9	01:35	5.02
1995	11	26	03:40	5.17
1995	12	8	02:00	4.46
1996	1	21	02:05	4.36
1996	2	20	02:15	4.26
1996	3	20	01:50	4.38
1996	4	3	01:00	4.3
1996	5	6	15:20	4.7
1996	6	21	16:30	4.9
1996	7	31	14:15	5.05
1996	8	2	15:10	5.2
1996	9	28	01:45	4.88
1996	10	29	03:05	5.2
1996	11	14	03:00	4.4
1996	12	12	02:15	4.05
1997	1	22	13:25	4.16
1997	2	9	02:35	4
1997	3	10	02:30	4.1
1997	4	8	14:55	4.06
1997	5	31	11:05	4.31
1997	6	7	15:05	4.66
1997	7	21	14:00	5.41
1997	8	5	14:45	5.21
1997	9	18	02:00	4.81
1997	10	2	14:30	4.72
1997	11	12	00:00	4.46
1997	12	14	01:00	3.91

YEAR	MONTH	DATE	TIME	HIGHEST
1998	1	1	03:00	3.91
1998	2	13	02:35	3.76
1998	3	29	14:30	4.26
1998	4	28	14:35	4.56
1998	5	28	14:30	5.01
1998	6	13	15:05	4.76
1998	7	12	15:05	5.21
1998	8	12	16:00	5.33
1998	9	8	14:00	5.43
1998	10	7	02:00	5.25
1998	11	23	03:20	5.14
1998	12	5	02:00	4.48
1999	1	4	03:00	4.24
1999	2	18	02:35	4.29
1999	3	27	23:45	4.53
1999	4	17	14:15	4.8
1999	5	29	13:05	4.75
1999	6	29	13:25	4.95
1999	7	14	13:50	5.43
1999	8	12	13:40	5.18
1999	9	11	14:20	4.91
1999	10	29	04:30	5.01
1999	11	24	01:45	4.7
1999	12	24	02:00	4.44
2000	1	22	02:15	4.18
2000	2	21	02:15	4.13
2000	3	21	01:50	4.31
2000	4	6	15:00	4.5
2000	5	8	16:35	5.07
2000	6	5	15:30	5.22
2000	7	18	14:50	5.44
2000	8	31	14:55	5.75
2000	9	1	03:25	5.35
2000	10	28	13:40	5.34
2000	11	13	01:50	4.74
2000	12	12	01:30	4.69
2001	1	12	03:10	4.34
2001	2	10	02:40	4.48
2001	3	12	03:35	4.33
2001	4	9	02:00	4.43
2001	5	23	13:40	4.73
2001	6	23	14:35	5.08
2001	7	21	13:30	5.13
2001	8	21	14:40	5.38
2001	9	17	13:15	4.93
2001	10	5	03:00	4.88
2001	11	2	01:45	4.83
2001	12	2	02:00	4.4
2002	1	1	02:45	4.15
2002	2	16	14:50	4.55
2002	3	17	14:10	4.75
2002	4	19	15:05	5.32
2002	5	1	14:05	5.07
2002	6	22	10:25	5.08
2002	7	23	11:15	5.37
2002	8	14	04:30	5.2
2002	9	9	13:55	4.93
2002	10	25	03:30	4.57
2002	11	6	02:00	4.82
2002	12	4	00:55	4.58
2003	1	20	02:30	4.07
2003	2	20	03:40	4.17
2003	3	19	01:45	4.19
2003	4	18	14:25	4.53
2003	5	17	14:00	4.95
2003	6	30	14:35	5
2003	7	2	14:40	5.05
2003	8	28	13:50	5.27
2003	9	1	16:30	5.1
2003	10	28	03:00	4.85
2003	11	25	01:50	4.67
2003	12	27	04:00	4.55
2004	1	22	01:35	4
2004	2	20	01:35	4.2
2004	3	25	03:50	4.37
2004	4	18	00:50	4.52
2004	5	20	14:10	4.8
2004	6	21	15:15	4.93
2004	7	21	15:30	5.2
2004	8	3	15:10	5.25
2004	9	15	14:00	5.3
2004	10	16	02:30	5.03
2004	11	10	11:45	4.68
2004	12	14	02:30	4.43
2005	1	11	02:00	4
2005	2	10	02:05	3.88
2005	3	28	14:00	4.85
2005	4	11	15:05	4.5
2005	5	25	14:15	4.77
2005	6	26	16:50	5.2
2005	7	24	15:15	5.18
2005	8	22	15:05	5.75
2005	9	18	13:30	5.35
2005	10	2	13:25	4.86
2005	11	1	00:50	4.76
2005	12	14	00:20	4.42
2006	1	30	01:35	4.35
2006	2	27	00:50	4.32
2006	3	31	03:00	4.5
2006	4	28	13:30	4.7
2006	5	13	13:30	5.1
2006	6	12	13:30	4.87
2006	7	12	14:10	5.25
2006	8	11	14:30	5.22
2006	9	8	14:00	4.97
2006	10	8	01:40	5.12
2006	11	6	01:30	4.52
2006	12	24	04:00	3.97
2007	1	21	02:30	4.02
2007	2	18	01:30	4.17
2007	3	21	02:30	4.27
2007	4	18	14:00	4.65
2007	5	15	12:00	5.27
2007	6	15	13:05	4.87
2007	7	16	14:30	5.17
2007	8	12	13:10	5.33
2007	9	13	02:00	5.5
2007	10	9	00:30	5.2
2007	11	25	00:30	5
2007	12	21	23:30	4.25
2008	1	11	03:00	4.4
2008	2	25	02:30	4.45
2008	3	23	02:30	4.8
2008	4	6	14:00	4.65
2008	5	6	13:40	5.2
2008	6	23	16:30	5.1
2008	7	4	14:00	5.3
2008	8	2	13:35	5.4
2008	9	17	02:00	5.42
2008	10	27	12:30	5.02
2008	11	16	03:00	4.61
2008	12	14	01:35	4.53
2009	1	11	01:00	4.06
2009	2	26	02:00	4.21
2009	3	29	15:00	4.32
2009	4	25	13:10	4.56
2009	5	26	14:15	5.47
2009	6	25	15:00	4.86
2009	7	22	13:20	5.2
2009	8	21	13:40	5.26
2009	9	8	15:00	5.1
2009	10	19	01:40	4.55
2009	11	4	01:35	4.56
2009	12	3	01:30	4.51
2010	1	31	13:35	4.26
2010	2	1	02:00	4.16
2010	3	31	14:30	4.72
2010	4	1	14:30	4.57
2010	5	27	13:00	4.77
2010	6	14	14:30	5.17
2010	7	14	15:00	5.07
2010	8	12	15:00	5.12
2010	9	9	13:30	5.19
2010	10	8	14:00	5.47
2010	11	7	02:00	4.97
2010	12	7	01:30	4.47
2011	1	21	02:00	4.37
2011	2	20	02:30	4.52
2011	3	21	02:00	4.72
2011	4	18	13:00	4.77
2011	5	16	12:30	4.83
2011	6	17	14:00	5.18
2011	7	17	14:30	5.03
2011	8	31	14:00	5.28
2011	9	1	14:30	5.18
2011	10	1	03:00	4.88
2011	11	11	02:00	4.53
2011	12	28	03:30	4.53
2012	1	11	02:30	4.3
2012	2	10	02:30	4.3
2012	3	10	02:00	4.5
2012	4	9	14:30	4.7
2012	5	8	14:30	4.93
2012	6	24	16:00	5.2
2012	7	21	14:30	5.25
2012	8	4	14:30	5.3
2012	9	17	13:30	5.1
2012	10	18	02:30	4.9
2012	11	15	01:30	4.7
2012	12	15	02:00	4.25
2013	1	13	02:00	4.4
2013	2	27	02:00	4.05
2013	3	13	02:30	4.45
2013	4	10	13:30	4.3
2013	5	28	15:30	5.25
2013	6	25	14:05	5.3
2013	7	24	14:00	5.2
2013	8	21	13:00	5.3
2013	9	8	14:30	5.05
2013	10	6	02:00	4.55
2013	11	5	01:30	4.5
2013	12	4	01:30	4.45
2014	1	4	01:30	4.35
2014	2	1	02:00	4.15
2014	3	31	14:00	4.4
2014	4	30	14:00	4.6
2014	5	15	13:30	4.65
2014	6	28	14:30	5
2014	7	14	14:30	5.5
2014	8	12	14:00	5.25
2014	9	9	13:00	5.28
2014	10	12	03:30	5.33
2014	11	9	02:30	4.88
2014	12	23	02:00	4.48
2015	1	22	02:00	4.53
2015	2	21	15:00	4.18
2015	3	22	03:00	4.58
2015	4	20	14:30	4.78
2015	5	19	14:00	4.93
2015	6	30	12:00	5.18
2015	7	31	13:00	5.78
2015	8	1	13:30	5.73
2015	9	1	14:30	5.63
2015	10	1	03:00	5.08
2015	11	27	02:00	4.78
2015	12	12	01:30	4.38

YEAR	MONTH	DATE	TIME	HIGHEST
2016	1	25	02:00	4.18
2016	2	24	02:30	4.48
2016	3	11	15:00	4.53
2016	4	8	14:00	4.88
2016	5	21	13:30	5.93
2016	6	6	14:00	5.38
2016	7	6	14:30	5.68
2016	8	21	15:00	5.58
2016	9	18	14:00	5.38
2016	10	21	17:00	5.43
2016	11	3	03:00	5.03
2016	12	15	02:00	4.98
2017	1	1	03:00	4.58
2017	2	1	04:00	4.33
2017	3	30	15:00	4.88
2017	4	26	13:00	5.03
2017	5	30	16:30	5.18
2017	6	12	15:00	5.73
2017	7	24	13:30	5.93
2017	8	23	14:00	5.58
2017	9	20	13:30	5.48
2017	10	21	14:00	5.72
2017	11	4	01:30	4.82
2017	12	11	20:30	4.57
2018	1	3	01:30	4.27
2018	2	1	01:30	4.12
2018	3	4	03:00	4.37
2018	4	18	15:00	4.67
2018	5	17	02:30	4.87
2018	6	15	14:30	5.72
2018	7	16	15:30	5.62
2018	8	14	15:30	5.57
2018	9	11	14:00	5.22
2018	10	11	14:30	5.02
2018	11	6	00:30	4.77
2018	12	6	00:30	4.27
2019	1	23	02:30	4.07
2019	2	20	14:00	4.07
2019	3	23	15:00	4.59
2019	4	21	14:30	4.44
2019	5	6	14:30	4.39
2019	8	3	0.607639	5.43
2020	8	20	0.572917	5.66
2021	5	26	0.524306	5.61
2022	10	25	0.003472	5.98

(4) Sandwip

Table 3-5 Monthly Maximum Tide Levels of SANDWIP (1977-2022)

SANDWIP

YEAR	MONTH	DATE	TIME	HIGHEST
1977	1	20	02:00	5.35
1977	2	20	02:55	5.23
1977	3	8	15:30	5.44
1977	4	4	13:40	6.08
1977	5	31	12:00	6.1
1977	6	4	15:05	6.43
1977	7	30	13:10	6.66
1977	8	1	14:30	6.62
1977	9	1	03:15	6.31
1977	10	15	02:45	6.21
1977	11	13	02:20	5.99
1977	12	11	01:30	5.77
1978	1	11	02:55	5.26
1978	2	8	01:50	5.37
1978	3	26	14:45	5.31
1978	4	24	14:30	5.58
1978	5	23	13:45	6.39
1978	6	22	14:15	6.22
1978	7	23	15:45	6.5
1978	8	19	13:55	6.63
1978	9	16	13:05	6.44
1978	10	4	02:10	6.6
1978	11	4	03:15	5.66
1978	12	2	02:05	5.6
1979	1	1	03:00	5.35
1979	2	27	01:55	5.23
1979	3	29	14:35	5.57
1979	4	28	14:40	5.61
1979	5	13	14:05	6.16
1979	6	29	04:00	6.83
1979	7	13	15:55	6.65
1979	8	8	13:15	7.08
1979	9	8	14:30	6.62
1979	10	6	13:15	6.86
1979	11	22	02:45	5.74
1979	12	5	02:00	5.44
1980	1	20	03:15	5.2
1980	2	18	02:50	5.42
1980	3	18	02:30	5.55
1980	4	16	14:30	5.72
1980	5	30	13:45	5.95
1980	6	30	14:45	6.31
1980	7	29	14:25	6.51
1980	8	27	14:00	6.84
1980	9	27	03:00	6.47
1980	10	25	01:50	6.68
1980	11	23	01:40	5.93
1980	12	23	02:15	5.45
1981	1	8	02:30	5.28
1981	2	8	03:35	5.13
1981	3	9	03:25	5.51
1981	4	5	14:05	5.69
1981	5	5	14:15	6.07
1981	6	5	15:35	6.41
1981	7	3	14:40	6.33
1981	8	3	15:40	6.49
1981	9	26	12:35	6.52
1981	10	16	02:50	6.37
1981	11	12	01:00	6.37
1981	12	11	00:50	6.51
1982	1	11	02:20	5.27
1982	2	9	02:10	5.23
1982	3	27	14:50	5.4
1982	4	26	14:50	5.92
1982	5	24	14:15	5.87
1982	6	22	13:55	6.39
1982	7	22	14:30	6.44
1982	8	20	14:20	6.58
1982	9	18	14:00	6.3
1982	10	5	02:25	6.13
1982	11	3	02:15	5.71
1982	12	31	01:50	5.3

YEAR	MONTH	DATE	TIME	HIGHEST
1983	1	30	02:25	5.43
1983	2	28	02:05	5.53
1983	3	16	02:25	5.82
1983	4	29	14:30	5.95
1983	5	13	13:45	5.92
1983	6	26	14:05	6.14
1983	7	11	14:00	6.34
1983	8	10	14:15	6.7
1983	9	7	14:15	6.58
1983	10	6	13:10	6.33
1983	11	6	01:40	6.2
1983	12	4	01:10	5.36
1984	1	20	02:25	5.59
1984	2	19	03:00	5.47
1984	3	19	02:40	5.79
1984	4	17	14:30	6.07
1984	5	15	13:10	6.17
1984	6	30	14:05	6.43
1984	7	30	14:50	6.58
1984	8	1	15:40	7.12
1984	9	26	14:15	6.3
1984	10	14	03:35	6.65
1984	11	24	01:50	5.86
1984	12	11	02:55	4.84
1985	1	22	02:10	4.82
1985	2	8	03:15	5.48
1985	3	8	02:30	5.48
1985	4	7	14:45	5.72
1985	5	24	16:00	6.38
1985	6	3	13:30	6.67
1985	7	5	15:15	6.56
1985	8	1	14:00	6.48
1985	9	15	13:35	6.5
1985	10	16	02:10	7.07
1985	11	NO DATA		
1985	12	14	02:50	5.45
1986	1	29	04:10	5.45
1986	2	27	03:40	5.69
1986	3	29	03:15	6.17
1986	4	13	16:15	6.9
1986	5	10	15:15	6.88
1986	6	8	13:45	6.95
1986	7	22	13:45	7.49
1986	8	20	13:50	6.97
1986	9	8	15:55	6.4
1986	10	6	15:25	6.97
1986	11	9	07:00	7.05
1986	12	4	15:30	5.57
1987	1	31	15:15	5.16
1987	2	3	17:30	5.4
1987	3	31	13:50	6.25
1987	4	1	14:30	6.25
1987	5	15	14:45	6.34
1987	6	13	14:30	6.17
1987	7	12	13:30	7.33
1987	8	11	14:30	7.18
1987	9	9	14:15	7.11
1987	10	7	01:45	6.86
1987	11	6	01:10	6.51
1987	12	22	01:50	6.04
1988	1	21	02:45	5.74
1988	2	17	01:02	5.81
1988	3	2	13:45	5.53
1988	4	17	14:10	6.78
1988	5	31	13:00	6.48
1988	6	3	15:00	6.92
1988	7	30	08:00	8.2
1988	8	29	14:20	7.26
1988	9	27	01:40	7.16
1988	10	26	01:15	6.74
1988	11	24	00:55	6.39
1988	12	12	02:45	6.06

YEAR	MONTH	DATE	TIME	HIGHEST
1989	1	10	03:00	5.8
1989	2	8	02:30	6.16
1989	3	10	15:05	6.19
1989	4	7	14:00	6.39
1989	5	26	18:00	6.61
1989	6	21	14:10	6.69
1989	7	22	15:30	7.38
1989	8	18	13:50	7.07
1989	9	18	02:40	6.95
1989	10	18	02:20	7.09
1989	11	15	01:50	6.22
1989	12	13	01:20	5.92
1990	1	23	03:10	5.5
1990	2	20	02:20	5.84
1990	3	21	14:15	6.35
1990	4	26	13:45	6.84
1990	5	25	13:25	6.8
1990	6	19	15:30	7.37
1990	7	23	13:55	7.33
1990	8	21	13:45	7.71
1990	9	6	14:00	7.35
1990	10	8	03:30	7.79
1990	11	4	14:00	7.19
1990	12	5	15:40	5.81
1996	1	21	01:45	5.83
1996	2	21	02:45	6.07
1996	3	9	15:55	5.64
1996	4	20	14:45	5.85
1996	5	5	14:45	6.88
1996	6	3	14:15	6.88
1996	7	31	14:00	7.45
1996	8	2	15:30	7.75
1996	9	28	01:50	7.22
1996	10	29	02:30	7.9
1996	11	13	02:10	6.5
1996	12	13	02:45	6.17
1997	1	11	02:45	6.05
1997	2	9	02:55	5.97
1997	3	10	02:00	6.13
1997	4	8	13:55	6
1997	5	20	12:10	7.35
1997	6	21	14:05	6.73
1997	7	21	14:15	6.8
1997	8	20	14:40	7.3
1997	9	19	03:15	6.97
1997	10	17	02:00	6.66
1997	11	14	00:50	6.37
1997	12	15	02:15	5.49
1998	1	1	03:15	5.52
1998	2	28	02:25	5.87
1998	3	29	14:30	6.04
1998	4	28	14:45	6.23
1998	5	26	13:30	6.83
1998	6	11	14:15	7.09
1998	7	11	14:30	7.06
1998	8	11	15:15	7.75
1998	9	NO DATA		
1998	10	NO DATA		
1998	11	20	01:45	6.62
1998	12	4	01:15	6.21
1999	1	4	02:40	5.91
1999	2	19	03:05	5.92
1999	3	19	02:25	6.8
1999	4	17	14:10	7.24
1999	5	16	13:45	6.72
1999	6	14	13:40	6.94
1999	7	14	14:20	7.04
1999	8	29	15:00	7.41
1999	9	27	02:20	7.12
1999	10	25	01:05	7.24
1999	11	24	01:25	6.69
1999	12	24	02:20	5.96

YEAR	MONTH	DATE	TIME	HIGHEST
2000	1	22	02:00	5.84
2000	2	21	02:30	5.86
2000	3	9	15:30	5.93
2000	4	6	14:30	6.34
2000	5	5	14:00	6.64
2000	6	5	15:10	7.09
2000	7	18	14:30	7.21
2000	8	30	14:00	7.84
2000	9	1	15:20	7.39
2000	10	28	13:45	7.79
2000	11	14	02:10	6.73
2000	12	12	01:30	5.98
2001	1	13	04:30	6.33
2001	2	26	03:00	6.28
2001	3	12	02:30	5.67
2001	4	27	15:30	6.12
2001	5	23	13:20	6.63
2001	6	23	14:25	6.87
2001	7	23	15:05	7.33
2001	8	20	14:10	7.45
2001	9	18	13:55	7.14
2001	10	17	01:25	7.12
2001	11	1	01:05	6.89
2001	12	3	02:35	6.19
2002	1	1	02:30	5.73
2002	2	28	02:05	5.31
2002	3	30	14:35	6.12
2002	4	30	14:40	6.29
2002	5	28	14:30	6.79
2002	6	25	13:20	6.98
2002	7	24	13:10	6.98
2002	8	11	15:00	7.46
2002	9	8	13:50	6.99
2002	10	6	00:50	6.81
2002	11	5	01:10	6.91
2002	12	22	03:05	5.81
2003	1	20	02:50	5.58
2003	2	19	02:55	5.43
2003	3	19	02:10	6.13
2003	4	17	02:00	6.58
2003	5	17	14:20	6.82
2003	6	14	13:00	6.59
2003	7	31	14:35	6.94
2003	8	28	13:40	7.27
2003	9	27	02:10	7.47
2003	10	9	00:50	7.31
2003	11	10	01:50	6.14
2003	12	10	02:10	5.89
2004	1	11	04:00	5.33
2004	2	5	13:40	5.63
2004	3	23	14:40	6.18
2004	4	18	13:00	6.57
2004	5	22	14:45	6.87
2004	6	3	13:00	7.45
2004	7	4	14:20	7.65
2004	8	5	16:10	7.75
2004	9	1	14:40	7.51
2004	10	16	14:30	7.04
2004	11	27	13:45	5.88
2004	12	13	14:00	6.27
2005	1	12	15:00	5.87
2005	2	10	14:35	5.42
2005	3	28	15:10	6.1
2005	4	27	15:00	6.42
2005	5	25	14:00	6.77
2005	6	25	15:00	7.07
2005	7	24	15:20	6.88
2005	8	20	13:40	6.88
2005	9	21	15:10	6.88
2005	10	17	14:30	6.15
2005	11	17	13:40	5.86
2005	12	3	14:30	5.12

YEAR	MONTH	DATE	TIME	HIGHEST
2006	1	3	15:45	4.94
2006	2	28	14:00	5.22
2006	3	30	14:00	5.67
2006	4	30	14:30	5.99
2006	5	30	14:35	6.34
2006	6	14	14:35	6.12
2006	7	13	14:00	5.42
2006	8	NO DATA		
2006	9	25	14:50	6.38
2006	10	9	14:00	6.58
2006	11	8	14:35	5.78
2006	12	23	15:00	5.17
2007	1	22	16:00	5.3
2007	2	19	14:40	5.55
2007	3	21	15:00	6.37
2007	4	18	13:30	6.67
2007	5	16	12:45	7.27
2007	6	3	14:40	6.57
2007	7	16	14:30	6.95
2007	8	13	13:45	7.88
2007	9	27	14:00	7.21
2007	10	12	14:30	7.11
2007	11	10	14:00	6.56
2007	12	13	15:45	5.86
2008	1	27	16:00	5.54
2008	2	24	15:30	5.89
2008	3	25	15:45	6.31
2008	4	10	15:00	6.41
2008	5	6	13:30	6.86
2008	6	21	14:30	6.86
2008	7	6	14:30	7.21
2008	8	22	15:30	7.84
2008	9	7	15:30	7.69
2008	10	17	15:00	6.74
2008	11	15	14:35	6.52
2008	12	15	15:20	6.18
2009	1	15	16:00	6
2009	2	13	16:00	5.9
2009	3	30	15:45	6.48
2009	4	27	14:30	6.65
2009	5	24	13:00	6.6
2009	6	26	15:30	6.84
2009	7	11	15:45	6.89
2009	8	10	15:45	7.04
2009	9	20	14:00	7.34
2009	10	19	13:45	6.54
2009	11	5	14:40	5.96
2009	12	4	14:45	5.95
2010	1	31	14:40	5.38
2010	2	2	15:50	5.73
2010	3	31	14:55	6.88
2010	4	20	16:25	6.99
2010	5	2	15:45	6.98
2010	6	15	15:20	7.8
2010	7	14	15:00	7.4
2010	8	NO DATA		
2010	9	26	15:50	7.36
2010	10	8	13:30	8.01
2010	11	30	08:30	7.69
2010	12	3	14:00	5.13
2011	1	15	10:00	6.61
2011	2	4	15:20	5.51
2011	3	23	15:55	7.16
2011	4	20	14:15	6.36
2011	5	21	15:20	6.71
2011	6	17	13:45	7.02
2011	7	31	15:00	7.01
2011	8	1	15:30	6.91
2011	9	27	13:30	6.99
2011	10	26	11:40	6.34
2011	11	13	15:15	5.79
2011	12	26	14:55	5.79

YEAR	MONTH	DATE	TIME	HIGHEST
2012	1	13	16:25	5.71
2012	2	12	16:20	5.57
2012	3	12	16:20	6.82
2012	4	10	16:00	7.33
2012	5	8	14:50	6.82
2012	6	5	14:30	7.62
2012	7	4	13:40	7.61
2012	8	5	15:10	7.83
2012	9	17	14:10	7.64
2012	10	18	15:20	7.34
2012	11	17	15:30	6.5
2012	12	15	15:00	5.95
2013	1	14	15:10	5.9
2013	2	12	15:00	5.64
2013	3	30	15:20	6.48
2013	4	28	15:00	6.81
2013	5	28	15:20	7.53
2013	6	24	14:20	7.7
2013	7	25	15:20	7.62
2013	8	23	15:10	7.97
2013	9	19	13:15	7.65
2013	10	7	15:15	7.15
2013	11	6	15:20	6.96
2013	12	5	15:25	6.24
2014	1	4	15:40	5.82
2014	2	1	14:40	5.73
2014	3	31	14:30	5.98
2014	4	30	14:20	6.48
2014	5	30	14:50	6.56
2014	6	29	15:00	6.71
2014	7	15	15:25	7.91
2014	8	13	15:40	7.66
2014	9	11	15:45	7.46
2014	10	11	15:30	7.09
2014	11	10	15:30	6.56
2014	12	7	14:10	5.87
2015	1	7	15:15	5.97
2015	2	23	17:00	5.4
2015	3	22	15:25	6.02
2015	4	21	15:45	6.36
2015	5	4	14:40	6.6
2015	6	30	12:05	6.87
2015	7	3	14:15	7.2
2015	8	1	14:00	7.72
2015	9	16	16:10	7.54
2015	10	15	15:45	7.53
2015	11	13	14:55	7.09
2015	12	14	16:10	6.29
2016	1	12	16:05	6.14
2016	2	12	16:40	5.72
2016	3	11	15:50	6.17
2016	4	10	15:00	6.72
2016	5	21	13:00	8.57
2016	6	7	14:15	7.6
2016	7	16	15:40	7.72
2016	8	1	15:00	7.92
2016	9	4	14:50	7
2016	10	7	13:10	5.74
2016	11	15	13:50	5.4
2016	12	20	14:50	4.82
2017	1	16	13:45	4.5
2017	2	14	15:40	4.7
2017	3	20	14:50	5.14
2017	4	23	14:40	5.96
2017	5	31	17:20	6.32
2017	6	16	15:40	5.7
2017	7	29	15:15	6.64
2017	8	13	15:00	6.6
2017	9	15	15:50	6.37
2017	10	21	12:30	6.97
2017	11	24	15:45	5.72
2017	12	4	12:45	5

YEAR	MONTH	DATE	TIME	HIGHEST
2018	1	18	14:40	4.89
2018	2	19	14:20	5.92
2018	3	22	15:20	6.5
2018	4	22	15:20	6.27
2018	5	19	15:10	6.54
2018	6	21	15:10	6.72
2018	7	26	15:20	6.72
2018	8	12	14:50	6.72
2018	9	15	15:40	6.32
2018	10	18	15:30	6.47
2018	11	12	13:40	5.87
2018	12	1	16:35	5.45
2019	1	25	15:40	4.97
2019	2	25	16:15	5.07
2019	3	28	15:00	5.46
2019	4	11	14:10	5.44
2019	5	16	15:40	5.47
2019	6	NO DATA		
2019	7	NO DATA		
2019	8	NO DATA		
2019	9	NO DATA		
2019	10	NO DATA		
2019	11	NO DATA		
2019	12	NO DATA		
2020	8	20	15:50	8.314
2021	8	12	16:00	7.72
2022	10	24	13:10	8.244

(5) Hatiya

Table 3-6 Monthly Maximum Tide Levels of Hatiya (1968-2024)

YEAR	MONTH	DATE	HIGHEST
1968	4	14	4.21
1968	5	13	4.42
1968	6	12	4.79
1968	7	10	4.82
1968	8	9	4.41
1968	9	9	4.27
1968	10	3	4.39
1968	11	22	3.54
1968	12	23	3.51
1969	1	22	3.1
1969	2	18	3.4
1969	3	18	3.63
1969	4	17	3.98
1969	5	31	4.22
1969	6	30	4.64
1969	7	30	5.2
1969	8	14	4.73
1969	9	26	4.64
1969	10	11	4.16
1969	11	8	3.84
1969	12	11	3.4
1970	1	12	3.29
1970	2	23	3.39
1970	3	27	3.9
1970	4	23	3.98
1970	5	23	4.5
1970	6	20	4.38
1970	7	20	5.18
1970	8	18	5.15
1970	9	3	4.7
1970	10	23	4.53
1970	11	30	4.07
1970	12	1	4.15
1971	1	30	4.62
1971	2	27	4.71
1971	3	1	4.42
1971	4	27	4.94
1971	5	25	5.2
1971	6	5	5.25
1971	7	23	5.5
1971	8	8	5.79
1971	9	6	5.82
1971	10	4	5.61
1971	11	1	5.03
1971	12	7	3.95
1972	1	20	3.92
1972	2	17	3.98
1972	3	17	3.84
1972	4	14	4.88
1972	5	13	4.21
1972	6	30	4.61
1972	7	1	4.61
1972	8	27	4.42
1972	9	10	4.56
1972	10	9	3.45
1972	11	21	3.11
1972	12	22	2.82
1973	1	20	2.49
1973	2	19	2.97
1973	3	20	3.01
1973	4	4	3.42
1973	5	4	3.69
1973	6	30	4.12
1973	7	19	4.13
1973	8	27	4.25
1973	9	15	3.86
1973	10	12	4.48
1973	11	8	3.95
1973	12	10	3.23
1974	1	13	2.88
1974	2	8	2.85
1974	3	26	3.31
1974	4	24	3.46
1974	5	7	3.71
1974	6	22	4.21
1974	7	21	4.5
1974	8	19	5.18
1974	9	17	4.22
1974	10	5	4.4
1974	11	29	3.33
1974	12	1	2.84
1975	1	30	2.84
1975	2	28	2.99
1975	3	29	2.97
1975	4	27	3.48
1975	5	14	3.6
1975	6	27	3.87
1975	7	12	3.9
1975	8	9	4.7
1975	9	7	4.44
1975	10	8	4.16
1975	11	3	4.01
1975	12	2	3.19
1976	1	19	2.72
1976	2	18	3.05
1976	3	18	3.49
1976	4	15	3.72
1976	5	15	3.84
1976	6	13	4.18
1976	7	28	4.47
1976	8	27	4.48
1976	9	11	4.35
1976	10	23	4.03
1976	11	23	3.19
1976	12	22	3.33
1977	1	8	2.84
1977	2	20	2.94
1977	3	8	3.23
1977	4	6	4.06
1977	5	31	4.03
1977	6	1	4.39
1977	7	30	4.76
1977	8	1	4.61
1977	9	12	4.24
1977	10	14	3.9
1977	11	13	3.37
1977	12	11	3.33
1978	1	10	3.04
1978	2	9	3.33
1978	3	27	3.49
1979	4	27	3.49
1979	5	12	4.19
1979	6	25	4.33
1979	7	13	4.7
1979	8	8	5.09
1979	9	8	4.73
1979	10	6	4.94
1979	11	5	3.51
1979	12	4	3.2
1980	1	23	2.93
1980	2	18	3.43
1980	3	18	3.81
1980	4	16	3.97
1980	5	31	4.38
1980	6	30	4.62
1980	7	29	4.62
1980	8	27	5.03
1980	9	26	4.33
1980	10	24	4.33
1980	11	23	3.78
1980	12	23	3.51
1981	1	7	2.96
1981	2	8	3.11
1981	3	7	3.28
1981	4	6	3.83
1981	5	5	4.35
1981	6	5	4.67
1981	7	3	4.53
1981	8	3	4.88
1981	9	26	4.97
1981	10	15	4.27
1981	11	12	4.1
1981	12	11	4.1
1982	1	11	3.04
1982	2	27	3.05
1982	3	27	3.52
1983	4	29	3.4
1983	5	14	3.37
1983	6	26	3.69
1983	7	12	3.75
1983	8	10	4.36
1983	9	7	4.06
1983	10	6	3.75
1983	11	5	3.36
1983	12	4	2.5
1984	1	4	2.41
1984	2	19	3.09
1984	3	19	3.49
1984	4	17	3.8
1984	5	14	4.34
1984	6	3	4.34
1984	7	31	4.86
1984	8	1	4.71
1984	9	26	3.73
1984	10	13	3.12
1984	11	24	2.19
1984	12	23	2.03
1985	1	8	1.7
1985	2	23	2.03
1985	3	9	2.79
1985	4	9	3.19
1985	5	24	4.47
1985	6	3	4.38
1985	7	3	4.41
1985	8	17	4.31
1985	9	15	4.32
1985	10	16	5.02
1985	11	13	3.31
1985	12	14	3.34
1986	1	12	2.34
1986	2	28	2.64
1986	3	29	3.16
1986	4	24	3.47
1986	5	24	3.71
1986	6	21	4.26
1986	7	22	4.59
1986	8	20	4.19
1986	9	10	3.8
1986	10	6	3.5
1986	11	3	3.16
1986	12	3	2.61
1987	1	31	2.7
1987	2	28	2.62
1987	3	31	3
1987	4	26	3.4
1987	5	14	3.58
1987	6	28	4.21
1987	7	11	4.37
1987	8	11	4.31
1987	9	10	3.97
1987	10	10	3.27
1987	11	4	2.82
1987	12	6	2.61
1988	1	6	2.45
1988	2	21	2.7
1988	3	19	2.97

YEAR	MONTH	DATE	HIGHEST
1988	4	16	3.86
1988	5	31	3.76
1988	6	14	4.01
1988	7	31	4.4
1988	8	2	4.59
1988	9	26	3.97
1988	10	25	3.55
1988	11	30	3.64
1988	12	11	3
1989	1	25	2.58
1989	2	23	3.43
1989	3	10	3.52
1989	4	8	3.64
1989	5	25	3.86
1989	6	7	3.89
1989	7	22	3.98
1989	8	18	3.83
1989	9	17	3.55
1989	10	18	3.22
1989	11	14	2.82
1989	12	13	2.3
1990	1	30	2.79
1990	2	27	2.88
1990	3	29	3.31
1990	4	27	3.89
1990	5	26	3.86
1990	6	26	4.22
1990	7	23	4.48
1990	8	21	4.53
1990	9	6	4.04
1990	10	8	4.04
1990	11	4	3.21
1990	12	18	2.51
1991	1	31	2.59
1991	2	3	2.75
1991	3	31	3.06
1991	4	29	3.72
1991	5	1	3.55
1991	6	14	3.92
1991	7	15	4.19
1991	8	12	4.6
1991	9	9	3.49
1991	10	25	3.2
1991	11	6	2.93
1991	12	23	2.84
1992	1	23	2.93
1992	2	22	2.96
1992	3	19	3.14
1992	4	19	3.38
1992	5	18	3.84
1992	6	17	4.12
1992	7	31	4.12
1992	8	2	4.39
1992	9	26	3.99
1992	10	12	3.47
1992	11	11	2.84
1992	12	1	2.41
1993	1	12	2.62
1993	2	9	3.2
1993	3	10	3.41
1993	4	7	3.78
1993	5	7	4.05
1993	6	23	4.18
1993	7	4	4.18
1993	8	20	5
1993	9	17	4.18
1993	10	16	3.72
1993	11	15	3.11
1993	12	31	3.35
1994	1	1	3.41
1994	2	28	3.41
1994	3	29	3.78

YEAR	MONTH	DATE	HIGHEST
1994	4	26	3.75
1994	5	25	3.51
1994	6	27	3.99
1994	7	13	4.51
1994	8	10	4.72
1994	9	6	4.36
1994	10	6	3.87
1994	11	5	3.66
1994	12	4	3.44
1995	1	31	3.14
1995	2	18	3.51
1995	3	27	3.9
1995	4	16	4.35
1995	5	6	6.12
1995	6	13	4.69
1995	7	14	4.92
1995	8	11	4.36
1995	9	26	4.36
1995	10	26	4.36
1995	11	10	3.96
1995	12	24	3.45
1996	1	8	3.11
1996	2	21	3.7
1996	3	20	3.66
1996	4	20	3.93
1996	5	6	4.08
1996	6	30	4.27
1996	7	31	4.84
1996	8	1	5.04
1996	9	27	4.63
1996	10	29	4.6
1996	11	12	3.44
1996	12	31	3.08
1997	1	11	3.26
1997	2	10	3.38
1997	3	10	3.65
1997	4	25	3.41
1997	5	22	4.02
1997	6	26	4.45
1997	7	22	4.78
1997	8	20	5.06
1997	9	18	4.54
1997	10	11	4.02
1997	11	14	3.78
1997	12	14	3.26
1998	1	31	3.46
1998	2	28	3.74
1998	3	27	4.11
1998	4	27	3.95
1998	5	26	4.46
1998	6	12	4.62
1998	7	11	4.88
1998	8	11	5.5
1998	9	8	5.5
1998	10	7	4.58
1998	11	22	4.07
1998	12	4	3.42
1999	1	3	3.04
1999	2	18	3.3
1999	3	18	3.64
1999	4	17	4.27
1999	5	16	4.25
1999	6	17	4.32
1999	7	15	4.61
1999	8	29	5.01
1999	9	10	4.69
1999	10	28	4.1
1999	11	24	3.67
1999	12	24	3.16
2000	1	22	3.1
2000	2	21	3.2
2000	3	9	3.75

YEAR	MONTH	DATE	HIGHEST
2000	4	6	3.83
2000	5	19	4.42
2000	6	19	4.29
2000	7	18	4.46
2000	8	30	4.72
2000	10	28	4.63
2000	11	14	3.75
2000	12	13	3.27
2001	1	11	3.06
2001	2	26	3.48
2001	7	23	4.57
2001	8	20	4.78
2001	9	18	4.38
2001	10	18	4.29
2001	11	1	3.74
2001	12	3	3.1
2002	1	31	2.71
2002	2	28	3.32
2002	3	30	3.63
2002	4	28	3.65
2002	5	26	4.17
2002	6	25	4.3
2002	7	26	4.21
2002	8	11	4.72
2002	9	11	4.48
2002	10	7	3.87
2002	11	5	3.63
2002	12	4	2.95
2003	1	19	2.7
2003	2	20	2.89
2003	3	20	3.28
2003	4	18	3.92
2003	5	16	4.28
2003	6	15	3.97
2003	7	15	4.38
2003	8	29	4.55
2003	9	13	4.13
2003	10	9	4.16
2003	11	25	3.27
2003	12	25	2.98
2004	1	23	2.53
2004	2	23	2.75
2004	3	23	3.54
2004	4	18	3.6
2004	5	20	4.06
2004	6	3	4.33
2004	7	3	4.31
2004	8	4	4.52
2004	9	16	4.46
2004	10	15	4.25
2004	11	14	3.14
2004	12	13	2.96
2005	1	12	2.72
2005	2	26	2.72
2005	3	2	4.12
2005	4	28	3.72
2005	5	23	3.84
2005	6	27	4.12
2005	7	25	4.42
2005	8	21	4.48
2005	9	18	4.45
2005	10	3	4.09
2005	11	3	3.38
2005	12	3	2.99
2006	1	2	2.84
2006	2	28	3.03
2006	3	31	3.21
2006	4	30	3.85
2006	5	29	3.91
2006	6	13	4
2006	7	14	4.18
2006	8	12	4.37

YEAR	MONTH	DATE	HIGHEST
2006	9	24	4
2006	10	7	4.01
2006	11	5	3
2006	12	4	2.29
2007	1	20	2.36
2007	2	19	2.71
2007	3	21	2.98
2007	4	19	3.32
2007	5	5	3.14
2007	6	16	3.05
2007	7	15	3.63
2007	8	31	3.93
2007	9	28	3.81
2007	10	8	3.44
2007	12	27	1.89
2008	1	24	2.47
2008	2	23	2.83
2008	3	10	3.06
2008	4	7	3.24
2008	5	6	3.61
2008	6	19	3.34
2008	7	19	3.52
2008	8	17	3.55
2008	9	16	4.36
2008	10	31	3.43
2008	11	1	3.12
2008	12	1	2.54
2009	1	27	2.21
2009	2	27	2.33
2009	3	29	3.03
2009	4	27	3.27
2009	5	25	4.37
2009	6	25	3.61
2009	7	22	3.67
2009	8	22	3.79
2009	9	8	4.04
2009	10	6	3.67
2009	11	4	3.09
2009	12	3	2.82
2010	1	17	2.36
2010	2	16	2.54
2010	3	31	3.09
2010	4	30	3.21
2010	5	31	3.49
2010	6	30	3.67
2010	7	27	3.73
2010	8	11	3.91
2010	9	10	3.98
2010	10	8	4.49
2010	11	10	3.43
2010	12	8	2.94
2011	1	22	2.54
2011	2	21	2.54
2011	3	20	3.34
2011	4	18	2.97
2011	5	21	3.4
2011	6	16	4.09
2011	7	17	3.91
2011	8	31	4.27
2011	9	1	4.18
2011	10	15	3.45
2011	11	27	3.05
2011	12	27	2.84
2012	1	11	2.56
2012	2	9	2.72
2012	3	10	3.11
2012	4	9	3.72
2012	5	24	3.24
2012	6	22	3.88
2012	7	3	4.18
2012	8	4	4.18
2012	9	18	3.84

YEAR	MONTH	DATE	HIGHEST
2012	10	2	3.39
2012	11	16	3.17
2012	12	16	2.84
2013	1	14	2.87
2013	2	13	2.54
2013	3	14	2.84
2013	4	28	3.27
2013	5	30	3.54
2013	6	25	3.88
2013	7	23	3.81
2013	8	24	3.97
2013	9	20	3.63
2013	10	20	3.4
2013	11	6	3.04
2013	12	5	2.88
2014	1	31	2.67
2014	2	2	2.85
2014	3	3	2.97
2014	4	30	3.04
2014	5	16	3.16
2014	6	30	3.37
2014	7	15	4.28
2014	8	12	4.04
2014	9	10	3.8
2014	10	11	3.16
2014	11	8	3.22
2014	12	8	3.13
2015	1	8	2.58
2015	2	22	2.36
2015	3	8	2.76
2015	4	21	3.34
2015	5	20	3.4
2015	6	21	3.52
2015	7	31	3.77
2015	8	31	3.92
2015	9	1	3.95
2015	10	1	3.25
2015	11	12	3.36
2015	12	27	2.82
2016	1	13	2.73
2016	2	11	2.82
2016	3	27	2.91
2016	4	23	3.35
2016	5	21	3.83
2016	6	21	3.98
2016	7	21	4.13
2016	8	19	4.3
2016	9	4	4.13
2016	10	5	3.64
2016	11	30	3.28
2016	12	1	3.31
2017	1	1	2.73
2017	2	28	2.76
2017	3	30	3.07
2017	4	28	3.34
2017	5	27	3.49
2017	6	12	4.04
2017	7	26	4.36
2017	8	24	4.35
2017	9	7	4.13
2017	10	21	4.41
2017	11	6	3.8
2017	12	20	3.37
2018	1	5	3.07
2018	2	3	2.94
2018	3	19	3.08
2018	4	19	3.43
2018	5	18	3.71
2018	6	30	3.89
2018	7	16	4.19
2018	8	15	4.38
2018	9	25	3.89

YEAR	MONTH	DATE	HIGHEST
2018	10	12	4.01
2018	11	9	3.28
2018	12	6	3.33
2019	1	9	2.67
2019	2	20	2.76
2019	3	8	3.1
2019	4	22	3.4
2019	5	5	3.8
2019	6	21	3.98
2019	7	31	4.19
2019	8	3	4.44
2019	9	1	4.25
2019	10	1	3.98
2019	11	9	4.13
2019	12	14	2.82
2020	1	14	2.55
2020	2	27	2.55
2020	3	27	2.97
2020	4	26	3.19
2020	5	26	3.89
2020	6	24	3.83
2020	7	23	4.1
2020	8	21	4.28
2020	9	11	4.4
2020	10	15	3.9
2020	11	22	3.64
2020	12	5	3.24
2021	1	14	2.6
2021	2	28	2.88
2021	3	31	3.1
2021	4	26	2.9
2021	5	26	2.92
2021	6	30	2.24
2021	7	8	2.73
2021	8	2	2.54
2021	9	6	2.44
2021	10	19	1.84
2021	11	13	1.64
2021	12	20	1.54
2022	1	9	1.44
2022	2	28	1.62
2022	3	10	1.8
2022	4	13	2.24
2022	5	24	1.66
2022	6	18	2.09
2022	7	20	2.34
2022	8	11	2.66
2022	9	13	2.29
2022	10	24	2.8
2022	11	27	1.41
2022	12	18	1.17
2023	1	20	1.12
2023	2	20	2.01
2023	3	10	1.86
2023	4	26	2.28
2023	5	13	2.36
2023	6	27	1.82
2023	7	27	1.7
2023	8	1	2.85
2023	9	2	1.75
2023	10	1	1.5
2023	11	16	1.76
2023	12	29	1.42
2024	1	23	1.5
2024	2	16	0.92
2024	3	28	1.4
2024	4	2	1.52
2024	5	27	2.6
2024	6	29	1.97
2024	7	11	2.51
2024	8	22	3.08
2024	9	16	1.97
2024	10	21	1.69

(6) Charchenga

Table 3-7 Monthly Maximum Tide Levels of CHARCHENGA (1980-2022)

CHARCHENGA

YEAR	MONTH	DATE	TIME	HIGHEST
1980	1	20	315	3.17
1980	2	18	245	3.31
1980	3	18	235	3.36
1980	4	16	1420	3.57
1980	5	30	1410	3.86
1980	6	30	1445	4.24
1980	7	29	1445	4.42
1980	8	26	1400	4.56
1980	9	27	325	3.98
1980	10	25	215	4.26
1980	11	23	200	3.71
1980	12	22	145	3.42
1981	1	7	215	3.24
1981	2	8	345	3.08
1981	3	9	325	3.33
1981	4	6	1440	3.54
1981	5	5	1425	3.89
1981	6	5	1545	4.18
1981	7	3	1455	4.1
1981	8	3	1530	4.38
1981	9	26	1200	4.56
1981	10	16	350	3.94
1981	11	12	115	4.21
1981	12	11	100	4.53
1982	1	11	225	3.24
1982	2	9	205	3.12
1982	3	27	245	3.12
1982	4	26	1515	3.79
1982	5	23	1335	3.89
1982	6	20	1230	4.17
1982	7	20	1345	4.2
1982	8	19	1410	4.31
1982	9	10	610	3.99
1982	10	5	255	3.82
1982	11	3	245	3.53
1982	12	31	200	3.27
1983	1	31	305	3.34
1983	2	28	205	3.4
1983	3	28	115	3.43
1983	4	29	1500	3.68
1983	5	1	1645	3.81
1983	6	25	1350	4.04
1983	7	11	1425	4.12
1983	8	9	1435	4.42
1983	9	7	1415	4.38
1983	10	6	1340	4.17
1983	11	5	140	4.06
1983	12	4	120	3.49
1984	1	20	235	3.63
1984	2	18	230	3.4
1984	3	19	245	3.66
1984	4	17	1440	3.79
1984	5	14	1310	4.17
1984	6	3	1615	4.54
1984	7	31	1600	4.87
1984	8	1	1635	4.73
1984	9	11	1440	4.04
1984	10	14	355	4.48
1984	11	24	210	3.57
1984	12	23	205	3.25

YEAR	MONTH	DATE	TIME	HIGHEST
1985	1	9	320	3.1
1985	2	7	250	3.34
1985	3	8	230	3.42
1985	4	8	1615	3.69
1985	5	25	405	4.88
1985	6	2	1300	4.2
1985	7	3	1420	4.29
1985	8	1	1420	4.24
1985	9	15	1415	4.21
1985	10	16	255	4.91
1985	11	13	140	3.9
1985	12	13	220	3.55
1986	1	12	255	3.24
1986	2	9	210	3.12
1986	3	29	1605	3.52
1986	4	25	1345	3.89
1986	5	24	1400	4.03
1986	6	21	1245	4.49
1986	7	22	1425	4.89
1986	8	20	1420	4.34
1986	9	11	630	3.96
1986	10	6	250	4.06
1986	11	9	805	4.12
1986	12	3	230	3.56
1987	1	31	300	3.29
1987	2	1	340	3.22
1987	3	1	150	3.22
1987	4	14	1320	3.56
1987	5	14	1340	3.82
1987	6	4	1835	4.41
1987	7	12	1440	4.85
1987	8	27	1530	4.43
1987	9	23	1410	4.33
1987	10	8	225	4.16
1987	11	23	220	3.86
1987	12	22	225	3.72
1988	1	21	255	3.4
1988	2	18	200	3.56
1988	3	20	1500	3.5
1988	4	15	1240	4.07
1988	5	20	1645	4.1
1988	6	3	1600	4.25
1988	7	17	1550	4.47
1988	8	2	1650	4.59
1988	9	28	320	4.3
1988	10	19	820	4.38
1988	11	29	1850	4.16
1988	12	12	350	3.59
1989	1	10	330	3.35
1989	2	8	200	3.45
1989	3	10	1600	3.37
1989	4	7	1450	3.56
1989	5	12	800	4.9
1989	6	21	1520	4.69
1989	7	22	1620	4.85
1989	8	17	1410	4.38
1989	9	17	240	4.3
1989	10	18	400	4.68
1989	11	14	220	3.78
1989	12	13	210	3.32

YEAR	MONTH	DATE	TIME	HIGHEST
1990	1	30	400	3.17
1990	2	27	250	3.2
1990	3	23	150	3.5
1990	4	26	1450	3.94
1990	5	25	1430	3.95
1990	6	13	1700	4.32
1990	7	23	1500	4.38
1990	8	21	1440	4.64
1990	9	4	1400	4.15
1990	10	9	440	4.48
1990	11	5	300	4.01
1990	12	26	2000	3.47
2000	1	23	240	3.45
2000	2	8	300	3.38
2000	3	9	250	3.78
2000	4	6	1400	4.01
2000	5	19	1430	3.91
2000	6	5	1550	4.52
2000	7	18	1515	4.47
2000	8	30	1430	4.72
2000	9	1	1600	4.32
2000	10	28	245	4.77
2000	11	14	225	3.9
2000	12	12	150	3.55
2001	1	10	145	3.43
2001	2	9	150	3.43
2001	3	10	120	3.38
2001	4	28	1650	3.61
2001	5	24	1440	4.02
2001	6	22	1400	4.27
2001	7	23	1510	4.47
2001	8	20	1440	4.73
2001	9	17	1400	4.2
2001	10	18	210	4.2
2001	11	1	135	4.12
2001	12	2	230	3.7
2002	1	3	410	3.3
2002	2	28	130	3.5
2002	3	1	200	3.59
2002	4	27	1220	3.65
2002	5	26	1340	4.12
2002	6	10	1335	5.72
2002	7	12	1515	4.26
2002	8	9	1400	4.65
2002	9	10	1600	4.36
2002	10	8	240	3.94
2002	11	5	105	4
2002	12	4	105	3.72
2003	1	20	210	3.32
2003	2	18	215	3.23
2003	3	19	120	3.37
2003	4	18	1410	3.79
2003	5	15	1220	4.24
2003	6	12	1135	4.04
2003	7	14	1405	4.17
2003	8	28	1425	4.22
2003	9	1	440	3.86
2003	10	27	235	3.78
2003	11	25	155	3.43
2003	12	24	205	3.23

YEAR	MONTH	DATE	TIME	HIGHEST
2004	1	22	200	3.25
2004	2	21	210	3.12
2004	3	23	1450	3.35
2004	4	7	1530	3.72
2004	5	20	1415	4.07
2004	6	3	1335	4.33
2004	7	4	1515	4.38
2004	8	4	1620	4.3
2004	9	16	1455	4.31
2004	10	16	245	3.94
2004	11	14	230	3.32
2004	12	13	215	3.4
2005	1	12	245	3.17
2005	2	10	240	3.06
2005	3	29	1605	3.26
2005	4	28	1610	3.59
2005	5	23	1315	3.81
2005	6	27	1755	4.22
2005	7	24	1545	4.34
2005	8	21	1455	4.43
2005	9	18	1325	4.26
2005	10	2	1325	3.81
2005	11	17	205	3.77
2005	12	1	115	3.62
2006	1	2	305	3.45
2006	2	28	135	3.39
2006	3	1	215	3.39
2006	4	30	1515	3.79
2006	5	12	1320	3.7
2006	6	30	1640	4.04
2006	7	14	1550	4.36
2006	8	12	1540	4.43
2006	9	21	1320	4.32
2006	10	8	155	4.26
2006	11	7	230	3.87
2006	12	23	330	3.35
2007	1	21	310	3.24
2007	2	19	220	3.29
2007	3	21	1440	3.42
2007	4	17	1300	3.71
2007	5	15	1230	4.4
2007	6	29	1310	4.32
2007	7	15	1425	4.26
2007	8	15	240	4.99
2007	9	29	300	4.39
2007	10	16	330	4.15
2007	11	16	455	4.51
2007	12	25	220	3.55
2008	1	11	315	3.48
2008	2	22	210	3.27
2008	3	8	155	3.44
2008	4	22	1515	3.64
2008	5	6	1355	4.47
2008	6	17	1335	4.15
2008	7	31	1255	4.44
2008	8	2	1410	4.61
2008	9	17	220	4.61
2008	10	27	30	4.45
2008	11	14	145	3.88
2008	12	13	140	3.8

YEAR	MONTH	DATE	TIME	HIGHEST
2009	1	12	220	3.49
2009	2	26	225	3.38
2009	3	29	1515	3.55
2009	4	27	1450	3.71
2009	5	25	1335	5.09
2009	6	25	1655	4.26
2009	7	20	1430	4.31
2009	8	21	1510	4.2
2009	9	8	1615	4.35
2009	10	6	315	4.14
2009	11	3	225	3.69
2009	12	4	320	3.83
2010	1	30	130	3.35
2010	2	1	230	3.33
2010	3	31	1350	3.93
2010	4	1	1450	3.84
2010	5	27	1250	4.24
2010	6	13	1405	4.43
2010	7	25	1340	4.35
2010	8	12	1505	4.29
2010	9	8	1315	4.45
2010	10	8	1330	4.9
2010	11	8	225	3.92
2010	12	6	135	3.62
2011	1	21	220	3.67
2011	2	18	240	3.61
2011	3	20	1355	4.09
2011	4	18	1325	3.91
2011	5	18	1405	3.98
2011	6	17	1410	4.58
2011	7	17	1500	4.32
2011	8	31	1445	4.52
2011	9	1	305	4.48
2011	10	1	345	4.03
2011	11	25	105	3.62
2011	12	19	805	3.63
2012	1	10	210	3.49
2012	2	25	340	3.5
2012	3	10	1455	3.59
2012	4	9	1450	4.21
2012	5	6	1320	3.97
2012	6	22	1505	4.5
2012	7	3	1250	4.63
2012	8	4	1432	4.7
2012	9	17	1400	4.37
2012	10	18	235	4.19
2012	11	16	240	3.94
2012	12	14	130	3.75
2013	1	12	131	3.53
2013	2	11	200	3.37
2013	3	28	1414	3.55
2013	4	28	1500	3.89
2013	5	28	1524	4.63
2013	6	25	1435	4.77
2013	7	23	1338	4.67
2013	8	21	1320	4.67
2013	9	19	1340	3.94
2013	10	7	217	3.56
2013	11	5	200	3.39
2013	12	20	300	3.66

YEAR	MONTH	DATE	TIME	HIGHEST
2014	1	3	240	3.59
2014	2	1	2019	3.39
2014	3	31	1404	3.55
2014	4	30	1420	3.92
2014	5	16	1425	3.97
2014	6	14	1401	4.37
2014	7	14	1433	4.94
2014	8	12	1447	4.76
2014	9	9	1330	4.48
2014	10	11	310	4.71
2014	11	8	150	4.27
2014	12	23	158	3.88
2015	1	22	224	3.85
2015	2	20	214	3.72
2015	3	21	145	3.7
2015	4	21	1500	4.01
2015	5	19	1408	3.85
2015	6	21	1620	4.15
2015	7	31	1315	4.6
2015	8	1	1417	4.86
2015	9	1	253	4.8
2015	10	1	320	4.36
2015	11	26	118	3.91
2015	12	13	220	3.75
2016	1	24	155	3.4
2016	2	10	227	3.88
2016	3	10	215	3.4
2016	4	23	1409	3.96
2016	5	7	1350	4.06
2016	6	6	1414	4.56
2016	7	3	1227	4.73
2016	8	4	1430	4.7
2016	9	19	250	4.48
2016	10	18	228	4.36
2016	11	15	122	4.12
2016	12	14	110	4.07
2017	1	15	310	3.78
2017	2	28	237	3.37
2017	3	30	1455	4.17
2017	4	27	1410	4.15
2017	5	30	1710	4.34
2017	6	25	1430	4.71
2017	7	24	1354	4.89
2017	8	22	1400	4.62
2017	9	20	120	4.6
2017	10	21	1415	4.94
2017	11	5	150	4.27
2017	12	5	220	4.09
2018	1	3	202	4.04
2018	2	2	240	3.81
2018	3	3	230	3.79
2018	4	18	1510	4.16
2018	5	18	1530	4.39
2018	6	15	1430	4.84
2018	7	15	1450	4.94
2018	8	13	1450	4.99
2018	9	10	1412	4.51
2018	10	11	242	4.51
2018	11	25	222	4.06
2018	12	24	225	3.87
2019	8	3	1500	2.012
2020	8	20	1405	2.012
2021	5	26	1300	2.012
2022	8	14	1455	2.012

(7) Patharghata

Table 3-8 Monthly Maximum Tide Levels of PATHARGHATA (1958-2024)

YEAR	MONTH	DATE	HIGHEST
1958	4	5	0.94
1958	5	18	1.01
1958	6	19	1.04
1958	7	17	1.07
1958	8	17	1.28
1958	9	12	1.52
1958	10	13	0.76
1958	11	10	0.82
1958	12	12	0.30
1959	1	13	0.12
1959	2	25	0.55
1959	3	26	1.01
1959	4	24	1.01
1959	5	24	1.04
1959	6	23	1.22
1959	7	21	1.45
1959	8	20	1.30
1959	9	30	1.30
1959	10	1	1.42
1959	11	1	0.92
1959	12	2	0.52
1960	1	30	0.20
1960	2	2	0.91
1960	3	15	0.40
1960	4	14	0.74
1960	5	28	1.18
1960	6	12	1.26
1960	7	9	1.19
1960	8	9	1.36
1960	9	24	1.19
1960	10	4	1.03
1960	11	3	0.74
1960	12	3	0.39
1961	1	21	0.56
1961	2	16	0.11
1961	3	18	0.92
1961	4	3	0.62
1961	5	31	1.19
1961	6	28	1.19
1961	7	30	1.25
1961	8	25	1.22
1961	9	24	1.19
1961	10	25	0.77
1961	11	9	0.58
1961	12	10	0.03
1962	1	9	0.18
1962	2	7	0.45
1962	3	8	0.51
1962	4	21	0.42
1962	5	31	1.31
1962	6	1	1.34
1962	7	21	1.15
1962	8	17	1.12
1962	9	17	1.25
1962	10	14	1.06
1962	11	1	0.79
1962	12	13	0.27
1963	1	28	0.18
1963	2	27	0.39
1963	3	26	0.55
1963	4	25	0.79
1963	5	25	0.88
1963	6	7	1.15
1963	7	24	0.97
1963	8	6	1.09
1963	9	5	1.15
1963	10	4	0.94
1963	11	2	0.94
1963	12	2	0.48
1964	1	1	0.18
1964	2	15	0.15
1964	3	30	0.55
1964	4	14	0.96
1964	5	13	1.03
1964	6	12	1.19
1964	7	12	1.00
1964	8	11	1.40
1964	9	24	1.34
1964	10	22	1.25
1964	11	6	0.88
1964	12	21	0.39
1965	1	19	0.12
1965	2	17	0.15
1965	3	19	0.48
1968	4	14	0.91
1968	5	13	1.18
1968	6	12	1.45
1968	7	28	1.42
1968	8	23	1.27
1968	9	9	1.15
1968	10	4	1.21
1968	11	22	0.57
1968	12	21	0.02
1969	1	20	-0.01

YEAR	MONTH	DATE	HIGHEST
1969	2	18	0.39
1969	3	21	0.57
1969	4	16	0.84
1969	5	31	0.81
1969	6	29	1.18
1969	7	30	1.85
1969	8	1	1.39
1969	9	26	1.33
1969	10	13	0.95
1969	11	8	1.07
1969	12	11	0.36
1970	1	10	0.46
1970	2	24	0.46
1970	3	24	0.65
1970	4	23	0.80
1970	5	6	1.26
1970	6	22	1.04
1970	7	21	1.56
1970	8	18	1.32
1970	9	3	1.26
1970	10	23	2.28
1970	11	12	1.35
1970	12	31	0.35
1971	1	28	0.62
1971	2	28	0.71
1971	3	28	1.07
1971	4	26	1.01
1971	5	9	1.44
1971	6	24	1.32
1971	7	12	1.29
1971	8	8	1.10
1971	9	5	1.29
1971	10	5	1.33
1971	11	3	0.87
1971	12	4	0.25
1972	1	21	0.36
1972	2	3	0.30
1972	3	17	0.52
1972	4	14	0.92
1972	5	29	0.92
1972	6	30	1.10
1972	7	14	1.29
1972	8	26	1.23
1972	9	10	1.31
1972	10	9	1.22
1972	11	21	0.37
1972	12	20	0.31
1973	1	21	0.19
1973	2	20	0.30
1973	3	7	0.26
1973	4	18	0.42
1973	5	18	0.81
1973	6	3	0.84
1973	7	19	1.10
1973	8	28	1.26
1973	9	14	1.13
1973	10	12	1.93
1973	11	9	1.44
1973	12	10	1.26
1974	1	11	0.74
1974	2	9	1.07
1974	3	25	0.72
1974	4	24	0.97
1974	5	6	1.36
1974	6	21	1.21
1974	7	22	1.15
1974	8	19	1.68
1974	9	30	1.21
1974	10	2	1.33
1974	11	14	0.89
1974	12	1	0.71
1975	1	1	0.25
1975	2	28	0.31
1975	3	31	0.58
1975	4	16	0.80
1975	5	27	1.13
1975	6	27	1.47
1975	7	25	1.15
1975	8	9	1.55
1975	9	8	1.61
1975	10	6	1.39
1975	11	3	1.26
1975	12	20	0.01
1976	1	29	0.28
1976	2	18	0.10
1976	3	31	0.20
1976	4	15	0.91
1976	5	15	1.13
1976	6	29	1.13
1976	7	30	1.26
1976	8	26	1.41
1976	9	11	1.41
1976	10	23	1.26
1976	11	23	0.71

YEAR	MONTH	DATE	HIGHEST
1976	12	23	0.68
1977	1	8	0.44
1977	2	21	0.41
1977	3	8	0.57
1977	4	4	0.75
1977	5	31	0.96
1977	6	4	1.45
1977	7	4	1.36
1977	8	1	1.45
1977	9	1	1.13
1977	10	14	1.27
1977	11	13	0.84
1977	12	11	0.90
1978	1	11	0.42
1978	2	9	0.49
1978	4	24	1.10
1978	5	24	1.68
1978	6	22	1.74
1978	7	21	1.41
1978	8	20	1.74
1978	9	18	1.47
1978	10	4	1.74
1978	11	2	0.95
1978	12	1	0.40
1979	1	2	0.37
1979	2	28	0.34
1979	3	31	0.59
1979	4	26	0.89
1979	5	14	1.13
1979	6	25	1.35
1979	7	11	1.38
1979	8	7	2.08
1979	9	10	1.07
1979	10	4	1.38
1979	11	4	0.81
1979	12	4	0.63
1980	1	19	0.23
1980	2	18	0.60
1980	3	20	0.52
1980	4	30	0.68
1980	5	31	0.98
1980	6	30	1.22
1980	7	29	1.50
1980	8	28	1.62
1980	9	26	1.35
1980	10	26	1.13
1980	11	22	0.80
1980	12	24	0.55
1981	1	21	0.37
1981	2	7	0.31
1981	3	22	0.68
1981	4	6	1.07
1981	5	31	1.29
1981	6	4	1.77
1981	7	1	1.50
1981	8	16	1.59
1981	9	26	1.65
1981	10	14	1.10
1981	11	12	1.12
1981	12	11	0.94
1982	1	11	0.20
1982	2	10	0.26
1982	3	25	0.40
1982	4	26	1.13
1982	5	9	0.77
1982	6	22	1.21
1982	7	23	1.81
1982	8	6	1.55
1982	9	9	2.24
1982	10	3	0.51
1982	11	15	0.31
1982	12	16	0.55
1983	1	17	0.26
1983	2	16	0.36
1983	3	26	0.52
1983	4	1	0.96
1983	5	25	0.96
1983	6	26	0.98
1983	7	12	0.99
1983	8	25	1.07
1983	9	7	1.43
1983	10	7	0.98
1983	11	9	1.03
1983	12	6	0.65
1984	1	19	0.43
1984	2	18	0.43
1984	3	20	0.48
1984	4	30	0.74
1984	5	17	1.44
1984	6	30	1.50
1984	7	31	2.50
1984	8	1	2.40
1984	9	10	1.50
1984	10	13	1.56

YEAR	MONTH	DATE	HIGHEST
1984	11	25	1.05
1984	12	10	0.40
1985	1	8	0.16
1985	2	7	1.35
1985	3	9	1.30
1985	4	7	1.20
1985	5	24	1.70
1985	6	3	1.60
1985	7	31	1.40
1985	8	3	1.50
1985	9	18	1.50
1985	10	16	2.00
1985	11	14	1.30
1985	12	13	1.10
1986	1	29	0.80
1986	2	28	0.70
1986	3	28	0.60
1986	4	26	1.20
1986	5	24	1.30
1986	6	27	1.30
1986	7	21	1.40
1986	8	20	1.70
1986	9	21	1.30
1986	10	6	1.30
1986	11	2	1.30
1986	12	1	0.70
1987	1	31	0.90
1987	2	4	1.10
1987	3	29	0.90
1987	4	15	1.20
1987	5	15	1.00
1987	6	26	1.10
1987	7	12	1.56
1987	8	11	1.36
1987	9	24	1.40
1987	10	7	1.28
1987	11	5	0.85
1987	12	5	0.69
1988	1	21	0.50
1988	2	20	0.63
1988	3	19	0.60
1988	4	16	1.11
1988	5	31	1.18
1988	6	17	1.27
1988	7	29	1.53
1988	8	1	1.55
1988	9	1	1.30
1988	10	27	1.10
1988	11	29	1.30
1988	12	11	0.51
1989	1	9	0.20
1989	2	22	0.10
1989	3	9	0.82
1989	4	7	1.00
1989	5	26	1.66
1989	6	21	1.60
1989	7	23	2.00
1989	8	17	1.65
1989	9	18	1.45
1989	10	17	1.41
1989	11	15	1.00
1989	12	13	0.38
1990	1	14	0.10
1990	2	27	0.75
1990	3	29	1.20
1990	4	24	1.44
1990	5	9	1.42
1990	6	23	1.88
1990	7	23	1.74
1990	8	22	2.08
1990	9	6	2.10
1990	10	4	1.84
1990	11	4	1.72
1990	12	5	1.19
1991	1	3	1.30
1991	2	2	0.85
1991	3	31	1.20
1991	4	29	1.70
1991	5	17	1.30
1991	6	30	1.58
1991	7	30	1.72
1991	8	12	1.75
1991	9	11	1.74
1991	10	8	1.52
1991	11	6	1.12
1991	12	23	0.94
1992	1	22	0.85
1992	2	21	1.19
1992	3	20	1.31
1992	4	18	1.26
1992	5	19	1.59
1992	6	17	2.10
1992	7	31	1.94
1992	8	29	2.05

YEAR	MONTH	DATE	HIGHEST
1992	9	26	1.71
1992	10	12	1.46
1992	11	21	0.91
1992	12	11	0.60
1993	1	11	0.63
1993	2	9	0.92
1993	3	23	1.15
1993	4	6	1.25
1993	5	7	1.61
1993	6	18	1.66
1993	7	23	1.56
1993	8	19	1.88
1993	9	17	1.73
1993	10	16	1.51
1993	11	15	1.05
1993	12	1	0.84
1994	1	30	0.80
1994	2	27	0.89
1994	3	29	1.49
1994	4	26	1.48
1994	5	26	1.48
1994	6	23	1.76
1994	7	11	1.76
1994	8	11	1.78
1994	9	5	1.69
1994	10	6	1.46
1994	11	5	1.11
1994	12	5	0.76
1995	1	2	0.86
1995	2	18	1.05
1995	3	19	1.40
1995	4	16	1.90
1995	5	16	2.45
1995	6	14	2.05
1995	7	15	2.25
1995	8	10	2.20
1995	9	10	1.95
1995	10	7	1.61
1995	11	10	1.53
1995	12	23	0.85
1996	1	21	0.68
1996	2	21	0.93
1996	3	20	1.03
1996	4	18	1.21
1996	5	17	1.80
1996	6	30	1.68
1996	7	31	2.03
1996	8	29	2.19
1996	9	27	2.08
1996	10	28	2.03
1996	11	11	1.25
1996	12	11	0.98
1997	1	10	0.93
1997	2	10	0.98
1997	3	10	1.06
1997	4	9	1.23
1997	5	23	1.63
1997	6	26	1.85
1997	7	21	1.98
1997	8	5	2.05
1997	9	18	1.29
1997	10	16	0.85
1997	11	14	0.58
1997	12	31	0.53
1998	1	30	0.67
1998	2	28	1.00
1998	3	29	1.29
1998	4	27	1.48
1998	5	26	1.86
1998	6	25	1.99
1998	7	11	2.01
1998	8	10	2.04
1998	9	9	2.09
1998	10	6	2.03
1998	11	22	2.07
1998	12	2	1.21
1999	1	20	0.83
1999	2	18	1.03
1999	3	18	1.23
1999	4	19	1.66
1999	5	28	1.83
1999	6	11	2.03
1999	7	30	2.03
1999	8	30	1.88
1999	9	12	1.83
1999	10	25	1.70
1999	11	22	1.38
1999	12	24	1.26
2000	1	22	0.78
2000	2	22	1.03
2000	3	22	1.23
2000	4	7	1.58
2000	5	19	1.73
2000	6	6	2.23

YEAR	MONTH	DATE	HIGHEST
2000	7	18	1.92
2000	8	30	2.21
2001	5	24	1.80
2001	6	7	1.70
2001	7	23	1.80
2001	8	21	2.30
2001	9	18	1.67
2001	10	18	1.70
2001	11	1	1.34
2001	12	2	1.00
2002	1	1	0.60
2002	2	28	1.15
2002	3	30	1.35
2002	4	27	1.63
2002	5	26	1.98
2002	6	23	1.95
2002	7	12	1.88
2002	8	10	2.16
2002	9	10	2.02
2002	10	6	1.65
2002	11	6	1.45
2002	12	5	1.25
2003	1	5	1.03
2003	2	18	1.03
2003	3	21	1.35
2003	4	18	1.85
2003	5	16	2.20
2003	6	16	1.99
2003	7	15	2.05
2003	8	29	2.40
2003	9	27	2.15
2003	10	8	1.95
2003	11	26	1.30
2003	12	23	1.15
2004	1	24	0.71
2004	2	21	1.10
2004	3	22	1.55
2004	4	19	1.85
2004	5	21	2.35
2004	6	3	2.35
2004	7	4	2.26
2004	8	4	2.36
2004	9	16	2.43
2004	10	15	1.83
2004	11	15	1.28
2004	12	14	1.43
2005	1	13	1.21
2005	2	12	0.81
2005	3	29	1.31
2005	4	26	1.76
2005	5	25	2.05
2005	6	25	2.26
2005	7	25	2.51
2005	8	20	2.26
2005	9	18	2.73
2005	10	3	2.10
2005	11	16	1.68
2005	12	17	1.58
2006	1	1	1.33
2006	2	15	1.25
2006	3	31	1.58
2006	4	15	1.58
2006	5	29	1.58
2006	6	26	1.74
2006	7	6	3.95
2006	8	12	2.60
2006	9	25	1.87
2006	10	25	1.42
2006	11	9	1.22
2006	12	31	1.29
2007	1	16	1.34
2007	2	18	1.25
2007	3	17	1.40
2007	4	3	1.43
2007	5	16	1.65
2007	6	29	2.33
2007	7	16	2.65
2007	8	14	2.65
2007	9	25	2.55
2007	10	14	2.35
2007	11	11	1.36
2007	12	9	1.22
2008	1	6	1.09
2008	2	20	1.22
2008	3	6	1.27
2008	4	3	1.40
2008	5	19	1.85
2008	6	5	1.95
2008	7	4	2.03
2008	8	31	2.25
2008	9	2	2.27
2008	10	1	1.70
2008	11	13	1.25
2008	12	10	1.20

YEAR	MONTH	DATE	HIGHEST
2009	1	23	1.33
2009	2	24	1.55
2009	3	26	1.70
2009	4	26	1.67
2009	5	25	3.15
2009	6	24	2.25
2009	7	22	1.87
2009	8	5	1.70
2009	9	18	2.30
2009	10	3	2.43
2009	11	2	1.96
2009	12	16	1.65
2010	1	31	1.50
2010	2	28	1.55
2010	3	30	2.00
2010	4	14	1.95
2010	5	28	2.15
2010	6	27	1.95
2010	7	25	2.40
2010	8	23	1.92
2010	9	6	1.59
2010	10	8	2.85
2010	11	5	1.60
2010	12	4	1.28
2011	1	19	1.25
2011	2	16	1.30
2011	3	17	2.40
2011	4	15	2.35
2011	5	2	2.37
2011	6	17	2.85
2011	7	31	2.40
2011	8	31	2.45
2011	9	1	2.35
2011	10	12	1.82
2011	11	24	1.45
2011	12	26	1.60
2012	1	10	1.65
2012	2	23	1.45
2012	3	11	2.50
2012	4	7	2.00
2012	5	21	2.05
2012	6	4	2.60
2012	7	3	2.66
2012	8	3	2.55
2012	9	15	2.40
2012	10	13	2.31
2012	11	26	2.10
2012	12	25	1.95
2013	1	9	1.93
2013	2	22	1.70
2013	3	23	1.76
2013	4	28	1.83
2013	5	25	2.55
2013	6	25	2.75
2013	7	24	2.70
2013	8	21	2.50
2013	9	20	2.35
2013	10	5	2.20
2013	11	3	2.01
2013	12	16	1.86
2014	1	31	1.96
2014	2	15	2.01
2014	3	1	2.03
2014	4	30	1.92
2014	5	27	2.10
2014	6	28	2.15
2014	7	13	2.80
2014	8	11	2.60
2014	9	22	2.35
2014	10	11	2.40
2014	11	8	1.70
2014	12	6	1.62
2015	1	4	1.52
2015	2	16	1.56
2015	3	18	1.58
2015	4	18	2.10
2015	5	18	1.99
2015	6	21	2.55
2015	7	1	2.47
2015	8	2	2.50
2015	9	1	2.35
2015	10	1	2.15
2015	11	11	1.60
2015	12	10	1.32
2016	1	9	1.21
2016	2	24	1.65
2016	3	9	1.56
2016	4	23	2.17
2016	5	22	2.40
2016	6	7	2.53
2016	7	4	2.60
2016	8	17	2.52
2016	9	18	2.25
2016	10	1	2.05

YEAR	MONTH	DATE	HIGHEST
2016	11	1	1.57
2016	12	16	1.37
2017	1	1	1.29
2017	2	28	1.11
2017	3	29	1.75
2017	4	27	2.03
2017	5	28	2.24
2017	6	25	2.45
2017	7	24	2.60
2017	8	23	2.30
2017	9	20	2.35
2017	10	20	2.63
2017	11	4	1.95
2017	12	3	1.62
2018	1	4	1.62
2018	2	2	1.42
2018	3	31	1.75
2018	4	18	2.05
2018	5	17	2.22
2018	6	14	2.68
2018	7	15	2.75
2018	8	14	2.75
2018	9	10	2.40
2018	10	10	2.50
2018	11	7	1.60
2018	12	7	1.37
2019	1	21	1.35
2019	2	5	1.00
2019	3	21	1.45
2019	4	5	1.50
2019	5	3	2.10
2019	6	17	1.77
2019	7	3	2.02
2019	8	2	2.17
2019	9	29	1.95
2019	10	1	2.00
2019	11	10	2.30
2019	12	12	1.07
2020	1	13	1.10
2020	2	27	1.15
2020	3	10	1.03
2020	4	8	1.75
2020	5	20	2.95
2020	6	6	2.22
2020	7	7	2.12
2020	8	20	2.35
2020	9	19	2.20
2020	10	18	2.18
2020	11	26	1.88
2020	12	15	1.45
2021	1	12	1.32
2021	2	28	1.58
2021	3	31	2.10
2021	4	27	2.13
2021	5	26	3.08
2021	6	25	2.43
2021	7	24	2.53
2021	8	10	2.23
2021	9	8	2.48
2021	10	20	2.25
2021	11	20	1.90
2021	12	6	2.10
2022	1	31	1.50
2022	2	1	1.60
2022	3	31	1.85
2022	4	18	2.02
2022	5	17	2.47
2022	6	15	2.50
2022	7	16	2.60
2022	8	14	3.10
2022	9	11	2.70
2022	10	25	2.40
2022	11	7	1.81
2022	12	25	1.65
2023	1	24	1.00
2023	2	22	1.37
2023	3	22	1.51
2023	4	21	1.70
2023	5	18	1.77
2023	6	5	1.75
2023	7	6	2.15
2023	8	2	2.42
2023	9	30	2.12
2023	10	1	1.98
2023	11	17	1.68
2023	12	12	0.64
2024	1	13	0.63
2024	2	13	0.88
2024	3	27	1.25
2024	4	9	1.40
2024	5	27	2.55
2024	6	5	1.75
2024	7	23	2.05
2024	8	21	1.95

(8) Khepupara

Table 3-9 Monthly Maximum Tide Levels of KHEPUPARA (1977-2024)

(1977~2019 : CD , 2020~2024 : MSL)

YEAR	MONTH	DATE	TIME	HIGHEST
1977	1	19	23:30	3.31
1977	2	6	6:30	3.47
1977	3	8	13:00	3.5
1977	4	4	11:15	4.01
1977	5	12	19:15	4.28
1977	6	3	12:00	4.65
1977	7	4	13:00	4.83
1977	8	1	23:50	4.63
1977	9	11	22:00	4.56
1977	10	1	6:30	4.34
1977	11	12	23:40	3.67
1977	12	11	23:40	3.66
1978	1	9	22:00	3.32
1978	2	6	23:20	3.31
1978	3	26	12:30	3.51
1978	4	22	10:30	3.44
1978	5	22	10:30	4.27
1978	6	21	11:00	4.18
1978	7	22	11:45	3.86
1978	8	17	10:30	4.14
1978	9	16	10:00	3.82
1978	10	3	23:20	4.17
1978	11	30	11:00	3.5
1978	12	2	0:00	3.49
1979	1	1	6:30	3.35
1979	2	26	23:00	3.35
1979	3	28	11:00	3.5
1979	4	12	11:30	3.38
1979	5	6	19:00	5.21
1979	6	24	11:00	4.11
1979	7	14	14:00	4.24
1979	8	7	11:30	4.56
1979	9	8	13:00	4.31
1979	10	5	22:30	3.8
1979	11	20	23:30	2.91
1979	12	21	6:30	3.04
1980	1	19	0:00	2.89
1980	2	18	0:00	3.09
1980	3	17	23:30	3.12
1980	4	15	0:00	3.15
1980	5	31	12:00	3.5
1980	6	30	13:00	3.85
1980	7	1	13:00	4.02
1980	8	26	16:00	4.09
1980	9	2	21:30	3.94
1980	10	26	12:00	3.73
1980	11	22	22:30	3.36
1980	12	21	23:30	3.46
1981	1	6	23:30	3.36
1981	2	6	0:00	3.2
1981	3	6	0:00	3.14
1981	4	5	11:30	3.51
1981	5	5	12:30	3.83
1981	6	21	12:30	4.16
1981	7	31	11:30	3.92
1981	8	3	13:30	4.1
1981	9	25	21:30	4.13
1981	10	2	6:30	3.55
1981	11	11	23:00	4.04
1981	12	11	10:30	4.22
1982	1	11	0:00	3.25
1982	2	9	0:00	3.25
1982	3	27	12:30	3.23
1982	4	26	12:30	3.62
1982	5	24	12:00	3.53
1982	6	22	12:00	4.2
1982	7	20	10:00	4.05
1982	8	20	11:30	4.06
1982	9	17	11:00	3.74
1982	10	3	11:00	3.68
1982	11	3	0:00	3.33
1982	12	30	23:30	3.16
1983	1	30	6:30	2.84
1983	2	28	0:00	2.92
1983	3	28	23:30	3.13
1983	4	29	12:30	3.16
1983	5	14	12:00	3.22
1983	6	25	10:30	3.65
1983	7	11	11:30	3.46
1983	8	11	12:30	3.79
1983	9	7	10:00	3.74
1983	10	7	23:30	3.53
1983	11	4	22:30	3.56
1983	12	21	0:00	3
1984	1	20	0:00	3.24
1984	2	19	6:30	2.99
1984	3	19	0:00	3.21
1984	4	16	23:30	3.24
1984	5	14	10:00	3.54
1984	6	14	11:30	3.81
1984	7	31	12:00	4.17
1984	8	1	12:30	4.04
1984	9	11	11:00	3.53
1984	10	14	6:30	4.01
1984	11	23	11:00	3.3
1984	12	24	0:00	2.89
1985	1	9	6:30	2.73
1985	2	7	0:00	3.07
1985	3	8	12:00	3.04
1985	4	9	13:30	3.01
1985	5	24	14:00	3.83
1985	6	2	10:00	3.6
1985	7	3	11:00	3.65
1985	8	1	11:00	4
1985	9	15	23:30	3.67
1985	10	15	23:30	4.37
1985	11	12	23:00	3.38
1985	12	12	23:30	3.1
1986	1	10	23:30	3.14
1986	2	24	23:30	3.09
1986	3	28	12:30	3.29
1986	4	9	23:30	4
1986	5	24	11:00	4.07
1986	6	21	10:00	4.27
1986	7	22	11:00	4.68
1986	8	19	10:30	4.32
1986	9	6	12:00	3.79
1986	10	4	23:30	3.95
1986	11	2	23:00	3.83
1986	12	1	23:00	3.43
1987	1	31	13:30	3.28
1987	2	28	23:30	3.39
1987	3	2	6:30	3.29
1987	4	14	11:00	3.52
1987	5	14	11:30	3.57
1987	6	12	11:30	3.91
1987	7	12	12:00	4.36
1987	8	10	11:30	3.92
1987	9	9	12:00	4.18
1987	10	7	23:30	3.84
1987	11	5	23:00	3.69
1987	12	22	0:00	3.61
1988	1	21	16:40	3.28
1988	2	21	14:10	3.7
1988	3	18	23:30	3.53
1988	4	15	10:10	3.9
1988	5	30	10:00	3.94
1988	6	12	21:30	4.19
1988	7	30	11:30	4.14
1988	8	2	13:50	4.32
1988	9	26	23:50	3.95
1988	10	25	23:00	3.83
1988	11	29	22:00	4.38
1988	12	11	0:00	3.49
1989	1	10	0:00	3.32
1989	2	7	23:50	3.63
1989	3	10	13:00	3.45
1989	4	7	11:40	3.59
1989	5	25	14:30	4.1
1989	6	21	13:00	4.1
1989	7	22	13:40	4.54
1989	8	17	11:25	4.28
1989	9	18	20:20	4.04
1989	10	18	11:10	4.27
1989	11	12	22:30	3.68
1989	12	12	23:30	3.33
1990	1	29	21:45	3.27
1990	2	27	0:00	3.41
1990	3	28	12:00	3.7
1990	4	25	11:00	4.31
1990	5	24	10:00	4.18
1990	6	23	11:10	4.51
1990	7	23	12:00	4.57
1990	8	21	11:00	4.85
1990	9	5	10:50	4.41
1990	10	8	16:40	4.78
1990	11	4	23:40	4.47
1990	12	19	0:00	3.62
1991	1	3	10:00	3.63
1991	2	1	0:00	3.25
1991	3	31	11:40	3.46
1991	4	29	11:00	3.88
1991	5	14	11:00	3.84
1991	6	14	12:20	4.24
1991	7	28	11:30	4.41
1991	8	12	12:10	4.53
1991	9	9	11:30	4.15
1991	10	8	23:20	4.18
1991	11	4	22:10	3.78
1991	12	23	0:00	3.75
1992	1	21	6:30	3.47
1992	2	17	22:25	3.58
1992	3	19	11:00	3.67
1992	4	18	11:30	3.77
1992	5	19	12:30	3.94
1992	6	17	12:10	4.51
1992	7	31	11:40	4.19
1992	8	2	13:00	4.27
1992	9	26	23:25	3.99
1992	10	26	23:30	3.96
1992	11	12	0:00	3.61
1992	12	10	23:40	3.39
1993	1	10	6:30	3.38
1993	2	9	16:40	3.44
1993	3	23	23:10	3.64
1993	4	7	11:45	3.73
1993	5	7	12:20	4.04
1993	6	17	22:30	3.96
1993	7	23	13:10	3.91
1993	8	19	12:30	4.28
1993	9	17	0:00	4.09
1993	10	15	23:30	4.17
1993	11	14	23:50	3.98
1993	12	1	0:00	3.72
1994	1	1	2:50	3.73
1994	2	28	6:30	3.65
1994	3	29	12:15	4.07
1994	4	1	21:10	3.61
1994	5	11	11:40	3.68
1994	6	23	11:10	4.23
1994	7	12	13:15	4.15
1994	8	10	12:20	4.54
1994	9	4	22:40	4.24
1994	10	7	12:00	3.92
1994	11	6	6:30	3.87
1994	12	2	23:00	3.55
1995	1	1	23:45	3.4
1995	2	15	23:25	3.43
1995	3	18	12:00	3.64
1995	4	16	11:20	3.91
1995	5	16	12:30	4.99
1995	6	14	12:40	4.3
1995	7	13	11:00	4.54
1995	8	10	11:00	4.34
1995	9	25	23:00	4.34
1995	10	8	23:00	3.91
1995	11	9	22:45	4.27
1995	12	24	13:00	3.6
1996	1	21	10:10	3.41
1996	2	20	0:00	3.51
1996	3	17	22:10	3.53
1996	4	19	12:00	3.64
1996	5	6	13:10	4.09
1996	6	30	10:00	4.11
1996	7	31	11:40	4.21
1996	8	1	12:30	4.4
1996	9	27	11:00	4.31
1996	10	29	20:20	4.66
1996	11	13	0:00	3.74
1996	12	12	0:00	3.41
1997	1	14	9:30	3.71
1997	2	9	0:00	3.6
1997	3	9	23:40	3.74
1997	4	8	11:50	3.71
1997	5	22	11:00	4.4
1997	6	7	12:10	4.3
1997	7	21	11:40	4.8
1997	8	20	12:20	4.95
1997	9	18	11:30	4.3
1997	10	1	22:50	4.06
1997	11	14	23:00	3.65
1997	12	1	0:00	3.18
1998	1	30	2:50	3.3
1998	2	26	23:30	3.48
1998	3	27	11:30	3.47
1998	4	26	11:00	3.81
1998	5	26	11:30	4.18
1998	6	11	11:30	4.14
1998	7	11	12:00	4.35
1998	8	11	12:30	4
1998	9	11	14:10	4.14
1998	10	7	0:00	4
1998	11	22	12:40	3.93
1998	12	3	23:30	3.48
1999	1	20	6:30	3.3
1999	2	3	20:00	3.16
1999	3	22	20:00	3.3
1999	4	17	14:00	3.64
1999	5	15	10:30	4.04
1999	6	11	18:00	4.3
1999	7	14	12:30	4.2
1999	8	29	13:00	4.26
1999	9	11	11:30	4.22
1999	10	29	6:30	4.31
1999	11	23	22:00	4.14
1999	12	23	23:30	3.91
2000	1	22	0:00	3.56
2000	2	7	6:30	3.45
2000	3	9	10:00	3.63
2000	4	6	12:30	3.77
2000	5	5	11:30	3.94
2000	6	6	13:30	4.45
2000	7	2	11:15	4.46
2000	8	30	12:00	4.39
2000	9	1	13:00	4.17
2000	10	27	23:30	4.64
2000	11	13	0:00	4.14
2000	12	8	22:00	3.44
2001	1	11	0:00	3.25
2001	2	9	0:00	3.35
2001	3	9	23:20	3.54
2001	4	25	12:30	3.25
2001	5	25	12:30	4.15
2001	9	17	11:00	4.15
2001	10	17	23:30	4.35
2001	11	3	0:00	4.1
2001	12	10	15:30	3.45
2002	1	14	1:30	3.3
2002	2	12	18:30	3.16
2002	3	31	1:30	3.31
2002	4	4	11:00	3.66
2002	5	5	13:00	4.26
2002	6	26	19:00	3.96
2002	7	29	8:00	4.26
2002	8	11	12:30	4.71
2002	9	9	13:00	4.81
2002	10	2	8:00	4.16
2002	11	6	12:00	4.11
2002	12	3	11:00	3.31
2003	1	19	12:00	3.26
2003	2	19	12:00	3.26
2003	3	21	14:00	3.63
2003	4	17	11:00	3.86
2003	5	17	11:30	4.4
2003	6	12	21:30	4.12
2003	7	27	10:20	4.2

YEAR	MONTH	DATE	TIME	HIGHEST
2003	8	29	12:20	4.59
2003	9	1	13:30	4.13
2003	10	25	23:00	4.28
2003	11	24	23:30	3.93
2003	12	7	23:00	3.35
2004	1	25	18:00	3
2004	2	20	23:30	3.58
2004	3	23	12:30	3.78
2004	4	6	11:40	3.99
2004	5	19	11:00	4.4
2004	6	4	12:00	4.53
2004	7	4	12:30	4.6
2004	8	4	13:20	4.58
2004	9	13	11:30	4.1
2004	10	10	18:00	3.97
2004	11	3	12:30	3.65
2004	12	12	23:30	3.9
2005	1	12	6:30	3.6
2005	2	10	6:30	3.63
2005	3	11	10:10	3.76
2005	4	9	12:00	3.78
2005	5	26	12:30	4.05
2005	6	23	12:00	4.25
2005	7	24	13:00	4.4
2005	8	20	11:00	4.42
2005	9	18	11:00	4.75
2005	10	3	11:00	4.12
2005	11	15	22:50	3.95
2005	12	1	23:10	3.86
2006	1	2	13:00	3.26
2006	2	28	12:30	3.4
2006	3	1	13:00	3.53
2006	4	29	12:00	4.13
2006	5	13	11:00	4.02
2006	6	30	14:30	4
2006	7	13	13:00	4.41
2006	8	12	16:00	4.75
2006	9	22	10:30	4.05
2006	10	7	11:00	4.1
2006	11	10	11:00	3.35
2006	12	22	13:00	3.1
2007	1	21	13:30	3.6
2007	2	5	13:30	3.78
2007	3	20	13:00	3.76
2007	4	17	10:30	3.79
2007	5	17	12:30	4.51
2007	6	29	10:00	4.04
2007	7	15	12:00	4.04
2007	8	13	12:30	4
2007	9	1	13:30	3.49
2007	10	22	14:00	3.19
2007	11	15	22:00	4.89
2007	12	12	10:00	3.25
2008	1	11	13:00	3.19
2008	2	22	0:00	3.61
2008	3	6	23:30	3.56
2008	4	8	12:30	3.79
2008	5	6	11:20	4.29
2008	6	20	11:45	4.22
2008	7	4	11:30	4.28
2008	8	3	12:00	4.43
2008	9	17	11:30	4.75
2008	10	26	21:30	4.52
2008	11	15	0:00	4.01
2008	12	12	23:30	3.85
2009	1	10	23:00	3.65
2009	2	26	12:00	3.63
2009	3	13	12:30	3.76
2009	4	25	11:30	3.85
2009	5	1	15:30	3.45
2009	6	16	12:00	3.45
2009	7	4	12:30	3.38
2009	8	21	11:30	3.78
2009	9	4	23:00	4.26
2009	10	5	22:00	3.91
2009	11	7	6:30	3.35
2009	12	4	23:45	3.54
2010	1	31	12:00	2.92
2010	2	1	12:30	3

YEAR	MONTH	DATE	TIME	HIGHEST
2010	3	31	12:00	3.66
2010	4	1	12:30	3.61
2010	5	27	11:00	3.86
2010	6	14	12:30	4.08
2010	7	26	13:00	3.92
2010	8	11	12:30	4.09
2010	9	8	10:30	4.13
2010	10	8	11:00	4.58
2010	11	8	0:00	3.68
2010	12	9	13:30	3.38
2011	1	6	6:30	3.27
2011	2	19	12:00	3.36
2011	3	20	11:30	3.98
2011	4	18	11:30	3.8
2011	5	18	11:30	3.91
2011	6	17	10:30	4.43
2011	7	17	12:00	4.12
2011	8	30	11:30	4.27
2011	9	1	12:30	4.12
2011	10	27	11:30	3.67
2011	11	25	11:30	3.31
2011	12	26	1:30	4.08
2012	1	10	12:30	3.22
2012	2	8	12:30	3.33
2012	3	10	12:30	3.68
2012	4	22	12:30	4.25
2012	5	5	11:30	3.93
2012	6	5	11:30	4.37
2012	7	3	10:00	4.39
2012	8	4	12:00	4.43
2012	9	17	11:30	4.22
2012	10	1	11:45	3.69
2012	11	13	10:30	3.49
2012	12	15	12:30	3.33
2013	1	12	13:00	3.22
2013	2	28	12:30	3.16
2013	3	28	12:00	3.53
2013	4	28	12:00	3.88
2013	5	28	13:30	4.54
2013	6	13	13:30	3.96
2013	7	23	11:30	4.43
2013	8	22	11:30	4.26
2013	9	19	10:00	4.14
2013	10	7	12:00	3.74
2013	11	4	11:00	3.58
2013	12	4	12:00	3.34
2014	1	13	15:30	3.08
2014	2	24	21:30	3
2014	3	25	11:30	3.1
2014	4	1	13:30	2.87
2014	5	15	15:30	2.89
2014	6	5	12:30	2.93
2014	7	6	15:30	2.93
2014	8	6	1:30	2.95
2014	9	1	22:00	2.8
2014	10	29	16:30	2.84
2014	11	30	12:00	2.75
2014	12	1	13:30	2.72
2015	1	23	15:30	2.73
2015	2	28	8:00	2.75
2015	3	1	18:00	2.74
2015	4	19	13:00	3.99
2015	5	28	15:30	3.99
2015	6	20	13:30	4.46
2015	7	31	10:30	4.61
2015	8	2	12:00	4.88
2015	9	1	12:00	4.66
2015	10	1	23:30	4.18
2015	11	27	23:30	3.96
2015	12	13	23:55	4.01
2017	1	12	23:30	3.6
2017	2	28	0:00	3.56
2017	3	30	12:15	4.07
2017	4	27	11:30	4.21
2017	5	27	12:00	4.16
2017	6	25	12:00	4.4
2017	7	10	11:30	4.1
2017	8	23	12:00	4.49
2017	9	20	10:30	4.61

YEAR	MONTH	DATE	TIME	HIGHEST
2017	10	7	12:00	4.32
2017	11	17	10:30	3.88
2017	12	31	11:00	3.33
2018	1	31	16:00	3.74
2018	2	1	16:30	3.7
2018	3	28	15:00	3.47
2018	4	11	18:00	3.4
2018	5	8	17:30	3.6
2018	6	15	17:20	3.62
2018	7	21	18:00	4.08
2018	8	15	14:00	3.89
2018	9	1	10:30	3.77
2018	10	28	11:30	3.79
2018	11	1	15:30	3.7
2018	12	28	15:30	3.75
2019	1	12	10:00	3.9
2019	2	12	15:30	3.88
2019	3	22	1:30	3.75
2019	4	4	11:30	3.97
2019	5	18	11:00	3.93
2019	6	18	1:30	4.16
2019	7	3	13:30	4.16
2019	8	2	11:50	4.34
2019	9	1	12:05	4.25
2019	10	1	6:30	4.2
2019	11	10	23:55	4.3
2019	12	12	23:35	3.62
2020	1	13	1:05	1.09
2020	2	11	0:45	1.13
2020	3	11	0:20	1.39
2020	4	9	12:15	1.67
2020	5	20	21:35	2.45
2020	6	5	10:40	1.97
2020	7	5	11:05	2.03
2020	8	20	11:15	2.46
2020	9	21	1:00	2.23
2020	10	17	23:30	2.13
2020	11	1	23:20	1.93
2020	12	13	22:40	1.62
2021	1	12	23:05	1.5
2021	2	27	23:50	1.47
2021	3	31	13:00	1.87
2021	4	28	12:05	1.91
2021	5	25	22:45	2.68
2021	6	25	11:35	2.06
2021	7	24	11:10	2.26
2021	8	10	12:10	1.91
2021	9	7	10:55	2.27
2021	10	18	22:45	1.9
2021	11	5	23:40	1.89
2021	12	7	0:30	2.11
2022	1	4	0:20	1.38
2022	2	3	0:40	1.49
2022	3	31	23:15	1.61
2022	4	17	11:50	1.77
2022	5	17	11:55	2.12
2022	6	14	10:55	2.09
2022	7	14	11:20	2.37
2022	8	14	12:30	2.65
2022	9	11	11:25	2.44
2022	10	24	22:05	2.55
2022	11	26	0:25	1.62
2022	12	25	0:15	1.69
2023	1	24	1:05	1.4
2023	2	20	23:55	1.62
2023	3	20	23:00	1.44
2023	4	21	12:15	1.64
2023	5	17	9:55	1.73
2023	6	5	11:50	1.74
2023	7	6	12:50	2.13
2023	8	2	11:10	2.38
2023	9	30	11:30	2.13
2023	10	1	0:00	2.06
2023	11	17	13:30	1.97
2023	12	13	23:50	1.15
2024	1	11	23:35	1.19
2024	2	12	0:55	1.22
2024	3	12	12:45	1.4
2024	4	9	11:45	1.62

YEAR	MONTH	DATE	TIME	HIGHEST
2024	5	27	0:20	2.92
2024	6	5	10:05	1.9
2024	7	26	14:10	2.05
2024	8	7	0:50	2.28
2024	9	3	23:25	2.19
2024	10	17	22:50	2.2
2024	11	15	23:05	1.7
2024	12	1	23:25	1.7

(9) Hiron Point

Table 3-10 Monthly Maximum Tide Levels of HIRON POINT (1991-2021)

HIRON POINT

YEAR	MONTH	DATE	TIME	HIGHEST
1991	1	3	00:15	3.11
1991	2	28	23:15	2.81
1991	3	31	11:30	2.93
1991	4	29	11:55	3.36
1991	5	2	12:15	3.27
1991	6	14	11:30	3.48
1991	7	28	11:40	3.65
1991	8	12	11:45	3.54
1991	9	9	10:45	3.51
1991	10	8	22:45	3.39
1991	11	4	21:40	3.14
1991	12	22	23:30	3.13
1992	1	22	00:15	2.99
1992	2	17	22:30	3.02
1992	3	18	22:40	3.02
1992	4	18	11:15	3.02
1992	5	19	12:15	3.3
1992	6	17	11:45	3.72
1992	7	27	08:40	3.63
1992	8	31	00:15	3.6
1992	9	26	22:35	3.49
1992	10	11	22:20	3.43
1992	11	11	23:15	3.25
1992	12	10	23:20	2.96
1993	1	9	23:50	2.93
1993	2	7	23:30	2.96
1993	3	23	23:00	2.89
1993	4	7	10:50	2.99
1993	5	7	11:10	3.33
1993	6	21	11:15	3.31
1993	7	4	10:30	3.28
1993	8	18	10:40	3.59
1993	9	16	22:45	3.45
1993	10	15	22:30	3.43
1993	11	13	22:05	3.22
1993	12	2	00:00	3.07
1994	1	1	00:15	2.95
1994	2	27	23:45	2.9
1994	3	29	12:00	3.22
1994	4	26	10:45	3.23
1994	5	25	10:30	3.29
1994	6	24	11:00	3.43
1994	7	11	11:50	3.47
1994	8	10	12:00	3.46
1994	9	4	09:20	3.4
1994	10	5	22:45	3.29
1994	11	4	23:05	3.26
1994	12	3	23:15	3.07
1995	1	1	23:10	2.95
1995	2	19	00:45	2.82
1995	3	18	11:30	2.88
1995	4	29	10:35	2.93
1995	5	16	11:30	3.78
1995	6	14	11:20	3.44
1995	7	13	11:10	3.66
1995	8	10	10:10	3.49
1995	9	26	11:10	3.57
1995	10	8	10:15	3.29
1995	11	29	03:50	3.72
1995	12	24	00:00	3.12

YEAR	MONTH	DATE	TIME	HIGHEST
1996	1	20	23:20	2.96
1996	2	19	23:48	2.99
1996	3	19	23:10	2.86
1996	4	19	11:30	3.07
1996	5	5	11:30	3.41
1996	6	3	11:20	3.36
1996	7	31	11:00	3.57
1996	8	1	11:35	3.63
1996	9	27	22:45	3.54
1996	10	28	23:40	3.82
1996	11	12	23:30	3.26
1996	12	13	00:15	3.06
1997	1	10	23:45	3.13
1997	2	8	23:35	3.05
1997	3	9	23:00	3.03
1997	4	7	22:45	2.97
1997	5	22	10:30	3.36
1997	6	26	14:40	3.46
1997	7	22	12:00	3.43
1997	8	19	10:45	3.68
1997	9	18	23:45	3.37
1997	10	16	22:45	3.26
1997	11	14	22:30	3.16
1997	12	14	23:30	2.77
1998	1	30	00:10	2.82
1998	2	27	23:30	2.96
1998	3	29	23:50	2.96
1998	4	23	20:50	3.17
1998	5	26	10:45	3.41
1998	6	25	11:15	3.54
1998	7	11	11:30	3.51
1998	8	10	12:00	3.59
1998	9	8	23:50	3.66
1998	10	6	23:00	3.56
1998	11	22	12:30	3.57
1998	12	2	21:50	3.25
1999	1	1	22:40	3.04
1999	2	1	23:30	2.85
1999	3	18	23:15	3.02
1999	4	17	11:20	3.22
1999	5	16	11:00	3.26
1999	6	10	19:00	3.57
1999	7	28	10:30	3.32
1999	8	29	12:00	3.37
1999	9	11	23:50	3.32
1999	10	29	01:00	3.62
1999	11	23	22:30	3.35
1999	12	25	00:00	3.25
2000	1	23	00:00	3.04
2000	2	20	23:45	3.07
2000	3	8	23:50	3.08
2000	4	6	11:40	3.19
2000	5	5	11:15	3.34
2000	6	5	12:30	3.6
2000	7	17	10:50	3.51
2000	8	30	11:00	3.64
2000	9	1	12:20	3.55
2000	10	27	23:00	4.02
2000	11	17	04:00	3.96
2000	12	11	23:00	3.23

YEAR	MONTH	DATE	TIME	HIGHEST
2001	1	10	23:15	3.12
2001	2	8	23:15	3.17
2001	3	10	23:40	3.09
2001	4	8	23:10	3.14
2001	5	24	11:30	3.51
2001	6	23	11:40	3.49
2001	7	22	11:20	3.6
2001	8	20	11:15	3.96
2001	9	17	10:30	3.61
2001	10	17	23:00	3.66
2001	11	1	22:45	3.55
2001	12	1	23:15	3.34
2002	1	2	00:30	2.99
2002	2	27	23:20	2.99
2002	3	1	00:30	3.05
2002	4	28	11:30	3.19
2002	5	26	10:30	3.4
2002	6	25	11:00	3.41
2002	7	26	11:40	3.4
2002	8	10	11:30	3.57
2002	9	10	12:40	3.43
2002	10	7	23:30	3.32
2002	11	4	22:30	3.47
2002	12	3	22:15	3.16
2003	1	19	23:45	3
2003	2	17	23:00	3
2003	3	18	23:10	3.08
2003	4	18	11:45	3.32
2003	5	17	11:30	3.63
2003	6	14	10:15	3.41
2003	7	15	11:50	3.46
2003	8	27	10:15	3.69
2003	9	12	11:30	3.41
2003	10	5	07:30	3.86
2003	11	24	23:00	3.4
2003	12	23	23:10	3.28
2004	1	22	23:45	2.94
2004	2	20	23:15	2.96
2004	3	20	23:00	3.12
2004	4	7	12:15	3.38
2004	5	19	10:45	3.64
2004	6	3	10:30	3.58
2004	7	3	11:15	3.78
2004	8	3	12:35	3.79
2004	9	15	11:00	3.64
2004	10	14	23:00	3.55
2004	11	13	23:15	3.25
2004	12	11	22:15	3.23
2005	1	11	23:45	3.08
2005	2	9	23:50	2.96
2005	3	10	23:30	2.96
2005	4	25	11:15	3.23
2005	5	23	10:00	3.41
2005	6	24	12:00	3.57
2005	7	24	12:40	3.63
2005	8	21	11:30	3.6
2005	9	18	10:30	3.9
2005	10	2	22:30	3.41
2005	11	15	22:30	3.34
2005	12	1	22:45	3.29

YEAR	MONTH	DATE	TIME	HIGHEST
2006	1	2	00:00	3.17
2006	2	28	23:20	3.05
2006	3	30	11:30	3.14
2006	4	28	10:50	3.34
2006	5	28	11:00	3.31
2006	6	13	11:35	3.28
2006	7	14	13:00	3.41
2006	8	12	12:40	3.66
2006	9	8	10:45	3.29
2006	10	7	23:00	3.51
2006	11	5	22:30	3.26
2006	12	21	23:45	2.85
2007	1	21	00:10	2.93
2007	2	16	22:40	3.49
2007	3	19	23:10	2.99
2007	4	18	11:10	3.32
2007	5	16	10:05	3.61
2007	6	29	09:45	3.6
2007	7	15	11:05	3.58
2007	8	12	10:30	3.55
2007	9	23	08:30	3.66
2007	10	26	22:30	3.47
2007	11	16	00:45	3.47
2007	12	27	00:45	2.96
2008	1	20	09:15	3.32
2008	2	21	23:30	3.02
2008	3	8	23:30	3.12
2008	4	7	11:30	3.32
2008	5	6	10:55	3.58
2008	6	6	12:30	3.32
2008	7	31	09:30	3.51
2008	8	16	10:20	4.43
2008	9	16	23:20	3.9
2008	10	15	22:50	3.4
2008	11	13	22:40	3.57
2008	12	11	22:10	3.28
2009	1	11	23:20	3.17
2009	2	15	04:40	3.54
2009	3	28	11:40	3.11
2009	4	25	10:30	3.22
2009	5	25	11:20	4.57
2009	6	25	12:15	3.6
2009	7	20	09:05	3.66
2009	8	20	10:20	3.49
2009	9	5	10:50	3.78
2009	10	5	23:00	3.61
2009	11	2	22:30	3.23
2009	12	3	23:20	3.25
2010	1	31	23:50	3.01
2010	2	2	00:45	3.02
2010	3	30	10:50	3.2
2010	4	29	11:00	3.2
2010	5	27	10:00	3.47
2010	6	13	11:10	3.47
2010	7	14	12:00	3.41
2010	8	11	11:15	3.51
2010	9	8	10:15	3.55
2010	10	8	10:45	3.78
2010	11	6	23:00	3.35
2010	12	9	00:35	3.14

YEAR	MONTH	DATE	TIME	HIGHEST
2011	1	20	23:30	3.2
2011	2	18	23:15	3.14
2011	3	20	11:00	3.32
2011	4	18	10:45	3.25
2011	5	18	11:05	3.34
2011	6	16	11:00	3.5
2011	7	16	10:55	3.41
2011	8	30	11:20	3.54
2011	9	1	00:15	3.4
2011	10	26	22:30	3.23
2011	11	24	22:15	3.08
2011	12	28	00:45	3.03
2012	1	9	23:30	2.9
2012	2	10	00:00	2.97
2012	3	10	12:00	3.14
2012	4	9	12:10	3.38
2012	5	6	10:45	3.32
2012	6	5	11:15	3.54
2012	7	3	10:00	3.6
2012	8	4	12:00	3.57
2012	9	17	23:30	3.54
2012	10	16	23:20	3.35
2012	11	14	23:00	3.34
2012	12	13	23:00	3.25
2013	1	11	22:50	3.09
2013	2	10	23:15	2.93
2013	3	29	12:00	2.97
2013	4	28	12:15	3.2
2013	5	26	11:20	3.58
2013	6	25	12:00	3.66
2013	7	24	11:40	3.55
2013	8	21	10:45	3.49
2013	9	6	11:00	3.45
2013	10	6	23:25	3.55
2013	11	4	23:15	3.25
2013	12	31	22:10	3.15
2014	1	2	23:55	3.29
2014	2	2	00:15	3.14
2014	3	31	11:30	3.17
2014	4	30	11:30	3.2
2014	5	28	10:15	3.37
2014	6	14	11:30	3.52
2014	7	13	11:15	3.83
2014	8	11	11:00	3.6
2014	9	8	10:00	3.44
2014	10	11	00:05	3.61
2014	11	7	23:15	3.41
2014	12	22	23:30	3.22
2015	1	21	23:45	3.22
2015	2	19	23:30	3.09
2015	3	20	23:10	3.14
2015	4	19	11:05	3.31
2015	5	19	11:30	3.34
2015	6	19	12:30	3.47
2015	7	3	11:30	3.43
2015	8	1	11:30	3.6
2015	9	1	12:30	3.51
2015	10	1	00:15	3.4
2015	11	26	23:10	3.28
2015	12	12	23:40	3.14

YEAR	MONTH	DATE	TIME	HIGHEST
2016	1	11	23:45	3.14
2016	2	11	00:15	3.16
2016	3	11	00:00	3.2
2016	4	7	23:30	3.44
2016	5	24	12:15	3.44
2016	6	5	10:50	3.6
2016	7	4	10:30	3.68
2016	8	17	10:30	3.7
2016	9	18	11:40	3.55
2016	10	2	23:25	4
2016	11	15	23:00	3.47
2016	12	14	23:00	3.31
2017	1	14	00:00	3.22
2017	2	27	23:45	3.06
2017	3	30	12:15	3.28
2017	4	25	22:15	3.29
2017	5	29	13:15	3.38
2017	6	13	12:45	3.72
2017	7	26	12:45	3.52
2017	8	23	11:45	3.5
2017	9	19	22:45	3.43
2017	10	20	23:30	3.7
2017	11	3	22:30	3.38
2017	12	4	23:30	3.38
2018	1	2	23:30	3.3
2018	2	1	23:50	3.23
2018	3	2	23:40	3.11
2018	4	18	12:20	3.18
2018	5	16	11:15	3.32
2018	6	14	11:05	3.44
2018	7	14	11:35	3.57
2018	8	14	13:05	3.63
2018	9	10	11:10	3.39
2018	10	10	23:50	3.5
2018	11	8	23:15	3.28
2018	12	23	23:30	3.32
2019	1	23	00:15	3.16
2019	2	21	00:00	3.18
2019	3	21	23:10	3.26
2019	4	21	12:10	3.15
2019	5	3	22:20	3.36
2019	6	21	13:10	3.49
2019	7	2	10:20	3.66
2019	8	2	11:40	3.64
2019	9	1	12:10	3.58
2019	10	1	00:00	3.39
2019	11	17	13:50	3.62
2019	12	3	14:40	3.18
2020	1	13	00:20	3.02
2020	2	11	00:00	2.98
2020	3	10	23:40	3.03
2020	4	9	11:30	3.27
2020	5	20	21:15	3.72
2020	6	5	10:20	3.45
2020	7	5	10:35	3.52
2020	8	20	11:40	3.79
2020	9	21	00:50	3.57
2020	10	22	02:00	3.52
2020	11	1	23:20	3.4
2020	12	13	22:00	3.2

3.4. Extracting yearly maximum or top three extreme tide elevations

Based on the above observed data, yearly maximum or top three extreme tide elevations for all target areas can be extracted manually and are shown as follows for each target area.

(1) Cox's Bazar

Table 3-11 Yearly maximum extreme tide elevations at Cox's Bazar (1983-2021)

Year	Max		Year	Max		Year	Max
1983	1.98		1996	2.52		2009	2.48
1984	2.02		1997	2.24		2010	2.65
1985	2.11		1998	2.19		2011	2.14
1986	2.36		1999	2.11		2012	1.76
1987	2.56		2000	2.23		2013	2.38
1988	2.06		2001	2.23		2014	2.09
1989	2.22		2002	2.22		2015	2.24
1990	2.14		2003	2.23		2016	2.04
1991	2.08		2004	2.29		2017	3.19
1992	2.20		2005	2.28		2018	2.27
1993	2.08		2006	2.18		2019	2.23
1994	1.71		2007	2.32		2020	2.36
1995	2.61		2008	2.47		2021	2.49

(2) Lemsikhali

Table 3-12 Yearly maximum extreme tide elevations at Lemsikhali (1969-2022)

Year	Max		Year	Max		Year	Max
1969	3.78		1987	2.9		2005	3.45
1970	3.99		1988	2.32		2006	3.4
1971	4.91		1989	0		2007	3.5
1972	4.9		1990	3.39		2008	2.25
1973	3.69		1991	3.72		2009	2.27
1974	4.08		1992	3.42		2010	2.22
1975	3.78		1993	3.22		2011	2.77
1976	3.62		1994	3.1		2012	2.62
1977	3.63		1995	3.85		2013	2.72
1978	3.41		1996	3.9		2014	2.82
1979	2.71		1997	4.2		2015	2.62
1980	0		1998	3.4		2016	3.81
1981	3.08		1999	3.45		2017	3.02
1982	3.18		2000	3.5		2018	2.77
1983	3.45		2001	3.4		2019	5.45
1984	3.25		2002	3.5		2020	4.21
1985	2.4		2003	3.5		2021	3.81
1986	2.71		2004	3.45		2022	3.39

Table 3-13 Yearly top three extreme tide elevations at Lemsikhali(1969-2022)

Year	Top 3 values
1969	3.78
1969	3.75
1969	3.6
1970	3.99
1970	3.93
1970	3.9
1971	4.91
1971	4.88
1971	4.75
1972	4.9
1972	4.69
1972	4.41
1973	3.69
1973	3.63
1973	3.6
1974	4.08
1974	3.75
1974	3.72
1975	3.78
1975	3.41
1975	3.35
1976	3.62
1976	3.57
1976	3.51
1977	3.63
1977	3.54
1977	3.51
1978	3.41
1978	3.41
1978	3.35
1979	2.71
1979	2.68
1979	2.67
1980	NO DATA
1980	NO DATA
1980	NO DATA
1981	3.08
1981	2.99
1981	2.99
1982	3.18
1982	3.08
1982	2.96
1983	3.45
1983	3.45
1983	3.37
1984	3.25
1984	3.25
1984	3.17
1985	2.4
1985	2.1
1985	1.92
1986	2.71
1986	2.62
1986	2.5
1987	2.9
1987	2.82
1987	2.8
1988	2.32
1988	2.2
1988	2
1989	NO DATA
1989	NO DATA
1989	NO DATA
1990	3.39
1990	3.29
1990	3.24
1991	3.72
1991	3.64
1991	3.62
1992	3.42
1992	3.32
1992	3.27
1993	3.22
1993	3.22
1993	3.12
1994	3.1
1994	3.02
1994	3.02
1995	3.85
1995	3.85
1995	3.75
1996	3.9
1996	3.8
1996	3.5
1997	4.2
1997	3.5
1997	3.3
1998	3.4
1998	3.35
1998	3.25
1999	3.45
1999	3.35
1999	3.35
2000	3.5
2000	3.45
2000	3.4
2001	3.4
2001	3.4
2001	3.35
2002	3.5
2002	3.45
2002	3.4
2003	3.5
2003	3.45
2003	3.45
2004	3.45
2004	3.45
2004	3.45
2005	3.45
2005	3.45
2005	3.4
2006	3.4
2006	3.4
2006	3.4
2007	3.5
2007	3.45
2007	3.45
2008	2.25
2008	2.22
2008	2.22
2009	2.27
2009	2.22
2009	2.22
2010	2.22
2010	2.22
2010	2.17
2011	2.77
2011	2.67
2011	2.47
2012	2.62
2012	2.62
2012	2.57
2013	2.72
2013	2.64
2013	2.62
2014	2.82
2014	2.82
2014	2.77
2015	2.62
2015	2.62
2015	2.62
2016	3.81
2016	3.67
2016	2.87
2017	3.02
2017	2.97
2017	2.82
2018	2.77
2018	2.72
2018	2.67
2019	5.45
2019	5.35
2019	4.98
2020	4.21
2020	4.21
2020	4.21
2021	3.81
2021	3.81
2021	3.66
2022	3.39
2022	3.19
2022	3.19

(3) Sadarghat

Table 3-14 Yearly maximum extreme tide elevations at Sadarghat (1980-2022)

Year	Max	Year	Max	Year	Max	Year	Max
1980	5.26	1991	5.19	2002	5.37	2013	5.30
1981	5.05	1992	5.04	2003	5.27	2014	5.50
1982	5.11	1993	5.87	2004	5.30	2015	5.78
1983	5.27	1994	5.34	2005	5.75	2016	5.93
1984	5.26	1995	5.52	2006	5.25	2017	5.93
1985	5.48	1996	5.20	2007	5.50	2018	5.72
1986	5.29	1997	5.41	2008	5.42	2019	5.43
1987	5.67	1998	5.43	2009	5.47	2020	5.66
1988	5.52	1999	5.43	2010	5.47	2021	5.61
1989	5.46	2000	5.75	2011	5.28	2022	5.98
1990	5.14	2001	5.38	2012	5.30		

Table 3-15 Yearly top three extreme tide elevations at Sadarghat(1980-2022)

Year	Top 3 values	Year	Top 3 values	Year	Top 3 values	Year	Top 3 values
1980	5.26	1990	4.98	2000	5.35	2011	5.28
1980	5.11	1990	4.92	2001	5.38	2011	5.18
1980	5.02	1991	5.19	2001	5.13	2011	5.18
1981	5.05	1991	5.10	2001	5.08	2012	5.30
1981	5.02	1991	5.08	2002	5.37	2012	5.25
1981	4.97	1992	5.04	2002	5.32	2012	5.20
1982	5.11	1992	4.89	2002	5.20	2013	5.30
1982	5.02	1992	4.88	2003	5.27	2013	5.30
1982	4.84	1993	5.87	2003	5.10	2013	5.25
1983	5.27	1993	5.74	2003	5.05	2014	5.50
1983	4.99	1993	5.63	2004	5.30	2014	5.33
1983	4.88	1994	5.34	2004	5.25	2014	5.28
1984	5.26	1994	5.33	2004	5.20	2015	5.78
1984	5.26	1994	5.30	2005	5.75	2015	5.73
1984	5.10	1995	5.52	2005	5.35	2015	5.63
1985	5.48	1995	5.20	2005	5.20	2016	5.93
1985	5.46	1995	5.20	2006	5.25	2016	5.68
1985	5.20	1996	5.20	2006	5.22	2016	5.58
1986	5.29	1996	5.20	2006	5.12	2017	5.93
1986	4.95	1996	5.05	2007	5.50	2017	5.73
1986	4.86	1997	5.41	2007	5.33	2017	5.72
1987	5.67	1997	5.21	2007	5.27	2018	5.72
1987	5.44	1997	4.81	2008	5.42	2018	5.62
1987	5.24	1998	5.43	2008	5.40	2018	5.57
1988	5.52	1998	5.33	2008	5.30	2019	5.43
1988	5.43	1998	5.25	2009	5.47	2019	4.59
1988	5.36	1999	5.43	2009	5.26	2019	4.44
1989	5.46	1999	5.18	2009	5.20	2020	5.66
1989	5.39	1999	5.01	2010	5.47	2021	5.61
1989	5.18	2000	5.75	2010	5.19	2022	5.98
1990	5.14	2000	5.44	2010	5.17		

(4) Sandwip

Table 3-16 Yearly maximum extreme tide elevations at Sandwip (1977-2022)

Year	Max	Year	Max	Year	Max
1977	6.66	1996	7.9	2010	8.01
1978	6.63	1997	7.35	2011	7.16
1979	7.08	1998	7.75	2012	7.83
1980	6.84	1999	7.41	2013	7.97
1981	6.52	2000	7.84	2014	7.91
1982	6.58	2001	7.45	2015	7.72
1983	6.7	2002	7.46	2016	8.57
1984	7.12	2003	7.47	2017	6.97
1985	7.07	2004	7.75	2018	6.72
1986	7.49	2005	7.07	2019	5.47
1987	7.33	2006	6.58	2020	8.313
1988	8.2	2007	7.88	2021	7.72
1989	7.38	2008	7.84	2022	8.244
1990	7.79	2009	7.34		

Table 3-17 Yearly top three extreme tide elevations at Sandwip (1977-2022)

Year	Top 3 values	Year	Top 3 values	Year	Top 3 values
1977	6.66	1991	NO DATA	2005	7.07
1977	6.62	1991	NO DATA	2005	6.88
1977	6.43	1991	NO DATA	2005	6.88
1978	6.63	1992	NO DATA	2006	6.58
1978	6.6	1992	NO DATA	2006	6.38
1978	6.5	1992	NO DATA	2006	6.34
1979	7.08	1993	NO DATA	2007	7.88
1979	6.86	1993	NO DATA	2007	7.27
1979	6.83	1993	NO DATA	2007	7.21
1980	6.84	1994	NO DATA	2008	7.84
1980	6.68	1994	NO DATA	2008	7.69
1980	6.51	1994	NO DATA	2008	7.21
1981	6.52	1995	NO DATA	2009	7.34
1981	6.51	1995	NO DATA	2009	7.04
1981	6.49	1995	NO DATA	2009	6.89
1985	6.56	1999	7.24	2013	7.65
1986	7.49	2000	7.84	2014	7.91
1986	7.05	2000	7.79	2014	7.66
1986	6.97	2000	7.39	2014	7.46
1987	7.33	2001	7.45	2015	7.72
1987	7.18	2001	7.33	2015	7.54
1987	7.11	2001	7.14	2015	7.53
1988	8.2	2002	7.46	2016	8.57
1988	7.26	2002	6.99	2016	7.92
1988	7.16	2002	6.98	2016	7.72
1989	7.38	2003	7.47	2017	6.97
1989	7.09	2003	7.31	2018	6.72
1989	7.07	2003	7.27	2019	5.47
1990	7.79	2004	7.75	2020	8.313
1990	7.71	2004	7.65	2021	7.72
1990	7.37	2004	7.51	2022	8.244

(5) Hatiya

Table 3-18 Yearly maximum extreme tide elevations at Hatiya (1968-2024)

Year	Max		Year	Max		Year	Max
1968	4.82		1987	4.37		2006	4.37
1969	5.20		1988	4.59		2007	3.93
1970	5.18		1989	3.98		2008	4.36
1971	5.82		1990	4.53		2009	4.37
1972	4.88		1991	4.60		2010	4.49
1973	4.48		1992	4.39		2011	4.27
1974	5.18		1993	5.00		2012	4.18
1975	4.70		1994	4.72		2013	3.97
1976	4.48		1995	6.12		2014	4.28
1977	4.76		1996	5.04		2015	3.95
1978	3.49		1997	5.06		2016	4.30
1979	5.09		1998	5.50		2017	4.41
1980	5.03		1999	5.01		2018	4.38
1981	4.97		2000	4.72		2019	4.44
1982	3.52		2001	4.78		2020	4.40
1983	4.36		2002	4.72		2021	3.10
1984	4.86		2003	4.55		2022	2.80
1985	5.02		2004	4.52		2023	2.85
1986	4.59		2005	4.48		2024	3.08

Table 3-19 Yearly top three extreme tide elevations at Hatiya (1968-2024)

Year	Top 3 values	Year	Top 3 values	Year	Top 3 values
1968	4.82	1987	4.37	2006	4.37
1968	4.79	1987	4.31	2006	4.18
1968	4.42	1987	4.21	2006	4.01
1969	5.20	1988	4.59	2007	3.93
1969	4.73	1988	4.40	2007	3.81
1969	4.64	1988	4.01	2007	3.63
1970	5.18	1989	3.98	2008	4.36
1970	5.15	1989	3.89	2008	3.61
1970	4.70	1989	3.86	2008	3.55
1971	5.82	1990	4.53	2009	4.37
1971	5.79	1990	4.48	2009	4.04
1971	5.61	1990	4.22	2009	3.79
1972	4.88	1991	4.60	2010	4.49
1972	4.61	1991	4.19	2010	3.98
1972	4.61	1991	3.92	2010	3.91
1973	4.48	1992	4.39	2011	4.27
1973	4.25	1992	4.12	2011	4.18
1973	4.13	1992	4.12	2011	4.09
1974	5.18	1993	5.00	2012	4.18
1974	4.50	1993	4.18	2012	4.18
1974	4.40	1993	4.18	2012	3.88
1975	4.70	1994	4.72	2013	3.97
1975	4.44	1994	4.51	2013	3.88
1975	4.16	1994	4.36	2013	3.81
1976	4.48	1995	6.12	2014	4.28
1976	4.47	1995	4.92	2014	4.04
1976	4.35	1995	4.69	2014	3.80
1977	4.76	1996	5.04	2015	3.95
1977	4.61	1996	4.84	2015	3.92
1977	4.39	1996	4.63	2015	3.77
1978	3.49	1997	5.06	2016	4.30
1978	3.33	1997	4.78	2016	4.13
1978	3.04	1997	4.54	2016	4.13
1979	5.09	1998	5.50	2017	4.41
1979	4.94	1998	5.50	2017	4.36
1979	4.73	1998	4.88	2017	4.35
1980	5.03	1999	5.01	2018	4.38
1980	4.62	1999	4.69	2018	4.19
1980	4.62	1999	4.61	2018	4.01
1981	4.97	2000	4.72	2019	4.44
1981	4.88	2000	4.63	2019	4.25
1981	4.67	2000	4.46	2019	4.19
1982	3.52	2001	4.78	2020	4.40
1982	3.05	2001	4.57	2020	4.28
1982	3.04	2001	4.38	2020	4.10
1983	4.36	2002	4.72	2021	3.10
1983	4.06	2002	4.48	2021	2.92
1983	3.75	2002	4.30	2021	2.90
1984	4.86	2003	4.55	2022	2.80
1984	4.71	2003	4.38	2022	2.66
1984	4.34	2003	4.28	2022	2.34
1985	5.02	2004	4.52	2023	2.85
1985	4.47	2004	4.46	2023	2.36
1985	4.41	2004	4.33	2023	2.28
1986	4.59	2005	4.48	2024	3.08
1986	4.26	2005	4.45	2024	2.60
1986	4.19	2005	4.42	2024	2.51

(6) Charchenga

Table 3-20 Yearly maximum extreme tide elevations at Charchenga (1980-2022)

Year	Max	Year	Max	Year	Max
1980	4.56	2001	4.73	2013	4.77
1981	4.56	2002	5.72	2014	4.94
1982	4.31	2003	4.24	2015	4.86
1983	4.42	2004	4.38	2016	4.73
1984	4.87	2005	4.43	2017	4.94
1985	4.91	2006	4.43	2018	4.99
1986	4.89	2007	4.99	2019	4.952
1987	4.85	2008	4.61	2020	5.462
1988	4.59	2009	5.09	2021	5.512
1989	4.9	2010	4.9	2022	5.512
1990	4.64	2011	4.58		
2000	4.77	2012	4.7		

Table 3-21 Yearly top three extreme tide elevations at Charchenga (1980-2022)

Year	Top 3 values	Year	Top 3 values	Year	Top 3 values	Year	Top 3 values
1980	4.56	1991	NO DATA	2002	5.72	2013	4.77
1980	4.42	1991	NO DATA	2002	4.65	2013	4.67
1980	4.26	1991	NO DATA	2002	4.36	2013	4.67
1981	4.56	1992	NO DATA	2003	4.24	2014	4.94
1981	4.53	1992	NO DATA	2003	4.22	2014	4.76
1981	4.38	1992	NO DATA	2003	4.17	2014	4.71
1982	4.31	1993	NO DATA	2004	4.38	2015	4.86
1982	4.2	1993	NO DATA	2004	4.33	2015	4.8
1982	4.17	1993	NO DATA	2004	4.31	2015	4.6
1983	4.42	1994	NO DATA	2005	4.43	2016	4.73
1983	4.38	1994	NO DATA	2005	4.34	2016	4.7
1983	4.17	1994	NO DATA	2005	4.26	2016	4.56
1984	4.87	1995	NO DATA	2006	4.43	2017	4.94
1984	4.73	1995	NO DATA	2006	4.36	2017	4.89
1984	4.54	1995	NO DATA	2006	4.32	2017	4.71
1985	4.91	1996	NO DATA	2007	4.99	2018	4.99
1985	4.88	1996	NO DATA	2007	4.51	2018	4.94
1985	4.29	1996	NO DATA	2007	4.4	2018	4.84
1986	4.89	1997	NO DATA	2008	4.61	2019	4.952
1986	4.49	1997	NO DATA	2008	4.61	2020	5.462
1986	4.34	1997	NO DATA	2008	4.47	2021	5.512
1987	4.85	1998	NO DATA	2009	5.09	2022	5.512
1987	4.43	1998	NO DATA	2009	4.35		
1987	4.41	1998	NO DATA	2009	4.31		
1988	4.59	1999	NO DATA	2010	4.9		
1988	4.47	1999	NO DATA	2010	4.45		
1988	4.38	1999	NO DATA	2010	4.43		
1989	4.9	2000	4.77	2011	4.58		
1989	4.85	2000	4.72	2011	4.52		
1989	4.69	2000	4.52	2011	4.48		
1990	4.64	2001	4.73	2012	4.7		
1990	4.48	2001	4.47	2012	4.63		
1990	4.38	2001	4.27	2012	4.5		

(7) Patharghata

Table 3-22 Yearly maximum extreme tide elevations at Patharghata(1958-2024)

Year	Max	Year	Max	Year	Max
1958	1.52	1980	1.62	2002	2.16
1959	1.45	1981	1.77	2003	2.40
1960	1.36	1982	2.24	2004	2.43
1961	1.25	1983	1.43	2005	2.73
1962	1.34	1984	2.50	2006	3.95
1963	1.15	1985	2.00	2007	2.65
1964	1.40	1986	1.70	2008	2.27
1965	0.48	1987	1.56	2009	3.15
1966	NO DATA	1988	1.55	2010	2.85
1967	NO DATA	1989	2.00	2011	2.85
1968	1.45	1990	2.10	2012	2.66
1969	1.85	1991	1.75	2013	2.75
1970	2.28	1992	2.10	2014	2.80
1971	1.44	1993	1.88	2015	2.55
1972	1.31	1994	1.78	2016	2.60
1973	1.93	1995	2.45	2017	2.63
1974	1.68	1996	2.19	2018	2.75
1975	1.61	1997	2.05	2019	2.30
1976	1.41	1998	2.09	2020	2.95
1977	1.45	1999	2.03	2021	3.08
1978	1.74	2000	2.23	2022	3.10
1979	2.08	2001	2.30	2023	2.42
				2024	2.55

Table 3-23 Yearly top three extreme tide elevations at Patharghata (1958-2024)

Year	Top 3 values	Year	Top 3 values	Year	Top 3 values	Year	Top 3 values
1958	1.52	1974	1.33	1991	1.74	2008	2.27
1958	1.28	1975	1.61	1991	1.72	2008	2.25
1958	1.07	1975	1.55	1992	2.10	2008	2.03
1959	1.45	1975	1.47	1992	2.05	2009	3.15
1959	1.42	1976	1.41	1992	1.94	2009	2.43
1959	1.30	1976	1.41	1993	1.88	2009	2.30
1960	1.36	1976	1.26	1993	1.73	2010	2.85
1960	1.26	1977	1.45	1993	1.66	2010	2.40
1960	1.19	1977	1.45	1994	1.78	2010	2.15
1961	1.25	1977	1.36	1994	1.76	2011	2.85
1961	1.22	1978	1.74	1994	1.76	2011	2.45
1961	1.19	1978	1.74	1995	2.45	2011	2.40
1962	1.34	1978	1.74	1995	2.25	2012	2.66
1962	1.31	1979	2.08	1995	2.20	2012	2.60
1962	1.25	1979	1.38	1996	2.19	2012	2.55
1963	1.15	1979	1.38	1996	2.08	2013	2.75
1963	1.15	1980	1.62	1996	2.03	2013	2.70
1963	1.09	1980	1.50	1997	2.05	2013	2.55
1964	1.40	1980	1.35	1997	1.98	2014	2.80
1964	1.34	1981	1.77	1997	1.85	2014	2.60
1964	1.25	1981	1.65	1998	2.09	2014	2.40
1965	0.48	1981	1.59	1998	2.07	2015	2.55
1965	0.15	1982	2.24	1998	2.04	2015	2.50
1965	0.12	1982	1.81	1999	2.03	2015	2.47
1966	NO DATA	1982	1.55	1999	2.03	2016	2.60
1966	NO DATA	1983	1.43	1999	1.88	2016	2.53
1966	NO DATA	1983	1.07	2000	2.23	2016	2.52
1967	NO DATA	1983	1.03	2000	2.21	2017	2.63
1967	NO DATA	1984	2.50	2000	1.92	2017	2.60
1967	NO DATA	1984	2.40	2001	2.30	2017	2.45
1968	1.45	1984	1.56	2001	1.80	2018	2.75
1968	1.42	1985	2.00	2001	1.80	2018	2.75
1968	1.27	1985	1.70	2002	2.16	2018	2.68
1969	1.85	1985	1.60	2002	2.02	2019	2.30
1969	1.39	1986	1.70	2002	1.98	2019	2.17
1969	1.33	1986	1.40	2003	2.40	2019	2.10
1970	2.28	1986	1.30	2003	2.20	2020	2.95
1970	1.56	1987	1.56	2003	2.15	2020	2.35
1970	1.35	1987	1.40	2004	2.43	2020	2.22
1971	1.44	1987	1.36	2004	2.36	2021	3.08
1971	1.33	1988	1.55	2004	2.35	2021	2.53
1971	1.32	1988	1.53	2005	2.73	2021	2.48
1972	1.31	1988	1.30	2005	2.51	2022	3.10
1972	1.29	1989	2.00	2005	2.26	2022	2.70
1972	1.23	1989	1.66	2006	3.95	2022	2.60
1973	1.93	1989	1.65	2006	2.60	2023	2.42
1973	1.44	1990	2.10	2006	1.87	2023	2.15
1973	1.26	1990	2.08	2007	2.65	2023	2.12
1974	1.68	1990	1.88	2007	2.65	2024	2.55
1974	1.36	1991	1.75	2007	2.55	2024	2.05
						2024	1.95

(8) Khepupara

Table 3-24 Yearly maximum extreme tide elevations at Khepupara (1977-2024)

Year	Max	Year	Max	Year	Max	Year	Max
1977	2.26	1989	1.97	2001	1.78	2013	1.97
1978	1.70	1990	2.28	2002	2.24	2014	0.53
1979	2.64	1991	1.96	2003	2.02	2015	2.31
1980	1.52	1992	1.94	2004	2.03	2016	NO DATA
1981	1.65	1993	1.71	2005	2.18	2017	2.04
1982	1.63	1994	1.97	2006	2.18	2018	1.51
1983	1.22	1995	2.42	2007	2.32	2019	1.77
1984	1.60	1996	2.09	2008	2.18	2020	2.46
1985	1.80	1997	2.38	2009	1.69	2021	2.68
1986	2.11	1998	1.78	2010	2.01	2022	2.65
1987	1.79	1999	1.74	2011	1.86	2023	2.38
1988	1.81	2000	2.07	2012	1.86	2024	2.92

Table 3-25 Yearly top three extreme tide elevations at Khepupara (1977-2024)

Year	Top 3 values	Year	Top 3 values	Year	Top 3 values	Year	Top 3 values
1977	2.26	1989	1.97	2001	1.78	2013	1.97
1977	2.08	1989	1.71	2001	1.58	2013	1.86
1977	2.06	1989	1.70	2001	1.58	2013	1.69
1978	1.70	1990	2.28	2002	2.24	2014	0.53
1978	1.61	1990	2.21	2002	2.14	2014	0.51
1978	1.60	1990	2.00	2002	1.69	2014	0.43
1979	2.64	1991	1.96	2003	2.02	2015	2.31
1979	1.99	1991	1.84	2003	1.83	2015	2.09
1979	1.74	1991	1.67	2003	1.71	2015	2.04
1980	1.52	1992	1.94	2004	2.03	2016	NO DATA
1980	1.45	1992	1.70	2004	2.01	2016	NO DATA
1980	1.37	1992	1.62	2004	1.96	2016	NO DATA
1981	1.65	1993	1.71	2005	2.18	2017	2.04
1981	1.59	1993	1.60	2005	1.85	2017	1.92
1981	1.56	1993	1.52	2005	1.83	2017	1.83
1982	1.63	1994	1.97	2006	2.18	2018	1.51
1982	1.49	1994	1.67	2006	1.84	2018	1.32
1982	1.48	1994	1.66	2006	1.56	2018	1.22
1983	1.22	1995	2.42	2007	2.32	2019	1.77
1983	1.17	1995	1.97	2007	1.94	2019	1.73
1983	1.08	1995	1.77	2007	1.47	2019	1.68
1984	1.60	1996	2.09	2008	2.18	2020	2.46
1984	1.47	1996	1.83	2008	1.95	2020	2.45
1984	1.44	1996	1.74	2008	1.86	2020	2.23
1985	1.80	1997	2.38	2009	1.69	2021	2.68
1985	1.43	1997	2.23	2009	1.34	2021	2.27
1985	1.26	1997	1.83	2009	1.28	2021	2.26
1986	2.11	1998	1.78	2010	2.01	2022	2.65
1986	1.75	1998	1.61	2010	1.56	2022	2.55
1986	1.70	1998	1.57	2010	1.52	2022	2.44
1987	1.79	1999	1.74	2011	1.86	2023	2.38
1987	1.61	1999	1.73	2011	1.70	2023	2.13
1987	1.35	1999	1.69	2011	1.55	2023	2.13
1988	1.81	2000	2.07	2012	1.86	2024	2.92
1988	1.75	2000	1.89	2012	1.82	2024	2.28
1988	1.62	2000	1.88	2012	1.80	2024	2.20

(9) Hiron Point

Table 3-26 Yearly maximum extreme tide elevations at Hiron Point (1991-2022)

Year	Max	Year	Max
1991	3.65	2007	3.66
1992	3.72	2008	4.43
1993	3.59	2009	4.57
1994	3.47	2010	3.78
1995	3.78	2011	3.54
1996	3.82	2012	3.6
1997	3.68	2013	3.66
1998	3.66	2014	3.83
1999	3.62	2015	3.6
2000	4.02	2016	4
2001	3.96	2017	3.72
2002	3.57	2018	3.63
2003	3.86	2019	3.66
2004	3.79	2020	3.79
2005	3.9	2021	4.17
2006	3.66	2022	3.98

Table 3-27 Yearly top three extreme tide elevations at Hiron Point (1991-2022)

Year	Top 3 values	Year	Top 3 values	Year	Top 3 values	Year	Top 3 values
1991	3.65	2000	4.02	2009	4.57	2018	3.63
1991	3.54	2000	3.96	2009	3.78	2018	3.57
1991	3.51	2000	3.64	2009	3.66	2018	3.5
1992	3.72	2001	3.96	2010	3.78	2019	3.66
1992	3.63	2001	3.66	2010	3.55	2019	3.64
1992	3.6	2001	3.61	2010	3.51	2019	3.62
1993	3.59	2002	3.57	2011	3.54	2020	3.79
1993	3.45	2002	3.47	2011	3.5	2020	3.72
1993	3.43	2002	3.43	2011	3.41	2020	3.57
1994	3.47	2003	3.86	2012	3.6	2021	4.17
1994	3.46	2003	3.69	2012	3.57	2021	3.72
1994	3.43	2003	3.63	2012	3.54	2021	3.7
1995	3.78	2004	3.79	2013	3.66	2022	3.98
1995	3.72	2004	3.78	2013	3.58		
1995	3.66	2004	3.64	2013	3.55		
1996	3.82	2005	3.9	2014	3.83		
1996	3.63	2005	3.63	2014	3.61		
1996	3.57	2005	3.6	2014	3.6		
1997	3.68	2006	3.66	2015	3.6		
1997	3.46	2006	3.51	2015	3.51		
1997	3.43	2006	3.41	2015	3.47		
1998	3.66	2007	3.66	2016	4		
1998	3.59	2007	3.61	2016	3.7		
1998	3.57	2007	3.6	2016	3.68		
1999	3.62	2008	4.43	2017	3.72		
1999	3.57	2008	3.9	2017	3.7		
1999	3.37	2008	3.58	2017	3.52		

3.5. Extreme Value Statistical Analysis

Given that the observed tide data represent the maximum values recorded each month, two distinct approaches for statistical analysis are considered. The first method involves extracting the highest yearly tide value and performing a statistical analysis to determine probabilistic values. The second method entails extracting the three highest monthly tide values for each year and calculating the statistical values based on this data.

3.6. Explanation of Extreme Value Statistical Analysis

Extreme value statistical analysis is an attempt to use statistical methods to estimate from data how often events of a scale that exceeds those previously experienced or those experienced in the past occur. The reason for using extreme values is that risk generally occurs when abnormally large (or abnormally small) values are observed, so the variation of very large (or very small) values is important, not the average of all observed data. By fitting these extreme values to a mathematical equation and reproducing the data appropriately, we can predict the variability of such anomalies as “the probability that a large value will appear once on average over a long period of time or over a large area”. The fitting method is to take the largest values of the observed data, mechanically order them in order of size, transform the order into a function of the reproduction period, and find a function that fits them. Theoretically, the functional form of the extreme value distribution can be one of three types: Gumbel, Fréchet, and Weibull distributions.

Extreme Value Type I distribution (Gumbel), Extreme Value Type II distribution (Fréchet) (k=2.50, 3.33, 5.00, 10.00) and Weibull distribution (k=0.75, 1.00, 1.40, 2.00) are shown below.

① Extreme Value Type I (Gumbel) $F(x) = \exp\left[-\exp\left(-\frac{x-B}{A}\right)\right]$ $: -\infty < x < \infty$

② Extreme Value Type II (Fréchet) $F(X) = \exp\left[-\left(1+\frac{x-B}{kA}\right)^{-k}\right]$ $: B - kA \leq x \leq \infty$

③ Weibull $F(x) = 1 - \exp\left[-\left(\frac{x-B}{A}\right)^{k}\right]$ $: B \leq x < \infty$

Here,

x: Maximum significant wave height for each event

F(x): function representing the non-exceedance probability (extreme value distribution function)

A, B and k: parameters of the distribution function (scale parameter, location parameter, shape parameter)

In practice, among the distributions that satisfy the rejection criteria (DOL and REC criteria) for these extreme value distributions, the distribution with the smallest MIR criterion (ratio of the residuals of the correlation coefficient to the mean of the residuals of the correlation coefficient) shall be adopted.

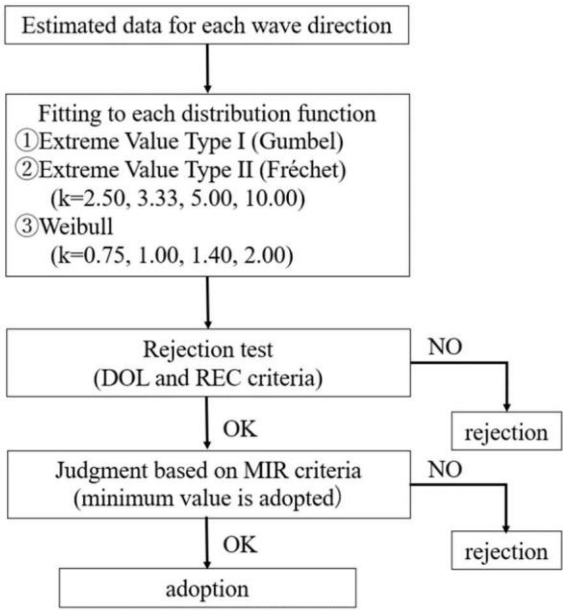


Figure 3-3 Flowchart of adoption

Source: JICA Expert Team

3.7. Setting Target Storm Surge Level for Each Target Area

By integrating the estimated maximum storm surge height obtained by simulation from the tropical cyclones and highest astronomical tide level (MSL + extreme tide elevation from the analysis), total estimated storm surge elevation of target coast can be evaluated.

4. Results of Tide Probability Analysis for Other Coastal Area

Considering that the same analysis provided in Calculation Manual, the analysis results for all nine target areas (Cox's Bazar, Lemsikhali, Sadarghat, Sandwip, Hatiya, Charchenga, Patharghata, Khepupara, and Hiron Point) are indicated as follows.

Table 4-1 Target Stations and their properties

No.	STATION	RIVER	Lat	Long
1	Cox's Bazar	Bakkhali	21.46	91.97
2	Lemsikhali	Kutubdia	21.81	91.88
3	Sadarghat	Karnaphuli	22.25	91.83
4	Sandwip	Satalkhal	22.47	91.46
5	Hatiya	Hatiya	22.25	91.14
6	Charchenga	Shahbazpuri	22.22	91.05
7	Patharghata	Bishkhali	22.01	89.96
8	Khepupara	Nilganj	21.83	89.83
9	Hiron Point	Pussur	21.78	89.47

4.1 Cox's Bazar

(1) Results based on yearly top highest tide data

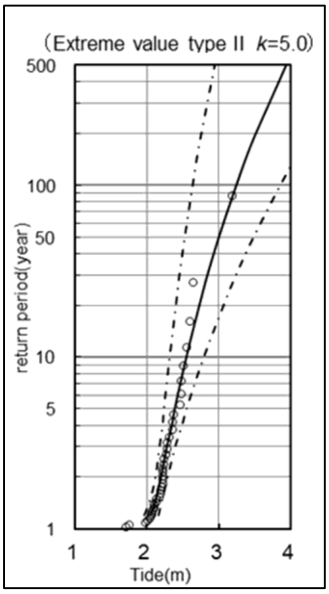


Table 4-2 Result of Tide Statistical Analysis at Cox's Bazar for different return period (Method

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.749	2.39
10	2.842	2.55
15	3.535	2.65
20	4.056	2.73
25	4.480	2.79
30	4.838	2.84
50	5.912	3.00
100	7.547	3.24
150	8.611	3.39
200	9.420	3.51

Figure 4-1 Tide Probabilistic values at Cox's Bazar station relevant to different return periods based on yearly top highest tide data by Plot Graph (Method 1)

4.2 Lemsikhali

(1) Results based on yearly top highest tide data

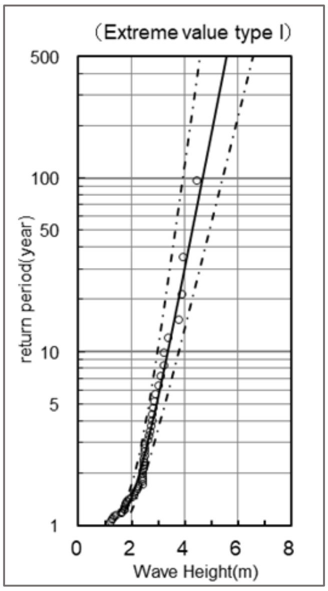


Table 4-3 Result of Tide Statistical Analysis at Lemsikhali for different return period (Method

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.458	2.95
10	2.211	3.37
15	2.635	3.60
20	2.931	3.77
25	3.160	3.90
30	3.346	4.00
50	3.864	4.29
100	4.562	4.68
150	4.969	4.91
200	5.258	5.07

Figure 4-2 Tide Probabilistic values at Lemsikhali station relevant to different return periods based on yearly top highest tide elevations by Plot Graph (Method 1)

(2) Results based on yearly top three highest tide data

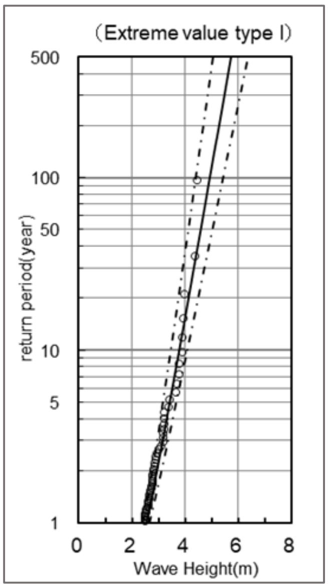


Table 4-4 Result of Tide Statistical Analysis at Lemsikhali for different return period (Method 2)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	3.014	3.21
10	3.974	3.57
15	4.561	3.79
20	4.990	3.96
25	5.331	4.08
30	5.615	4.19
50	6.437	4.50
100	7.620	4.94
150	8.350	5.22
200	8.886	5.42

Figure 4-3 Tide Probabilistic values at Lemsikhali station relevant to different return periods based on yearly three highest tide elevations by Plot Graph (Method 2)

4.3 Sadarghat

(1) Results based on yearly top highest tide data

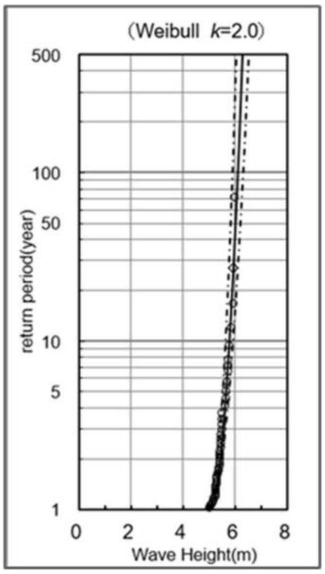


Table 4-5 Result of Tide Statistical Analysis at Sadarghat for different return period (Method 1)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.269	5.65
10	1.517	5.78
15	1.646	5.85
20	1.731	5.89
25	1.794	5.92
30	1.844	5.95
50	1.978	6.02
100	2.146	6.11
150	2.238	6.16
200	2.302	6.19

Figure 4-4 Tide probabilistic values at Sadarghat Station relevant to different return periods based on yearly top highest tide data by Plot Graph (Method 1)

(2) Results based on yearly top highest tide data

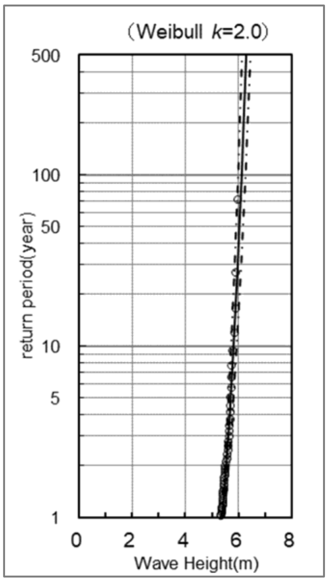


Table 4-6 Result of Tide Statistical Analysis at Sadarghat for different return period (Method 2)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.631	5.71
10	1.831	5.82
15	1.939	5.88
20	2.012	5.92
25	2.066	5.95
30	2.110	5.98
50	2.228	6.04
100	2.378	6.13
150	2.462	6.17
200	2.520	6.20

Figure 4-5 Tide probabilistic values at Sadarghat Station relevant to different return periods based on yearly three highest tide data by Plot Graph (Method 2)

4.4 Sandwip

(1) Result based on yearly top highest tide data

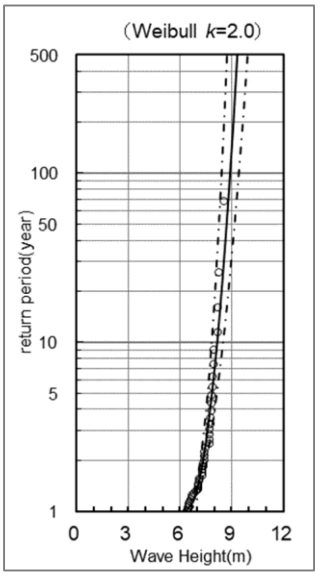


Table 4-7 Result of Tide Statistical Analysis at Sandwip for different return period (Method 1)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.269	7.80
10	1.517	8.09
15	1.646	8.23
20	1.731	8.33
25	1.794	8.40
30	1.844	8.46
50	1.978	8.61
100	2.146	8.81
150	2.238	8.91
200	2.302	8.98

Figure 4-6 Tide probabilistic values at Sandwip Station relevant to different return periods based on yearly top highest tide data by Plot Graph (Method 1)

(2) Result based on yearly top three highest tide

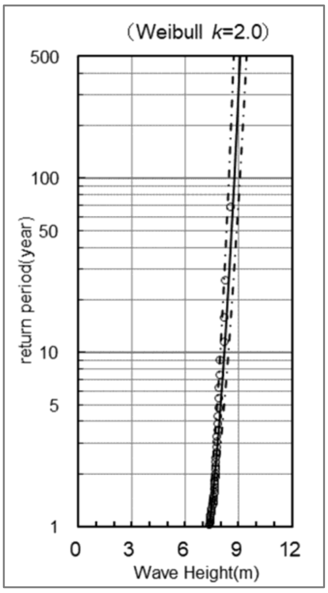


Table 4-8 Result of Tide Statistical Analysis at Sandwip for different return period (Method 2)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.629	7.93
10	1.830	8.12
15	1.937	8.22
20	2.010	8.29
25	2.065	8.34
30	2.108	8.38
50	2.226	8.49
100	2.377	8.63
150	2.461	8.70
200	2.519	8.76

Figure 4-7 Tide probabilistic values at Sandwip Station relevant to different return periods based on yearly three highest tide data by Plot Graph (Method 2)

4.5 Hatiya

(1) Results based on yearly top highest tide data

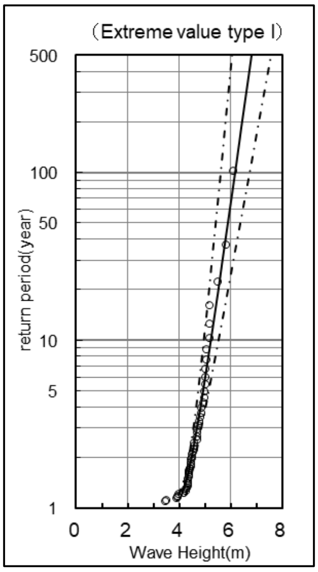


Table 4-9 Result of Tide Statistical Analysis at Hatiya for different return period (Method 1)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.500	4.94
10	2.250	5.24
15	2.674	5.41
20	2.970	5.53
25	3.199	5.62
30	3.384	5.69
50	3.902	5.90
100	4.600	6.18
150	5.007	6.34
200	5.296	6.45

Figure 4-8 Tide probabilistic values at Hatiya Station relevant to different return Periods based on yearly top highest data by Plot Graph (Method 1)

(2) Results based on yearly top three highest tide data

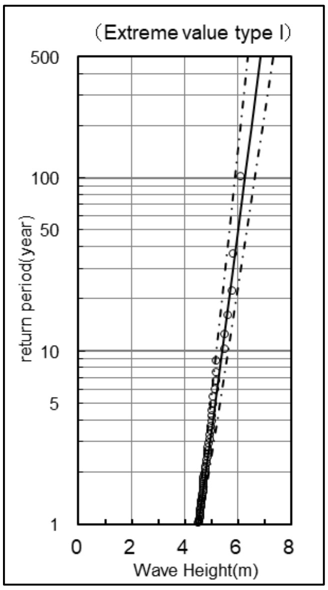


Table 4-10 Results of Tide Statistical Analysis at Hatiya for different return period (Method 2)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	2.674	5.15
10	3.384	5.41
15	3.795	5.56
20	4.086	5.67
25	4.311	5.75
30	4.494	5.82
50	5.007	6.01
100	5.702	6.26
150	6.108	6.41
200	6.396	6.52

Figure 4-9 Tide probabilistic values at Hatiya Station relevant to different return periods based on yearly three top highest tide data by Plot Graph (Method 2)

4.6 Charchenga

(1) Results based on yearly top highest tide data

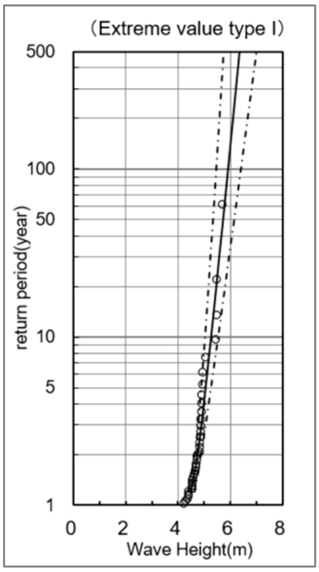


Table 4-11 Result of Tide Statistical Analysis at Charchenga for different return period (Method 1)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.500	5.07
10	2.250	5.28
15	2.674	5.40
20	2.970	5.48
25	3.199	5.54
30	3.384	5.59
50	3.902	5.74
100	4.600	5.93
150	5.007	6.04
200	5.296	6.12

Figure 4-10 Tide Probabilistic values at Charchenga station relevant to different return periods based on yearly top highest tide data by Plot Graph (Method 1)

(2) Results based on yearly top three highest tide data

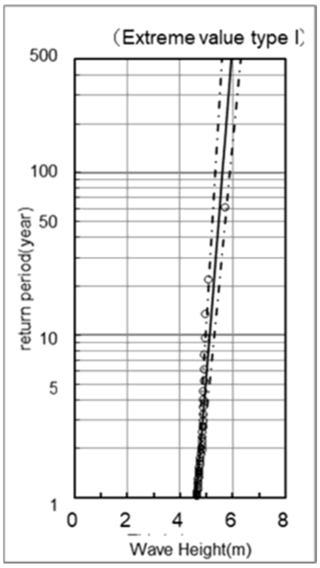


Table 4-12 Result of Tide Statistical Analysis at Charchenga for different return period (Method 2)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	2.589	4.98
10	3.301	5.13
15	3.713	5.22
20	4.004	5.28
25	4.229	5.32
30	4.412	5.36
50	4.925	5.47
100	5.620	5.61
150	6.026	5.70
200	6.314	5.76

Figure 4-11 Tide Probabilistic values at Charchenga station relevant to different return periods based on yearly three highest tide elevations by Plot Graph (Method 2)

4.7 Patharghata

(1) Results based on yearly top highest tide data

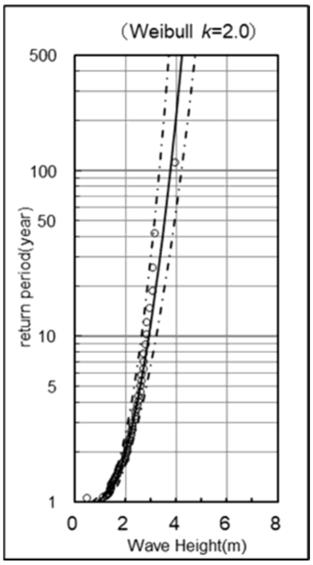


Table 4-13 Results of Tide Statistical Analysis at Pathargahta for different return period (Method 1)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.269	2.58
10	1.517	2.92
15	1.646	3.09
20	1.731	3.20
25	1.794	3.29
30	1.844	3.36
50	1.978	3.54
100	2.146	3.77
150	2.238	3.89
200	2.302	3.98

Figure 4-12 Tide probabilistic values at Patharghata Station relevant to different return periods based on yearly top highest data by Plot Graph（Method 1）

(2) Results based on yearly top three highest data

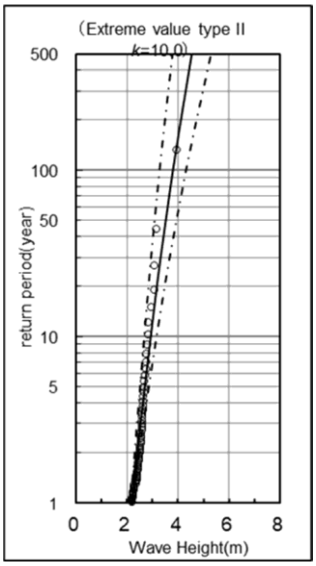


Table 4-14 Results of Tide Statistical Analysis at Patharghata for different return period (Method 2)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	3.038	2.69
10	3.999	2.92
15	4.587	3.06
20	5.017	3.16
25	5.358	3.24
30	5.642	3.31
50	6.466	3.51
100	7.651	3.79
150	8.382	3.97
200	8.919	4.10

Figure 4-13 Tide probabilistic values at Patharghata Station relevant to different return periods based on yearly top three highest data by Plot Graph (Method 2)

4.8 Khepupara

(1) Results based on yearly top highest tide data

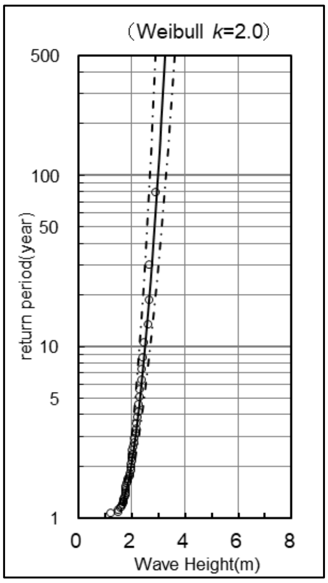


Table 4-15 Result of Tide Statistical Analysis at Khepupara for different return period (Method 1)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.260	2.30
10	1.510	2.49
15	1.639	2.59
20	1.725	2.66
25	1.788	2.71
30	1.839	2.75
50	1.973	2.85
100	2.141	2.98
150	2.234	3.06
200	2.297	3.10

Figure 4-14 Tide probabilistic values at Khepupara Station relevant to different return periods based on yearly top highest tide data by Plot Graph (Method 1)

(2) Results based on yearly top three highest tide

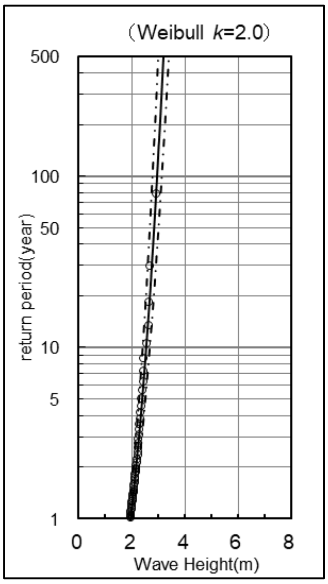


Table 4-16 Result of Tide Statistical Analysis at Khepupara for different return period (Method 2)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.639	2.39
10	1.839	2.54
15	1.946	2.62
20	2.018	2.68
25	2.073	2.72
30	2.116	2.75
50	2.234	2.84
100	2.384	2.95
150	2.467	3.01
200	2.525	3.06

Figure 4-15 Tide probabilistic values at Khepupara Station relevant to different return periods based on yearly three highest tide data by Plot Graph (Method 2)

4.9 Hiron Point

(1) Results based on yearly top highest tide data

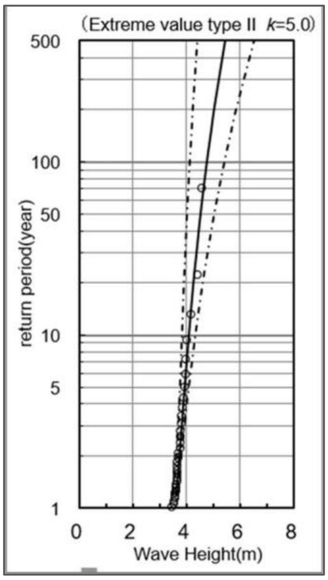


Table 4-17 Result of Tide Statistical Analysis at Hiron Point for different return period (Method 1)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	1.749	3.92
10	2.842	4.08
15	3.535	4.19
20	4.056	4.26
25	4.480	4.32
30	4.838	4.38
50	5.912	4.53
100	7.547	4.77
150	8.611	4.93
200	9.420	5.05

Figure 4-16 Tide probabilistic values at Hiron Point Station relevant to different return periods based on yearly top highest tide data by Plot Graph (Method 1)

(2) Results based on yearly top three highest tide

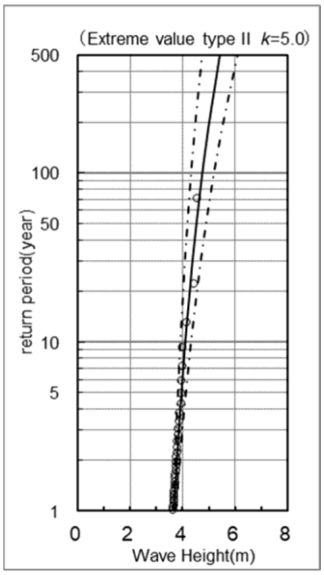


Table 4-18 Result of Tide Statistical Analysis at Hiron Point for different return period (Method 2)

Return Period R	Standardized variable yR	Tide Elevation xR(m)
5	3.535	3.95
10	4.838	4.10
15	5.682	4.19
20	6.321	4.26
25	6.841	4.32
30	7.284	4.37
50	8.611	4.51
100	10.640	4.74
150	11.964	4.88
200	12.969	4.99

Figure 4-17 Tide probabilistic values at Hiron Point Station relevant to different return periods based on yearly three highest tide data by Plot Graph (Method 2)

4.10 Summary

This study analyzed and estimated the probabilistic tide elevations with 20-year, 25-year, and 50-year return periods for nine target areas: Cox's Bazar, Lemsikhali, Sadarghat, Sandwip, Hatiya, Charchenga, Patharghata, Khepupara, and Hiron Point, with extreme tide elevations relative to Mean Sea Level (MSL), respectively (see Table 4-19 and Figure 4-18). The estimated values are adopted by bigger ones, comparing the results of the yearly highest tide data and yearly top three highest data.

Table 4-19 Maximum Statistical Tide Elevation (m) for nine target areas

Station	Maximum Statistical Tide Elevation(m)		
	Return Period 20	Return Period 25	Return Period 50
Cox's Bazar	MSL+2.73	MSL+2.79	MSL+3.00
Lemsikhali	MSL+3.73	MSL+3.83	MSL+4.11
Sadarghat	MSL+3.62	MSL+3.65	MSL+3.74
Sandwip	MSL+4.82	MSL+4.89	MSL+5.10
Hatiya	MSL+5.67	MSL +5.75	MSL+6.01
Charchenga	MSL+3.47	MSL+3.53	MSL+3.73
Patharghata	MSL+3.20	MSL+3.29	MSL+3.54
Khepupara	MSL+2.68	MSL+2.72	MSL+2.85
Hiron Point	MSL+2.40	MSL+2.46	MSL+2.67

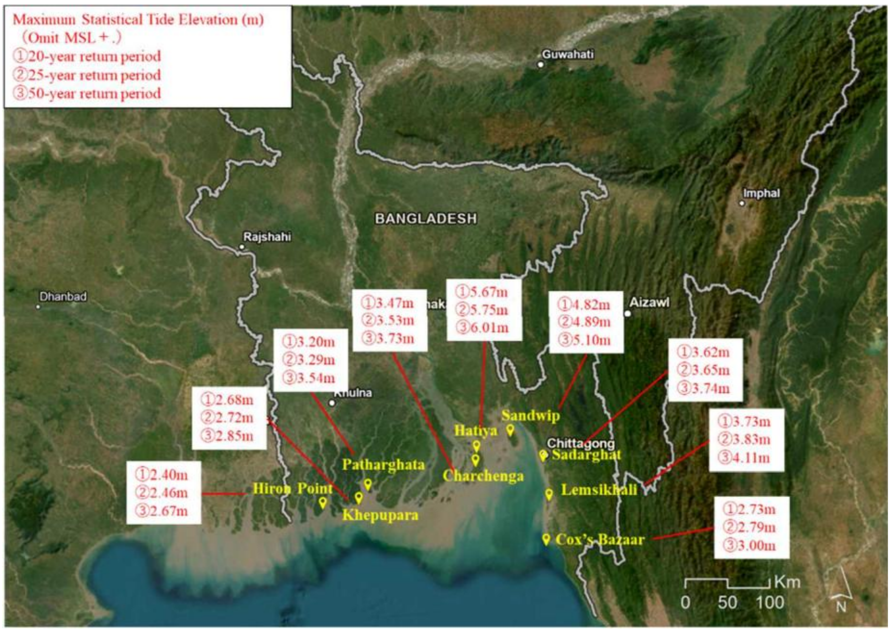


Figure 4-18 Maximum Statistical Tide Elevation(m)

Based on tidal levels and topographical features, and further considering administrative boundaries, the divisions are shown in Figure 4-19. Primarily, the areas are divided by whether the differences in probabilistic tidal levels are not significant, whether they are located at the inner part of a bay, and whether they face the same direction towards the sea, with further consideration of administrative boundaries.

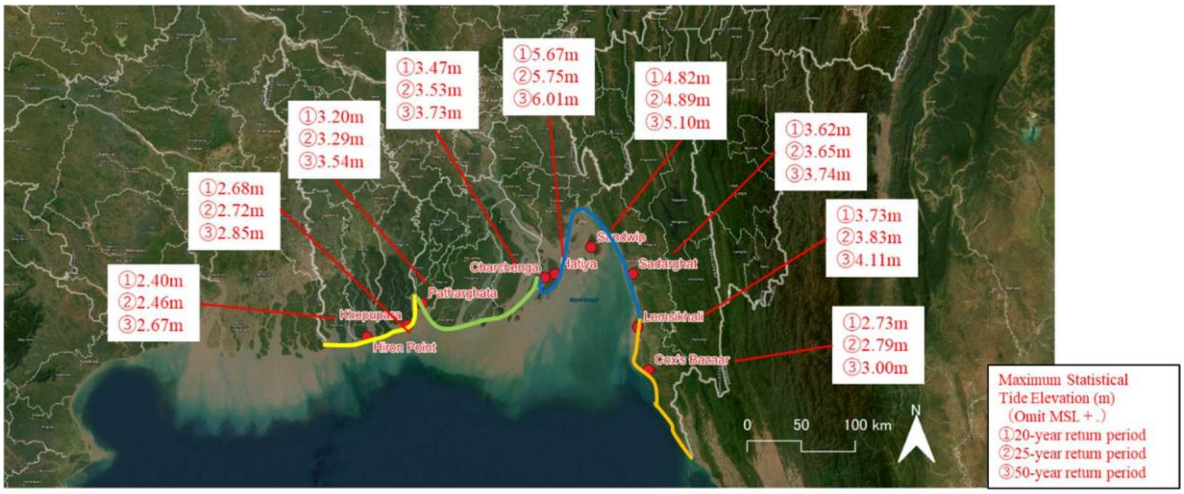


Figure 4-19 Zoning based on tidal and topographic characteristics, and administrative boundary

5. Way Forward for Other Coastal Area Application

(1) Discussions of methodology among the related organizations

Certainly, the detailed method is better than the simplified one. But the detailed method requires costs, time and human resources. Therefore, the detailed method should be applied in the future with funding. In the meantime, the simplified method can be used for nationwide analysis.

(2) Setting Target Hazard

In this guideline, the 9 tide stations which have more than 20 years of data are considered. Target hazard levels were divided into four sections which represent natural conditions and administrative boundaries etc. If more critical data are obtained such as severe cyclone attack, probability analysis should be performed again using the latest data of each station. Future analysis should be updated after accumulating more data with consideration of other observation data.

(3) Inundation Analysis

Now, only free DEM (global model) is available for nationwide analysis. If new accurate DEM are developed by the related organizations (e.g., SOB), such DEM should be utilized for more accurate analysis.

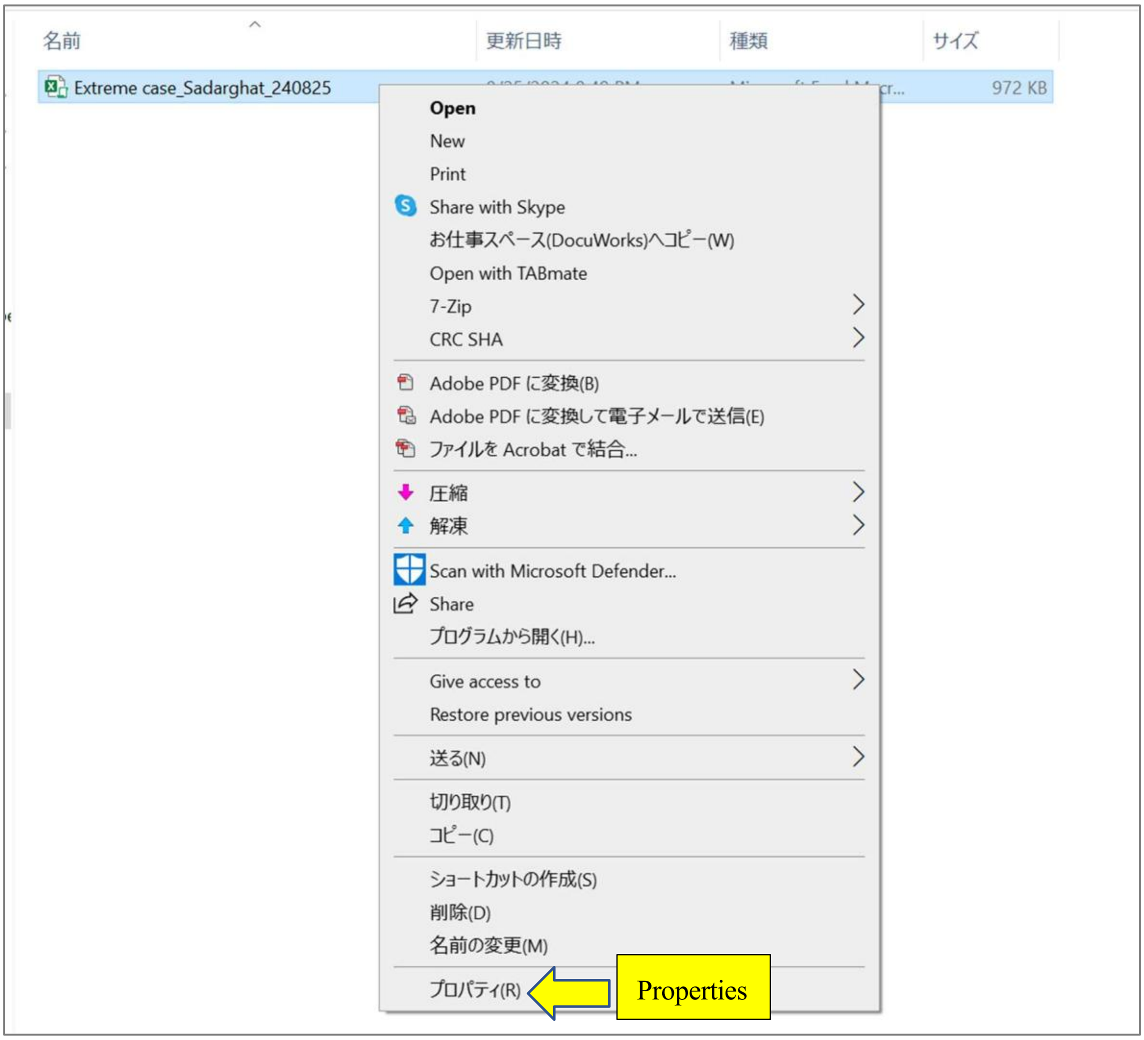
(4) Important Notes at using Macros

While using Macros program in the excel file, firstly we need to allow the Macros running in the background.

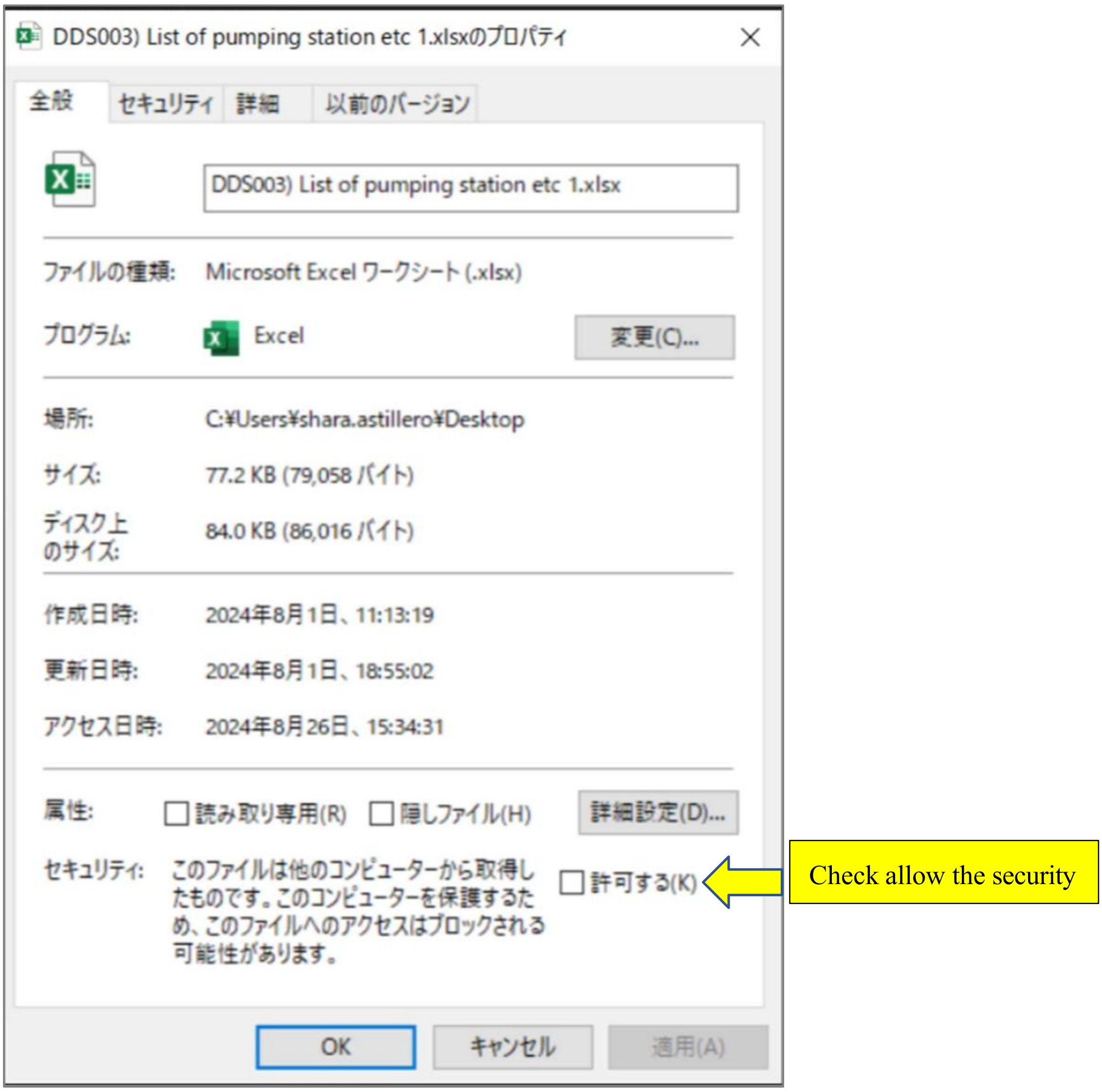
If the calculation button does not work well, save the excel file and close firstly.

The following procedures might help you to use macros and calculate properly.

1) Right click the file name, then click property.



2) In the property tab, check 'Allow' button for Macros to be used in the sheet calculation, then apply and click 'OK'.



3) Open the excel file again and continue the calculation process.

ANNEX 5: Technical Manual for Sediment Disasters Analysis

Table of Contents

1. INTRODUCTION

The purpose of sediment disaster analysis is to understand the sediment disaster hazard in the Upazila through the estimation of the area susceptible to the occurrence of the disaster.

In this manual, the type of sediment disaster considered is slope failure and the analysis method proposed is a relatively simple method using only topographic information of the target area such as digital elevation model (DEM) and GIS software.

1.1. Basic Definitions

Disaster:

“Disaster” is defined as a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts. (source: UNDRR Terminology)

Hazard:

“Hazard” is defined as a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. (source: UNDRR Terminology)

Vulnerability:

“Vulnerability” is defined as the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. (source: UNDRR Terminology)

Sediment Disaster:

“Sediment Disaster” is defined as the phenomena that cause direct or indirect damage to the lives and properties, inconveniences to the life of people, and/or deterioration of the environment through a large-scale movement of soil and rock. (source: APFM (2011): Integrated Flood Management Tools Series No.12)

Landslide:

“Landslide” is defined as the movement of a mass of rock, debris, or earth down a slope. Landslides are a type of "mass wasting," which denotes any down-slope movement of soil and rock under the direct influence of gravity. The term "landslide" encompasses five modes of slope movement: falls, topples, slides, spreads, and flows. These are further subdivided by the type of geologic material (bedrock, debris, or earth). Debris flows (commonly referred to as mudflows or mudslides) and rock falls are examples of common landslide types. (source: USGS)

Landslide Hazard:

"Landslide hazard" is defined as the probability of occurrence of a landslide event in a given area in a specific time frame. (source: Varnes et al. (1984), Landslide Hazard Zonation: a Review of Principles and Practice)

Landslide Hazard Yellow Zone:

"Landslide Hazard Yellow Zone" is defined as the area that is susceptible to landslide and called as "Yellow Zone" for brevity. The resistance capacity of normal buildings in Yellow Zone is expected to be larger than force acting on buildings due to the moving debris and earth of landslides.

Landslide Hazard Red Zone:

"Landslide Hazard Red Zone" is defined as the area where there is a high risk of damage to buildings and threat to people due to landslide and called as "Red Zone" for brevity. The force acting on buildings due to the moving debris and earth of landslides in Red Zone is expected to be larger than the resistance capacity of normal buildings. Therefore, normal buildings in Red Zone would be completely destroyed by the moving debris and earth of landslides.

2. METHODS FOR CALCULATION OF SLOPE FAILURE HAZARD LEVELS

2.1. Overall Flow

The hazard levels of slope failures are calculated based on only topographical information. The overall flow of the calculation is shown in Figure 1.

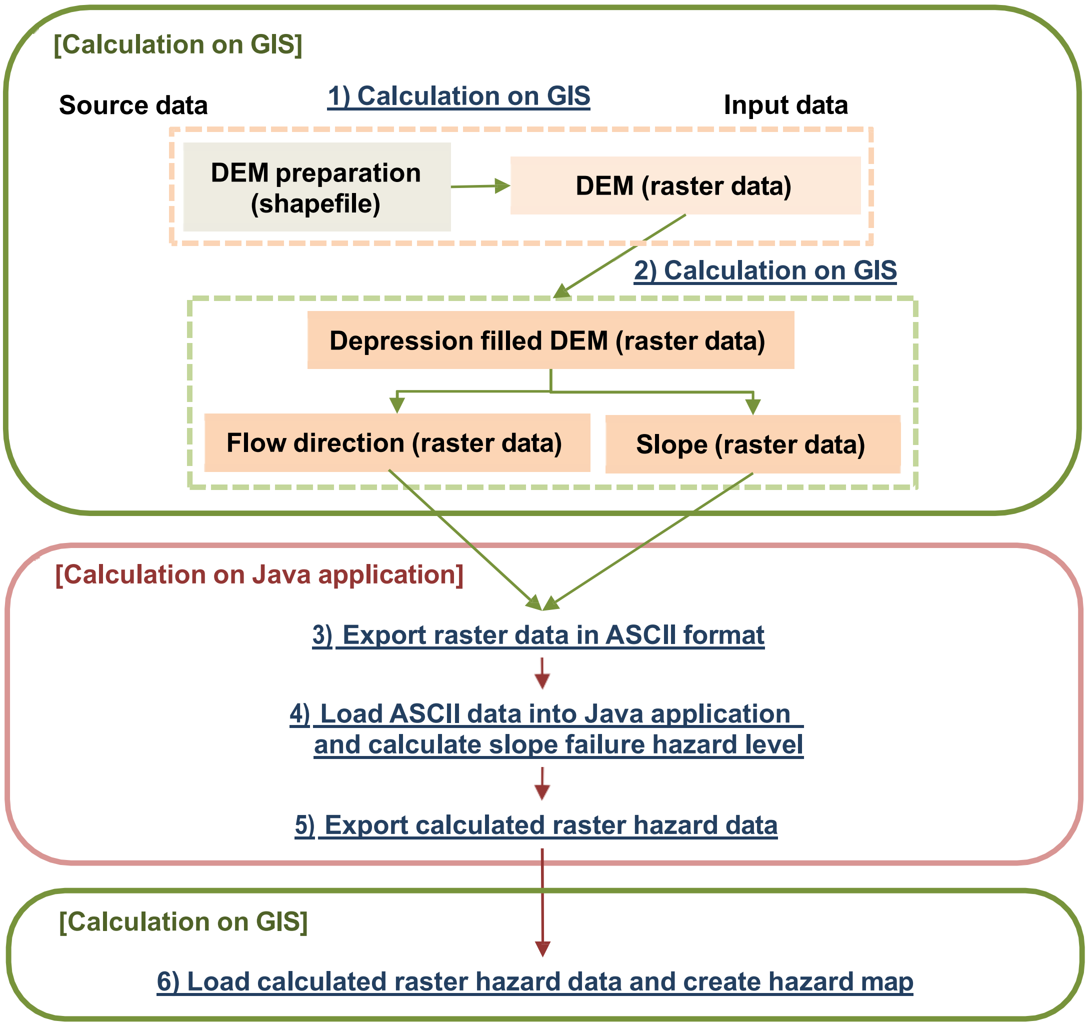


Figure 1 Overall flow of hazard level calculation

2.2. Calculation of Slope Failure Hazard Level

Algorithm

Basic concept to calculate the slope failure hazard levels (Yellow and Red zones: Y/R) is shown in Figure 2. The Y/R is calculated based on the following condition by using DEM.

<Red zone: R>

- Height of slope: $H > 5\text{m} \cap$ Slope: $S > 30$ degree
- $1H$ (horizontal) from the lower edge of the steep slope

<Yellow zone: Y>

- 10m (horizontal) from the upper edge of the steep slope
- $2H$ (horizontal) from the lower edge of the steep slope (maximum 100m)

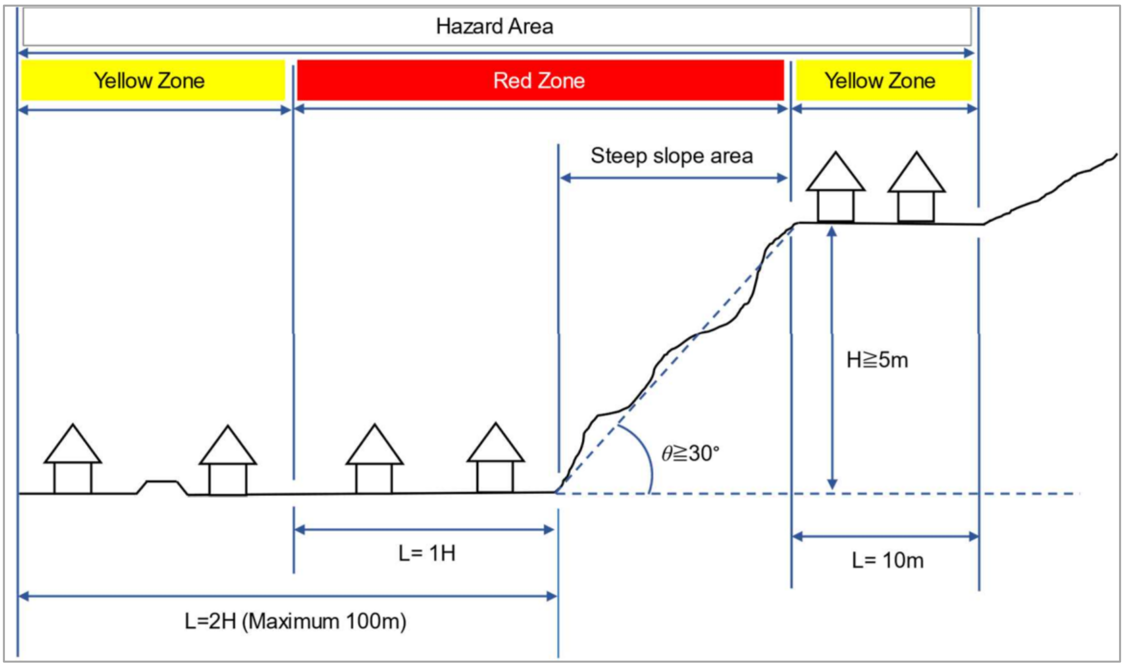


Figure 2 Basic concept for calculation of slope failure Y/R

Source data:

Elevation data (raster data): Digital elevation model (DEM) data of the target area such as SRTM, AW3D, etc.

Base map data: 1:25,000 topographic map (Survey of Bangladesh), Google map, Open Street map, etc.

Software

GIS software (Qgis, ArcGIS)	:	to fill depressions in the DEM, to calculate slope (gradient or steepness) and flow direction and to make hazard maps using outputs of the calculation.
Java application	:	developed to calculate slope failure hazard levels (Y/R) from the DEM, flow direction and slope.

Procedure

(a) Load DEM on GIS

(b) Calculate depression filled DEM on GIS

(c) Calculate slope raster on GIS using the depression filled DEM

(d) Calculate flow direction raster on GIS using the depression filled DEM

(e) Export the depression filled DEM, slope, and flow direction raster data into ASCII file

(f) Load the ascii format raster data on the Java application

(g) Set parameters on the Java application

(h) Calculate slope failure Y/R raster on the Java application

(i) Export the calculated Y/R raster

(j) Load the calculated Y/R raster on GIS and draw a hazard map

Interpretation of Calculation Result

The meaning of values resulting from the calculation are as follows:

- Value 1: Yellow Zone (area that is susceptible to landslide)
- Value 2: Red Zone (area where there is a high risk of damage to buildings and threat to people due to landslide)
- Value 3: Excepted Red Zone (larger than 50 degrees)

3. ANANLYSIS

3.1. Slope Failure Hazard Calculation

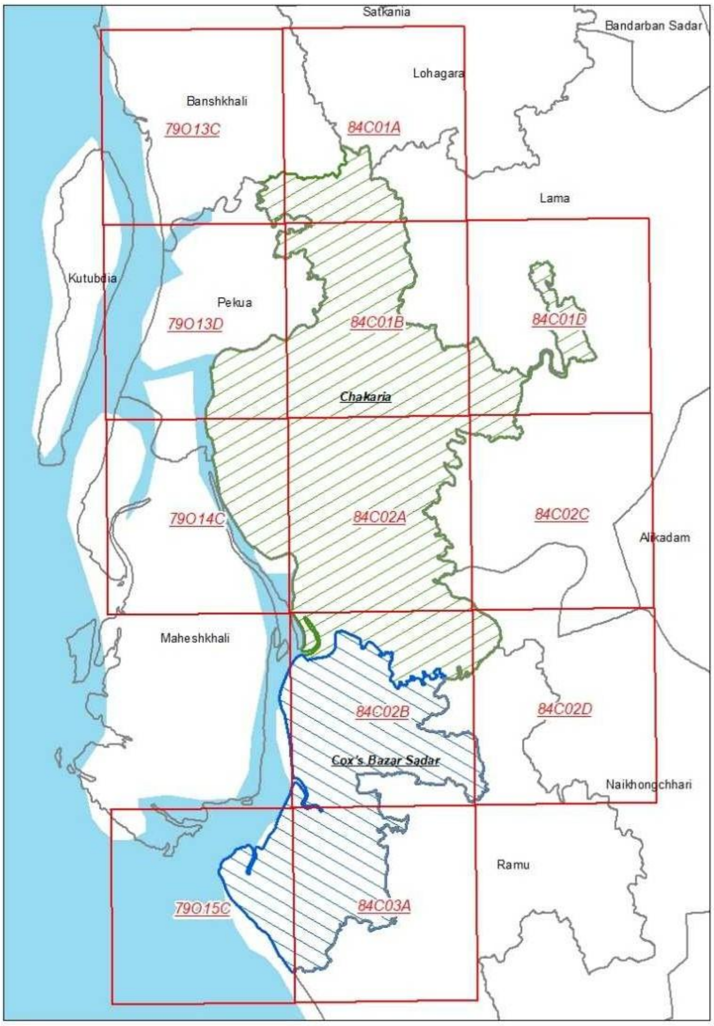
Here, the calculation method is explained using ArcGIS software.

Step 1. DEM preparation

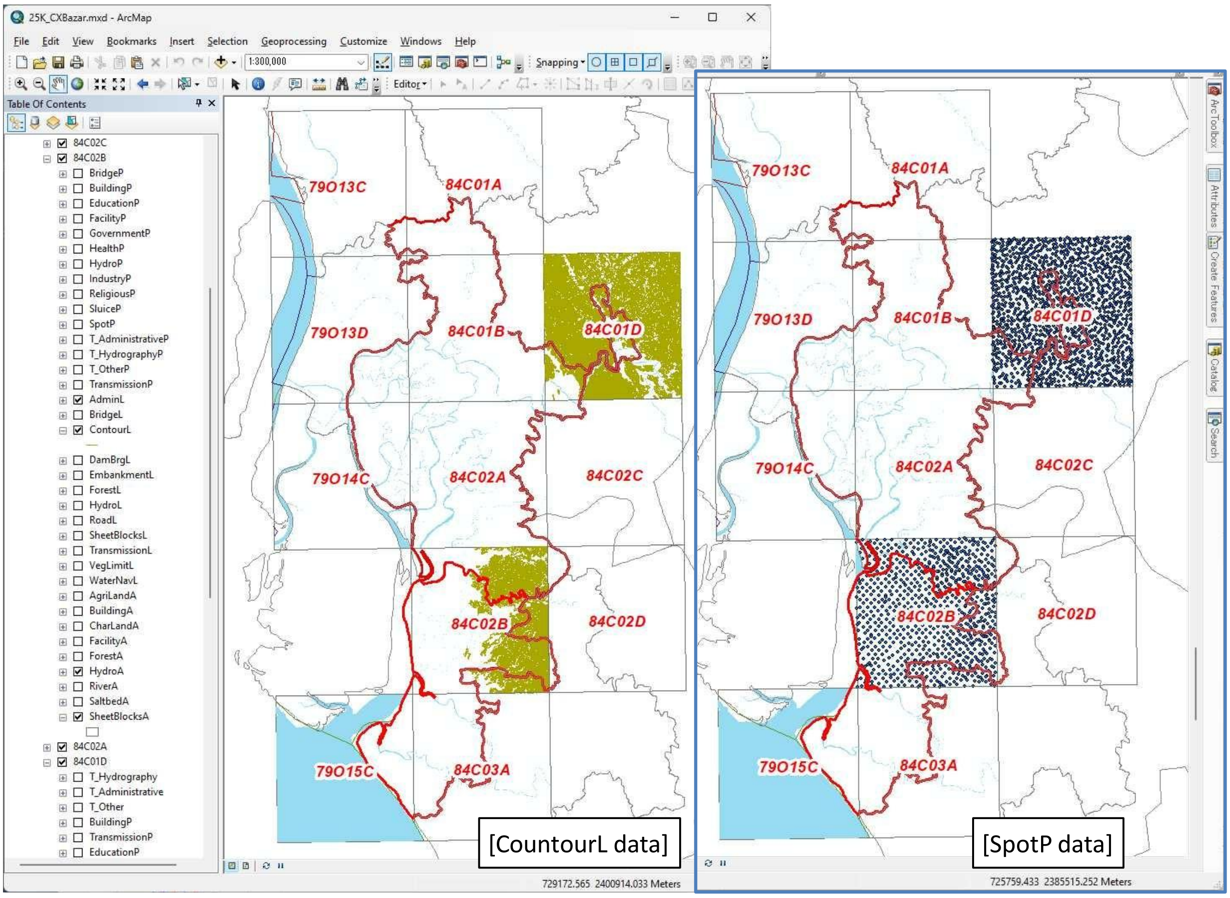
A method of generating DEM of the target area based on the GIS data (shapefiles) of 1/25,000 scale topographic map provided by the Survey of Bangladesh (SOB) was adopted here. The shapefile data utilized are SpotP shapefile (elevation point data) and ContourL shapefile (elevation line data).

As example, DEM for of Chakaria and Cox's Bazar Sadar Upazilas will be created here. 1/25,000 map sheets used here are as follows:

- 79O/13A
- 79O/13D
- 79O/14C
- 79O/14C
- 84C/ 1A
- 84C/ 1B
- 84C/ 1D
- 84C/ 2A
- 84C/ 2B
- 84C/ 2C
- 84C/ 2D
- 84C/ 3A

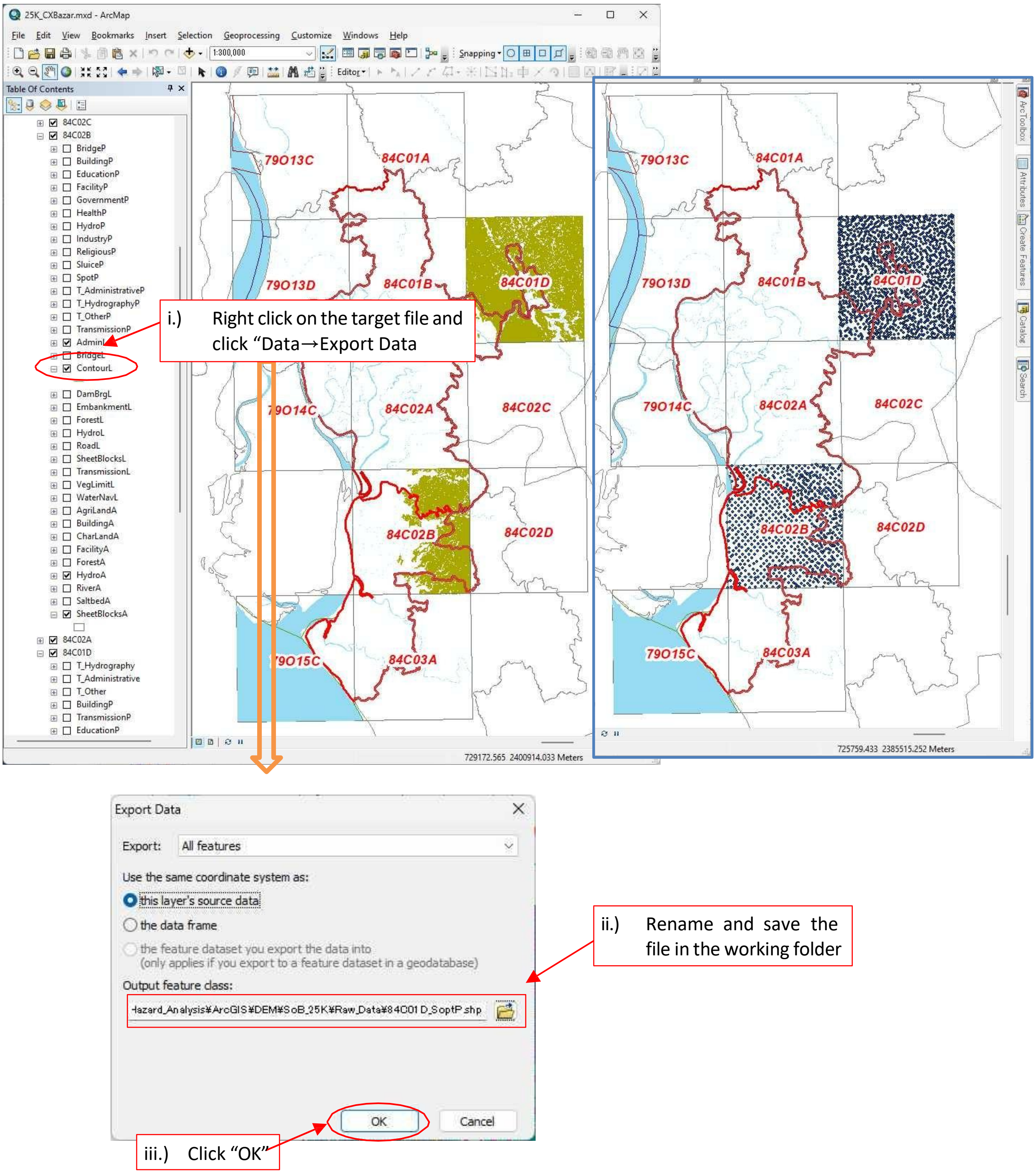


(k) Load the ContourL and SpotP shapefiles of the target area



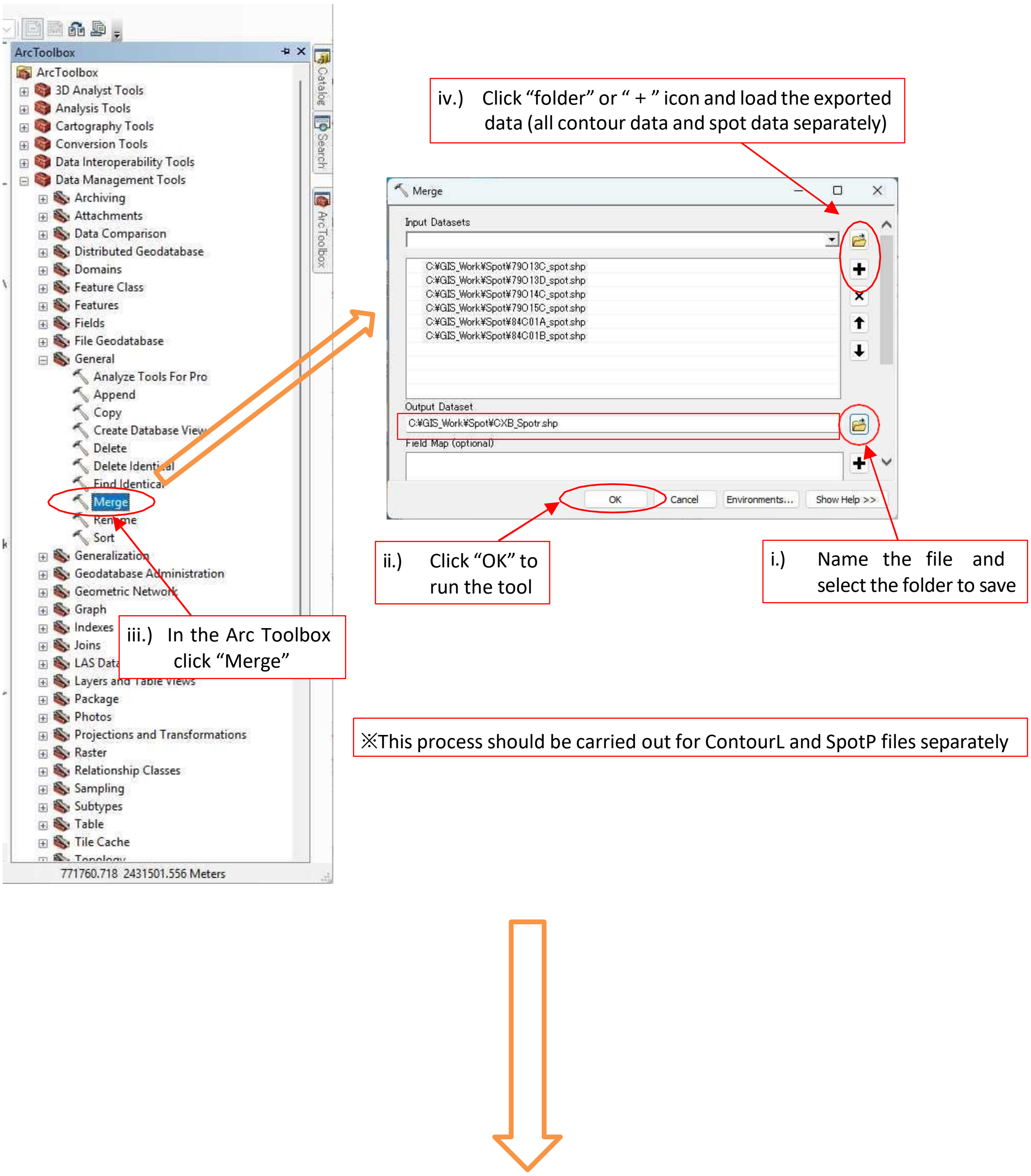
(l) Shapefiles data of each sheet are stored in a folder or geodatabase (.gbd) with the name of the respective sheet. However, data such as ContourL and SpotP files are stored with the same name for all sheets.

So, in order to preserve the original data, it is recommended to load the data into the GIS once, then export and save it under a different name (for example 84C2B_Spot.shp). By performing this step, not only the shapefile but also other data associated with it (e.g. .dbf, .prj, .sbn files, etc.) will be saved with the same name. Another way is to make a copy in a different folder and rename the data manually but in this case not only ContourL or SpotP shapefiles should be renamed, but also all others associated files should be renamed and it results in hard work spending a lot of time renaming the files one by one, depending on the quantity of sheets.


25K_CXBazar.mxd - ArcMap
i.) Right click on the target file and click “Data→Export Data
Export Data
Export: All features
Use the same coordinate system as:
this layer's source data
the data frame
the feature dataset you export the data into
(only applies if you export to a feature dataset in a geodatabase)
Output feature class:
ii.) Rename and save the file in the working folder
OK
Cancel
iii.) Click “OK”

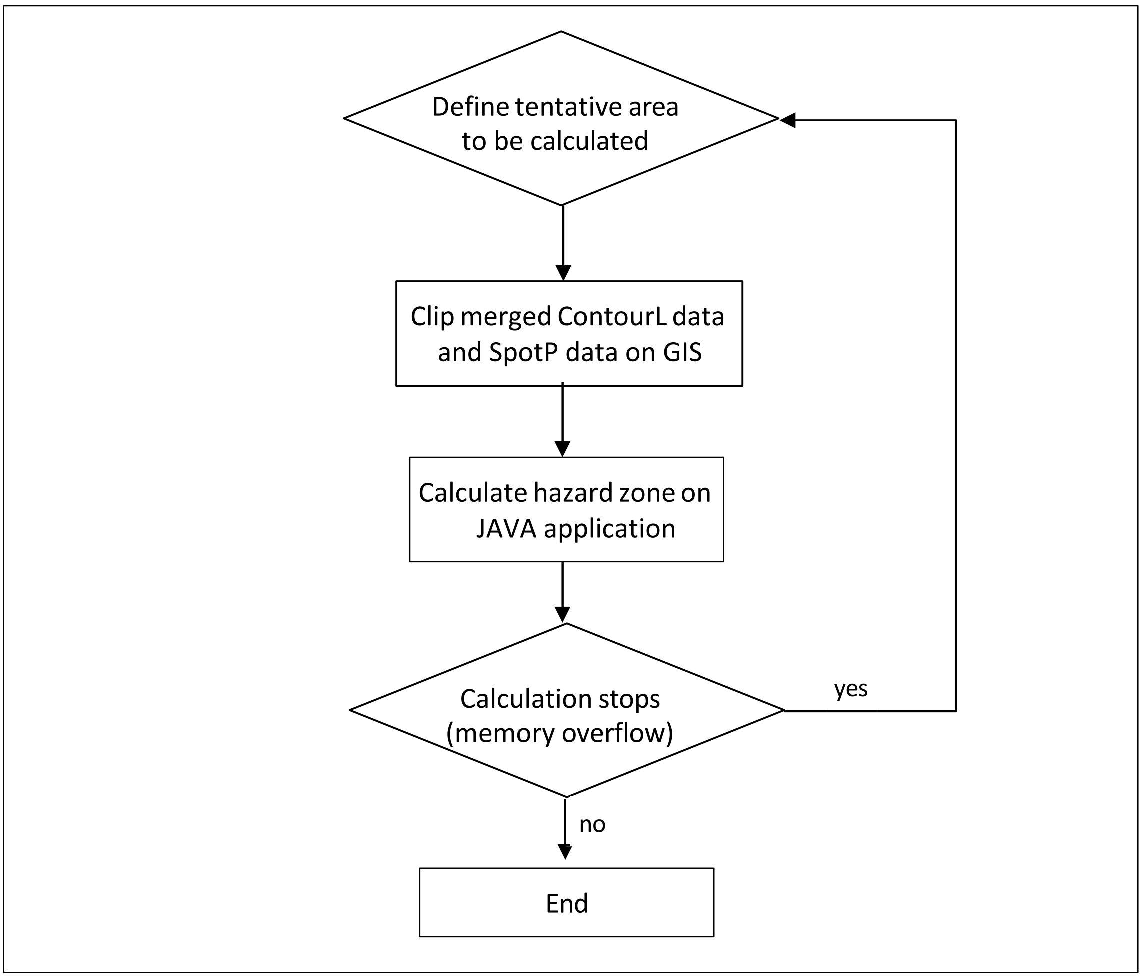
(m) Merging exported ContourL data and SpotP data

Load all exported CountourL data, merge all and save it with an appropriate name. Do the same process with the exported SpotP file.

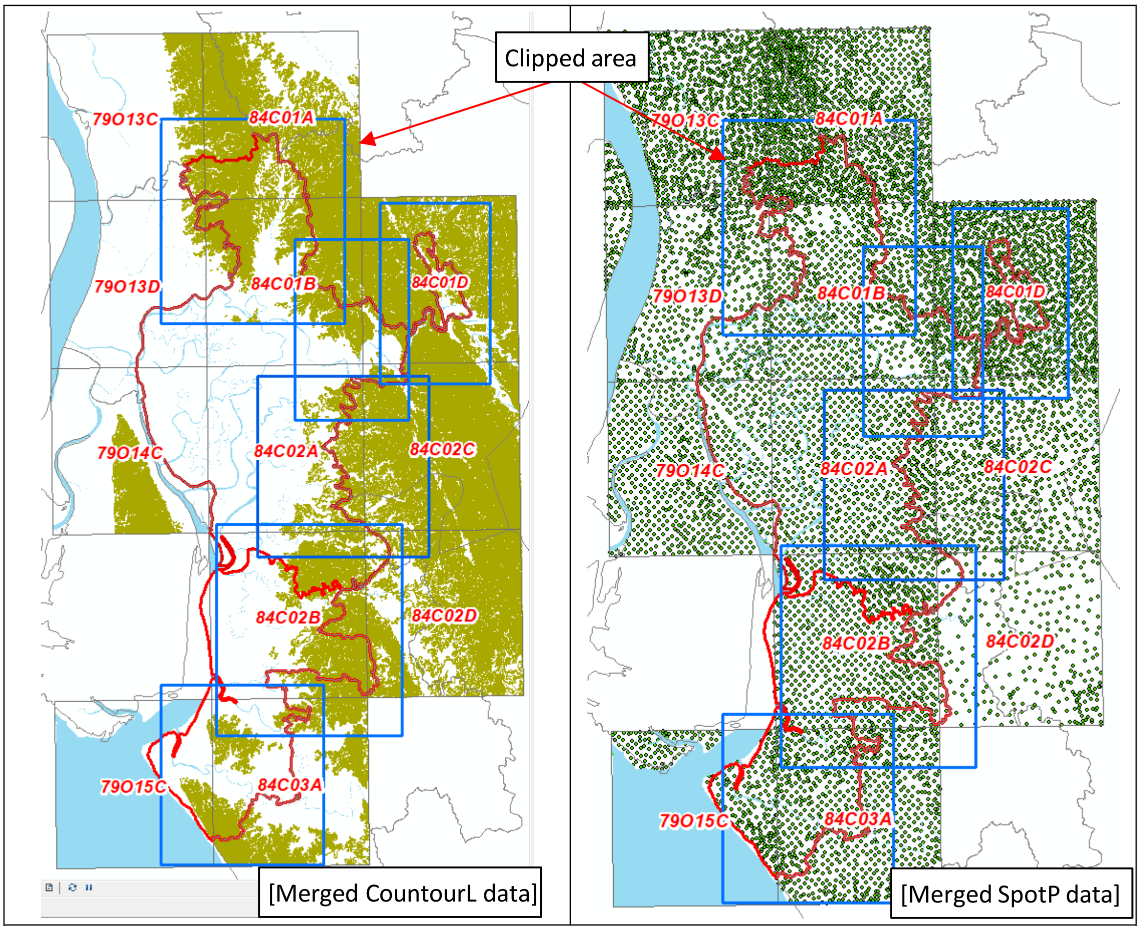


(n) Clipping merged ContourL and SpotP data

When calculating hazard zone using the JAVA application, due to memory limitation of the computer, the size of the area that can be calculated at one time is limited. So, by trial and error, the area to be calculated shall be defined as follows.

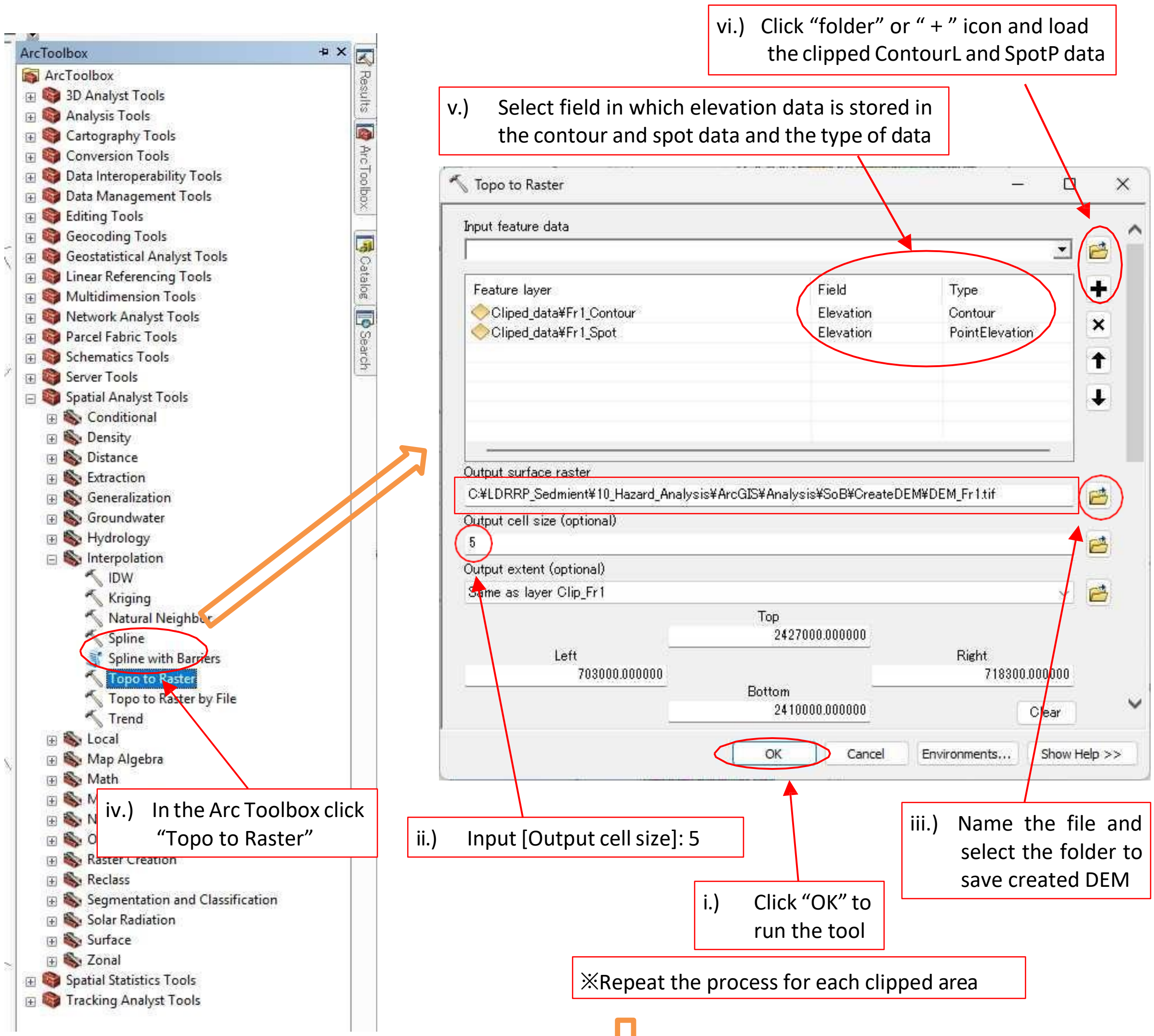


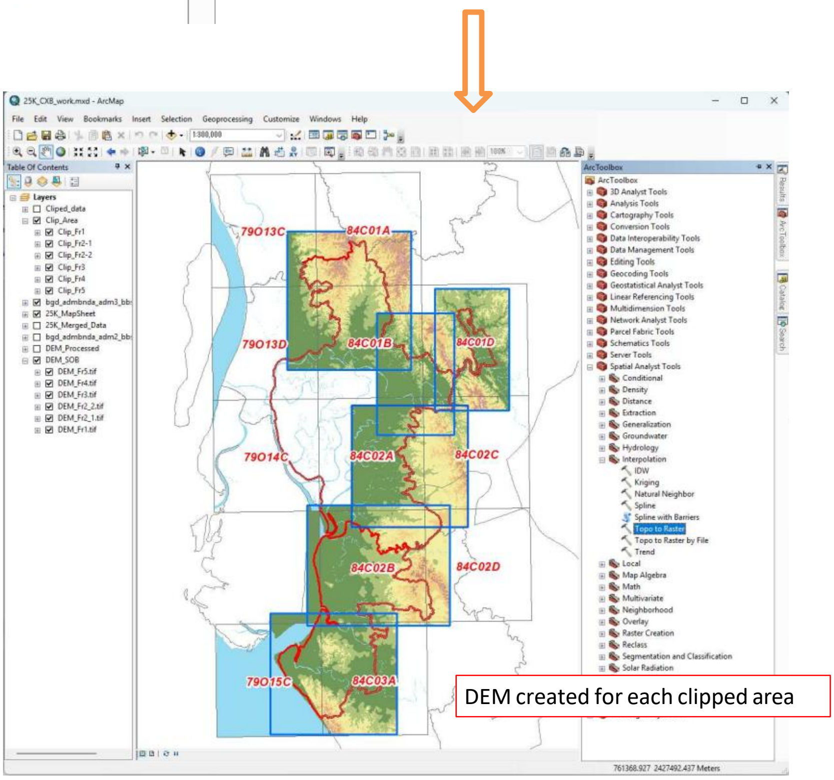
(o) Creating DEM of each clipped area



Merged ContourL and SpotP data

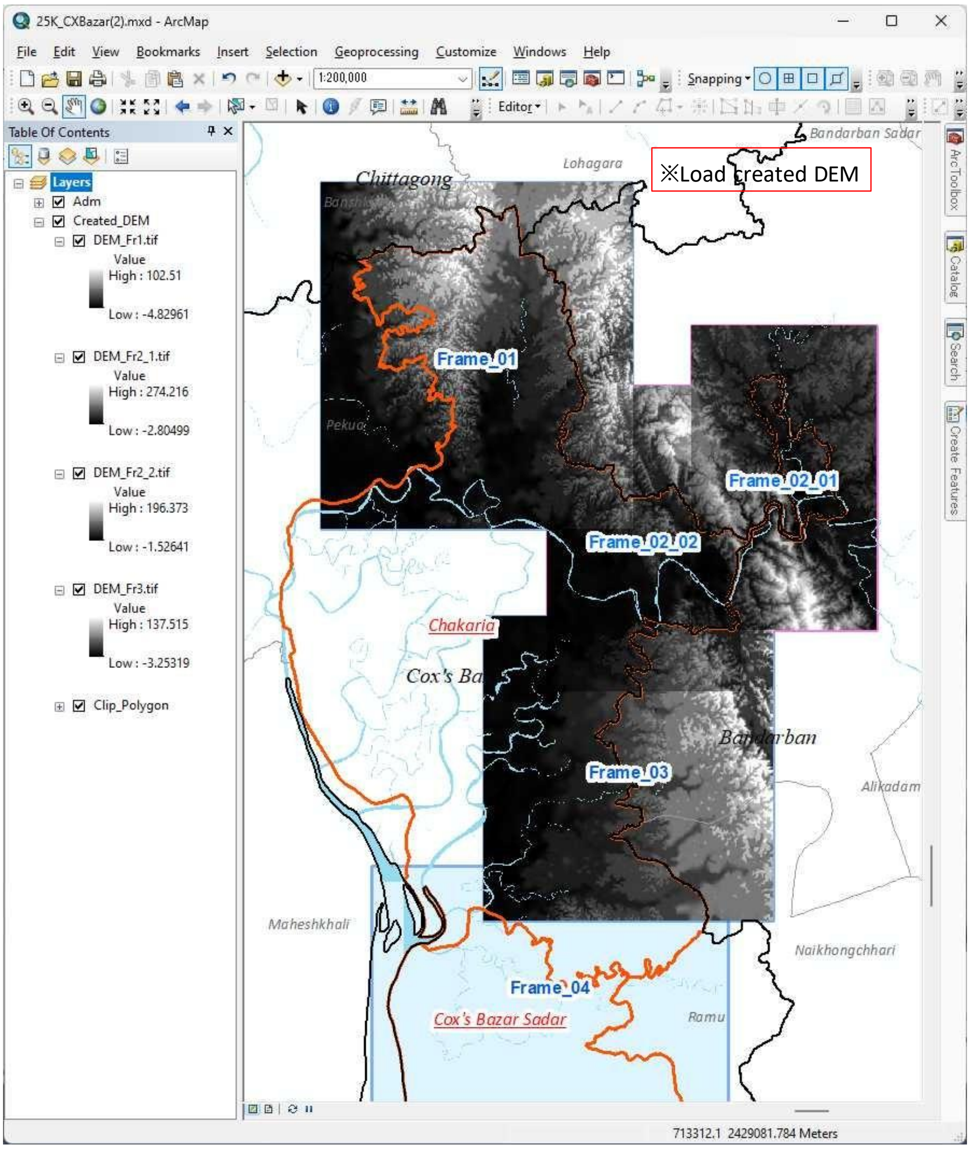
Load the clipped ContourL and SpotP data and create DEM using [Topo to Rater] toll of ArcGIS.


vi.) Click “folder” or “ + ” icon and load the clipped ContourL and SpotP data
v.) Select field in which elevation data is stored in the contour and spot data and the type of data
Topo to Raster
Input feature data
Feature layer
Field
Type
Cliped_data¥Fr1_Contour
Elevation
Contour
Cliped_data¥Fr1_Spot
Elevation
PointElevation
Output surface raster
C:¥LDRRP_Sediment¥10_Hazard_Analysis¥ArcGIS¥Analysis¥SoB¥CreateDEM¥DEM_Fr1.tif
Output cell size (optional)
5
Output extent (optional)
Same as layer Clip_Fr1
Top
2427000.000000
Left
703000.000000
Right
718300.000000
Bottom
2410000.000000
Clear
OK
Cancel
Environments...
Show Help >>
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
Data Interoperability Tools
Data Management Tools
Editing Tools
Geocoding Tools
Geostatistical Analyst Tools
Linear Referencing Tools
Multidimension Tools
Network Analyst Tools
Parcel Fabric Tools
Schematics Tools
Server Tools
Spatial Analyst Tools
Conditional
Density
Distance
Extraction
Generalization
Groundwater
Hydrology
Interpolation
IDW
Kriging
Natural Neighbor
Spline
Spline with Barriers
Topo to Raster
Topo to Raster by File
Trend
Local
Map Algebra
Math
Raster Creation
Reclass
Segmentation and Classification
Solar Radiation
Surface
Zonal
Spatial Statistics Tools
Tracking Analyst Tools
iv.) In the Arc Toolbox click “Topo to Raster”
ii.) Input [Output cell size]: 5
iii.) Name the file and select the folder to save created DEM
i.) Click “OK” to run the tool
※Repeat the process for each clipped area


79O13C
84C01A
79O13D
84C01B
84C01D
79O14C
84C02A
84C02C
84C02B
84C02D
79O15C
84C03A
DEM created for each clipped area

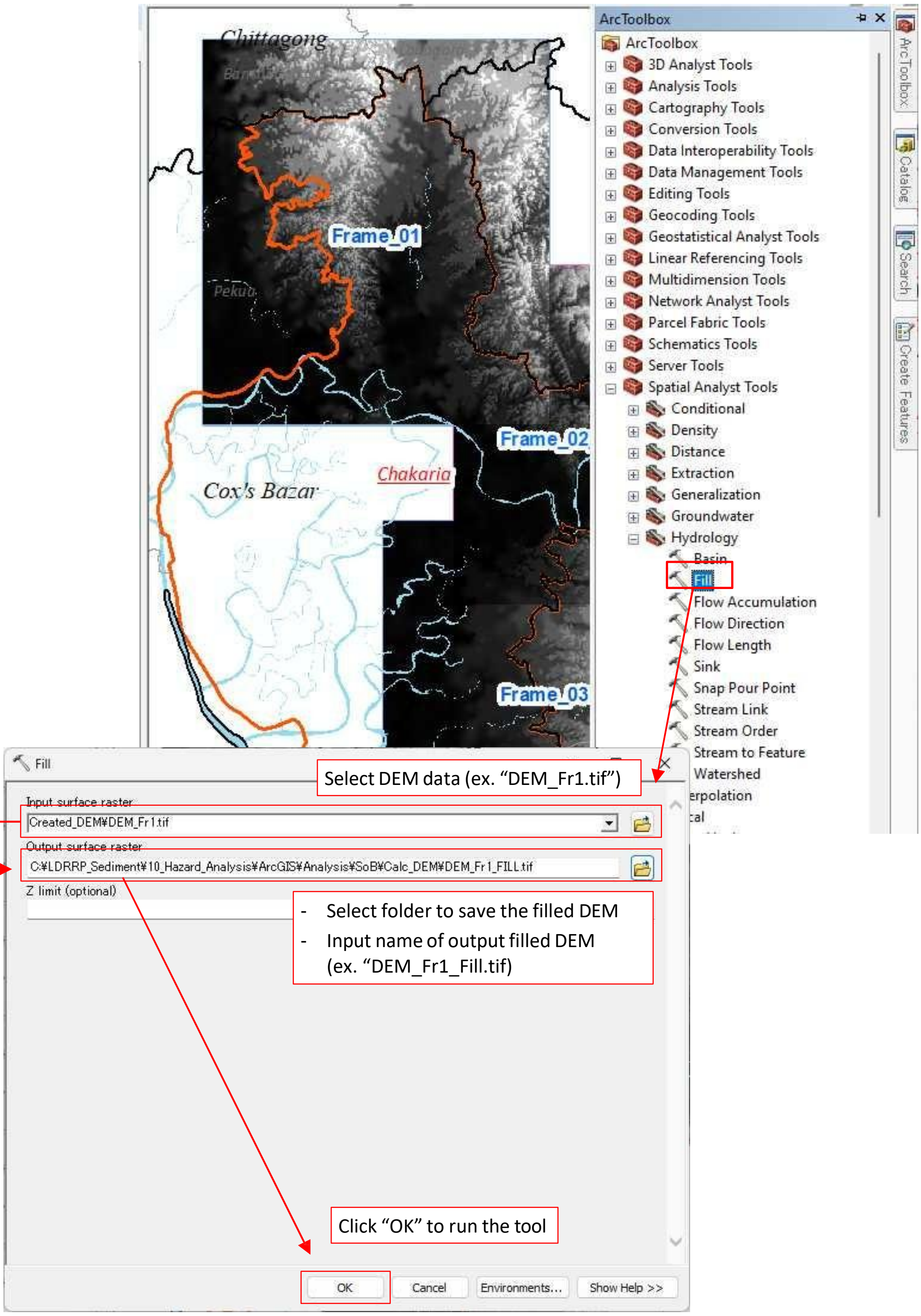
Step 2. Preparing and creating data for calculation on JAVA application

Load created DEM of the area of interest on GIS. The coordinate of DEM must be *projected coordinate* (unit is in meters, not longitude and latitude, e.g. BUTM2010). If DEM is in geographic coordinate (longitude and latitude, unit in degree), it must be converted into projected coordinate.

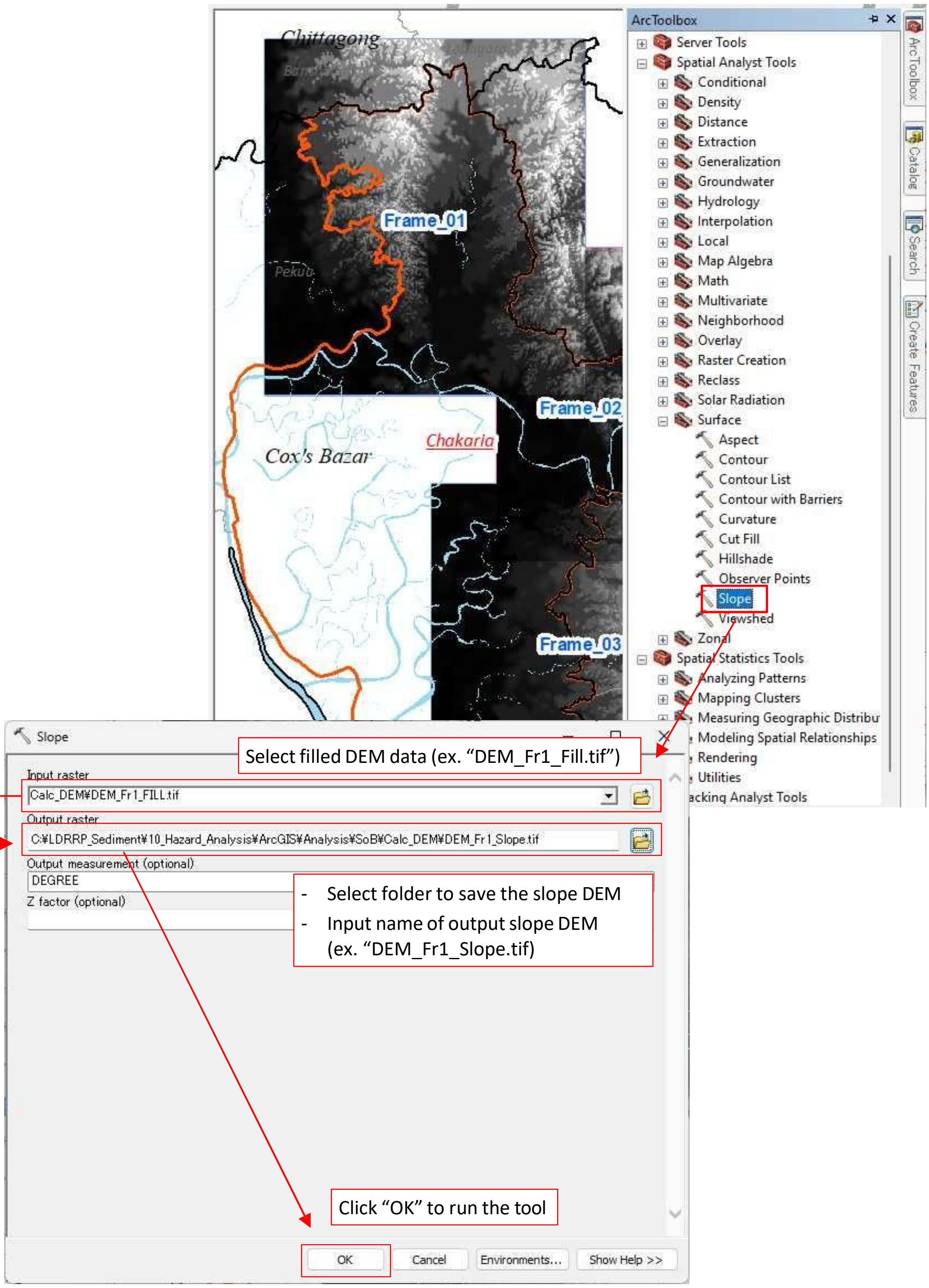


Step 3. Calculate depression filled DEM on GIS

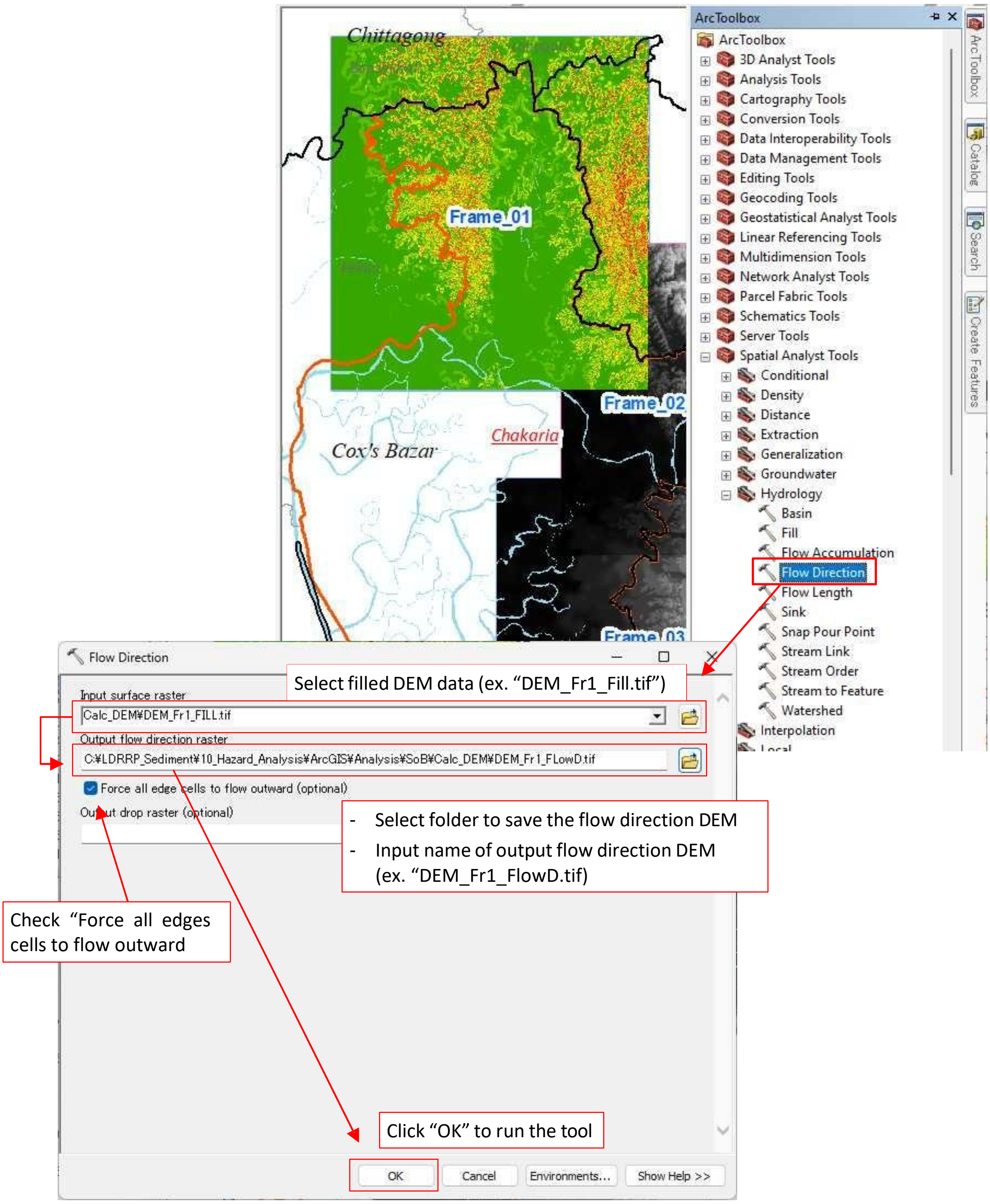
Calculate depression filled DEM by **"Spatial Analyst Tools – Hydrology – Fill"**



Step 4. Calculate slope raster on GIS using the depression filled DEM Calculate slope by **"Spatial Analyst Tools – Surface – Slope"**

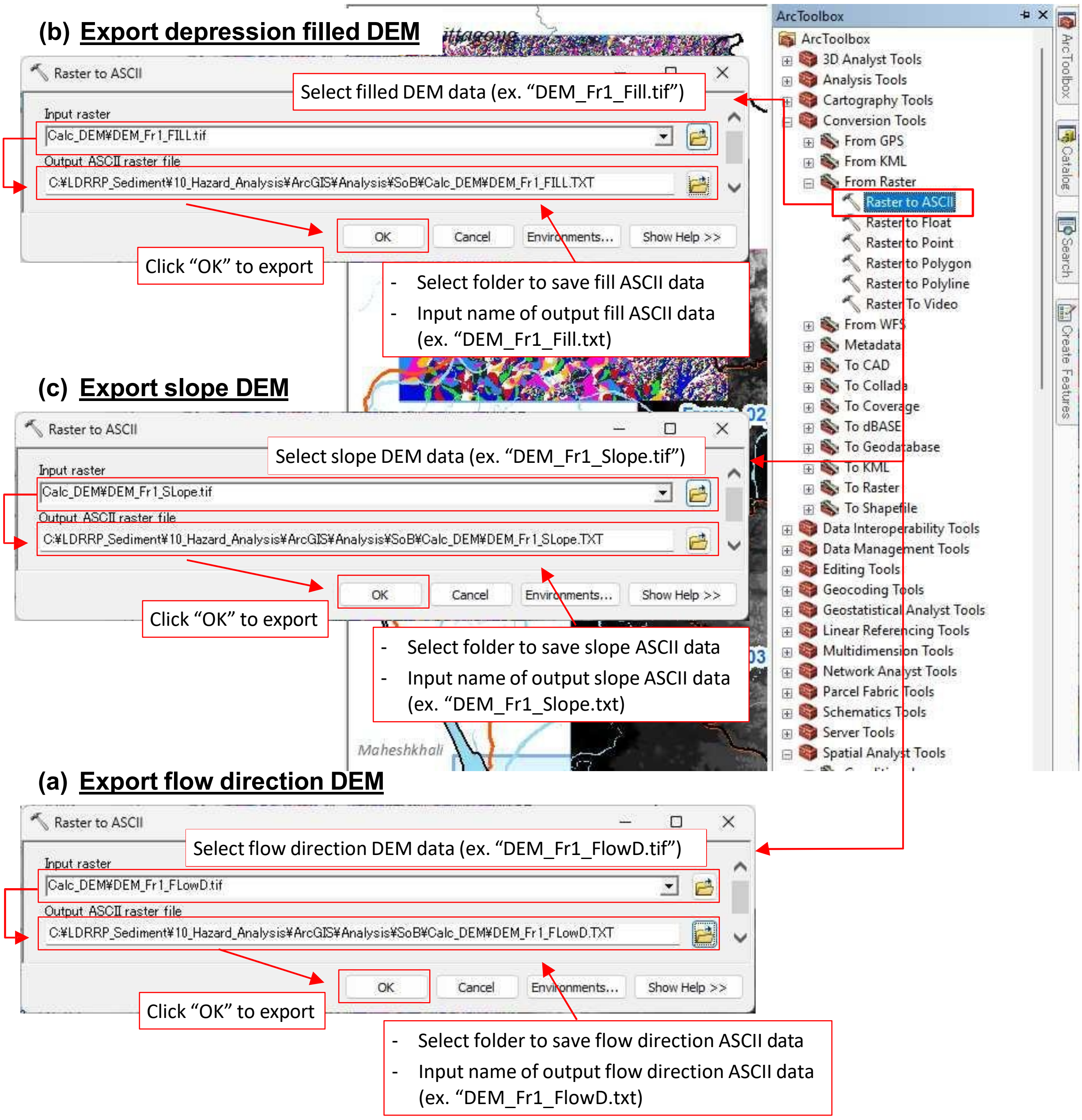


<u>Step 5.</u> Calculate flow direction raster on GIS using the depression filled DEM Calculate flow direction by "Spatial Analyst Tools – Hydrology – Flow Direction"



Step 6. Export the depression filled DEM, slope and flow direction raster data into ascii file

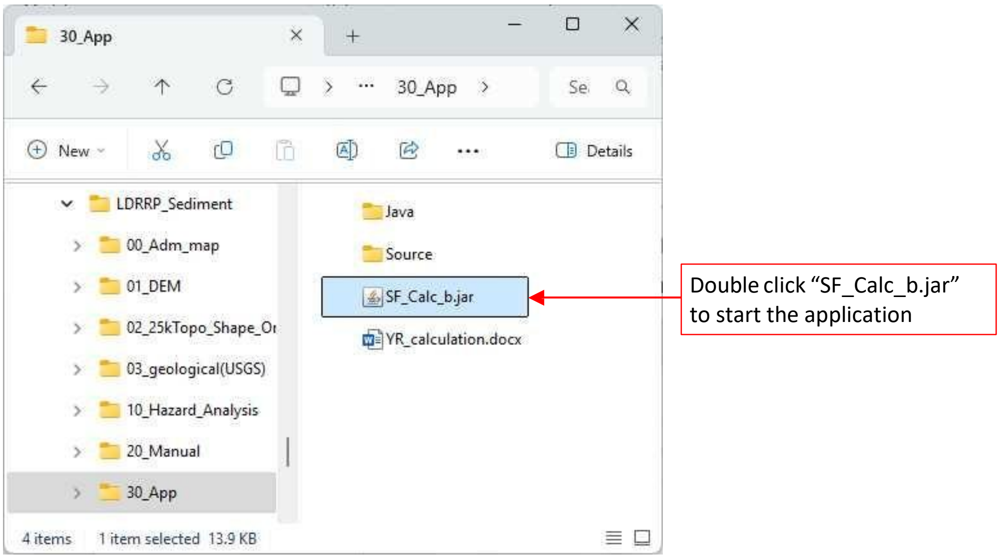
Export the depression filled DEM, slope and flow direction raster data into ascii file by **“Conversion Tools – From Raster – Raster to ASCII”**

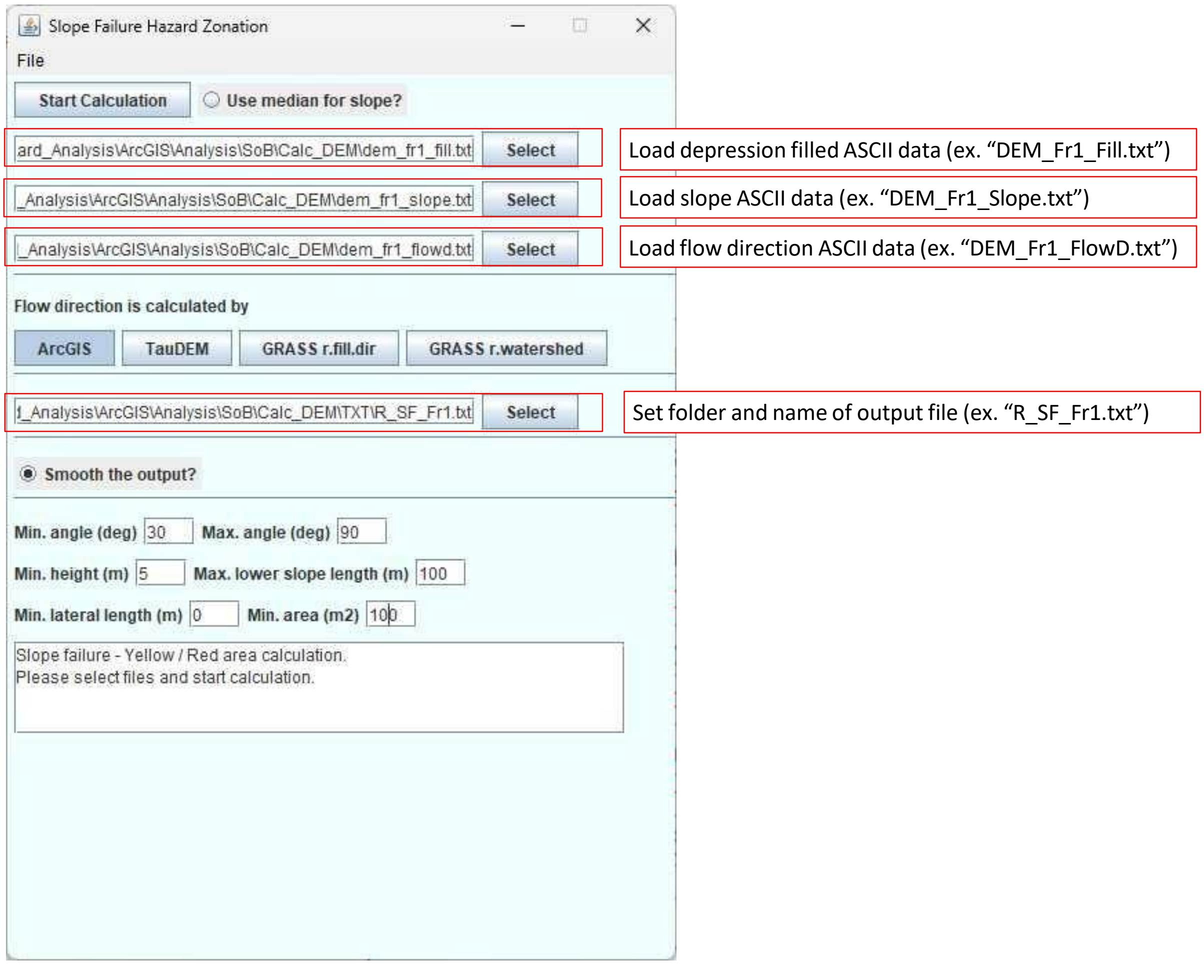


Step 7. Load the ASCII raster data on the Java application

Run "SF_Calc.jar" and load the DEM, slope and flow direction. In addition, input file name of output file which contains calculation results.

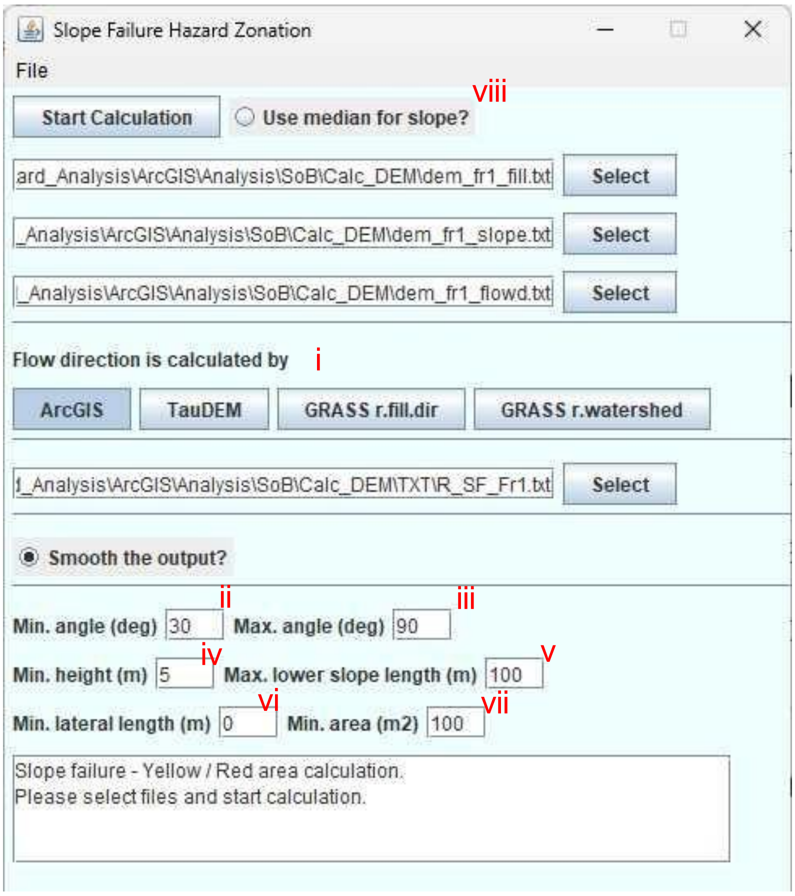
If JAVA Runtime Environment (JRE) is not installed in the computer, install it following the instructions described in Chapter 4.





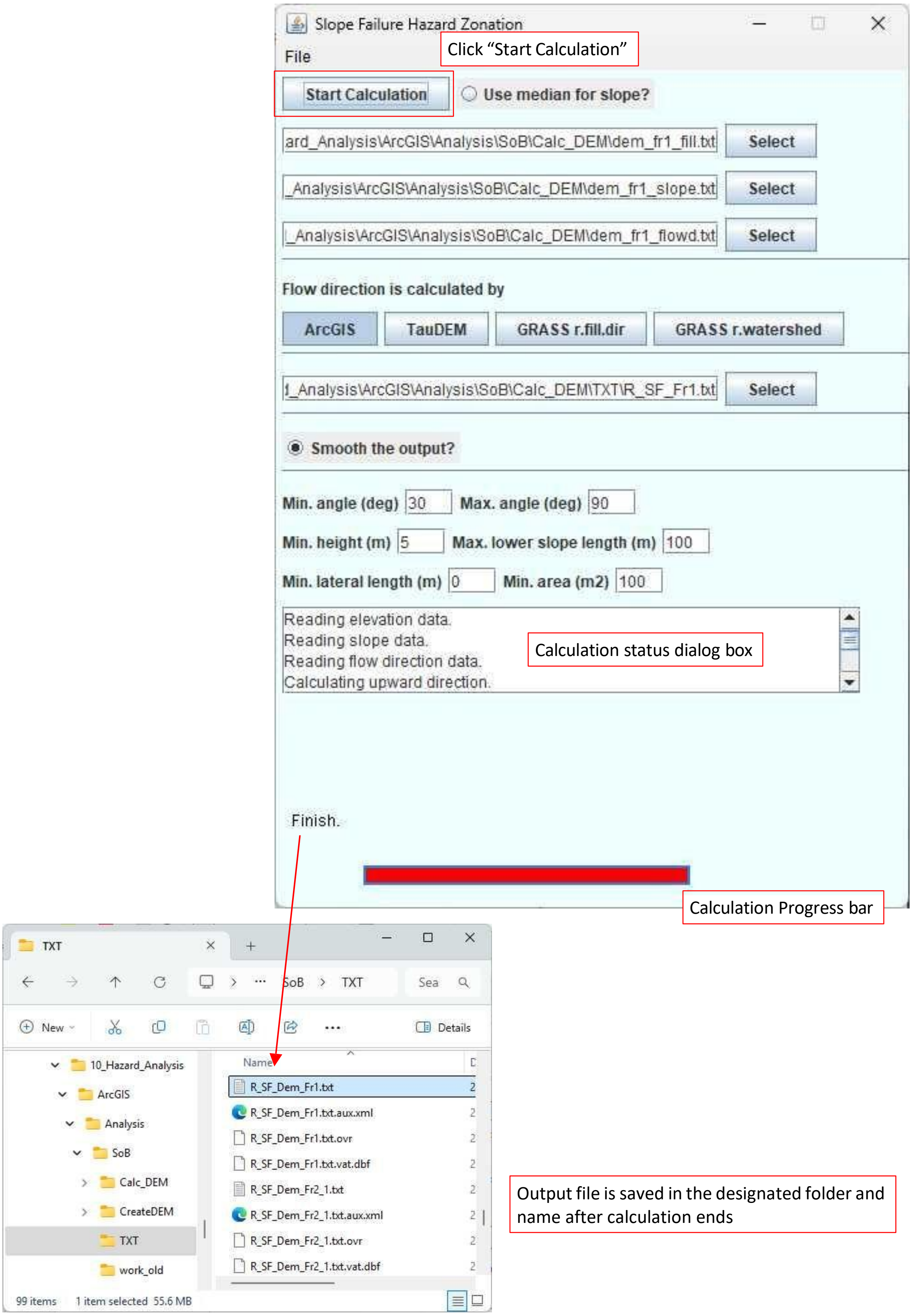
Step 8. Set parameters on the Java application and start calculation

i. Select tool used to calculate flow direction (calculation tool)
ii. Minimum angle to determine red slope (30 degrees)
iii. Maximum angle to determine red slope (50 degrees)
iv. Minimum height to determine red slope (5m)
v. Maximum lower slope length (100m)
vi. Minimum lateral length of slopes (if detected red slopes are shorter than this value, the slopes are neglected)
vii. Minimum area of slopes (if detected red slopes are smaller than this value, the slopes are neglected)
viii. (Option) median of slope in the slope raster is utilized for calculation
ix. "Start Calculation"



Step 9. Run the application and calculate slope failure Y/R

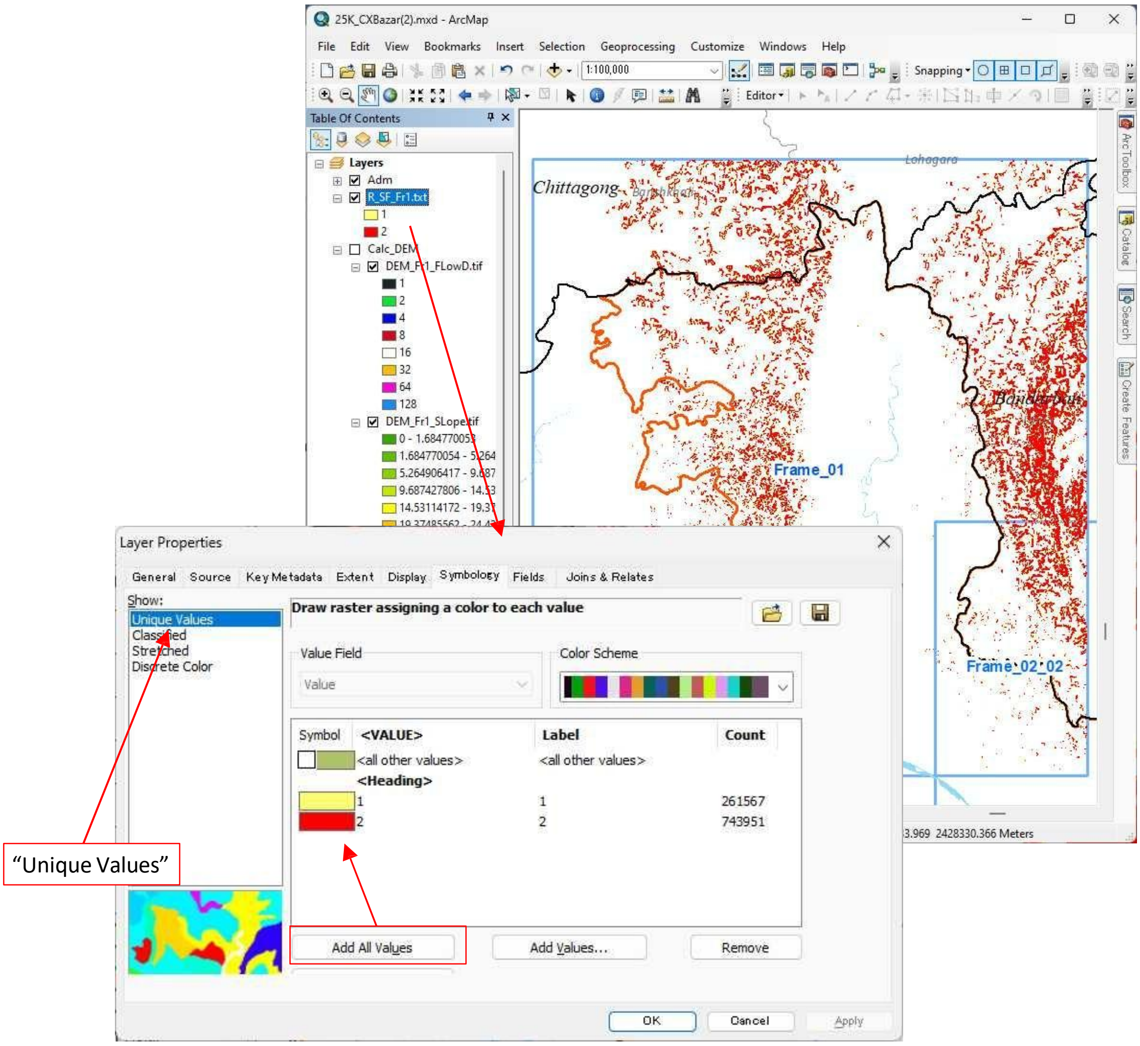
Click "Start Calculation" button, then calculation is started, and progress of calculation is shown in the window.



Step 10. Display calculated Y/R raster on GIS

Load the result of calculated Y/R raster data (ex. R_SF_Dem_Fr1.txt) on GIS and set up symbology.

- Drag and drop calculated Y/R raster data (.txt) to the table of contents of GIS
- Right click the Y/R layer y→Property→Symbology
  - Set "Unique Values" →



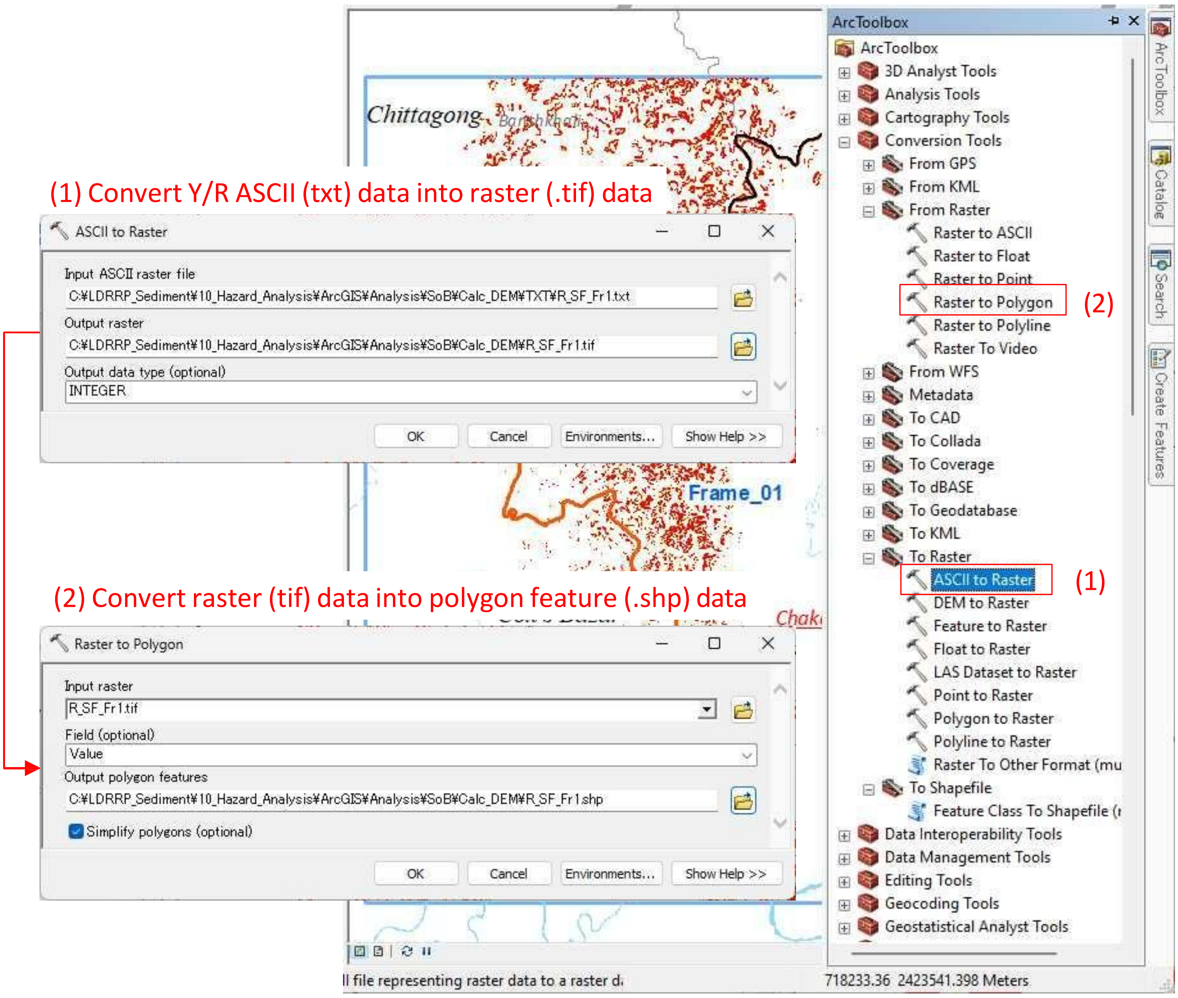
Click "Add All Values" and set colors of values

The meaning of values in the Y/R data are as follows:

- Value 1: Yellow Zone
- Value 2: Red Zone
- Value 3: Expected Red Zone (slopes larger than maximum slope angle in case parameter is set smaller than 90 degrees)

Step 11. Export calculated Y/R ASCII raster data

Calculated Y/R result output is in ASCII file (.txt). Convert this file into raster data (.tif) or polygon shapefile (.shp) according to convenience. Set coordinate system if necessary.



4. INSTALLING JAVA RUNTIME ENVIROMENT (JRE)

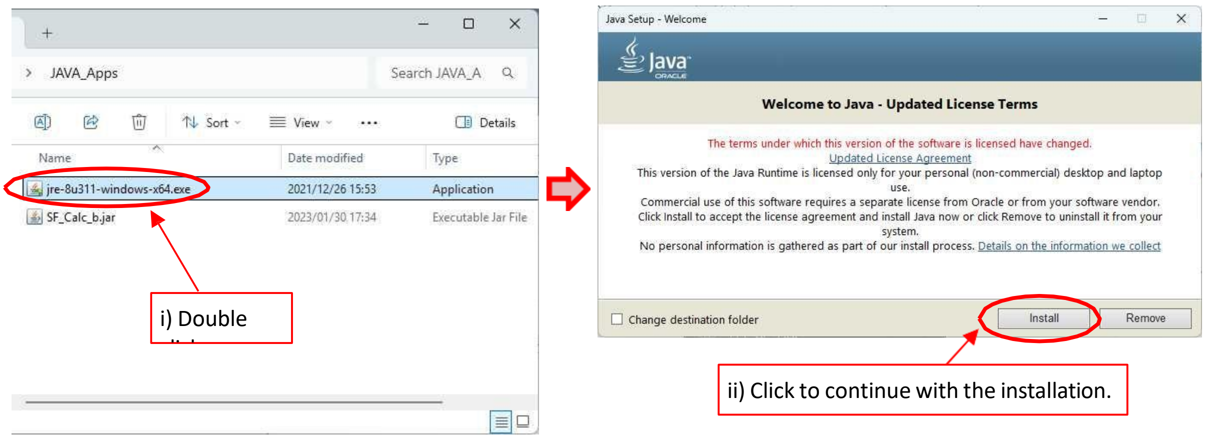
JRE is required to run the Java application. The following explains the procedure to install JRE (if JRE is already installed, there is no need to re-install it):

(a) Install "jre-8u341-windows-x64.exe" and follow the installation instructions.

i) Double-click on the saved file to start the installation process.

ii) Click the Install button to continue with the installation.

iii) A few brief dialogs confirm the last steps of the installation process; click Close on the last dialog. This will complete Java installation process.



* Access the link to download JRE: https://www.java.com/en/download/manual.jsp
Newest version of JRE is available here

(b) Configuring system to run JAVA

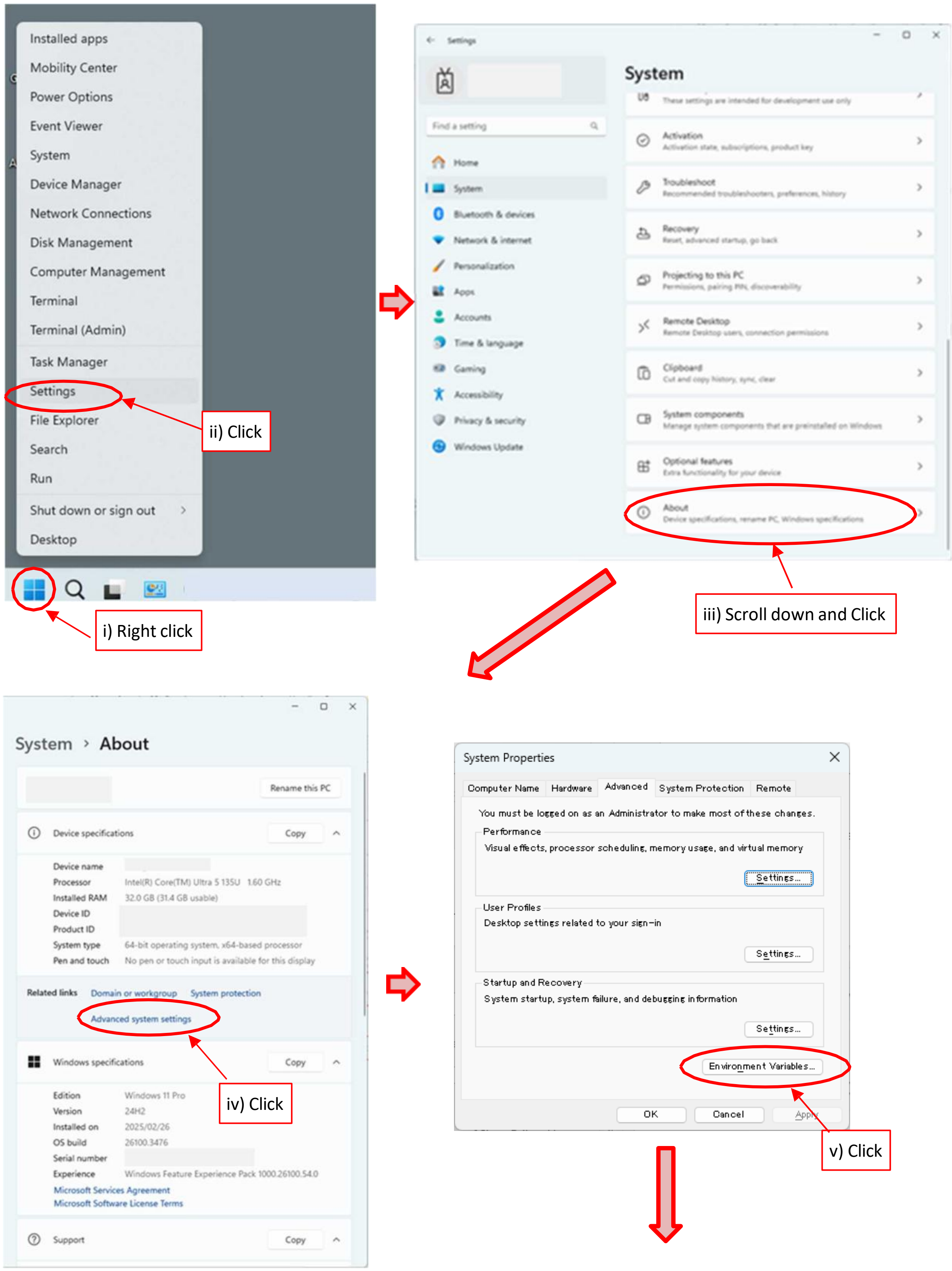
i) Right click the "Start" button (windows logo in the taskbar) → Quick Link Menu

ii) Click "Settings" → Settings- System window

iii) Scroll-down and click "About" → Settings - System - About window

iv) Click "Advanced System Settings"

v) Click "Environmental Variables"


Installed apps
Mobility Center
Power Options
Event Viewer
System
Device Manager
Network Connections
Disk Management
Computer Management
Terminal
Terminal (Admin)
Task Manager
Settings
File Explorer
Search
Run
Shut down or sign out
Desktop
i) Right click
ii) Click
System
Home
System
Bluetooth & devices
Network & internet
Personalization
Apps
Accounts
Time & language
Gaming
Accessibility
Privacy & security
Windows Update
Activation
Troubleshoot
Recovery
Projecting to this PC
Remote Desktop
Clipboard
System components
Optional features
About
iii) Scroll down and Click
System › About
Rename this PC
Device specifications
Copy
Device name
Processor
Installed RAM
Device ID
Product ID
System type
Pen and touch
Related links
Domain or workgroup
System protection
Advanced system settings
Windows specifications
Edition
Version
Installed on
OS build
Serial number
Experience
Microsoft Services Agreement
Microsoft Software License Terms
Support
iv) Click
System Properties
Computer Name
Hardware
Advanced
System Protection
Remote
You must be logged on as an Administrator to make most of these changes.
Performance
Visual effects, processor scheduling, memory usage, and virtual memory
Settings...
User Profiles
Desktop settings related to your sign-in
Settings...
Startup and Recovery
System startup, system failure, and debugging information
Settings...
Environment Variables...
OK
Cancel
Apply
v) Click

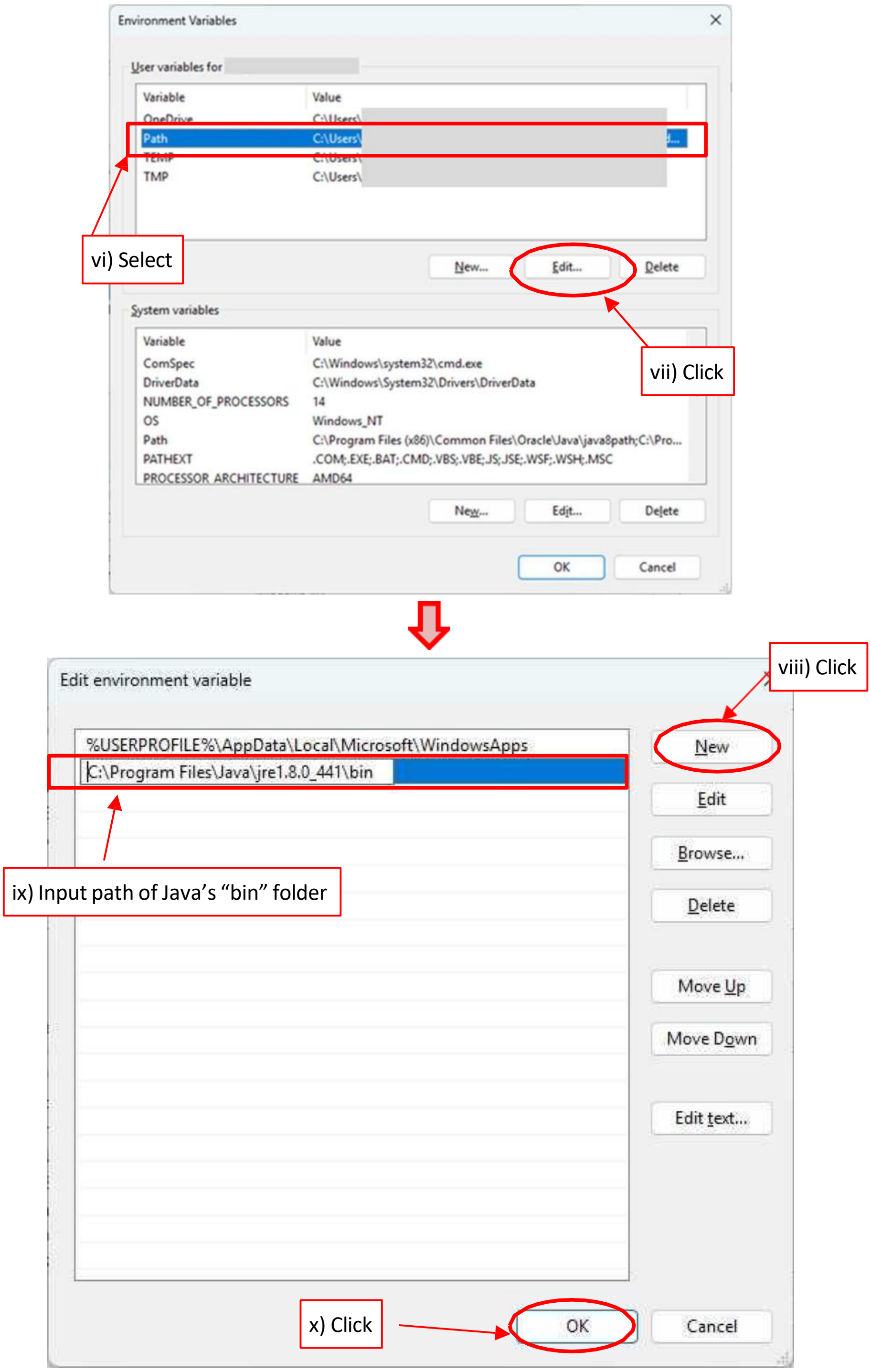
vi) Select “Path”

vii) Click “Edit”

viii) Click “New”

ix) Input path of JRE bin folder, in this case “C: \ Program Files \ Java \ jre1.8.0_441 \ bin”
*Usually, JAVA’s “bin” folder is in “Program Files→JAVA” folder unless save location of the application have changed during the installation.

x) Click “OK” to finish setting.



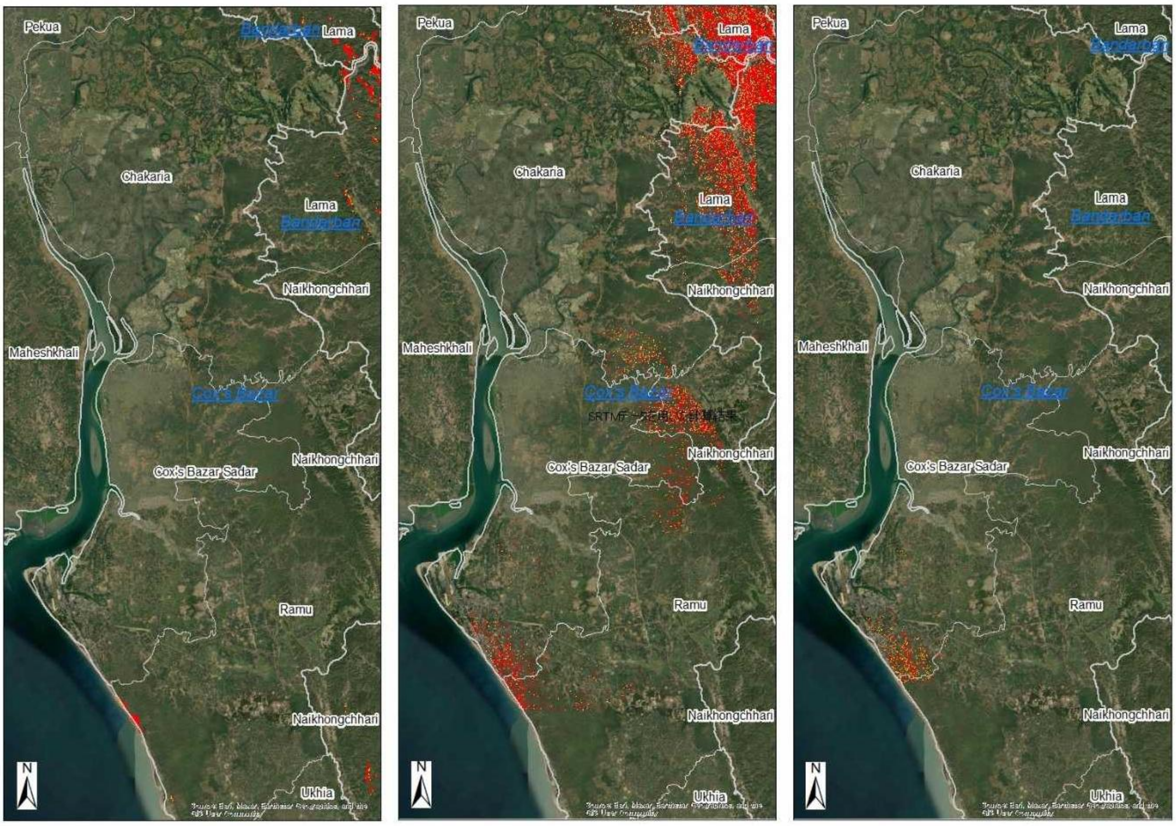
5. DIGITAL ELEVATION MODEL (DEM) FOR ANALYSIS

Usually, DEM can be derived from sources like remote sensing (e.g., LiDAR, photogrammetry) or radar data. Or can be derived by processing, for example, elevation points data (acquired by a GPS device) using GIS software for example.

The results of slope failure analysis depend heavily on the resolution of the DEM. For example, DEMs (such as SRTM, ALOS, etc.) that can be obtained for free from the internet have a maximum resolution of 30m (1 arcsecond), so that there are cases where micro-topography may be overlooked. High-resolution DEMs (2.5m, 1m, 0.5m, etc.) improve the accuracy of analysis, but it must be purchased at an expensive cost.

Therefore, the Project recommends a method of generating DEMs of the target area based on the GIS data (shapefiles) of 1/25,000 scale digital topographic maps provided by the Survey of Bangladesh (SOB). SOB's digital topographic maps cover the entire country of Bangladesh, and it is possible to purchase only the data of interest (e.g. spot height and contour data). As a result, a DEM with sufficient resolution to perform the slope failure analysis can be generated at a relatively low cost, making it easier to expand the analysis method nationwide.

The following Figure 5.1 shows the comparison of the analysis results using SRTM, ALOS DEM data and DEM data created from the data obtained from SOB.



a. Analysis result using SRTM DEM data (resolution 30m)	b. Analysis result using GIS data obtained from SOB (resolution 5m)	c. Analysis result using high-resolution ALSOS DEM data (resolution 2.5m)

Figure 5.1 Comparison of analysis result using different DEMs

Figure c. above shows the analysis result using high-resolution ALOS DEM (2.5m) that covers the

southern area of Cox's Bazar Sadar Upazila, and it is evident that in comparison with the result obtained by using SRTM DEM data (Figure a.), topographical features were overlooked. In the other hand, analysis result using DEM created from data of SOB (Figure b.) covers the overlooked topographical features in Figure a. and shows a closer result to ALOS DEM.

6. IMPLEMENTING HAZARD ZONING ANALYSIS NATIONWIDE

The MRVAM Project elaborated a nationwide level landslide susceptibility map and based on it, created a categorized population exposure map to landslide at Upazila/Thana level as shown in Figure 6.1

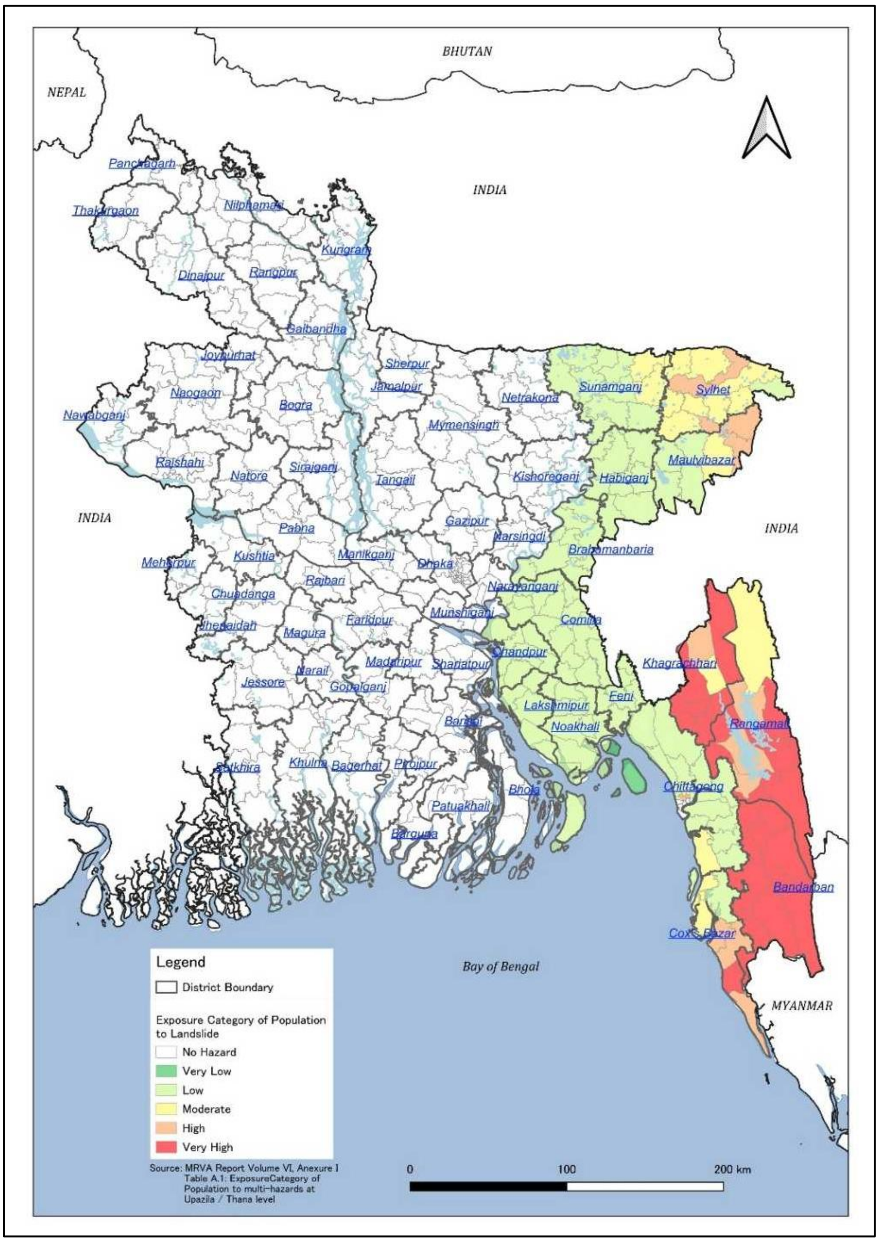


Figure 6.1 Exposure category level of population to landslide hazard at Upazila / Thana level

Source: MRVAM Report Volume VI, Anexure1, Table A.1: Exposure Category of Population to Multi-Hazards at Upazila/Thana Level

According to this map, the population exposed to landslides are in the eastern part of the country. When conducting a nationwide slope failure hazard analysis at Upazila level, it is recommendable to prioritize the Districts and Upazilas categorized as Very High and High for the elaboration of UzDRRP, based on the result of the map. Figure 6.2 below shows the index of 1/25,000 digital topographic maps provided by the SOB for the execution of the hazard analysis.

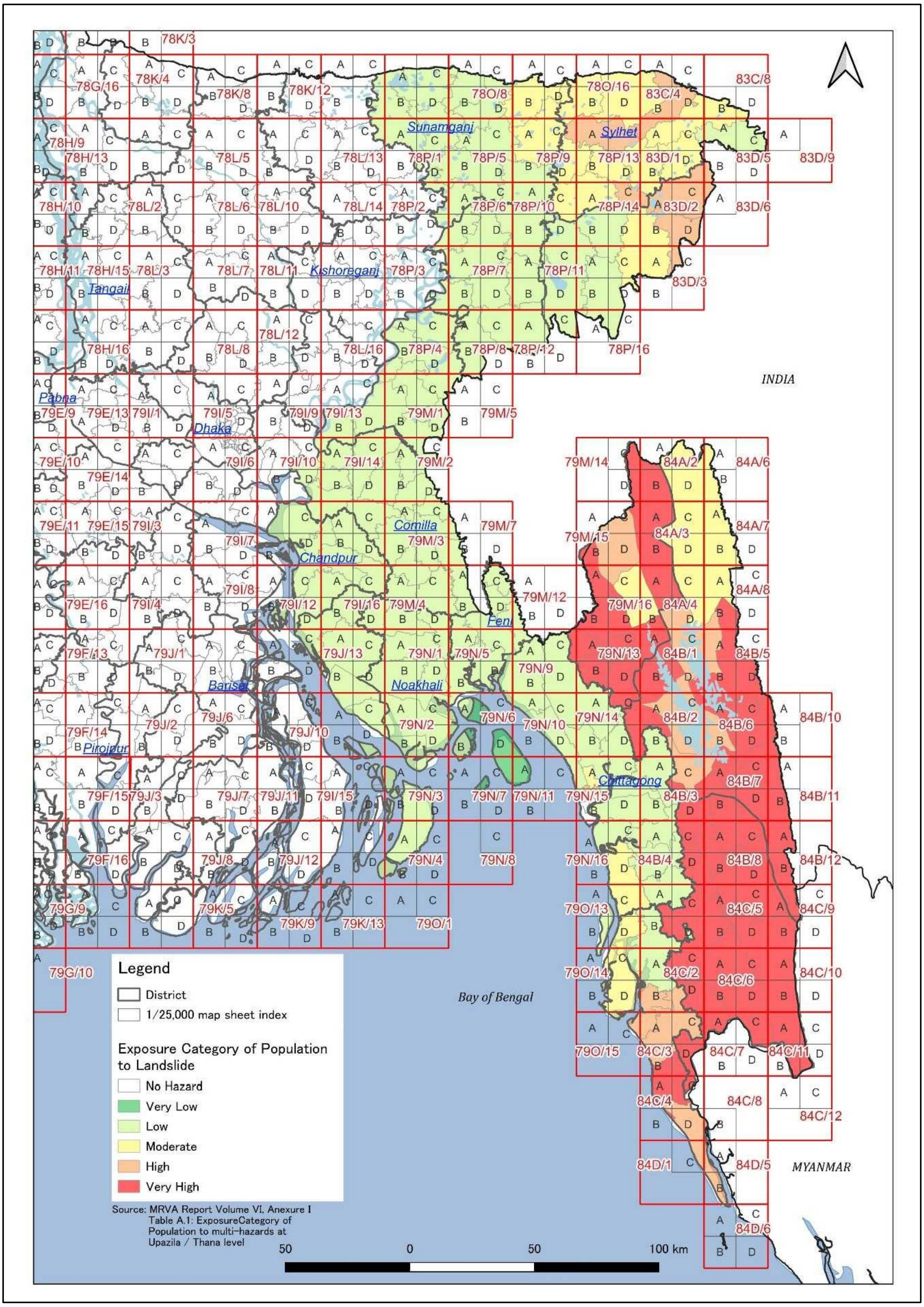


Figure 6.2 1/25,000 topographical map index for the area for analysis

ANNEX 6: Technical Manual for Earthquake Shaking Analysis

(Updated April. 2025)

Table of Contents

1. Introduction

Figure 1-1 shows the flow chart of the estimation of the strength of earthquake shaking (Peak Ground Acceleration: PGA) in each Union. Details are described in the following sub-sections.

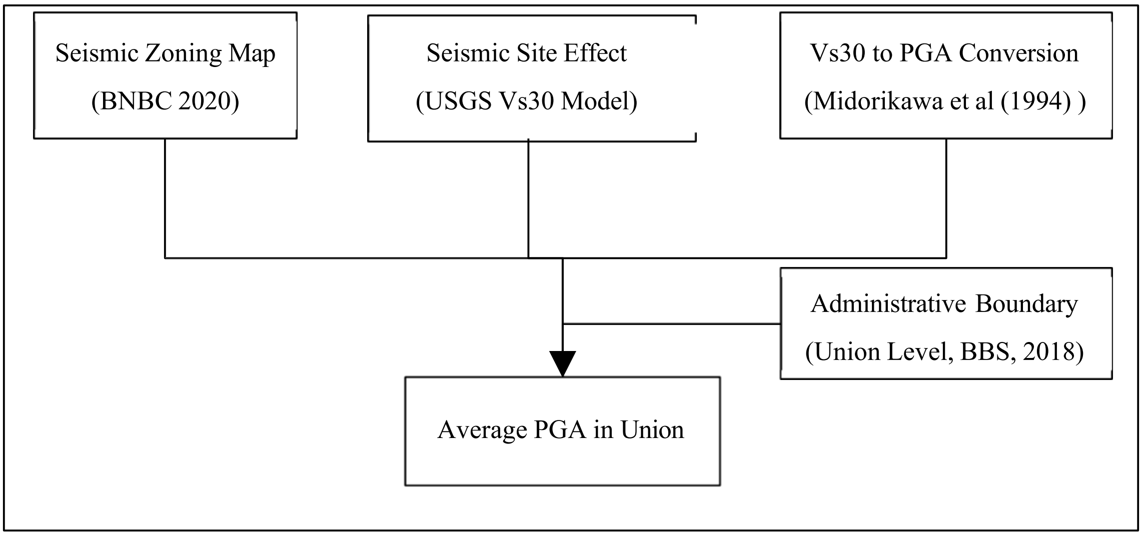


Figure 1-1 Process of Estimating Strength of Earthquake Shaking in Union

2. Estimating Strength of Earthquake Shaking in Union

2.1. Seismic Zoning Map

Based on the Seismic Zoning Map (Figure 6.2.24) on the Bangladesh National Building Code 2020 (BNBC 2020), the seismic zoning coefficient (Z) for the target area is identified. Then, the Peak Ground Acceleration on very stiff soil/rock (PGAr) is calculated.

$$PGAr = Z \times g$$

PGAr: the maximum considered Peak Ground Acceleration on very stiff soil/rock

Z: seismic zoning coefficient

g: acceleration due to gravity, $9.8m/s^2$

Several unions (e.g., located inside of the river) are not overlayed by the Seismic Zoning Map. JET manually assigned the Zone number and Z-value to such un- covered unions, based on the surrounding situation of each union.

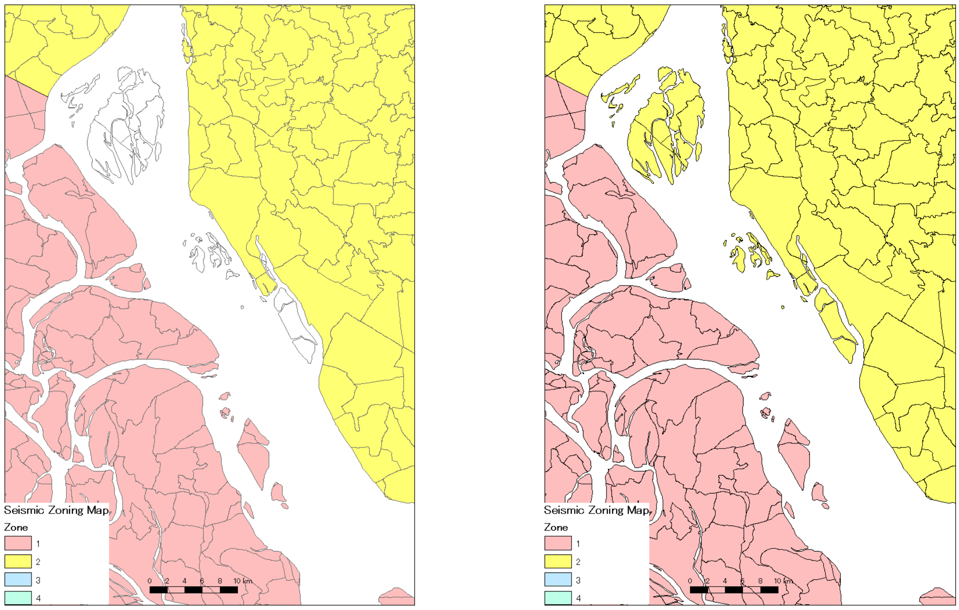


Figure 2-1 Before (left) and after (right) of manually assigning Zone Number in Union

2.2. USGS Vs30 Model

The Seismic Site Effect (shallow layer effect) is evaluated based on the United States Geological Survey's Vs30 Model (Vs30 Model). The Vs30 Model is a time- averaged shear-wave velocity to 30 m depth, using topographic slope as a proxy for seismic site-conditions. The grid resolution is 30 arcsecond.

(Source: <https://earthquake.usgs.gov/data/vs30/>)

Note 1: Water-covered areas (600 m/s) should be removed.

Note 2: The resolution of 30 arcsecond-grid means around 925 m (North-South) × 860 m (East-West) near Cox's Bazar Sadar Upazila in Cox's Bazar District.)

2.3 Administrative Boundary

In the Project, "bgd_adm_bbs_20180430.gdb" (Esri file geodatabase format) is introduced as administrative boundary GIS data (polygon). It includes the National (admin0Pcod), Division (admin1Pcod), District (admin2Pcod), Upazila (admin3Pcod), and Union (admin4Pcod) boundaries.

2.4. Calculation formulas of PGA in 30 arcsecond grid

Based on the Vs30 Model, the Amplification Factor (G) of PGAr is calculated by an empirical formula of Midorikawa et al. (1994, Proc. 9th Japan Earthq. Eng.

Symp., E-085 - E-090.).

For each 30 arcsecond grid:

$$\text{Log (G)} = 1.35 - 0.47 \text{ Log (Vs30)} - 0.18 \qquad (\textit{Midorikawa et al. (1994)})$$

$$\therefore \quad G = 10\text{^}(1.35 - 0.47 \text{ Log (Vs30)} - 0.18)$$

Vs30: Shear-Wave Velocity (USGS Vs30 Model)
G: Amplification Factor of PGAr

Eventually, PGA in each 30 arcsecond grid is as follows:

$$PGA = G \times PGAr = G \times Z \times g$$

PGA: Peak Ground Acceleration
PGAr: the maximum considered Peak Ground Acceleration on very stiff soil/rock
Z: seismic zoning coefficient (Figure 6.2.24, BNBC 2020)
g: acceleration due to gravity = 9.8 m/s^2

2.5. Calculation procedures of PGA in 30 arcsecond grid

For calculation of PGA in each grid, the downloaded Vs30 Model file (global_vs30.grd) is converted to a polygon shapefile. Then, convert the attribute table of the Vs30 shapefile (DBF format) into an Excel file.

Apply the formula above to the Excel file,

a. Calculate the Amplification Factor G from Vs30 (unit: m/s),
b. Calculate the Peak Ground Acceleration (PGA, unit: m/s^2) using G and Z.

The table below shows an example of PGA and the intermediate values.

Table 2-1 Example of the Excel file for PGA

GRID ID	Vs30	Log G	G	PGA
0	183	0.106102	1.276739	4.50
1	197	0.091826	1.235452	4.36
2	180	0.109530	1.286857	4.54
3	185	0.104019	1.270630	4.48
4	191	0.097699	1.252272	4.42
5	204	0.084514	1.214825	4.29

2.6. Calculation of average PGA in each Union

a. Export the attribute table of Vs30 shapefile to an Excel file.
b. using Table Join Function (Add Join) by ArcMap.
c. Create Identity Polygon of Union Boundary (polygon) and PGA grid (polygon) by [Geoprocessing]-[Identity] Tool of ArcMap.
d. Export the attribute table of the Identity Polygon to an Excel file.
e. Calculate the averaged PGA of each Union (admin4Pcod) using the pivot table function of Excel.

Table 2-2 Example: average PGA in each Union

adnin4Pcod	avePGA
10040913	1.41
10040915	1.35
10040923	1.4
10040939	1.36
10040943	1.35
10040947	1.37
10040963	1.37
10040971	1.4
10040979	1.39
10040987	1.4
10040991	1.31
10040994	1.36
10040995	1.39
10040996	1.19
10040999	1.3
10041923	1.31
10041947	1.37
10041971	1.33
10041995	1.32
10042817	1.33

A few unions (e.g., mismatch between Vs30 Model and Union Boundary) are not connected by the pivot table result through admin4Pcod. JET manually assigned the PGA value to such un-matched unions, referring to the nearest/highest values of the surrounding situation of each union.

2.7. Limitation of Damage Estimation

There are several assumptions that are introduced for numerical estimations in the Project.

(1) For calculation of building number based on CENSUS 2011, it is assumed that 1 (one) household uses 1 (one) building.

(2) 4 (four) building structure types of CENSUS 2011 (Pucca, Semi-pucca, Kutcha, and Jhupri) are assigned to the building structure types of Nepal (Masonry 1, Masonry 2, Masonry 4, and RC 1).

(3) PGA amplification factors for very stiff soil/rock are referred from BNBC 2020.

(4) PGA amplification factors for shallow layer are calculated based on the USGS Vs30 Model and the empirical formula by Midorikawa et al. (1994). (The empirical formula by Midorikawa et al. (1994) is based on the observation during the 1987 Chiba-Ken-Toho-Oki Earthquake, Japan.)

(5) Building Fragility Curve of the 2015 Nepal Earthquake are referred to identify the damage ratio for each building structure type.

(6) Mathematically, the estimated damage values have 2 (two) significant figures.