Ministry of Water Resources

Bangladesh Water Development Board

Coastal Embankment Improvement Project, Phase-I (CEIP-I)

Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)

Component-5: Finalization of approach for reconstruction of the Polder at different coastal zones including their phasing and construction Program

Component-5A: Drainage Modelling of Five Polders at Different Coastal Zones in Assessing Infrastructure need for Water Management

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Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone

Office: Flat #3/B, House #4, Road #23/A, Banani, Dhaka 1213, BANGLADESH Phone +880 1307 693299

Memo No: CEIP/LTMRA/0821/126 31 August 2021

Project Management Unit
Coastal Embankment Improvement Project, Phase-I (CEIP-I)
House No.15, 4th Floor, Road
No.24(CNW) Gulshan, Dhaka-1212

Attn: Mr. Syed Hasan Imam, Project Director

Dear Mr Imam,

Subject: Submission of Drainage Modelling of Five (05) Polders at Different Coastal Zones in Assessing Infrastructure need for Water Management

It is our pleasure to submit herewith two copies of the Drainage Modelling of Five (05) Polders at Different Coastal Zones in Assessing Infrastructure need for Water Management. This report contains the summary of survey work as per requirement of the modelling work, present hydrological situation, and selection of design hydrological flood event condition of the selected five polders. This report also contains the detailed mathematical modelling (hydrological and hydrodynamic modelling) of the selected polders. Inundation depth duration maps for the present hydrological situation and design flood event conditions also included into this report.

Remaining work on preparing the boundary conditions (scenarios), polder drainage improvement options and establishment of design parameters including polder management plan are also described in this report.

Thanking you,

Yours sincerely,

Dr Ranjit Galappatti
Team Leader

Copies: Engineer Mr. Fazlur Rashid, Director General, BWDB
Engr. Md. Mizanur Rahman, ADG (Planning), BWDB
Dr Kim Wium Olesen, Project Manager, DHI
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Mr Zahirul Haque Khan, Deputy Team Leader
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Swarna Kazi, Sr. Disaster Risk Management Specialist, World Bank

Joint Venture of DHI and Deltares in partnership with
IWM, University of Colorado, Boulder and Columbia University

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ACRONYMS AND ABBREVIATIONS

ADCP- Acoustic Doppler Current Profiler

BDP2100- Bangladesh Delta Plan 2100

BIWTA- Bangladesh Inland Water Transport Authority

BMD- Bangladesh Meteorological Department

BoB - Bay of Bengal

BWDB- Bangladesh Water Development Board

CBA- Coast Benefit Analysis

CCP- Chittagong Coastal Plain

CDMP-Comprehensive Disaster Management Program

CDSP- Char Development Settlement Project

CEA- Cost Effectiveness Analysis

CEGIS- Centre for Environmental and Geographic Information Services

CEIP- Coastal Embankment Improvement Project

CEP- Coastal Embankment Project

CERP-Coastal Embankment Rehabilitation Project

CPA- Chittagong Port Authority

CPP-Cyclone Protection Project

CSPS-Cyclone Shelter Preparatory Study

DDM- Department of Disaster Management

DEM- Digital Elevation Model

DOE- Department of Environment

EDP- Estuary Development Program

FAP- Flood Action Plan

FM- Flexible Mesh

GBM- Ganges Brahmaputra Meghna

GCM- General Circulation Model

GIS- Geographical Information System

GNSS- Global Navigation Satellite System

GPS- Global Positioning System

GTPE- Ganges Tidal Plain East

GTPW- Ganges Tidal Plain West

HD- Hydrodynamic

IGDCZ- Interactive Geo-Database for Coastal Zone

InSAR- Interferometric Synthetic Aperture Radar

IPCC- Intergovernmental Panel for Climate Change

IPSWAM- Integrated Planning for Sustainable Water Management

IWM- Institute of Water Modelling

LCC- Life Cycle Costs

LGED- Local Government Engineering Department

LGI- local Government Institute

LRP- Land Reclamation Project

MCA- Multi Criteria Analysis

MES- Meghna Estuary Study

MoWR- Ministry of Water Resources

MPA- Mongla Port Authority

NAM - Nedbor Afstromnings Model

PPMM- Participatory Polder Management Model

RCP- Representative Concentration Pathways

RSET-MH- Rod surface elevation table – marker horizon

RTK- Real-Time Kinematic

SET-MH- Surface Elevation Tables – Marker Horizons

SLR- Sea Level Rise

SOB- Survey of Bangladesh

SSC- Suspended Sediment Concentration

SWRM- South West Region Model

TBM- Temporary Bench Mark

ToR- Terms of Reference

WARPO- Water Resources Planning Organization L - Water Level

1 INTRODUCTION

According to ToR (Component-5), conceptual planning and design of five (05) polders were recommended under Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone project. In this regard, at the initial stage, eleven (11) polders were considered and later, five (05) polders were selected based on the multicriteria analysis. Several key parameters like very little freshwater flow from upstream River (Ganges); influence of strong tidal action and acute salinity problem, peripheral river sedimentation problem which creates drainage problem; experiencing prolonged water logging and river-bank erosion problem due to thalweg migration; vulnerable to cyclonic storm surge, these were considered during fixation of zone-wise coastal polders under this project. Selections of polders were considered in a way that represents physical characteristics of the four coastal zones of Bangladesh (South-West, South-Central, South-East, and Eastern Hilly zone).

The scope of works is to establish designs for 05 polders considering climate change, subsidence, possible land heights, land use, economic activities, required infrastructure for water management, and drinking water facilities for long-term stability. Also prepare to make a cost estimation for the redesign of the polders and to assess the benefits and beneficiaries for the proposed improved interventions. In accordance with the ToR, long term polder improvement measures and polder development Plan both will be included in this technical report. The developed concept of planning and design of these five polders would guide the overall development plan for the rest of the polders entire coastal zone of Bangladesh. Therefore, improvement and investment plan can be fixed based on this improvement plan. Figure 1.1 presents the Geographical Settings of the selected Coastal Polders in the Long-Term Research and Monitoring Project.

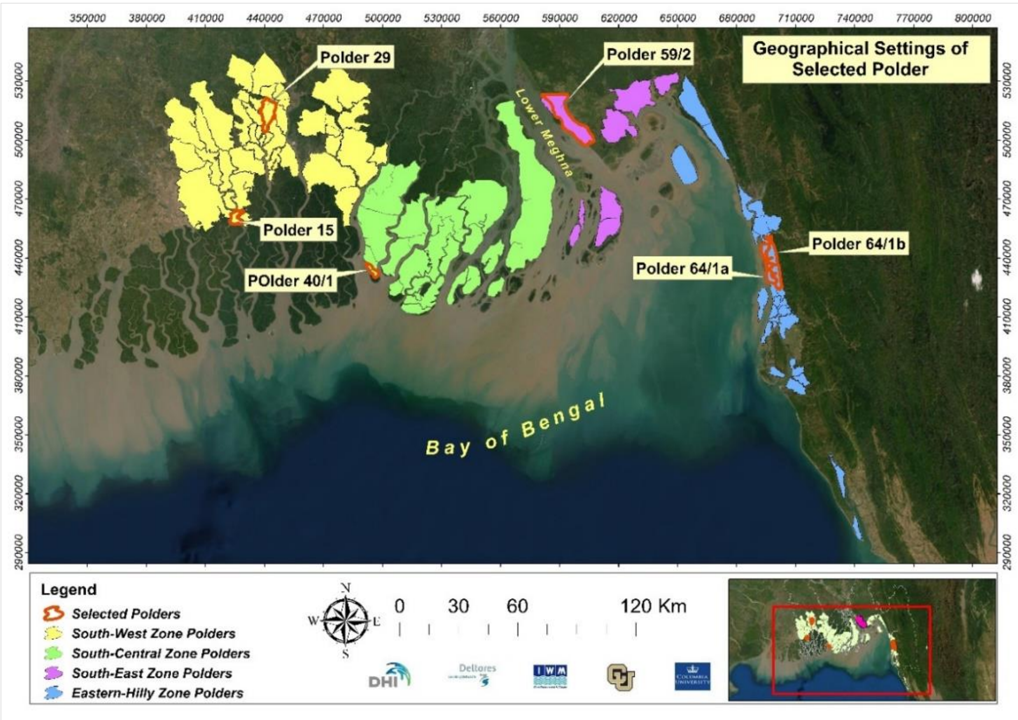


Figure 1.1: Geographical Settings of the selected Coastal Polders in the Long-Term Research and Monitoring Project

2 DATA COLLECTION

Two types of data collection have been carried out in the Long-Term Research and Monitoring Program. Hydrological data has been carried out as a secondary data and detailed polder information has been carried out as a primary data. IWM developed three calibrated and validated regional models (i South-West Regional Model, ii) South-East Regional Model and iii) Eastern Hilly Regional Model) also used as secondary data sources.

2.1 Primary Data Collection

One dedicated survey campaign has been carried out to collect the field data for the selected polders. Modelling team prepared the data requirement as per mathematical model development for the polder system. The following data collection has been carried out in this project.

- Polder Embankment Alignment;
- Polder Embankment cross sections @ 500m interval or less interval;
- Drainage channels/khals alignment;
- Drainage channels/khals cross section @ 400m interval or less interval;
- Detailed information of the water control structures (drainage regulators and flushing regulators information)
    - Types of regulators;
    - Geometric position of the regulators (latitude and longitude);
    - No. of vents;
    - Vent size (width x height);
    - Invert level;
    - Deck level;
    - Soffit level;
    - Country side and river side loose apron length;
    - Existing condition of regulators;
    - Upstream and downstream photos of all regulators;
- Water level at polder side and country side;
- Topographic land level of all polders;
- Peripheral river cross sections of all polders;

The present status of the data collection is presented in the following Table 2.1:

Table 2.1: Status of the data collection plan

Sl No.	Polder No	Location	Status of the Survey Work: Embankment (Km)	Structure Inventory (nos.)	Drainage Channels (Km)	Peripheral River section (Nos.)	Topo Survey (Km^2)	Progress of the Field Survey: Embankment (Km)	Structure Inventory (nos.)	Drainage Channels (Km)	Peripheral River section (Nos.)	Topographic Survey (Km2)	Remarks
1	40/1	Patharghata, Barguna	23	27	27	43	20	Complete	Complete	Complete	Complete	Surveyed under LTM Project	scattered very fine resolution
2	29	(Dumuria, Botiaghata), Khulna	49	41	121	120	79.3						
3	59/2	(Char Alexander, Kamalnagar), Noakhali	88.5	20	73	61	209						
4	64/1a	Bishkhali, Chittagong	53.7	19	41.6	56	65						
5	64/1b	Bishkhali, Chittagong	83	31	63	24	76.3						
6	15	Shymnagar, Satkhira	27	12	20	36						carried out in 2015	Topo data collected during 2015 by IWM will be utilized for drainage model

As an example, a detailed survey work of the Polder 40/1 has been presented in the Figure 2.1**.** The detailed survey map presents the internal drainage channels/khals alignment, cross sections of the internal khals, peripheral rivers, peripheral polder alignment and cross sections, structure locations and detailed information, topographic level of the polders. All the surveyed items have been used in the polder drainage model for presenting the physical hydrological process of each polder.

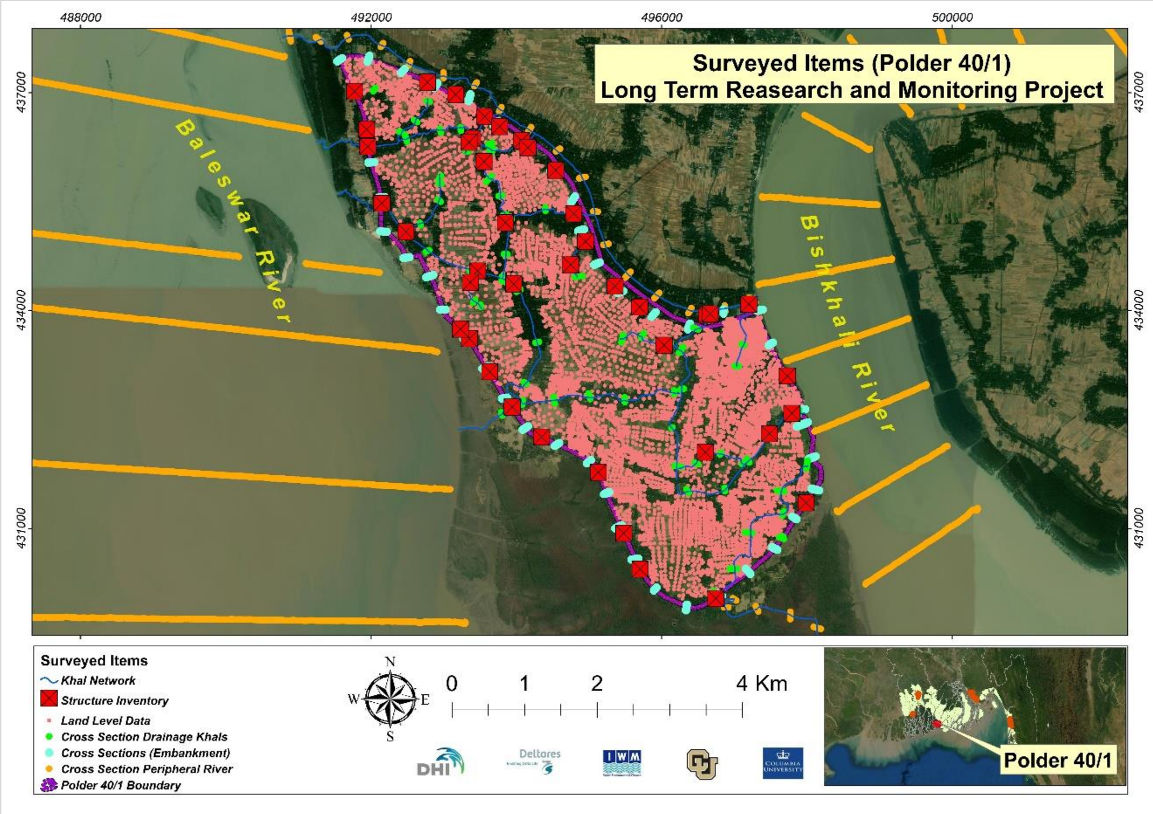


Figure 2.1: Map showing the surveyed information of Polder 40/1

2.1.1 Peripheral River and Khal/ drainage channel Cross Sections

Peripheral River cross sections of the selected polders have been measured under this project[1] @400m intervals or closer intervals depending on the river geometric shape. In this regards, Single beam echo sounder has been used to survey the river bathymetry along predetermined cross section run lines. Geometry of all khals/channels were also surveyed during the data collection period at intervals of 400m or less as per polder drainage modelling requirement. Single beam echo-sounder has been applied for the wider width of the drainage channels and sounding method has been applied in the smaller drainage khals. Cross sections at upstream and downstream of all regulators have been measured which are used in the developed Water-Flow model to control the regulators operation rules. The following Figure 2.2 presents the overall cross sections of the peripheral rivers and the internal drainage channels/khals which were measured under this Project.

[1] Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics), Coastal Embankment Improvement Project, Phase-I (CEIP-I), between Bangladesh Water Development Board and Joint Venture of DHI and Deltares in partnership with, IWM, University of Colorado, Boulder and Columbia University

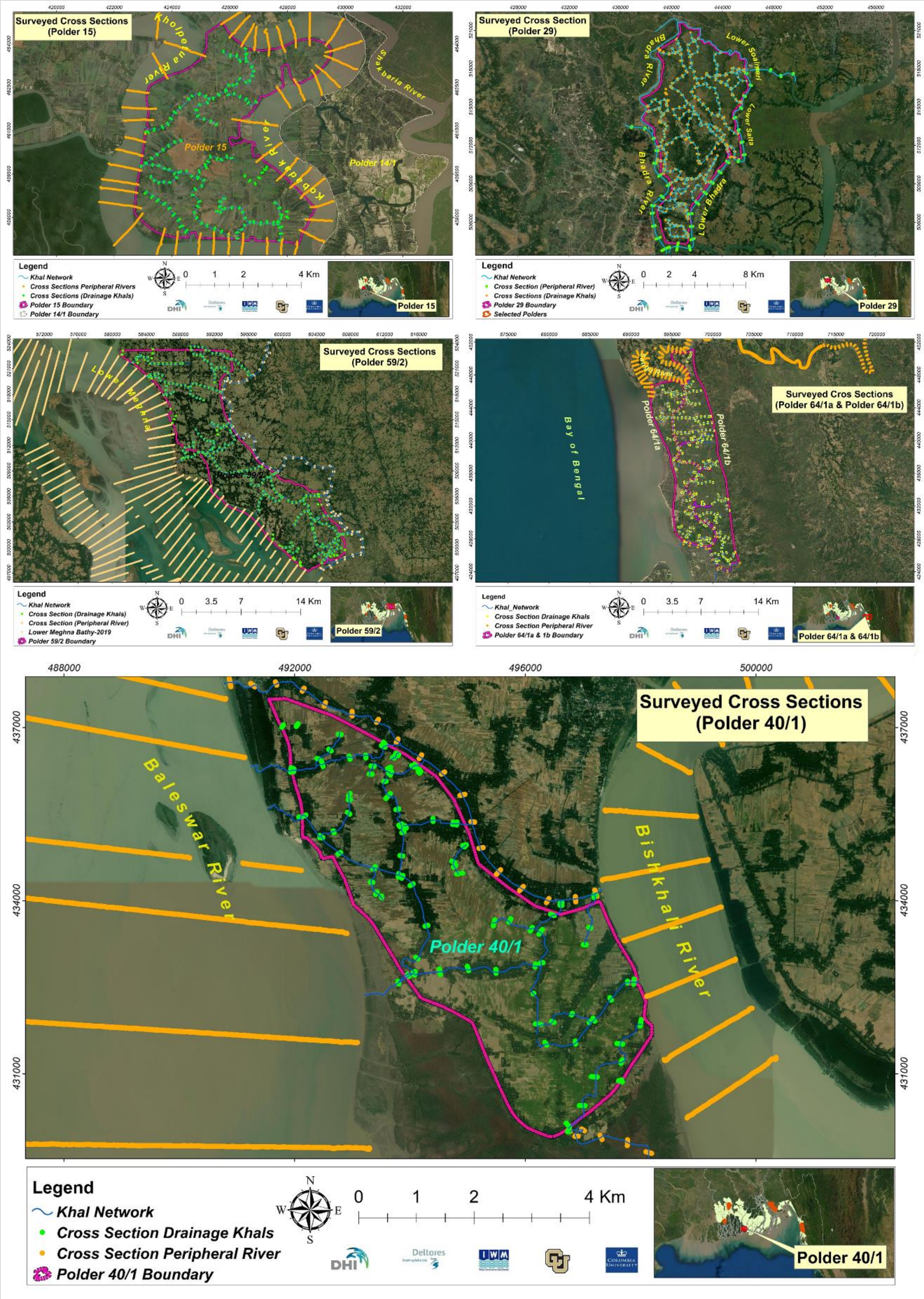


Figure 2.2: Locations of the peripheral rivers and internal drainage channels measured cross sections

One typical cross section at upstream and downstream of the drainage regulators (DS-02, Padma Sluice as called by Local Community) of the Polder 40/1 has been presented in the following Figure 2.3. The upstream and downstream khal cross sections of all regulators of all polders have been surveyed during the survey campaign and these cross sections provides water level in the polder drainage model- usually head difference developed at these two locations to perform the regulator gate operation into the model.

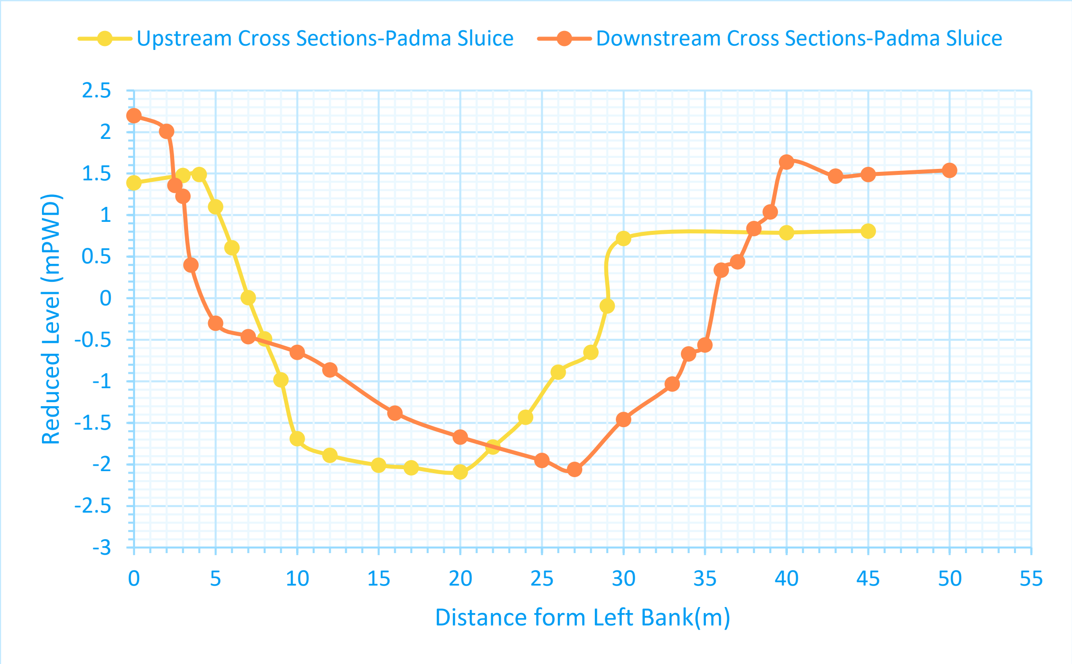


Figure 2.3: Upstream and downstream cross sections at the drainage regulator, DS-02 of the selected Polder 40/1

2.1.2 Water Level Data

About 10 locations have been considered for measuring water levels covering the whole coastal area of Bangladesh. The water level observed locations are i. Kaikhali in the Ichamoti River, ii. Hiron Point in the downstream of Pussur-Shibsa River, iii. Nalian in the Shibsa River, iv. Joymoni in the Pussur River, v. Char Doani in the Baleswar River, vi. Taltoli in the downstream of Bishkhali-Buriswar River, vii. Dhulasar in the downstream of Tentulia River, viii. Dasmina in the right bank of the Tentulia River, ix. Daulatkhan in the right bank of the Lower Meghna River and x. Chanua in the Sangu River. The following Figure 2.4 presents the observed water level locations in the coastal area of Bangladesh.

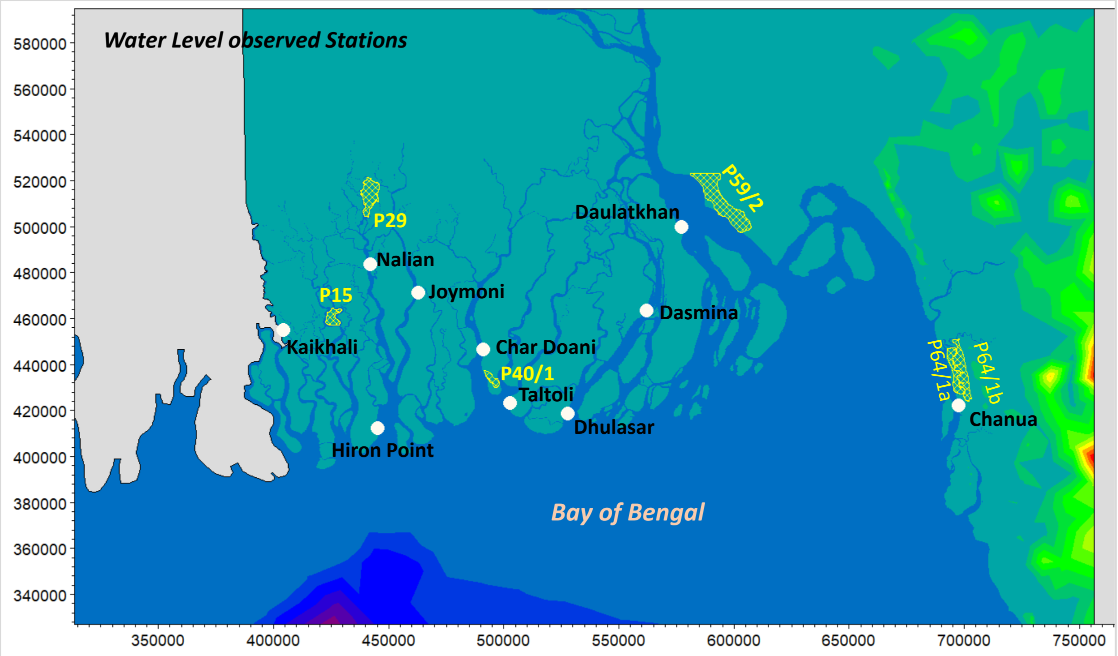


Figure 2.4: Water level measurement locations in the coastal area of Bangladesh under Long Term Research and Monitoring Project

These locations have been selected in a way which covers the selected polders under the Long-Term Research and Monitoring Project. The observed water level has been used for preparing the downstream boundary conditions and calibrating the newly updated South-West Regional Model. Figure 2.5 presents the observed water level hydrograph for four locations.

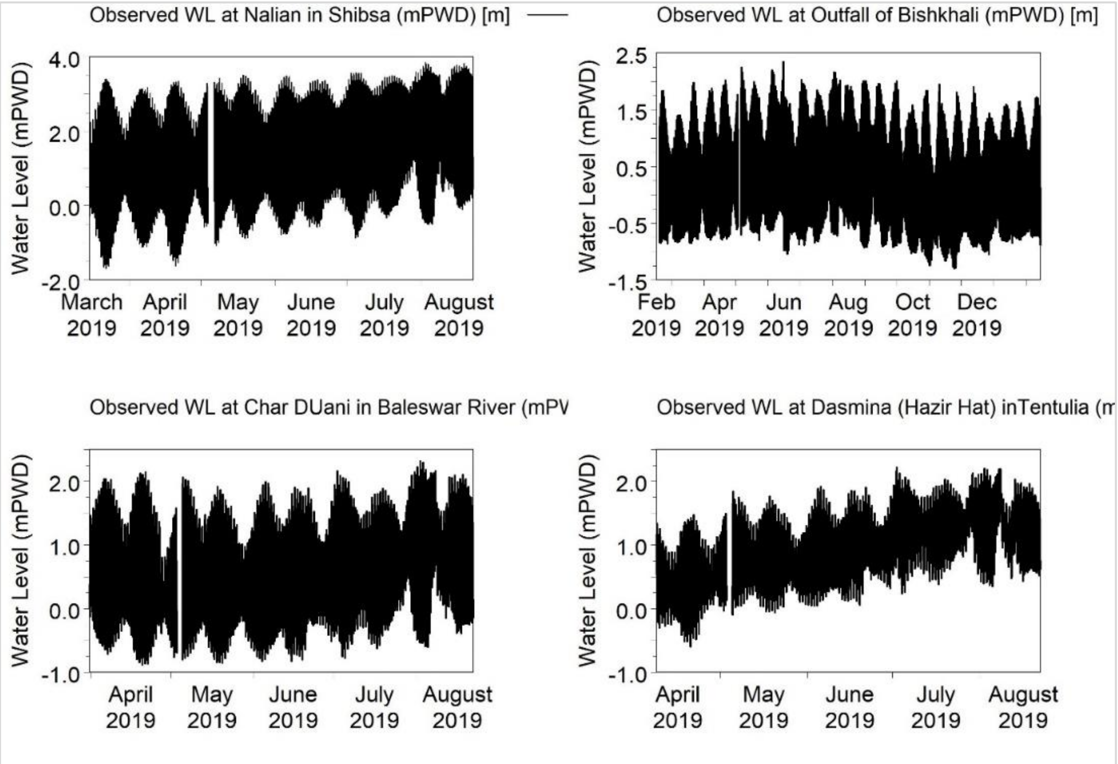


Figure 2.5: Observed water level at different locations in the coastal area of Bangladesh

Besides the water level measurement in the peripheral river system of the polders, two locations have been selected in the Polder 40/1 for measuring the inside polder water level and outside of the polder water level (Figure 2.6).

Figure 2.6: Locations of the installed pressure sensors and water level gauges in the Polder 40/1

The main objective of these two water levels is to understand gate operation timing of the Polder 40/1. Therefore, two pressure sensors have been installed at the upstream and downstream of the regulator Padma Sluice (DS-02). One pressure sensor has been installed at the polder side (upstream of DS-02) and another is installed at the river side (downstream of DS-02). The installed pressure sensors have been customized to collect data every 10mins intervals. Two manual water level measuring gauge also been installed at the same locations where pressure sensors have been installed. The main purpose of these two manual gauges installation is to calibrate the pressure sensor data. Figure 2.7 shows the observed pressure sensor data.

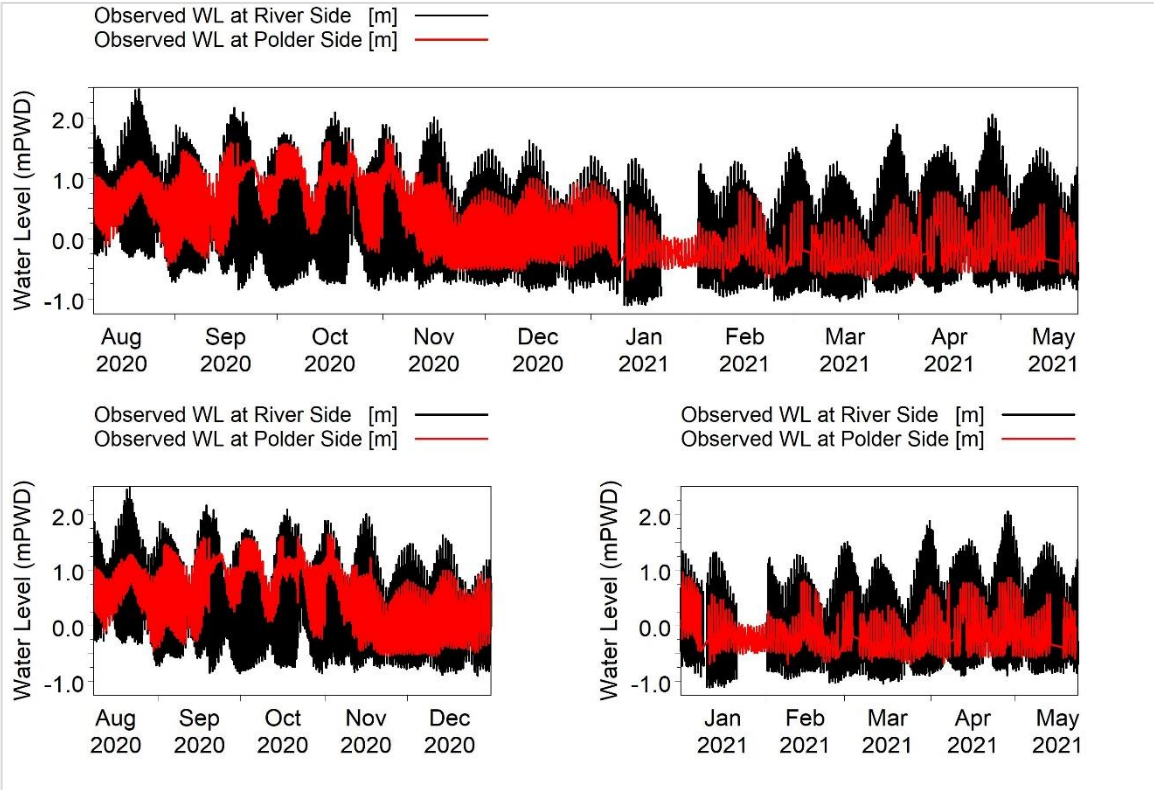


Figure 2.7: Water level data at polder side and river side of the drainage regulator DS-02

Note: The red color line water level indicates the polder side water level and the black color line define the river side water level of the drainage regulator DS-02.

The observed time series river side water level of the Polder 40/1 has been used as the boundary conditions of the downstream of all regulators of the developed Polder 40/1 hydrodynamic Model. However, uses of this water level as the boundary conditions of all regulators has been described in the Section 4.2.1.5.

2.1.3 Topographic Data

Scattered but very fine resolution land level data has been collected for all selected six (06) polders-Polder 15, Polder 29, Polder 40/1, Polder 59/2, Polder 64/1a and Polder 64/1b. The collected land level data has been used for preparing the Digital Elevation Model (DEM) for the selected polders using Inverse distance weighted (IDW) interpolation (a linearly weighted combination of a set of sample points) technique by Geographic Information System (GIS). The frequency distribution of the topographic levels of the selected polders has been generated by GIS statistical tools, presents in the following Figure 2.8.

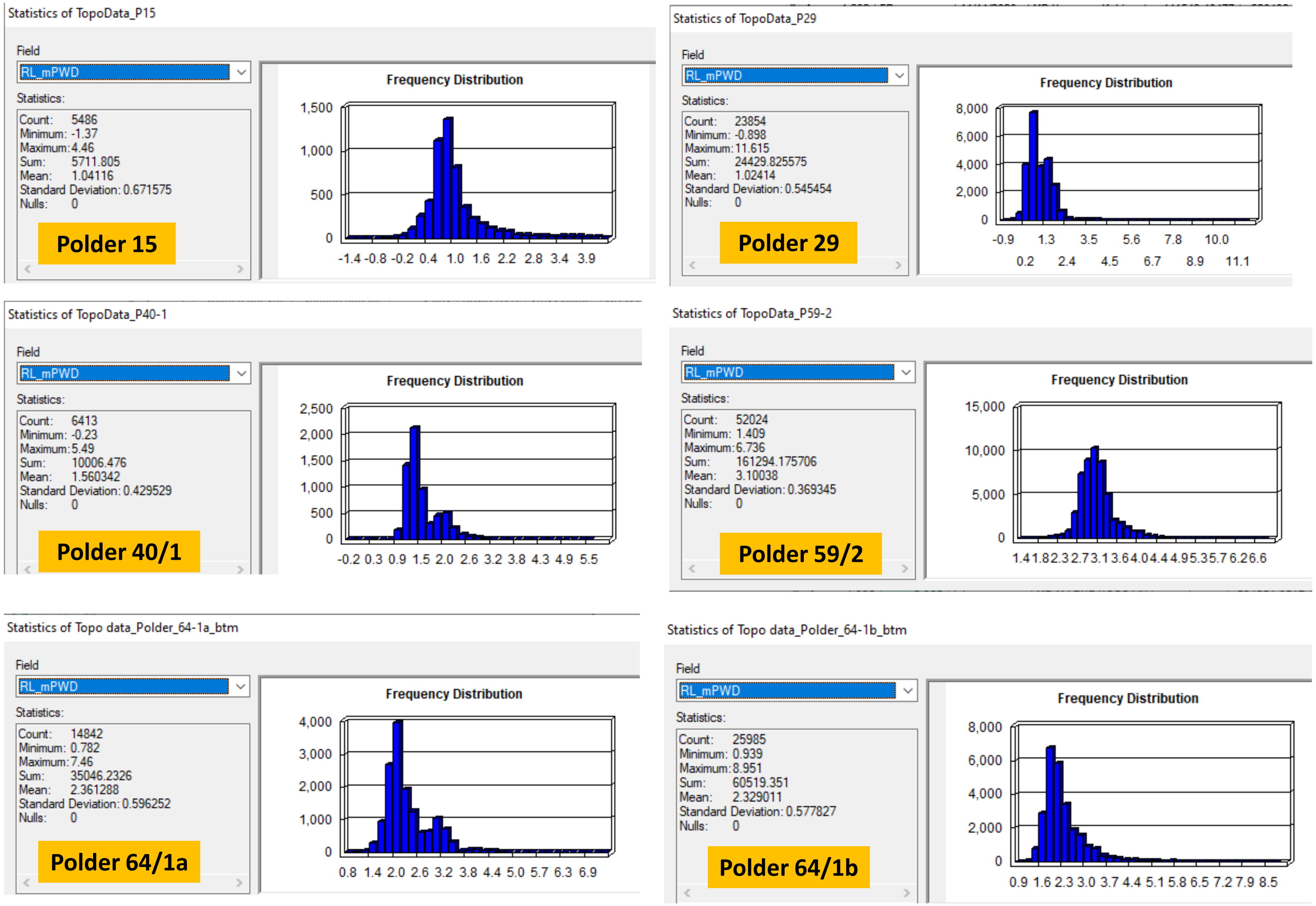


Figure 2.8: Land level information of the selected Polders

The maximum, minimum and average land levels are estimated from the surveyed topographic data where land levels are included for sand filling area, embankment height, road levels, home stead, agricultural lands etc. The following Table 2.2 presents the polder-wise land level variation of the selected Polders. As per example, the average land level of the polder 40/1 is found 1.56 mPWD where the maximum and minimum land level is 5.49 mPWD and (-) 0.23 mPWD respectively.

Table 2.2: Average land level information of the selected polders

SL No.	Polder Name	Maximum Land Level (mPWD)	Minimum Land Level (mPWD)	Average Land Level (mPWD)
1	Polder 15	4.46	-1.37	1.04
2	Polder 29	4.54	-0.89	1.02
3	Polder 40/1	5.49	-0.23	1.56
4	Polder 59/2	6.74	1.41	3.1
5	Polder 64/1a	7.46	0.782	2.36
6	Polder 64/1b	8.95	0.94	2.33

Area elevation curve (Figure 2.9) of each polder also shows the similar land level information of the selected polders. The developed area-elevation curve also helps to fix the invert level of the regulators and overall land level information of each polder.

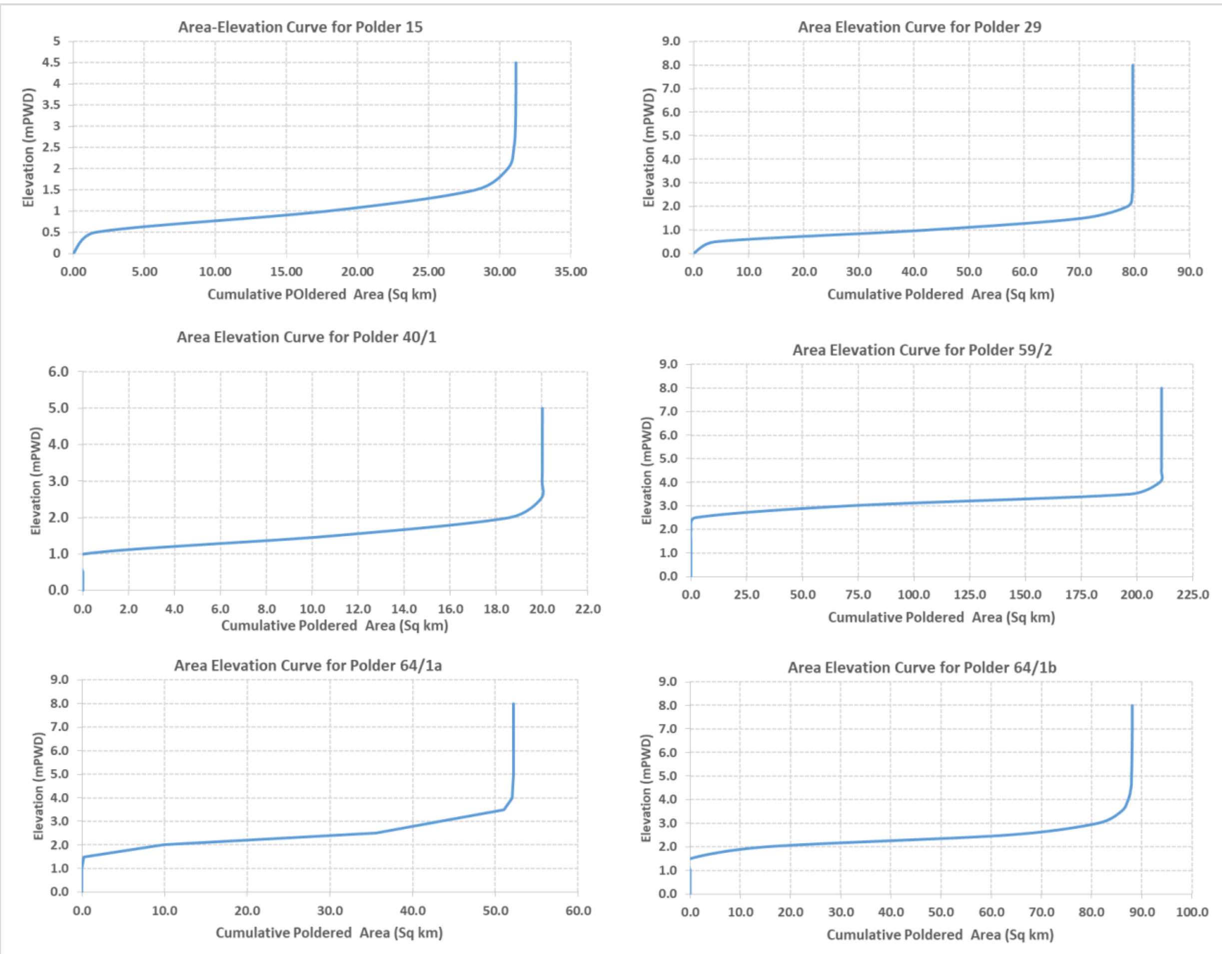


Figure 2.9: Area elevation curve of the selected polders

Using the collected land level information, digital elevation model has been prepared for the selected polders. These developed digital elevation model has been used to generate the inundation depth duration map for the polders. As an example, the digital elevation model of the selected Polders presented in the Figure 2.10.

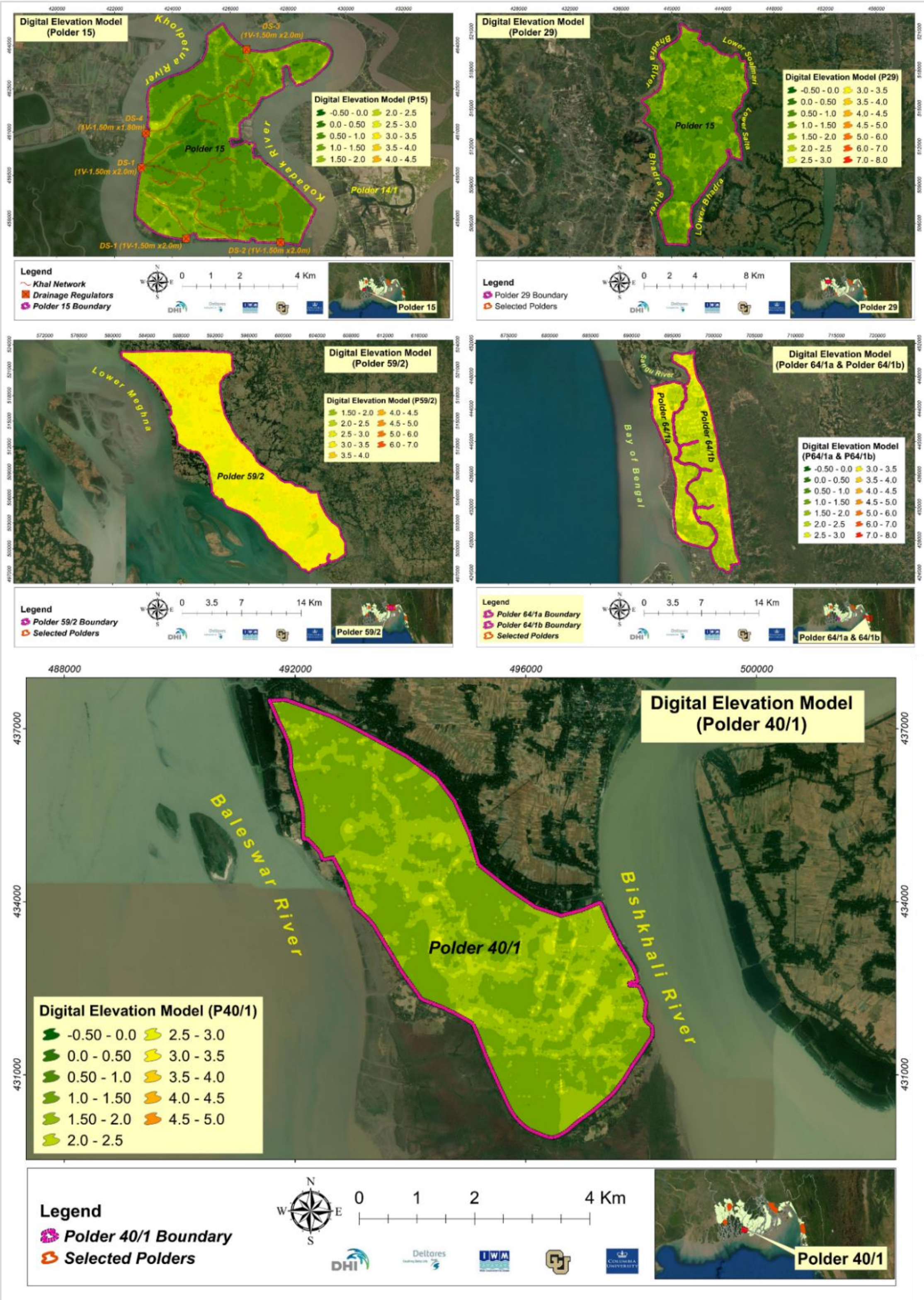


Figure 2.10: Digital Elevation Model for the selected Polders

2.1.4 Structure Information

Detailed structure information for the selected polders has been carried out during the data collection period. Photographs of the regulator upstream and downstream conditions also be taken to understand the existing physical conditions of the regulator. Detailed information of the drainage and flushing regulators like types of regulators, geometric position of the regulators (lat and long), no. of vents, vent size (width x height), invert level, deck level, soffit level, country side and river side loose apron length, existing condition of regulators, upstream and downstream photos of all regulators, all information has been collected as per model team requirement. The following Figure 2.11 presents the regulator information of the selected polders.

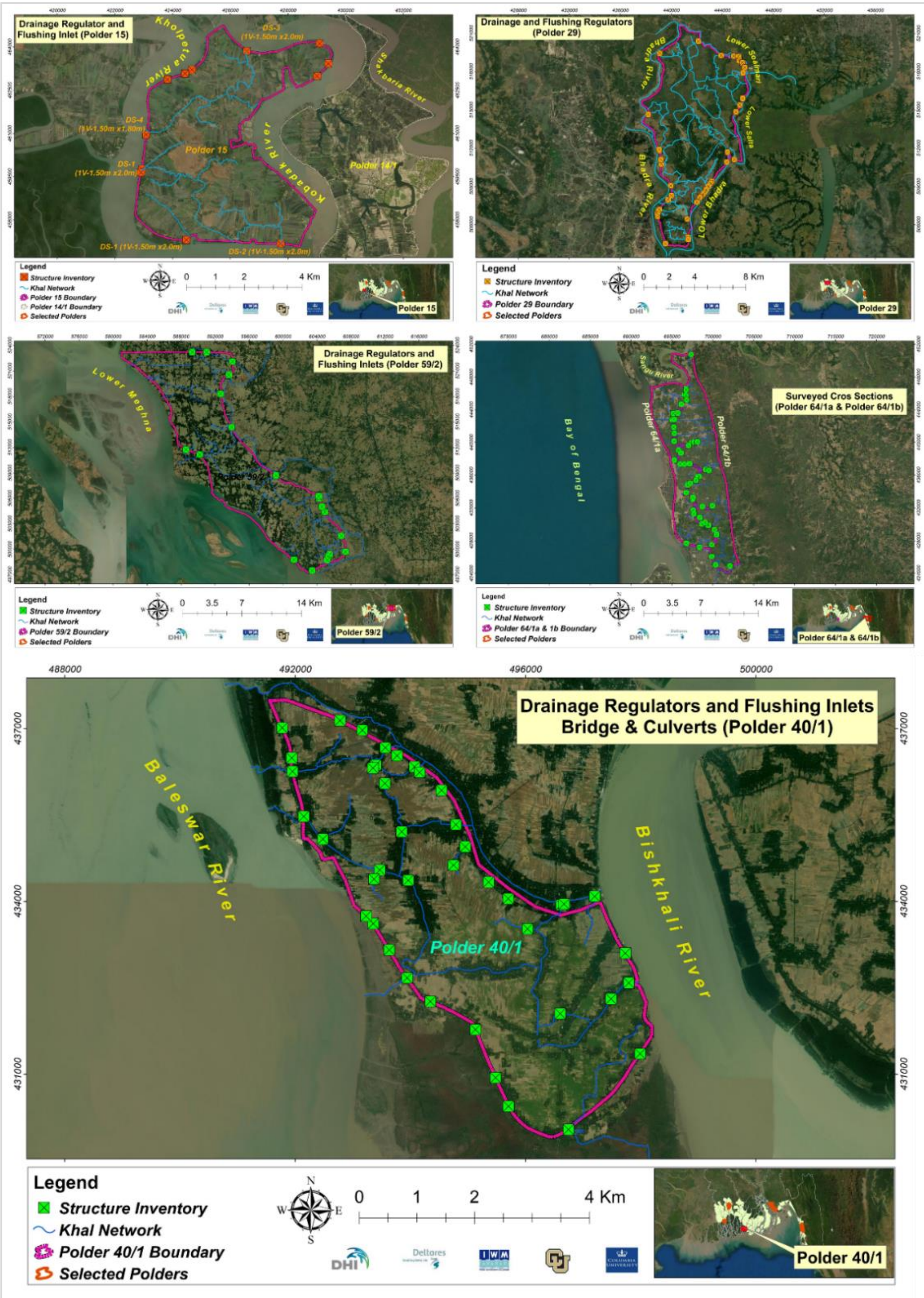


Figure 2.11: Locations of the detailed structure inventory collection of the specific selected polders

As an example, the upstream and downstream condition of the drainage regulator Padma Sluice (DS-2) and flushing inlet, FS-06 of the Polder 40/1 are presented in the following Figure 2.12 and Figure 2.13 respectively. These photographs and detailed information of the regulators have helped the modelling team during preparing the drainage model of the selected polders at existing condition.

Figure 2.12: Polder side and river side information of the drainage regulator DS-2 (Padma Sluice)

Figure 2.13: Polder side and river side information of the flushing inlet FS-06

In the Water-Flow model, the structure information has been included as the field condition to generate the existing condition of the Polder 40/1 and the other polders.

2.1.5 Embankment Alignment and Cross Sections

Embankment alignment and cross sections of the existing embankment of all selected polders have been surveyed @500m interval or less based on the existing physical and geometric conditions of the embankment. The measured cross section will help to design the crest level of the existing embankment height, fixation of drainage regulators deck level and computation of earth works of the total embankment. One typical embankment cross section profile at different locations (embankment chainage Ch 21+000, Ch 21+500 and Ch 22+000) of the selected Polder 40/1 has been plotted in the following Figure 2.14 .

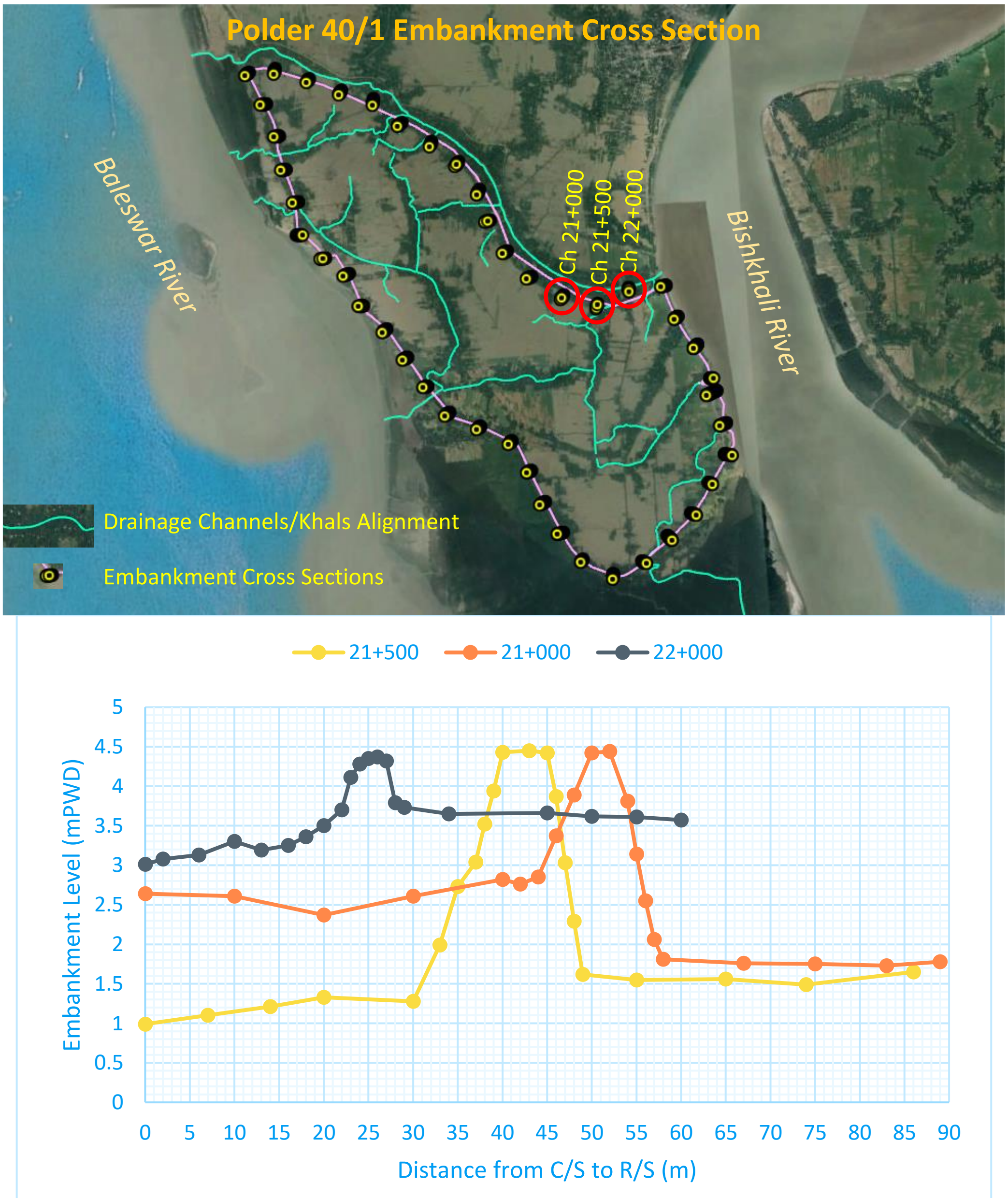


Figure 2.14: Polder 40/1 Embankment cross section at different chainages

2.2 Secondary Data Collection

2.2.1 Hydrological Data

Hydrological data like rainfall and evaporation both are collected as secondary data from Bangladesh Water Development Board (BWDB). Theisen polygon method was applied to identify the influence of each rainfall station in the selected polders (Polder 15, Polder 29, Polder 40/1, Polder 59/2 and Polder 64/1a & Polder 64/1b). After that, rainfall information of the selected rainfall stations has been used for determining seasonal rainfall variation and calculating the design flood event condition for each polder.

2.2.2 Regional Models

The calibrated and validated South-West Regional Model (SWRM) covers the selected polders – Polder 15, Polder 29 and Polder 40/1, South-East Regional Model (SERM) covers one selected Polder 59/2 and Eastern Hilly Regional Model (EHRM) covers the Polder 64/1a & Polder 64/1b. During the Long-Term Research and Monitoring (LTRM) project, these models have been updated by the recent river cross sections, upstream and downstream boundary conditions and used for preparing the boundary conditions. These data sets are used as secondary sources.

2.2.2.1 South-West Regional Model

The selected polders-Polder 15, Polder-29 and Polder 40/1 are incorporated into the existing calibrated and validated South West Regional Model for developing the Polder drainage model (Figure 2.15). In the original Southwest Regional Model polder information was not included. Hence, this model is updated by incorporating newly surveyed cross-section data of the internal drainage channels, peripheral river systems and existing water control structures within the polder area. Detailed catchments distribution for the internal drainage channels as well as the drainage regulators also be included in the South-West Regional Model for preparing the polder drainage model. The developed polder drainage model able to process the whole hydrological system of the polder in a frame.

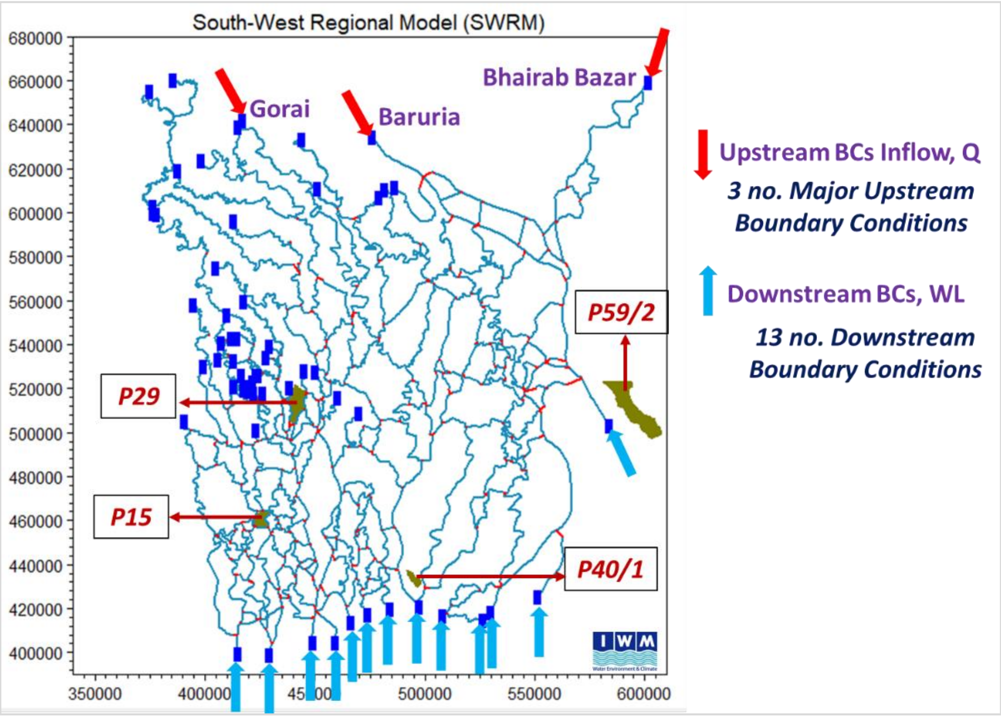


Figure 2.15: River Network and boundary conditions of South-West Regional Model

2.2.2.2 South-East Regional Model

The existing calibrated and validated South-East Regional Model (SERM) has been used for developing the drainage model of the Polder 59/2 (Figure 2.16). This model also contains only the river network, river cross sections and upstream & downstream boundary conditions. Few peripheral khals are flowing to the eastern side of the Polder 59/2. The boundary conditions of these peripheral khals have been derived from the SERM model. One dedicated polder drainage model has been prepared using the Polder 59/2 internal khal/channel network, internal khal cross sections and the exiting regulator information. Few boundary conditions of the dedicated Polder 59/2 drainage model are generated from the calibrated and validated South-East Regional Model (SERM) and few boundary conditions are generated from the South-West Regional Model (SWRM).

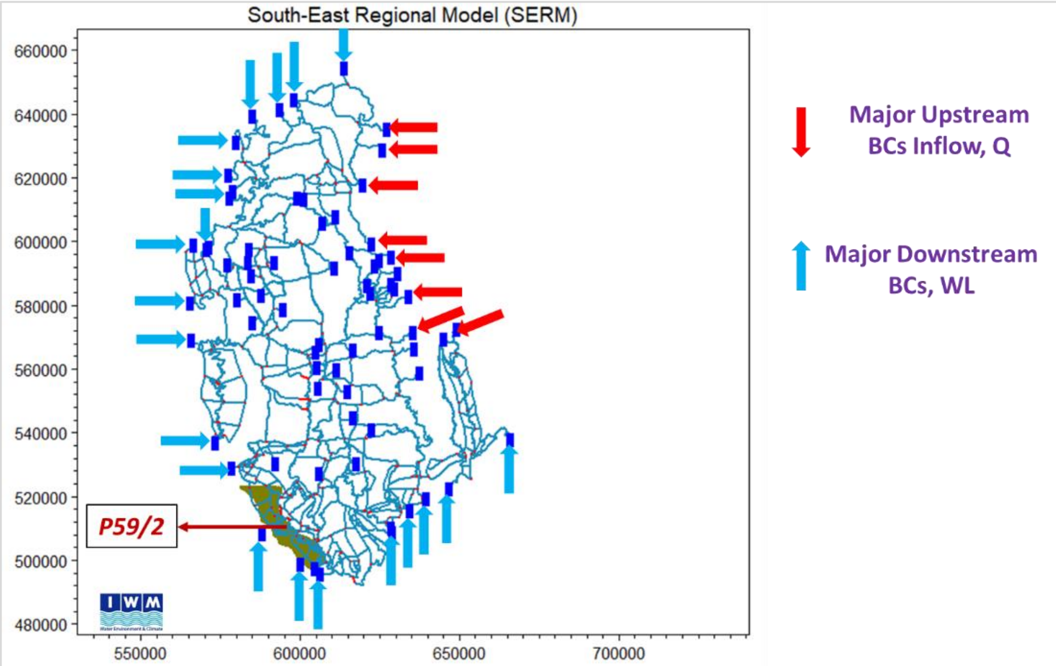


Figure 2.16: River Network and boundary conditions of South-East Regional Model

2.2.2.3 Eastern Hilly Regional Model (EHRM)

Eastern Hilly Regional Model (EHRM) is a very simple model containing Karnaphuli River, Halda River, Sangu and Matamuhuri River (Figure 2.17). Similarly, this regional model only presents the river networks, river cross sections and boundary conditions. Polders were not included into the EHRM model. The selected polders-Polder 64/1a and Polder 64/1b only connected with the Sangu River where tides and flash flood happen regularly. Therefore, during development of the polder drainage model for the Polder 64/1a and Polder 64/1b, Sangu River and the peripheral River are considered to drain the polder indie water through the regulators. The downstream boundary conditions of the dedicated Polder 64/1a & Polder 64/1b are developed from the Easter Hilly Regional Model.

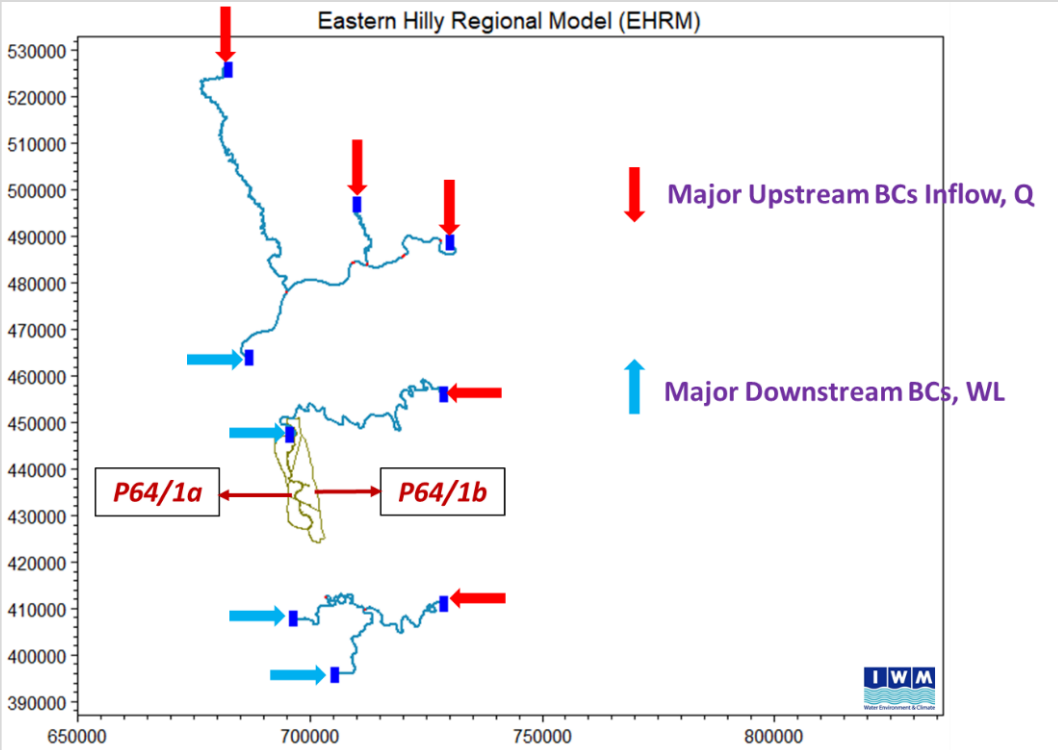


Figure 2.17: River Network and boundary conditions of Eastern Hilly Regional Model

3 Data Analysis and Development of Climate Change Scenarios

Polder drainage performance depends on mainly four (04) observations, i) Peripheral River/Outfall conditions (geometrical condition-sedimentation or live channel and tidal Phase) ii) Conditions of the drainage regulators (adequate opening, gate operation and gate condition), iii) Conveyance capacity of the drainage channels (cross sections, longitudinal slope, blockage in the khals and connection between each drainage channels) and iv) amount of rainfall during monsoon. Therefore, it is very important to know the exact amount rainfall happen into the Polder and how much water generated from these rainfall events and how much water is capable to drain out through the drainage channels and regulators in all conditions (existing conditions and future climate change conditions).

To understand the total physical processes of a polder, the following considerations needs to carry on i) Hydrological Analysis ii) Development of Rainfall generated Runoff and iii) Inclusion of rainfall generated runoff into the Polder Hydrodynamic Model where all drainage channels, drainage regulators, internal physical process and peripheral condition will be included. However, planning and designing of a polder, incorporation of future changes like hydrological and hydraulic changes should be considered for a selected design flood events to run the polder system in all worst scenarios.

3.1 Hydrological Analysis

Polder 15, Polder 29, Polder 40/1, Polder 59/2, and Polder 64/1a & Polder 64/1b, these six polders have been selected under the Long-Term Research and Monitoring Project. Bangladesh Meteorological Department (BMD) and Bangladesh Water Development Board (BWDB), both institutes are measuring rainfall stations in district wise/Upazila wise covering the whole Bangladesh. Among them, BWDB covers Upazila level rainfall measuring station. There are some rainfall stations which are maintaining in the coastal area also. The following Figure 3.1 presents the available rainfall stations in the coastal area of Bangladesh.

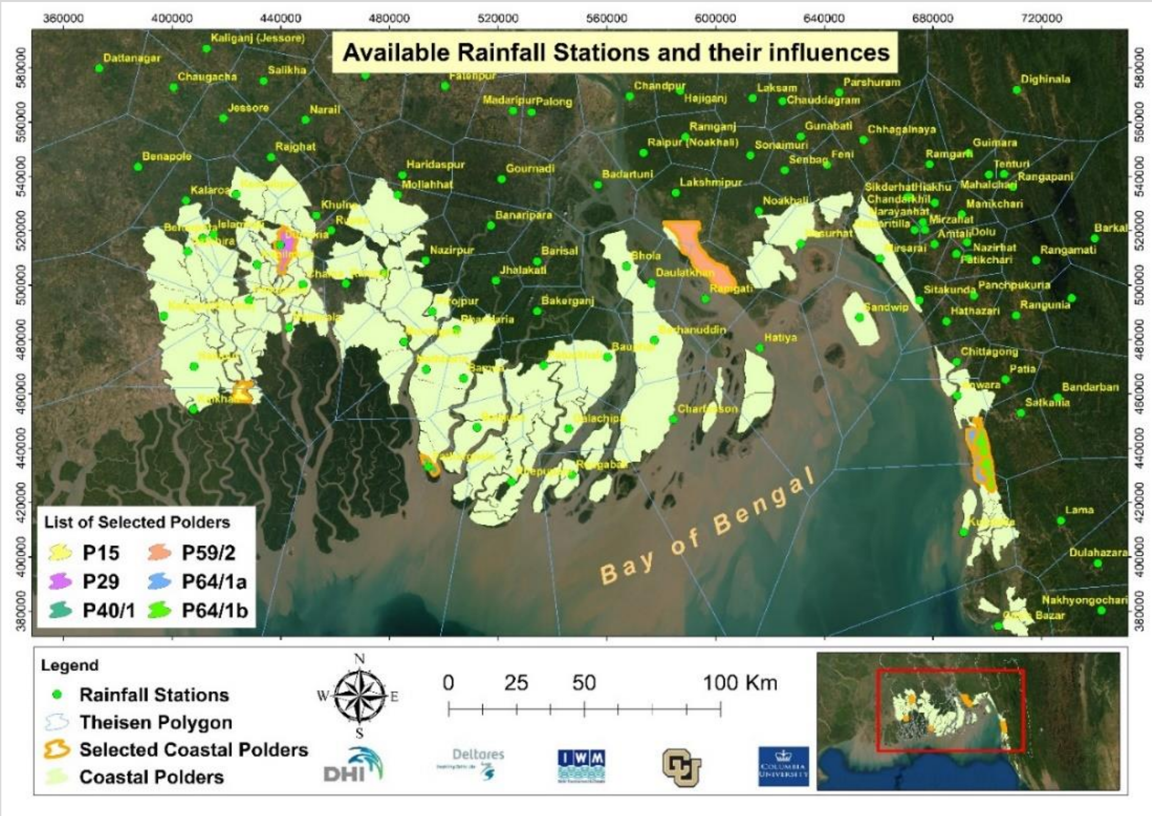


Figure 3.1: Available rainfall stations and their influences on the coastal polders

The influence on each rainfall station on the selected coastal polders has been calculated by the Theisen Polygon Technique. The contribution of each rainfall station on the selected polders has been presented in the following Table 3.1.

Table 3.1: Influence of each rainfall station on the selected coastal polders

Polder SL	Polder ID	Rainfall Stations	Influenced Area (Sq. km)	Total Area (Sq. km)	% of Influenced Rainfall station	Total
1	Polder 15	**Kaikhali**	21.51	31.14	69%	100%
		Nakipur	9.63		31%	
2	Polder 29	**Dumuria**	76.12	79.76	95%	100%
		Chalna	1.75		2%	
		Kapilmuni	1.88		2%	
3	Polder 40/1	**Patharghata**	20.03	20.03	100%	100%
4	Polder 59/2	**Ramgati**	135.12	204.74	66%	100%
		Lakshmipur	69.62		34%	
5	Polder 64/1a	**Anwara**	23.63	52.24	45%	100%
		Satkania	7.85		15%	
		Kutubdia	20.76		40%	
6	Polder 64/1b	Anwara	16.33	88.83	18%	100%
		Satkania	50.65		57%	
		Kutubdia	21.85		25%	

It has been observed that two (02) rainfall stations (Kaikhali and Nakipur) are influencing the Polder 15 area where 69% area are influencing by Kaikhali rainfall station and rest of 31% of area are influencing by Nakipur rainfall station. As Kaikhali rainfall is influencing most of the polder, therefore detail rainfall analysis (i) determination of yearly maximum rainfall, ii) calculation of design rainfall event, iii) trend analysis of pre-monsoon, monsoon, and post-monsoon rainfall) has been carried out for Kaikhali rainfall information.

Similarly, the highest influence of Dumuria rainfall station (95%) on the Polder 29, Patharghata rainfall station (100%) on the Polder 40/1, Ramgati rainfall station (66%) on the Polder 59/2, Anwara rainfall station (45%) on the Polder 64/1a and Satkania rainfall station (57%) on the Polder 64/1b has been calculated by Theisen Polygon Technique. In the Polder 64/1a, the influence of the Anwara rainfall station is 45% and the Kutubdia rainfall station is 40% has been determined. Though both of the rainfall stations are influencing the Polder 64/1a, but the detail analysis of Kutubdia rainfall station has been ignored in the study as Kutubdia Channels lies between the Polder 64/1a and the Kutubdia Island (rainfall station locations). In this section, hydrological analysis of each polder has been described step by step.

3.1.1 Hydrological Analysis of Polder 40/1

Patharghata rainfall station is influencing the hydrology of the whole Polder 40/1. This rainfall station specially covers the right bank of Baleswar River mangrove forest area up to the Pussur-Shibsa River downstream part and the right bank of Baleswar River including Polder 40/1 & Polder 40/2, downstream part of the Polder 42 and Polder 45. The following Figure 3.2 depicts the coverage of this rainfall station.

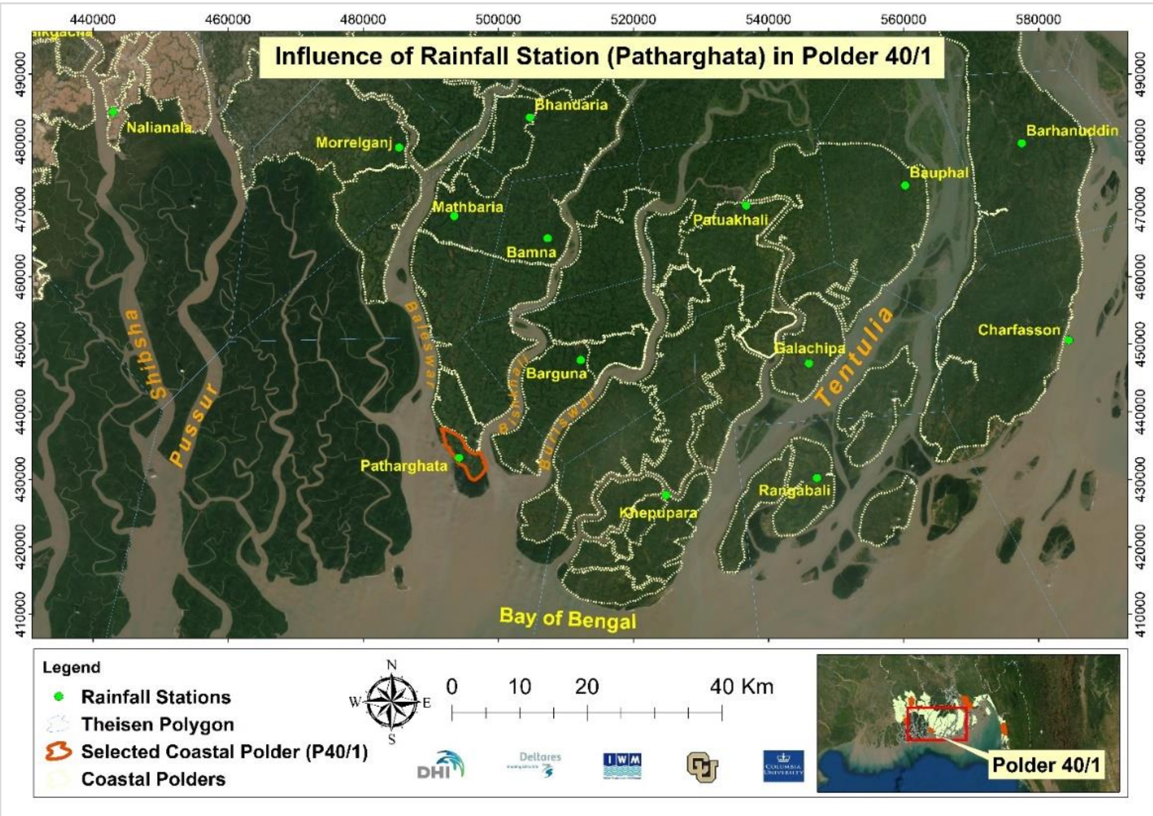


Figure 3.2: Influence of Patharghata rainfall station in and around of the study area

As Patharghata rainfall is influencing most of the polder, therefore detail rainfall analysis of the Patharghata rainfall station has been carried out for the following analysis (i) determination of yearly maximum rainfall, (ii) calculation of design rainfall event, (iii) trend analysis of pre-monsoon, monsoon, and post-monsoon rainfall.

3.1.1.1 Analysis of daily rainfall

The daily rainfall data of Patharghata rainfall station has been collection from BWDB database. Later this data has been checked and used for further analysis. There were some missing year or season where rainfall information was missing, rainfall data from nearby stations were averaged and used them for filling the missing data. At first, 35 years (from 1985 to 2020) daily rainfall data has been used for analysing the yearly maximum rainfall data. In that case Pivot Table method has been applied. The following Figure 3.3 presents the daily rainfall (top Figure 3.3) and yearly maximum data (bottom Figure 3.3) of Patharghata rainfall station.

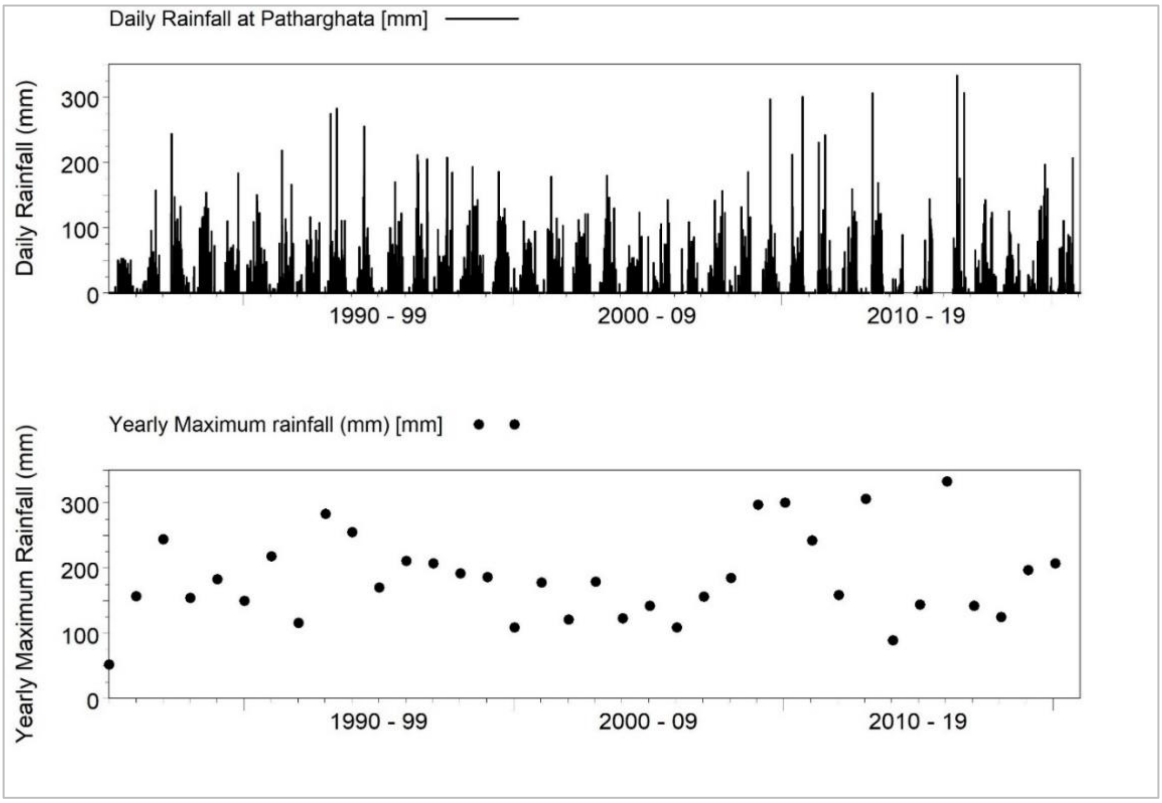


Figure 3.3: Daily rainfall and yearly maximum rainfall information of Patharghata rainfall station

Later, the daily rainfall data has been converted to assess the cumulative rainfall effects in the polder area. This daily rainfall data has been converted into 2-days cumulative, 3-days cumulative, 4-days cumulative and 5-days cumulative rainfall data. The main objective of these analyses has been carried out to assess the inundation conditions inside the polder. Excess amount of water during the monsoon and shortage of water during the dry season, both hydrological conditions have been simulated jointly (combination of movement of tidal water into the khal systems through regulators and daily rainfall & consecutive rainfall). The following Figure 3.4 shows the cumulative effects of the Patharghata rainfall station.

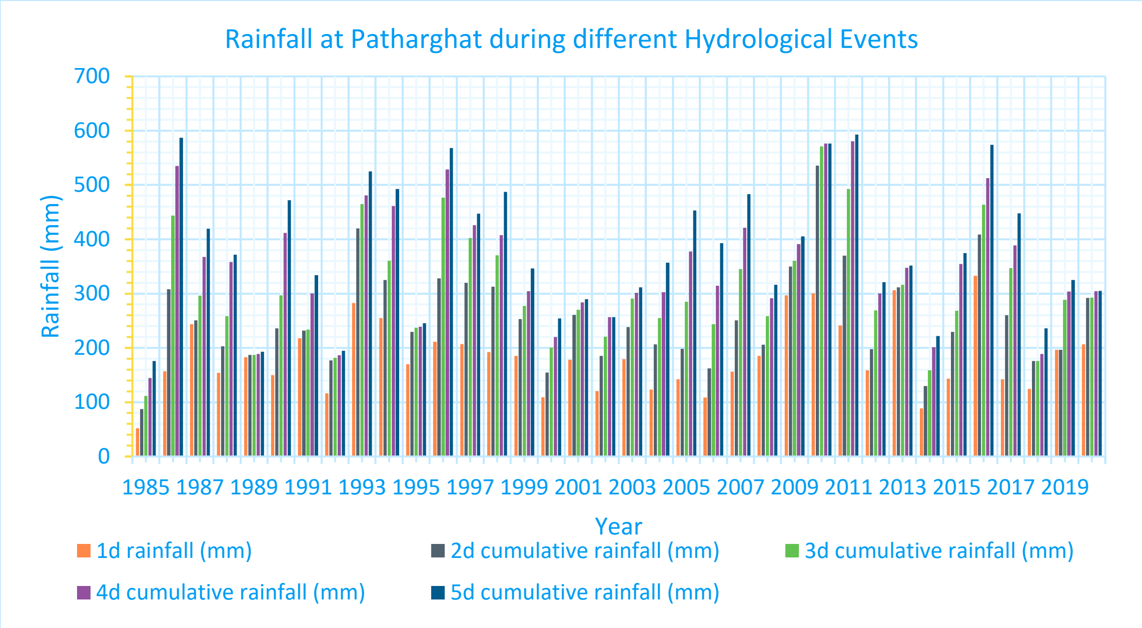


Figure 3.4: Cumulative rainfall information of the Patharghata rainfall station

Maximum rainfall 333mm rainfall has been recorded in 2016 from 35 years rainfall history. 2-days cumulative maximum rainfall has been calculated 536mm which has been happed in 2016. 3-days cumulative rainfall has recorded 571mm which happened in 2010. Similarly, 4-days and 5-days cumulative rainfall has been calculated and estimated 580mm happened in 2011 and 593mm happed in 2011, respectively. Therefore, it can be concluded that hydrological flood events are happens in different years where 5-days cumulative rainfall events happened in 2011. Considering this, year 2011 has been simulated for generating the runoff for 5-day cumulative rainfall.

3.1.1.2 Seasonal Rainfall Characteristics

The climate of Bangladesh has been classified into three season, pre-monsoon (March to 15 June), monsoon (16 June to Sep) and post-monsoon (Oct-Nov). The collected daily rainfall data has been analyzed for the season-wise to assess the seasonal effects and changes of the historical trends. The analysis has been carried out for two hydrological events i) seasonal variation for daily rainfall data ii) seasonal variation for 5-days cumulative rainfall data. These two methods have been considered for assessing the hydrological impact inside the polders when rainfall and tide play jointly.

Seasonal Variation of Daily Rainfall

35-years rainfall information (Figure 3.5) presents that the maximum rainfall 306mm was happened during the year of 2013 Pre-monsoon period, 333mm rainfall was recorded in the year 2016 Monsoon period. The maximum Post-Monsoon rainfall 306mm was recorded in 2016. The statistics indicates that the maximum rainfall is happening in the recent last decade.

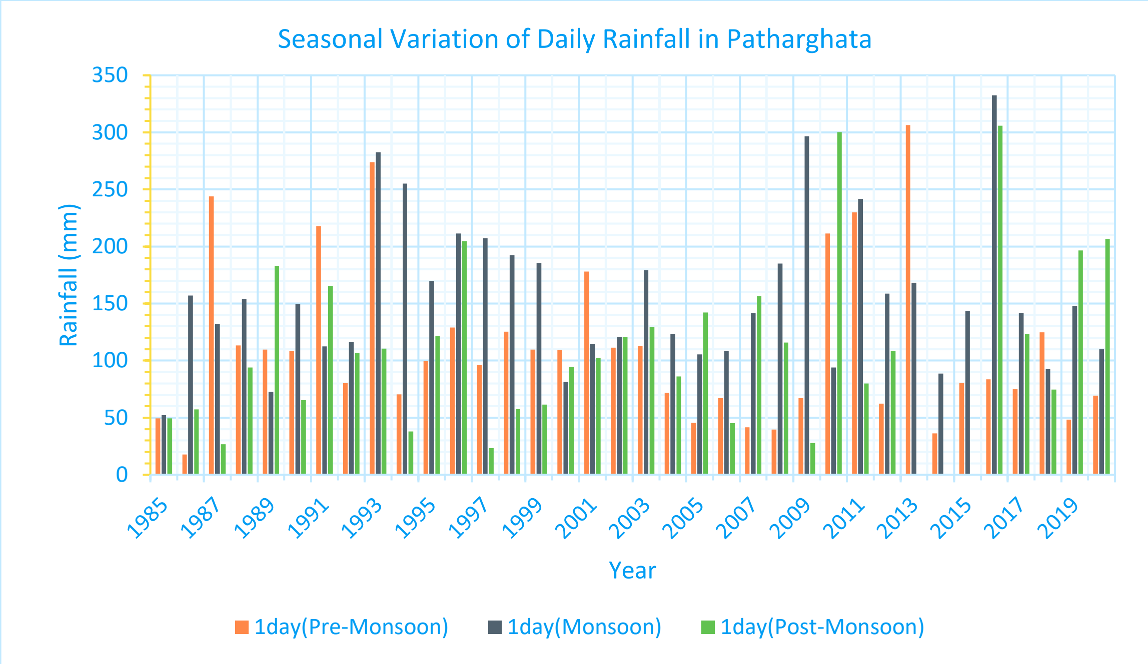


Figure 3.5: Seasonal variation of daily rainfall of Patharghata rainfall station

Trend analysis of the daily rainfall data also been carried out to assess the rainfall pattern over the year. This analysis is also required for selecting the suitable season for assessing the hydrological condition inside the polder. It has been observed from the analysis (Figure 3.6) that 35-years rainfall during pre-monsoon is decreasing sharply whereas the monsoon rainfall is increasing gradually. Most dramatic change has been observed in the post-monsoon rainfall which is increasing rapidly.

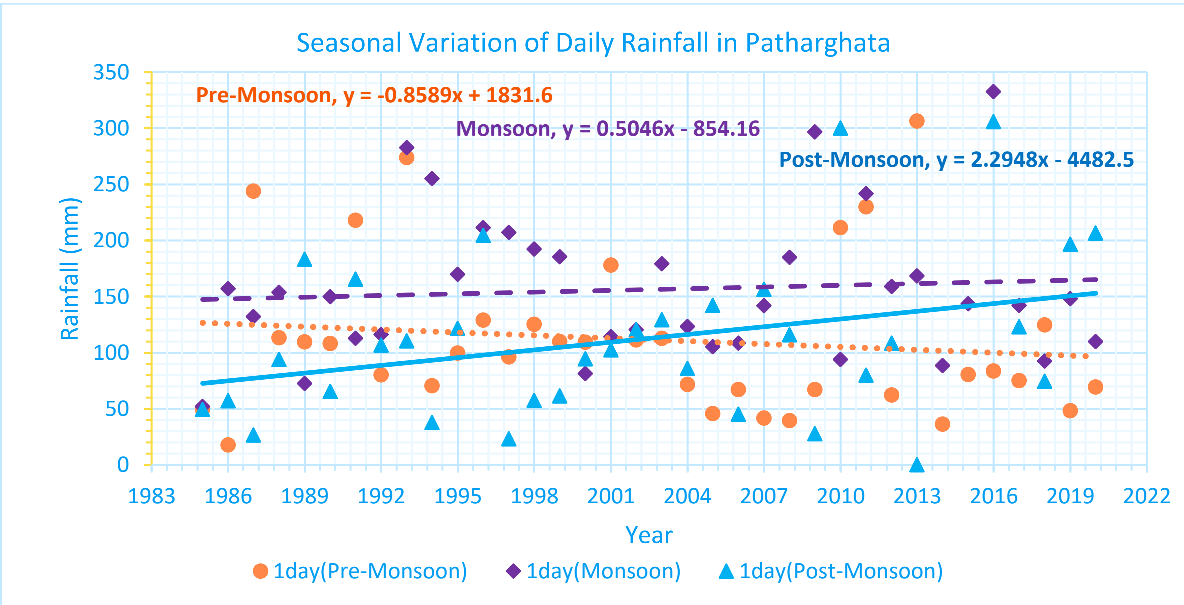


Figure 3.6: Seasonal rainfall trend of daily rainfall of Patharghata rainfall station

Hydrological condition inside the polder depends on the rainfall and water level condition of the drainage channels. It has been summarized that during preparation of the inundation depth map for the existing hydrological condition, the water level conditions inside the polder during monsoon and post-monsoon has been considered based on the amount of rainfall generated runoff contribute into the drainage channels and the water level conditions outside of the peripheral river system.

Seasonal Variation of 5-days Cumulative Rainfall

Seasonal variation also been carried out for 5-days cumulative rainfall data of Patharghata rainfall station. The analysis has been carried out to assess the cropping pattern response at that hydrological condition. It has been observed in the Figure 3.7 that about 525mm maximum pre-monsoon rainfall happened in 1993. However, the maximum 5-days cumulative monsoon and post-monsoon rainfall happened in 2011 and 2010 which are 593mm and 573mm accordingly.

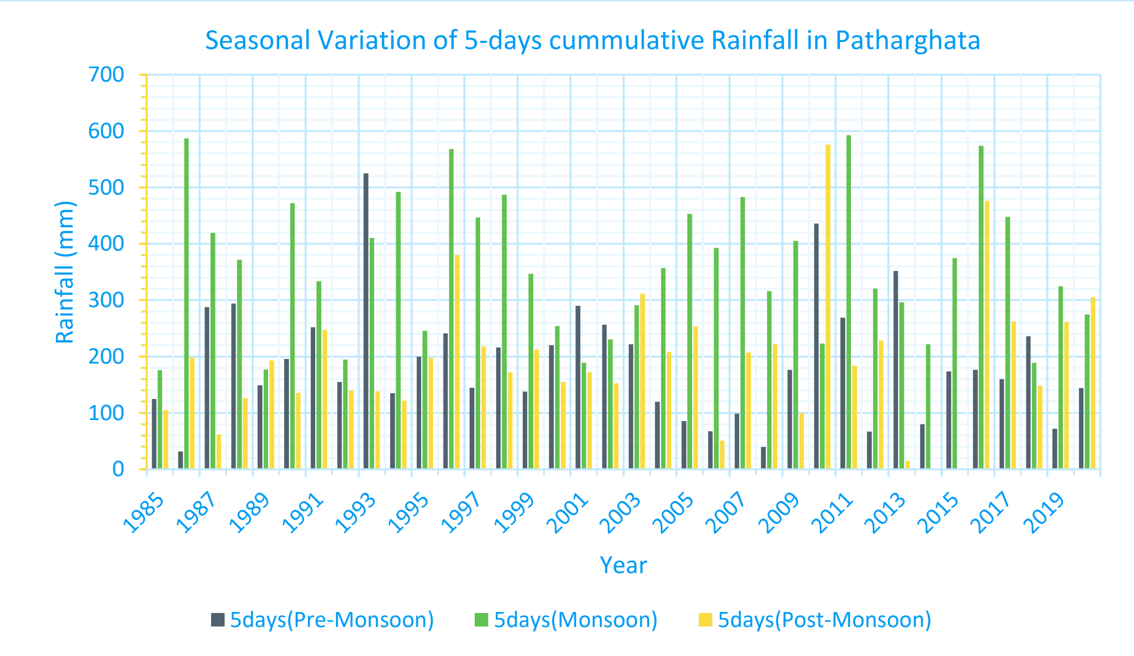


Figure 3.7: Seasonal variation of 5-dys cumulative rainfall of Patharghata rainfall station

Seasonal rainfall characteristics also prepared for 5-days cumulative rainfall for assessing the impact of rainfall into the polder system. It has been observed that pre-monsoon and monsoon rainfall of the last 35-years is decreasing and post-monsoon is showing increasing trend (Figure 3.8). Though the post-monsoon rainfall is showing the increasing trend but the maximum rainfall for 5-days cumulative rainfall occurred during the monsoon period (Figure 3.4).

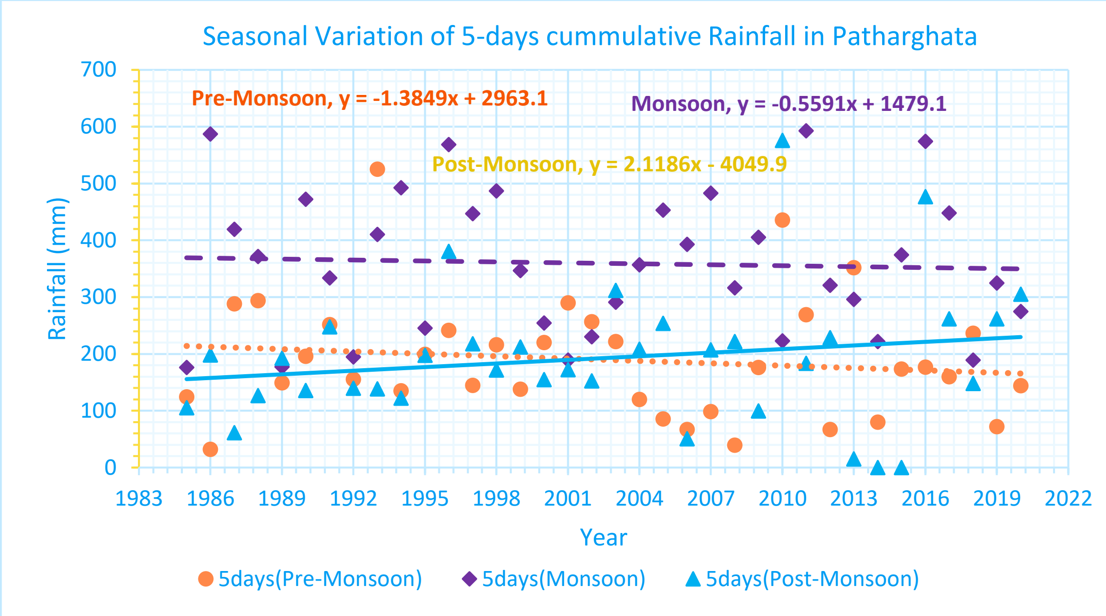


Figure 3.8: Seasonal rainfall trend of 5-days cumulative rainfall of Patharghata rainfall station

Hydrological analysis proves that daily rainfall and 5-days cumulative rainfall of the monsoon period is dominating the hydrological system of the Polder 40/1, though the post-monsoon rainfall is also showing increasing trend. Considering the influence of the rainfall, monsoon rainfall contribution has been considered for planning and designing of polder water management system for the future. However, polder planning and design has been carried out in a way that the polder water management system can sustain for longer period and an able to carry worst climate scenario. Therefore, combination of design hydrological condition (design flood event) with the future climate condition has been considered for conceptual planning and design of the Polder 40/1.

3.1.1.3 Determination of Design Flood Event

It is already discussed in the previous section that Patharghata rainfall station is influencing the study area mostly. Therefore, design rainfall event has been calculated using the rainfall information of Patharghata. Different rainfall event has been analyzed from the daily rainfall data to determine the consecutive rainfall effects in the study area. Analysis indicates that, yearly maximum rainfall data for 35 years (1985-2020) has been calculated for determining 1-day, 2-day, 3-day, 4-day, and 5-day cumulative rainfall events. Table 3.2 shows the yearly maximum rainfall event for the last 35 years.

Table 3.2: Yearly maximum rainfall of Patharghata for different rainfall event

Year	1d rainfall (mm)	2d cumulative rainfall (mm)	3d cumulative rainfall (mm)	4d cumulative rainfall (mm)	5d cumulative rainfall (mm)
1985	52	88	112	144	176
1986	157	308	444	535	587
1987	244	251	296	368	420
1988	154	203	259	358	372
1989	183	187	187	189	193
1990	150	236	297	412	472
1991	218	232	234	300	334
1992	116	177	182	187	195

Year	1d rainfall (mm)	2d cumulative rainfall (mm)	3d cumulative rainfall (mm)	4d cumulative rainfall (mm)	5d cumulative rainfall (mm)
1993	283	420	465	481	525
1994	255	325	361	461	492
1995	170	230	237	239	246
1996	211	328	477	529	568
1997	207	320	402	426	447
1998	192	313	371	408	487
1999	186	253	277	304	347
2000	109	155	201	220	254
2001	178	261	271	284	290
2002	121	186	220	257	257
2003	179	239	291	302	312
2004	123	207	255	303	357
2005	142	198	285	378	453
2006	109	162	243	314	393
2007	156	251	345	421	483
2008	185	206	258	292	316
2009	297	350	361	391	405
2010	300	536	571	576	576
2011	242	370	493	580	593
2012	159	198	269	301	321
2013	306	312	316	347	352
2014	89	130	159	201	222
2015	144	230	269	355	375
2016	**333**	409	464	513	574
2017	142	260	347	389	448
2018	125	176	176	189	236
2019	197	197	289	304	325
2020	207	292	293	304	305

These 35 years yearly maximum rainfall data have been taken into consideration and used them to determine the different return period rainfall information for all rainfall events. Three statistical distribution methods have been considered for determining the rainfall for different return period. Gumbel (Gum), Log Pearson Type III (LP3) and Long Normal Distribution (LN2) statistical distribution methods have been tested to fit the raw rainfall data. Methods of Moment (MOM) has been used as an estimation method and Monte Carlo method has been used for uncertainty calculations. Goodness of fit has been tested with Chi-Square method.

Six different return periods (1 in 2.33, 1 in 10, 1 in 20, 1 in 25, 1 in 50 and 1 in 100 year) have been considered to estimate the design rainfall. Among them, 1 in 50-year rainfall is considered as design rainfall for designing any structure according to BWDB design manual. However, in this study, 1 in 50 has considered for planning and designing the polder water management system for the future. Table 3.3 presents the design rainfall for different return periods

Table 3.3: Design rainfall of Patharghata for different return periods for different rainfall events

Item	Hydrological Events	1day rainfall (mm)			3-days cumulative rainfall (mm)			5-days cumulative rainfall (mm)		
	Return Period [years]/Methods	LP3	LN2	GUM	LP3	LN2	GUM	LP3	LN2	GUM
Estimated Design Rainfall of Patharghata Rainfall Station for different return periods	2.33	192	184	184	312	306	305	391	384	381
	10	272	282	270	444	450	440	549	558	540
	20	298	324	307	495	511	499	607	631	608
	25	306	337	318	510	530	517	625	654	630
	50	***328***	***379***	***354***	***555***	***590***	***574***	***676***	***725***	***697***
	100	347	421	390	597	648	631	724	795	763
Goodness-of-fit statistics	CHISQ	1.72	3.28	**0.94**	**2.89**	4.44	4.44	**2.89**	**2.89**	6.78

Goodness-of-fit has been tested with the Chi-Squares method. It has been observed that the Gumbel (GUM) statistical distribution method provides the lower Chi-Square value during calculation of 1-day design rainfall compared to Log Normal (LN2) and Log Pearson Type 3 (LP3) statistical distribution methods. It means Gumbel distribution method fitted well with the yearly maximum rainfall for the daily rainfall information. However, when we consider 3-days cumulative rainfall, Log Pearson Type 3 (LP3) method gives the lower Chi-Square values compared to the rest of the two other methods. Different scenario has been observed during calculation of design rainfall for 5-days cumulative rainfall. It has been observed that both Log Normal and Log Pearson Type 3 provides the same value of Chi-Square but Log Normal provides higher design rainfall compared to Log Pearson Type 3 method. It is already determined that the polder water management system will be designed for 5-days cumulative rainfall event and 1 in 50-year return periods rainfall considered as design rainfall. As there is lots of investment and safety involved, Log Normal statistical distribution has been taken for ensuring the safety of the polder under the extreme flood event condition. Considering this, the water management system of the Polder 40/1 will be designed for 725mm design rainfall. The following Figure 3.9 and Figure 3.10 shows the typical return period plot for 1-day and 5-days cumulative rainfall event, respectively.

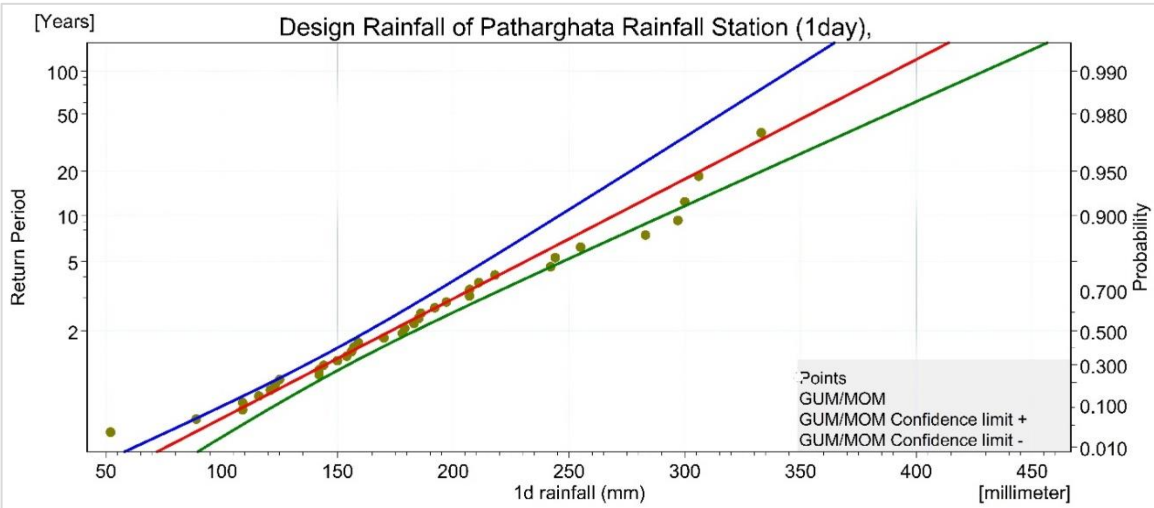


Figure 3.9: Design rainfall for 1-day by Gumbel statistical distribution method

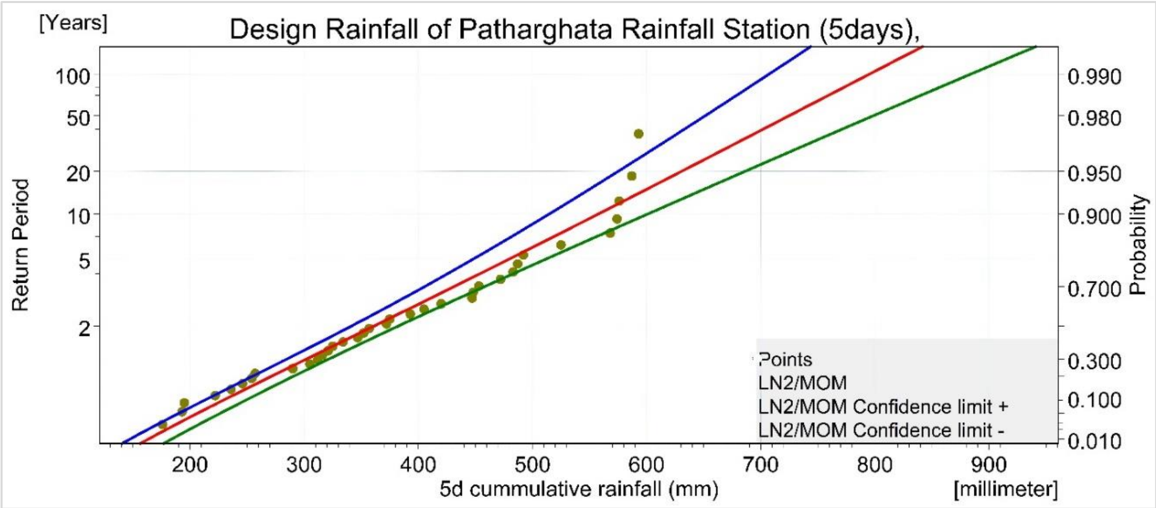


Figure 3.10: Design rainfall for 5-days cumulative rainfall by Log Normal statistical distribution method

Different statistical distribution methods have been tested for fitting the hydrological conditions which has been described in the earlier section. Table 3.4 presents the suitable statistical distribution method contains the design rainfall. The design rainfall (1 in 50 year) for 1-day hydrological rainfall event has been estimated 354 mm which is the nearest rainfall 333mm happened in 2016. Similarly, the design rainfall for 5-days cumulative rainfall has been estimated 725 mm and nearest rainfall is 593 mm already happened in 2011. It indicates that the computed design rainfall is 22% higher than the yearly maximum rainfall of 2011. This statistic confirms that during generation of design runoff for the design rainfall events, 22% additional rainfall should be added with the daily rainfall data of 2011 for getting the expected design runoff.

Table 3.4: Selected design rainfall for Polder 40/1 at different rainfall events with suitable statistical method

Item	Hydrological Events	1day rainfall (mm)	3-days cumulative rainfall (mm)	5-days cumulative rainfall (mm)
	Return Period [years]/Methods	GUM	LP3	LN2
Estimated Design Rainfall of Patharghata Rainfall Station for different return periods	2.33	184	312	384
	10	270	444	558
	20	307	495	631
	25	318	510	654
	50	**354**	**555**	**725**
	100	390	597	795

3.1.2 Hydrological Analysis of Polder 15

There are two rainfall stations in and around of the Polder 15, stations are-Kaikhali (BWDB Rainfall ID: 506), Nakipur (BWDB Rainfall ID: 513) and Nalianala (BWDB Rainfall ID: 514). Theisen Polygon technique has been applied for determining the influence of each rainfall station in the Polder 15. It has been observed that there is no influence of Nalianala rainfall station into the Polder 15 whereas the influences of Kaikhali and Nakipur rainfall station into the Polder 15 are 69% and 31% respectively (Table 3.5). Time series historical rainfall information of Nakipur rainfall station is also missing.

Considering the data availability, only Kaikhali rainfall station rainfall data has been used for further analysis.

Table 3.5: Influence of the rainfall stations in the Polder 15

Polder SL	Polder ID	Rainfall Stations	Influenced Area (Sq. km)	Total Area (Sq. km)	% of Influenced Rainfall station	Total
1	Polder 15	Kaikhali	21.51	31.14	69%	100%
		Nakipur	9.63		31%	

3.1.2.1 Determination of Design Flood Event

It is already discussed in the previous section that Kaikhali rainfall station is influencing the study area mostly. Therefore, daily time series rainfall information of the Kaikhali rainfall station has been used for calculating the design rainfall for different rainfall events (1-day, 2-day, 3-day, 4-day, and 5-day cumulative rainfall events). Different rainfall events have been analyzed from 34 years (1985-2019) daily rainfall data for proper hydrological planning and design of the Polder 15. Table 3.6 shows the yearly maximum rainfall information of different rainfall events for the last 35 years.

Table 3.6: Yearly maximum rainfall of Kaikhali for different rainfall events

Year	1d rainfall (mm)	2d cumulative rainfall (mm)	3d cumulative rainfall (mm)	4d cumulative rainfall (mm)	5d cumulative rainfall (mm)
1985	118	139	148	152	152
1986	226	411	525	573	648
1987	158	158	180	203	221
1988	123	183	227	302	385
1989	138	183	188	190	192
1990	155	261	267	271	283
1991	198	219	329	349	372
1992	161	172	266	277	281
1993	80	126	152	168	206
1994	64	101	132	141	154
1995	128	170	170	175	187
1996	76	137	149	180	180
1997	83	127	152	175	184
1998	208	255	255	255	257
1999	89	121	158	226	231
2000	119	183	193	206	214
2001	125	161	161	171	208
2002	105	174	186	200	200
2003	195	226	307	338	338
2004	151	214	254	273	297
2005	189	260	290	297	316
2006	17	17	17	17	20
2007	250	361	428	459	494
2008	117	138	138	138	184
2009	176	193	222	287	316
2010	188	232	242	251	251
2011	125	221	311	373	466
2012	110	190	240	273	273
2013	116	146	243	259	274
2014	123	187	187	187	206

Year	1d rainfall (mm)	2d cumulative rainfall (mm)	3d cumulative rainfall (mm)	4d cumulative rainfall (mm)	5d cumulative rainfall (mm)
2015	114	161	236	248	256
2016	141	180	271	293	299
2017	95	171	243	314	362
2018	120	141	188	217	256
2019	131	146	158	168	184

These 34 years yearly maximum rainfall data of different rainfall events have been taken into consideration and used them to determine the different return period's rainfall information for all rainfall events. Three statistical distribution methods have been considered for determining the rainfall for different return period. Gumbel (Gum), Log Pearson Type III (LP3) and Long Normal Distribution (LN2) statistical distribution methods have been tested to fit the raw rainfall data. Methods of Moment (MOM) has been used as an estimation method and Monte Carlo method has been used for uncertainty calculations. Goodness of fit has been tested with Chi-Square method.

Six different return periods (1 in 2.33, 1 in 10, 1 in 20, 1 in 25, 1 in 50 and 1 in 100 year) have been considered to estimate the design rainfall for the specific rainfall events (1-day, 3-days and 5-days consecutive rainfall). Among them, 1 in 50-year rainfall is considered as design rainfall in this project for planning and designing of the polder water management system of the selected Polder 15. Table 3.7 presents the design rainfall for different return periods for different rainfall events (1-day, 3-days cumulative and 5-days cumulative rainfall events).

Table 3.7: Design rainfall of Patharghata for different return periods for different rainfall events

Item	Hydrological Events	1day rainfall (mm)			3-days cumulative rainfall (mm)			5-days cumulative rainfall (mm)		
	Return Period [years]	GUM	LP3	LN2	GUM	LP3	LN2	GUM	LP3	LN2
Estimated Design Rainfall of Kaikhali Rainfall Station for different return periods	2.33	135	153	135	223	261	224	267	311	267
	10	198	184	217	341	295	345	414	360	417
	20	225	187	254	391	297	397	477	362	483
	25	234	188	266	407	297	414	497	363	504
	50	**260 (250, 2007)**	189	303	457	297	**466 (428, 2007)**	**559 (494, 2007)**	363	570
	100	286	189	341	506	297	519	621	364	637
Goodness-of-fit statistics	CHISQ	**5.2**	15.6	10	10.4	28.8	**10.3**	**1.6**	26.4	2.4

Goodness-of-fit has been tested with the Chi-Squares method. It has been observed that the Gumbel (GUM) statistical distribution method provides the lower Chi-Square value during calculation of 1-day design rainfall compared to Log Normal (LN2) and Log Pearson Type 3 (LP3) statistical distribution methods. It means Gumbel (GUM) distribution method fitted well with the yearly maximum rainfall for the daily rainfall information. However, when we consider 3-days cumulative rainfall, Log Normal (LN2) method gives the lower Chi-Square values compared to the rest of the two other methods. In case of 5-days cumulative rainfall, Gumbel (GUM) statistical method also provides lower value of Chi-Square compared to other two methods. It is already discussed that the polder water management system will be designed for 5-days cumulative rainfall event and 1 in 50-year return period design rainfall. As there is lots of investment and safety involved, Gumbel (GUM) statistical distribution method has been taken for ensuring the safety of the polder under the extreme flood event condition. Considering this, the water management infrastructure of the Polder 15 will be designed for 559mm design rainfall. The following Figure 3.11 shows the different return period design rainfall for 5-days cumulative rainfall event.

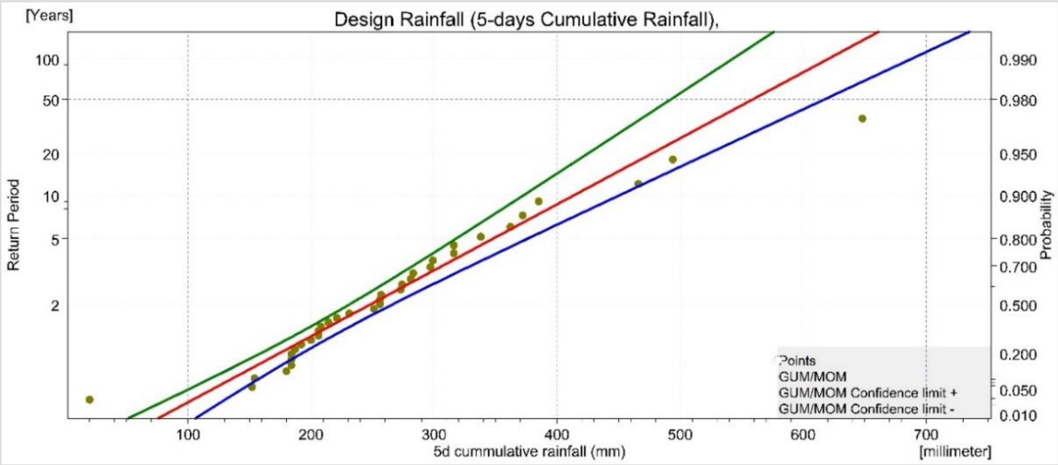


Figure 3.11: Design rainfall of Polder 15 for 5-days cumulative rainfall by Gumbel statistical distribution method

Different statistical distribution methods have been tested for fitting the hydrological conditions which has been described in the earlier section. Table 3.8 presents the suitable statistical distribution method contains the design rainfall. The design rainfall (1 in 50 year) for 1-day hydrological rainfall event has been estimated 260 mm which is the nearest yearly maximum rainfall (205mm) of 2005. The design rainfall for the 3-days cumulative rainfall is 466mm which coincides with the year of 2007 yearly maximum rainfall (428mm). It is estimated that the design rainfall is 8% higher than 2007 yearly maximum rainfall. Similarly, the design rainfall for 5-days cumulative rainfall has been estimated 559 mm and nearest rainfall is 494 mm, happened in 2007. It indicates that the computed design rainfall is 13% higher than the yearly maximum rainfall of 2007. This statistic confirms that during generation of design runoff for the design rainfall events from the hydrological model, 13% additional rainfall should be added with the daily rainfall data of 2007 for getting the expected design runoff.

Table 3.8: Selected design rainfall for Polder 15 at different rainfall events with suitable statistical method

Item	Hydrological Events	1day rainfall (mm)	3-days cumulative rainfall (mm)	5-days cumulative rainfall (mm)
	Return Period [years]	GUM	LN2	GUM
Estimated Design Rainfall of Kaikhali Rainfall Station for different return periods	2.33	135	224	267
	10	198	345	414
	20	225	397	477
	25	234	414	497
	50	**260**	**466**	**559**
	100	286	519	621

Note: GUM=Gumbel, LN2: Log Normal

3.1.3 Hydrological Analysis of Polder 29

There are several rainfall stations which are maintaining in and around of the Polder 29 (Figure 3.12). Dumuria (BWDB Rainfall ID: 504), Chalna (BWDB Rainfall ID: 503) and Kapilmuni (BWDB Rainfall ID: 509), these Three (03) stations are the nearest rainfall station of the Polder 29.

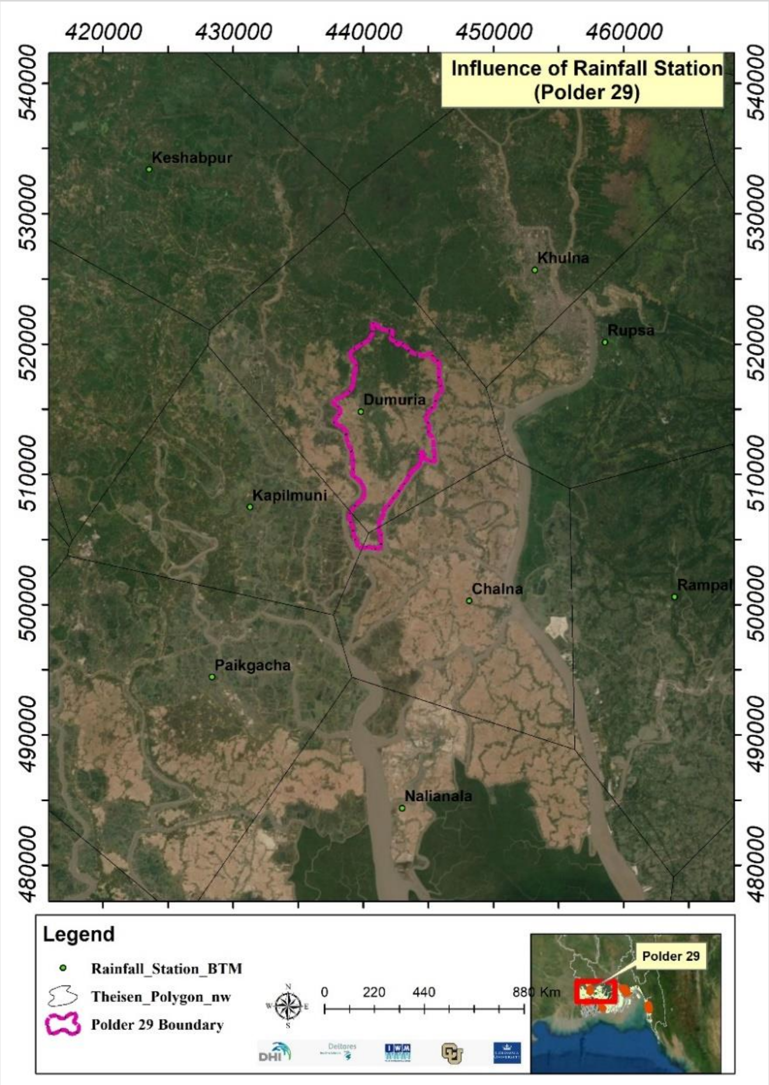


Figure 3.12: Available rainfall stations in and around of the Polder 29Ba

The influence of each rainfall station on the Polder has been calculated by the Theisen Polygon GIS Technique. It has been observed that Dumuria rainfall station mostly influence the Polder 29 and northern part of the polder is influenced by Kapilmuni and Chalna (

Table 3.9).

Table 3.9: Influence of each rainfall station on the selected coastal polders

SL No.	Polder ID	Rainfall Stations	Influenced Area (Sq. km)	Total Area (Sq. km)	% of Influenced Rainfall station	Total
1	Polder 29	**Dumuria**	78.5	79.32	99%	100%

As Dumuria rainfall is influencing most of the polder, detail rainfall analysis of the Dumuria rainfall station has been carried out for following analysis (i) determination of yearly maximum rainfall, (ii) calculation of design rainfall event

3.1.3.1 Determination of Design Flood Event

It is already discussed in the previous section that Dumuria rainfall station is influencing the study area mostly. Therefore, different design rainfall events have been calculated using Dumuria rainfall station information. Different rainfall events have been analyzed from the daily rainfall data to understand the consecutive rainfall effects in the study area. Yearly maximum rainfall data for 33 years (1986-2019) has been carried out for determining 1-day, 2-days, 3-days, 4-days, and 5-days cumulative rainfall events to prepare the polder planning and designing plan. Table 3.10 shows the yearly maximum rainfall event for the last 33 years at Dumuria.

Table 3.10: Yearly maximum rainfall of Dumuria for different rainfall event

Year	1d rainfall (mm)	2d cumulative rainfall (mm)	3d cumulative rainfall (mm)	4d cumulative rainfall (mm)	5d cumulative rainfall (mm)
1986	126	243	321	359	370
1987	121	235	273	297	300
1988	171	273	273	284	290
1989	152	155	158	268	268
1990	180	210	221	256	275
1991	80	155	205	205	205
1992	75	90	100	120	140
1993	172	187	190	220	250
1994	100	170	230	270	305
1995	260	305	345	345	345
1996	281	287	347	442	527
1997	255	283	470	536	595
1998	110	156	202	239	294
1999	104	193	278	305	312
2000	120	238	268	289	296
2001	258	263	278	292	302
2002	245	371	401	465	485
2003	171	302	312	312	312
2004	229	436	604	782	870
2005	109	135	139	140	145
2006	6	6	6	6	6
2007	110	142	191	192	195
2008	36	60	60	62	75
2009	130	204	223	286	364
2010	27	51	51	51	51
2011	195	350	520	520	533
2012	106	185	218	235	259
2013	107	172	204	209	240
2014	166	195	208	246	257
2015	41	71	81	108	119
2016	102	189	215	226	226
2017	144	251	341	341	345
2018	87	87	132	133	161
2019	200	310	317	399	497

These 33 years yearly maximum rainfall data have been taken into consideration and used them to determine different return period rainfall information for all rainfall events. Three statistical distribution methods have been considered for determining the rainfall for different return period. Gumbel (Gum), Log Pearson Type III (LP3) and Long Normal Distribution (LN2) statistical distribution methods have been tested to fit the raw rainfall data. Methods of Moment (MOM) has been used as an estimation method and Monte Carlo method has been used for uncertainty calculations. Goodness of fit has been tested with Chi-Square method.

Six different return periods (1 in 2.33, 1 in 10, 1 in 20, 1 in 25, 1 in 50 and 1 in 100 year) have been considered to estimate the design rainfall. Among them, 1 in 50-year rainfall is considered as design rainfall for designing any structure according to BWDB design manual. However, in this study, 1 in 50 has considered for planning and designing the polder water management system for the future. Table 3.11 presents the design rainfall for different return periods.

Table 3.11: Design rainfall of Dumuria for Polder 29 at different return periods for different rainfall events

Item	**Hydrological Events**	**1day rainfall (mm)**			**3-days cumulative rainfall (mm)**			**5-days cumulative rainfall (mm)**		
	Return Period [years]	**LP3**	**LN2**	**GUM**	**LP3**	**LN2**	**GUM**	**LP3**	**LN2**	**GUM**
Estimated Design Rainfall of Dumuria Rainfall Station for different return periods	2.33	7	27	17	9	47	26	9	52	30
	10	187	166	169	333	290	297	407	354	360
	20	217	242	222	370	418	390	450	517	474
	25	222	268	238	375	461	418	455	572	509
	50	232	**352**	286	383	**600**	502	464	**753**	611
	100	236	445	332	386	751	584	466	951	710
Goodness-of-fit statistics	CHISQ	5.18	**3.77**	8.35	5.53	**5.28**	5.38	16.47	8.88	**8.00**

Goodness-of-fit has been tested with the Chi-Squares method. It has been observed that the Log Normal (LN2) statistical distribution method provides the lower Chi-Square value during calculation of 1-day design rainfall compared to Gumbel (GUM) and Log Pearson Type 3 (LP3) statistical distribution methods. It means Log Normal (LN2) distribution method fitted well with the yearly maximum rainfall for the daily rainfall information. However, when we consider 3-days cumulative rainfall, Log Normal (LN2) method also gives the lower Chi-Square values compared to the rest of the two other methods. Though Gumbel distribution method is fitted well for 5-days cumulative rainfall, but Log Normal statistical method has been taken into consideration to determine the design period (1 in 50-year return period) for proper planning and design of the Polder 29 water management infrastructures. As there is lots of investment and safety involved, Log Normal statistical distribution has been considered for ensuring the safety of the Polder 29 under the extreme flood event condition. Considering this, the water management system of the Polder 29 will be designed for 753mm design rainfall. The following Figure 3.13 shows the typical return period plot for 5-days cumulative rainfall event.

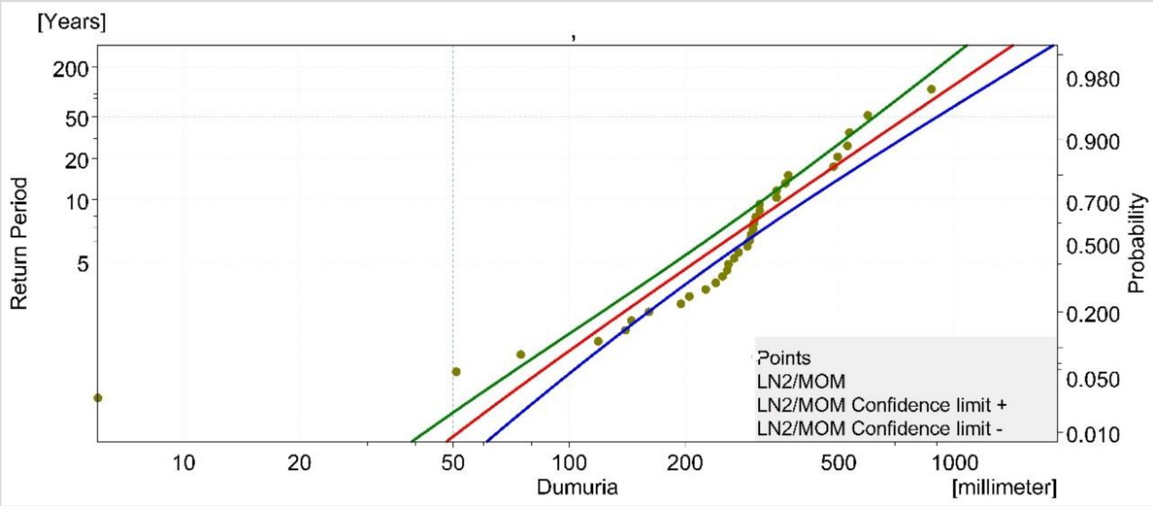


Figure 3.13: Design rainfall of Polder 29 for 5-days cumulative rainfall by Log Normal statistical distribution method

Different statistical distribution methods have been tested for fitting the hydrological conditions which has been described in the earlier section.

Table 3.12 presents the suitable statistical distribution method contains the design rainfall for different rainfall events. The design rainfall (1 in 50 year) for 1-day hydrological rainfall event has been estimated 352 mm which is the nearest rainfall 286 mm happened in 1996. However, the design rainfall is 23% higher that the rainfall that happened in 1996. Similarly, the design rainfall for 5-days cumulative rainfall has been estimated 753 mm and nearest rainfall is 870 mm which was happened in 2004. It indicates that the computed design rainfall is 15.5% less than the yearly maximum rainfall of 2004. This statistic confirms that during generation of design runoff for the design rainfall event, 15.5% rainfall will be reduced from 2004 daily rainfall data for getting the expected design runoff from the hydrological model.

Table 3.12: Selected design rainfall for Polder 29 at different rainfall events with suitable statistical method

Item	Hydrological Events	1day rainfall (mm)	3-days cumulative rainfall (mm)	5-days cumulative rainfall (mm)
	Return Period [years]	LN2	LN2	LN2
Estimated Design Rainfall of Dumuria Rainfall Station for different return periods	2.33	27	47	52
	10	166	290	354
	20	242	418	517
	25	268	461	572
	50	**352**	**600**	**753**
	100	445	751	951

3.1.4 Hydrological Analysis of Polder 59/2

There are some rainfall stations which are maintaining in and around of the Polder 59/2 (Figure 3.14). Ramgati (BWDB ID: R375), Lakshmipur (BWDB ID: R364 and Daulatkhan (BWDB ID: R261), these three (03) stations are the nearest rainfall station in and around of the Polder 59/2.

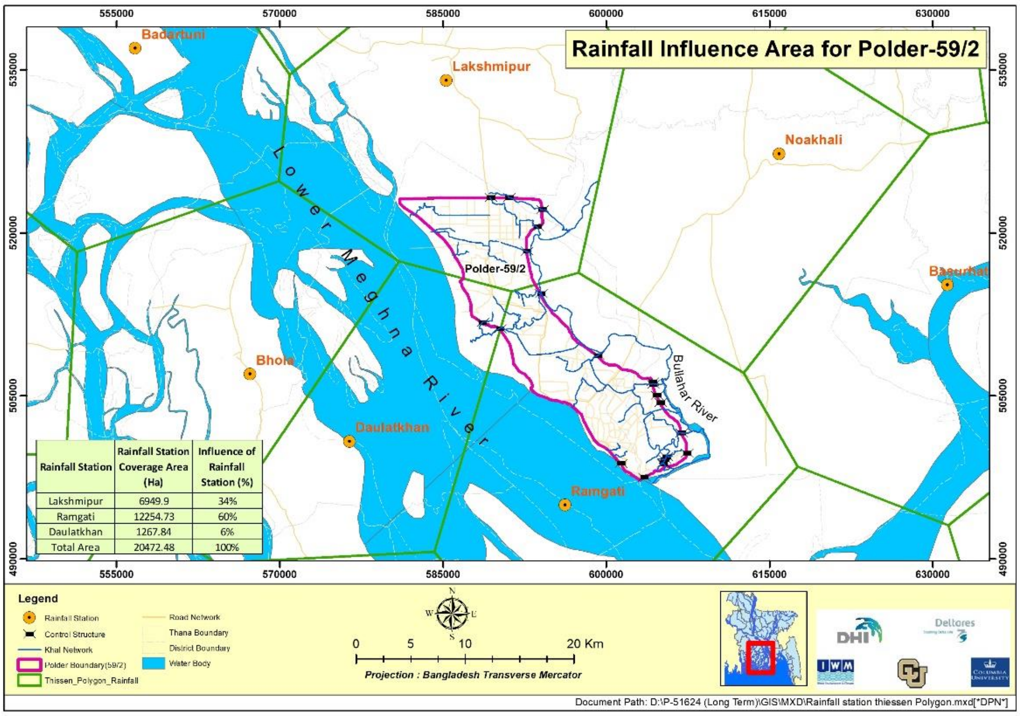


Figure 3.14: Available in rainfall stations and around of the Polder 59/2

The influence of each rainfall station on the Polder has been calculated by the Theisen Polygon GIS Technique. It has been observed that Ramgati rainfall station influences the Polder 59/2 by 60% whereas the Lakshmipur rainfall station is 34% and Daulatkhan is 6% (Table 3.13).

Table 3.13: Influence of each rainfall station on the selected coastal polders

SL No.	Polder ID	Rainfall Stations	Influenced Area (Sq. km)	Total Area (Sq. km)	% of Influenced Rainfall station	Total
1	Polder 59/2	**Ramgati**	122.54	204.72	60%	100%
2	Polder 59/2	Lakshmipur	69.49		34%	
3	Polder 59/2	Daulatkhan	12.67		6%	

As Ramgati rainfall is influencing most of the polder, therefore detail rainfall analysis of Ramgati rainfall station has been carried out for determining the following analysis (i) determination of yearly maximum rainfall and (ii) calculation of design rainfall event.

3.1.4.1 Determination of Design Flood Event for the Polder 59/2

It is already discussed in the previous section that Ramgati rainfall station is influencing the Polder 59/2 significantly. Therefore, design rainfall event has been calculated using 34 years (2019-1985) rainfall information of Ramgati and this rainfall information also used to determine the consecutive rainfall effects (1-day, 2-day, 3-day, 4-day, and 5-day cumulative rainfall events) in the Poldered area. Table 3.14 shows the yearly maximum rainfall of Ramgati for the last 34 years.

Table 3.14: Yearly maximum rainfall of Ramgati (Polder 59/2) for different rainfall event

Year	1d rainfall (mm)	2d cumulative rainfall (mm)	3d cumulative rainfall (mm)	4d cumulative rainfall (mm)	5d cumulative rainfall (mm)
1985	113.00	194.30	247.60	275.60	303.50
1986	114.30	223.50	330.20	388.60	424.20
1987	180.30	242.50	344.20	422.90	504.20
1988	137.20	271.80	384.80	517.00	630.00
1989	60.00	110.00	153.00	175.00	185.00
1990	170.00	250.00	350.00	360.00	380.00
1991	130.00	180.00	250.00	325.00	385.00
1992	115.00	210.00	260.00	340.00	435.00
1993	230.00	285.00	415.00	535.00	665.00
1994	220.00	385.00	510.00	575.00	640.00
1995	195.00	385.00	445.00	495.00	495.00
1996	120.00	205.00	250.00	270.00	270.00
1997	118.00	180.00	228.00	263.00	293.00
1998	115.00	155.00	205.00	255.00	315.00
1999	90.80	136.30	161.20	176.20	197.40
2000	75.70	131.00	161.50	197.20	207.20
2001	160.69	236.19	266.19	311.69	326.69
2002	90.69	150.69	210.98	241.27	256.27
2003	125.00	204.00	265.30	325.00	400.30
2004	106.80	137.00	191.60	246.80	278.80
2005	82.50	120.30	166.90	201.00	261.70
2006	189.00	352.00	437.00	462.70	481.70
2007	100.00	180.50	235.30	283.40	335.20
2008	90.40	155.70	225.90	261.60	291.90
2009	118.50	189.10	284.50	325.90	416.10
2010	187.00	224.80	291.20	351.20	361.50
2011	105.80	184.30	223.00	277.80	325.70
2012	70.20	135.90	171.20	181.50	202.20
2013	87.50	158.00	217.30	262.60	300.80
2014	132.50	181.10	250.80	349.30	399.30
2015	118.50	213.80	282.30	334.60	380.20
2016	108.30	182.80	251.10	325.60	332.10
2017	181.30	260.80	294.00	309.60	314.70
2018	143.00	180.20	222.90	258.10	301.30
2019	175.20	242.70	268.00	268.00	314.90

These 34 years yearly maximum rainfall data have been taken into consideration and used them to determine different return period rainfall information for all rainfall events. Three statistical distribution methods have been considered for determining the rainfall for different return period. Gumbel (Gum), Log Pearson Type III (LP3) and Long Normal Distribution (LN2) statistical distribution methods have been tested to fit the raw rainfall data. Methods of Moment (MOM) has been used as an estimation method and Monte Carlo method has been used for uncertainty calculations. Goodness of fit has been tested with Chi-Square method.

Six different return periods (1 in 2.33, 1 in 10, 1 in 20, 1 in 25, 1 in 50 and 1 in 100 year) have been considered to estimate the design rainfall. Among them, 1 in 50-year rainfall is considered as design rainfall for planning and designing of any infrastructure of the Polder 59/2. Table 3.15 presents the design rainfall for different return periods.

Table 3.15: Design rainfall of Ramgati for different return periods for different rainfall events

Item	**Hydrological Events**	**1day rainfall (mm)**			**3-days cumulative rainfall (mm)**			**5-days cumulative rainfall (mm)**		
	Return Period [years]	**LP3**	**LN2**	**GUM**	**LP3**	**LN2**	**GUM**	**LP3**	**LN2**	**GUM**
Estimated Design Rainfall of Ramgati Rainfall Station for different return periods	2.33	131	131	130	267	272	270	359	363	360
	10	188	188	186	384	380	383	518	515	516
	20	212	212	211	437	424	431	587	578	583
	25	220	220	218	455	437	446	609	598	604
	50	**243**	243	242	**510**	479	494	678	**658**	670
	100	265	266	265	567	520	541	748	717	735
Goodness-of-fit statistics	CHISQ	**3.6**	**3.6**	5.6	**3.6**	4.4	5.2	3.6	**3.2**	3.6

Goodness-of-fit has been tested with the Chi-Squares method. It has been observed that the Log Normal (LN2) and Log Pearson Type 3 (LP3) statistical distribution method provides the lower Chi-Square value during calculation of 1-day design rainfall compared to Gumbel (GUM) statistical distribution method. It means Log Normal (LN2) and Log Pearson Type 3 (LP3) distribution, both methods fitted well with daily rainfall information. However, when we consider 3-days cumulative rainfall, Log Pearson Type 3 (LP3) method gives the lower Chi-Square values compared to the rest of the two other methods. It has been observed that Log Normal provides the lower value of Chi-Square but Log Pearson Type III and Gumbel provide higher design rainfall compared to Log Normal method. It is already determined that the polder water management system will be designed for 5-days cumulative rainfall event and 1 in 50-year return periods rainfall considered as design rainfall. As there is lots of investment and safety involved, best fitted Log Normal statistical distribution has been taken for ensuring the reliability and safety of the polder under the extreme flood event condition. Considering this, the water management system of the Polder 59/2 will be designed for 658mm design rainfall. The following Figure 3.15 shows the typical return period plot for 5-days cumulative rainfall event.

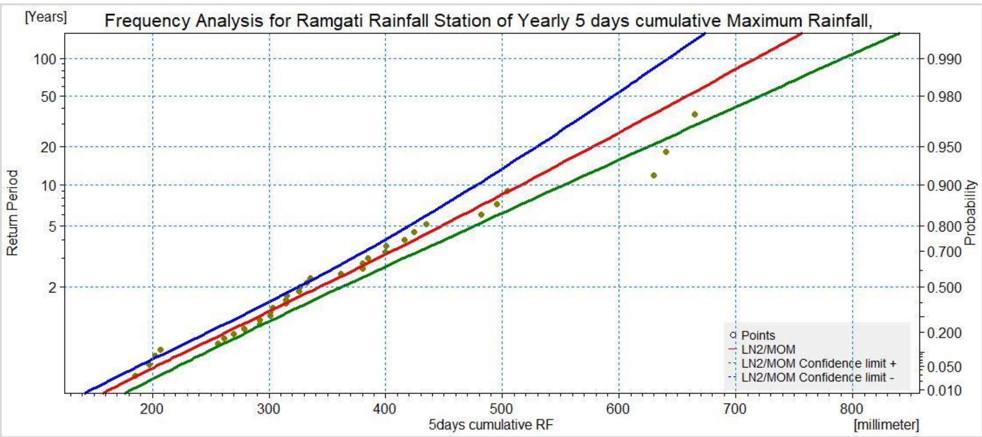


Figure 3.15: Design rainfall for Ramgati at 5-days cumulative rainfall by Log Normal statistical distribution method

Different statistical distribution methods have been tested for fitting the hydrological conditions which has been described in the earlier section. Table 3.16 presents the suitable statistical distribution method contains the design rainfall for rainfall events. The design rainfall (1 in 50 year) for 1-day hydrological rainfall event has been estimated 243 mm which is the nearest rainfall 230mm was happened in 1993. Similarly, the design rainfall for 5-days cumulative rainfall has been estimated 658 mm and nearest rainfall is 665 mm was happened in 1993. It indicates that the computed design rainfall is almost similar of the yearly maximum rainfall of 1993 and no rainfall correction has been applied during computation of design runoff from the hydrological model.

Table 3.16: Selected design rainfall for Ramgati at different rainfall events with suitable statistical method

Item	Hydrological Events	1day rainfall (mm)	3-days cumulative rainfall (mm)	5-days cumulative rainfall (mm)
	Return Period [years]	LP3	LP3	LN2
Estimated Design Rainfall of Ramgati rainfall Station for different return periods	2.33	131	267	363
	10	188	384	515
	20	212	437	578
	25	220	455	598
	50	**243**	**510**	**658**
	100	265	567	717

3.1.5 Hydrological Analysis of Polder 64/1a and Polder 64/1b

There are three rainfall stations which are maintaining in and around of the Polder 64/1a and 64/1b (Figure 3.16). Anwara (BWDB Rainfall ID: R302), Kutubdia (BWDB Rainfall ID: R316) and Satkania (BWDB Rainfall ID: R332), these three (03) stations are the nearest rainfall stations for the polders mentioned above.

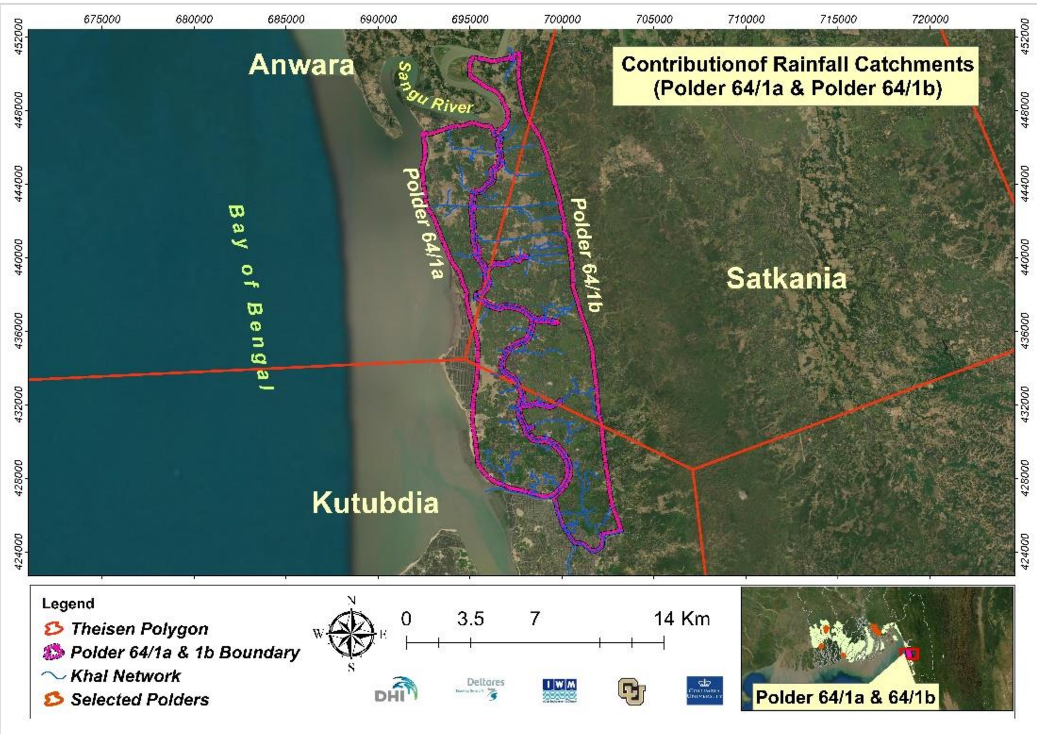


Figure 3.16: Available rainfall stations in and around of the Polder 64/1a and Polder 64/1b

The influence of each rainfall station on the Polder has been determined by the Theisen Polygon Technique. It has been observed that Satkania rainfall station greatly influences the Polder 64/1a and 1b about 42% of the total area of these polders (Table 3.17) whereas Kutubdia has the second highest influence.

Table 3.17: Influence of each rainfall station on the selected coastal polders

SL No.	Polder ID	Rainfall Stations	Influenced Area (Sq. km)	Total Area (Sq. km)	% of Influenced Rainfall station	Total
1	Polder 64/1a and 1b	Anwara	38.85	139.48	28%	100%
2	Polder 64/1a and 1b	Kutubdia	41.96	139.48	30%	100%
3	Polder 64/1a and 1b	Satkania	58.67	139.48	42%	100%

As Satkania rainfall station is influencing most of the polder, therefore detailed rainfall analysis of the Satkania rainfall station has been carried out for the following analysis (i) determination of yearly maximum rainfall and (ii) calculation of design rainfall event.

3.1.5.1 Determination of Design Flood Event for the Polder 64/1a and Polder 64/1b

It is already discussed in the previous section that Satkania rainfall station is influencing the study area mostly about 42% of the total area. Therefore, design rainfall event has been calculated using the rainfall information of Satkania. Different rainfall event has been analyzed from the daily rainfall data to determine the consecutive rainfall effects in the study area. Analysis indicates that, yearly maximum rainfall data for 34 years (1985-2019) has been calculated for determining 1-day, 2-day, 3-day, 4-day, and 5-day cumulative rainfall events. Table 3.18 shows the yearly maximum rainfall event for the last 34 years.

Table 3.18: Yearly maximum rainfall of Satkania (Polder 64/1a and Polder 64/1b) for different rainfall event

Year	**1d rainfall (mm)**	**2d cumulative rainfall (mm)**	**3d cumulative rainfall (mm)**	**4d cumulative rainfall (mm)**	**5d cumulative rainfall (mm)**
1985	92.20	102.90	128.30	168.90	168.90
1986	228.60	448.60	551.00	585.30	600.50
1987	120.70	155.00	191.10	212.70	222.90
1988	235.00	354.40	363.30	400.10	424.20
1989	98.00	121.00	121.00	141.00	156.00
1990	325.00	365.00	400.00	402.00	407.00
1991	227.00	303.00	356.00	362.00	438.00
1992	207.50	225.50	246.50	246.50	248.50
1993	80.00	110.00	115.00	133.00	158.00
1994	115.50	117.50	125.50	135.80	169.80
1995	105.50	142.70	151.90	151.90	172.70
1996	167.30	322.30	322.30	322.30	322.30
1997	225.00	345.00	450.00	480.00	510.00
1998	210.00	300.00	360.50	406.30	437.00
1999	210.00	330.60	360.60	405.70	465.70
2000	195.00	255.00	300.00	365.00	415.00
2001	150.00	195.00	225.00	240.00	312.80
2002	100.00	135.00	148.00	200.00	235.00
2003	75.00	120.00	130.00	130.70	131.50
2004	180.00	290.00	365.00	410.00	485.00

Year	1d rainfall (mm)	2d cumulative rainfall (mm)	3d cumulative rainfall (mm)	4d cumulative rainfall (mm)	5d cumulative rainfall (mm)
2005	128.00	248.00	283.00	313.00	341.00
2006	189.00	299.00	404.00	434.00	452.00
2007	190.00	370.00	400.00	450.00	495.00
2008	150.00	290.00	386.00	476.00	542.00
2009	180.00	275.00	391.00	461.00	476.00
2010	105.00	167.00	223.00	260.00	290.00
2011	140.00	237.00	262.00	295.00	360.00
2012	185.00	315.00	388.00	493.00	531.00
2013	105.00	185.00	253.00	328.00	358.00
2014	149.00	254.00	329.00	389.00	419.00
2015	225.00	420.00	600.00	735.00	780.00
2016	150.00	270.00	327.00	357.00	372.00
2017	220.00	290.00	380.00	455.00	470.00
2018	160.00	275.00	365.00	395.00	395.00
2019	345.00	465.00	614.00	749.00	854.00

These 34 years (1985-2019) yearly maximum rainfall data have been taken into consideration and used them to determine different return period rainfall information for all rainfall events. Three statistical distribution methods have been considered for determining the rainfall for different return period. Gumbel (Gum), Log Pearson Type III (LP3) and Long Normal Distribution (LN2) statistical distribution methods have been tested to fit the raw rainfall data. Methods of Moment (MOM) has been used as an estimation method and Monte Carlo method has been used for uncertainty calculations. Goodness of fit has been tested with Chi-Square method.

Six different return periods (1 in 2.33, 1 in 10, 1 in 20, 1 in 25, 1 in 50 and 1 in 100 year) have been considered to estimate the design rainfall. Among them, 1 in 50-year rainfall is considered as design rainfall for designing any infra-structure of the Polder 64/1a and Polder 64/1b. Table 3.19 presents the design rainfall for different return periods.

Table 3.19: Design rainfall of Satkania for different return periods for different rainfall events

Item	Hydrological Events	1day rainfall (mm)			3-days cumulative rainfall (mm)			5-days cumulative rainfall (mm)		
	Return Period [years]	LP3	LN2	GUM	LP3	LN2	GUM	LP3	LN2	GUM
Estimated Design Rainfall of Satkania Rainfall Station for different return periods	2.33	172	171	171	325	311	315	398	384	389
	10	257	258	253	502	522	485	621	641	606
	20	291	296	289	567	619	559	704	759	699
	25	302	308	300	586	651	582	730	797	728
	50	335	345	335	641	751	654	**803**	918	819
	100	367	382	369	691	854	725	871	1042	910
Goodness-of-fit statistics	CHISQ	9.60	9.60	**7.20**	**8.00**	11.60	8.40	**6.00**	6.40	8.00

Goodness-of-fit has been tested with the Chi-Squares method. It has been observed that the Gumbel (GUM) statistical distribution method provides the lower Chi-Square value during calculation of 1-day design rainfall compared to Log Normal (LN2) and Log Pearson Type 3 (LP3) statistical distribution methods. It means Gumbel distribution method fitted well with the yearly maximum rainfall for the daily rainfall information. However, when we consider 3-days cumulative rainfall, Log Pearson Type 3 (LP3) method gives the lower Chi-Square values compared to the rest of the two other methods. In case of 5-days cumulative rainfall, it has been observed that Log Pearson Type 3 provides lower value of Chi-Square compared to Gumbel and Log Normal distribution method. It is already determined that the polder water management system will be designed for 5-days cumulative rainfall event and 1 in 50-year return periods rainfall considered as design rainfall. Considering this, the water management system of the Polder 64/1a and 1b will be designed for 803mm design rainfall. The following Figure 3.17 shows the typical return period plot for 5-days cumulative rainfall event.

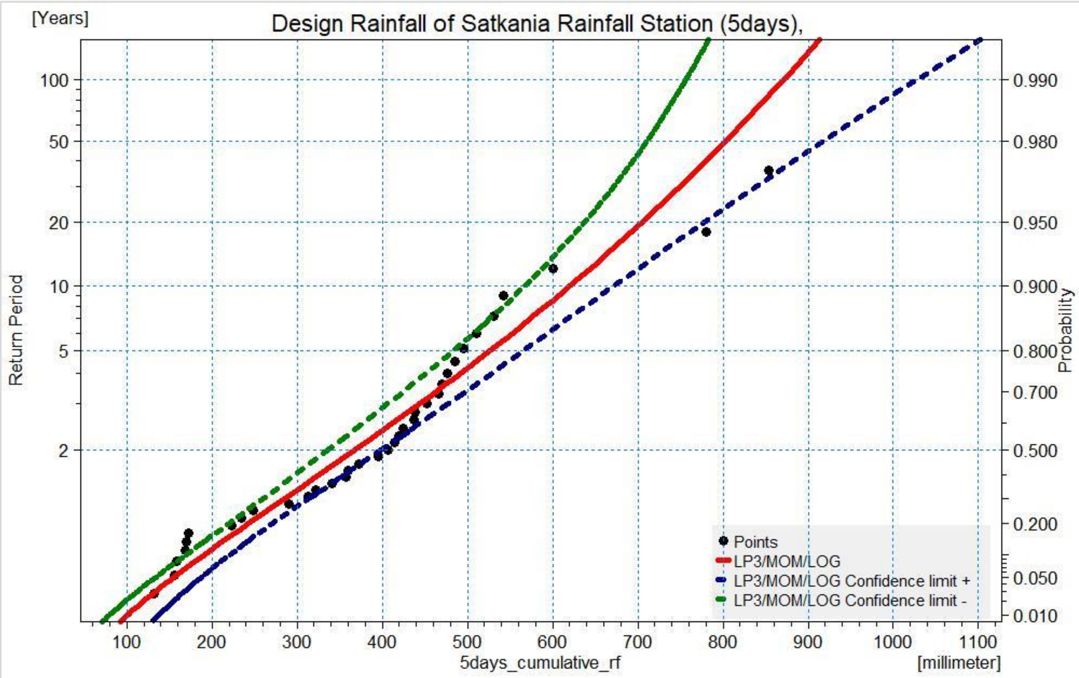


Figure 3.17: Design rainfall for 5-days cumulative rainfall by Log Pearson Type 3 statistical distribution method

Different statistical distribution methods have been tested for fitting the hydrological conditions which has been described in the earlier section. Table 3.20 presents the suitable statistical distribution method contains the design rainfall. The design rainfall (1 in 50 year) for 1-day hydrological rainfall event has been estimated 335 mm which is the nearest rainfall 225mm happened in 2015. Similarly, the design rainfall for 5-days cumulative rainfall has been estimated 803 mm and nearest rainfall is 780 mm already occurred in 2015. It indicates that the computed design rainfall is about 3.0% higher than the yearly maximum rainfall of 2015. This statistic confirms that during generation of design runoff for the design rainfall events, 3% additional rainfall should be added with the daily rainfall data of 2015 for getting the expected design runoff. Although yearly maximum for 5 days cumulative for 2019 is 854 mm but that is closer to 100 years event which is 871 mm thus 2015 is taken as design flood year.

Table 3.20: Selected design rainfall of Satkania for different rainfall events with suitable statistical method

Item	Hydrological Events	1day rainfall (mm)	3-days cumulative rainfall (mm)	5-days cumulative rainfall (mm)
	Return Period [years]	GUM	LP3	LP3
Estimated Design Rainfall of Satkania Rainfall Station for different return periods	2.33	171	325	398
	10	253	502	621
	20	289	567	704
	25	300	586	730
	50	335	641	**803**
	100	369	691	871
Goodness-of-fit statistics	CHISQ	**7.20**	**8.00**	**6.00**

The statistical analysis indicates that existing flood event and the design flood event is similar, the year 2015.

3.2 Determination of Climate Change Scenarios

Future changes on the upstream flow and downstream water level conditions will be generated from the Global Hydrological and hydraulic models. At the same time, projections on the rainfall and temperature also required to generate the rainfall induced runoff in the polder system for climate changes projections. The changes in the rainfall and temperature will produce the future runoff amount into polder system for the design flood event which should be drain out through the regulators to make the polder operation level. The changes in the upstream flow boundaries and downstream water level boundaries will be added into the hydrodynamic model and regulator invert level should be designed considering the future water level conditions at the peripheral river system.

3.2.1 Development of Future Projection on Precipitation

The consultant team published a report on “Climate Change Scenarios in June 2021” where the experts are developed the climate projection for five selected polders considering three-time horizons (2040, 2070 and 2100) for three scenarios (low, median, and high) covering the whole year and four specific seasons (pre-monsoon, monsoon, post-monsoon and winter) (Table 3.21). The changes in the precipitation have been devised relative to precipitation of 2020. The three scenarios low, median, and high scenarios correspond to 20-, 50- and 80-percentiles of the changes generated from the various Global Circulation Model (GCM) simulations.

Table 3.21: Proposed precipitation scenarios for the five selected polders

Season	Year:	2040			2070			2100		
	Scenario:	low	median	high	low	median	high	low	median	high
Year	polder 59/2	-6.20	-0.10	5.20	-0.50	5.90	15.90	3.00	11.50	21.20
	polder 29	-4.60	0.80	7.80	-0.10	6.50	16.60	5.00	9.80	22.20
	polder 15	-5.20	-0.80	6.60	-0.50	5.20	13.60	2.80	10.00	17.60
	polder 64/1a+64/1b	-4.50	-1.20	4.40	-1.10	5.70	10.30	1.50	7.80	12.80
	polder 40	-6.20	-1.10	5.90	-1.10	5.30	13.40	3.00	10.40	18.20
	polder 59/2	-17.10	-4.40	3.10	-7.60	6.50	17.70	8.20	17.90	23.80

Season	Year:	2040			2070			2100		
	Scenario:	low	median	high	low	median	high	low	median	high
Pre-monsoon	polder 29	-15.50	-3.50	8.10	-4.80	8.00	26.80	7.50	24.70	31.60
	polder 15	-12.50	-0.60	5.10	-3.70	8.70	27.70	8.00	22.00	33.20
	polder 64/1a+64/1b	-15.40	-5.40	-1.50	-8.10	2.60	17.90	0.70	7.30	28.70
	polder 40	-12.30	-1.10	4.30	-5.50	8.10	23.30	8.80	24.50	30.00
Monsoon	polder 59/2	-3.60	1.70	7.00	1.20	5.10	15.80	8.00	10.40	23.40
	polder 29	-4.00	1.20	8.60	0.50	5.50	16.40	7.10	12.40	25.30
	polder 15	-4.70	0.30	6.90	-0.10	4.00	13.80	6.50	9.20	19.60
	polder 64/1a+64/1b	-2.80	0.00	5.80	-1.80	5.40	11.20	0.40	9.00	13.00
	polder 40	-4.60	0.70	6.60	-0.60	4.00	14.30	5.00	9.00	18.90
Post-monsoon	polder 59/2	-21.20	0.30	17.70	-12.10	4.90	26.60	-13.60	4.60	30.10
	polder 29	-22.90	1.50	19.70	-12.30	5.40	27.70	-17.40	4.70	30.80
	polder 15	-23.00	1.20	18.50	-13.20	5.20	27.30	-16.20	5.20	30.70
	polder 64/1a+64/1b	-16.20	-0.40	10.50	-14.00	6.20	24.20	-10.60	7.10	24.80
	polder 40	-22.50	-1.30	19.60	-11.30	4.80	25.90	-12.50	5.90	30.90
Winter	polder 59/2	-9.60	14.10	39.40	-40.10	8.00	49.60	-67.60	-15.80	15.90
	polder 29	-8.10	8.10	43.10	-37.40	5.20	37.30	-55.80	-7.10	13.10
	polder 15	-8.90	8.80	40.50	-40.50	2.80	34.90	-57.90	-11.20	12.70
	polder 64/1a+64/1b	-11.50	6.30	24.20	-36.30	-10.00	47.20	-56.30	-14.80	15.80
	polder 40	-9.80	13.20	42.60	-43.90	4.00	39.90	-66.10	-13.90	12.60

Source: Climate Change Scenarios, Deliverable 4C: Meteorology, June 2021

Note: The numbers represent the percentage change in daily mean precipitation, relative to the year 2020. However, proper planning and design, month-wise rainfall is required for determining the actual design runoff which is required to drain out during the extreme flood event condition.

3.2.2 Development of Future Projection on Temperature

Similar type of projection has been carried out for the temperature (Table 3.22). The numbers represent the change in daily mean temperature in degrees, relative to the year 2020. Month-wise temperature projection is required to generate the future changes of evaporation.

Table 3.22: Proposed temperature scenarios for the five selected polders

Season	Year:	2040			2070			2100		
	Scenario:	low	median	high	low	median	high	low	median	high
Year	polder 59/2	0.60	0.70	1.00	1.10	1.50	2.30	1.30	2.20	3.60
	polder 29	0.60	0.70	1.00	1.00	1.40	2.20	1.30	2.20	3.50
	polder 15	0.60	0.70	0.90	1.00	1.40	2.10	1.20	2.10	3.30
	polder 64/1a+64/1b	0.50	0.70	1.00	1.00	1.50	2.20	1.30	2.20	3.50
	polder 40	0.60	0.70	0.90	1.00	1.40	2.10	1.20	2.10	3.30
Pre-monsoon	polder 59/2	0.50	0.70	1.10	1.00	1.50	2.40	1.50	2.20	3.80
	polder 29	0.50	0.70	1.20	0.90	1.60	2.40	1.40	2.20	3.70
	polder 15	0.50	0.60	1.00	0.90	1.50	2.20	1.30	2.10	3.40
	polder 64/1a+64/1b	0.50	0.70	1.10	1.00	1.40	2.40	1.30	2.10	3.70
	polder 40	0.50	0.60	1.10	0.90	1.50	2.10	1.30	2.10	3.30
Monsoon	polder 59/2	0.40	0.60	0.80	0.70	1.20	1.90	1.00	1.80	3.10

Season	Year:	2040			2070			2100		
	Scenario:	low	median	high	low	median	high	low	median	high
	polder 29	0.40	0.60	0.80	0.70	1.30	1.90	0.90	1.80	3.10
	polder 15	0.40	0.60	0.80	0.70	1.20	1.80	0.90	1.80	2.90
	polder 64/1a+64/1b	0.40	0.60	0.80	0.70	1.20	1.90	0.90	1.80	3.00
	polder 40	0.40	0.60	0.80	0.70	1.20	1.80	1.00	1.70	2.90
Post-monsoon	polder 59/2	0.60	0.90	1.00	1.10	1.70	2.10	1.30	2.50	3.20
	polder 29	0.60	0.90	1.00	1.10	1.70	2.10	1.30	2.50	3.20
	polder 15	0.60	0.80	1.00	1.00	1.70	2.00	1.20	2.40	3.10
	polder 64/1a+64/1b	0.60	0.80	0.90	1.10	1.60	2.00	1.30	2.40	3.20
	polder 40	0.60	0.80	1.00	1.10	1.60	2.00	1.20	2.40	3.10
Winter	polder 59/2	0.70	0.80	1.10	1.30	1.70	2.50	1.60	2.50	3.80
	polder 29	0.70	0.80	1.10	1.30	1.60	2.40	1.50	2.40	3.60
	polder 15	0.70	0.80	1.00	1.30	1.50	2.30	1.40	2.30	3.50
	polder 64/1a+64/1b	0.70	0.80	1.10	1.30	1.60	2.40	1.50	2.30	3.80
	polder 40	0.60	0.70	1.00	1.30	1.50	2.30	1.40	2.30	3.50

Source: Climate Change Scenarios, Deliverable 4C: Meteorology, June 2021

3.2.3 Development of Future Upstream Boundary Conditions

The Hydrotrend consultant team is preparing the future changes of upstream catchment flow. Consultant team will prepare future changes of flow at three locations, i) at Gorai Railway Bridge considering Ganges River Basin ii) at Baruria considering the Brahmaputra River Basin iii) at Bhairab Bazar Railway Bridge considering Meghna River Basin (Figure 3.18).

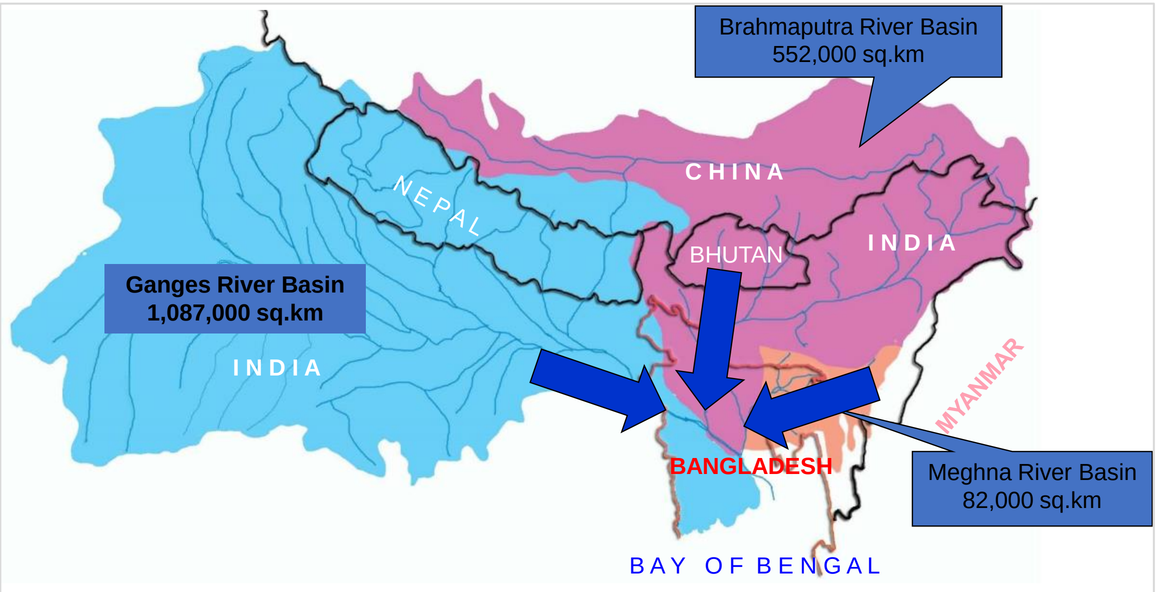


Figure 3.18: Extent of Ganges, Brahmaputra, and Meghna River Basin

Note: Bangladesh rivers receive runoff from a catchment of 1.72 million sq. km, around 12 times its land area.

3.2.4 Development of Future Relative Mean Sea Level Rise

Consultant team already published the future projection on sea level rise in the Bay of Bengal near the coastal area of Bangladesh in "Climate Change Scenarios, Deliverable 4C: Meteorology, June 2021" Final Report[2].

Regional Absolute Sea Level Rise (ASLR) projections were extracted at the five closest locations along the Bangladesh coast in the Bay of Bengal based on SROCC (Special Report on the Ocean and Cryosphere in a Changing Climate) regional projections (IPCC, 2019; Oppenheimer et al. 2019) (Figure 3.19).

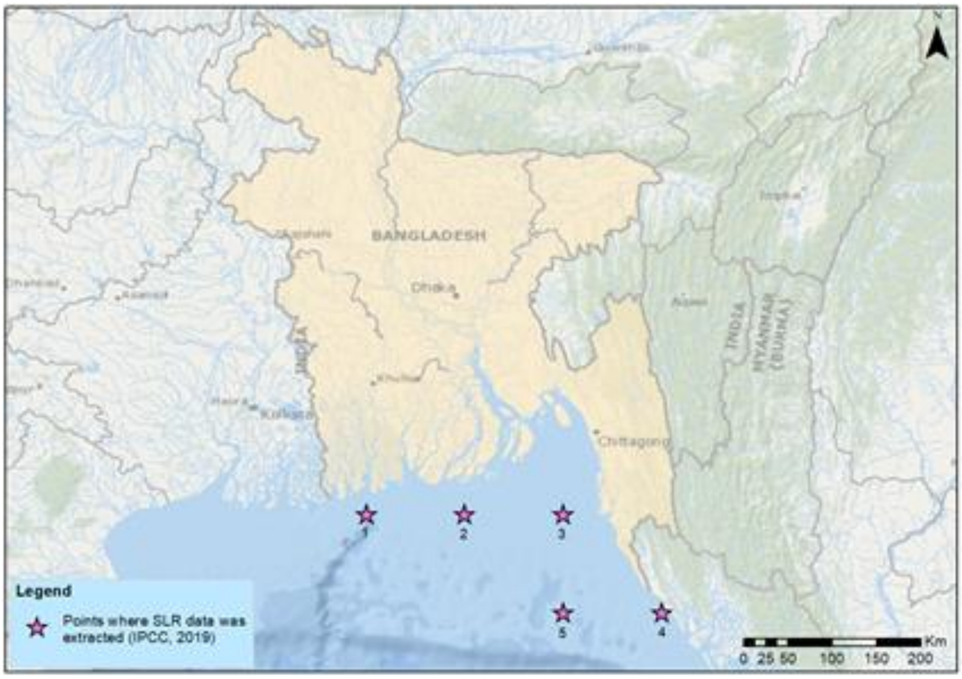


Figure 3.19: Locations at which ASLR value were extracted.

Averaged ASLR values along the Bangladesh coastline in the Bay of Bengal are shown in the Figure 3.20, both for moderate RCP 4.5 and extreme RCP 8.5 scenarios and including the 5%-95% confidence interval. Predicted values at five (05) locations (Figure 3.19) are shown in the Table 3.23 and Table 3.24, respectively for RCP 4.5 and RCP 8.5 scenario. Estimated ASLR presents minor difference at these different locations, showing the differences of a few centimetres only, and within the confidence interval. Therefore, mean values among the different stations have been recommended for future use. It has been estimated mean ASLR 47cm and 76cm for the year 2100 at the moderate (RCP 4.5) extreme climate change condition (RCP 8.5) respectively.

[2] Climate Change Scenarios, Deliverable 4C: Meteorology (June 2021), "Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)", Coastal Embankment Improvement Project, Phase-I (CEIP-I), Bangladesh Water Development Board

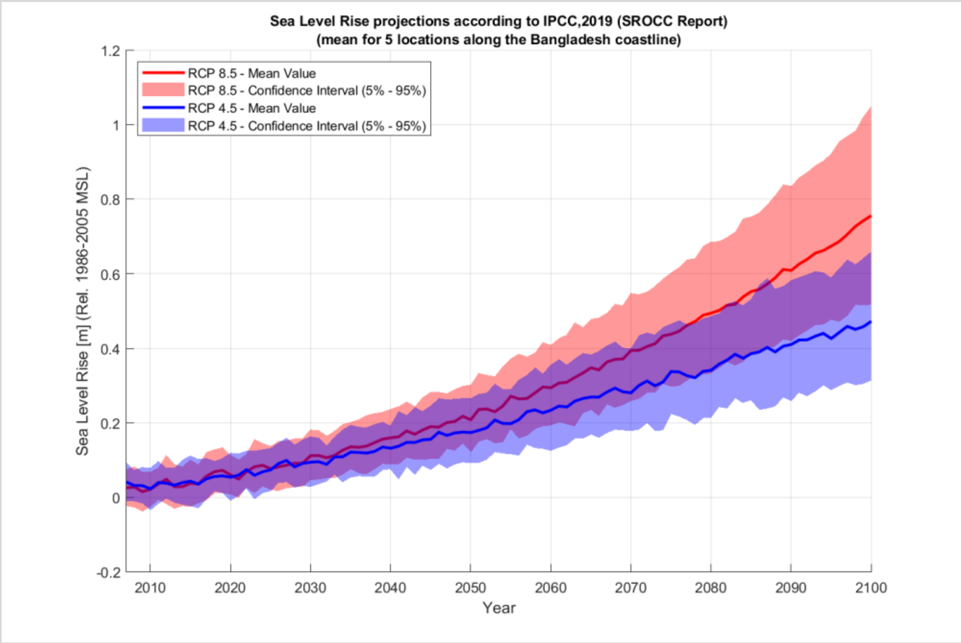


Figure 3.20: Averaged SLR projections for the 21st century and associated uncertainties.

Table 3.23: Regional and global ASLR projections for the 21st century at the five closest locations along the Bangladesh coast in the Bay of Bengal

Time	Total Sea Level Rise – RCP 4.5 [m] (Rel. to 1986 to 2005)						
	1	2	3	4	5	mean	GMSL
2020	**0.057**	**0.053**	**0.055**	**0.054**	**0.055**	**0.055**	**0.081**
	[-0.006 to 0.121]	[-0.016 to 0.123]	[-0.01 to 0.121]	[-0.001 to 0.109]	[-0.014 to 0.124]	[-0.009 to 0.12]	[0.057 to 0.104]
2040	**0.135**	**0.137**	**0.126**	**0.129**	**0.133**	**0.132**	**0.172**
	[0.067 to 0.208]	[0.069 to 0.21]	[0.078 to 0.179]	[0.082 to 0.183]	[0.088 to 0.184]	[0.077 to 0.193]	[0.124 to 0.221]
2050	**0.181**	**0.185**	**0.164**	**0.164**	**0.176**	**0.174**	**0.228**
	[0.079 to 0.297]	[0.081 to 0.301]	[0.09 to 0.247]	[0.103 to 0.233]	[0.104 to 0.255]	[0.091 to 0.266]	[0.165 to 0.293]
2060	**0.235**	**0.234**	**0.23**	**0.231**	**0.24**	**0.234**	**0.288**
	[0.115 to 0.373]	[0.111 to 0.366]	[0.126 to 0.345]	[0.137 to 0.34]	[0.137 to 0.354]	[0.125 to 0.356]	[0.206 to 0.373]
2080	**0.351**	**0.35**	**0.329**	**0.336**	**0.341**	**0.341**	**0.417**
	[0.207 to 0.515]	[0.201 to 0.515]	[0.211 to 0.466]	[0.221 to 0.468]	[0.229 to 0.47]	[0.214 to 0.487]	[0.296 to 0.545]
2100	**0.487**	**0.489**	**0.458**	**0.457**	**0.471**	**0.473**	**0.549**
	[0.301 to 0.699]	[0.303 to 0.702]	[0.324 to 0.627]	[0.315 to 0.628]	[0.323 to 0.648]	[0.313 to 0.661]	[0.385 to 0.724]

Note: averaged values of the five locations, according to RCP 4.5 scenario. Mean values are provided in bolds while associated uncertainties (5 and 95%) are included in brackets.

Table 3.24: Regional and global ASLR projections for the 21st century at the five closest locations along the Bangladesh coast in the Bay of Bengal

Time	Total Sea Level Rise – RCP 8.5 [m] (Rel. to 1986 to 2005)						
	1	**2**	**3**	**4**	**5**	**mean**	**GMSL**
2020	**0.059**	**0.058**	**0.059**	**0.064**	**0.062**	**0.061**	**0.085**
	[0.008 to 0.114]	[0.007 to 0.11]	[0.004 to 0.115]	[0.011 to 0.118]	[0.012 to 0.114]	[0.008 to 0.114]	[0.061 to 0.109]
2040	**0.165**	**0.166**	**0.153**	**0.154**	**0.162**	**0.16**	**0.195**
	[0.084 to 0.25]	[0.088 to 0.251]	[0.084 to 0.227]	[0.09 to 0.223]	[0.096 to 0.233]	[0.088 to 0.237]	[0.142 to 0.250]
2050	**0.216**	**0.213**	**0.197**	**0.206**	**0.209**	**0.208**	**0.268**
	[0.117 to 0.325]	[0.112 to 0.325]	[0.115 to 0.287]	[0.135 to 0.284]	[0.133 to 0.295]	[0.122 to 0.303]	[0.196 to 0.343]
2060	**0.295**	**0.296**	**0.286**	**0.296**	**0.299**	**0.294**	**0.353**
	[0.187 to 0.416]	[0.19 to 0.416]	[0.19 to 0.398]	[0.197 to 0.407]	[0.203 to 0.41]	[0.193 to 0.409]	[0.259 to 0.454]
2080	**0.505**	**0.506**	**0.475**	**0.486**	**0.5**	**0.494**	**0.568**
	[0.323 to 0.715]	[0.326 to 0.711]	[0.332 to 0.652]	[0.332 to 0.672]	[0.344 to 0.681]	[0.331 to 0.686]	[0.415 to 0.738]
2100	**0.764**	**0.764**	**0.741**	**0.75**	**0.76**	**0.756**	**0.842**
	[0.506 to 1.081]	[0.509 to 1.078]	[0.514 to 1.021]	[0.521 to 1.028]	[0.532 to 1.037]	[0.516 to 1.049]	[0.609 to 1.105]

Note: averaged values of the five locations, according to RCP 8.5 scenario. Mean values are provided in bolds while associated uncertainties (5 and 95%) are included in brackets.

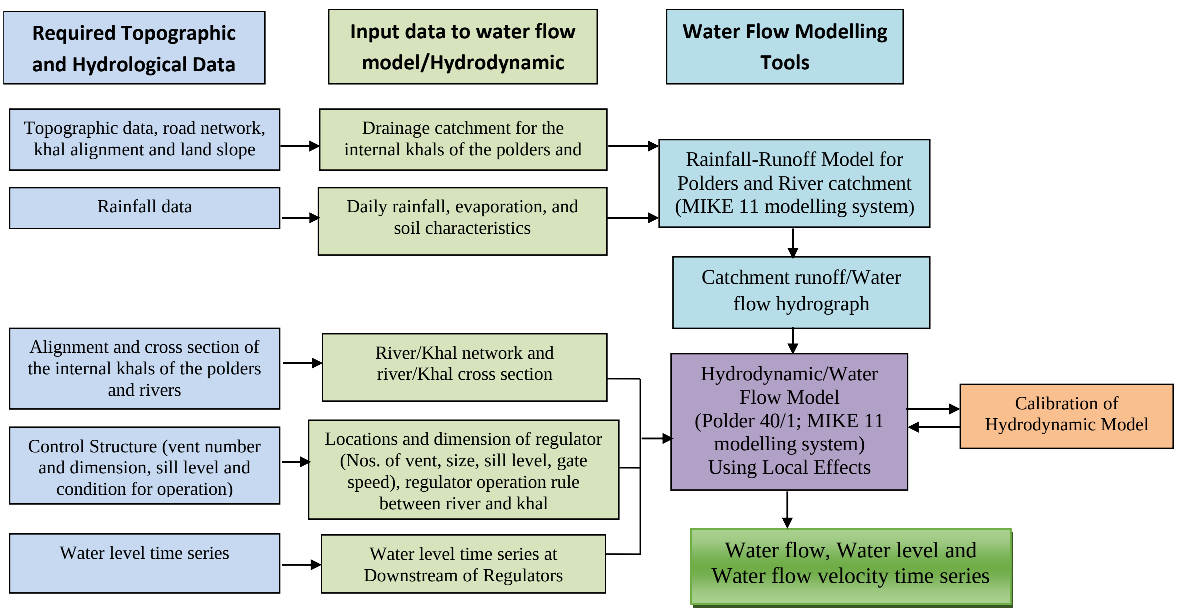
Zone wise (south-west, south-central, south-east, and eastern hilly) land subsidence rate will be added for calculating the relative mean sea level with the absolute sea level rise. Syvitski's law (2009) will be applied for determining the RMSL.

4 Development of Mathematical Model

The polder drainage model is developed by incorporating newly surveyed cross-section data of the internal drainage channels/khals and existing water control structures within the polder area including detailed catchments distribution for the internal drainage channels and peripheral river systems. The polder drainage networks are connected to the peripheral rivers through drainage khals and water control structures. The structures have been included in the model providing the input data on their dimensions/size, number of vents and invert levels together with their operating rules of gates.The operation rules is defined in such a way that if outside water level is higher than that of polder water level in the drainage khals/channel, the gates of the structure is closed automatically and vice versa. Within the polder the runoff generated from the catchment is routed into the respective drainage khals in proportion to their respective drainage areas which eventually drained towards the peripheral khals through the structures.

Two types of mathematical models have been developed for each polder for planning and designing of the polder water management system. The models are: i) Polder Hydrological Model and ii) Polder Hydrodynamic Model/ Polder Water-Flow Model. The developed Hydrological Model (Rainfall Runoff model) is one kind of lumped and conceptual model which presents the rainfall contribution as a surface runoff into khal system for each catchment. Hydrodynamic Model (Water-Flow Model) which is the illustration of water-flow into the internal Khal/canal systems with the proper operation of control structures (regulators). These two models ensure the planning and design of water availability and water flow direction into the polder system properly. Typical mathematical modelling input parameters and outcomes are presented in the following flow chart for better underestanding the modelling activities at a glance.

Flow Chart on Drainage Modelling

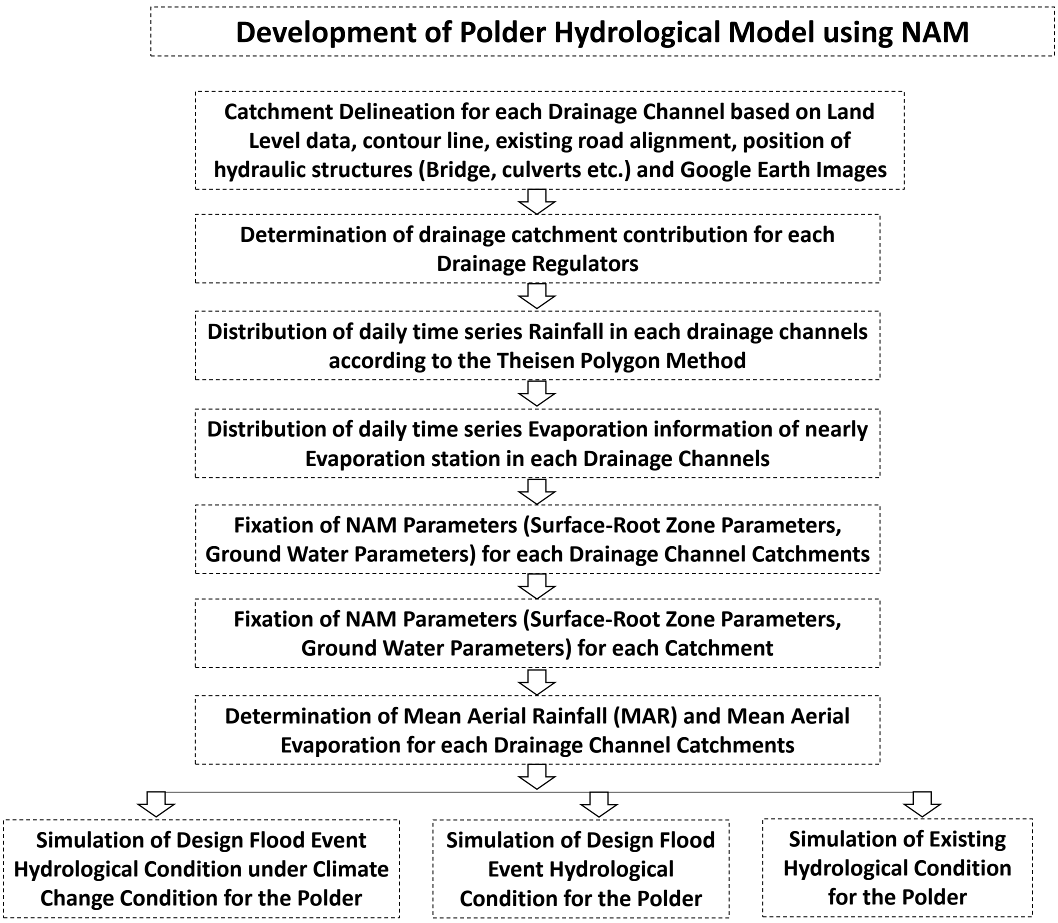


Detailed description, methodology of each modeling system has been described below. Development of the Polder Drainage Model of Polder 40/1 will be decribed in this chapter in detail and the polder drainage modelling of the remaining polders will be described in summarized form.

4.1 Development of Rainfall Runoff Model

Rainfall-Runoff model for the selected polders has been developed to estimate the rainfall generated runoff. As the study area is influenced by the astronomical tide, therefore, discharge of this rainfall generated runoff through the regulators depends mainly on the tidal phase conditions (flood tide and ebb tide) in the peripheral rivers. If the extreme rainfall occurs during flood tide, there is the highest probability that waterlogging would occur during that period. The stagnant water will be drained out during ebb tide. Hence, the rainfall generated runoff from the hydrological model will be linked with the astronomical tide conditions to model the physical process of the polder water drainage.

The model takes into consideration the basin characteristics including specific yield, initial soil moisture contents and initial ground water level and irrigation/abstraction from the surface or ground water sources. The catchments delineation of all selected polders is important to distribute the contribution of runoff into the internal drainage khals/channels as a lateral flow. The overall hydrological model development concept is illustrated in the following flow chart.



Polder 40/1 has been selected for showing the detailed model concepts and methodology.

4.1.1 Input Parameters

The input parameters of the rainfall-runoff model have been described below

4.1.1.1 Catchment Delineation

Rainfall-Runoff model has been prepared for the polder 40/1 considering the individual catchment of each drainage khal/canal system (Figure 4.1). The main purpose of the catchment delineation is to sub-divide the whole polder area for the existing drainage networks and hydraulic structures incorporated in the drainage model set-up and distribution of rainfall runoff effects into the khal systems as lateral flow. In the process of catchment delineation single or multiple channels are grouped together to form a single hydrological unit which drained through a single structure. Delineation of catchments area has been done based on:

- Land level data of the polder;
- Alignment of existing khals, hydraulic structures, and other topographical features including road networks;
- Fixation of alignment of road networks, khal and position of the bridges/culverts from Google Earth Pro;

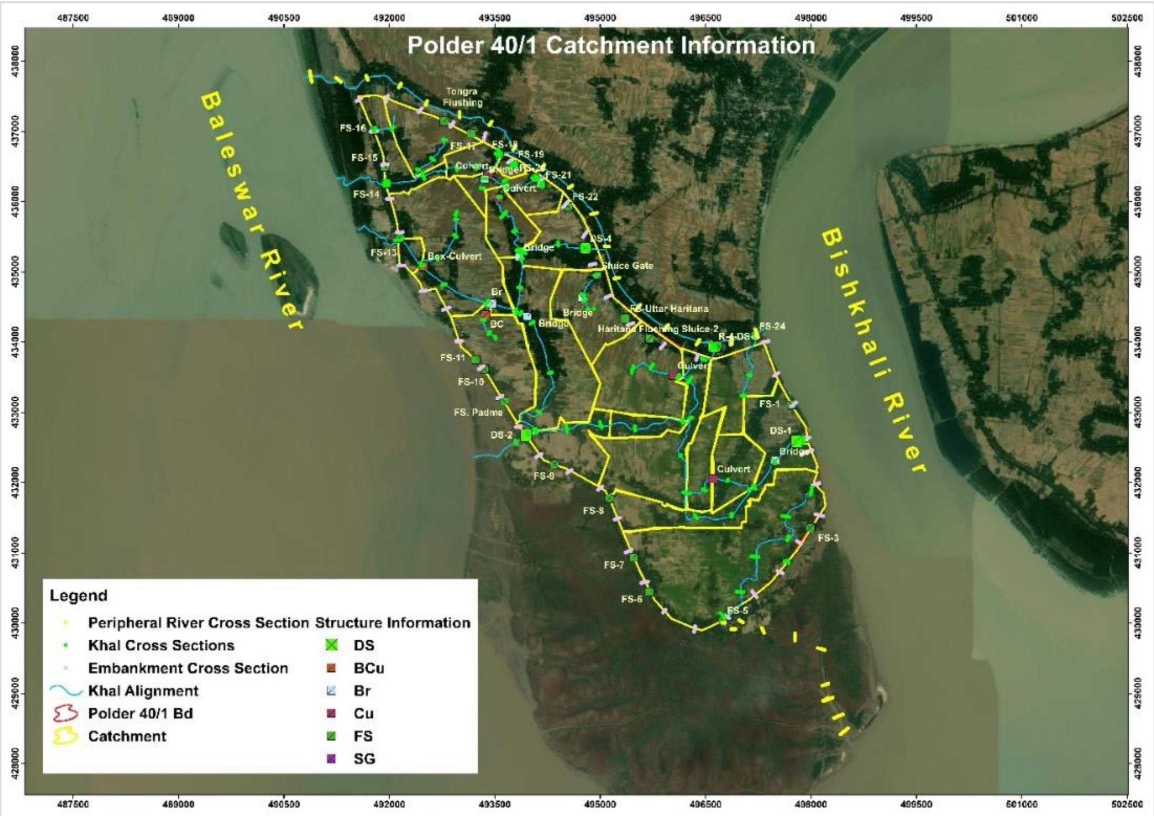


Figure 4.1: Catchment information of Polder 40/1

The delineated catchments area of the Polder 40/1 is presented in the Figure 4.2.Catchment area is calculated in sq. km.

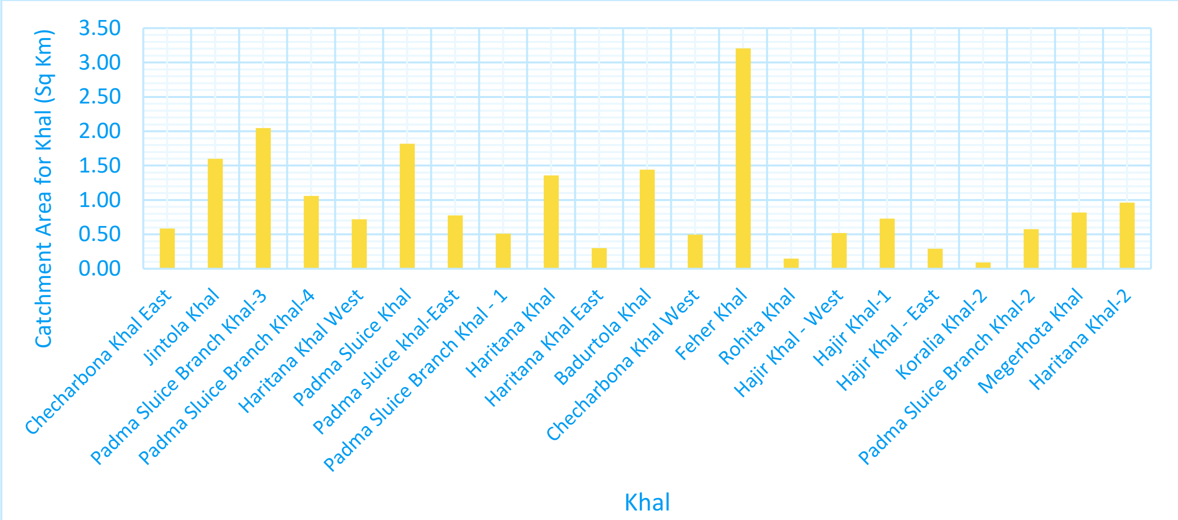


Figure 4.2: Delineated catchment area of the Polder 40/1

4.1.1.2 Rainfall Information

The study area is covered by one rainfall station Patharghata which is maintaining by Bangladesh Water Development Board (BWDB). The observed rainfall station is located at almost near the drainage regulator DS-2 (Padma Sluice). However, contribution of this rainfall information has been distributed into the whole polder system uniformly and it has been checked by GIS Technique Theisen Polygon Method. The study area (Polder 40/1) has been defined by the different flowing channels/khals and Table 4.1 shows the contribution of Patharghata rainfall stations in each khal/channel catchment.

Table 4.1: Effects of rainfall stations in each catchment

SL	Khal Name/Catchment	Area(km^2)	Rainfall Station	Influence Factor
1	Checharbona Khal East	0.58	Patharghata	1
2	Jintola Khal	1.60		1
3	Padma Sluice Branch Khal-3	2.05		1
4	Padma Sluice Branch Khal-4	1.06		1
5	Haritana Khal West	0.72		1
6	Padma Sluice Khal	1.82		1
7	Padma sluice khal-East	0.78		1
8	Padma Sluice Branch Khal - 1	0.51		1
9	Haritana Khal	1.36		1
10	Haritana Khal East	0.30		1
11	Badurtola Khal	1.44		1
12	Checharbona Khal West	0.50		1
13	Feher Khal	3.20		1
14	Rohita Khal	0.15		1
15	Hajir Khal - West	0.52		1
16	Hajir Khal-1	0.73		1
17	Hajir Khal - East	0.29		1
18	Koralia Khal-2	0.09		1
19	Padma Sluice Branch Khal-2	0.57		1
20	Megerhota Khal	0.82		1
21	Haritana Khal-2	0.96		1

4.1.1.3 Evaporation Information

There are three evaporation measurement stations like Patuakhali, Pirojpur and Khepupara covering the study area though these are far away from the Polder 40/1. However, there are three station in and around of the Polder 40/1, Khepupara evaporation information has been considered for further use (model development).

4.1.1.4 Soil Characteristics

The influenced selected River catchments are mostly covered with agricultural land, few water storages like ponds, canals etc. However, the study area (Polder 40/1) soil is covered with agricultural land, drainage khals, some fish ghers where overland flow will attain the peak intermediately-in some catchments, overland flow will attain the peak flow slowly and other catchments, overland flow will attain the peak quickly, depending on the catchment’s physical properties. Therefore, variable runoff coefficient has been considered 0.65 to represent combination of high agricultural land and grass land and 0.50 to represents the wetland and mostly covered forest canopy system. Individual catchments have individual soil properties which reflections have been applied in the rain-runoff model.

Surface & Root Zone Parameters are described below
Maximum water content in surface storage (U_{max}) =7.0~9.0mm;
Maximum water content in root zone storage (L_{max}) = 65~75mm;
Overland flow runoff coefficient (CQ_{OF}) = 0.65~0.50;
Time constant for interflow (CK_{IF}) =40~48 hrs.
Time constants for routing overland flow ($CK_{1, 2}$) = 8.0~10 hrs.
Root zone threshold value for overland flow (T_{OF}) = 0;
Root zone threshold value for inter flow (T_{IF}) = 0
The following Ground Water Parameters are considered in this hydrological model:
Time constant for routing base flow (CK_{BF}) = 200 hrs;
Root zone threshold value for ground water recharge (T_g) = 500;

4.1.2 Estimation of Runoff at Existing Hydrological Condition

Catchment of each regulator has been distributed according to the contribution from the remote locations of each tertiary, secondary and primary drainage khals. The contribution of each similar size regulator may be different based on the tidal characteristics at each outlet to the peripheral river system, human interventions into the drainage channels/khals, existence of culverts, bridges, and conditions of the regulators. However, in the hydrological model of each polder system has been simulated as an ideal condition using the MIKE 11 NAM which is lumped and conceptual model. Only rainfall generated runoff has been calculated for each catchment by using the soil characteristics, meteorological information, canopy characteristics and ground water properties. However, ground water properties are not included in this model. One typical plot of catchment runoff generated from the rainfall for the Padma sluice (DS-2) of the Polder 400/1 has been presented in the Figure 4.3.

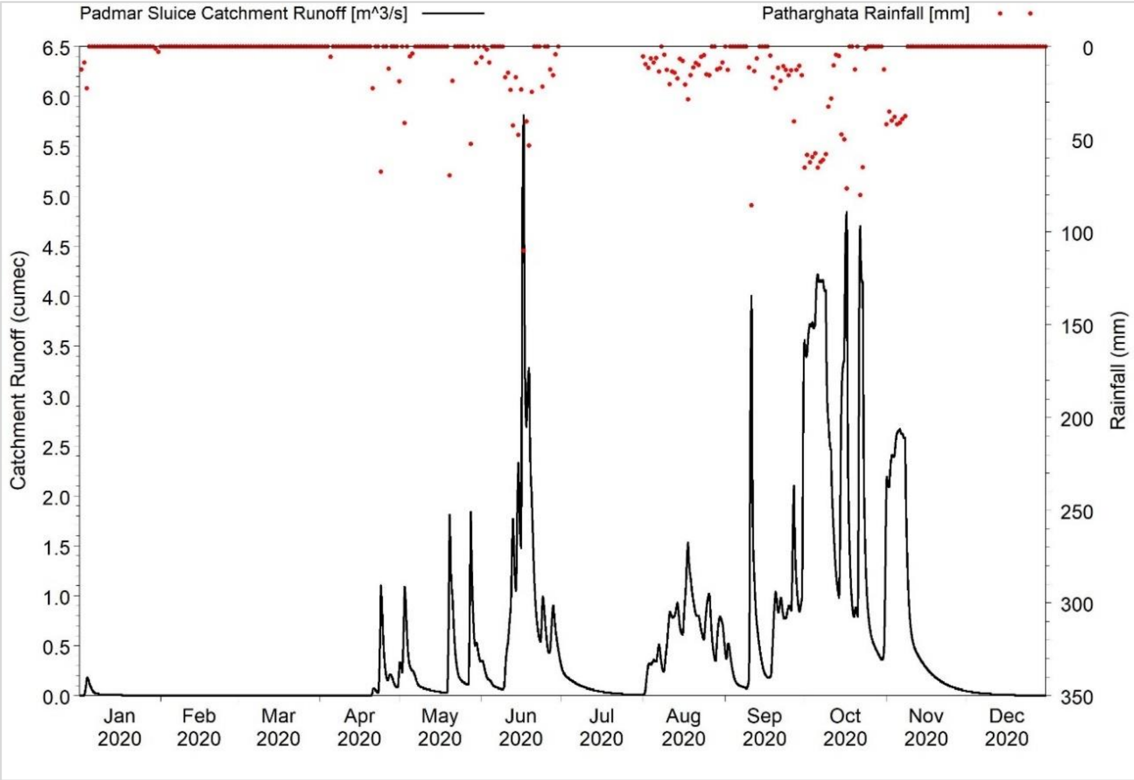
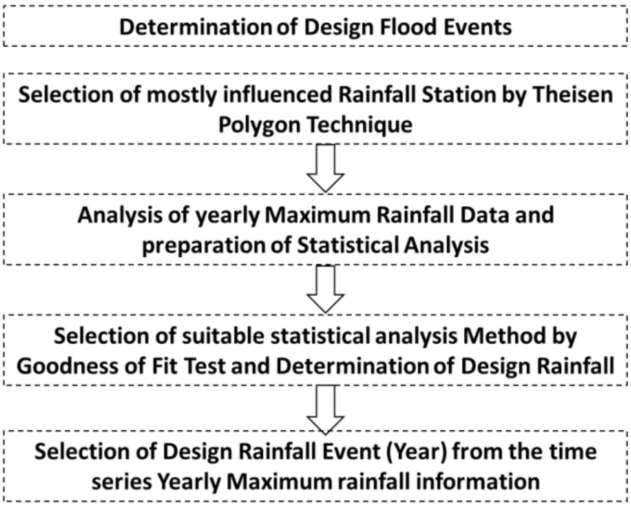


Figure 4.3: Rainfall generated runoff for the Padmar sluice (DS-2) of the Polder 40/1

Similarly, rainfall generated runoff has been generated for all khal catchments and generated runoff is linked with the Polder 40/1 Water-Flow model (Hydrodynamic Model) drainage channels/khals network as a lateral flow. The generated runoff is used in the hydrodynamic channel network as linearly routing method considering the catchment area and the length of the khals/channels.

4.1.3 Estimation of Design Flood Runoff

Year 2011 has been selected as design flood event by statistical analysis. The analysis has been discussed in the previous "Data Analysis" chapter. The following steps are followed for determining the design runoff from the design rainfall event.



Later the rainfall data for the year 2011 has been converted into 2019 to compare the rainfall generated design runoff with the existing rainfall generated runoff. The following Figure 4.4 presents the comparison of these two runoffs.

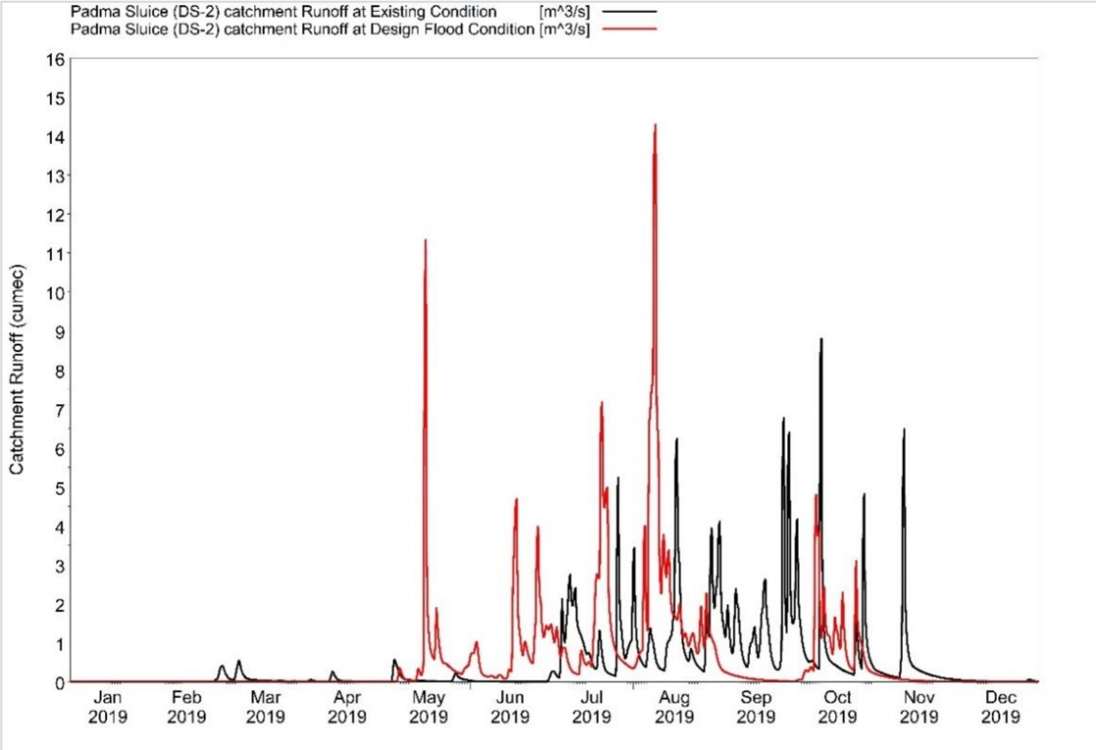


Figure 4.4: Rainfall generated runoff at existing and design flood event condition

The Figure 4.4 indicates that the maximum runoff generated in the Padmar regulator (DS-02) covering the catchment at the existing condition in the month of late September and early of October 2019. However, during design flood period, the maximum runoff occurred at the end of July in the same catchment that has to be drain out through the Padmar drainage regulator (DS-02) of the polder. Similarly, the developed hydrological model of the Polder 40/1 generated runoff for all regulator catchments.

The methodology has been used in the Polder 40/1 for generating the rainfall generated runoff, same methodology has been applied to develop the hydrological model for the rest of the selected polders (Polder 15, Polder 29, Polder 59/2, Polder 64/1a and Polder 64/1b).

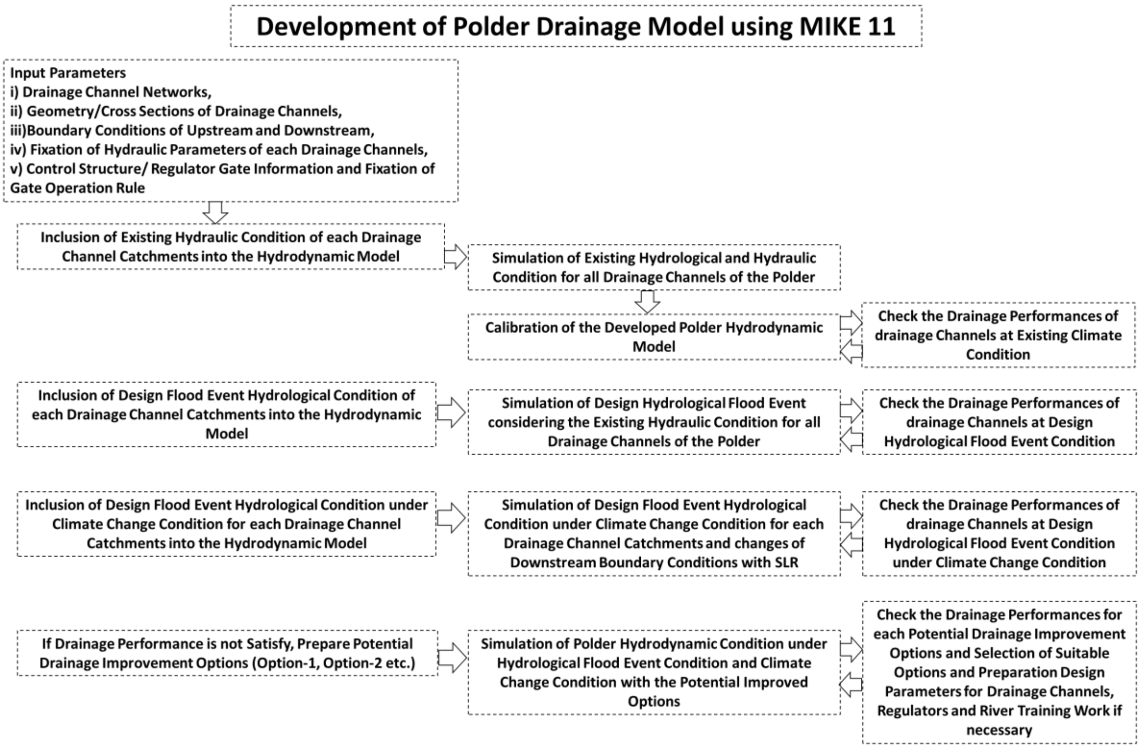
4.1.4 Estimation of Design Flood Runoff under Climate Change Condition

Changes in the rainfall and temperature for the future will be added with the existing meteorological data to develop the climate change scenario. This time series projected rainfall data and evaporation data projected by the temperature will be added with the design flood event hydrological model to develop the hydrological mode under climate change condition.

4.2 Development of Polder Water-Flow (Hydrodynamic) Model

Khal/branch networks, branch cross sections, characteristics of the branch sections, initial conditions of each branch, bed roughness of each cross section, boundary conditions and contribution of rainfall runoff, all are required input parameters of a Polder

Water-Flow Model. The overall polder hydrodynamic model/polder drainage model has been developed based on the following flow chart.



The above discussed mathematical modelling methodology has been followed for all polder drainage models. In this chapter, polder drainage modelling for the Polder 40/1 has been described in details and rest of the polder's drainage modelling described in the summary format. In this report, detail description of the Polder 40/1 has been described below and the required input parameters for the polder drainage model are described below by highlighting the Polder 40/1.

4.2.1 Input Parameters

Drainage canals/khals network, geometric profile, and characteristics (cross sections) of the drainage channels, detail information of the regulators, boundary conditions of the downstream and upstream of the drainage channels, contribution of rainfall generated runoff into the drainage channels, these parameters are the input parameters of the polder hydrodynamic model.

4.2.1.1 Network development

About 24 no. of khals/drainage channels are included in the Polder Water-Flow (Hydrodynamic) model (Figure 4.5). There are some khals which upstream are not connected each other but downstream are connected with other khals. There are four major khals which are controlled by drainage regulators and downstreams are connected with the peripheral river system.

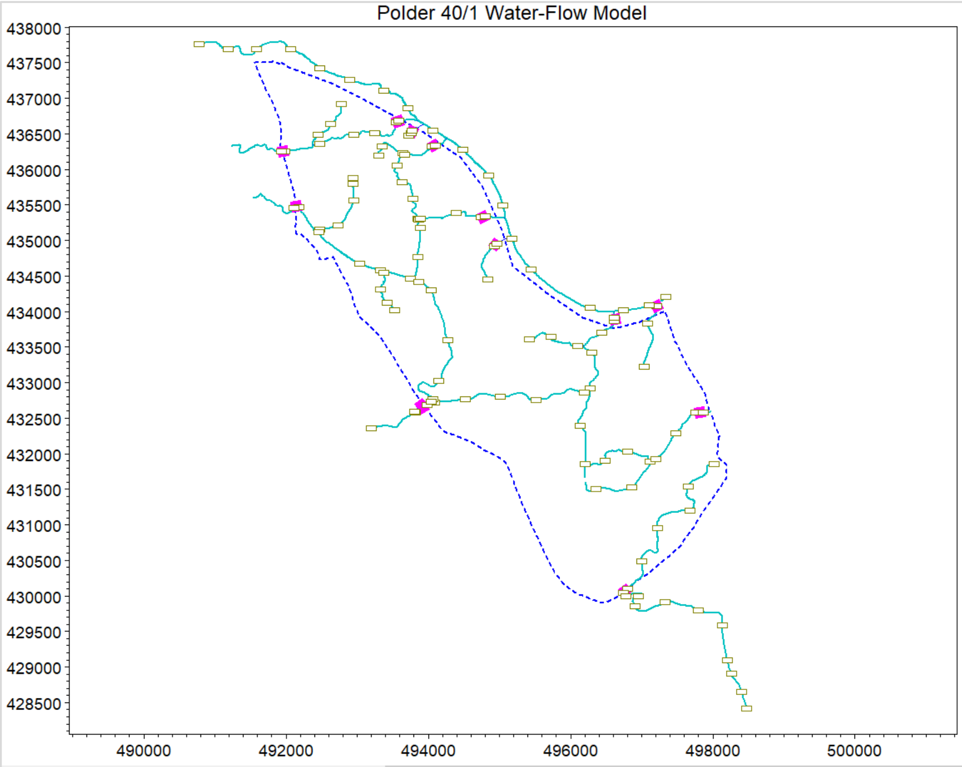


Figure 4.5: Internal drainage khal and peripheral river network including regulators, cross sections

The list of drainage khal networks and connection of each other khals are presented in the Table 4.2.

Table 4.2: List of drainage channels and internal connections of each other khals of the Polder 40/1

Branch Name	Branch Length (m)	Upstream connection Name	Upstream connection chainage	Downstream connection Name	Downstream connection chainage
Badurtola Khal	2780			Peripheral khal-1	7803
Checharbona Khal East	610			Jintola Khal	1231
Checharbona Khal West	505	Checharbona Khal East	0	Badurtola Khal	148
Feher Khal	2800				
Hajir Khal-1	780			Hajir Khal - West	466
Hajir Khal - East	1275			Peripheral khal-1	3679
Hajir Khal - West	1865	Hajir Khal - East	0		
Haritana Khal	875			Badurtola Khal	2063
Haritana Khal-2	650			Peripheral khal-1	5889
Haritana Khal East	1200	Haritana Khal West	0	Badurtola Khal	1278
Haritana Khal West	1115			Padma Sluice Khal	3230
Jintola Khal	2395				
Koralia Khal-2	215			Peripheral khal-1	3779
Megerhota Khal	970			Peripheral khal-1	8400

Branch Name	Branch Length (m)	Upstream connection Name	Upstream connection chainage	Downstream connection Name	Downstream connection chainage
Padma Sluice Branch Khal-2	1265			Peripheral khal-1	4171
Padma Sluice Branch Khal-3	2605			Padma Sluice Khal	870
Padma Sluice Branch Khal-4	665			Padma Sluice Branch Khal-3	2152
Padma Sluice Branch Khal - 1	1140	Padma Sluice Khal	0	Padma Sluice Branch Khal-2	554
Padma Sluice Khal	4230				
Padma sluice khal-East	1250	Padma Sluice Khal	8.47908849	Peripheral khal-1	5623
Peripheral khal-1	8565				
Rohita Khal	1340	Padma Sluice Branch Khal-3	1057.99193		
Peripheral khal-2	3270	Feher Khal	2800		
Padma Sluice Khal link	280	Padma Sluice Khal	3256.14062	Padma Sluice Khal	3539

4.2.1.2 Cross Section Data

Cross sections of all khals have been surveyed approximately 400m intervals and all cross sections are included in the hydrodynamic model. A typical khal cross section is presented in the Figure 4.6.

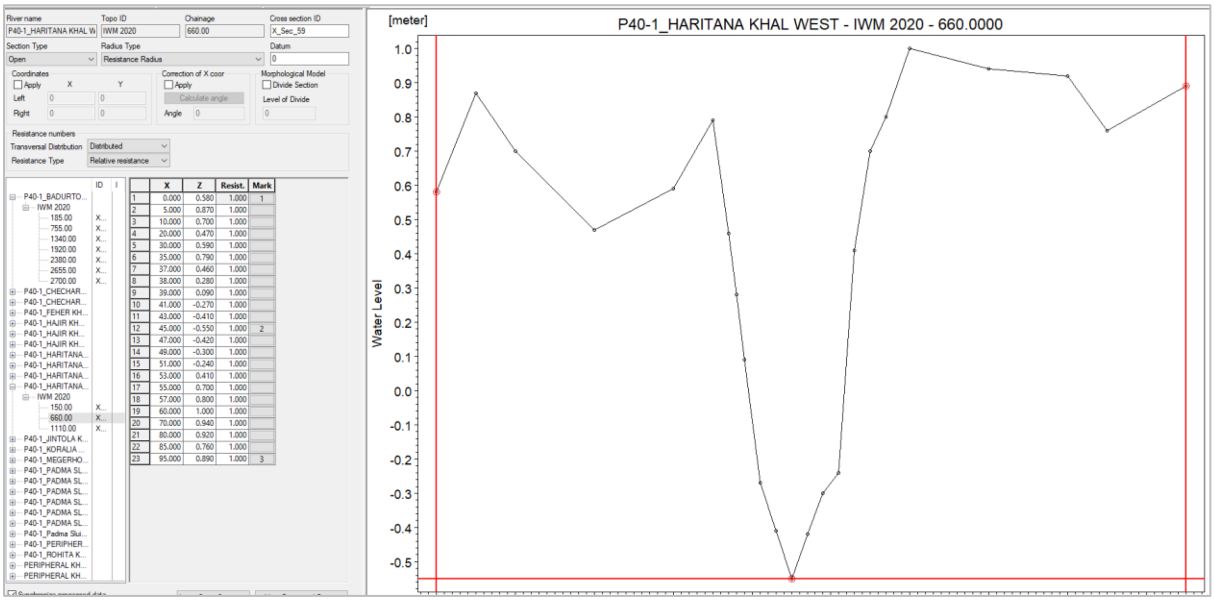


Figure 4.6: Typical cross section plot for Haritana Khal (West)

4.2.1.3 Control Structures

There are four (04) drainage regulators and full polder area drain out through these regulators. Among the six regulators, only 2 regulators, DS-1 and DS-2 are draining the whole polder catchment water. DS-1 (Jintola) is connected with Buriswar River and DS-2 (Padma) are connected with Baleswar River and rest of the 02 (two) drainage regulators are connected with silted up peripheral river at the north of the Polder 40/1. The another eight (08) flusing inlets are included into the Polder 40/1 hyrdrydynamic system but operation of these flushing inlets are not included into the system.There are box culverts, bridges are available into the existing drainage khals but these are not included into the polder water flow model. Table 4.3 presents the list of structure which are included into the polder water-flow model and Figure 4.7 presents the structure input cross section in the model network.

Table 4.3: List of drainage channels and connection

Branch Name	Structure Chainage	Structure ID	Flow Type	No. of Vents	Regulator Invert Level (mPWD)
Jintola Khal	2235	DS-1_1V	Underflow	1	-1.41
Padma Sluice Khal	3400	DS-2_1V	Underflow	1	-1.10
Padma sluice khal-East	950	DS-4_PIPE 3V	Underflow	3	-0.79
Badurtola Khal	2680	DS-5_3V	Underflow	3	1.03
Koralia Khal-2	150	FS-19_PIPE SLUICE	Underflow	1	-0.27
Padma Sluice Branch Khal-2	1050	FS-20_BOX SLUICE	Underflow	1	-0.14
Haritana Khal-2	600	SLUICE_BOX 1V	Underflow	1	0.50
Megerhota Khal	940	FS-24_PIPE SLUICE_1V	Underflow	1	0.36
Feher Khal	2760	FS-5_PIPE SLUICE	Underflow	1	-0.19
Rohita Khal	520	FS-13_PIPE SLUICE	Underflow	1	-0.39
Hajir Khal - West	925	FS-14_DAMAGE	Underflow	1	0.20
Hajir Khal - East	1000	FS-18_PIPE	Underflow	1	-0.13

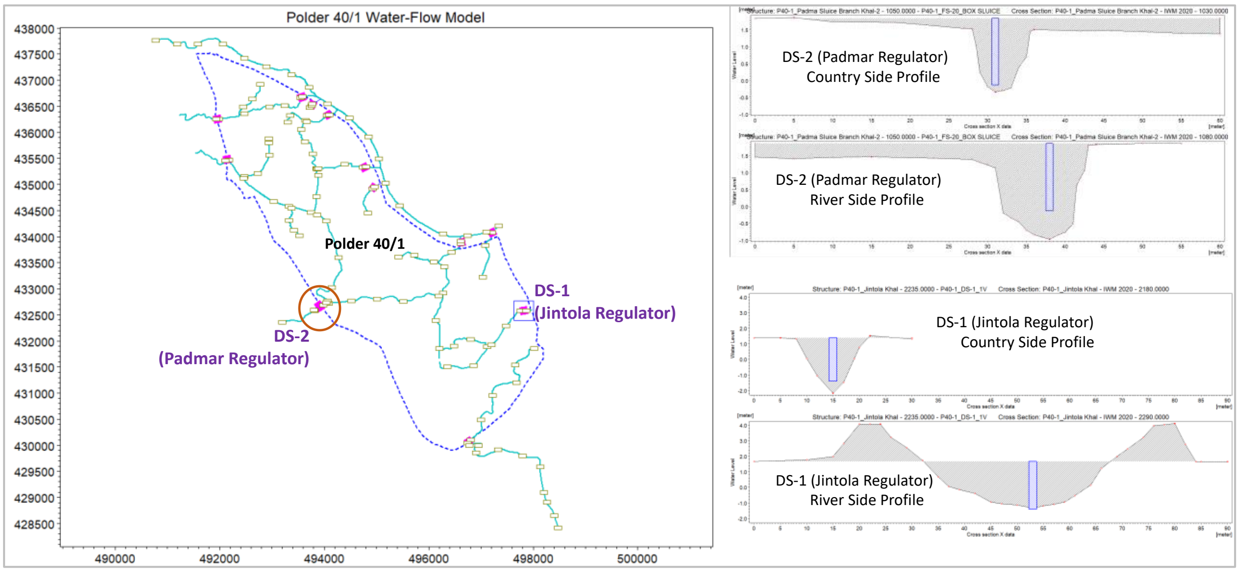


Figure 4.7: Typical cross section plots for DS-2 (top) and DS-1 (bottom) regulator

Regulator Gate Operation

In the Polder Water Management modelling, control structure like regulators are operating as underflow condition and gate operation is controlled by water level difference (Figure 4.8 anf Figure 4.9). The following regulator gate control strategy has been fixed in the following way

Water Level differences = country side water level- river side water level

- Water Level difference > 0, Gate will be at Soffit level (Gate fully Open)
- Water Level difference = 0, Gate will be at Invert level (Gate fully Closed)
- Water Level difference < 0, Gate will be at Invert level (Gate fully Closed)

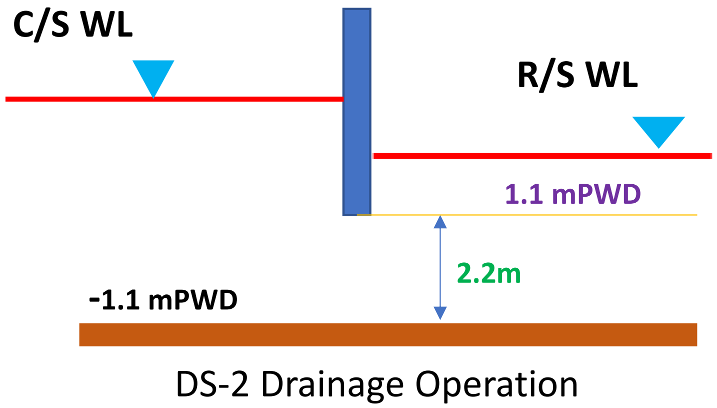


Figure 4.8: Physical operation of a drainage regulator

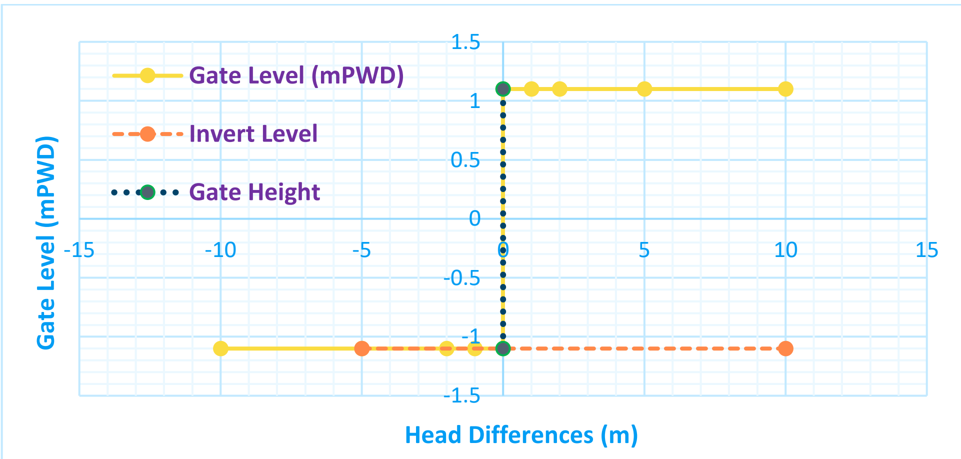


Figure 4.9: Drainage regulator gate operation rule of DS-2 (Padmar Regulator)

4.2.1.4 Hydrodynamic Parameters

Initial conditions like initial water level and initial discharge both has been assumed as 0.5m and 0.50 cumec respectively. Different roughness (Manning's M, inverse of rougness coefficient) of all khals/canals cross sections are considered as 20 to 30 $m^{(1/3)}$/s (by trial basis).

4.2.1.5 Defining Boundary Condition

About 24 no.of khals are includded in the Polder 40/1 Water-Flow (Hydrodynamic) model. Among them, upstream of few khals are open (not connected with other khals) and few khals are connected with the peripheral river through the drainage and flushing regulators. In this Polder hydrodynamic model, we assumed constant inflow like 0.10 m^3/s at the upstream open boundaries. Green color and blue color of the Figure 4.10 define the upstream boundary conditions and downstream boundary bounary locations of the khal systems respectively. At the upsream boundary conditions, inflow and at the downstream boundary condition, water level time sries information has been applied.

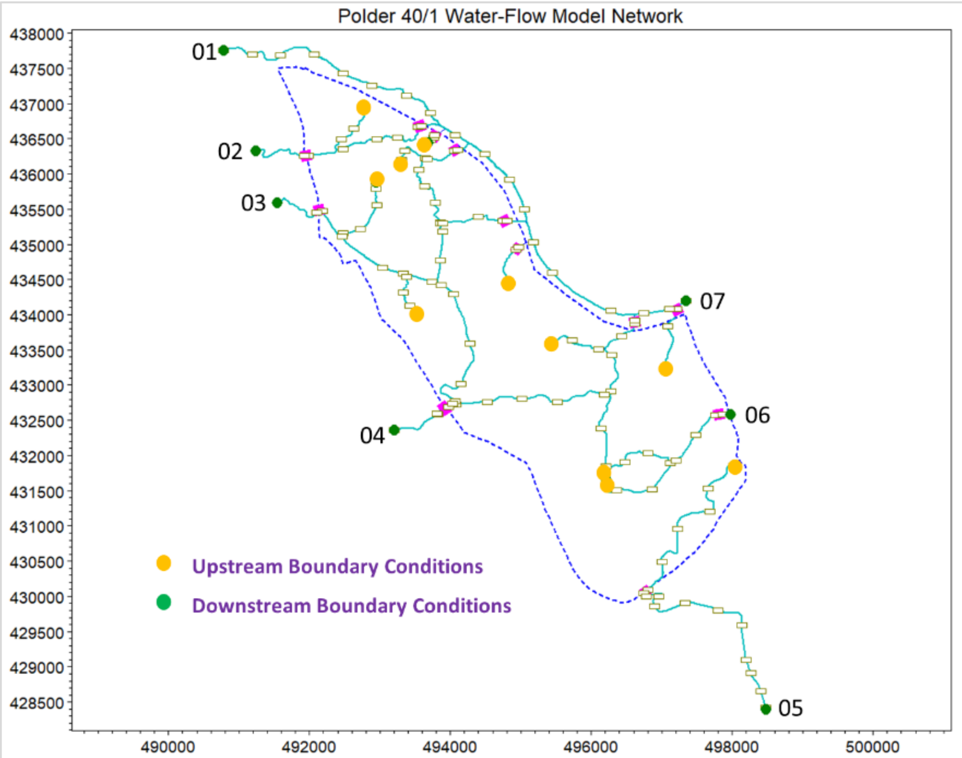


Figure 4.10: Polder 40/1 hydrodynamic boundary conditions

There are 07 (seven) number downstream boundary conditions in the developed hydrodynamic model of Polder 40/1. Downstream boundary conditions have been defined in this hydrodynamic model by two ways, i) time series water level information from the calibrated and validated regional South-West Model ii) real-time time series water level information which is measuring in this project. Time series water level information from the calibrated and validated regional South-West Model has been applied for assessing the existing drainage performances during the monsoon and defnging the drought area during the dry season. Real-time time series water level information has been used for calibrating the developed Polder Water-Flow Model and for the development regulator gate operation performance.

The existing 07 (seven) downstream boundary conditions where 04 (four) khals are connected with the Baleswar River (serial 01 to 04) and 03 (three) khals are connected with Bishkhali River. Baleswar River and Bishkhali River, both are included in the South-West Regional Model. Therefore, water level time series has been extracted from the South-West Regional Model and boudary conditions 01 to 04 have been extracted from Baleswar River network and 05 to 07 extracted from Bishkhali River network. Figure 4.11 shows the water level information of the downstream boundary boundary conditions of the internal drainage khals as well as water level information of Baleswar and Bishkhali River.

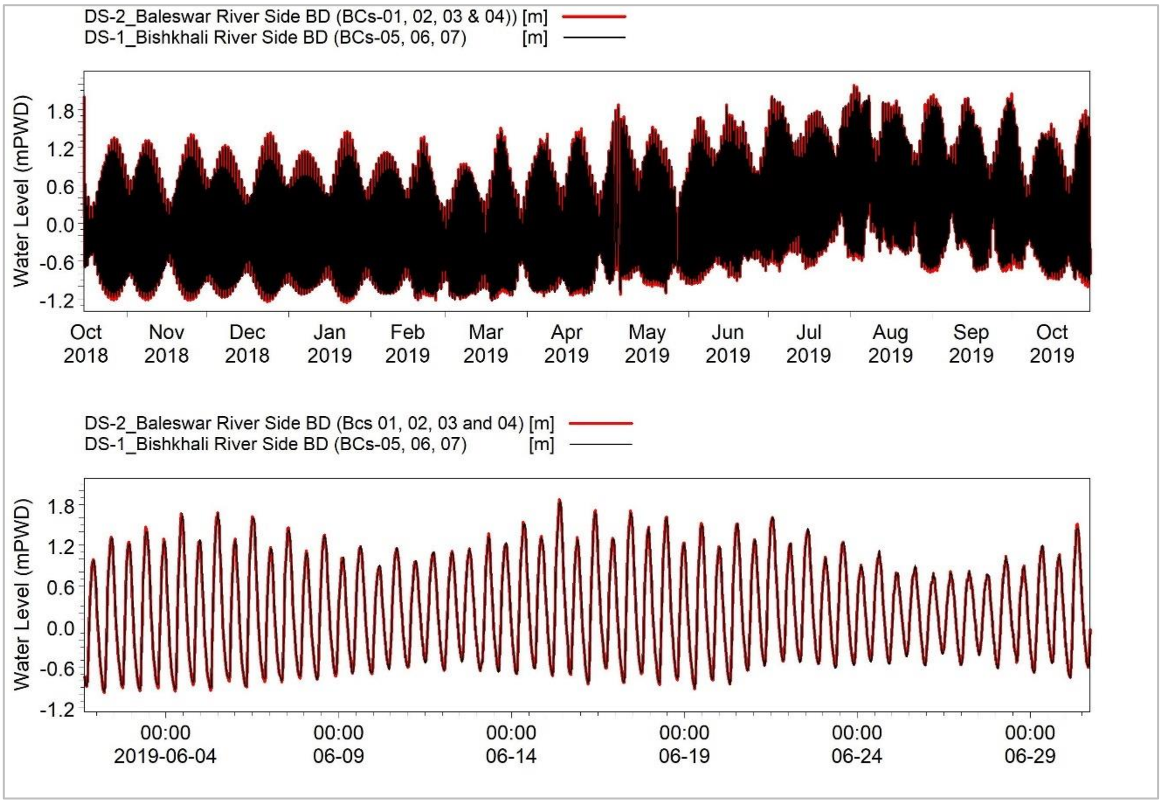


Figure 4.11: Downstream boundary conditions of the internal drainage khals of the Polder 40/1

It has been observed that the water levesl at Baleswar and Bishkhali are almost similar, no phase differences and variation of amplitudes are observed in these locations.These time series have been applied in the downstream boundary conditions for preparing the inside polder water availability map (drought and water logging identification maps).

Two (02) presessure sensors (automated) and two (02) water level guages (manual gauges) have been istalled inside the polder and outside of the polder. The maunual water level gauges have been installed for calibrating the pressure sensor data. The pressure sensors are recording the water pressure information every 10 mins whereas manual water level information has been collected every 30 mins interval. The outside polder water level (River side water level) information has been used for generating the time series water level information at the downstream boundary conditions (Figure 4.12) of all outfall of the drainage channels of the Polder 40/1. This water level information has been used in all 07 (seven) open boundary locations (Figure 4.10) as there is no phase difference and amplitude variation (described in the section 4.2.1.5) in that seven locations.

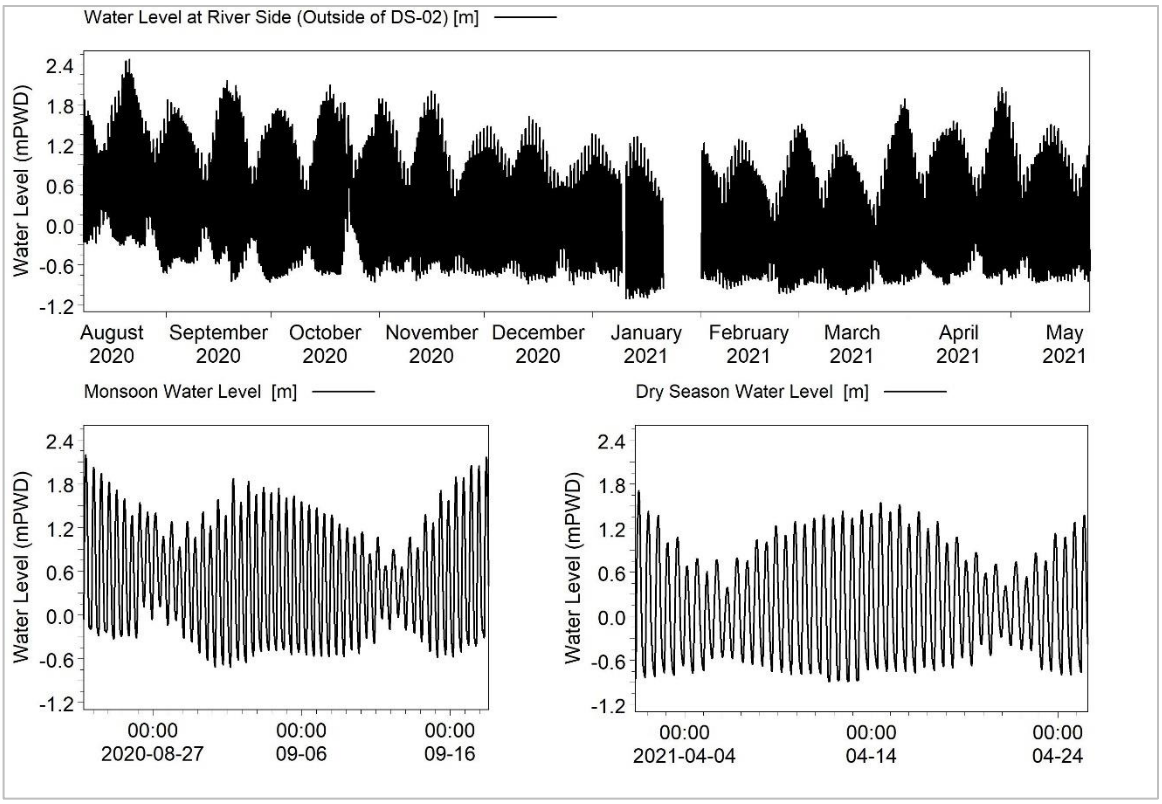


Figure 4.12: Observed water level at outside of DS-2 in the Polder 40/1

The observed water level at the downstream of the Padmar regulator is measured from 08th Aug 2020 and measurement is on progress at the location. The tidal range during the spring tide at that locations was observed 2.31m in the month of Aug 2020 and 2.29m during the dry season. During the neap tide in the monsoon, the tidal range is observed 1.41m during the neap tide and 1.26m in the dry season at the same location. The observed water level (Table 4.4) ensures the downstream of the Padmar khal is strongly influenced by the astronomical tide.

Table 4.4: Tidal range at the downstream of the Padmar Regulator in the Baleswar River

Tidal Range (m) in the Baleswar River				
Monsoon Season			Dry Season	
Spring	Neap		Spring	Neap
2.31	1.41		2.29	1.26

4.3 Development of Polder Drainage Model for the Polder 15

The polder 15 drainage model is developed by incorporating newly surveyed cross-sections of the internal drainage channels/khals and existing regulators within the polder area including detailed catchments distribution for the internal drainage channels and peripheral river systems (Table 4.5).

Table 4.5: Catchment distribution of the Polder 15 according to the drainage channels/khals

Polder ID	Khal Name/Catchment Name	Area (sq. km)	US Chainage (m)	DS Chainage (m)	Rainfall Station
P-15	9 no sora Khal	2.18	0	2250	Kaikhali
P-15	chadnimokagora	0.42	0	900	Kaikhali
P-15	Chakbora Khal	1.06	0	1500	Nakipur
P-15	Chakbora Khal	4.59	1500	5050	Kaikhali
P-15	Dumuria Khal	1.33	0	1850	Kaikhali
P-15	Dumuriasisha_2	1	0	1540	Kaikhali
P-15	Gabura 1 Khal	4.15	0	2940	Nakipur
P-15	Gabura_2	1.58	0	1040	Nakipur
P-15	Garar khal	3	0	690	Kaikhali
P-15	Garar khal	1.22	690	3200	Kaikhali
P-15	Khalishabuni	1.34	0	1700	Kaikhali
P-15	Khat-Khal-2	0.18	0	350	Kaikhali
P-15	Kulirshishi Khal	1.21	0	980	Kaikhali
P-15	Kulirshishi Khal	1.29	980	1650	Kaikhali
P-15	Sora khal-Branch	3.89	0	2060	Kaikhali
P-15	Sora khal-Dumuriasisha_1	2.09	0	3280	Kaikhali
P-15	Sora khal-Dumuriasisha_1	0.61	3280	5800	Kaikhali

The hydrological model of the Polder 15 is developed by using the Table 4.5 mentioned information (catchment area and influenced rainfall stations). Soil properties and other hydraulic properties have been fixed based on the polder physical and hydrological conditions. The rainfall generated runoff has been developed for each khal catchments by the developed polder hydrological model and the generated runoff has been added into the drainage channels/khals network as a lateral flow. The hydrological model has been developed for two hydrological conditions- i) hydrological model for Polder 40/1 at existing condition and ii) hydrological model for Polder at design flood event condition (1 in 50 year return period, discussed in the Hydrological analysis section). The following Figure 4.13 presents the rainafall generated runoff at the drainage regulator, DS-04 catchment covering the Chakbor khal and Khalishabuni Khal catchment.

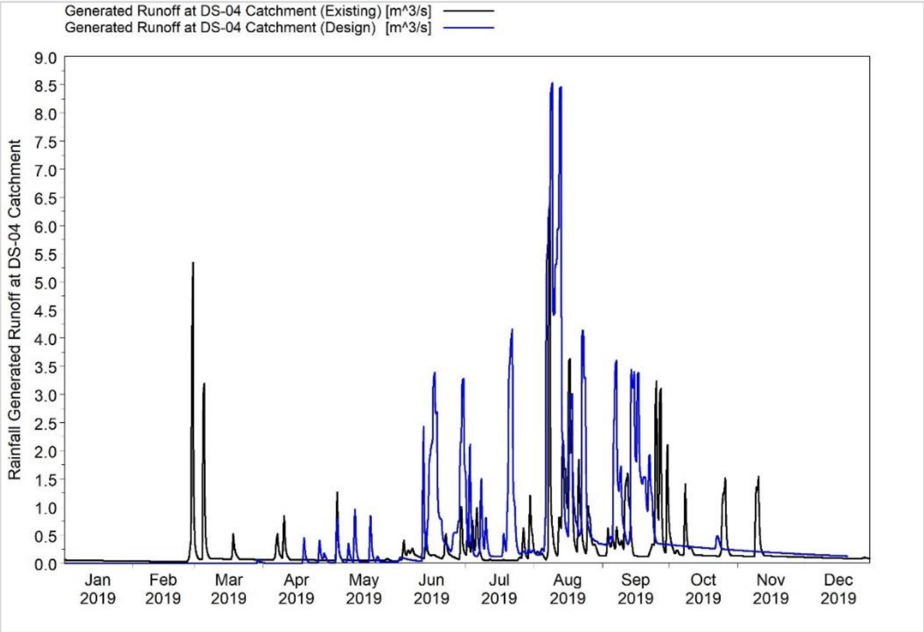


Figure 4.13: Rainfall generated runoff at regulator DS-04 catchment in the Polder 15

The polder drainage khal/channel networks are connected to the peripheral rivers through drainage khals and water control structures. The structures have been included in the model providing the input data on their dimensions/size, number of vents and invert levels together with their operating rules of gates. The operation rules are defined in such a way that if outside water level is higher than that of polder water level in the drainage khals/channel, the gate of the structure is closed automatically and vice versa. Within the polder the runoff generated from the catchment is routed into the respective drainage khals in proportion to their respective drainage areas which eventually drained towards the peripheral khals through the structures. The detailed physical processes including drainage channels/khals, regulators, khal cross sections and peripheral river systems are presented in the Figure 4.14. The upstream and downstream boundary conditions of the peripheral river systems have been generated from the calibrated and validated south-West regional model.

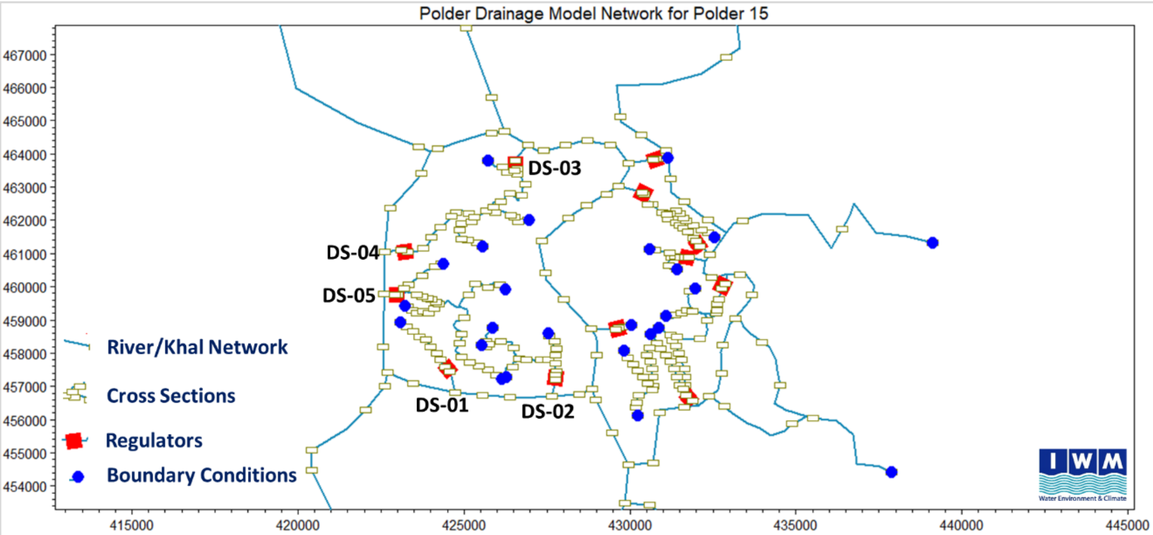


Figure 4.14: Polder 15 drainage model network

The developed polder drainage model provides the water levels at the cross-section locations and water flow in between two cross sections, current speed at the cross-section locations. The model generated water level at different locations/chainages has been used for generating the inundation depth duration map. Similarly, the existing drainage network and polder drainage model setup will used for simulating the design flood event considering climate change condition and used for simulation of Improved Potential options.

4.4 Development of Polder Drainage Model for the Polder 29

Drainage canals/khals network, geometric profile, and characteristics (cross sections) of the drainage channels, detail information of the regulators, boundary conditions of the downstream and upstream of the drainage channels, contribution of rainfall generated runoff into the drainage channels, these parameters are the input parameters of the polder hydrodynamic model. The following Table 4.6 presents list of drainage channels which are included into the Polder 29 drainage model (combination of hydrological model and hydrodynamic model).

Table 4.6: Catchment distribution of the Polder 29 according to the drainage channels/khals

Catchment Name	Catchment Area (sq. km)	Branch Name	U/S Chainage (m)	D/S Chainage (m)
Agunkhali Khal	1.03	Agunkhali Khal	0	2060
Amorar Khal	0.89	Amorar Khal	0	1240
Aro Khal	1.48	Aro Khal	0	1100
Ashanagar Khal	0.90	Ashanagar Khal	0	2240
Baniakhali Khal	1.18	Baniakhali Khal	0	1250
Bhadra River	14.21	Bhadra River	0	19000
Bhadra_Diversion Khal	1.10	Bhadra_Diversion Khal	0	1550
Biddadhari Khal	0.37	Biddadhari Khal	0	620
Bokultala Khal	0.11	Bokultala Khal	0	420
Charar Khal	1.58	Charar Khal	0	1110
Chingrakhali Khal	0.20	Chingrakhali Khal	0	1530
Danibunia Khal (Extra)	0.41	Danibunia Khal (Extra)	0	1580
Danibunia Khal (Extra) Branch	0.19	Danibunia Khal (Extra) Branch	0	810
Dholbhanga Khal	5.99	Dholbhanga Khal	0	6180
Doykhali Khal	1.52	Doykhali Khal	0	2810
Gazir Dhopar Branch Khal	0.13	Gazir Dhopar Branch Khal	0	380
Gazir Dhopar Khal	0.55	Gazir Dhopar Khal	0	1740
Ghopar_Duani Khal	0.33	Ghopar_Duani Khal	0	1170
Hira_Bostomir Khal	0.66	Hira_Bostomir Khal	0	930
Jhaltola Khal	1.83	Jhaltola Khal	0	2430
Jharlar Khal	0.78	Jharlar Khal	0	1710
Jhautola Khal	0.63	Jhautola Khal	0	640
Jhilakhali Khal	1.12	Jhilakhali Khal	0	1050
Kainmarai Khal	0.68	Kainmarai Khal	0	1270
Kaminibari Khal	0.32	Kaminibari Khal	0	1010
Kanchannagar_Hazibunia Khal	5.33	Kanchannagar_Hazibunia Khal	0	6290
Kantar Khal	0.32	Kantar Khal	0	1240
Katakhal	2.07	Katakhal	0	1950
Katakhal Branch	0.30	Katakhal Branch	0	830
Katakhali Khal	1.48	Katakhali Khal	0	1740
Keyakhali Khal	1.77	Keyakhali Khal	0	1610
Khal-28	0.69	Khal-28	0	1890
Khal-48	0.48	Khal-48	0	720
Khichimichi River	1.94	Khichimichi River	0	2980
Koler Khal	1.97	Koler Khal	0	2380
Kollangar Khal	0.11	Kollangar Khal	0	360
Kudlar Khal	2.27	Kudlar Khal	0	3900
Kudlar_Branch-2 Khal	0.25	Kudlar_Branch-2 Khal	0	360
Kudlar_Branch Khal	0.50	Kudlar_Branch Khal	0	943
Machmara Khal	1.05	Machmara Khal	0	1530
MadarShisha Khal	0.67	MadarShisha Khal	0	1630
Mohular Khal	0.90	Mohular Khal	0	1340
Moikhali Khal	0.28	Moikhali Khal	0	890
Natomari Khal	1.01	Natomari Khal	0	770
Nolghuna Branch-2	0.74	Nolghuna Branch-2	0	890
Nolghuna Khal	5.03	Nolghuna Khal	0	4380
Ramakhali Branch	0.20	Ramakhali Branch	0	600
Ramakhali Khal	4.54	Ramakhali Khal	0	4670

Catchment Name	Catchment Area (sq. km)	Branch Name	U/S Chainage (m)	D/S Chainage (m)
Ruhitmara Khal	0.97	Ruhitmara Khal	0	2440
Sitamari Khal	0.41	Sitamari Khal	0	1550
Sudurtala Khal	1.00	Sudurtala Khal	0	2800
Sudurtala_Branch Khal	0.53	Sudurtala_Branch Khal	0	1110

Catchment (presents in the Table 4.6) of each regulator has been distributed according to the contribution from the remote locations of each tertiary, secondary and primary khal. The contribution of each similar size regulator may be different based on the tidal characteristics of the peripheral river system, human interventions into the drainage channels/khals, existence of culverts, bridges, and conditions of the regulators. However, in the hydrological model of each polder system has been simulated as an ideal consideration using the MIKE 11 NAM which is lumped and conceptual model. Only rainfall generated runoff has been calculated for each catchment by using the soil characteristics, meteorological information. Design flood event has been developed using 34 years of rainfall data and year 2004 has been selected as design flood event. However, during simulation of design flood event, 2004 rainfall data has been converted into existing year 2019 rainfall and generated the design runoff and applied into the Polder 29 drainage model. One typical plot of catchment runoff generated from the rainfall for the Bokultola sluice has been presented in the Figure 4.15.

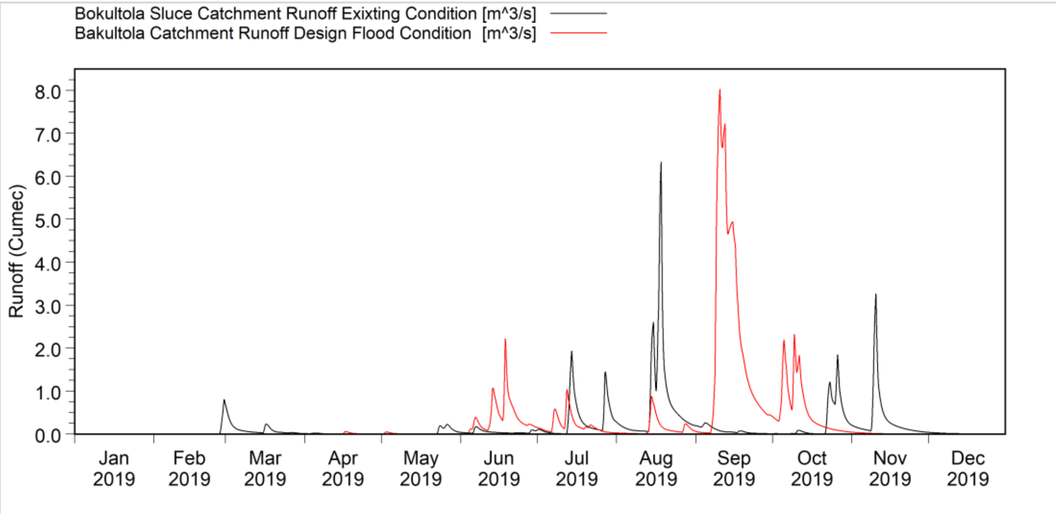


Figure 4.15: Rainfall generated runoff at Bokultola regulator (DS-04) catchment in the Polder 29

About 54 drainage channels/khals are included in the Polder 29 Water-Flow (Hydrodynamic) model (Figure 4.16). There are some khals which upstream are not connected each other but downstream are connected with other khals and with the peripheral river systems (Bhadra, lower Bhadra and lower Salta) through regulators. The upstream and downstream boundary conditions of the peripheral river systems have been generated from the calibrated and validated south-West regional model. Fourteen (14) drainage regulators have been added into the polder drainage models which are operating as underflow condition and gate operation is controlled by water level difference. Twenty six (26) flusing inlets are included into the Polder 29 hyrdynamic system but operation of these flushing inlets are not included into the polder water flow modelling as these are using in the polder for Shirmp firming.

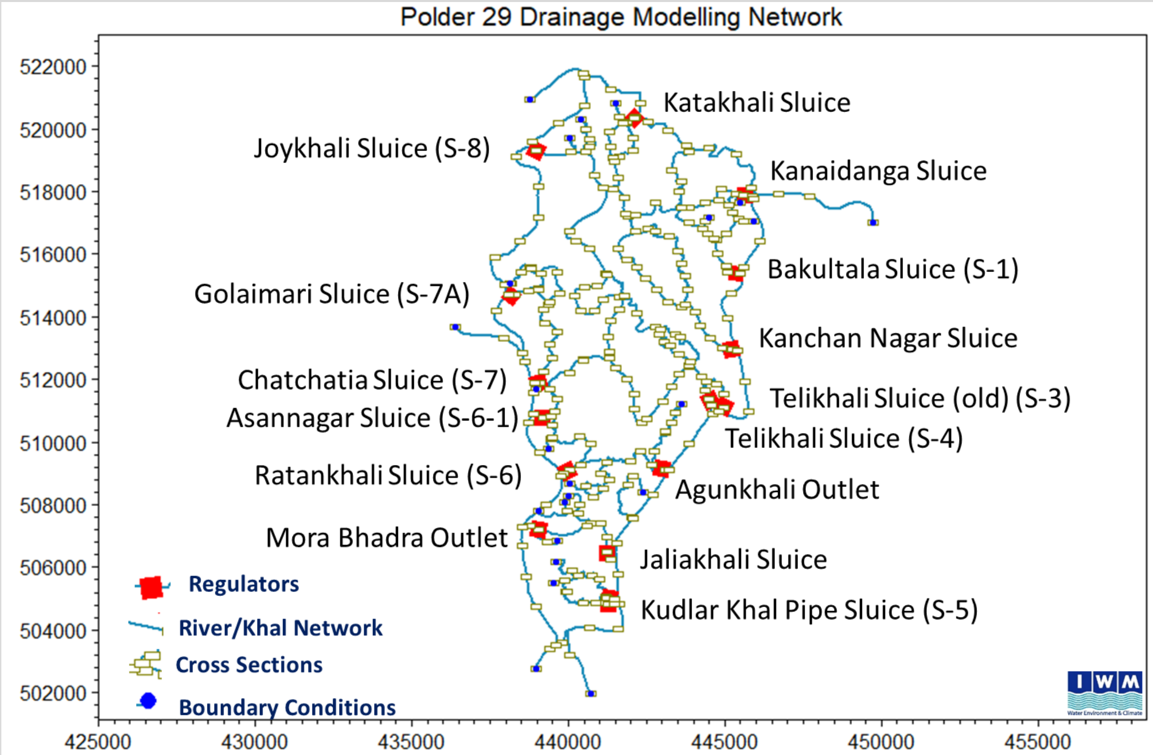


Figure 4.16: Polder 29 drainage model network including regulators, cross sections and boundary conditions

The developed drainage model of the Polder 29 provides the water levels at the locations where cross section are included and water flow in between two cross sections, current speed at the cross-section locations. The model generated water level at different locations/chainages has been used for generating the inundation depth duration map. Similarly, the existing drainage network and polder drainage model setup will used for simulating the design flood event considering climate change condition and used for simulation of Improved Potential options.

4.5 Development of Polder Drainage Model for the Polder 59/2

Internal drainage canals/khals network, surveyed cross sections of all drainage khals and hydraulic parameters of the drainage channels/khals, detail information of the regulators, upstream and downstream boundary conditions of the drainage channels and river systems, contribution of rainfall generated runoff into the drainage channels/khals according to their catchments, are the key input parameters of the polder hydrodynamic/water-flow/drainage model. The following Table 4.7 presents list of drainage channels which are included into the Polder 59/2 drainage model (combination of hydrological model and hydrodynamic model).

Table 4.7: Catchment distribution of the Polder 59/2 according to the drainage channels/khals

Catchment Name	Catchment Area (Sq. Km)	Branch Name	U/S Chainage (m)	D/S Chainage (m)
Battir_Khal	18.72	Battir_Khal	0	9615
Khal_11	2.42	Khal_11	0	2120
Mc_Khal	6.61	Mc_Khal	0	7295

Catchment Name	Catchment Area (Sq. Km)	Branch Name	U/S Chainage (m)	D/S Chainage (m)
Khal_10	2.61	Khal_10	0	1780
Khal_11_A	1.01	Khal_11_A	0	1120
Katakhali_Khal_Extra	7.35	Katakhali_Khal_Extra	0	2800
Extra_Khal_1	8.83	Extra_Khal_1	0	4235
Polder_Khal_1	8.86	Polder_Khal_1	0	3225
Jangalia_Khal	5.91	Jangalia_Khal	0	6630
Amzadia_Khal	11.27	Amzadia_Khal	0	6300
Jarirdona_Khal	24.78	Jarirdona_Khal	0	12240
Ratachora_Khal_29	7.16	Ratachora_Khal_29	0	4850
Ratachom_Khal_28	19.89	Ratachom_Khal_28	0	6340
Moshar_Khal	8.21	Moshar_Khal	0	4660
Katakhali_Khal	6.79	Katakhali_Khal	0	2840
Kata_Khal	4.16	Kata_Khal	0	4830
Gota_Khal	2.45	Gota_Khal	0	3390
Extra_Khal_2	7.28	Extra_Khal_2	0	2890
Khal_39	6.60	Khal_39	0	2050
Polder_Khal_2	4.41	Polder_Khal_2	0	1695
Chori_Khal	6.83	Chori_Khal	0	5330
Polder_Khal_3	1.87	Polder_Khal_3	0	2855
Ratachom_Khal_28_2	5.10	Ratachom_Khal_28_2	0	4225
Khotar_Branch_Khal_27	11.82	Khotar_Branch_Khal_27	0	9970
Kaissar_Khal_1	2.56	Kaissar_Khal_1	0	1975
Chari_Khal_2	1.36	Chari_Khal_2	0	3690
Polder_Khal_4	0.02	Polder_Khal_4	0	172
Polder_Khal_5	1.15	Polder_Khal_5	0	960
Polder_Khal_6	0.32	Polder_Khal_6	0	665
Polder_Khal_7	0.61	Polder_Khal_7	0	3658
Polder_Khal_8	4.19	Polder_Khal_8	0	3616
Mushar_Khal_West	1.65	Mushar_Khal_West	0	2070
Mushar_Khal_East	1.94	Mushar_Khal_East	0	1430

Delineated catchment (presents in the Table 4.7) of each regulator has been distributed according to the contribution from the most remote locations of each tertiary, secondary and primary khal. The contribution of each similar size regulator may be different based on the tidal characteristics of the peripheral river system, human interventions into the drainage channels/khals, existence of culverts, bridges, and conditions of the regulators. However, in the hydrological model of the Polder 59/2 has been simulated as an ideal consideration using the MIKE 11 NAM which is lumped and conceptual model. Only rainfall generated runoff has been calculated for each catchment by using the soil characteristics, meteorological information like evaporation and rainfall and other ground water parameters. Design flood event has been developed using 34 years of rainfall data and year 1993 has been selected as design flood event. However, during simulation of design flood event, 1993 rainfall data has been converted into existing year 2019 rainfall and generated the design runoff and applied into the Polder 59/2 drainage model. One typical plot of catchment runoff generated from the rainfall for the Jorirdona 3-vent regulator has been presented in the Figure 4.17.

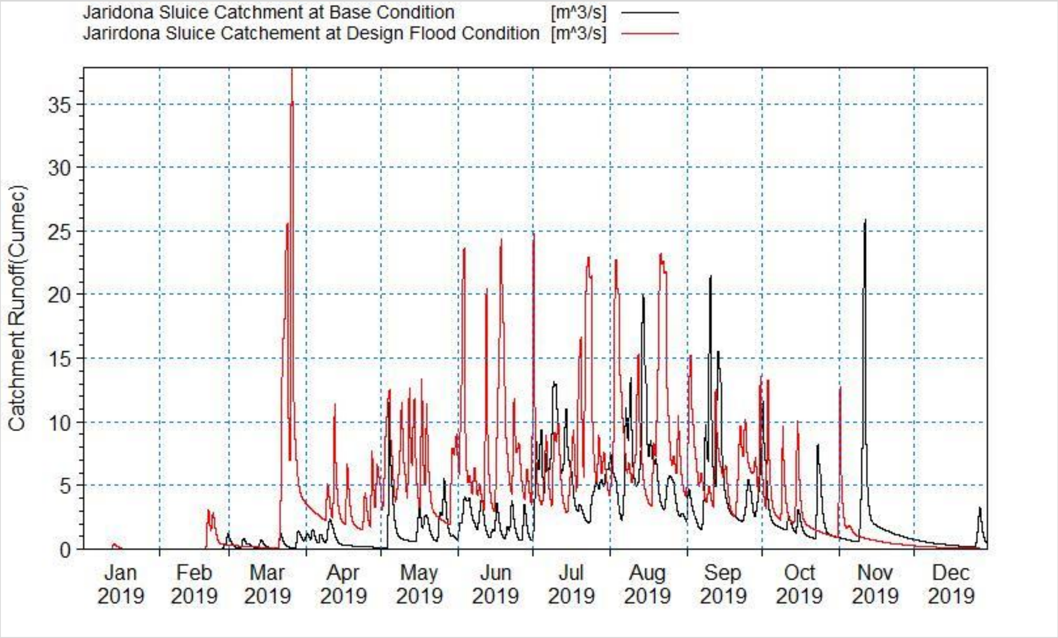


Figure 4.17: Rainfall generated runoff at Jarirdona 3-vent regulator catchment in the Polder 59/2

The available 30 no. of khals are included in the Polder 59/2 drainage model setup (Figure 4.18). There are some khals which upstream have not connected each other but downstream are connected with other khals and with the peripheral river systems (Lower Meghna River, Jarirdona River and Bhullar Khal) through the drainage regulators. The upstream and downstream boundary conditions of the peripheral river systems have been generated from the calibrated and validated south-West regional model and South-East Regional Model. Thirteen (13) number drainage regulators have been included into the polder drainage models which are operating as underflow condition and gate operation is controlled by water level difference.

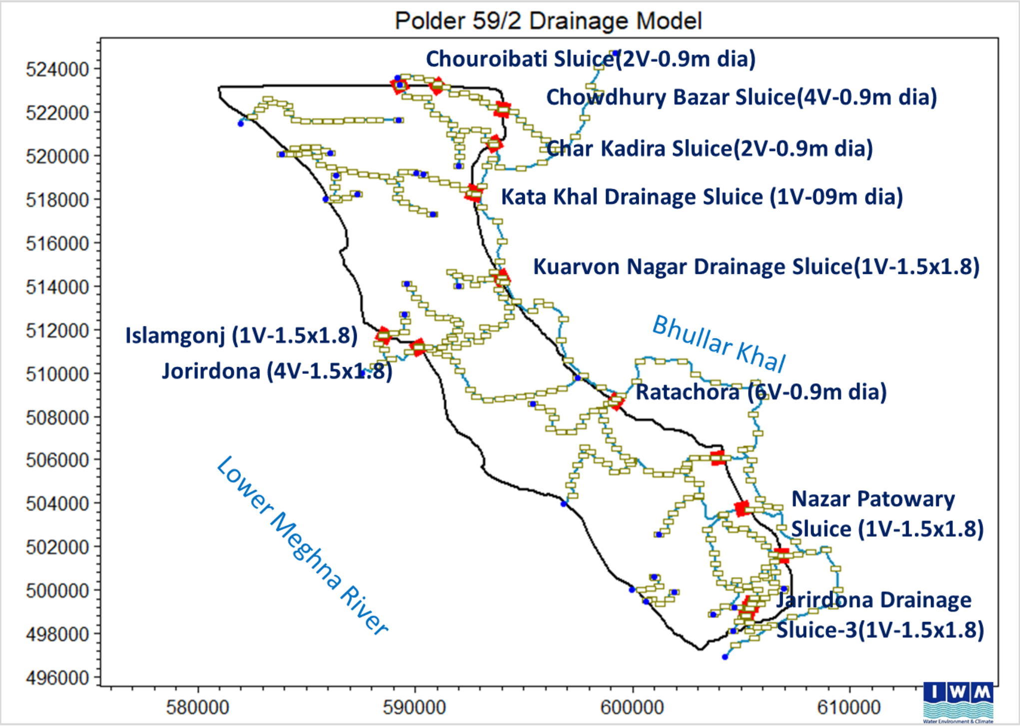


Figure 4.18: Polder 59/2 drainage model network including regulators, cross sections, and boundary conditions

The developed drainage model of the Polder 59/2 provides the water levels at the locations where cross section are included and water flow in between two cross sections, current speed at the cross-section locations. The model generated water level at different locations/chainages has been used for generating the inundation depth duration map. Similarly, the existing drainage network and polder drainage model setup will used for simulating the design flood event considering climate change condition and used for simulation of Improved Potential options

4.6 Development of Polder Drainage Model for the Polder 64/1a and Polder 64/1b

The polder 64/1a and Polder 64/1b drainage model is developed combindly by incorporating newly surveyed cross-sections of all internal drainage channels/khals and existing regulators within the polder area including detailed catchments distribution for the internal drainage channels and peripheral river systems (Table 4.8).

Table 4.8: Catchment distribution of the Polder 64/1a and Polder 64/1b according to the drainage channels/khals

Catchment Name	Catchment Area (sq. km)	Branch Name	U/S Chainage (m)	D/S Chainage (m)
P_64_1a_Khal_2	1.28	P_64_1a_Khal_2	0	603
P_64_1a_Khal_3	2.12	P_64_1a_Khal_3	0	2076
P_64_1a_Khal_4_A	2.28	P_64_1a_Khal_4_A	0	962
P_64_1a_Khal_4	2.55	P_64_1a_Khal_4	0	2316
P_64_1a_Khal_4_B	2.01	P_64_1a_Khal_4_B	0	990
P_64_1a_Khal_5	2.66	P_64_1a_Khal_5	0	1399
P_64_1a_Khal_6	1.90	P_64_1a_Khal_6	0	549
P_64_1a_Khal_7	0.86	P_64_1a_Khal_7	0	337
P_64_1a_Khal_8	2.45	P_64_1a_Khal_8	0	1082
P_64_1a_Khal_10	1.63	P_64_1a_Khal_10	0	548
P_64_1a_Khal_11	2.04	P_64_1a_Khal_11	0	879
P_64_1a_Khal_12	2.76	P_64_1a_Khal_12	0	1313
P_64_1a_Khal_13	1.41	P_64_1a_Khal_13	0	796
P_64_1a_Khal_15	1.11	P_64_1a_Khal_15	0	762
P_64_1a_Khal_14	2.82	P_64_1a_Khal_14	0	1510
P_64_1a_Khal_19	2.10	P_64_1a_Khal_19	0	2394
P_64_1a_Khal_17	2.17	P_64_1a_Khal_17	0	1651
P_64_1a_Khal_18	1.47	P_64_1a_Khal_18	0	2095
P_64_1a_Khal_17_C	0.28	P_64_1a_Khal_17_C	0	606
P_64_1a_Khal_17_A	0.10	P_64_1a_Khal_17_A	0	358
P_64_1a_Khal_1_A	0.65	P_64_1a_Khal_1_A	0	626
P_64_1a_Khal_13_A	0.10	P_64_1a_Khal_13_A	0	114
P_64_1a_Khal_14_A	1.11	P_64_1a_Khal_14_A	0	555
P_64_1a_Khal_19_E	0.32	P_64_1a_Khal_19_E	0	313
P_64_1a_Khal_19_B	0.27	P_64_1a_Khal_19_B	0	678
P_64_1a_Khal_19_D	0.31	P_64_1a_Khal_19_D	0	591
P_64_1a_Khal_19_A	1.63	P_64_1a_Khal_19_A	0	1857
P_64_1a_Khal_19_C	0.43	P_64_1a_Khal_19_C	0	564
P_64_1a_Khal_18_C	0.57	P_64_1a_Khal_18_C	0	439
P_64_1a_Khal_18_B	0.14	P_64_1a_Khal_18_B	0	211

Catchment Name	Catchment Area (sq. km)	Branch Name	U/S Chainage (m)	D/S Chainage (m)
P_64_1a_Khal_18_A	0.07	P_64_1a_Khal_18_A	0	342
P_64_1a_Khal_17_B	0.07	P_64_1a_Khal_17_B	0	209
P_64_1a_Khal_9	2.82	P_64_1a_Khal_9	0	1350
P_64_1a_Khal_16	0.58	P_64_1a_Khal_16	0	652
P_64_1a_Khal_1_B	0.46	P_64_1a_Khal_1_B	0	751
P_64_1a_Khal_1_C	0.05	P_64_1a_Khal_1_C	0	220
P_64_1a_Khal_1_D	0.06	P_64_1a_Khal_1_D	0	197
P_64_1a_Khal_1	6.01	P_64_1a_Khal_1	0	4184
P_64_1b_Khal_23_A	0.14	P_64_1b_Khal_23_A	0	247
P_64_1b_Khal_1	4.71	P_64_1b_Khal_1	0	2614
P_64_1b_Khal_3	0.95	P_64_1b_Khal_3	0	1557
P_64_1b_Khal_4	3.49	P_64_1b_Khal_4	0	2073
P_64_1b_Khal_5	5.27	P_64_1b_Khal_5	0	3328
P_64_1b_Khal_6	2.08	P_64_1b_Khal_6	0	1284
P_64_1b_Khal_7	2.10	P_64_1b_Khal_7	0	4858
P_64_1b_Khal_8	0.81	P_64_1b_Khal_8	0	135
P_64_1b_Khal_7_A	3.34	P_64_1b_Khal_7_A	0	3141
P_64_1b_Khal_9	4.18	P_64_1b_Khal_9	0	5202
P_64_1b_Khal_10	2.42	P_64_1b_Khal_10	0	493
P_64_1b_Khal_11	0.66	P_64_1b_Khal_11	0	654
P_64_1b_Khal_12_A	1.37	P_64_1b_Khal_12_A	0	1782
P_64_1b_Khal_12_A_I	0.63	P_64_1b_Khal_12_A_I	0	1460
P_64_1b_Khal_12	0.87	P_64_1b_Khal_12	0	4576
P_64_1b_Khal_12_B_I	2.17	P_64_1b_Khal_12_B_I	0	2109
P_64_1b_Khal_12_B	1.14	P_64_1b_Khal_12_B	0	1125
P_64_1b_Khal_13	0.89	P_64_1b_Khal_13	0	453
P_64_1b_Khal_14	0.99	P_64_1b_Khal_14	0	552
P_64_1b_Khal_17	3.35	P_64_1b_Khal_17	0	1128
P_64_1b_Khal_17_A	0.47	P_64_1b_Khal_17_A	0	603
P_64_1b_Khal_15	1.05	P_64_1b_Khal_15	0	186
P_64_1b_Khal_16	0.66	P_64_1b_Khal_16	0	289
P_64_1b_Khal_18_B	0.55	P_64_1b_Khal_18_B	0	533
P_64_1b_Khal_18	4.93	P_64_1b_Khal_18	0	3810
P_64_1b_Khal_19	1.05	P_64_1b_Khal_19	0	647
P_64_1b_Khal_20	3.73	P_64_1b_Khal_20	0	2832
P_64_1b_Khal_21	0.99	P_64_1b_Khal_21	0	1200
P_64_1b_Khal_22	1.70	P_64_1b_Khal_22	0	574
P_64_1b_Khal_24_A	0.88	P_64_1b_Khal_24_A	0	1039
P_64_1b_Khal_24_B	0.25	P_64_1b_Khal_24_B	0	733
P_64_1b_Khal_24	6.49	P_64_1b_Khal_24	0	6426
P_64_1b_Khal_23	1.02	P_64_1b_Khal_23	0	480
P_64_1b_Khal_25_A	0.47	P_64_1b_Khal_25_A	0	593
P_64_1b_Khal_25_B	1.46	P_64_1b_Khal_25_B	0	914
P_64_1b_Khal_25	5.15	P_64_1b_Khal_25	0	4045
P_64_1b_Khal_26	0.82	P_64_1b_Khal_26	0	404
P_64_1b_Khal_27	0.23	P_64_1b_Khal_27	0	153
P_64_1b_Khal_28	4.76	P_64_1b_Khal_28	0	4389

Catchment Name	Catchment Area (sq. km)	Branch Name	U/S Chainage (m)	D/S Chainage (m)
P_64_1b_Khal_29	1.90	P_64_1b_Khal_29	0	3069
P_64_1b_Khal_29_A	0.87	P_64_1b_Khal_29_A	0	650
P_64_1b_Khal_29_B	0.33	P_64_1b_Khal_29_B	0	918
P_64_1b_Khal_30_A	0.33	P_64_1b_Khal_30_A	0	1359
P_64_1b_Khal_30	0.94	P_64_1b_Khal_30	0	1200
P_64_1b_Khal_31	3.11	P_64_1b_Khal_31	0	2525
P_64_1b_Khal_2	0.83	P_64_1b_Khal_2	0	1281
P_64_1b_Khal_18_A	1.33	P_64_1b_Khal_18_A	0	817

The hydrological model of the Polder 64/1a and Polder 64/1b is developed by using the mentioned Table 4.8 information (catchment area). Soil properties and other hydraulic properties have been fixed based on the polder physical, geographical and hydrological conditions. The developed rainfall-runoff model has been used to generate runoff by generating Mean Aerial Rainfall (MAR) and Mean Aerial Evaporation (MAE) for each khal catchments and the generated runoff has been linked with the drainage channels/khals networks as a lateral flow.

The hydrological model has been developed for two hydrological conditions- i) hydrological model for Polder 40/1 at existing condition and ii) hydrological model for Polder at design flood event condition (1 in 50 year return period, discussed in the Hydrological analysis section). Due to data availability, year 2015 has been considered as existing flood event. 34 years rainfall analysis ensures, design rainfall (1 in 50 year return period rainfall) also already back in 2015. Therefore, 2015 is also considered as design flood year.The following Figure 4.19 presents the rainafall generated runoff at the drainage regulator, DS-01 catchment in the Polder 64/1a and DS-24 regulator catchment in the Polder 64/1b. The yearly maximum rainfall for 5-days cumulative was estimated 780mm whereas design rainfall was estimated 803mm. It indicates design rainfall is almost nearest rainfall of 2015 which is 3% higher than the yearly maximum rainfall of 2015. During computation of rainfall generated runoff, 3% additional rainfall has been added with the existing rainfall (year 2015 rainfall).

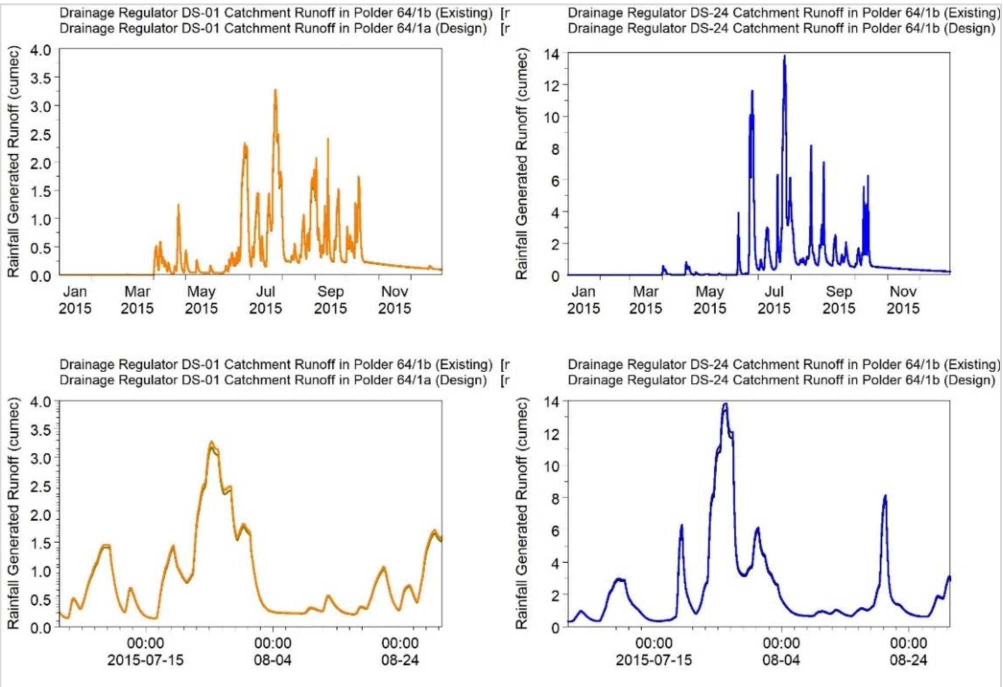


Figure 4.19: Rainfall generated runoff at regulator DS-04 catchment in the Polder 64/1a

The polder drainage khal/channel networks are connected to the peripheral rivers through drainage khals and different size regulators. The structures have been included in the model as an input data on their dimensions/size, number of vents and invert levels together with their operating rules of gates as drainage regulator.The operation rules is defined in such a way that if outside water level is higher than that of polder water level in the drainage khals/channel, the gates of the structure is closed automatically and vice versa. Within the polder the runoff generated from the catchment is routed into the respective drainage khals in proportion to their respective drainage areas which eventually drained towards the peripheral khals through the structures. Typical example is plotted in the Figure 4.19. The detailed physical processes including drainage channels/khals, regulators, khal cross sections and peripheral river systems are presented in the Figure 4.20.

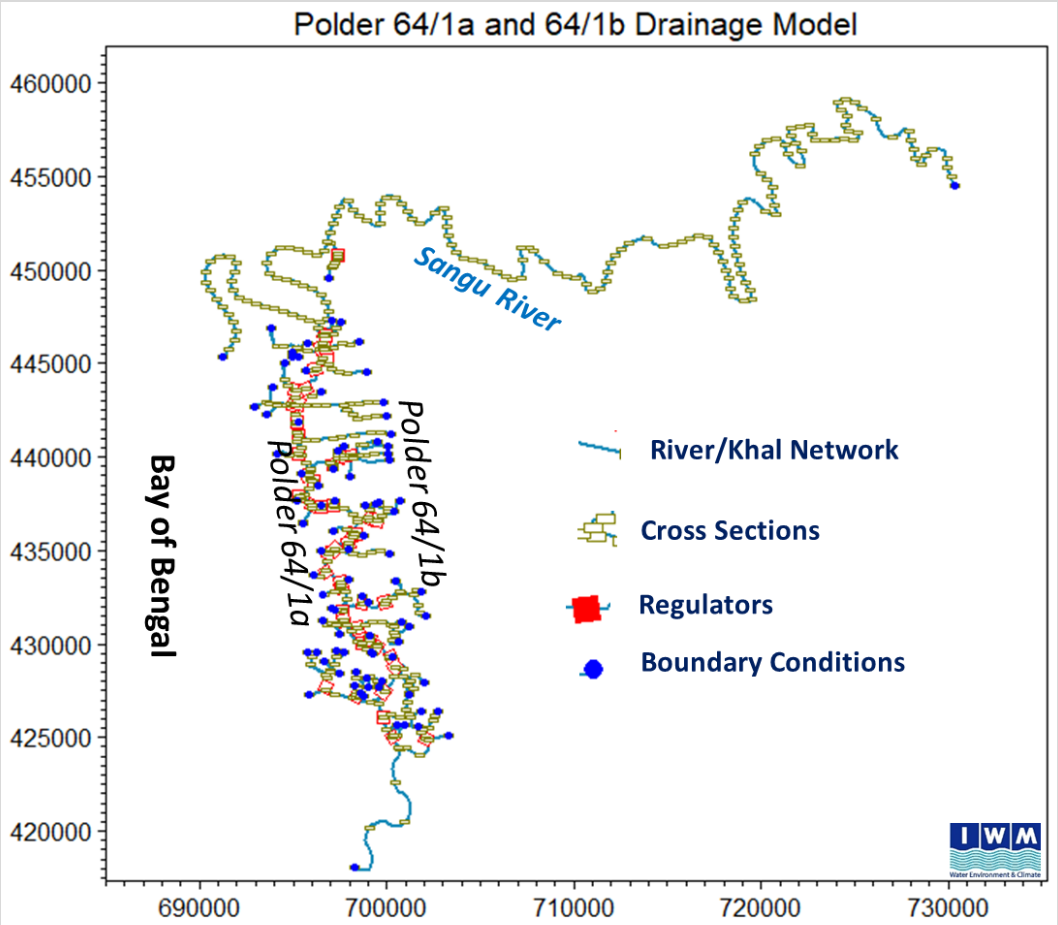


Figure 4.20: Polder 64/1a and Polder 64/1b drainage model network including regulators, cross sections, and boundary conditions

The developed drainage model of the Polder 64/1a and Polder 64/1b provides the water levels at the cross-section locations and water flow in between two cross sections, current speed at the cross-section locations. The model generated water level at different locations/chainages has been used for generating the inundation depth duration map. Similarly, the existing drainage network and polder drainage model setup will used for simulating the design flood event considering climate change condition and also used for simulation of Improved Potential options.

5 Calibration of the Polder Water-Flow Model and Regional Models

Calibration of the polder drainage model completely depends on the operation of polder water management system. Local factors are dominating the polder water management system and these local parameters are added into the model to calibrate the developed polder Water-Flow Model. In this chapter, detailed calibration of the Polder water-flow model will be described for the Polder 40/1 and calibration of the regional models (South-West Regional Model and Eastern Hilly Regional Model) will be described briefly.

5.1 Calibration factors of the Polder 40/1 Water-Flow Model

The polder water management completely depends on the operation of regulators. However, some physical processes and hydrological processes also involved. At the same time, peripheral river water level conditions also play an important role in the operation of polder details.

5.1.1 Local Effects

Local factors are regulator gate operation and management, artificial cross dam into the khal system, water withdrawal from the khals for irrigation and domestic purposes, spatial variation of monsoon rainfall etc. These local parameters are added into the mode to calibrate the developed polder Water-Flow Model of the Polder 40/1.

5.1.1.1 Gate Operation

Two Gauge readers were involved at the drainage regulator DS-02 (Padmar Regulator) for collecting the water level information every 30mins interval from 6:00 AM to 6:00 PM. At the same time, log sheet is maintaining for collecting the Gate operation information. The following information is collecting for operating the Gate (Table 5.1).

Table 5.1: DS-2 (Padma Sluice) gate operation time series information

Regulator Gate	Gate Condition	Gate Level (mPWD)
Polder Side Gate	Fully Open	(+ve) 1.10 mPWD
River Side Gate	Fully Open	(+ve) 1.10 mPWD
Polder Side Gate	Fully Open	(+ve) 1.10 mPWD
River Side Gate	Fully Closed	(-ve) 1.10 mPWD
Polder Side Gate	Fully Closed	(-ve) 1.10 mPWD
River Side Gate	Fully Open	(+ve) 1.10 mPWD
Polder Side Gate	Fully Closed	(-ve) 1.10 mPWD
River Side Gate	Fully Closed	(-ve) 1.10 mPWD

Note: Gate Invert Level= -1.10 mPWD, Gate Height= 2.20m,

When Gate is fully Open= (-ve) 1.10 mPWD +2.20 mPWD = +1.10 mPWD)

Figure 5.1 presents the observed gate operation of the drainage regulator (Padmar regulator, DS-2) where (-ve) 1.10 mPWD indicates regulator gate is completely closed and (+ve 1.10 mPWD defines the regulator gate is completely open.

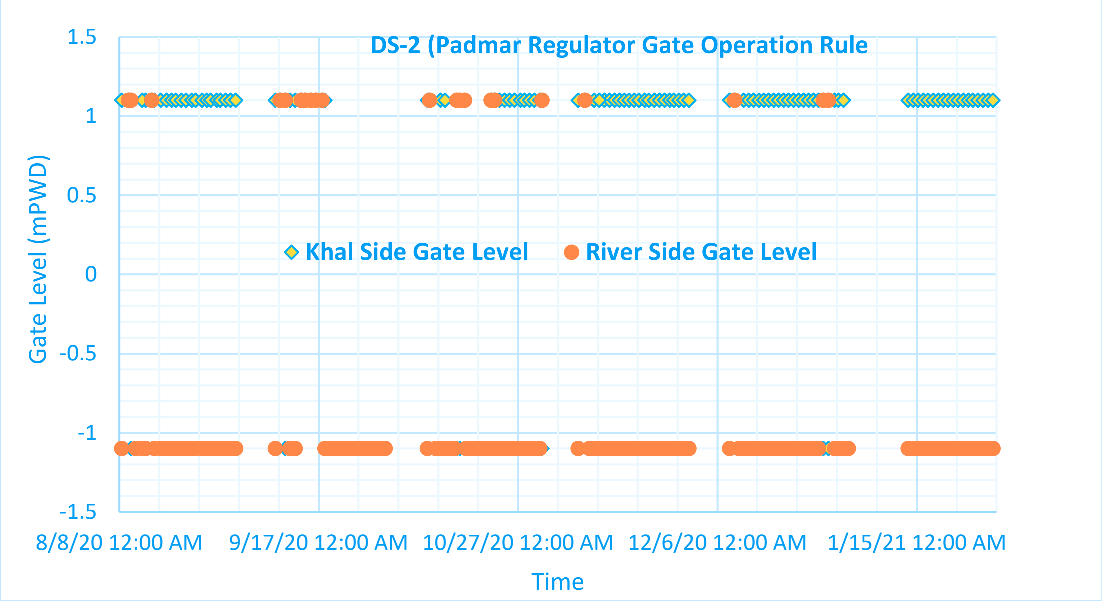


Figure 5.1: DS-2 (Padmar Regulator) Gate Operation

5.1.1.2 Spatial Variation of Rainfall

Local information is required for determining the exact rainfall contribution into the drainage regulator (DS-02) catchment. Figure 5.2 presents the rainfall information at BWDB observed station in Patharghata and the rainfall at the catchment of DS-02. It is noted that, the rainfall of DS-2 catchment was not monitored, and it has been generated by the backward process (developed by observing the Polder-flow model result).

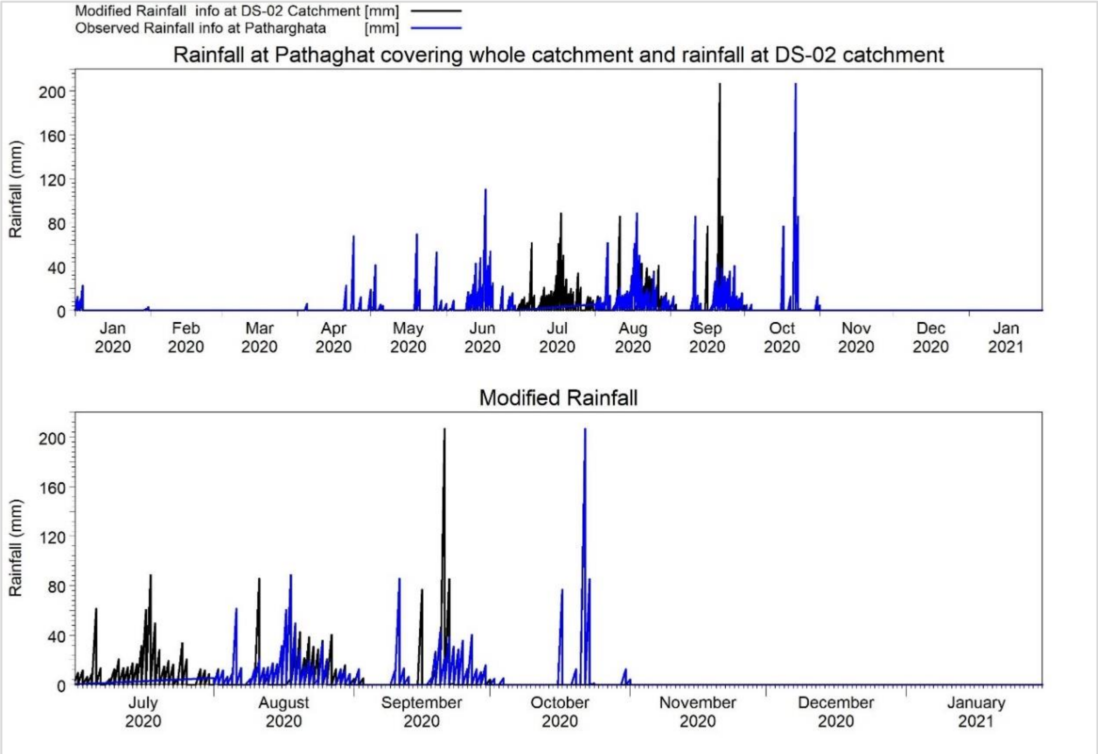


Figure 5.2: Variation of BWDB observed rainfall station (Patharghata) and DS-2 catchment rainfall

It has been observed that in July 2020 there is observed rainfall recorded in the BWDB observed station but rainfall during July 2020 has been added into the model to get the appropriate water level at the upstream of the drainage regulator DS-02. At the same time, BWDB observed station provide rainfall in the month of October which is missing the local level (catchment of DS-02). Therefore, it is very important to know the exact rainfall information to develop the Gate Operation Rule (GOR) for any polder.

5.1.1.3 Other local effects

Withdrawal effects of water at any locations of the internal khal systems of the Polder 40/1 has not been considered in the developed Polder water model. At the same time, construction of cross dams into the khals also not included into this model. Locations of the cross dams (earthen dams) have not identified during the survey campaign. Moreover, inclusion of internal structural structures like bridges, culverts not considered in the hydrodynamic system. It is assumed that the effects of the water flow into the khals are very less compared to construction of cross dams and water withdrawal. The following Figure 5.3 presents few locations where local people construct cross dams for their own/community interest and restrict the flow. These local effects are not included into the polder hydrodynamic mode/polder drainage model.

Figure 5.3: Cross dam locations in the peripheral river and in the internal drainage channels/khals

5.1.2 Calibration of the Polder 40/1 Water-Flow Model

The hydrodynamic model (water-flow model) has been simulated for three ways based on the field conditions. The simulation options are-

- Drainage regulator (DS-02), gate operation functions as drainage purpose with observed rainfall information
- Drainage regulator (DS-2) gate operation functions as real time gate operation with observed rainfall information
- Drainage regulator (DS-2) gate operation function as real time gate operation with modified rainfall information

5.1.2.1 Drainage regulator (DS-02), gate operation functions as drainage purpose with observed rainfall information

The drainage regulator, Padmar Sluice (DS-02) has two gates, i) river side gate and ii) polder side gate). Both gates are flap gate and gates are operated based on water level differences (Figure 5.4). Water level difference is defined by subtraction of river side water level from the polder side water level.

Water level difference = Water Level at Polder Side – Water Level at River Side

River Side Gate of Padmar Regulator

Country-Side Gate of Padmar Regulator

Figure 5.4: Existing gate system of the Padma Regulator

If the Polder side water level is higher than the river side water level, the local community raises the country side gate and the river side automatically opens due to the water pressure from polder side water. On the other hand, if the river side water level is higher than the country side gate, the river side gate automatically closed though the polder side gate is still lifted. This concept has been applied in the hydrodynamic model for developing the ideal gate operation rule. The following Figure 5.5 gives the clear idea about the drainage performance of the Padmar sluice (DS-02).

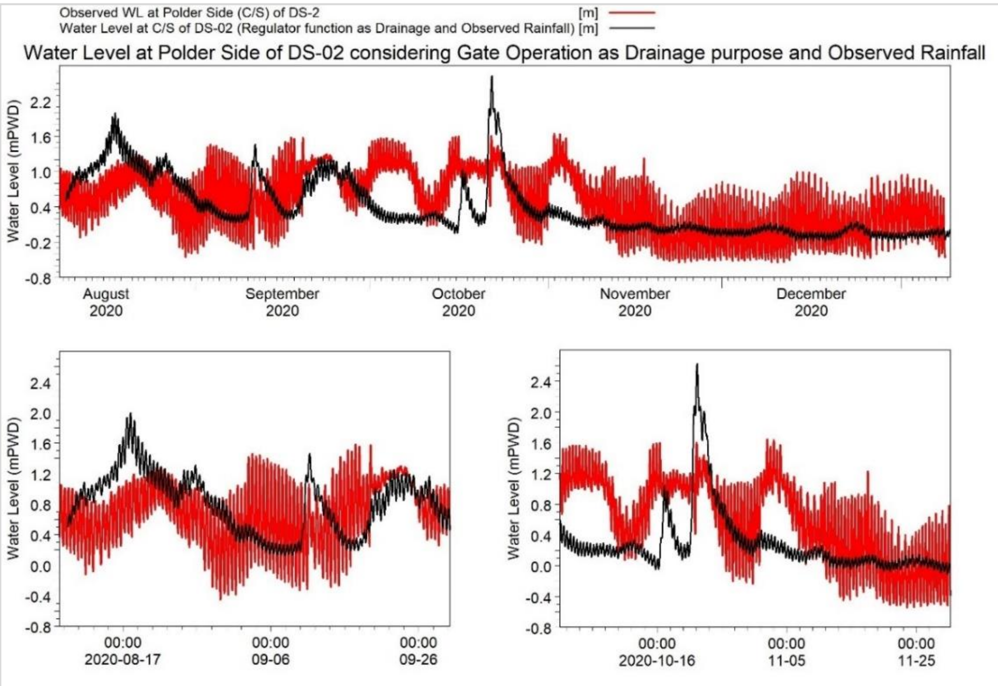


Figure 5.5: Water level comparison at upstream of DS-02 regulator when River Side Gate performs as a drainage regulator

Red colour line defines the polder side water level whereas the black colour defines the polder side water level. The Figure 5.5 indicates that the Padmar Sluice is not functioning as an ideal drainage regulator. Manual gate operation is involved here for preparing the similar trend of water levels. Considering the summary of the water level plot, the manual operation is included into the model to get the expected water level trend.

5.1.2.2 Drainage regulator (DS-2) gate operation functions as real time gate operation with observed rainfall information

Gate operation rule has been applied based on real time gate operation time series. One dedicated local person was involved for maintaining the gate operation log sheet by providing tick mark according to item wise. If the gate polder side gate open, the reader put tick mark into the log sheet and if the river side closed, he put tick mark into the closed option. Later, this log sheet information has applied into the model for generating the water level time series at the polder side. One pressure sensor and one water level measuring manual gauge has been installed for observing the water level time series.

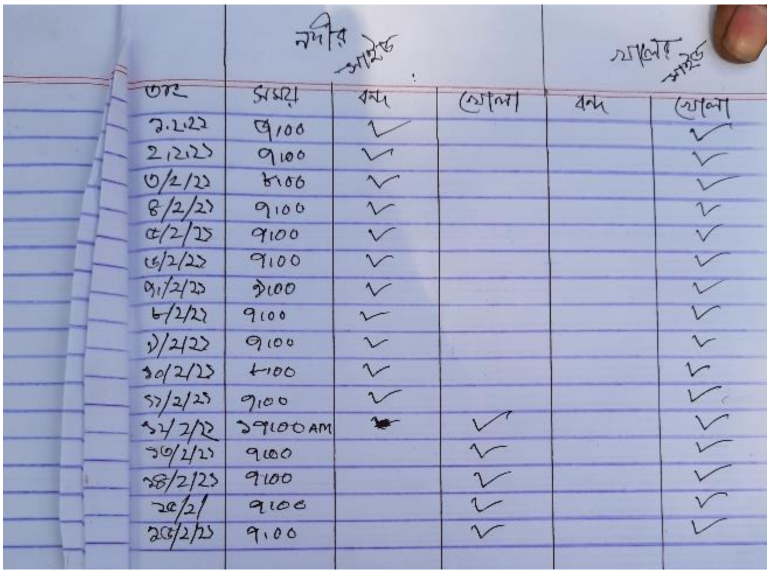


Figure 5.6: Gate operation log sheet

Figure 5.7 presents the model generated time series water level and observed water level at the polder side to check the performance of the developed Polder 40/1 water-flow model.

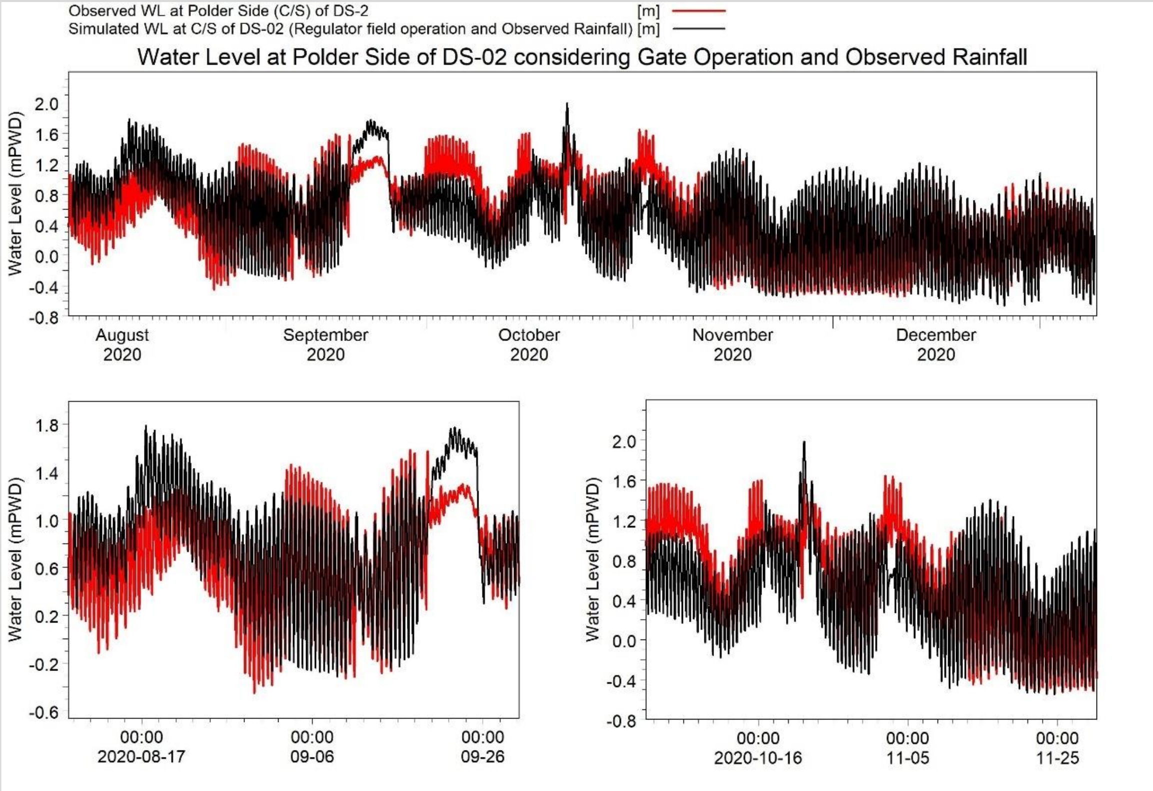


Figure 5.7: Water level comparison at upstream of DS-02 regulator when real time gate operation rule applied in the River Side Gate

The developed model gives the water level trend with the observed water level but not providing good agreement with the observed water level. It is investigated that the model could not generated the peak of water levels as spatial distribution and contribution of local rainfall into the khal system as direct runoff or ground water runoff are missing. It is cleared in the Figure 5.7, where red line (observed water level) shows higher elevation than the black line (model simulated water level). Therefore, it is necessary to include the local rainfall information to get the proper drainage performance when real time gate operation is involved. Considering this issue, it is recommended to introduce rainfall measuring devices in the most influenced regulator catchments to get the accurate water level information.

5.1.2.3 Drainage regulator (DS-2) gate operation function as real time gate operation with modified rainfall information

In this option, the observed rainfall information has been updated based on the water level trend at the polder side. This updated rainfall information is defined as modified rainfall. It has been found that the observed water at polder side is increasing where two factors may be involved-i) contribution of rainfall generated runoff and ii) removal of cross dams and increase water level at the regulator site (if cross dams are available). However, the observed water level is showing increasing trend not only one day or two days, but it is also following more than a week. It indicates the effects of consecutive local rainfall that is missing in the Patharghata rainfall information for that period. Thus, addition of rainfall has been added in the Patharghata rainfall station data and simulated the model to check the water level condition at the upstream of the DS-02 regulator. It has been carried by trial-and-error method to check the updates. Continuous discharge measurement has not been carried out at the upstream of the DS-02 regulator as the regulator is influenced by the astronomical tide. Figure 5.8 presents the water level comparison at the upstream of the drainage regulator DS-02 with the modified rainfall information.

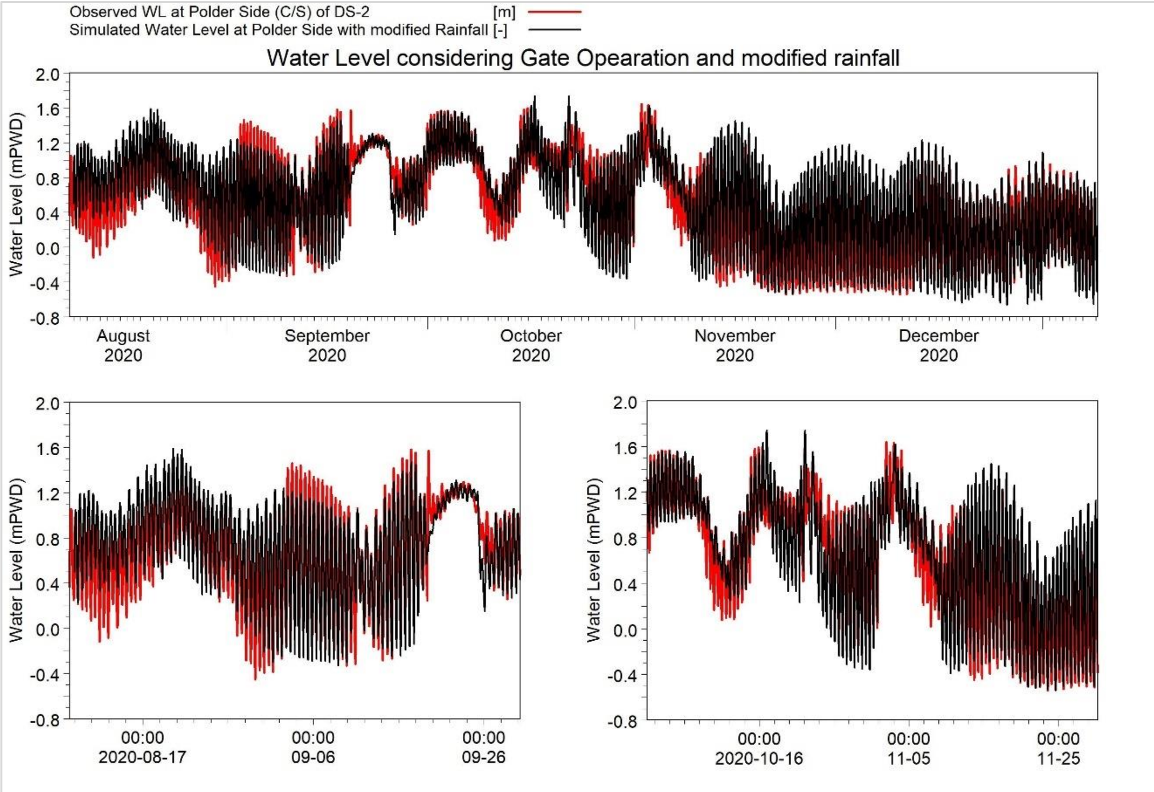
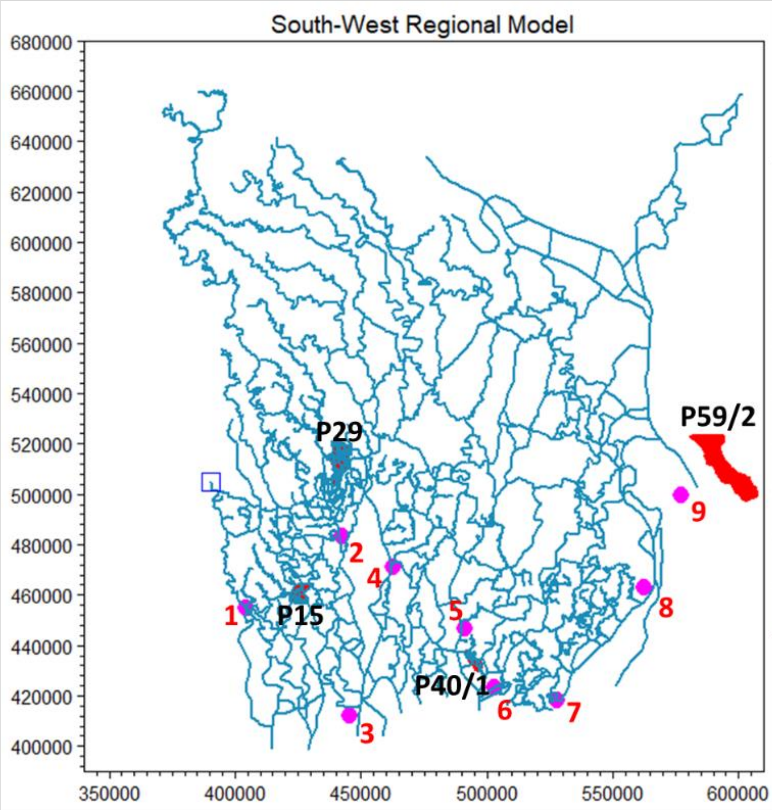


Figure 5.8: Water level comparison at upstream of DS-02 regulator when real time gate operation rule applied in the River Side Gate with modified rainfall

There are few days in the month of September when the simulated water level is not showing the good agreement with the observed water level information even addition of local rainfall generated runoff contribution. Maybe it can be solved by adding the other local factors like addition of ground water flow, withdrawal of water for irrigation or domestic purposes etc.

5.2 Calibration of the Regional Models

The South-West Regional Model has been updated under the Long-Term Research and Monitoring Project. Later this model has been calibrated and validated with the observed water level and water flow. The following Figure 5.9 presents the observed water level stations where water levels have been measured in the Long-Term Research and Monitoring Project.



Observed WL stations

SL	Name
1	Kaikhali
2	Nalian
3	Hiron Point
4	Joymoni
5	Charduani
6	Taltoli
7	Dhularshar
8	Dashmina
9	Daulatkhan

Figure 5.9: Locations of South-West Regional model calibration locations

Calibration of water levels at these locations have been done in this project. Water flow also calibrated at the observed location. Two calibration plots against water level at Joymoni in the Pussur River and at Taltoli in the downstream of the Bishkhali and Buriswar River are presented in the following Figure 5.10 and Figure 5.11 respectively.

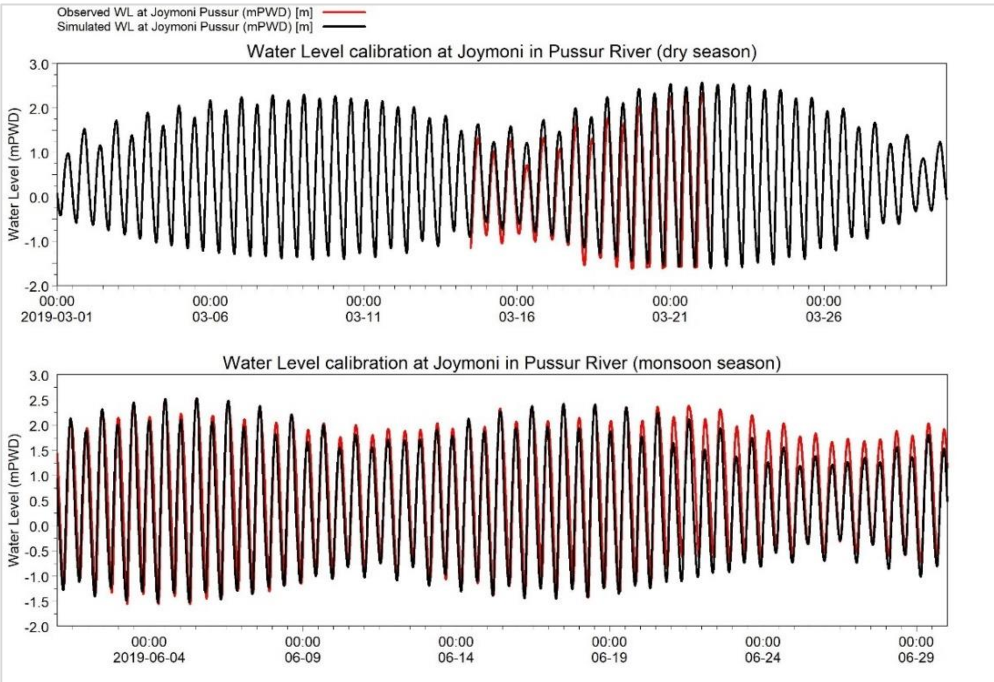


Figure 5.10: Water level calibration at Joymoni in the Pussur River

Note: Red colour line presents the observed water level and black colour line present the simulated water level. In the Figure 5.10, top and bottom water level hydrograph presents the water level comparison for presenting the dry season and wet season calibration respectively.

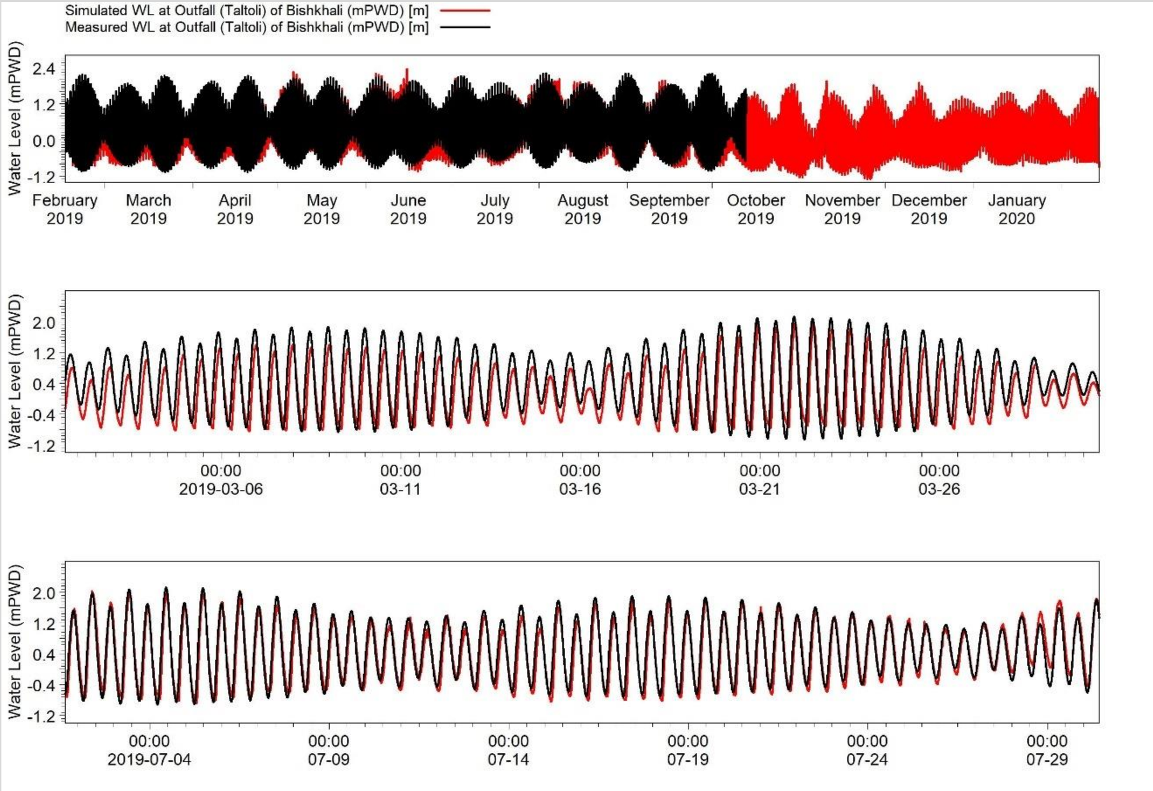


Figure 5.11: Water level calibration at Taltoli in the downstream of Bishkhali and Baleswar River

Note: Red colour line presents the observed water level and black colour line present the simulated water level. In the Figure 5.11, top hydrograph shows the water level comparison from the month of Feb 2019 to middle of Oct 2019. Middle and bottom water level hydrograph presents the water level comparison for presenting the dry season and wet season calibration respectively.

The selected Polder 64/1a and Polder 64/1b are in the Eastern Hilly Region. Sangu River is flowing Northern side of these polders and other river systems of the Eastern Hilly zone have not connected each other. Therefore, during development of the drainage model of the Polder 64/1a and Polder 64/1b, only Sangu River and other peripheral river systems are considered. The hydraulic properties of the Sangu River are fixed up by calibrating the water flow at Tailardwip in the Sangu River (Figure 5.12). The following Figure 5.13 presents the water flow calibration at Tailardwip in the Sangu River.

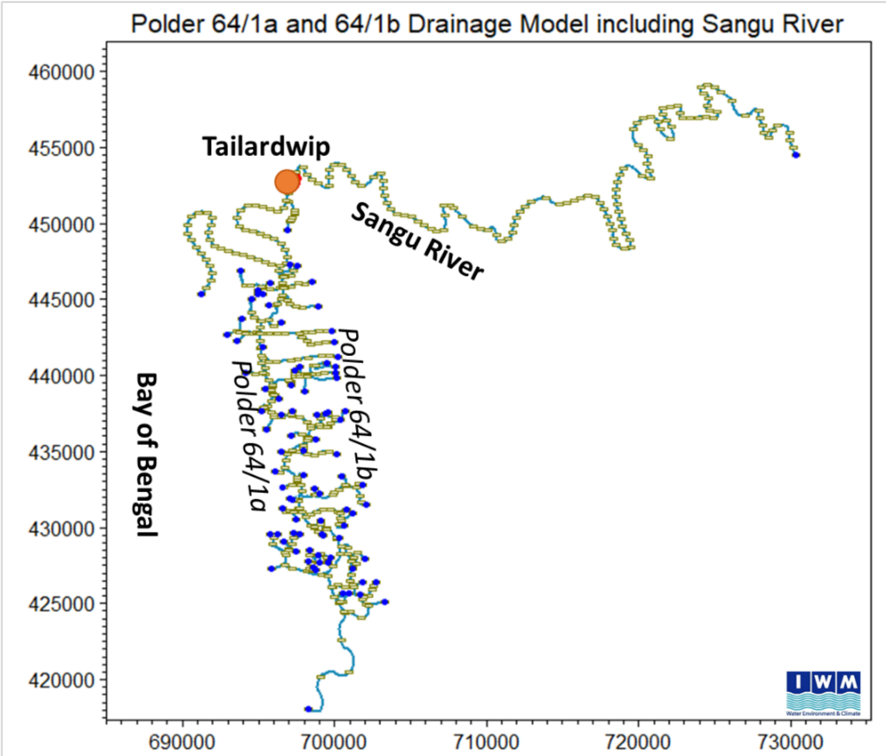


Figure 5.12: Water flow calibration location in the Sangu River

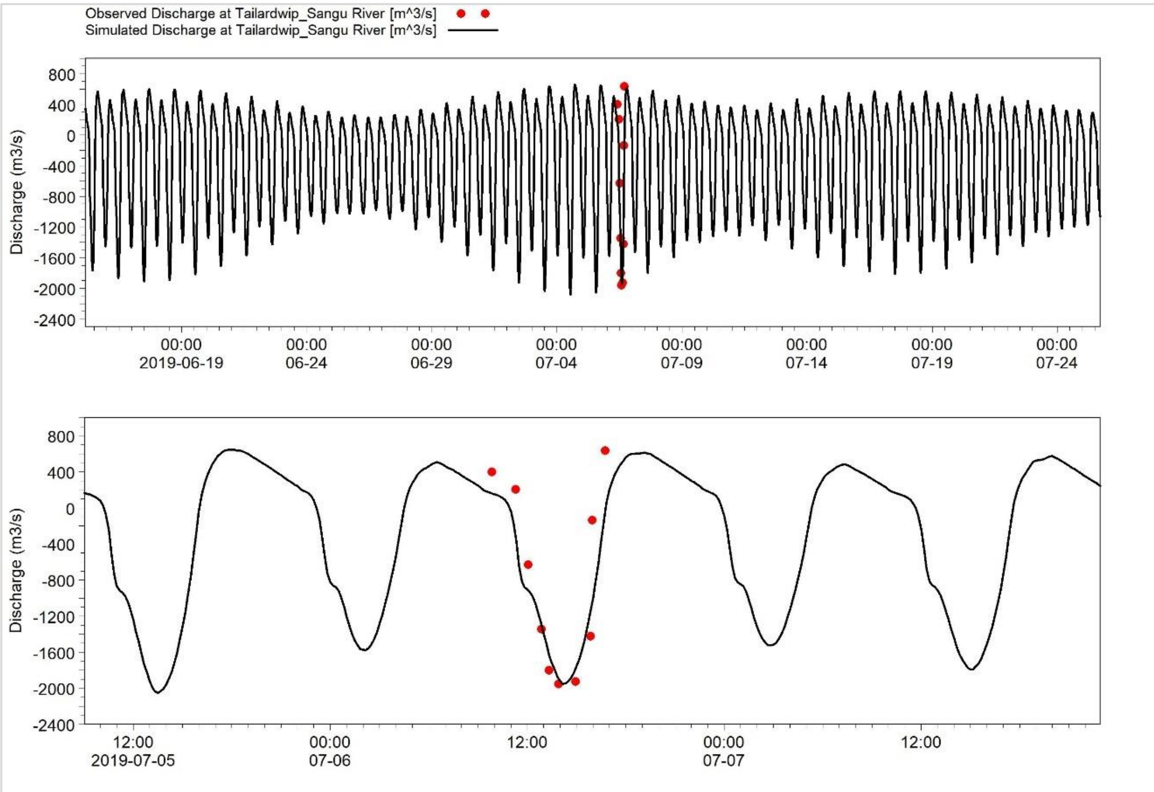
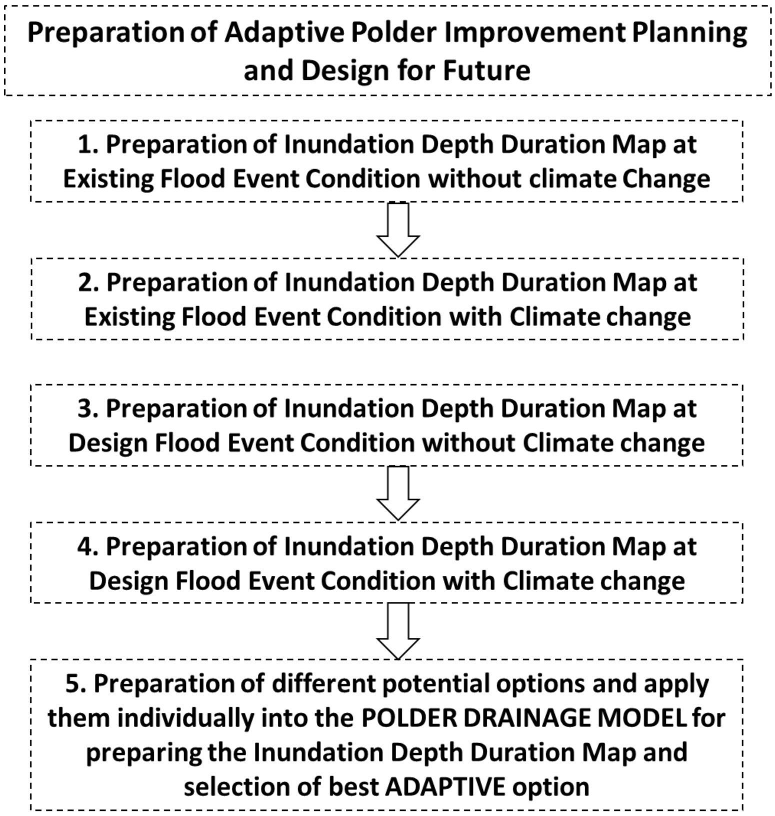


Figure 5.13: Calibration of water flow at Tailardwip in the Sangu River

Note: Black line presents the simulated water flow at Tailardwip in the Sangu River. The red color filled circle presents the observed discharge.

6 Planning and Design of Future Polders

Planning and Design of the polder system has been developed based on the inundation depth duration map. The developed inundation depth duration map helps to assess the present water logging and future water logging problem under climate change condition and guided to the consultants for preparing adaptive improved options for planning and design of a polder. The following Flowchart will help to understand the route plan for preparing the adaptive Polder Improvement Planning and Design for the future.



The existing drainage regulators, internal drainage channels/khals geometry, catchment area covering the individual drainage channels/khals and peripheral river morphological conditions are used in an integration way to calculate the water level conditions at different locations of the internal khal systems. Model generated water level time series has been used to prepare consecutive 3-days maximum water levels at different locations of the drainage channels/khals for the preparing the inundation conditions at existing situation. 5-days cumulative rainfall event and 1 in 50-year return period water levels (3-days consecutive maximum water levels) have been calculated to develop the design hydrological condition. In future, change in precipitation amount and trend, variation of flow from the upstream rivers and sea level rise at the downstream will affect the drainage performance of the coastal area as well as the selected polders. Therefore, climate change scenarios will be applied into the existing condition and design flood event condition to observe the drainage performance of the selected polders. The drainage performances and needs of the drainage improvement of the selected polder systems will be assessed in times of changing climate. Potential drainage improvement options will be developed from the participatory discussion with BWDB officials and final simulations of drainage models will be prepared based on consultation with local community and field investigation and analysis of modelling results. The overall planning and design of improved polder water management system has been described in this section step by step.

6.1 Preparation of Inundation Depth Map for Polder 40/1

Inundation depth duration maps have been prepared for 05 (five) hydrological and physical conditions of polder for assessing the existing drainage performance, existing drainage performance under climate change condition, drainage performance at design flood event condition, drainage performance at design flood event condition with climate change condition and for future drainage improvement options. Connecting to all, five steps have been followed to prepare the land classification. Steps are

Setp-1: Development of Digital Terrain Model from the topographic land level;

Step-2: Development of water surface (water surface prepared for consecutive 3-days maximum water level) for polder physical and hydrological conditions;

Step-3: Preparation inundation depth duration map by subtracting the topographic raster file (digital elevation model) from the water surface (prepared for 3-days consecutive maximum water level) raster file;

Step-4: Calculate the number cells according to land classes;

Step-5: Multiply the class-wise cells with each cell area to get the inundation area;

Detailed analysis of preparing inundation depth duration map for different physical and hydrological conditions of the Polder 40/1 has been describe in the following section. The overall summary for rest of the polders also discussed in this section.

6.1.1 Preparation of Inundation Depth Duration Map for Polder 40/1 at Existing Condition

1st step: Preparation of digital elevation model:

Preparation of Digital elevation model from the topographic land level already described in the earlier Chapter (Chapter Two).

2nd step: Preparation of water surface raster from different water level conditions:

Water level conditions inside the polder depends on several conditions. The major conditions are as follows i) peripheral river hydrological conditions, ii) drainage capacity of the internal channels, iii) existing condition of the control structures, iv) operation and management of the control structures, and v) operation of water management system by the local community. Considering these physical components, water level conditions have been generated for monsoon season. Water level conditions inside the polder has been generated for 5-days consecutive rainfall during the monsoon season.

Water-flow model has been simulated for the monsoon period (Jun-Sep) of 2019. Water level at each cross-section locations of the water-flow model network has been extracted from the water-flow model simulation result to generate the 3-days consecutive maximum water level conditions. The following Figure 6.1 shows the typical 3-days maximum water level condition at the upstream of Padma Sluice regulator (DS-2) of the Polder 40/1.

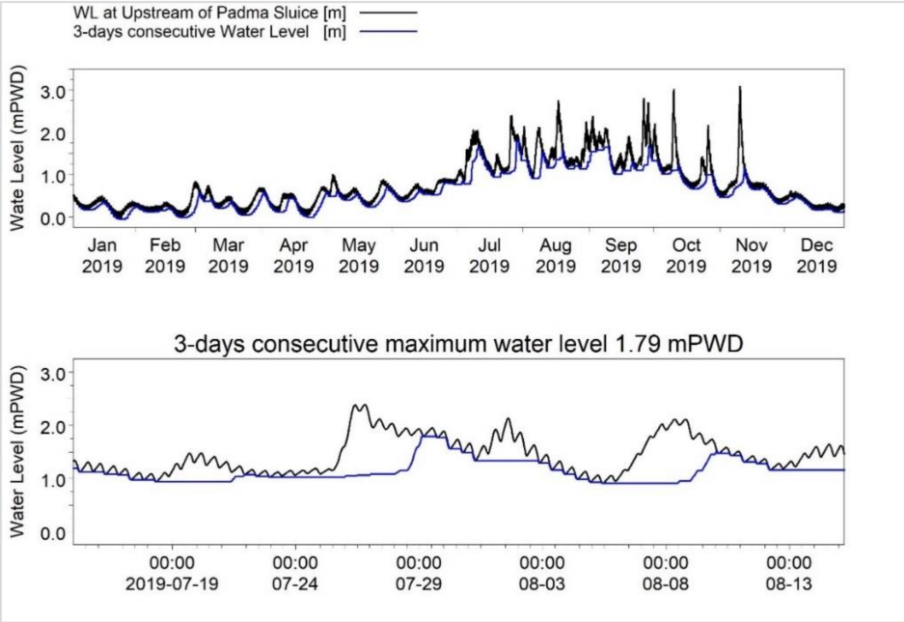


Figure 6.1: 3-days consecutive maximum water level at the upstream of Padma Regulator of the Polder 40/1

The 3-days consecutive maximum water level at the upstream of the Padma regulator has been determined 1.79mpWD (Figure 6.1). There are some peak water levels observed during the monsoon and post-monsoon period which are drain out when gate is open or sustain 1-day or 2-days consecutively. However, in this study 3-days consecutive maximum water level has been selected considering the crop production issue inside the polder during the monsoon period. Similar technique has been applied for generating 3-days consecutive maximum water levels in all locations of the drainage channels/khals of the Polder 40/1. The spatial distribution for 3-days consecutive maximum water level has been presented in the following Figure 6.2.

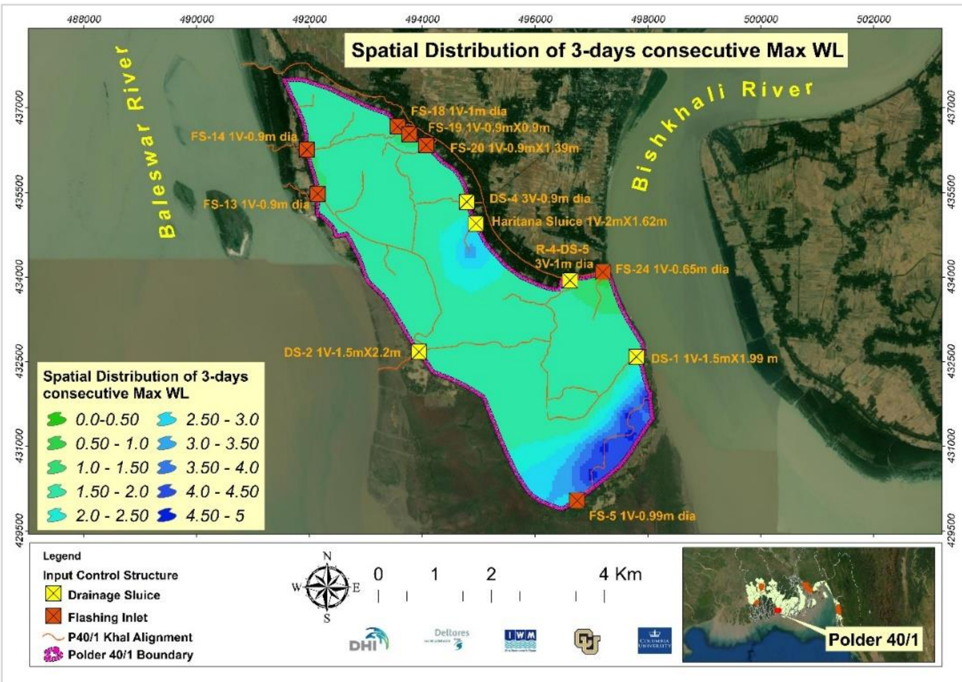


Figure 6.2: Spatial distribution of 3-days consecutive maximum water level inside the Polder 40/1

Step-3: Preparation of Inundation depth Duration Map for the Polder 40/1 at existing condition

Inundation depth duration map at existing/present condition is prepared for simulated 3-days consecutive water level and this water level has been prepared from 5-days cumulative rainfall hydrological condition. Year 2019 is selected for presenting the existing physical and hydrological condition of the Polder 40/1. Existing physical condition defines the present drainage regulator conditions (regulator condition-broken/damage, inclusion of functioning or not functioning characteristics, existing invert level of the regulators, dimension of the regulators) and the existing geometry of the drainage channels/khals. Existing hydrological conditions defines the existing rainfall, evaporation information. The inundation depth map is nothing but subtracting the elevation surface of the polder from the water surface raster file.

The main objective of this map is to check the drainage performance of the existing water control structures and the drainage capacity of the drainage channels. The effectiveness of drainage system is assessed with the percentage of flood inundation depth for 3-days duration of the polder area (land classification) based on model result and findings of field investigations. Flood inundation depth maps for 3-days duration showing the area of different classes of land (F0, F1, and F2& F3) is prepared applying GIS tool. Figure 6.3 presents the existing inundation condition of the Polder 40/1.

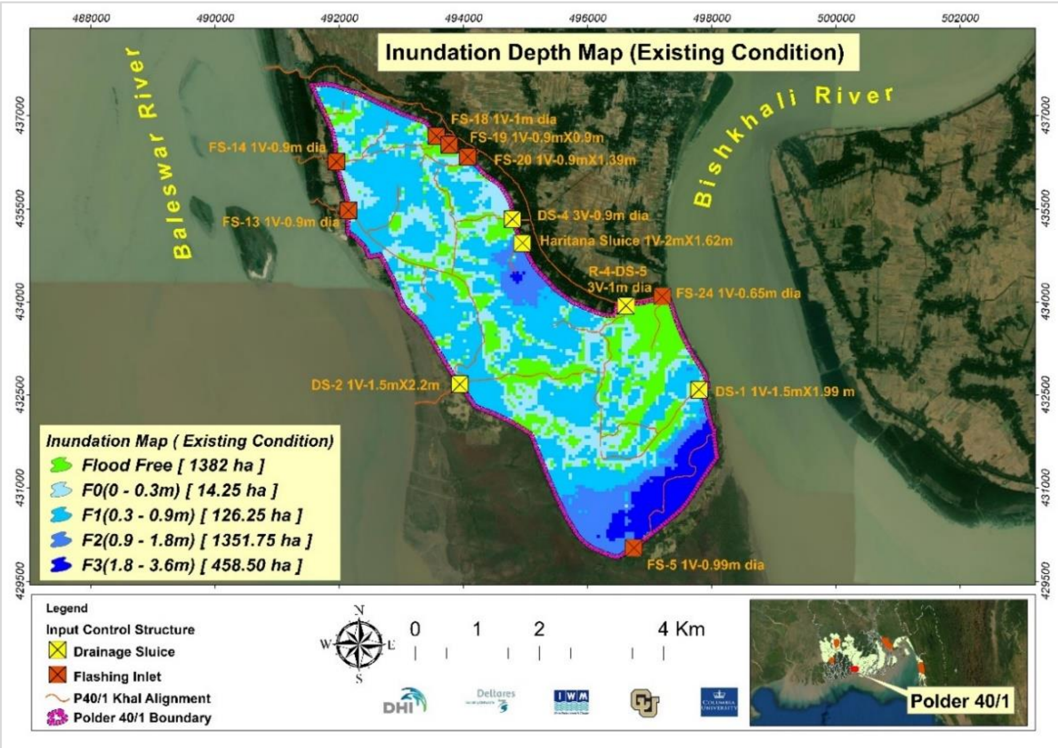


Figure 6.3: Inundation depth map of Polder 40/1 for existing hydrological flood condition

4th and 5th Step: In this step, number of cells have been calculated according to land classes and then multiply the number cells for specific land class with each cell area to get the inundation area for the specific land class. Table 6.1 presents different land class of the Polder 40/1 at existing condition where 43.77% lands are flood free (FF+F0 land) and 56.23% lands are under deep water (water depth greater than 30cm). The most inundation areas are showing the most southern part of the Polder.

Table 6.1: Existing inundation condition of the Polder 40/1

Inundation Area of Polder 40/1 at Existing Condition (Physical and Hydrological) (without climate Change)		
Type	Area(ha)	Percentage (%)
FF (<0)	382.00	19.44%
F0(0.0-0.30m)	478.00	24.33%
F1(0.3-0.90m)	806.50	41.04%
F2(0.90-1.80m)	166.25	8.46%
F3(1.80-3.60m)	132.25	6.73%
Total Area	1965.00	100.00%

6.1.2 Preparation of Inundation Depth Duration Map for Polder 40/1 at Design Hydrological Flood Event Condition

Inundation depth duration map also prepared for the Polder 40/1 at design flood event condition. The design hydrological flood event has been calculated from the historical rainfall information of Patharghata. Year 2011 has been selected as the design hydrological flood event (1 in 50-year return period) by the statistical analysis. The main purpose of this inundation depth duration map is to assess the drainage performance of the existing drainage regulators and the drainage channels if such design flood event repeats again what will be happened in the polder. Figure 6.4 presents the inundation situation during hydrological design flood event condition inside the Polder 40/1.

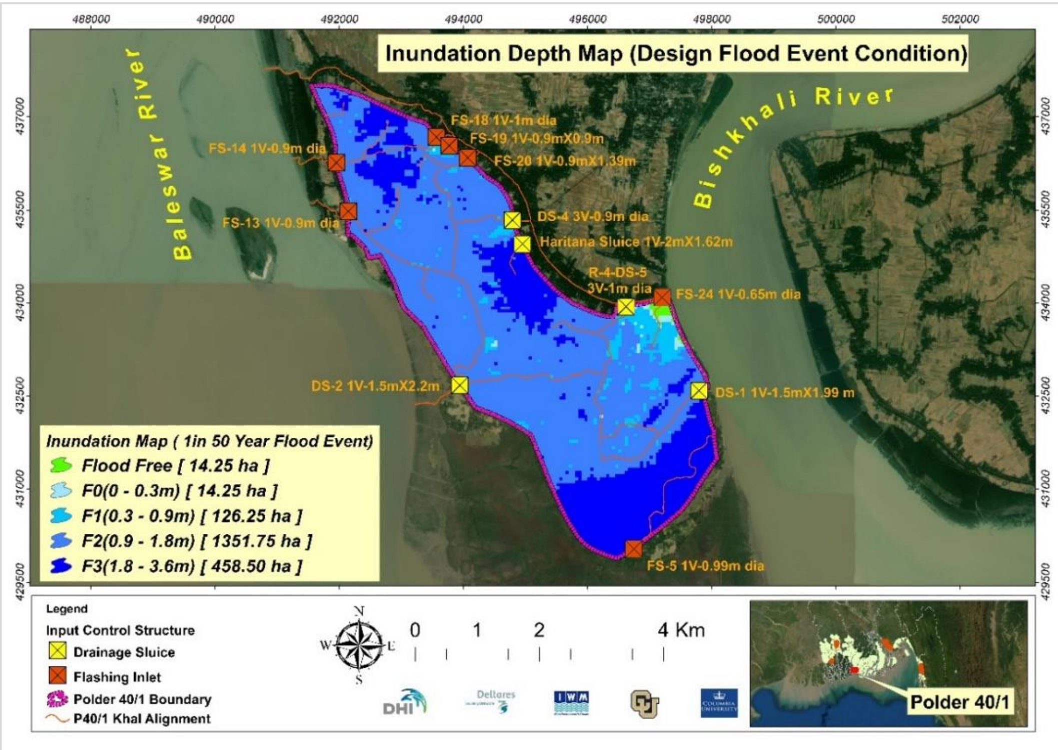


Figure 6.4: Inundation depth map of Polder 40/1 for 1 in 50-year design hydrological flood event

Simulation of rainfall event for 5-days and 50yr (design hydrological event) return period hydrological condition is carried out for the existing drainage system i.e., without changing the physical conditions of regulators and khals. Simulation results enable to examine the inundation depth in the polder and land classes. The inundation area and percentage of inundation area for the individual land class of Polder 40/1 during hydrological design flood condition is presented in the Table 6.2. It is observed that, only 1.46% lands are showing flood free (FF+F0), up to 30cm of water depth. About 6.42% lands are showing under water up to 90cm depth of water. The rest of the area, about 92.12% lands are under deep water (water depth greater than 90cm). It can be summarized that the polder is most vulnerable to water logging problem and if the design flood events happened again, the existing polder system becomes inactive. Therefore, potential improvement in the polder water management system is required to overcome the design flood event condition. However, potential improvement option should be considered under climate change condition for facing new challenges in future and make the polder robust in all worst scenarios.

Table 6.2: Inundation condition of the Polder 40/1 during 1 in 50-year flood event condition

Inundation Area of Polder 40/1 at Design Flood Event Condition (Physical and Design Hydrological Event) (without climate Change)		
Type	**Area(ha)**	**Percentage (%)**
FF (<0)	14.25	0.73%
F0(0.0-0.30m)	14.25	0.73%
F1(0.3-0.90m)	126.25	6.42%
F2(0.90-1.80m)	1351.75	68.79%
F3(1.80-3.60m)	458.50	23.33%
Total Area	1965.00	100.00%

6.2 Preparation of Inundation Depth Map for Polder 15

The existing drainage regulators and internal drainage channels/khals and peripheral river (Kobadak and Kholpetua River) morphological conditions are used for preparing the inundation depth duration map for the Polder 15. In this regards, consecutive 3-days maximum water level which is generated by 5-days cumulative rainfall event has been applied. Drainage performance of the Polder 15 has been assessed by generating the inundation depth map considering design rainfall event (1in 50-year return period). Inundation depth duration map at design hydrological condition presents the drainage performance of the existing infrastructures if such flood come back again how the existing water management operation of the Polder 15 functions. Planning and designing of the Polder 15 also requires future climate conditions specially contribution of rainfall generated runoff inside and outside of the polder, changes in the upstream water flow and downstream water level. Incremental rate of runoff and shifting the highest peak generated by rainfall, increment of upstream flow and rising of downstream water level will affect the polder drainage performance. These future changes will be included into the existing Polder 15 infrastructures and assess the drainage performance. Adaptive drainage improvement planning, and design will be devised from the inundation depth duration map at design flood event condition under the climate change condition. During the planning and design of the Polder 15, participatory water management issue, consultation with BWDB officials and local community and interpretation of the polder drainage modelling results will be the highest priority.

6.2.1 Preparation of Inundation Depth Duration Map for Polder 15 at Existing Condition

Similar technique has been applied during preparation of the inundation depth duration map of the Polder 15. The existing cross sections of the drainage channels/khals, existing dimensions (no. of opening, opening width, opening height, invert level of the existing regulators, existing regulator gate operation performance, existing condition of the regulator upstream and downstream cross sections, existing physical condition of whole reaches of all drainage khals/channels, morphological conditions of the peripheral Kobadak and Kholpetua River; all existing physical conditions have been applied into the Polder Drainage Model of the Polder 15.

3-days consecutive maximum water levels at different location of the drainage khals/channels have been generated from the simulated polder drainage model result. The generated water levels have been used for preparing the water surface of the Polder 15. The developed digital elevation model (generated from the topographic level) has been subtracted from the 3-days consecutive water surface to prepare the inundation depth duration map (Figure 6.5) of the Polder 15 at existing condition. The overall inundation depth duration map preparation, generation of water surface and development of digital elevation model, all are prepared by GIS technique.

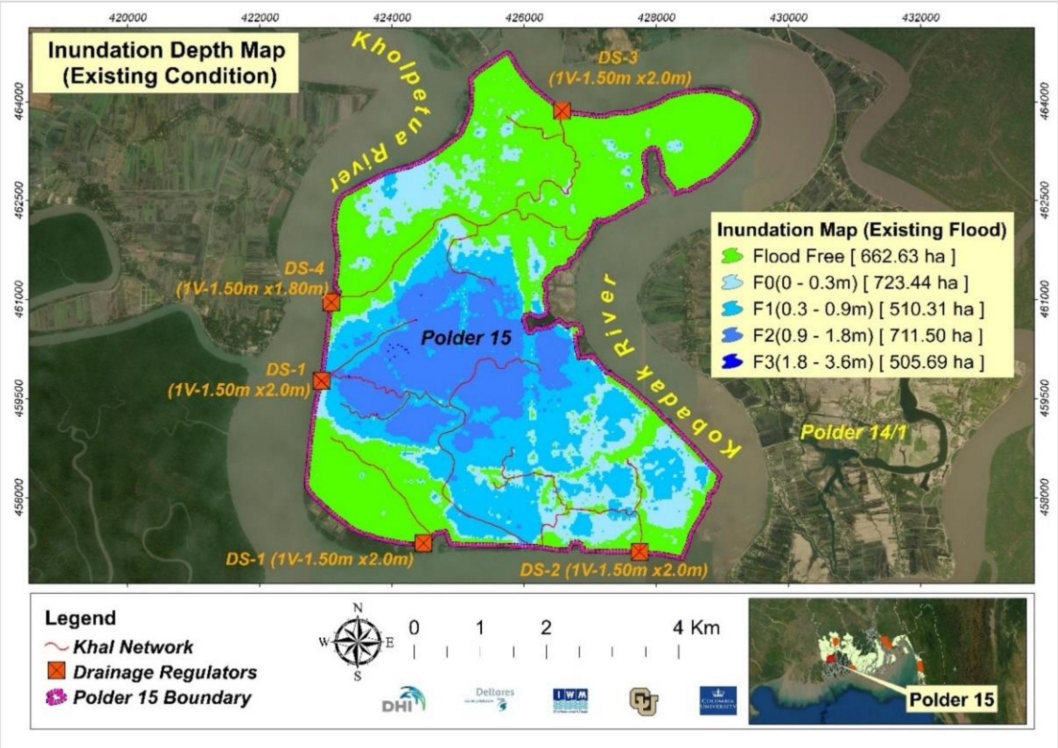


Figure 6.5: Inundation depth map of Polder 15 for existing hydrological flood condition

The inundation area and percentage of inundation area for the individual land class of Polder 15 without climate change condition during the present polder system (without engineering interventions, crest levels and sluices configuration) is presented in the Table 6.3. It is observed that, the flood free area is about 44.52% including flood free and F0 land where FF land covers about 21.28% of the polder area (Figure 6.5 and Table 6.3). The fulfilment of drainage criteria under the climate change condition requires about (85~90) % (CEIP-1, 2018) of flood free and F0 land. It implies that a drainage improvement plan is immediately required if we consider the existing polder system.

Table 6.3: Existing inundation condition of the Polder 15

Inundation Area of Polder 15 at Existing Condition (Physical and Hydrological) (without climate Change)		
Type	**Area(ha)**	**Percentage (%)**
FF (<0)	662.63	21.28%
F0(0.0-0.30m)	723.44	23.24%
F1(0.3-0.90m)	510.31	16.39%
F2(0.90-1.80m)	711.50	22.85%
F3(1.80-3.60m)	505.69	16.24%
Total Area	3113.56	100.00%

6.2.2 Preparation of Inundation Depth Duration Map for Polder 15 at Design Hydrological Flood Event Condition

The hydrological design flood event has been determined from 34-year rainfall information where 2007 has been fixed as design flood (1 in 50-year return period) year. The year 2007 rainfall has been used for generating the runoff from the Polder 15 hydrological model for each khal catchments and added the generated design runoff into the polder drainage model to assess the existing drainage performance of the Polder 15. The physical properties of the Polder 15 drainage khals/channels geometry, regulator information all is kept similar to generate the 3-days consecutive water levels at different locations of the khals. The generated 3-days consecutive water levels for 5-days cumulative rainfall at design flood event (1 in 50-year return period) condition have used to generate the water surface raster for the Polder 15. Then the digital elevation of the polder subtracted from the design water surface raster for preparing the inundation depth duration map at design hydrological condition. The following Figure 6.6 presents the inundation depth duration map for the Polder 15 at hydrological design condition.

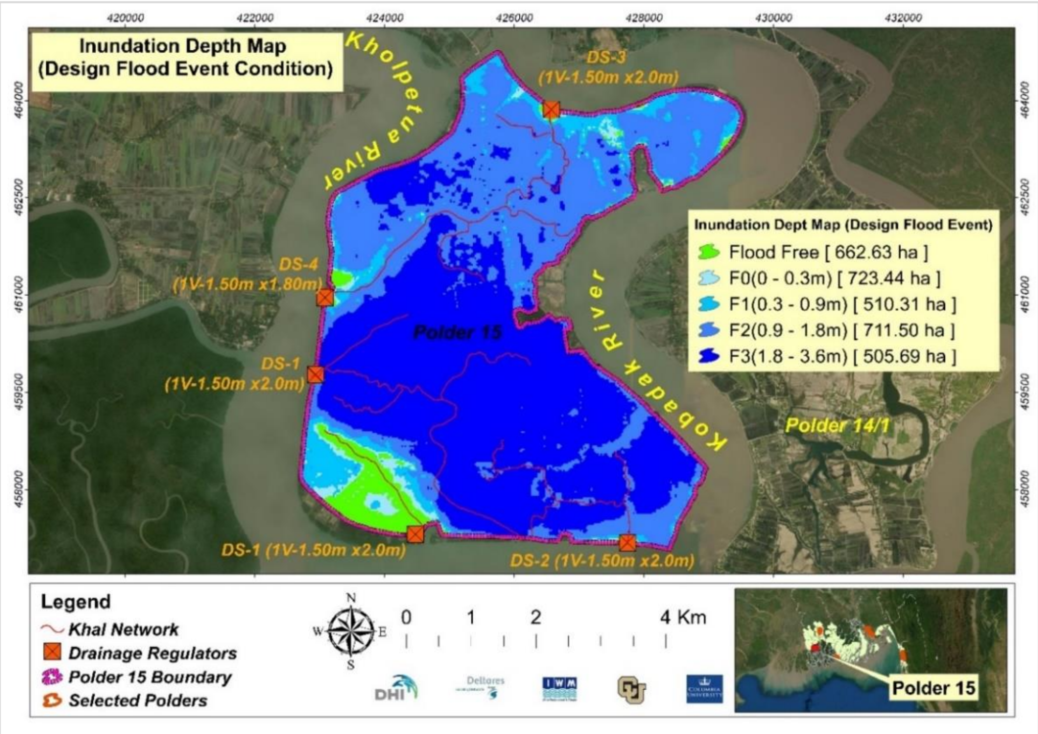


Figure 6.6: Inundation depth map of Polder 15 for 1 in 50-year design hydrological flood event

Inundation depth duration map at design flood event condition indicates only 4.66% lands are flood free (including FF+F0 land). It implies that about 95.34% (combination of F1+F2+F3) lands are submerged under design flood event condition due to inadequate drainage system. Simulation results and field investigation suggest that existing drainage system is not adequate enough for draining the design rainfall event and requires improvement measures immediately.

Table 6.4: Inundation condition of the Polder 15 during 1 in 50-year flood event condition

Inundation Area of Polder 15 at Design Flood Event Condition (Physical and Design Hydrological Event) (without climate Change)		
Type	**Area(ha)**	**Percentage (%)**
FF (<0)	51.63	1.66%
F0(0.0-0.30m)	93.38	3.00%
F1(0.3-0.90m)	75.31	2.42%
F2(0.90-1.80m)	287.19	9.22%
F3(1.80-3.60m)	2606.31	83.71%
Total Area	3113.81	100.01%

6.3 Preparation of Inundation Depth Map for Polder 29

Water level condition at different locations of the Polder 29 has been used for preparing the inundation depth duration map of the polder. In that case, water-flow model has been simulated for the including pre-monsoon, monsoon, and post-monsoon period (Mar-Dec) of 2019. Water level at different locations of the water-flow model network have been extracted from the simulated water-flow model result to generate the 3-days consecutive maximum water level conditions. 3-day depth duration water level has been selected considering the agricultural aspect of the Polder 29 specially Kharif-II. The following Figure 6.7 shows the typical 3-days maximum water level condition at the upstream of Bokultola regulator.

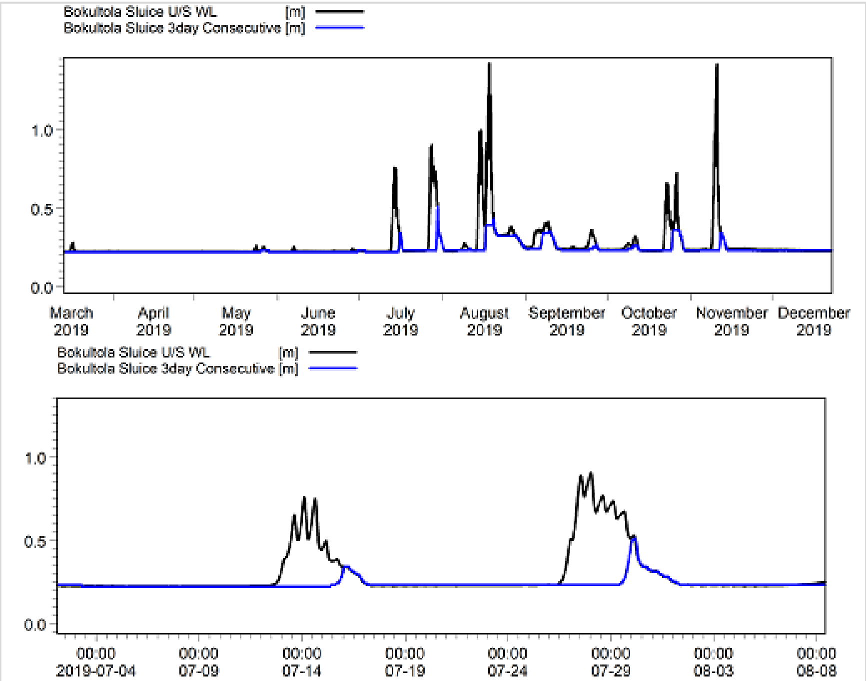


Figure 6.7: 3-days consecutive maximum water level at the upstream of Bokultola Regulator

The 3-days consecutive maximum water level at the upstream of the Bokultola regulator has been determined 0.69mpWD (Figure 6.7). There are some peak water levels observed during the monsoon and post-monsoon period which are drain out when gate is open or sustain 1-day or 2-days consecutively. However, in this study 3-days consecutive maximum water level has been selected considering the crop production and survivability inside the polder during the monsoon period.

6.3.1 Preparation of Inundation Depth Duration Map for Polder 29 at Existing Condition

Inundation depth duration map at the existing condition is prepared from the simulated 3-days consecutive water level at different locations of the internal drainage channels/khals and 5-days cumulative rainfall event. Year 2019 is selected for presenting the existing condition of the Polder 29. Existing condition defines the present drainage regulator conditions (regulator condition- broken/damage, inclusion of functioning or not functioning characteristics, existing invert level of the regulators, dimension of the regulators) and the existing geometry of the drainage channels/khals, sedimentation at the upstream and downstream of the regulator. The inundation depth duration map is prepared by subtracting the topographic level generated surface elevation raster file of the polder from the consecutive 3-days water level generated water surface raster file.

The main objective of this map is to check the drainage performance of the existing water control structures and the drainage capacity of the drainage channels. The effectiveness of drainage system is assessed with the percentage of flood inundation depth for 3-days duration of the polder area (land classification) based on showing the area of different classes of land (F0, F1, F2 and F3) is prepared applying GIS tool model result and findings of field investigations. Flood inundation depth maps for 3-days duration presents the existing inundation condition of the Polder 29 (Figure 6.8).

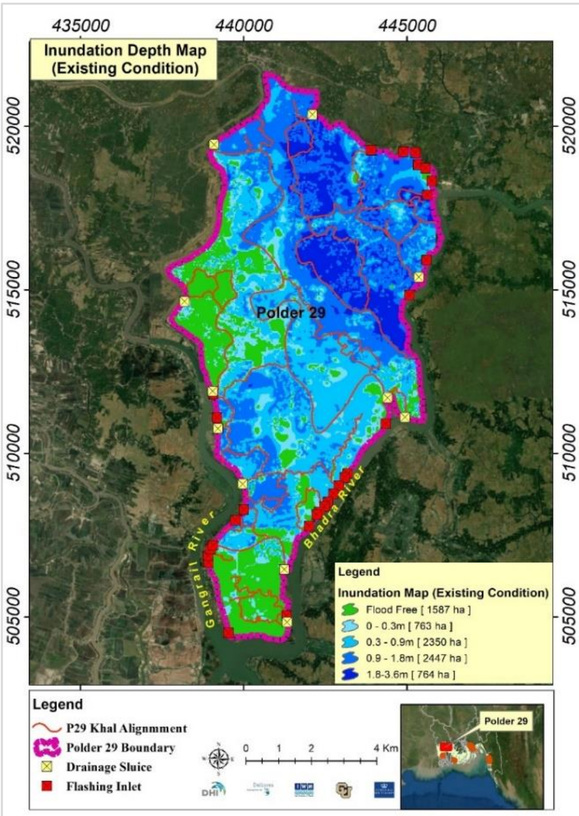


Figure 6.8: Inundation depth map of the Polder 29 for existing hydrological flood condition

Table 6.5 presents different land class of the Polder 29 at existing condition where 29.70% lands are flood free (FF+F0 land) and 70.30% lands are under deep water (water depth greater than 30cm). Mainly this inundation is from existing ghers (Fish ponds). The most inundation areas are showing the most Northern and Middle part of the Polder.

Table 6.5: Existing inundation condition of the Polder 29

Inundation Area of Polder 29 at Existing Condition (Physical and Hydrological) (without climate Change)		
Type	**Area(ha)**	**Percentage (%)**
FF (<0)	1587.00	20.06%
F0(0.0-0.30m)	763.00	9.64%
F1(0.3-0.90m)	2350.00	29.71%
F2(0.90-1.80m)	2447.00	30.93%
F3(1.80-3.60m)	764.00	9.66%
Total Area	7911.00	100.00%

6.3.2 Preparation of Inundation Depth Duration Map for Polder 29 at Design Hydrological Flood Event Condition

Future water management of the Polder 29 will be prepared based on inundation depth duration map. In that regards, the design hydrological flood event has been calculated from the historical rainfall information of Dumuria. Year 2004 has been selected as the hydrological flood event (1 in 50-year return period) by the statistical analysis. The main purpose of this water logging condition into the polder is required to assess the drainage performance of the drainage regulators and the drainage channels if such flood event repeats again what will be happened in the polder water management system. Figure 6.9 presents the inundation situation for 1 in 50-year return period hydrological flood event condition inside the Polder 29.

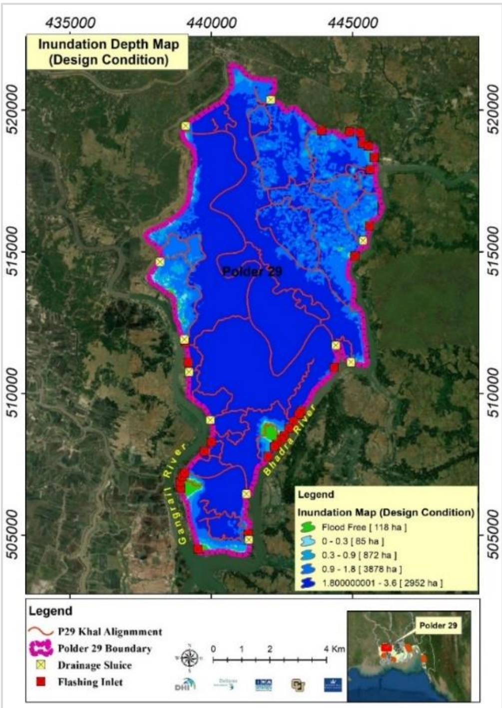


Figure 6.9: Inundation depth map of the Polder 29 for 1 in 50-year design hydrological flood event

Simulation of rainfall event of 5-days cumulative rainfall for 1 in 50yr (design hydrological event) return period is carried out for the existing drainage system i.e., without changing the regulators and khals. Simulation results enable to examine the inundation depth in the polder and land classes. The inundation area and percentage of inundation area for the individual land class of Polder 29 during hydrological design flood condition is presented in the Table 6.6.

Table 6.6: Inundation condition of the Polder 29 during 1 in 50-year flood event condition

Inundation Area of Polder 29 at Design Flood Event Condition (Physical and Design Hydrological Event) (without climate Change)		
Type	**Area(ha)**	**Percentage (%)**
FF (<0)	118.00	2.79%
F0(0.0-0.30m)	85.00	2.38%
F1(0.3-0.90m)	872.00	11.02%
F2(0.90-1.80m)	3678.00	46.49%
F3(1.80-3.60m)	2952.00	37.32%
Total Area	7911.00	100.00%

It is observed that, only 5.18% lands are showing flood free (FF+F0), up to 30cm of water depth. About 11.02% lands are showing under water up to 90cm depth of water. The rest of the area, about 83.8% lands are under deep water (water depth greater than 90cm). It can be summarized that the polder is most vulnerable to water logging problem and if the design flood events happened again, operation of the existing polder system becomes inactive. Therefore, potential improvements in the polder water management system are required to overcome the design flood event condition. However, potential improvement option should be considered under climate change condition for facing new challenges in future and make the polder robust in all worst scenarios.

6.4 Preparation of Inundation Depth Map for Polder 59/2

Water level at the different reaches of the internal drainage khals/channels has been used for preparing the inundation depth duration map of the Polder 59/2. Water level has been generated from the developed Polder 59/2 water-flow model which has been simulated for 2019. Inundation depth duration map at the existing condition has been prepared for 3-days consecutive maximum water level conditions. 3-days consecutive water level has been selected considering the cropping system (Kharif-II) during monsoon. The following Figure 6.10 shows the typical 3-days maximum water level condition at the upstream of Jaridona regulator.

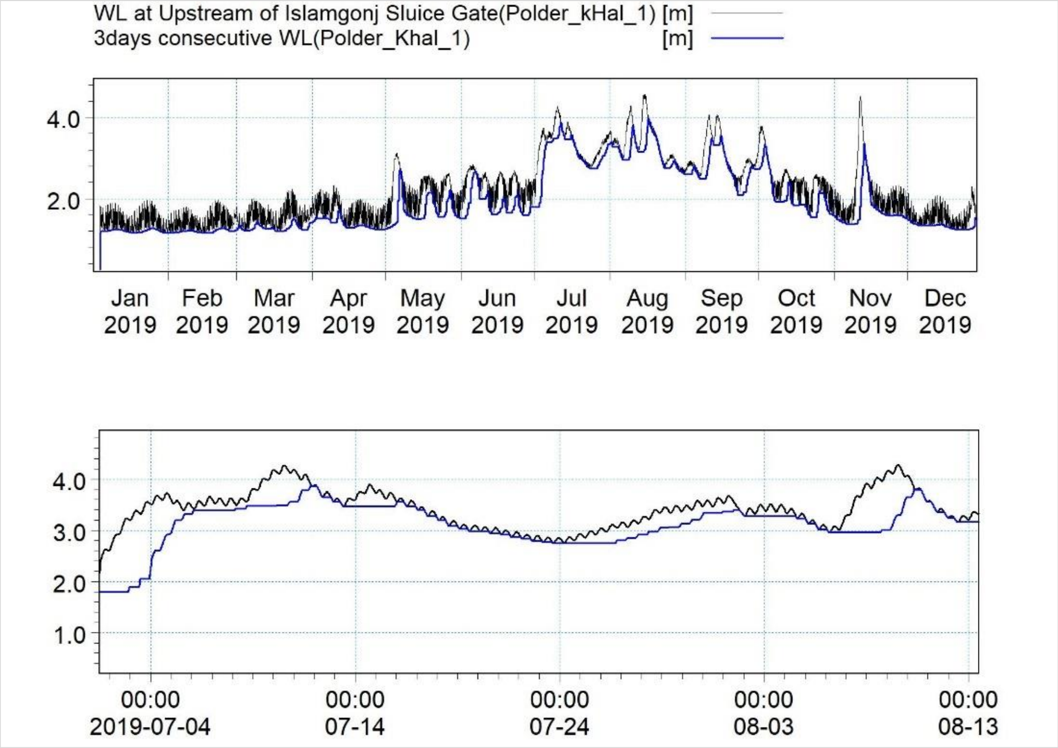


Figure 6.10: 3-days consecutive maximum water level at the upstream of Islamganj regulator

The 3-days consecutive maximum water level at the upstream of the Islamganj regulator has been determined 3.7mpWD (Figure 6.10). There are some peak water levels observed during the monsoon and post-monsoon period which are drain out when gate is open or sustain 1-day or 2-days consecutively. However, in this study 3-days consecutive maximum water level has been selected considering the crop production and survivability inside the polder during the monsoon period.

6.4.1 Preparation of Inundation Depth Duration Map for Polder 59/2 at Existing Condition

Inundation depth duration map at existing/present condition is prepared for simulated 3-days consecutive water level and 5-days cumulative rainfall event. Year 2019 is selected for presenting the existing condition of the Polder 59/2. Existing condition defines the present drainage regulator conditions (regulator condition- broken/damage, inclusion of functioning or not functioning characteristics, existing invert level of the regulators, existing dimension of the regulators, sedimentation at the upstream and downstream of the regulator) and the existing geometry of the drainage channels/khals. The existing hydrological condition defines available rainfall and evaporation information. The inundation depth map is nothing but subtracting the elevation surface of the polder from the water surface raster file.

The inundation depth duration map is prepared to check the drainage performance of the existing water control structures and the drainage capacity of the drainage channels. The effectiveness of drainage system is assessed with the percentage of flood inundation depth for 3-days duration of the polder area (land classification) based on model result and findings of field investigations. Flood inundation depth maps for 3-days duration showing the area of different classes of land (F0, F1, F2 & F3) is prepared applying GIS tool. Figure 6.11 presents the existing inundation condition of the Polder 59/2.

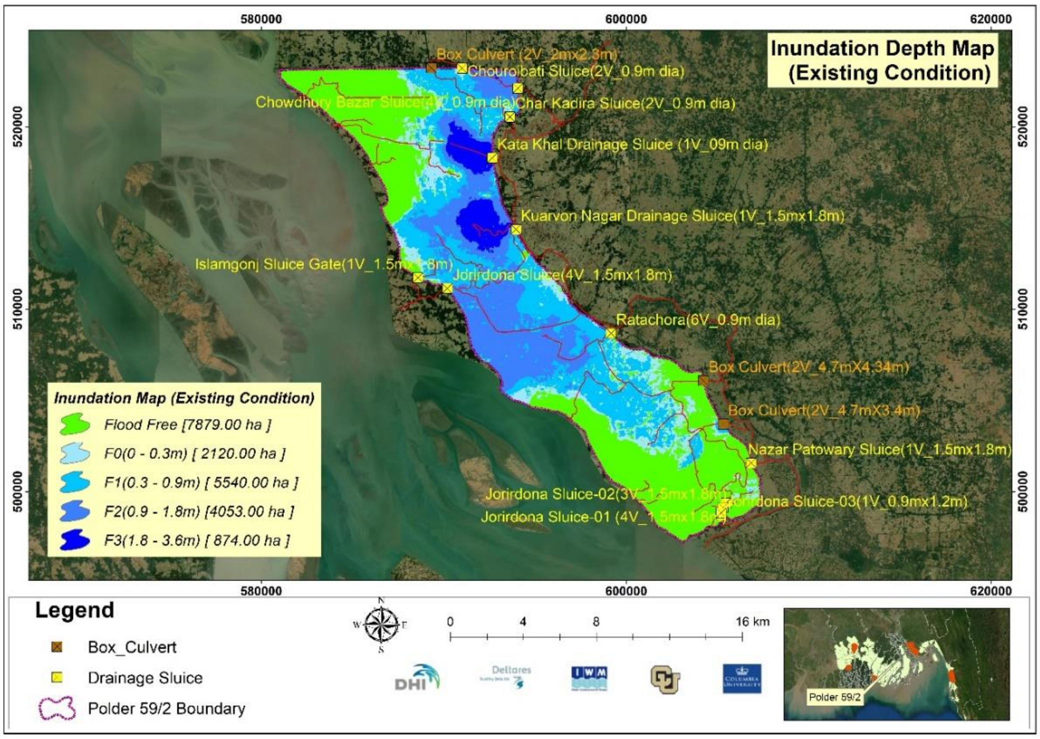


Figure 6.11: Inundation depth map of the Polder 59/2 for existing hydrological flood condition

Table 6.7 presents different land class of the Polder 59/2 at existing condition where 48% lands are flood free (FF+F0 land) and 52% lands are under deep water (water depth greater than 30cm). The most inundation areas are showing the most eastern part of the Polder due to less conveyance capacity of the peripheral Jarirdona khal. The western side is showing flood free as the western side of the polder is open and internal drainage channels are directly connected with the mighty Lower Meghna River. Internal water can flush easily during the ebb tide.

Table 6.7: Existing inundation condition of the Polder 59/2

Inundation Area of Polder 59/2 at Existing Condition (Physical and Hydrological) (without climate Change)		
Type	Area(ha)	Percentage (%)
FF (<0)	7879	38%
F0(0.0-0.30m)	2120	10%
F1(0.3-0.90m)	5540	27%
F2(0.90-1.80m)	4053	20%
F3(1.80-3.60m)	874	4%
Total Area	20466	100%

6.4.2 Preparation of Inundation Depth Duration Map for Polder 59/2 at Design Hydrological Flood Event Condition

Future water management of the polder will be prepared based inundation depth duration map for the hydrological design flood event. Design hydrological flood event has been determined from the historical rainfall information of Ramgati and Lakshmipur. Year 1993 has been selected as the hydrological flood event (1 in 50-year return period) by the statistical analysis. The main purpose of this water logging condition into the polder system is required to assess the drainage performance of the existing drainage regulators and the drainage channels if such flood event repeats again what will be happened in the polder water management system. Figure 6.12 presents the inundation situation for 1 in 50-year return period hydrological flood event condition inside the Polder 59/2.

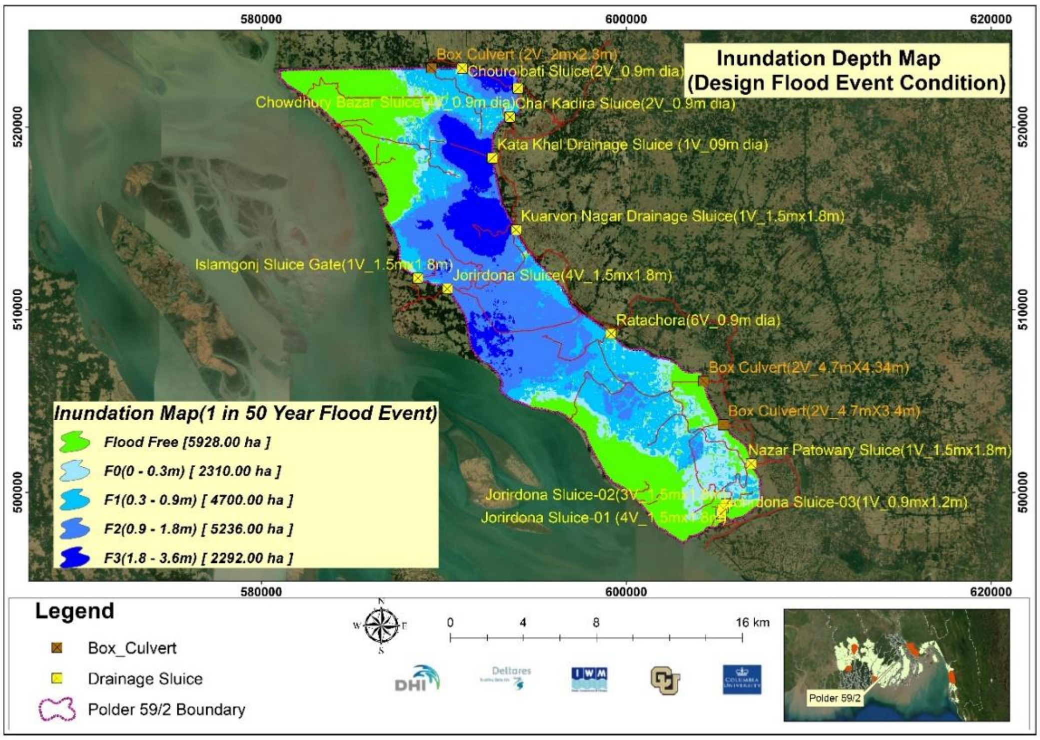


Figure 6.12: Inundation depth map of the Polder 59/2 for 1 in 50-year design hydrological flood event

Simulation of rainfall event of 5-days cumulative rainfall for 1 in 50yr (design hydrological event) return period is carried out for the existing drainage system i.e., without changing the regulators conditions and existing khal condition. Simulation results enable to examine the inundation depth in the polder and land classes. The inundation area and percentage of inundation area for the individual land class of Polder 59/2 during hydrological design flood condition is presented in the Table 6.8.

Table 6.8: Inundation condition of the Polder 59/2 during 1 in 50-year flood event condition

Inundation Area of Polder 59/2 at Design Flood Event Condition (Physical and Design Hydrological Event) (without climate Change)		
Type	**Area(ha)**	**Percentage (%)**
FF (<0)	5928	29%
F0(0.0-0.30m)	2310	11%
F1(0.3-0.90m)	4700	23%
F2(0.90-1.80m)	5236	26%
F3(1.80-3.60m)	2292	11%
Total Area	20466	100%

It is observed that, only 40% lands are showing flood free (FF+F0), up to 30cm of water depth. About 23% lands are showing under water up to 90cm depth of water. The rest of the area, about 37% lands are under deep water (water depth greater than 90cm). It can be summarized that the polder is most vulnerable to water logging problem and if the design flood events happened again, the existing polder system becomes inactive. Therefore, potential improvements in the polder water management system are required to overcome the design flood event condition. However, potential improvement option should be considered under climate change condition for facing new challenges in future and make the polder robust in all worst scenarios.

6.5 Preparation of Inundation Depth Map for Polder 64/1a and 64/1b

Water level at the different chainages of the internal drainage khals/channels has been extracted from the polder drainage model and used them for preparing 3-days consecutive maximum water level and also used for preparing the spatial distribution map of the Polder 59/2 at exiting and design flood event condition. Spatial water surface distribution map for existing and design flood event condition has been for the year 2015. Due to not availability of the boundary conditions, year 2015 has been selected as existing flood event. Statistical analysis indicates design flood event (1 in 50-year return period) also occurred in the year 2015. Maintaining the design criteria, 3-days consecutive water levels at different locations of the khals has been considered for the sustainability of the cropping system (Kharif-II) during monsoon. The following Figure 6.13 shows the typical 3-days maximum water level water surface distribution map for the Polder 64/1 and Polder 64/1b.

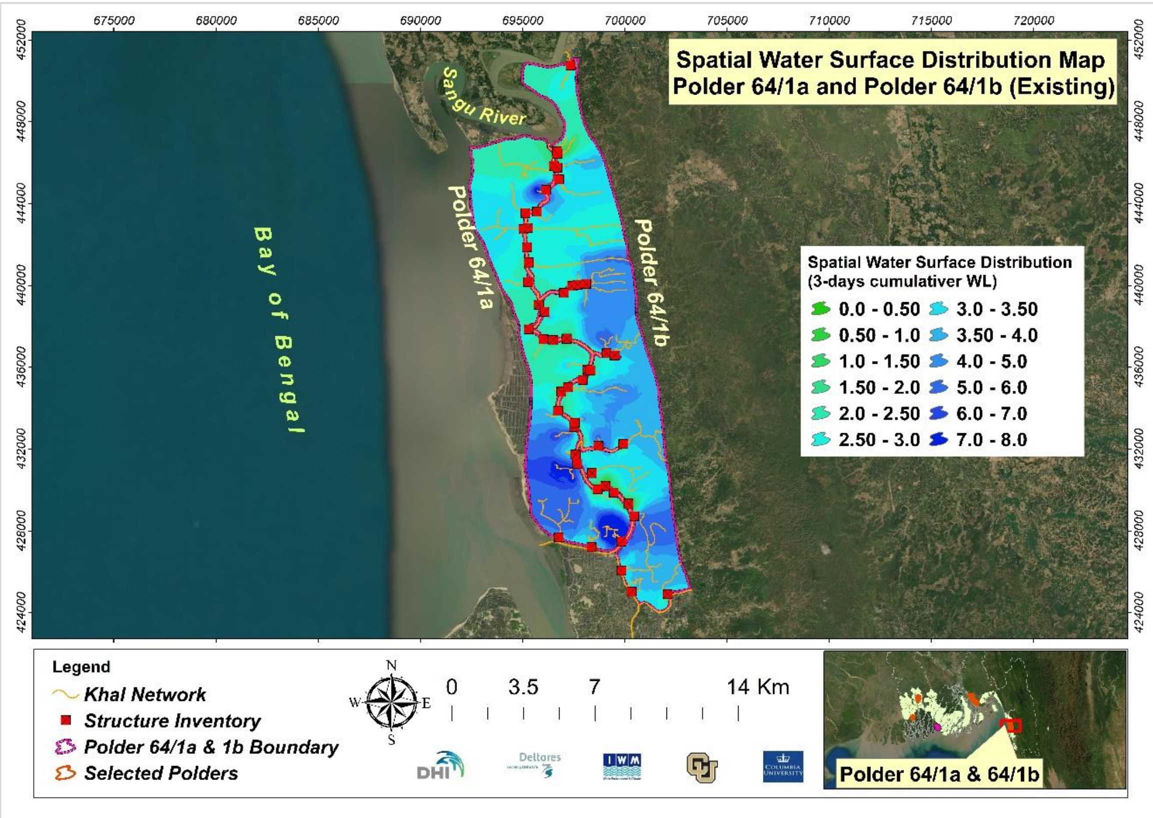


Figure 6.13: 3-days consecutive maximum water level spatial distribution in the Polder 64/1a and Polder 64/1b at existing condition

6.5.1 Preparation of Inundation Depth Duration Map for Polder 64/1a and Polder 64/1b at Existing Condition

Inundation depth duration map at existing/present condition is prepared for simulated 3-days consecutive water level and 5-days cumulative rainfall event. Year 2015 is selected for presenting the existing condition of the Polder 64/1a and Polder 64/1b jointly. Existing condition defines the present drainage regulator conditions (regulator condition-broken/damage, inclusion of functioning or not functioning characteristics, existing invert level of the regulators, existing dimension of the regulators, sedimentation at the upstream and downstream of the regulator) and the existing geometry of the drainage channels/khals. The existing hydrological condition defines available rainfall and evaporation information. The inundation depth map is nothing but subtracting the elevation surface of the polder from the water surface raster file.

The inundation depth duration map is prepared to check the drainage performance of the existing water control structures and the drainage capacity of the drainage channels and peripheral river/khal system. The effectiveness of drainage system is assessed with the percentage of flood inundation depth for 3-days duration of the polder area (land classification) based on model result and findings of field investigations. Flood inundation depth maps for 3-days duration showing the area of different classes of land (F0, F1, F2 & F3) is prepared applying GIS application. Figure 6.14 presents the existing inundation condition of the Polder 64/1a and Polder 64/1b jointly.

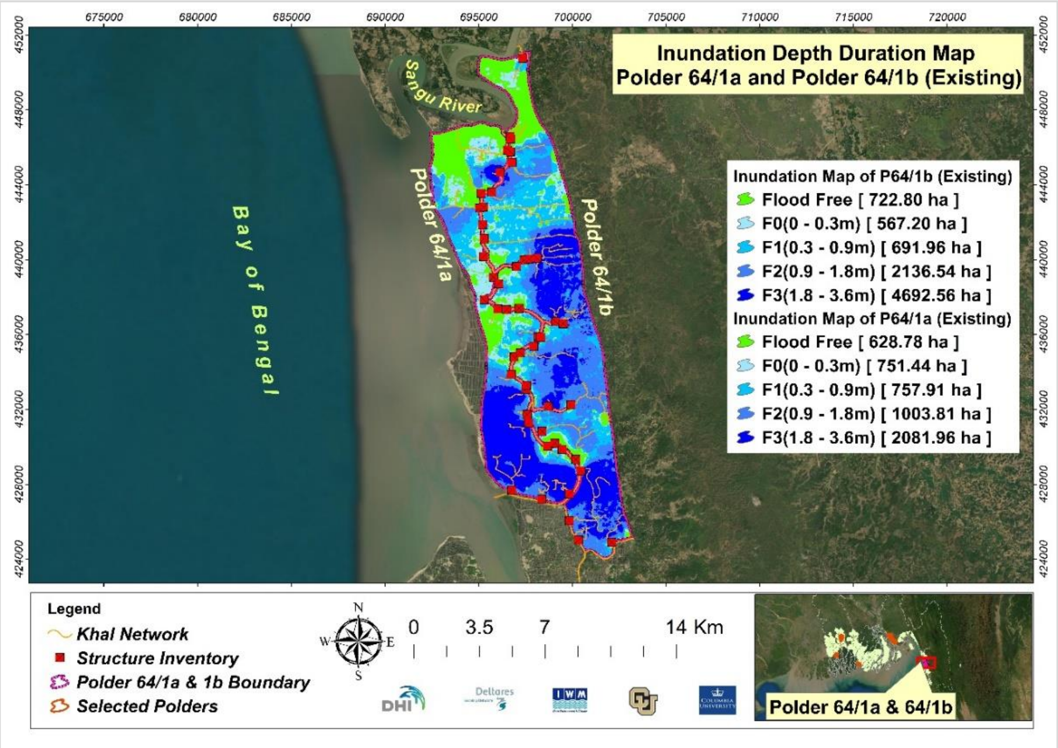


Figure 6.14: Inundation depth map of the Polder 64/1a and 64/1b for existing hydrological flood condition

Table 6.9 presents different land class of the Polder 64/1a and Polder 64/1b individually and jointly at existing condition where 26.42% and 14.64% lands are flood free (FF+F0 land) in the Polder 64/1a and Polder 64/1b respectively. About 19.03% lands are flood free if we consider these polders combinedly. It has been observed that 73.58% lands and 85.36 lands are under deep water (water depth greater than 30cm) in the Polder 64/1and Polder 64/1b accordingly. About 80.97% lands were under deep water in 2015 for 3-days in the Polder 64/1a and Polder 64/1b. The most inundation areas are showing the most northern part (down) of the Polder 64/1a due to less conveyance capacity of the internal drainage khals and inadequate drainage regulators. Similar scenario also observed in the Polder 64/1 at the northern (down) side and middle of the Polder 64/1b. Similar problems like insufficient conveyance capacity of the internal khals and peripheral river/khal and inadequate drainage capacity of the drainage regulators also found in this polder. The problem of the water logging into these polders presented in the Table 6.9.

Table 6.9: Existing inundation condition of the Polder 64/1a and Polder 64/1b

Inundation Area of Polder 64/1a and Polder 64/1b at Existing Condition (Physical and Hydrological) (without climate Change)						
Type	Polder 64/1a		Polder 64/1b		Polder 64/1a & 64/1b	
	Area(ha)	Percentage (%)	Area(ha)	Percentage (%)	Area(ha)	Percentage (%)
FF (<0)	628.78	12.04%	722.8	8.20%	1351.58	9.63%
F0(0.0-0.30m)	751.44	14.38%	567.2	6.44%	1318.64	9.40%
F1(0.3-0.90m)	757.91	14.51%	691.96	7.85%	1449.87	10.33%
F2(0.90-1.80m)	1003.81	19.22%	2136.54	24.25%	3140.35	22.38%
F3(1.80-3.60m)	2081.96	39.85%	4692.56	53.26%	6774.52	48.27%
Total Area	5223.90	100%	8811.06	100%	14034.96	100%

6.5.2 Preparation of Inundation Depth Duration Map for Polder 64/1a and Polder 64/1b at Design Hydrological Flood Event Condition

Future water management of the polder will be prepared based inundation depth duration map considering the hydrological design flood event. Design hydrological flood event has been determined from the historical rainfall information of Satkania. Year 2015 has been selected as the hydrological flood event (1 in 50-year return period) by the statistical analysis. The main purpose of this inundation depth duration map during the design flood event condition into the polder system is required for assessing the drainage performance of the existing drainage regulators, drainage channels/khals and peripheral river system if such flood event repeats again how the water management system operate at this condition. Figure 6.15 presents the inundation situation for 1 in 50-year return period hydrological flood event condition inside the Polder 64/1a and Polder 64/1b jointly.

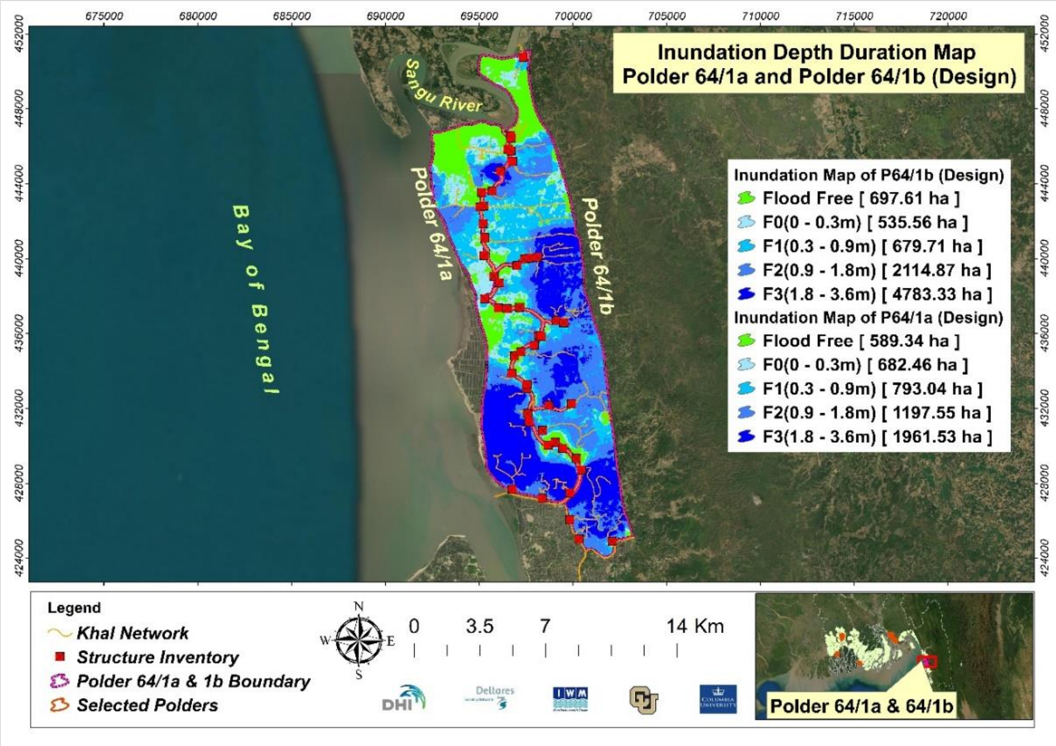


Figure 6.15: Inundation depth map of the Polder 64/1a and Polder 64/1b for 1 in 50-year design hydrological flood event

Simulation of rainfall event of 5-days cumulative rainfall for 1 in 50yr (design hydrological event) return period is carried out for the existing drainage system i.e., without changing the regulators conditions and existing khal condition. Simulation results enable to examine the inundation depth in the polder and land classes. The inundation area and percentage of inundation area for the individual land class of Polder 64/1a and Polder 64/1b during hydrological design flood condition is presented in the Table 6.10.

Table 6.10: Inundation condition of the Polder 64/1a and Polder 64/1b during 1 in 50-year flood event condition

Inundation Area of Polder 64/1a and Polder 64/1b at Design Flood Event Condition (Physical and Design Hydrological Event) (without climate Change)						
	Polder 64/1a		Polder 64/1b		Polder 64/1a & 64/1b	
Type	Area(ha)	Percentage (%)	Area(ha)	Percentage (%)	Area(ha)	Percentage (%)
FF (<0)	589.34	11.28%	697.61	7.92%	1286.95	9.17%
F0(0.0-0.30m)	682.46	13.06%	535.56	6.08%	1218.02	8.68%
F1(0.3-0.90m)	793.04	15.18%	679.71	7.71%	1472.75	10.49%
F2(0.90-1.80m)	1197.55	22.92%	2114.87	24.00%	3312.42	23.60%
F3(1.80-3.60m)	1961.53	37.55%	4783.33	54.29%	6744.86	48.06%
Total Area	5223.92	100%	8811.08	100%	14035	100%

It is observed that, only 17.85% lands are showing flood free (FF+F0) in the Polder 64/1a and Polder 64/1b jointly. About 24.35% lands and 14% lands are showing flood free in the Polder 64/1a and Polder 64/1b respectively. The rest of the area, about 82.15% lands of the Polder 64/1a and Polder 64/1b will be under deep water (water depth greater than 30cm) if such flood repeats again in future. It can be summarized that both of the polders are the most vulnerable to water logging problem and if the design flood events happened again, the existing polder system becomes inactive. Therefore, potential improvements in the polder water management system are required to overcome the design flood event condition. However, potential improvement option should be considered under climate change condition for facing new challenges in future and make the polder robust in all worst scenarios.

6.6 Remaining Work

The remaining works are listed below

- Development of month-wise rainfall and temperature projection for the four hydrological coastal zones (South-West, South Central, South-East and Eastern Hilly coastal zone);
- Fixation of Relative Mean Sea Level Rise (RMSL) at the downstream boundary conditions of the river system;
- Fixation of changes of Upstream Flow at Gorai Railway Bridge considering Ganges River Basin, at Baruria in the Padma River considering the Brahmaputra River Basin and at Bhairab Bazar in the Upper Meghna considering the Meghna River Basin;
- Simulation of Polder drainage model for the selected polders (P15, P29, P40/1, P59/2 and //P64/1& P64/1b) for the design flood event under climate change condition;
- Development of Potential Drainage Improvement Plan for all Polders;
- Simulation of Polder drainage model for the selected polders (P15, P29, P40/1, P59/2 and //P64/1& P64/1b) based on the drainage improved plan for the design flood event under climate change condition for assessing the effectiveness of the improvement plan;
- Preparation of inundation depth duration map based on different improved options and select the suitable one;
- Fixation of design parameters for all drainage regulators, drainage khals and peripheral river system;
- Determination of suitable potential slope protection and bank protection work if required and fixation of design parameters;
- Fixation of the crest level of the selected polders for designing the climate resilient coastal polder embankment height and fixation of deck level of the drainage regulators;

7 Summary

This report contains summary of the survey work which were carried out during the survey campaign as per requirement of the modelling works. Later, baseline hydrological analysis for the selected polders (Polder 15, Polder 29, Polder 40/1, Polder 59/2, Polder 64/1a & Polder 64/1b) based on 35-years rainfall data. The historical rainfall data (35-years) sets also used for determining the design hydrological flood year.

Detailed survey work like cross section of the peripheral river system, cross sections of the internal drainage khals/channels, structure (regulator) information were considered for preparing the polder drainage model (hydrodynamic model) for the selected polders. Year 2019 was considered as present (base) year for simulating the polder drainage model based on the availability of boundary conditions and meteorological data. Polder drainage model also prepared for the design flood event condition for assessing the performance of the existing drainage channels, peripheral rivers geometric condition, existing drainage regulators upstream, downstream condition, openings of the drainage regulators. Existing local effects like construction of cross dams/ blockages into the flow path, lifting of water for irrigation purpose, existing gate operation rules, etc. are not included into the Polder Hydrodynamic model.

Inundation depth duration maps were prepared for both existing and design hydrological flood event conditions. Inundation depth duration maps of the selected polders at the existing condition and design flood event condition showing very poor drainage performance and indicates existing drainage khals and drainage regulators are not able to drain the existing flood as well as design flood. Therefore, all the selected polder needs proper planning and design for combatting the polder community livelihood including the polder water management at the existing and design flood event condition.

There is a huge investment involve in preparing the detail planning and design of the polder water management issue and polder community livelihood. Therefore, future hydrological and hydrodynamic condition of inside polders and outside polders and land motion (vertical), innovation in the regulator operation system including the polder embankment crest levels will be considered during the planning and design of the future polders.

8 References

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f) CEIP-1,IWM (2018), “Technical Report on Storm Surge, Wave, Hydrodynamic Modelling and Design Parameters on Drainage System and Embankment Crest Level, Volume-I: Package-3, March 2018 (Coastal Embankment Improvement Project, Phase–I (CEIP-I), The Government of the People’s Republic of Bangladesh, Ministry of Water Resources, Bangladesh Water Development Board, in association with Royan Haskoning DHV and DevConsultants Ltd.