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Flash Flood Early Warning System for North Eastern Part of Bangladesh

FINAL REPORT

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Flood Forecasting and Warning Centre

Flash Flood Early Warning System for North Eastern Part of Bangladesh

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Acronyms & Abbreviations

ADPC	Asian Disaster Preparedness Center
ASCII	American Standard Code for Information Interchange
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
BUET	Bangladesh University of Engineering and Technology
CDMP-II	Comprehensive Disaster Management Program Phase II
DANIDA	Danish International Aid Agency
DGPS	Differential Global Positioning System
DHI	Danish Hydraulic Institute
FFF	Flash Flood Forecast
FFWC	Flood Forecasting and Warning Centre
FFWS	Flood Forecasting and Warning Services
GBM	Ganges Brahmaputra Meghna
GIS	Geographical Information System
HD	Hydrodynamic
HILIP	Haor Infrastructure and Livelihood Improvement Project
IWM	Institute of Water Modelling (erstwhile SWMC)
IWFM	Institute of Water and Flood Management
LGED	Local Government Engineering Department
MM	Millimeter
MoU	Memorandum of Understanding
MoDMR	Ministry of Disaster Management and Relief
NAM	Rainfall Runoff Model
NE	North-East
NERM	Northeast Region Model
RADAR	Radio Detection and Ranging
RFP	Request for Proposal
RTK-GPS	Real Time Kinematic-Global Positioning System
SQL	Structured Query Language
SMS	Short Message Service
Sq. km.	Square Kilometer
ToR	Terms of Reference
WL	Water Level
WRF	Weather Research and Forecasting Model

Glossary

Catchment Area:

A river's catchment (or basin) is the land area from which rainfall will ultimately contribute to the river discharge. The catchment area of the Ganges, Brahmaputra and Meghna Rivers are 907 X 10^3 km^2, 583 X 10^3 km^2 and 65 X 10^3 km^2, respectively, of which only 8% lies in Bangladesh. More than 90% of the water that flows into the Bay of Bengal enters Bangladesh through its borders with India.

Danger level:

In Bangladesh danger level at a river location is the level above which it is likely that the flood may cause damages to nearby crops and homesteads. In a river having no embankment, danger level is about annual average flood level. In an embanked river, danger level is fixed slightly below design flood level of the embankment. The danger level at a given location needs continuous verification as e.g. embankments may be breached, whereby some danger levels may be not precise.

Floods:

The floods in Bangladesh are divided into monsoon river flood, flash flood, local rainfall flood and storm surge flood. Monsoon river flood is an annual event forced mainly by intensive river inflow through Ganges, Brahmaputra and Meghna Rivers and rainfall over Bangladesh as causes the water level in the rivers to rise and fall slowly during the monsoon season. Flash flood occurs only in the northeastern Bangladesh in the period pre- to post-monsoon forced by intense rainfall in the Meghalaya Hills and in parts of eastern Bangladesh in the post-monsoon. Local rainfall flood is, as the name states, forced by local heavy rainfall over a location inside Bangladesh. Storm surge flood is a coastal phenomenon forced by cyclones hitting the Bangladeshi coastline

Flood Condition:

FFWC disseminates flood warnings during most of the monsoon season. The warning is related to the measured and forecasted water levels and the danger levels: a) Normal condition: water level at any particular location (gauge point) is more than 50 cm below the danger level at that point; b) Warning: water level is below but within the 50 cm of the danger level c) Flood: Water level is above danger level and 100 cm above danger level; and d) Severe Flood: water level is more than 100 cm above danger level. Warnings are disseminated through a daily flood bulletin, e-mail, FFWC home page, IVR, newspapers, radio and television

(Source: http://www.ffwc.gov.bd/index.php/definitions)

EXECUTIVE SUMMARY

E.1 Introduction:

The Northeast Region (NE) of Bangladesh comprises 17.5% of the total area of Bangladesh. There are altogether 373 Haors distributed in the districts of Sylhet, Sunamganj, Moulvibazar, Habiganj, Netrokona, Kishoreganj and Brahmanbaria in this region. The Northeast region experiences flash flood during pre-monsoon and monsoon seasons. Early flash floods during the months of April-May damage the main crop Boro rice nearly or just before the harvesting. About 60% of the total runoff in the region is produced, mostly in the form of flash flood occurring outside Bangladesh, by the three Indian catchments- the Meghalaya River catchments, the Barak River catchment, and the Tripura River catchments. It is evident that only structural measures are not sufficient in long term for managing pre-monsoon flash flood in haor areas. Early Warning of flash flood thus found helpful for both protected and non-protected areas in North East Region. Considering the fact, Bangladesh Water Development Board (BWDB) has signed a MoU with Local Government Engineering Department (LGED) as Partnership institution during June 2015 to conduct a study titled as" Flash Flood Early Warning System (FFEWS)" supported by the 'Climate Adaptation and Livelihood Protection Project (CALIP)', a component of the 'Haor Infrastructure and Livelihood Improvement Project (HILIP)' under LGED, Ministry of LGRD funded by the International Fund for Agricultural Development (IFAD). Later, BWDB engaged IWM as consultant for the study and signed a formal contract with Institute of Water Modelling (IWM) on March 1, 2016.

The Local Government Engineering Department (LGED) has started implementing the Haor Infrastructure and Livelihoods Improvement Project (HILIP) funded jointly by the International Fund for Agriculture Development (IFAD), the Spanish Trust Fund and the Government of Bangladesh (GoB) with plans to cover 28 Haor Upazilas in five districts. The HILIP project has five components: i) Communication infrastructure; ii) Community infrastructure that includes village protection works; iii) Community resource management; iv) Livelihoods protection; and v) Project management. Although HILIP addresses several key environmental and natural resource management concerns of the Haor population, the adverse impact of climate change has not been fully integrated. In this regard, through IFAD's Adaptation for Smallholder Agriculture Programme (ASAP), an additional grant financing was allocated to further deepen adaptation to climate change activities within the HILIP. These new activities have been designed as a project titled the Climate Adaptation and Livelihood Protection (CALIP) project to supplement HILIP. CALIP was built on existing HILIP activities and tested various adaptation technologies and approaches, and scale-up those that prove to be effective. The CALIP project has four components: a) *Component A:* Village Protection and Enhancement; b) *Component B:* Livelihoods Protection and Diversification; c) *Component* C: Building Resilience to Climate Change; and d) Component D: Project management. Under the Component C, one critical activity is 'Capacity building in weather and flash flood warning'. These descriptions of services referred to the development of a low-cost and effective weather and flash flood early warning system (FFEWS) involving 4 national institutions (FFWC, BMD, IWFM and IWM) and various communities in the HILIP project areas that come under component C of CALIP and a new component 6 of combined CALIP/HILIP project was formed.

The overall objective of the CALIP-BWDB part study is to develop a dedicated Early Warning System of Flash Flood in the NE region of Bangladesh for saving Boro rice cultivated both in protected and non-protected areas. The other objectives are

a) Update and establish flash flood forecasting model at FFWC, BWDB
b) Increase number of flash flood forecast stations up to 25 locations;
c) Produce diversified forecast outputs and make operational of the Flash Flood Early Warning System at FFWC of BWDB;
d) Update website of FFWC, BWDB (Flash flood forecasting page) for wide spread dissemination of flash flood forecast;
e) Develop and disseminate the flash flood advisory to the stakeholders (targeted community of the project area)
f) Capacity building of FFWC professionals in flash flood forecasting.

To comply with these objectives of the study, the major tasks that have been carried out are as follows;

- Data collection through survey campaign and monitoring of real-time rainfall and water level gauges
- Update of flash flood forecast model of NE region of Bangladesh
- Increase forecast stations and expand forecast coverage area.
- Produce various flash flood forecast outputs (Hydrograph, Bulletin, Embankment based forecast etc.)
- Develop dedicated flash flood forecast website and mobile apps for dissemination
- Technology transfer through intensive training and on-the-job training
- Submission of milestone reports, arranging field visits and organizing workshops

The study was started on March 2016 and completed in June 2019. This is the final report presenting the findings and output of the study and incorporating compliance of comments made on Draft Final Report. The activities done, observation and achievement under the study are outlined in the following sections.

E.2 Data Collection & Monitoring

To update the existing North-East Region Model using recent cross-sections by replacing most old sections of some selected rivers of North East region, a cross-section survey campaign has been carried out for two consecutive years during 2016 and 2017 for updating the existing flash flood forecast model. The river cross-section survey has been done utilizing state of the art-technology for survey equipment. Condition checking and Bench Mark survey for the selected 25 nos. stations has been carried out under this study to check whether any datum correction or repair works is required or not for that gauge station.

Table E-1-1: List of surveyed cross-sections

Serial No	River Name	Length of River surveyed	No of Cross-sections Surveyed	Remarks
1	SUTANG	55 km	29	Cross-section survey carried out in 2017
2	KULIACHARA	23 km	5	
3	KARANGI	22 km	7	
4	SARIGOWAIN	33 km	22	
5	JAFFLONG	9 km	5	
6	ACTIVE CHELA	11 km	5	
7	NAWAGANG	12 km	8	
8	SURMA	50 km	18	
9	SOMESWARI	28 km	-	
10	NITAI	22 km	13	
11	SARIGOWAIN	27 km	9	Cross-section survey carried out in 2016
12	BAULAI	42 km	14	
13	LOWER-CHAMTI	39 km	13	
14	MOGRA	42 km	14	
15	OLDKUSHIYARA	36 km	12	
16	PHINGLI_NADI	42 km	14	
17	PIYAN_RIVER	54 km	18	
18	SAIDULBARUNI	51 km	17	
19	SEKRA	18 km	6	
Total		616 km @ 3-4 km interval	229	

Two Radar Sensor based water level auto-gauges have been installed at Gowainghat on Sarigowain river during April 2017 and at Lourergorh on Jadukata river during December 2017 to collect real-time water level data and to supplement automatic real-time data collection system of FFWC. Both the gauges have been made operational since its installation. To update the rating equations of the border locations, discharge measurement campaign has been carried out during 2016 and 2018 and discharge data were applied to validate the rating equations for Bijoypur and Lourergorh. However, due to limited budget provision, not all rating curves have been updated with observed discharge data. To enhance the rainfall-runoff model through rainfall distribution within the North-East Region particularly at the border locations, additional 12 nos. rainfall stations maintained by Hydrology, BWDB have been identified and incorporated in the real-time data collection system of FFWC under this project. A total 17 number of water Level monitoring stations have been made real-time and incorporated into the Forecast System under this study. These stations are now providing real-time water level data to FFWC through mobile SMS technology.

E.3 Forecast Stations and Area Coverage

A total 17 number of new water level forecast stations have been incorporated into the Forecast System under this project. Thus, including past 8 nos. forecast stations (Amalshid, Sheola, Sherpur, Kanairghat, Sylhet, Sunamganj, Lourergorh, Jariajanjail) initiated in the

MoDMR study period, the total no. of Flash Flood Forecast stations has been increased up to 25 nos. Figure E.1 shows the flash flood forecast stations in the NE region of Bangladesh.

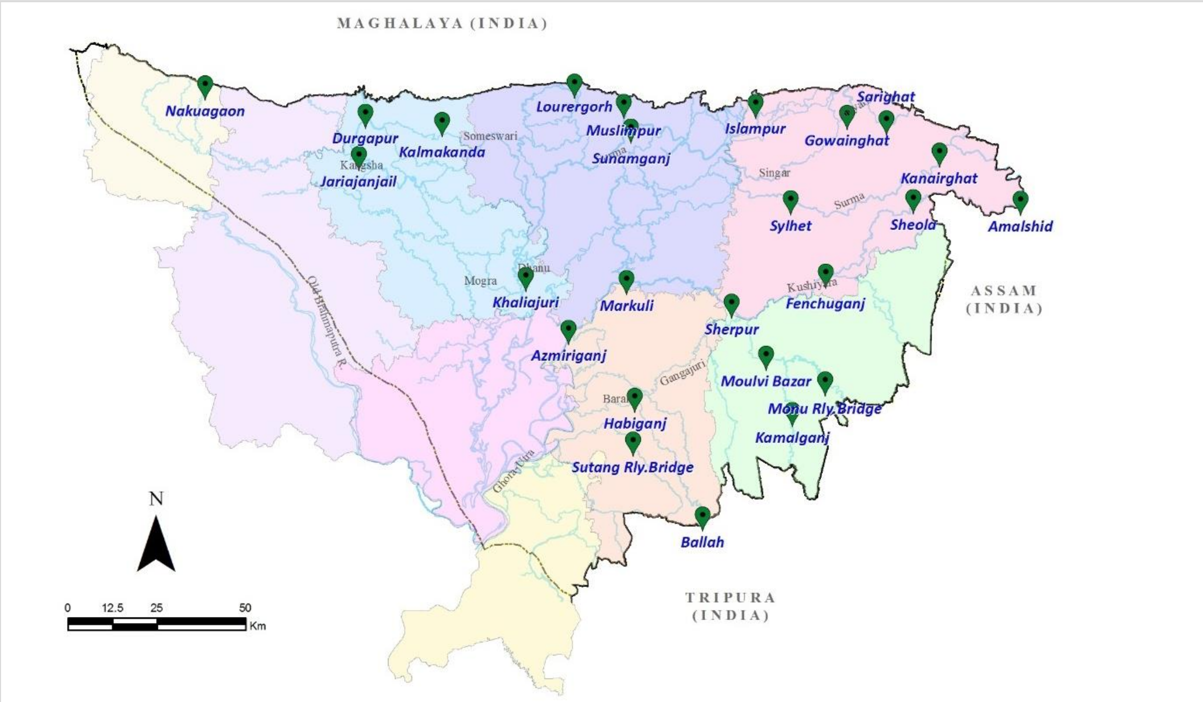


Figure E-1: Flash flood forecast stations

E.4 Flash Flood Forecast Model

The Flash Flood Forecast Model developed in the CDMP-II of MoDMR study has been utilized in this project with necessary updating, adjustment and expansion. Three separate modules of one-dimensional mathematical modelling tools developed by DHI Water and Environment, Denmark have been utilized in carrying out this study. The modules are Rainfall-Runoff (MIKE11 NAM) Model for hydrological modelling, One-dimensional River Model (MIKE 11 HD) for hydraulic modelling of North-East Region, Bangladesh and Barak Basin, India coupled with flood forecast module (MIKE 11 FF) for flood forecasting. The Rainfall-Runoff model coupled with Hydrodynamic model for North-East Region operated with flood forecast module is combinedly called as "Flash Flood Forecast Model". Flash flood in the Northeast Bangladesh occurs from the inflow coming from the cross-border catchments. The hydrological component (NAM) of the FFF model comprises 39 sub catchments inside Bangladesh and 18 cross-border sub catchments within India except the Barak river basin. The Barak Basin itself comprises of 8 catchments and combined runoff enters Bangladesh border near at Amalshid through hydrological routing. Total 71 nos. station rainfall data collected from FFWC, BWDB and Indian Meteorological Department (IMD) websites are utilized for this rainfall-runoff model with necessary weightage distribution applying Thiessen-Polygon method. Parameters of hydrological model (NAM) have been calibrated extensively during 1999-2000 and updated during 2016 to 2018 under this project. The hydrodynamic model has been updated through incorporating surveyed cross-sections, updated link channels and updated boundary discharges. Barak HD model comprises the entire watershed of the Barak River up to bifurcation of the river at Amalshid of Zakiganj, Sylhet. Ground measured daily rainfall data at 20 stations of last 4 years (2016-2019) collected from public domain (websites) from IMD have been used for calibration of the Barak HD model. However, the Flash Flood Forecast model has been calibrated for 2017 flash flood event and validated for 2016 and 2018. After nearly satisfactory calibration and validation, this flash flood forecast model has been made operational to forecast 2019 flash flood event. The model validation shows good agreement in most cases (19 stations namely Amalshid, Azmiriganj, Ballah, Fenchuganj, Kalmakanda, Kanaighat, Khaliajuri, Lourergorh, Manu RB, Markuli, Sarighat, Sherpur, Sunamganj, Sylhet, Moulvibazar, Sheola, Islampur, Jariajanjail and Gowainghat), satisfactory agreement in some cases (Habiganj, Muslimpur and Sutang) while in some cases (Nakuagaon, Durgapur and Kamalganj) the validation founds as poor.

E.5 Flash flood forecast outputs

The forecasting model and operational forecast system for the flash flood prone North-East Region has been developed in this project for FFWC. The major outputs of this forecasting system are station wise forecast hydrograph, observed bulletin, forecast bulletin and summary bulletin (Bangla and English version) produced on daily basis. Also, Quantitative Precipitation Forecast (QPF) and Embankment based forecast are significant outputs in this study. To ease this forecast product generation, an automatic forecasting system has been developed under this project as shown in figure E-2.

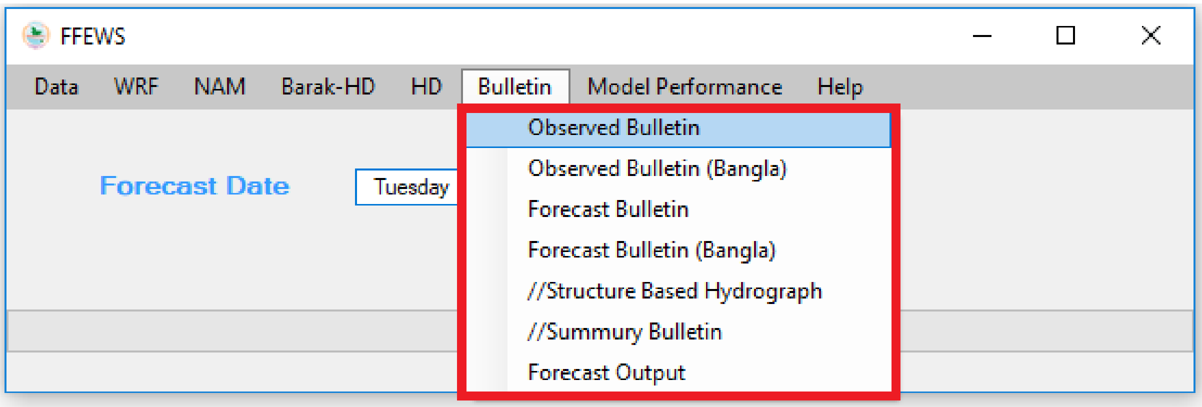


Figure E-2: Automatic forecasting system

All the forecast products can be successfully uploaded and disseminated through a dedicated website developed under this study and hosted in FFWC main webpage as link. One can access the webpage and can explore by visiting the following address link as (www.ffwc.gov.bd) then to http://geo.iwmbd.com:2000/flashflood/ .To enhance the dissemination of forecast products to the end users, a mobile apps has been developed under this study. The application is open for publicly use. No authentication is required to use this application. One can download the application using Android device from the following link as provided.

http://geo.iwmbd.com:2000/flashflood/mobile_apps.php. The mobile apps contain a home tab, application menu, general tab and feedback tab.

E.6 Pre-monsoon Danger Level

In Bangladesh, danger level at a river location is the level above which it is likely that the flood may cause damages to nearby crops and homesteads. In pre-monsoon time, flash flood often hits the North-East Region and causes severe damage although in most cases, water level doesn't even touch the danger level or close to it. To represent the severity of flash flood relative to realistic danger level, pre-monsoon danger level for the selected flash flood forecast stations in North East Region has been proposed and applied under this project. Comparing with existing FFWC danger level and embankment height of adjacent haors, new levels has been proposed as pre-monsoon danger level for the said stations by statistical analysis. These pre-monsoon danger levels will only applicable up to May 15 and then usual danger levels will be followed.

ক্রঃ নং	স্টেশন	নদীর নাম	বর্তমানের monsoon বিপদসীমা (mPWD)	প্রস্তাবিত pre-monsoon (mPWD)
১	Ajmiriganj	Kalni	5.49	5.00
২	Amalshid	Kushiyara	15.85	13.50
৩	Ballah	Khowai	[illegible]	21.80
৪	Kamalganj	Dhalai	19.82	19.50
৫	Durgapur	Someswari	13.00	11.25
৬	Fenchuganj	Kushiyara	9.91	8.20
৭	Gowainghat	Sarigowain	11.28	9.10
৮	Habiganj	Khowai	9.50	9.10
৯	Islampur	Dhalagang	-	10.70
১০	Jariajanjail	Kangsha	11.00	6.80
১১	Kalmakanda	Someswari	7.00	5.35
১২	Kanairghat	Surma	13.20	11.35
১৩	Khaliajuri	Baulai	8.50	4.60
১৪	Lourergorh	Jadukata	8.53	6.40
১৫	Manu RB	Manu	18.00	16.90
১৬	Markuli	Kalni	8.50	6.40
১৭	Moulvibazar	Manu	11.75	10.00
১৮	Muslimpur	Jhalukhali	-	6.90
১৯	Nakuagaon	Bhugai	22.40	21.25
২০	Sarighat	Sarigowain	12.80	11.15
২১	Sheola	Kushiyara	13.50	11.15
২২	Sherpur	Kushiyara	9.00	8.25
২৩	Sunamganj	Surma	8.25	6.50
২৪	Sutang RB	Sutang	5.79	5.40
২৫	Sylhet	Surma	11.25	8.75

Figure E-3: list of pre-monsoon danger level for NE region

E.7 Automation of Operational Forecast

Flash Flood occurs within 6 to 12 hours of any rainfall event. Hence fast data collection and processing is very important for operational flash flood forecasting system. To receive and to process rainfall data from Indian part and Bangladesh part, to simulate the weather forecast model and hydrological, hydrodynamic and forecast module and to process the model outputs in a quick and efficient manner, a software tool has been developed under this study. The automatic forecast system is comprised with four modules; a) Data Processing Module, b) Weather Model Data Processing Module, c) MIKE Packages and d) Post-Processing Modules.

E.8 Training and Technology Transfer

Several on-the job trainings to the FFWC professionals have been carried out throughout the project tenure. Also, one week-long intensive training has been arranged at FFWC two times within this time. Gauge readers training, training on WRF model and developed Flash Flood Forecast Model have been discussed in these training programs. The fully operational flash flood forecast system has also been successfully handed over to FFWC and demonstrated them on the developed system. A user manual is also have been provided.

E.9 Reports, Workshops and Field Visits

Several milestone reports have been submitted throughout the study. Starting with Inception report, 3 nos. Annual Progress Reports, around 12 nos. Quarterly Progress Reports and one Draft Final Report have been submitted so far. This is the Final report submitted after incorporating compliances of the comments received on DFR. Four nos. Stakeholder consultation workshops have been arranged at Netrokona, Habiganj, Sunamganj and B.Baria. Another workshop was scheduled to be held at Kishoreganj but postponed later due to National Election Program. Several field visits have been made in the study area to understand the project requirement, check the gauge conditions and verify pre-monsoon danger levels and for installing two nos. automatic water level measurement gauges.

E.10 Conclusions and Recommendations

This study comprised some activities which was difficult to complete within the budget and available resources. Despite difficulty, the study team tried and successfully provided the following required outputs:

1. Flash flood forecast with lead time of 3 days which is operational at FFWC
2. A tool for generating forecast products including capturing Indian rainfall data and make available for model simulation
3. Haor Embankment based forecast which creates opportunities for local level flash flood management.
4. Incorporation of BMD generated forecast in the hydrological model forecast of FFWC
5. Pre-monsoon danger levels for NE region

The following recommendations have been made for better performance of the developed flash flood forecasting system:

1. Short duration rainfall data of higher frequency should be made available to simulate flash flood event during pre-monsoon.
2. Probabilistic flood forecast techniques should be adopted in future for relatively accurate forecast product as supplement to deterministic forecast product.
3. Installation of automatic discharge measurement system at the entry point of border rivers in the NE Region should be initiated
4. Regular updating of hydrological and hydrodynamic models is necessary
5. Flood forecast is the mandate of BWDB; thus, in any future flood forecasting activities BWDB should lead the project.
6. Increased man power and capacity building process of FFWC should be taken good care of.

1. INTRODUCTION

1.1 Background

The Northeast Region (NE) of Bangladesh comprises an area of about 24,200 km^2 which is 17.5% of the total area of Bangladesh. The region has special natural features called the Haors where abundant natural resources can be extracted for best productive use if planned efficiently. Due to its enormous resource potential, substantial numbers of water management projects have been implemented by Bangladesh Water Development Board (BWDB) in the region, Haor area in particular. Haors are large bowl-shaped flood plain depressions covering about 25% of the entire NE region. There are altogether 373 Haors distributed in the districts of Sylhet, Sunamganj, Moulvibazar, Habiganj, Netrokona, Kishoreganj and Brahmanbaria. The haors comprise an area of about 8590 sq. km out of which about 4000 sq. km are deeply flooded characteristics.

The Northeast region experiences some of the most severe hydrological conditions of the country. The annual rainfall ranges from 2,200 mm along the western boundary to 5,800 mm in its northeast corner and as high as 12,000 mm in a few of the catchments in Meghalaya of India. The Haor areas are frequently affected by the flash flood, generated in the steep upland catchments adjacent to the region in India. These flash floods spill onto low-lying flood plain lands in the region, inundating crops, damaging infrastructure by erosion and channel shifting and often causing loss of lives and properties. Channel shifts and avulsions during flash floods often result in substantial quantity of coarse sand being deposited on agricultural land or in drainage channels. In recent days, the navigability of the regional rivers has reduced drastically due to sedimentation.

Flash flood usually occurs during pre-monsoon and monsoon seasons. The flood destroys agricultural products of large land areas, causing death, damage to property, environmental pollution and destruction to roads and bridges. Early flash floods during the months of April-May damage the main crop Boro rice nearly or just before the harvesting. About 60% of the total runoff in the region is produced, mostly in the form of flash flood occurring outside Bangladesh, by the three Indian catchments- the Meghalaya River catchments, the Barak River catchment, and the Tripura River catchments. The early flash flood of April 2004 caused a colossal damage to live, crops and properties of the Haor project areas. In 2016, due to excess rainfall in the catchments of Meghalaya and Barak at the end of April, flash flood affected the Boro crop in some areas of Sunamganj and Netrokona. Submergible embankments in few haors (Shanir haor, Chandrasona Thal Haor and Baram haor) were also overtopped/breached. In 2017, heavy rains in late March and early April triggered severe flash floods over northeastern parts of the country, affecting approximately 850 000 households and causing severe damage to food crops, housing and infrastructure, including bridges and roads. The most affected districts were Sylhet, Moulvibazar, Sunamganj, Habiganj, Netrokona and Kishoregani. According to official estimates, the floods in April caused severe damage to nearly 220 000 hectares of crops, mostly to the ready-to-be harvested “boro” paddy crop in low-lying areas. From the bitter experience of recurrent damages, some protection and managing activities have already been carried out in the region which mainly includes rehabilitation of submersible embankments. There is also continuing effort to establish a satisfactory flash flood forecasting mechanism in the region.

There are all together around 118 water management projects: Flood Control and Drainage projects 60 nos., Flood Control Drainage and Irrigation projects 46 nos., Flood Control projects 10 nos., Drainage project 1 no., and irrigation project 1 no. in the NE region. Flood control projects are harnessed with either full flood control or submersible embankments. Most of these projects are administered by BWDB. Submersible embankments usually go under water in the monsoon and thus, they are recurrently damaged during overtopping as well as manual cut for the passage of boats which involves a significant maintenance cost each year. Sometimes damaged embankments reach is not properly repaired due to financial and time constraint. Moreover, major drainage channels in the Haor areas are getting sedimentation which in turn basically is demanding increased height of embankments. Therefore, it is evident that only structural measures are not sufficient in long term for managing pre-monsoon flash flood in haor areas. Early Warning of flash flood could be very helpful for both protected and non-protected areas. From early warning, the government agencies as well as stakeholders may identify the areas of embankments to be vulnerable to the imminent flood before one to several days earlier for taking quick and specific actions for protection. Early warning system can also lead to the farmers of planting boro rice in non-protected areas by providing warning of flood before 1 to 3 days earlier to harvest partially or fully matured crops before getting complete inundation.

Together with Flood Forecasting and Warning Centre (FFWC) of BWDB, Institute of Water Modelling (IWM) carried out research programs since more than past ten years. The institute conducted a pilot study for two cross border catchments of the region to simulate flash flood in 2008. In 2009 IWM carried out another research study together with Asian Disaster Preparedness Centre (ADPC), and FFWC of BWDB for simulating flash flood at three selected catchments. Later on, a webpage along with a database of NE region "Haor Information System" was developed under a DANIDA financed project carried out by IWM (2010-2011). Recently IWM developed a Flash Flood Forecasting Model of the NE region together with FFWC under the finance of Ministry of Disaster Management and Relief (MoDMR) through CDMP II. Under the CDMP study, experimental flash flood forecast has been generated (April-May 2013 & 2014) at 11 selected locations in the region which is being disseminated by FFWC through their website.

Flood Forecasting and Warning Services (FFWS) in Bangladesh is the mandate of Bangladesh Water Development Board (BWDB) under Ministry of Water Resources. Flood Forecasting and Warning Center (FFWC) of BWDB is carrying out this responsibility on behalf of BWDB. The objectives of FFWS are to enable and persuade people, community and organizations to be prepared for the flood and take action for safety and reduce damage. Its goal is to alert the combat agencies to enhance preparedness and motivate communities to undertake protective measures. Significant improvement has been made in the area of river based monsoon flood forecast in Bangladesh up to 5-days deterministic forecast and 10-days lead time probabilistic forecast. But in the area of flash flood especially for the North-East area, research and development is needed. During Pre-monsoon period (March April and May) sudden on-rush of huge water often caused flash flood in the North-East region of Bangladesh, damages the standing Boro crop. There is public demand for the pre-monsoon flash flood forecasting system in the North-East region of Bangladesh. Thus, it is required to extend the flash flood forecasting in more area of northeast region

In this regard, Bangladesh Water Development Board (BWDB) has signed a MoU with Local Government Engineering Department (LGED) as Partnership institution to conduct a study titled as" Flash Flood Early Warning System for North Eastern Part of Bangladesh" and intends to engage Institute of Water Modelling (IWM) for this study. And, accordingly, BWDB has requested Institute of Water Modelling (IWM) for submitting a proposal to carry out the study. Based on the proposal, BWDB has signed a formal contract with Institute of Water Modelling (IWM) on March 1, 2016. This is the Final Report submitted after incorporating compliances of the comments received on DFR and describes the project target and achievements as per Terms of Reference (ToR) of the study.

1.2 Objectives

The prime objective of the project is to develop a dedicated Early Warning System of Flash Flood in the NE region of Bangladesh for saving Boro rice cultivated both in protected and non-protected areas. The specific objectives are:

a) Update and establish flash flood forecasting model at FFWC, BWDB;
b) Increase number of flash flood forecast stations up to 25 locations;
c) Enhance/develop the ICT infrastructure of FFWC;
d) Produce diversified forecast outputs and make operational of the Flash Flood Early Warning System at FFWC of BWDB;
e) Update website of FFWC, BWDB (Flash flood forecasting page) for wide spread dissemination of flash flood forecast;
f) Develop and disseminate the flash flood advisory to the stakeholders (targeted community of the project area);
g) Capacity building of FFWC professionals in flash flood forecasting.

1.3 Scope of Works

The scopes of work for the aforesaid assignment are as follows:

a) Review of base line settings of NE region comprising climate and hydrology, topography, population, agriculture, infrastructure, administration settings, flood and inundation characteristics, etc.

b) Review of existing flash flood management activities, hydro-meteorological data collection system, water management practices and potential for availability of real time data in the cross-border areas of the NE region;
c) Conduct field data campaign for measuring cross border inflow and measure real time water level as supplement to available data;
d) Conduct field survey for cross sections of rivers and other necessary topographic information;
e) Application of RADAR estimated rainfall data provided by BMD in the forecast model, and evaluation of performance if available;
f) Updating of stage-discharge relations at significant cross border inflow points for efficient estimation of cross-border inflows added in the NE region from India;
g) Updating of Forecast model developed under CDMP-II of MoDMR using updated stage-discharge relations, rainfall forecast of BMD, latest available field data and information;
h) Generate flash flood forecast at 25 stations instead of 8 stations established under CDMP-II of MoDMR;
i) Updating the database of the existing Haor Information System incorporating latest hydro-meteorological data, topographic data, infrastructure data, and all available data and information of baseline settings in the NE region;
j) Evaluation of forecast performance for three consecutive years, and make recommendations for further scope of increase performance and expansion of area under forecast;
k) Provide training to FFWC for capacity building on updated Flash Flood Forecasting system;
l) Operation of the developed system as experimental, updating based on feedback from the stakeholders and decision makers;
m) Provide support to make operational of the Early Warning System of Flash Flood Forecast at FFWC of BWDB.
n) Develop Flash Flood advisory in consultation with the project stakeholders and disseminate to the targeted community at the project area.

1.4 Study Outputs

Outputs of the study are:

a) Two sets of Flash flood model for generating 48-hours lead time flash flood for the North-East region of Bangladesh will be developed, one by the IWM under this study and another by the IWFM-BUET independently and make them operational at FFWC, BWDB;
b) Evaluation of the two sets of Flash Flood Model will be done on regular basis jointly by all the stakeholders (LGED, IWFM, IWM and FFWC). Based on the evaluation, the development and improvement activities will be taken by the IWFM and IWM;

c) Increased number of flash flood forecast stations/points in Northeast Region to develop Flash Flood Forecasting system up to 2days lead-time with more accuracy, in more points with improved resolution and enhance disseminations up to the community level. In addition, IWM will try to increase the lead time 3 to 5 days on experimental basis and evaluate its performance.
d) Flash flood forecast with maximum lead time following 1.4.c along some selected submersible embankments of NE region;
e) Flash flood forecast with maximum lead time following 1.4.c along some selected national important infrastructure and submersible embankments of North East region;
f) FFWC website updated with detail flash flood forecast outputs;
g) FFWC, BWDB professional trained in advance aspect of flash flood forecasting.

1.5 Structure of the Report

This is the Final Report which is comprised of 7 chapters including reference chapter.

Chapter 1 describes the project background

Chapter 2 describes the data collection and processing

Chapter 3 describes model development for flash flood

Chapter 4 describes flash flood forecast outputs

Chapter 5 describes training and technology transfer, workshops and field visits

Chapter 6 concludes and recommends for further improvement

Chapter 7 reference

This report also provides five appendices. The appendices are as follows;

Appendix-A: ToR, Technical Committee Meeting Minutes and Notices

Appendix-B: Forecast Performance Evaluation

Appendix-C: Maps & Miscellaneous

Appendix-D: Comments and Compliances on Draft Final Report

Appendix-E: Compilation of Comments and compliances of previous reports

2. DATA COLLECTION AND ANALYSIS

2.1 General

The significant activities carried out under this study comprises data collection, engineering survey and mathematical modeling. Several types of data that were necessitated to carry out the study includes hydro-meteorological data, topographic data, Infrastructure information, Weather forecast data and GIS layers/maps have been collected both from primary sources through field survey as well as from secondary sources. Secondary data have been collected mostly from Processing and Flood Forecasting Circle, BWDB, database of IWM and public domain through websites. Primary data have been collected through field data campaign carried out by IWM. Under this study, a data collection program has been conducted including rainfall measurement data from tea estates, water level measurement data using auto-gauge sensor and cross-sections data and discharge measurement data through survey campaigns.

2.2 Primary Data Collection

A field data campaign was carried out by survey team of IWM for collection of primary data. The field data collected under the study included the followings: a) Cross-sections survey of significant rivers, b) River stage (water level) by auto-gauges and c) River flow (discharge) at selected locations of North East Region. Also gauge monitoring and verification of gauge zero values of selected forecast stations prior to forecast dissemination have been made in the first year. The subsequent sections describe the primary data collection activities carried out throughout the study tenure.

2.2.1 Water Level Data from Auto-gauges

Bangladesh Water Development Board through its hydrology division maintains nearly 343 surface water level stations, 102 surface water discharge stations, 269 rainfall measurement stations including 40 evaporation stations and most of them are manually operated as of now. On the other hand, Flood Forecasting and Warning Center (FFWC) of BWDB maintains 94 nos. water level and 59 nos. rainfall stations as real-time stations during monsoon time. During pre-monsoon time before this study, FFWC could collect data only from 17 nos. rainfall stations and 20 nos. water level stations of the whole northeast region as real-time data. However, during 2014-16, Hydrology, BWDB has started maintaining 9 nos. auto-gauges for real-time water level data collection in the North-East Region under two BWDB projects i.e. WMIP project and HKH-HYCOS project based on Radar Level sensor technology.

Radar level sensor is a non-contact sensor with pulse radar technology. RLS based auto-gauges are best way to collect real-time water level data from field during pre-monsoon and monsoon period. To supplement this automatic real-time data collection of BWDB at locations where BWDB didn't install any auto-gauges but specifically important for capturing flash flood, two nos. gauges have been setup. These auto-gauges have been installed at Gowainghat, Sylhet in the first year and at Lourergorh, Sunamganj in the second year under this project. Necessary site selection visit, seeking permission for frame construction for hanging the auto-gauge, anchoring the solar panel, cutting channel to drag water beneath the radar sensor and instill the data logger and telemetry system into safe location have been done. Figure 2-1 shows the auto-gauges installation at Gowainghat and Lourergorh respectively while figure 2-3 shows the locations in the map.

Figure 2-1: Auto-gauges installed at Gowainghat and Lourergorh under this project

FFWC can collect real-time data from these auto-gauges by browsing the path as defined in the website. Figure 2-2 and 2-4 shows real-time water level data at Gowainghat and Lourergorh auto-gauge respectively. A regular maintenance is being carried out to protect the installation from future malfunctioning and theft.

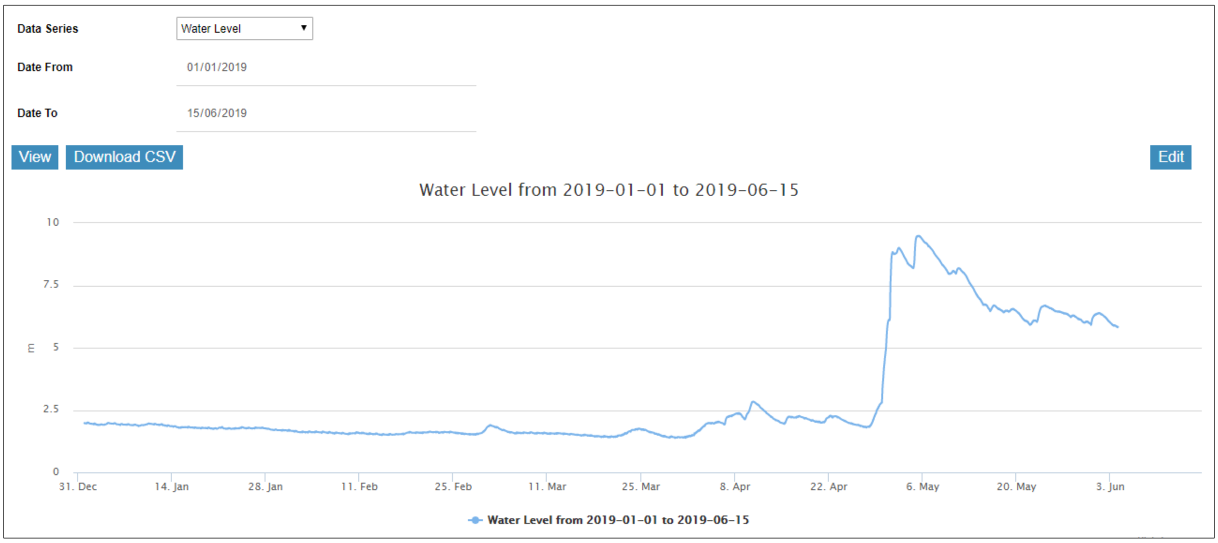


Figure 2-2: Real-time water level at Gowainghat Auto gauge (2019)

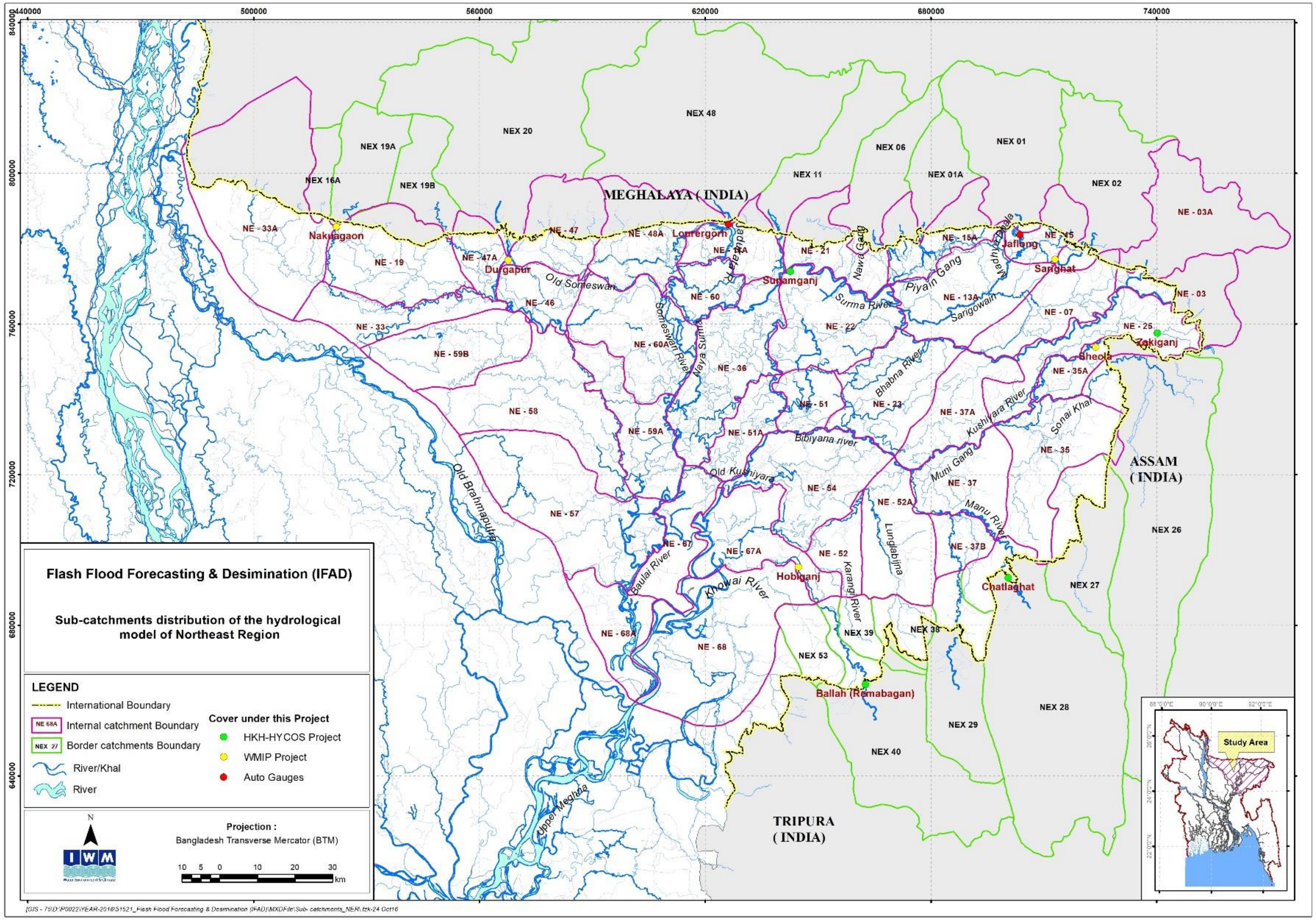


Figure 2-3: Map shows auto-gauge locations installed under this project

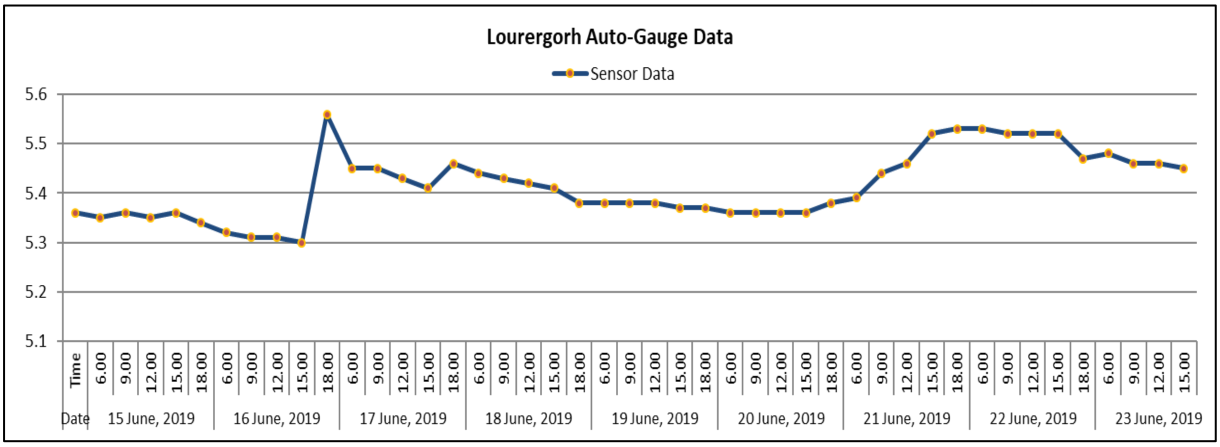
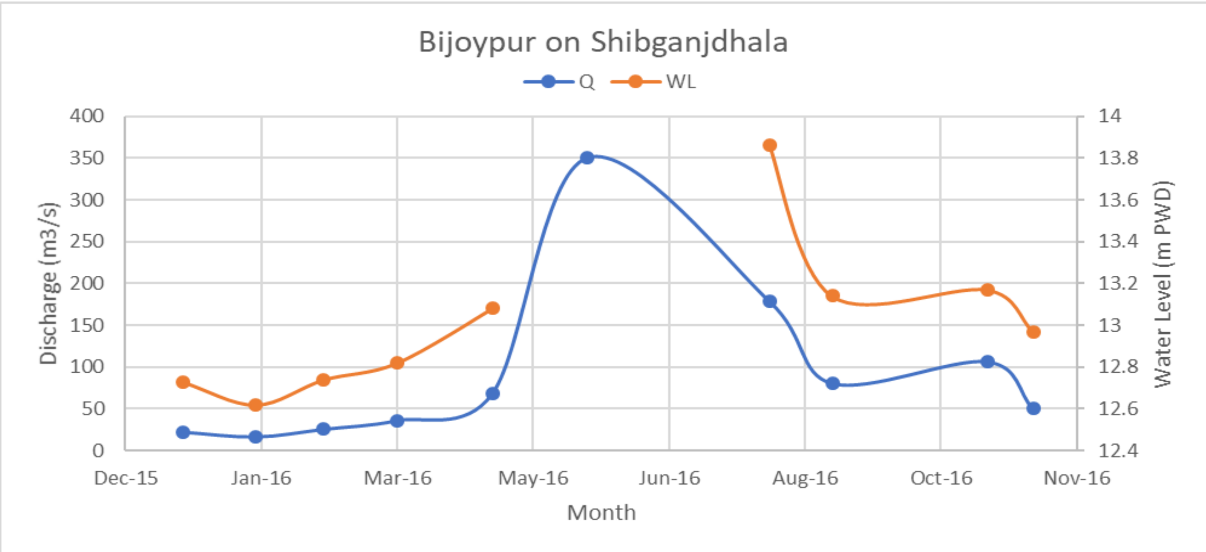


Figure 2-4: Real-time Water level at Lourergorh Auto-gauge (2019)

2.2.2 Discharge Measurements for Rating Curves

Inflows into the system added from outside of the model area, outflows leaving the system, and catchment runoffs resulting from local precipitation are introduced as boundaries in the hydrodynamic model. There are 21 inflow boundaries that carry flows generated within Indian Territory. Rating relations (stage-discharge relations) at 14 inflow boundaries are available at North East Region. To update these rating relations, discharge measurements have been made on significant locations over North East Region. Discharge measurement through IWM survey team has been done to supplement the discharge measurement done by BWDB. Figure 2-5 shows measured discharge data with corresponding water level at Bijoypur and Nakuagaon station on Shibganjdhala and Bhugai river respectively during 2016. Rating equations have been verified by measured discharge data of both BWDB and IWM. Figure 2-6 shows comparison of the rated discharge with the observed data.



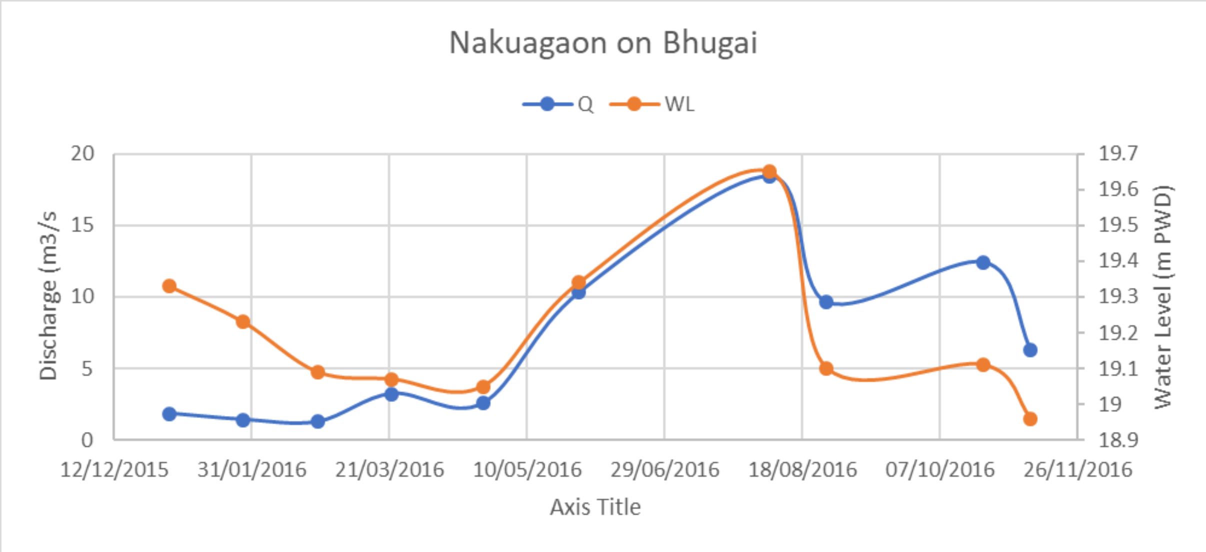


Figure 2-5: Discharge Measurement for updating Rating Equations

During 2016 in the Flash Flood Forecast model setup, only 4 rating equations were used due to availability of real-time water level data and importance of the discharge boundary at Amalshid, Manu RB, Durgapur and Sarighat. Generated time series discharges data have been incorporated in the model as inflows using measured real-time water level data at these stations. Later under this study, real-time water level stations have been increased and incorporated in the SMS based data collection system. Presently at 12 nos. inflow boundaries, real-time rated discharge data has been used based on real-time water level data at additional 8 locations. The list of rating curves is provided in table 2-1.

Table 2-1: List of Rating Equations for Inflow Boundaries during 2019

Parameters of Rating Curves: $Q = a\,(H - H_o)^{n}$

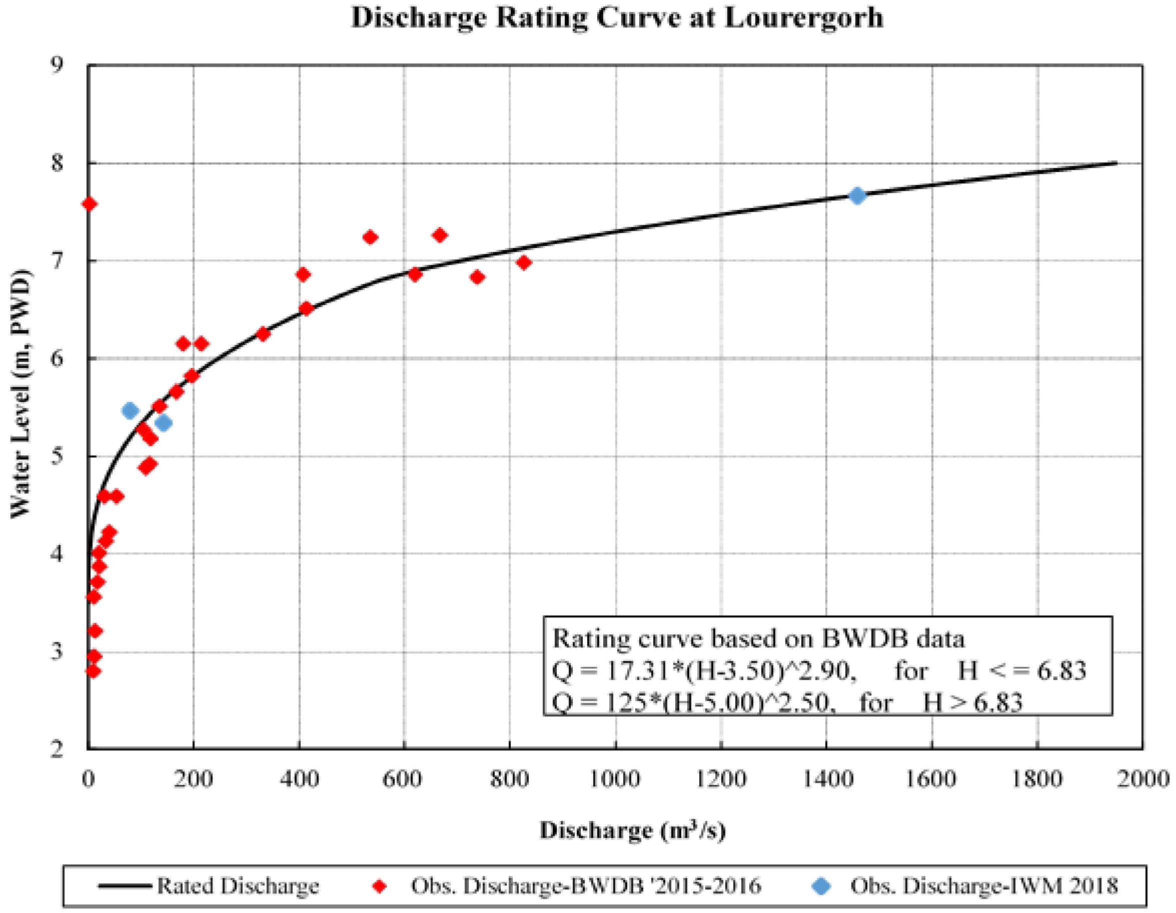
Station Name	River Name	a	n	H_o
1. Amalshid	Kushiyara	2.43	2.53	2.20, h < = 14.75
		4.55	2.81	6.95, h > 14.75
	Surma	3.39	2.55	5.96
2. Bijoypur	Shibganjdhala	22.45	2.91	12.14
3. Durgapur	Shibganjdhala	123.67	2.24	10.25
4. Islampur	Dhalagang	11.87	2.93	7.80
5. Jafflong	Jafflong	9.92	2.69	7.06
6. Kamalganj	Dhalai	8.25	2.17	15.92

Station Name	River Name	a	n	H_o
7. Lourergorh	Jadukata	17.31 125	2.90 2.50	3.50, h <= 6.83 5.00, h >6.83
8. Lubhachara TG	Lubhachara	0.49	2.87	3.53
9. Manu Railway Bridge	Manu	10.0	2.25	11.80
10. Muslimpur	Jhalukhali	10.75 41.53	1.50 1.50	2.70, h < 6.65 5.04, h >= 6.65
11. Nakuagaon	Bhugai	25.57	1.98	19.58
12. Sarighat	Sarigowain	2.42	2.64	3.92

The applicability of rating curves has been assessed based on discharge data collected by BWDB and IWM during pre-monsoon of 2016-19 and found that rating curve is somehow suitable for pre-monsoon flood with necessary adjustment. Table 2-2 provides a recent discharge measurement done by IWM in the North-East Region during 2018 Pre-monsoon and early monsoon.

Table 2-2: Discharge measurement by IWM

Serial No.	Station Name	River Name	Date of Observation	Position in UTM		Average Velocity	Observed Discharge (m^3/s)
				Easting	Northing	(m/s)	
1	Lourergor	Jadukata	24/05/2018	323965	2787330	0.15	140.29
			11/06/2018	323965	2787330	0.20	82.61
			03/07/2018	323766	2787326	1.11	1459.23
2	Gowainghat	Sari-Gowain	23/05/2018	398069	2775627	0.20	114.48
			12/06/2018	397979	2775687	0.18	114.78
			04/07/2018	397989	2775709	1.10	1553.84
3	Kanaighat	Surma	24/04/2018	425640	2765663	0.69	228.17
			15/05/2018	425581	2765730	0.92	863.69
			10/06/2018	425568	2765656	0.87	592.93
			02/07/2018	425600	2765565	1.12	1592.69
4	Sheola	Kushiyara	24/04/2018	418283	2753007	0.43	469.38
			15/05/2018	418280	2753120	0.60	1071.77
			10/06/2018	418285	2753044	0.59	949.10
			02/07/2018	418278	2753124	0.74	1549.64



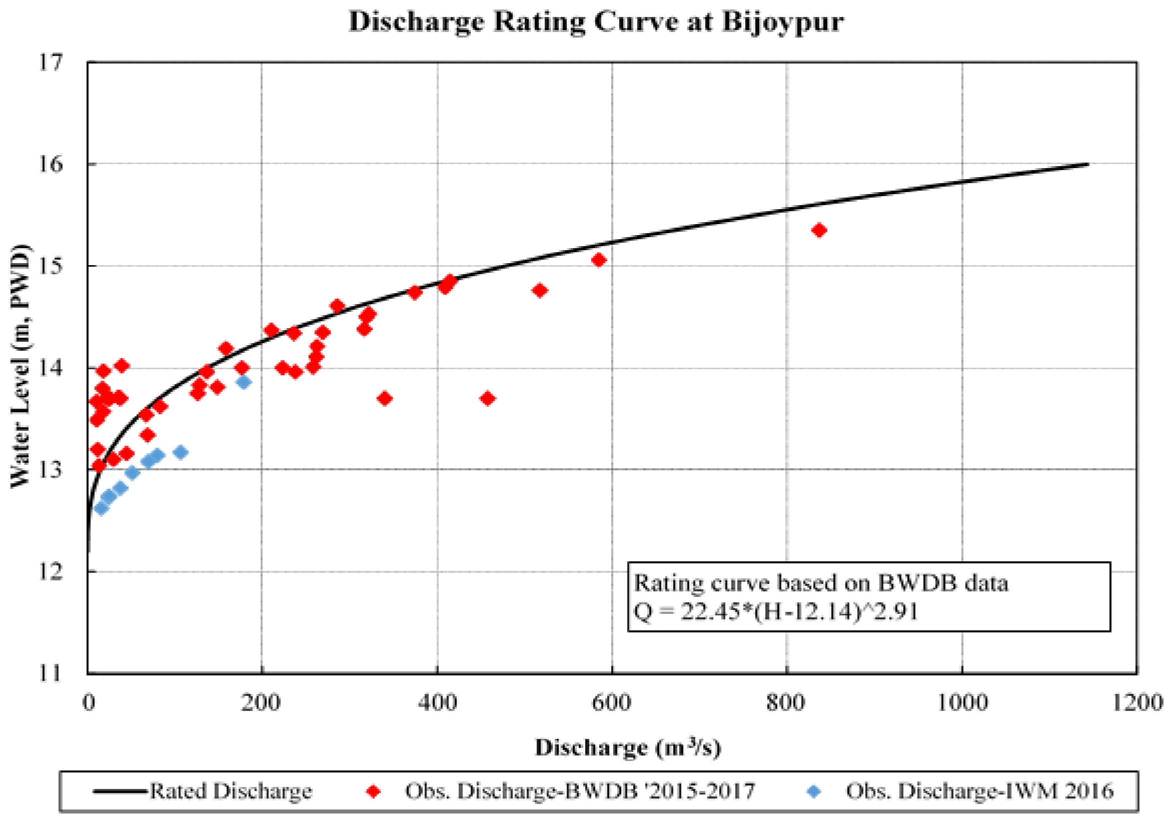


Figure 2-6: Comparison of rated discharge with observation

2.2.3 Cross-Sections Survey

Inclusion of recently surveyed cross-sections and floodplains are important to update the flash flood forecast model and improve its performance. To update the existing North-East Region Model using recent cross-sections by replacing most old sections of selected rivers of North East region, a cross-section survey campaign has been carried out during 2016-17. IWM has carried out river cross section survey for two consecutive years for updating the existing flash flood forecast model. Figure 2-7 shows the river reaches of the north-east region covered under 1st year and 2nd year program. The river cross-section survey has been done utilizing state of the art-technology for survey equipment. The cross-sections have been surveyed, then processed and visualized for errors. After satisfactory checking, cross-sections have been incorporated into existing North-East Region model for updating. Table 2-3 provides the list of cross-sections surveyed under this study.

Table 2-3: The list of surveyed cross-sections

Serial No	River Name	Length of River surveyed	No of Cross-sections Surveyed	Remarks
1	SUTANG	55 km	29	Cross-section survey carried out in 2017
2	KULIACHARA	23 km	5	
3	KARANGI	22 km	7	
4	SARIGOWAIN	33 km	22	
5	JAFFLONG	9 km	5	
6	ACTIVE CHELA	11 km	5	
7	NAWAGANG	12 km	8	
8	SURMA	50 km	18	
9	SOMESWARI	28 km	-	
10	NITAI	22 km	13	
11	SARIGOWAIN	27 km	9	Cross-section survey carried out in 2016
12	BAULAI	42 km	14	
13	LOWER-CHAMTI	39 km	13	
14	MOGRA	42 km	14	
15	OLDKUSHIYARA	36 km	12	
16	PHINGLI_NADI	42 km	14	
17	PIYAN_RIVER	54 km	18	
18	SAIDULBARUNI	51 km	17	
19	SEKRA	18 km	6	
Total		616 km @ 3-4 km interval	229	

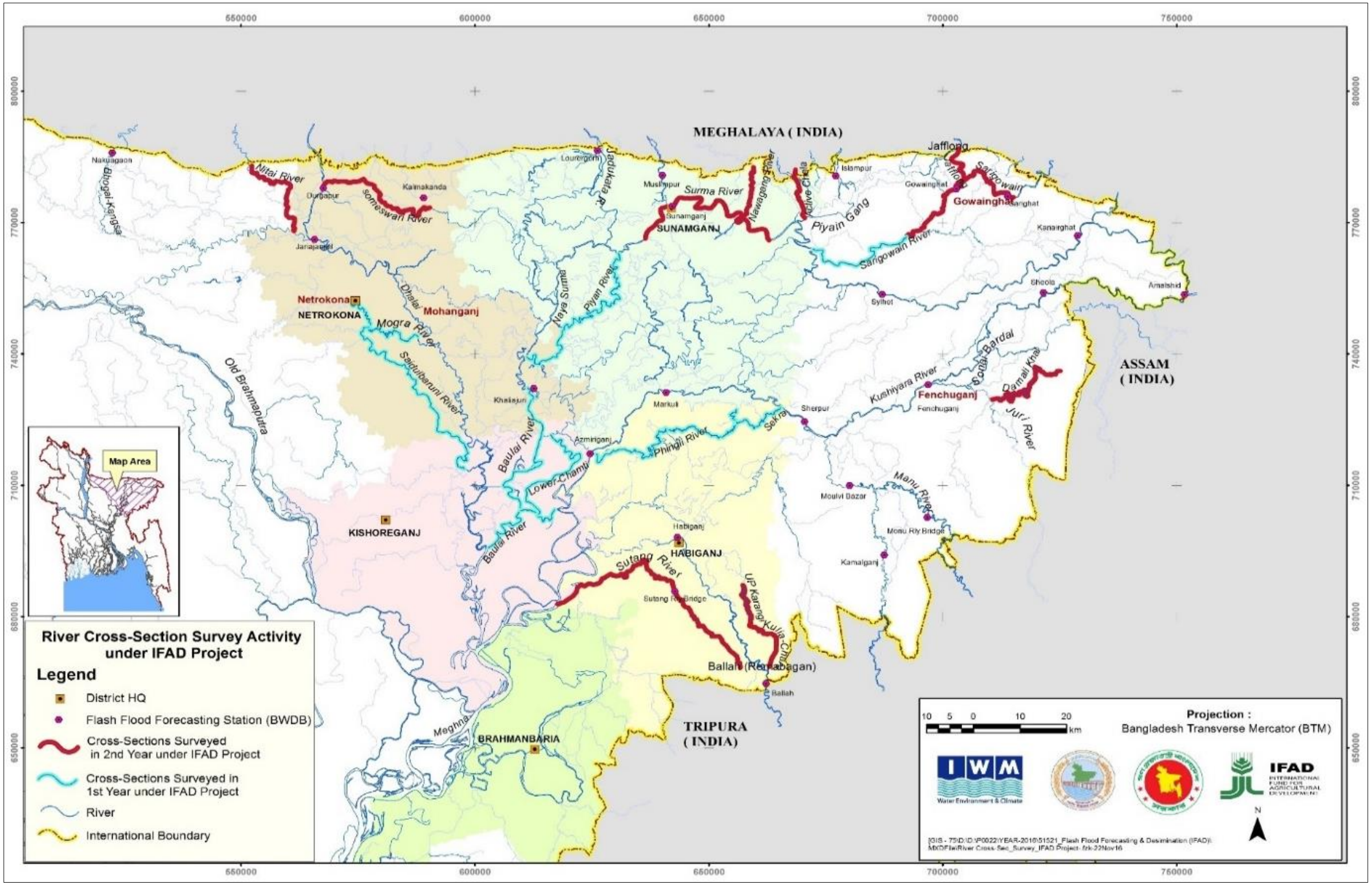


Figure 2-7: Map showing Cross-sections surveyed under this study

2.3 Secondary Data Collection

Bangladesh Water Development Board (BWDB) routinely maintains measurement of rainfall, evaporation, water level and discharge at significant stations throughout the country (Table 2-4). The measured data are checked, processed and archived at Processing and Flood Forecasting Circle(P&FFC) of BWDB. To calibrate and validate the flash flood forecast model and to evaluate the forecast performance, secondary data at yearly basis and real-time basis have been utilized throughout the project period. IWM has collected these data time to time under this project and archive it in the developed database. Also, historical hydro-meteorological data at required stations for last 30 years have been collected from database of IWM. The recent hydro-meteorological data have been collected from Flood Forecasting and Warning Center (FFWC) of BWDB. Bangladesh Meteorological Department (BMD) also routinely maintains measurement of meteorological data including rainfall, temperature, evaporation, etc. Available rainfall forecast data from Bangladesh Meteorological Department (BMD) for the study area have also been collected.

2.3.1 Hydrometric Data

Flood Forecasting and Warning Center collects 84 nos. water level data and 59 nos. rainfall data from all over Bangladesh on daily basis maintained by Bangladesh Water Development Board (BWDB). However, FFWC used to collect and utilize real-time water level from 20 nos. and rainfall data from 17 nos. stations respectively in the North-East Region before implemented this project. To supplement the rainfall measurement done by BWDB, an attempt has been made under this study to collect rainfall data from several tea-estates of Sylhet region who have their own measurement and recording mechanism. However, these tea-estate rainfall stations data are mainly distributed at Habiganj, Moulvibazar and Sylhet districts. Figure 2-8 shows possible tea estate rainfall stations spread over North Eastern districts of Bangladesh.

The main challenge of any flash flood model is to receive rainfall data at catchment scale and within shortest possible time. However, most influential rainfall stations in the North-East region are located outside Bangladesh and specifically at Meghalaya, Tripura and Barak basins of India. On the other hand, until 2018 FFWC received real-time rainfall data from only 13 nos. stations in the North-East Region. The stations were sparsely distributed within the region and hence capturing the short-term rainfall induced flash flood particularly for the catchments outside Bangladesh were difficult. To enhance the rainfall-runoff model through rainfall distribution within the North-East Region particularly at the border locations, additional 12 nos. rainfall stations maintained by Hydrology, BWDB have been identified and incorporated in the real-time data collection system. The list of existing and new stations is provided in Table 2-5 and shown in figure 2-9.

Table 2-4: List of data collection program done by Hydrology, BWDB during 2019-20

Status of Data Collection Program of Surface Water Hydrology, BWDB for 2019-2020 Fiscal Year												
Serial	Type of Data Collection	North-Eastern Measurement Division, Dhaka		South-Western Measurement Division, Faridpur		Northern Measurement Division, Pabna		South-Eastern Measurement Division, Comilla		Total Stations		Remarks
		Total	**Active**	**Total**	**Active**	**Total**	**Active**	**Total**	**Active**	**Total**	**Active**	Non-Functioning
1	Water Level Stations	97	69	87	69	95	74	75	75	354	287	67
2	Discharge Measurement Station	42		13		43		24		122		
3	Rainfall Station	68		61		85		60		274		
4	Evaporation Station	11		9		12		7		39		
5	FFWC Stations	70		17		32		38		157		
6	Water Sampling Station	10		0		4		3		17		
7	Sediment Sampling Station	5		3		3		7		18		
8	Salinity Measurement	0		70		0		30		100		Stagnant
9		0		66		0		0		66		Moving
10	Repair & Maintenance	132		132		159		38		461		

Source: Surface Water Hydrology, BWDB

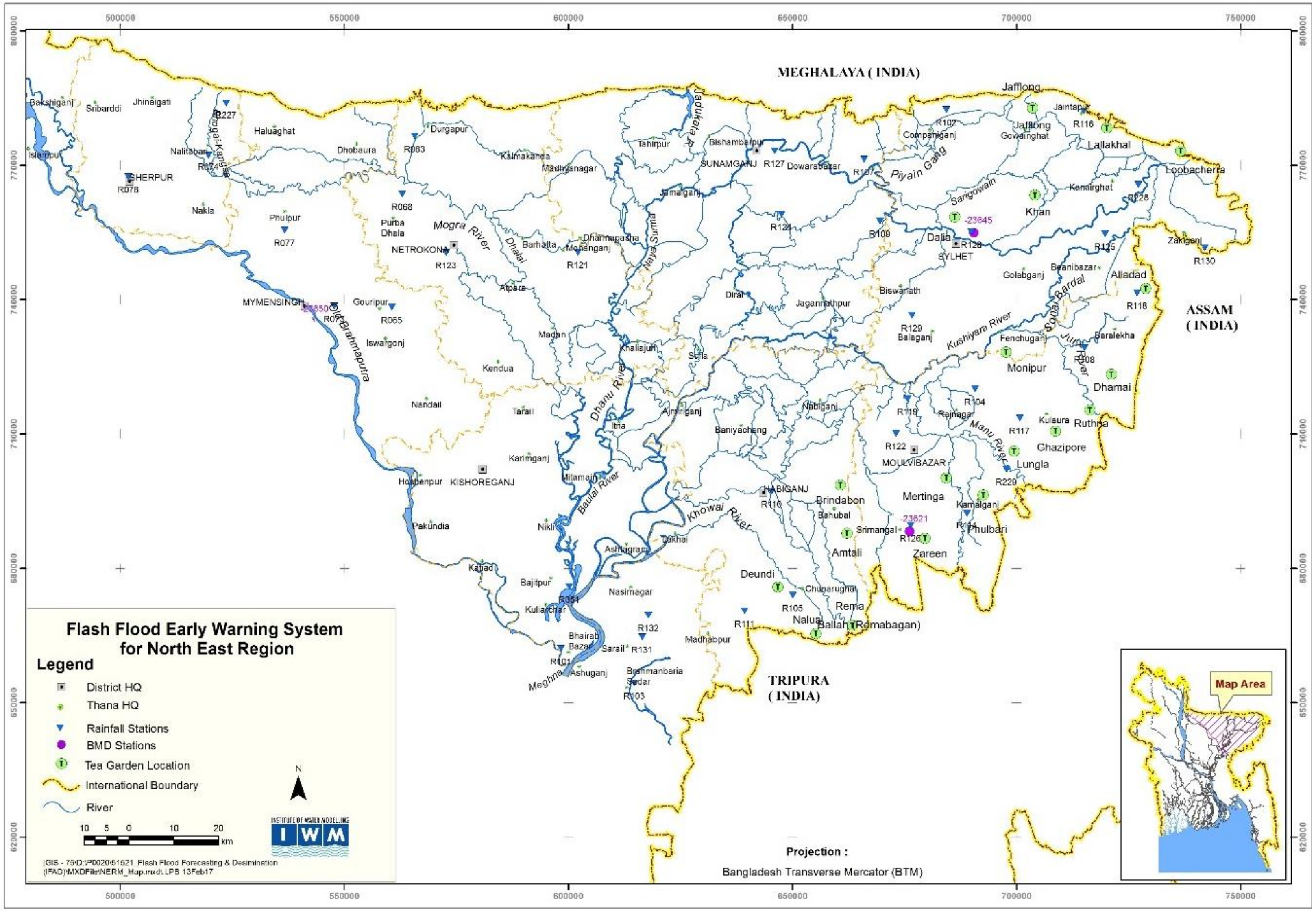


Figure 2-8: Different Tea Estates of the Region having their own Rainfall Measurement Stations

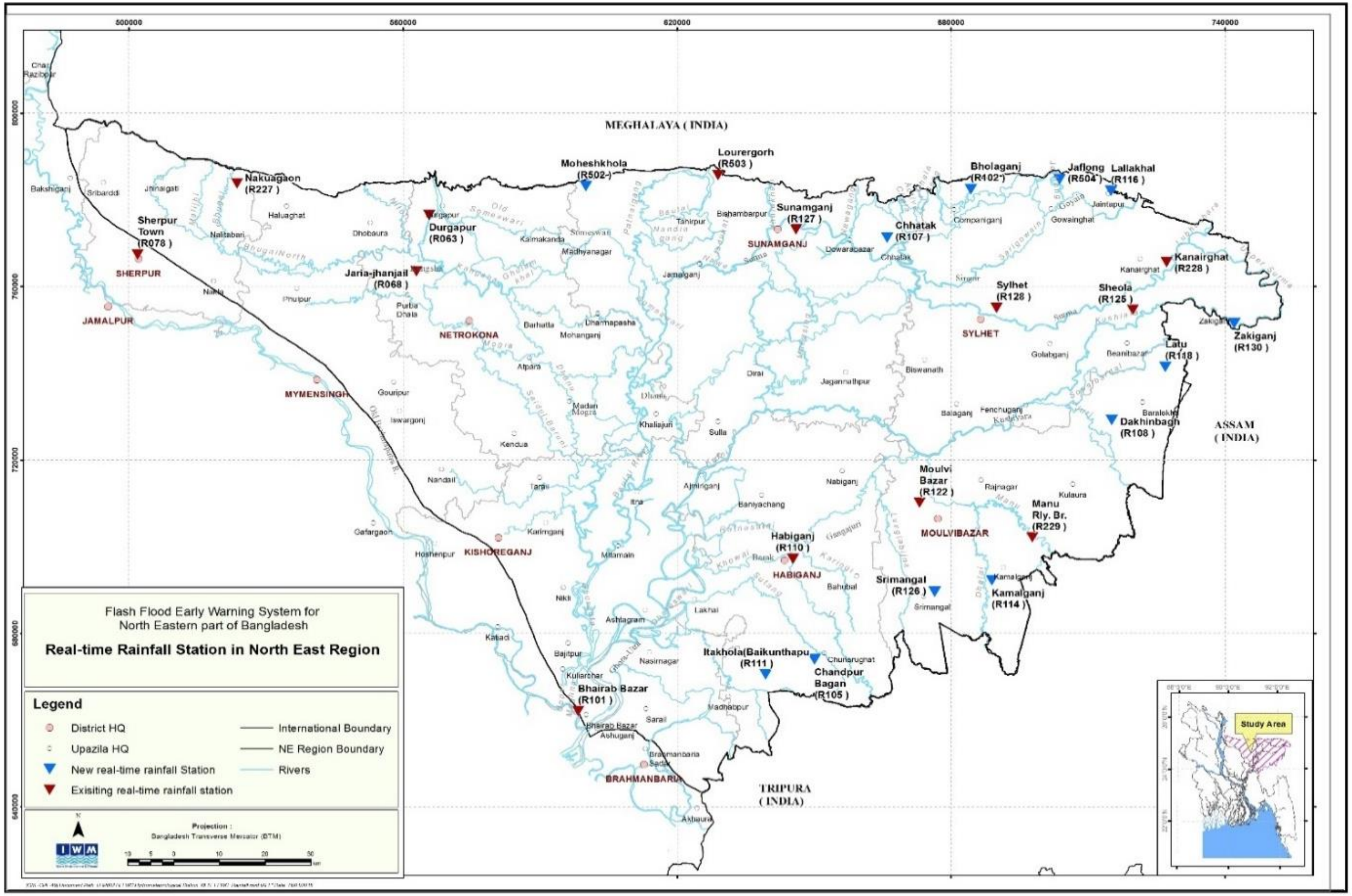


Figure 2-9: New Rainfall Stations with Existing Real-Time Rainfall Stations in the NE Region

Table 2-5: List of existing and new rainfall stations

SL.	Station Name	Station ID	Status
1	Kanaighat	R228	Existing
2	Sylhet	R128	Existing
3	Sunamganj	R127	Existing
4	Sheola	R125	Existing
5	Moulvibazar	R122	Existing
6	Manu rly br.	R229	Existing
7	Habiganj	R110	Existing
8	Sherpur	R078	Existing
9	Durgapur	R063	Existing
10	Lorergarh	R503	Existing
11	Nakuagaon	R227	Existing
12	Jariajanjail	R068	Existing
13	Bhairabbazar	R101	Existing
14	Zakiganj	R130	New
15	Lallakhal	R116	New
16	Jafflong	R504	New
17	Bholaganj	R102	New
18	Chattak	R107	New
19	Moheshkhola	R502	New
20	Chandpur Bagan	R105	New
21	Kamalganj	R114	New
22	Dakhsinbag	R108	New
23	Sreemongal	R126	New
24	Latu	R118	New
25	Itakhola	R111	New

Along with forecast stations, monitoring stations also play significant role to monitor the flood situation and hence BWDB have introduced several water level monitoring stations in the most flood vulnerable Haor areas as temporary basis only dedicated for flash flood season. A total 17 number of water Level monitoring stations have been made real-time and incorporated into the Forecast System under this study. These stations are now providing real-time water level data to FFWC through mobile SMS technology. Necessary adjustment in the SMS solution software and inclusion in the observed bulletin have been done. The list of the additional water level stations is shown in table 2-6. Figure 2-10 shows real time water level forecast stations.

Table 2-6: List of New Real-time Water Level Stations at North-East Region operational during Pre-monsoon

Sl. No	Real-Time WL Station	River Name	Remarks
1	Markuli	Kushiyara	Forecast Station
2	Islampur	Dhalagang	Forecast Station
3	Muslimpur	Jhalukhali	Forecast Station
4	Kalmakanda	Someswari	Forecast Station
5	Gowainghat	Sari-Gowain	Forecast Station
6	Fenchuganj	Kushiyara	Forecast Station
7	Brahmanbaria	Titas	Forecast Station
8	Sutang RB	Sutang	Forecast Station
9	Azmiriganj	Kalni	Forecast Station
10	Khaliajuri	Baulai	Forecast Station
11	Continala	Juri	Monitoring Station

12	Jaflong	Piyang	Monitoring Station
13	Lubachara	Lubachara	Monitoring Station
14	Bijoypur	Shibganjdhala	Monitoring Station
15	Solemanpur	Patnaigang	Monitoring Station
16	Akhterpara	Mahasing	Monitoring Station
17	Jagannathpur	Nohanni	Monitoring Station

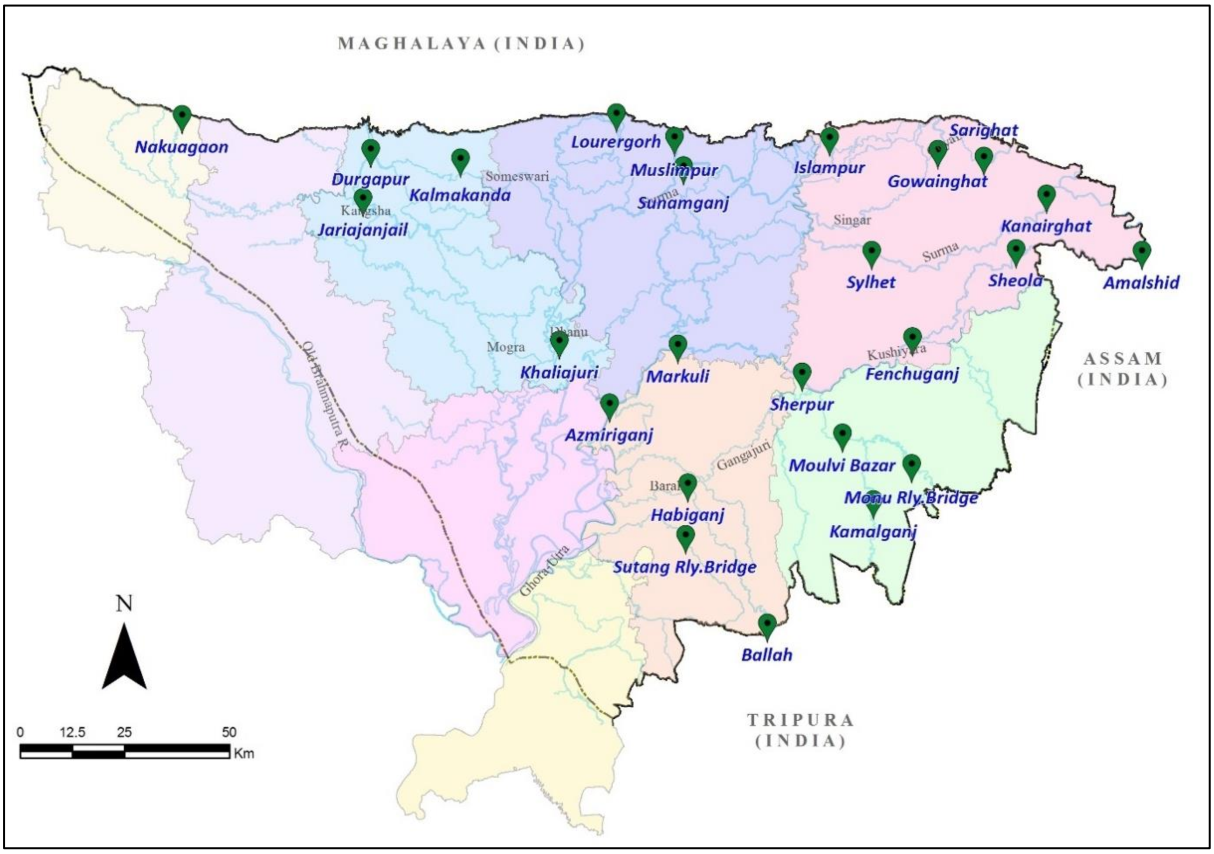


Figure 2-10: Map showing Real-Time Water Level Forecast Stations

2.3.2 Indian Cross-Border Data

The hydrological component of the North-East region comprises with 38 sub catchments inside Bangladesh and 20 cross-border sub catchments within India except the Barak river basin. Figure 2-11 shows cross-border catchments of North East region. These catchments are located in the Meghalaya Plateau and in Tripura Hill ranges. Most of these catchments are in Indian territory and responsible for contributing flash floods in the region. Catchments located in Meghalaya Plateau (13466 sq. km) contribute 63 km^3/year, or 31 % of the regional water supply and those in Tripura ranges (6845 sq. km) contribute 10 km^3/year, or 5 % of the regional water supply (FAP 6).

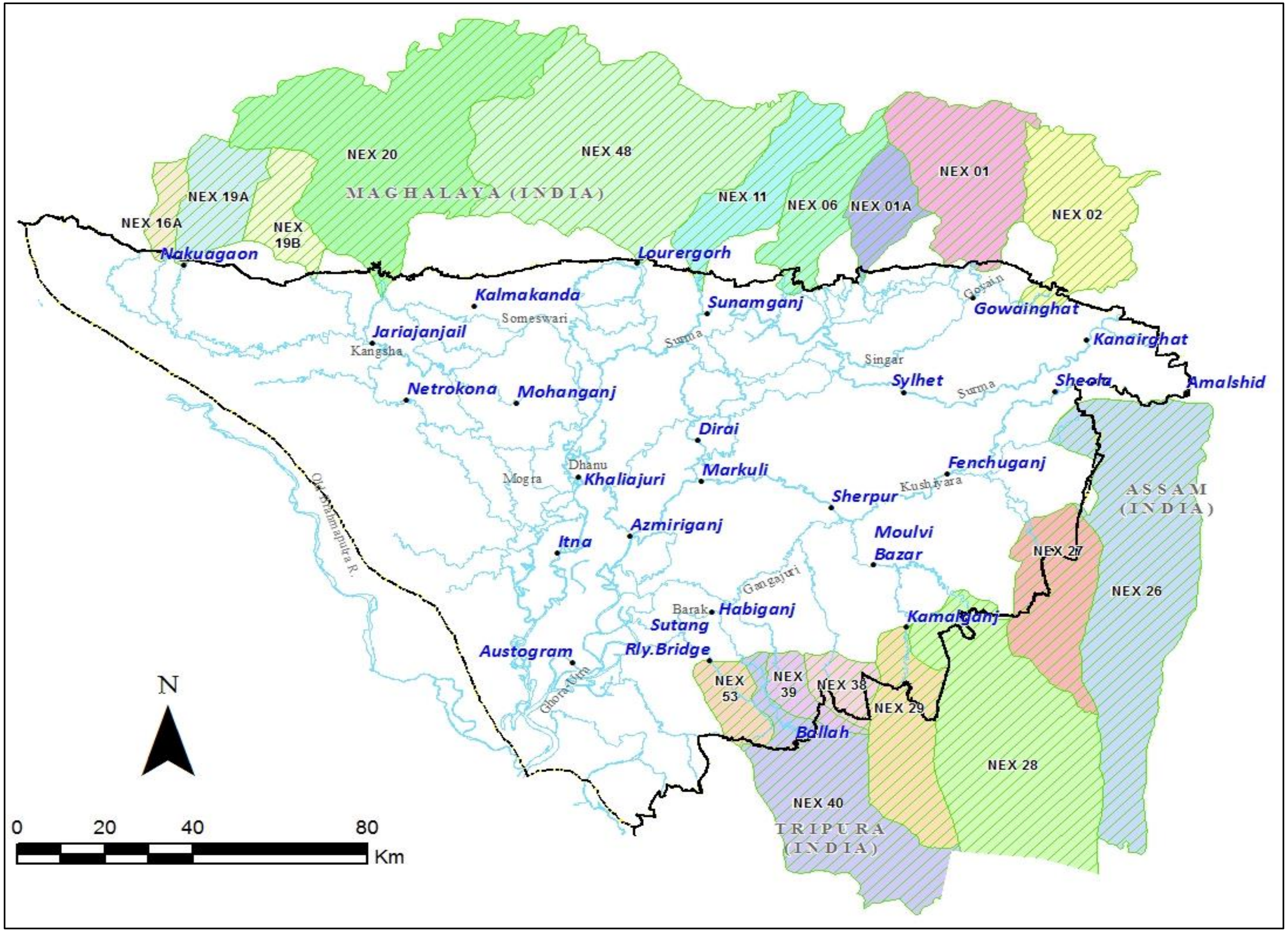


Figure 2-11: Cross-border Catchments of North East Region

Indian rainfall data available at public domain websites for stations specifically located within Meghalaya, Tripura and Barak basin area have been downloaded and stored in a database maintained at IWM. These Indian rainfall stations have been considered and applied in the re-distribution of the weightage factors for the catchments which are titled as "NEX" catchments and situated outside Bangladesh border and finally applied in the flash flood forecast model. The major Indian rainfall stations of this region important for flash flood forecasting system are listed in Table 2-7.

Table 2-7: List of Indian Rainfall Stations

Sl. No	Station Name	Status	Sl. No	Station Name	Status	Sl. No	Station Name	Status
01	Annapurna Ghat	Regular	11	Amraghat	Regular	21	Cherrapunji	Regular
02	Aizwal	Regular	12	Gharmura	Regular	22	Wiliamnagar	Irregular
03	Arundhutinagar	Regular	13	Lakhipur	Regular	23	Tura	Irregular
04	Agartola	Regular	14	Silchar	Regular	24	Lumding	Regular
05	Khowai	Regular	15	Karimganj	Regular			
06	Lengpui	Regular	16	Matijuri	Regular			
07	Gandhachera	Regular	17	Haflong	Regular			
08	Kanchanpur	Regular	18	Jowai	Irregular			
09	Dharmanagar	Regular	19	Shilong	Regular			
10	Dholai	Regular	20	Nongstoin	Regular			

The Indian rainfall data used are collected from available websites in the public domain. One can access the following weblinks to fetch the rainfall data for the Meghalaya, Tripura and Barak Basin.

http://14.139.247.11/citywx/localwx.php

http://www.india-water.gov.in/ffs/

http://www.imdguwahati.gov.in/dwr.pdf

These three websites publish daily accumulated rainfall outside of North-East periphery (Indian part). The developed FFEWS automated system collect and store these daily rainfall data from above mentioned website automatically.

2.4 Bench Mark Connection and Conversion to m MSL Datum

It has been observed that benchmarks of water level gauges maintained by BWDB with the available SoB datum often varies and that's why a continuous gauge monitoring and benchmark correction has carried out. During 2017, the following gauges have been visited, measured with BWDB and SoB benchmarks and came up with the following corrections provided in table 2-8. In addition, under JICA Haor study 2015-17, the following gauge corrections have been observed during survey activities carried out in 2016 in the North-East Region and provided in table 2-9.

Table 2-8: Bench mark survey carried out during 2nd year in 2017

Water Level Station	River Name	SOB BM_RL (mPWD)	IWM connected BM/TBM RL (mPWD)	BWDB present field BM/TBM RL (mPWD)	Correction to be applied (m)
Ballah	Khowai	25.37	24.03	24.18	0.15
Habiganj	Khowai	7.93	8.79	9.61	0.82
Islampur	Dhalagang	12.91	13.88	13.96	0.08
Jariajanjail	Kangsha	10.38	11.53	12.13	0.61
Kalmakanda	Someswari	8.50	7.91	8.08	0.17
Kanairghat	Surma	14.34	14.56	15.06	0.50
Lourergorh	Jadukata	7.79	12.81	12.91	0.10
Manu RB	Manu	17.10	16.59	17.00	0.41
Muslimpur	Jhalukhali	9.39	9.39	9.92	0.53
Sarighat	Sarigowain	12.69	14.30	14.89	0.59
Sutang RB	Sutang	13.59	6.11	6.50	0.39
Sylhet	Surma	12.84	11.75	12.49	0.74

Table 2-9: Bench mark survey carried out during 1st year in 2016

Water Level Station	River Name	SOB BM_RL (m PWD)	IWM connected BM/TBM RL (m PWD)	BWDB present field BM/TBM RL (m PWD)	Correction to be applied (m)
Ajmiriganj	Kalni	6.20	7.04	7.76	0.72
Sunamganj	Surma	9.43	7.80	8.45	0.65
Moulavibazar	Manu	11.91	11.54	12.14	0.60
Kamalganj	Dhalai	13.67	21.10	22.02	0.92
Derai	Old Surma	8.22	8.30	9.02	0.72
Mohanganj	Lower Kangsha	8.73	8.34	8.54	0.20
Khaliajuri	Baulai	8.60	7.39	8.39	1.00
Bhairab Bazar	Upper Meghna	7.15	7.57	8.18	0.61
Durgapur	Someswari	18.10	18.31	19.01	0.70
Markuli	Kushiyara	6.20	7.50	8.19	0.70

Bangladesh Water Development Board (BWDB) is the largest hydrological and hydrometric data collection organizations of Bangladesh. As per recent Government Rule, all agencies must follow Survey of Bangladesh (SoB)'s Bench Marks for datum and consequently BWDB have already checked and updated their benchmarks for the North-East Region of Bangladesh. Under this circumstance, a decision was made in the 2nd Technical Committee Meeting that the website should reflect the bench mark correction and should show all the graphs and tables in meter MSL, not in meter PWD datum for the dissemination during pre-monsoon. FFWC and IWM then jointly worked on this and updated the websites. Figure 2-12 and 2-13 shows the pre-monsoon and historical hydrographs with MSL datum respectively while Table 2-10 provides the datum correction factor found from FFWC.

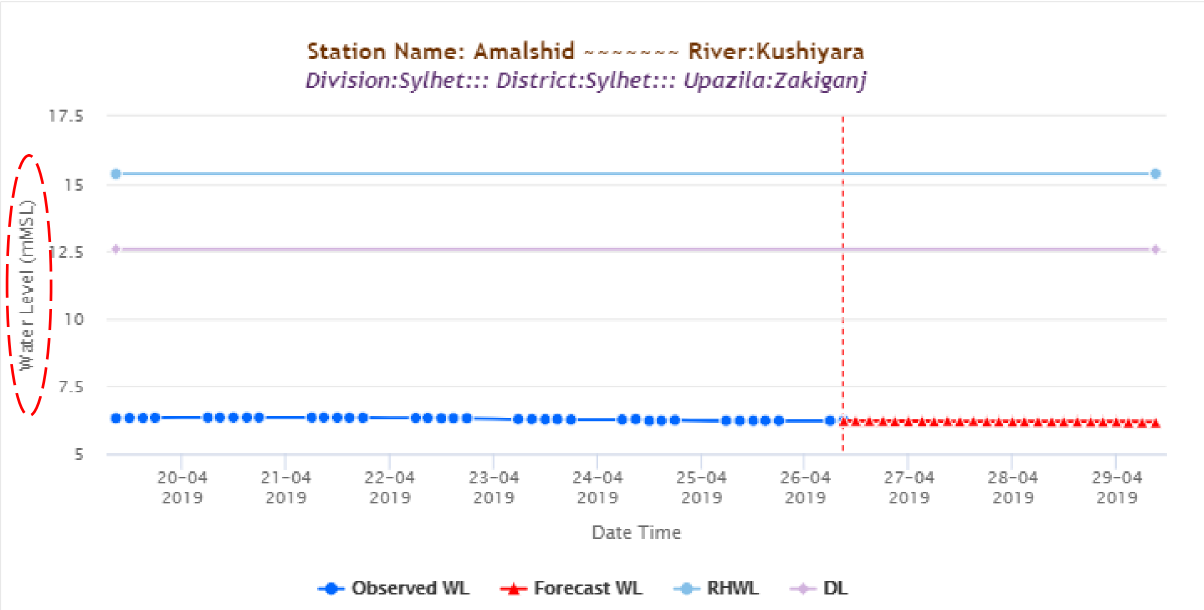


Figure 2-12: Pre-monsoon Hydrographs show MSL datum instead of PWD datum.

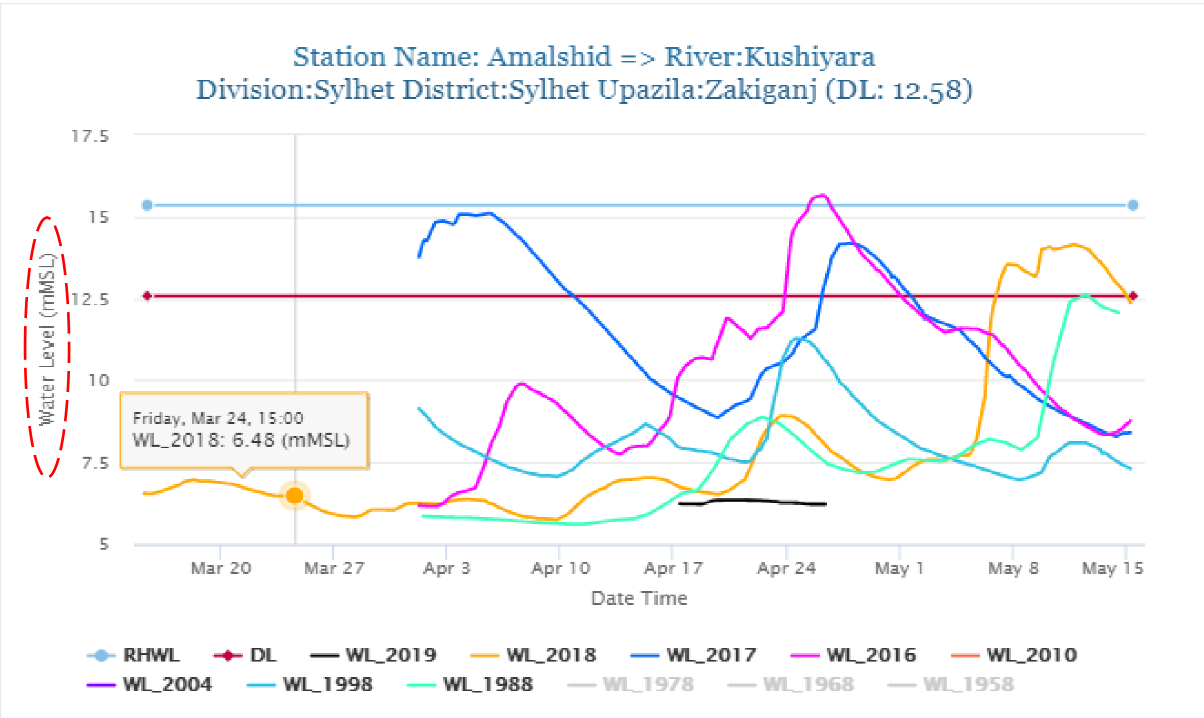


Figure 2-13: Historical hydrographs show MSL datum instead of PWD datum.

BWDB and other government departments refer water levels to the Public Works Datum (PWD). PWD is a horizontal datum believed originally to have zero at a determined Mean Sea

Level (MSL) at Calcutta. PWD is located approx. 1.5 feet (0.46 meter) below the MSL established in India under the British Rule and brought to Bangladesh during the Great Trigonometric Survey. (Source: FFWC).

Table 2-10: Datum correction factors found from FFWC

বাপাউবো'র উত্তর-পূর্বাঞ্চলের পানি সমতল স্টেশনসমূহের PWD এবং SoB মানের পার্থক্য

ক্রমিক নং	স্টেশনের নাম	PWD এবং SoB মানের পার্থক্য (m)	বিপদসীমা		সর্বোচ্চ রেকর্ডকৃত পানি সমতল		মন্তব্য
			পূর্বের PWD মান (m)	বর্তমানের SoB মান (m)	পূর্বের PWD মান (m)	বর্তমানের SoB মান (m)	
১	কানাইঘাট	০.৯৫১৬	১৩.২	১২.২৫	১৫.২৬	১৪.৩১	
২	সিলেট	১.০৯১	১১.২৫	১০.১৫	১২.৪৪	১১.৩৫	
৩	সুনামগঞ্জ	১.০২৮৮	৮.২৫	৭.২	৯.৭৫	৮.৭২	
৪	অমলশীদ	০.৯২	১৫.৮৫	১৪.৯৫	১৮.২৮	১৭.৩৬	
৫	শেওলা	০.৯৯৫	১৩.৫	১২.৫	১৪.৬	১৩.৬১	
৬	শেরপুর-সিলেট	০.৯৫৭	৯	৮.০৫	৯.৬৮	৮.৭২	
৭	মারকুলি	১.০৩	৮.৫	৭.৪৫	৮.৫১	৭.৪৮	
৮	সারিঘাট	১.০৩	১২.৮	১১.৭৫	১৪.৪৮	১৩.৪৫	
৯	মনু রেলওয়ে ব্রিজ	০.৮৪৬	১৮	১৭.১৫	২০.৪২	১৯.৫৭	
১০	মৌলভীবাজার	১.০৪৫	১১.৭৫	১০.৭	১৩.২৫	১২.২১	
১১	বাল্লা	০.৩৮	২১.৬৪	২১.৪	২৬.১২	২৫.৭৪	
১২	হবিগঞ্জ	০.৪৭৩৩	৯.৫	৯.০৫	১২.৩	১১.৮৩	
১৩	কমলগঞ্জ	০.৯৩৩	১৯.৮২	১৮.৮৫	২১.১৮	২০.২৫	
১৪	দিরাই	১.১৯২	৭	৫.৮	৭.৭৫	৬.৫৬	
১৫	খালিয়াজুরি	১.৪৫১৬	৮.৫	৭.০৫	৯.৫২	৮.০৭	
১৬	নাকুয়াগাঁও	০.৪৯৬	২২.৪	২১.৯	২৬.০১	২৫.৫১	
১৭	লরেরগড়	০.৫২২	৮.৫৩	৮	১১.৮৫	১১.৩৩	
১৮	মুসলিমপুর	১.০১	-	-	-	-	
১৯	দুর্গাপুর	০.৫৯৭	১৩	১২.৪	১৫.২	১৪.৬	
২০	জারিয়াজঞ্জাইল	১.০৬৭	১১	৯.৯৫	১৩.৩৭	১২.৩	
২১	ব্রাহ্মণবাড়িয়া	১.০২৬৯	৫.৫	৪.৪৫	৬.৫	৫.৪৭	
২২	ভৈরববাজার	১.০৮৯	৬.২৫	৫.১৫	৭.৭৮	৬.৬৯	
২৩	নরসিংদী	০.৮১	৫.৭	৪.৯	৭.০১	৬.২	
২৪	মেঘনা ব্রিজ	১.৫২	৫.০৩	৩.৫৫	-	-	
২৫	কুমিল্লা	১.০১	১১.৭৫	১০.৭৫	১৩.৫৬	১২.৫৫	
২৬	দেবীদ্বার	০.৬২	৮.৫	৭.৯	-	-	
২৭	চাঁদপুর L.W.L.	০.৫১	৪	৩.৫	৪.৯২	৪.৪১	
	চাঁদপুর H.W.L.				৫.৩৫	৪.৮৪	
২৮	বিজয়পুর	১.১১৫	-	-	-	-	
২৯	কলমাকান্দা	০.৬৫৩৮	৭	৬.৩৫	-	-	
৩০	আজমিরিগঞ্জ	১.২০	-	-	-	-	
৩১	দুর্লভপুর	১.০৮১	-	-	-	-	
৩২	সুখদেবপুর	০.৫৮৯	-	-	-	-	
৩৩	দলুরা	০.৮৪৯	-	-	-	-	
৩৪	আকতারপাড়া	-	-	-	-	-	সম্পূর্ণ নতুন স্টেশন
৩৫	জগন্নাথপুর						ঐ
৩৬	মধ্যনগর	-	-	-	-	-	ঐ
৩৭	দক্ষিণ শ্রীপুর	-	-	-	-	-	ঐ
৩৮	দক্ষিণ হাসানপুর	-	-	-	-	-	ঐ

2.5 Pre-monsoon Danger Level

In Bangladesh, danger level at a river location is the level above which it is likely that the flood may cause damages to nearby crops and homesteads. In a river having no embankment, danger level is about annual average flood level. In an embanked river, danger level is fixed slightly below design flood level of the embankment. In pre-monsoon time, flash flood often hits the North-East Region and causes severe damage although in most cases, water level doesn't even touch the danger level or close to it. To represent the severity of flash flood relative to realistic danger level, it has been sought in many discussions that BWDB should fix pre-monsoon danger level for the selected flash flood forecast stations in North East Region.

ক্র নং	স্টেশন	নদীর নাম	বর্তমানের monsoon বিপদসীমা (mPWD)	প্রস্তাবিত pre-monsoon (mPWD)
১	Ajmiriganj	Kalni	5.49	5.00
২	Amalshid	Kushiyara	15.85	13.50
৩	Ballah	Khowai	-	21.80
৪	Kamalganj	Dhalai	19.82	19.50
৫	Durgapur	Someswari	13.00	11.25
৬	Fenchuganj	Kushiyara	9.91	8.20
৭	Gowainghat	Sarigowain	11.28	9.10
৮	Habiganj	Khowai	9.50	9.10
৯	Islampur	Dhalagang	-	10.70
১০	Jariajanjail	Kangsha	11.00	6.80
১১	Kalmakanda	Someswari	7.00	5.35
১২	Kanairghat	Surma	13.20	11.35
১৩	Khaliajuri	Baulai	8.50	4.60
১৪	Lourergorh	Jadukata	8.53	6.40
১৫	Manu RB	Manu	18.00	16.90
১৬	Markuli	Kalni	8.50	6.40
১৭	Moulvibazar	Manu	11.75	10.00
১৮	Muslimpur	Jhalukhali	-	6.90
১৯	Nakuagaon	Bhugai	22.40	21.25
২০	Sarighat	Sarigowain	12.80	11.15
২১	Sheola	Kushiyara	13.50	11.15
২২	Sherpur	Kushiyara	9.00	8.25
২৩	Sunamganj	Surma	8.25	6.50
২৪	Sutang RB	Sutang	5.79	5.40
২৫	Sylhet	Surma	11.25	8.75

In this connection, historical measured data has been collected and statistically analyzed to calculate average year or 2.33 years return period water level. Comparing with existing FFWC danger level and embankment height of adjacent haors, new levels has been proposed as pre-monsoon danger level for the said stations. Table 2-11 shows the calculation of Pre-monsoon danger level for flash flood forecast stations of North East Region of Bangladesh. Existing monsoon danger level has been evaluated for the North-East Region particularly for the pre-monsoon period up to 15th May and proposed water levels corresponding to 2.33-year return period with rounding to its closest value is applied as experimental pre-monsoon danger level for the haor region following an office order dated on 19th march, 2018 issued by processing and flood forecasting circle, Hydrology, BWDB. Two hydrographs, one at Sunamganj and another at Sherpur (Sylhet) has shown in Figure 2-14 to 2-15 indicating the importance of the pre-monsoon danger level fixation.

Table 2-11: Pre-monsoon Danger Level Calculation

Sl. No.	Station	River	Pre-Monsoon RHWL (m PWD) (Up to 15 May)	Statistical Analysis		Existing Monsoon Danger Level of FFWC, BWDB (m PWD)	Adjacent Haor and Submersible Embankment Height (m PWD)			Proposed Pre-monsoon DL
				2.33-yr Return Period	10-yr Return Period		Name *(Source: Haor Rehabilitation Project, 2005)*	Embankment design crest Level (m PWD)	Approximate Distance from Station (km)	
1	Ajmiriganj	Kushiyara	7.63	4.94	6.68	-	Bhanda Beel	3.10	11.6	4.94
2	Amalshid	Kalni	16.28	12.99	15.76	15.85	Shafique Haor	13.56	18.7	12.99
3	Ballah	Khowai	25.28	21.78	23.47	21.64	-			21.78
4	Kamalganj	Dhalai	21.18	19.53	20.64	19.82	-			19.53
5	Durgapur	Someswari	13.84	11.86	12.83	13.00	Updakhali Haor	8.46	22.0	11.86
6	Fenchuganj	Kushiyara	11.3	8.18	10.23	-	Kawadighi Haor	11.87	7.5	8.18
7	Gowainghat	Sarigowain	11.46	9.11	11.27	-	-			9.11
8	Habiganj	Khowai	11.5	9.03	10.61	9.50	Hail Haor	11.37	22.0	9.03
9	Islampur	Dhalagang	13.25	11.42	12.78	-	Pathar Chauli Haor-2	9.08	6.7	11.42
10	Jariajanjail	Kangsha	9.43	6.78	8.58	9.75	Upadakhali Haor	8.94	20.4	6.78
11	Kalmakanda	Someswari	6.07	5.16	5.88	-	Updakhali Haor	7.35	2.8	5.16

12	Kanairghat	Surma	15.26	10.96	14.09	13.20	**Shafique Haor**	**15.21**	**4.6**	10.96
13	Khaliajuri	Baulai	5.77	4.32	5.25	8.50	**Nawtana Haor, Katikota Haor, Balali Padmasree Haor**	**4.95**	**4.5**	4.32
14	Lourergorh	Jadukata	7.61	6.46	7.50	8.53	**Matian**	**7.75**	**7.7**	6.46
15	Manu RB	Manu	20.42	17.68	19.18	18.00	**Hail Haor**	**7.28**	**24.7**	17.68
16	Markuli	Kalni	7.82	6.34	7.57	8.50	**Makalkandi Haor, Tangua Haor, Bhanda Beel**	**5.82**	**2.1**	6.34
17	Moulvibazar	Manu	12.96	9.91	11.87	11.75	**Kawadighi Haor**	**12.96**	**0.7**	9.91
18	Muslimpur	Jhalukhali	9.9	7.79	9.35	-	**Kalner Haor-3, Karchar Haor**	**9.48**	**4.2**	7.79
19	Nakuagaon	Bhugai	23.06	21.25	22.27	22.40	-			21.25
20	Sarighat	Sarigowain	14.07	12.24	13.65	12.80	**Shafique Haor**	**15.21**	**4.6**	12.24
21	Sheola	Kushiyara	14.22	10.85	13.16	13.50	**Bardal Haor**	**14.15**	**5.0**	10.85
22	Sherpur	Kushiyara	8.9	8.01	9.10	9.00	**Kawadighi Haor**	**11.22**	**6.5**	8.01
23	Sunamganj	Surma	8.35	6.34	7.75	8.25	**Karcha Haor**	**7.46**	**2.1**	6.34
24	Sutang RB	Sutang	7.51	5.19	6.79	-	**Hail Haor**	**12.67**	**25.3**	5.19
25	Sylhet	Surma	10.77	8.14	11.06	11.25	**Ziker Haor-1**	**11.17**	**4.5**	8.14

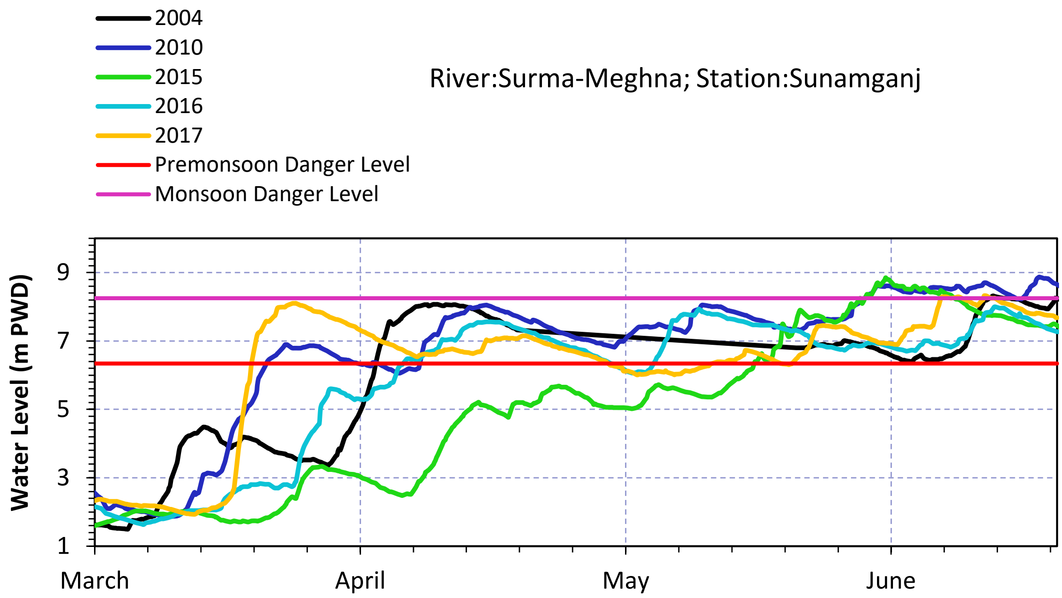


Figure 2-14: Comparison between Pre-monsoon and Monsoon Danger Level at Sunamganj

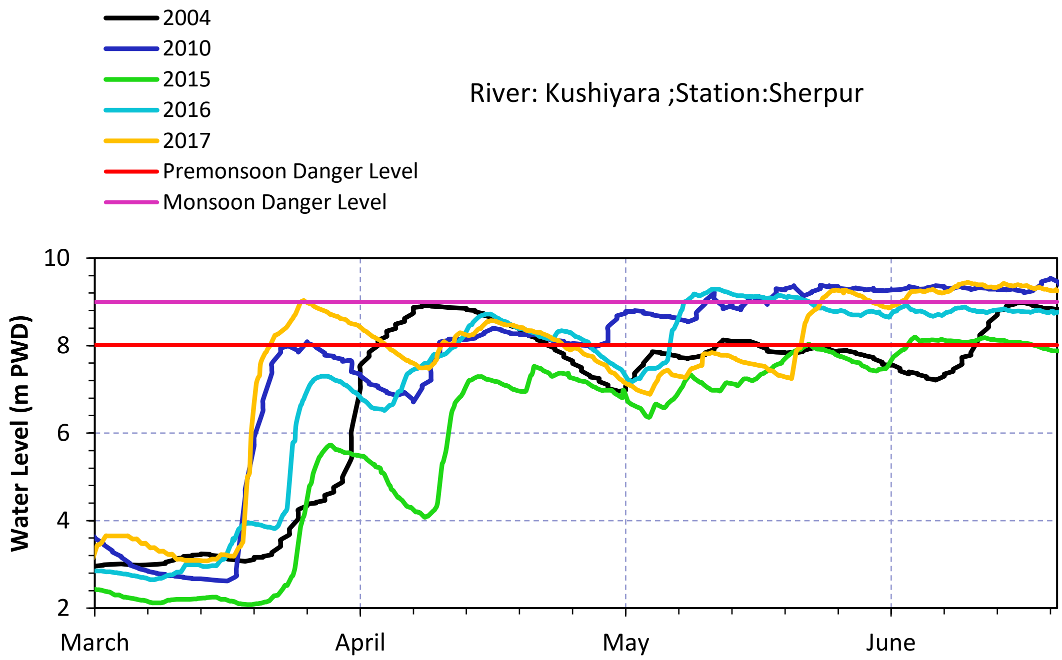


Figure 2-15: Comparison between Pre-monsoon and Monsoon Danger Level at Sherpur

The proposed pre-monsoon danger levels will only be valid for the period of April 01 to May 15 each year and after that period regular danger level set by BWDB will prevail.

2.6 BMD Radar Rainfall

Bangladesh Meteorological Department (BMD) maintains 5 nos. Radar Stations at Dhaka, Cox's Bazar, Khepupara, Rangpur and Moulvibazar. Moulvibazar Radar station is of Doppler Radar type and most suitable for utilizing in the flash flood forecasting of North East Region of Bangladesh. Figure 2-16 shows area coverage of Moulvi-Bazar Radar Station. JICA established the Meteorological Doppler Radar System in Moulvibazar to improve the precision of flood forecasting in the Meghna basin in the northeast area of Bangladesh as the previously existing systems were unable to measure the rainfall amount of the total catchment area of Meghna River located beyond the Bangladesh border into the hilly regions of Meghalaya state of India. It is an S-Band (wave length ~10 cm), dual polarization, magnetron radar system [WMO Radar Database].

Doppler radar of Moulvibazar perform PPI scan and the output data of this type are reflectivity (dBZ), Doppler velocity (m/s), precipitation rate (mm/h) etc. The precipitation rate (mm/h) data are stored in sixteen statuses. The precipitation rate is retrieved from the precipitation status using the following equations. The hourly precipitation rate HPR is defined as

$$HPR = (1/N) \sum_{I=1}^{I=N} R_I$$

where R_I is the instantaneous precipitation rate per unit area in a particular grid box, and N is the total number of scans per hour with

$$R_I = (1/A) \sum_{r=1}^{r=n} S_r A_{R,r}$$

where A is the grid area, S the status precipitation rate averaged from the possible values in a status, and AR the rainy area corresponding to each status in the particular grid box. R is the number of precipitation status band in a PPI scan.

Doppler Radar System is capable of detecting the motion of rain droplets in addition to the intensity of the precipitation. Doppler radar returns echoes from targets ("reflectivity") and they are used to analyze the precipitation rate in the scanned volume. Reflectivity perceived by the radar varies by the sixth power of the rain droplets' diameter (D) according to Marshall-Palmer. The relationship between reflectivity and precipitation rate is sometimes generalized to the form Z = aRb, where a and b are adjustable parameters. The relationship is Z = 190 R 1.72 (J. S. Marshall, and W. McK. Palmer, 1947), where Z (mm6 m-3) is the reflectivity factor and R (mm h-1) is the rainfall rate can be used to calculate precipitation rate.

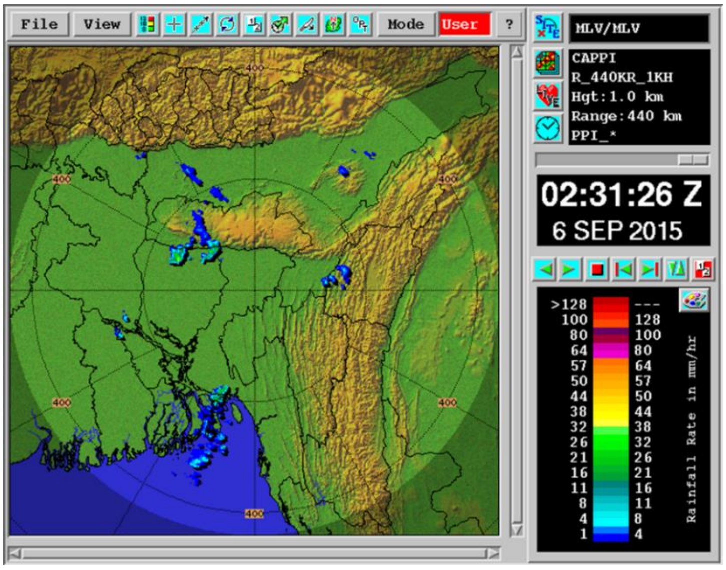
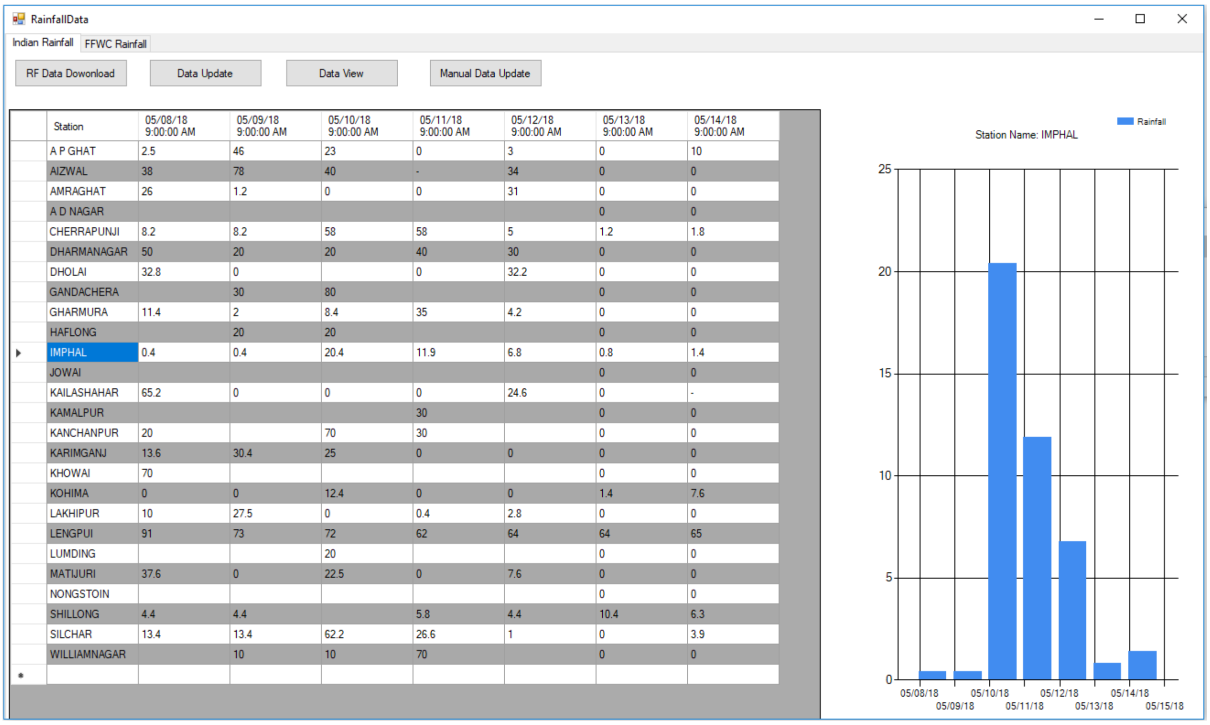


Figure 2-16: Map showing area coverage of Moulvi-Bazar Radar Station

At present, there is no reliable way to retrieve precipitation from the Bangladesh Meteorological Department (BMD) radar data. A precise Z (Reflectivity) - R (Rain rate) relationship is needed for utilizing this radar data which is not available at this moment. Prior to pre-monsoon of 2017, BMD provided some raw data from Moulvibazar Radar station but it was not being possible to incorporate these data into flash flood forecast modelling system. Thus, utilization of radar data has not been applied in this project.

2.7 Haor Database Management System

Starting since March 2016, the project titled as "Flash flood early warning system for North Eastern Part of Bangladesh" has been carried out for four pre-monsoon seasons until May 15, 2019. During this time, real-time rainfall from Bangladesh and Indian part, real-time water level data from manual gauge and auto-gauges, discharge measurements and rated discharges at the border stations have been collected and or generated and stored in a SQL database. This SQL database is termed as "Haor Database Management System". Also, the weather forecasted Rainfall, embankment crest levels of Shanir Haor and Matian Haor of Sunamganj has also been stored in this system. Figure 2-17 shows screenshot of Indian Rainfall Database within the Haor Database Management System.



Station	05/08/18 9:00:00 AM	05/09/18 9:00:00 AM	05/10/18 9:00:00 AM	05/11/18 9:00:00 AM	05/12/18 9:00:00 AM	05/13/18 9:00:00 AM	05/14/18 9:00:00 AM
A P GHAT	2.5	46	23	0	3	0	10
AIZWAL	38	78	40	-	34	0	0
AMRAGHAT	26	1.2	0	0	31	0	0
A D NAGAR						0	0
CHERRAPUNJI	8.2	8.2	58	58	5	1.2	1.8
DHARMANAGAR	50	20	20	40	30	0	0
DHOLAI	32.8	0		0	32.2	0	0
GANDACHERA		30	80			0	0
GHARMURA	11.4	2	8.4	35	4.2	0	0
HAFLONG		20	20			0	0
IMPHAL	0.4	0.4	20.4	11.9	6.8	0.8	1.4
JOWAI						0	0
KAILASHAHAR	65.2	0	0	0	24.6	0	-
KAMALPUR				30		0	0
KANCHANPUR	20		70	30		0	0
KARIMGANJ	13.6	30.4	25	0	0	0	0
KHOWAI	70					0	0
KOHIMA	0	0	12.4	0	0	1.4	7.6
LAKHIPUR	10	27.5	0	0.4	2.8	0	0
LENGPUI	91	73	72	62	64	64	65
LUMDING			20			0	0
MATIJURI	37.6	0	22.5	0	7.6	0	0
NONGSTOIN						0	0
SHILLONG	4.4	4.4		5.8	4.4	10.4	6.3
SILCHAR	13.4	13.4	62.2	26.6	1	0	3.9
WILLIAMNAGAR		10	10	70		0	0

Figure 2-17: Indian Rainfall Database

This database is also linked with Hydrological, Hydrodynamic and Weather Forecasting modelling system and indirectly preserve the river cross-sections database as well. The real-time rainfall and water level stations data within North-Eastern Bangladesh part are collected through SMS based data collection system operational at FFWC, BWDB. This "SMS Solution" software is also connected with this Haor Database Management System.

3.1 General

Flash Flood forecasting is one of the most challenging and difficult problems in hydrology. However, it is also one of the most important problems in hydrology due to its critical contribution in reducing economic and life losses. In many regions of the world, flood forecasting is one among the few feasible options to manage floods. Reliability of forecasts has increased in the recent years due to the integration of meteorological and hydrological modelling capabilities, improvements in data collection through satellite observations and advancements in knowledge and algorithms for analysis and communication of uncertainties.

Flash flood usually occurs during pre-monsoon season. The flood destroys agricultural products of large land areas, causing death, damage to property, environmental pollution and destruction to roads and bridges. In Bangladesh perspective, early flash floods during the months of April-May in the North-Eastern region damage the main crop Boro rice nearly or just before the harvesting. About 60% of the total runoff in the region is produced, mostly in the form of flash flood occurring outside Bangladesh, by the three Indian catchments- the Meghalaya River catchments, the Barak River catchment and the Tripura River catchments. The flash flood events of early April 2004, end of April 2016 and heavy rains in late March and early April in 2017 triggered severe flash floods over northeastern parts of the country, affecting approximately 850 000 households and causing severe damage to food crops, housing and infrastructure, including bridges and roads.

From the bitter experience of recurrent damages, a continuous effort to establish an operational flash flood forecasting system based on mathematical modelling in the region is ongoing.

3.2 Review of Past Models

Steps taken on flash flood forecasting in Bangladesh were not extensive and only few studies were available in this regard until a research project was carried out during 2011-2014 at FFWC funded by Comprehensive Disaster Management Program-II of UNDP. The significant flash flood forecasting model initiative done earlier to this project is described briefly in the subsequent sections.

3.2.1 Expansion of Flood Forecasting and Warning Services (1997)

The three-year project with the objective of improved information to aid national preparedness for floods and to mitigate flood impacts commenced in January 1995 with the assistance from Danida. Development of a pilot forecast system for two flashy rivers was one of the six important outputs of the project. Figure 3-1 shows Pilot Flash Flood Models (FAP10). The study tried to develop flash flood forecasting of the Manu River system in the Northeast region. The upstream boundaries of the pilot models were defined at stations close to Indo-Bangladesh border within Bangladesh i.e. Manu Railway Bridge in the Manu River.

The Manu Railway Bridge is located some eight kilometres within Bangladesh from the Indo-Bangladesh border. The Manu, and subsequently Moulvi Bazar city, experience flash floods due to rainfall across the border and by rainfall within the Manu catchment itself. More than 80% of the Manu catchment is located in the mountainous Tripura region of India for which no rainfall/flow data is available. Due to the hydrological features of the river and its catchment, only very short lead times can be obtained, i.e. of the order of a few hours. At the time of the study, continuously measured rainfall and water level data were available via telemetry stations at Manu Railway Bridge and Sherpur.

In order to provide forecast boundary conditions for the model an approach based on the use of Artificial Neural Network (ANN) was adopted. It is based on recognition of patterns, in this case rate of rise patterns of water levels at the two gauging stations related to the observed flood intensity. The MLP algorithm was implemented in this study to forecast river water levels up to a 24-hour time horizon with an input of the past 24 hours. The inputs were presented to the ANN as hourly values (FFWC, 2005). The key findings of the study are as follows:

- MIKE11 performs well enough to simulate flash flood,
- One of the main difficulties in flash flood forecasting is the estimation of boundaries, i.e. upstream inflows and rainfall over the catchment,
- Quantitative estimation of rainfall from remote sensing data is invaluable to improve estimation of flash flood boundaries,
- Decision support tools based on statistics or artificial neural networks (ANN) need to be developed to aid boundary estimation.

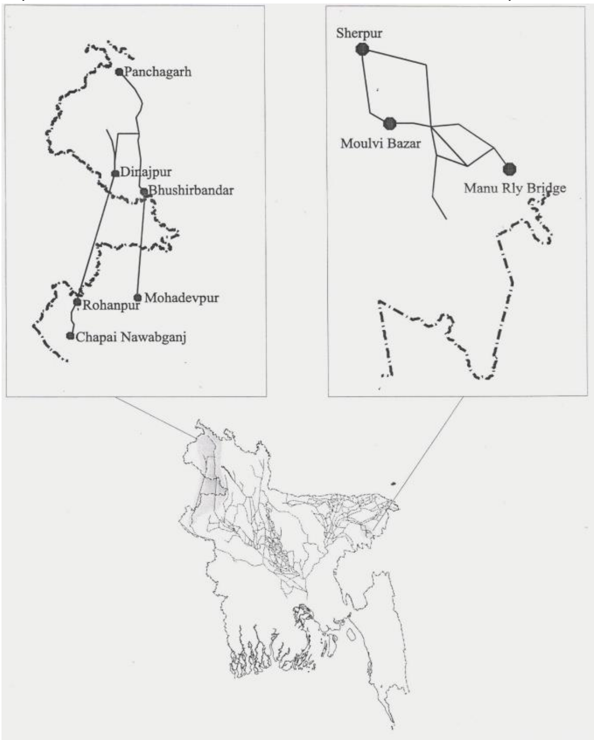


Figure 3-1: Pilot Flash Flood Models (FAP10)

3.2.2 Flash Flood Forecasting in Northeast Region of Bangladesh (2008)

ADPC has carried out this study "Flood Forecast Technology for Disaster Preparedness in Bangladesh" under financial assistance of USAID during 2008 to develop flash flood forecast technology in Northeast Bangladesh. In order to improve the accuracy of flash flood forecasting using the ADPC rainfall forecast, this project has developed hydrological models of four cross-border catchments: the Jadukata river, the Khowai river, the Manu river and the Barak river catchments in the North-East Region of Bangladesh. Figure 3-2 shows study catchments. The hydrological models of the four catchments have been developed using MIKE11 and SWAT modelling software and found that performance of model developed based on MIKE 11 is better than the performance of the SWAT model. The major findings of the study were:

- The rainfall forecast produced by ADPC do not sufficiently correspond to the sudden localized intense rainfall that occur in the cross-border catchments.
- There is no rainfall recording station within the Jadukata river and Khowai river catchments, and inadequate number of rainfall recording stations within the Manu river and the Barak river catchments;
- Except the Barak river, the basin lag time of other catchments is small, shorter than a day. Thus, daily rainfall records are not adequate for fine calibration of the models;

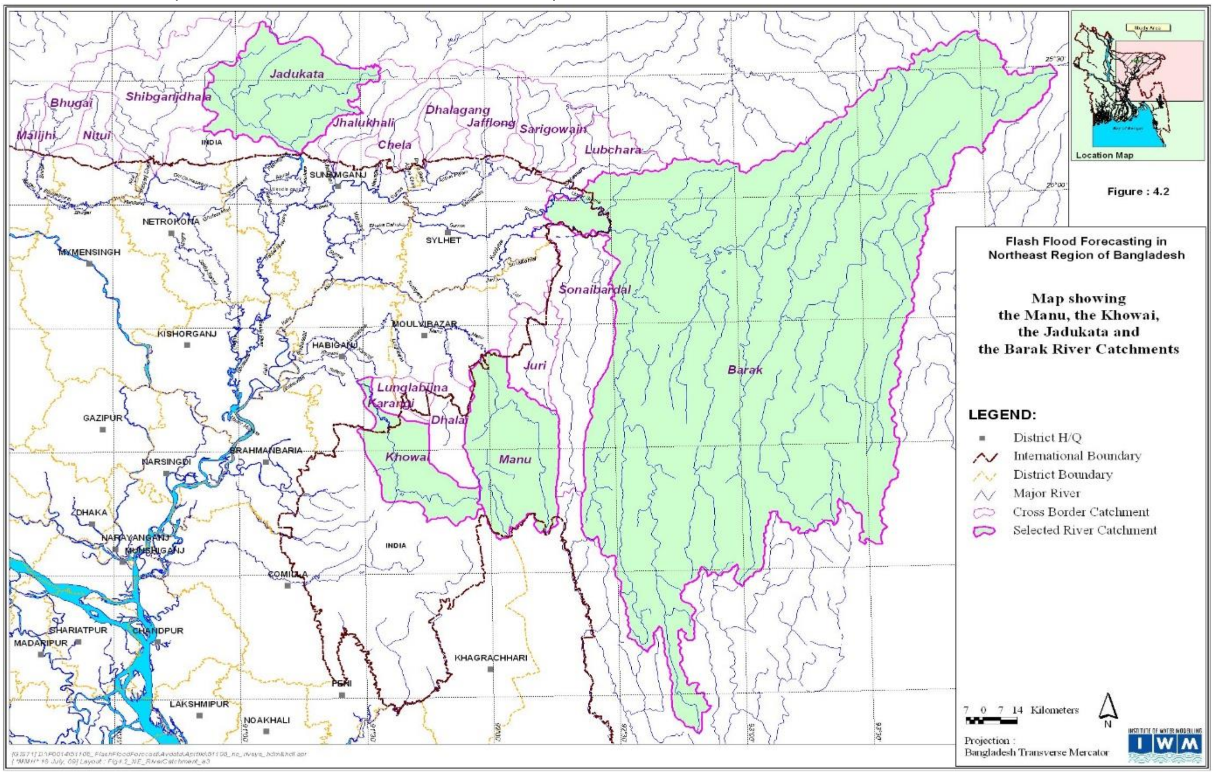


Figure 3-2: Map showing study catchments

3.2.3 Comprehensive Disaster Management Program-II Model (2014)

This research and prediction modelling study was undertaken jointly by FFWC of BWDB and IWM under Comprehensive Disaster Management Programme II (CDMP II), *project of* Department of Disaster Management (DDM) under the Ministry of Disaster Management and Relief (MoDMR). One of the objectives of the study was to d*evelop* flash flood model for selected basins of north east region of the country. The study was started on June 2011 and continued up to June 2014. A mathematical model for generating flash flood forecast (FFF) in the NE region of Bangladesh with lead time of 2 days has been developed which was based on MIKE 11 and MIKE BASIN software of DHI. The flash flood forecast was generated through combined use of real time hydro-meteorological data and Quantitative Weather Prediction (QPF) produced through simulation of Weather Research Forecast (WRF) model. The FFF model was simulated for 7 days prior (hind cast) and 3 days after the date of forecast.

Experimental forecast was generated at 8 stations located on the Surma and Kushiyara river system. The forecast products comprised flood forecast hydrographs as well as flood bulletin. The lead time of forecast was 2 days. Performance of flash flood forecast at different stations observed in 2013 was almost satisfactory. However, this study found that real time data made available both from public domain and FFWC are not sufficient. Satellite estimated rainfall available so far was not found to be effective in generation of flash flood forecast in northeast Bangladesh. It is expected that installation of additional real-time rainfall recording stations following periphery of the northeast region could enhance the performance of flash flood forecast.

3.3 Updating of Flash Flood Forecast (FFF) Model

The Flash Flood Forecast Model developed in the CDMP-II study has been utilized in this project with necessary updating, adjustment and expansion. Model updating is a continuous process specifically for morpho-dynamically active river system like in North East region of Bangladesh. Three separate modules of one-dimensional mathematical modelling tool developed by DHI, Denmark have been utilized in carrying out this study. The modules are Rainfall-Runoff (MIKE11 NAM) for hydrological modelling, One-dimensional River Model (MIKE 11 HD) for hydraulic modelling of North-East Region, Bangladesh and Barak Basin, India coupled with flood forecast module (MIKE 11 FF) for flood forecasting. The Rainfall-Runoff model coupled with Hydrodynamic model for North-East Region operated with flood forecast module is combinedly called as “Flash Flood Forecast Model” under this study.

3.3.1 Rainfall-Runoff Model

Flash flood in the Northeast Bangladesh occurs from the inflow coming from the cross-border catchments. The cross-border catchments are located within India and thus to capture this inflow, application of hydrological models is very important. Hydrological model considering these catchments have been developed incorporating all collected data and information and Mike 11 NAM have been utilized as model tool. The hydrological component (NAM) of the NERM comprises 39 sub catchments inside Bangladesh and 18 cross-border sub catchments within India except the Barak river basin. The internal catchments are classified into two classes: Flood Cell catchments and Flood Plain Catchments. Based on nature and location, the flood plain catchments are categorized in four groups. The main basis for such division is the difference in the time required for routing the runoff. Figure 3-3 shows sub-catchments in the hydrological model.

On the other hand, Barak Basin is the largest flow contributor in the Meghna Basin. The Barak Basin itself comprises of 8 catchments and combined runoff enters Bangladesh border near at Amalshid through hydrological routing. Thus, separate hydrological model has been developed for Barak Basin and finally coupled with separate hydrodynamic model called “Barak HD Model”. However, to ease the modelling activities all 65 catchments are simulate simultaneously. Total 71 nos. station rainfall data collected from FFWC, BWDB and Indian

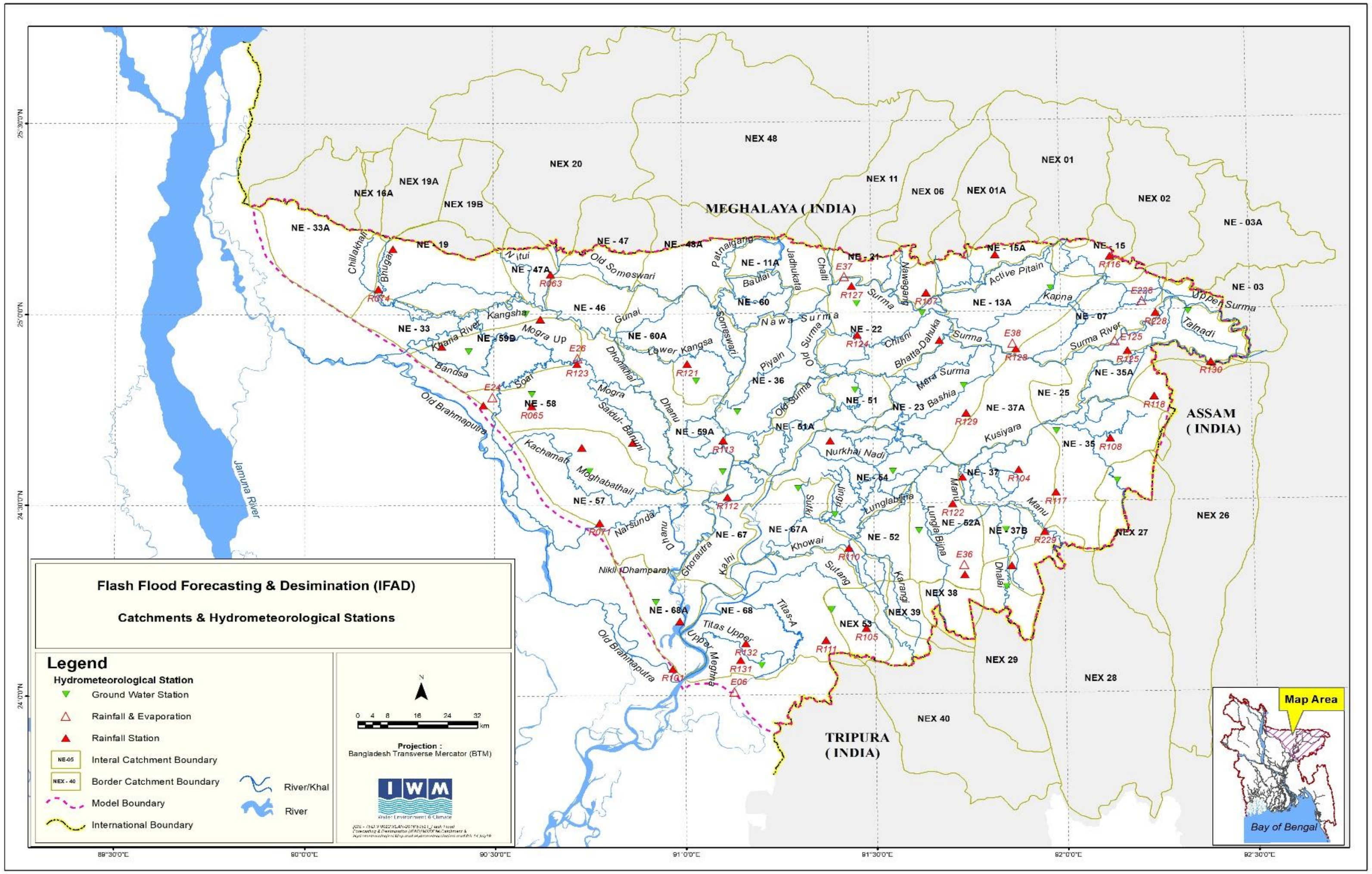


Figure 3-3: Map showing Sub-catchments of North East Region

Meteorological Department (IMD) websites are utilized for this rainfall-runoff model. The rainfall distribution map along with Thiessen-Polygon lines of North-East Bangladesh and Barak basin are shown in figure 3-4 and 3-5 respectively.

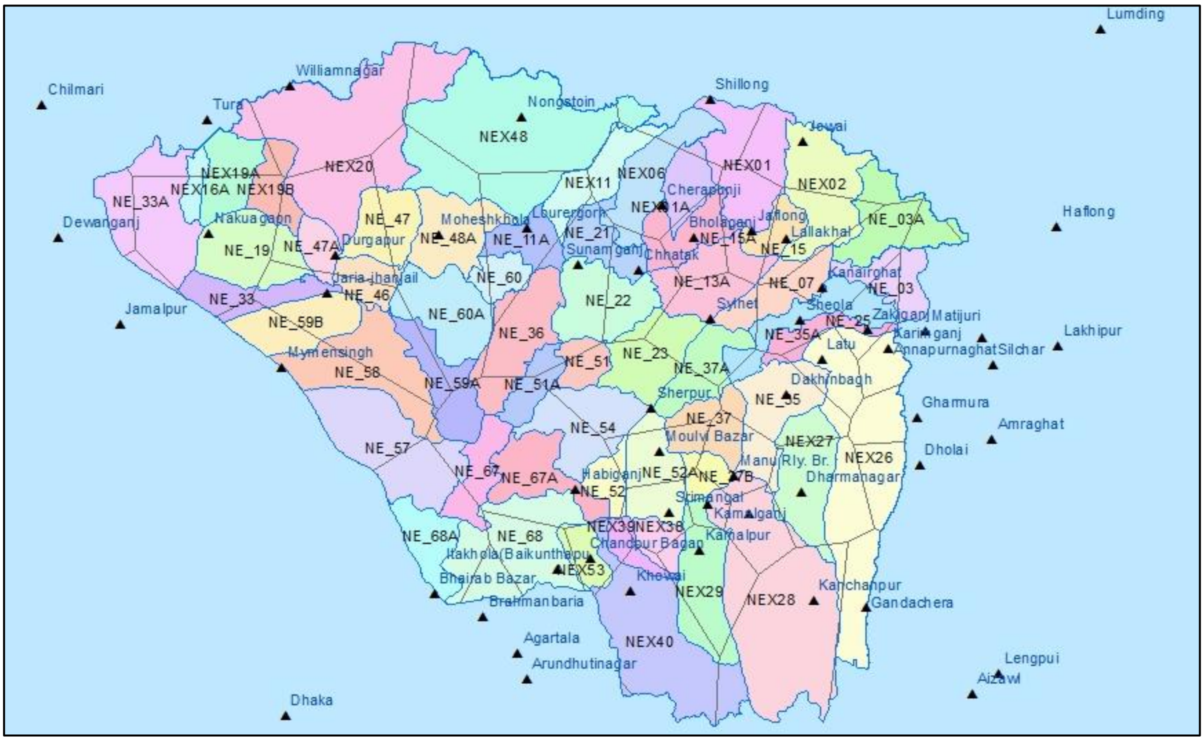


Figure 3-4: Map showing Thiessen Polygons generated based on Real-time Rainfall data collected from Indian websites and FFWC, BWDB for Meghalaya, Tripura and NE Bangladesh

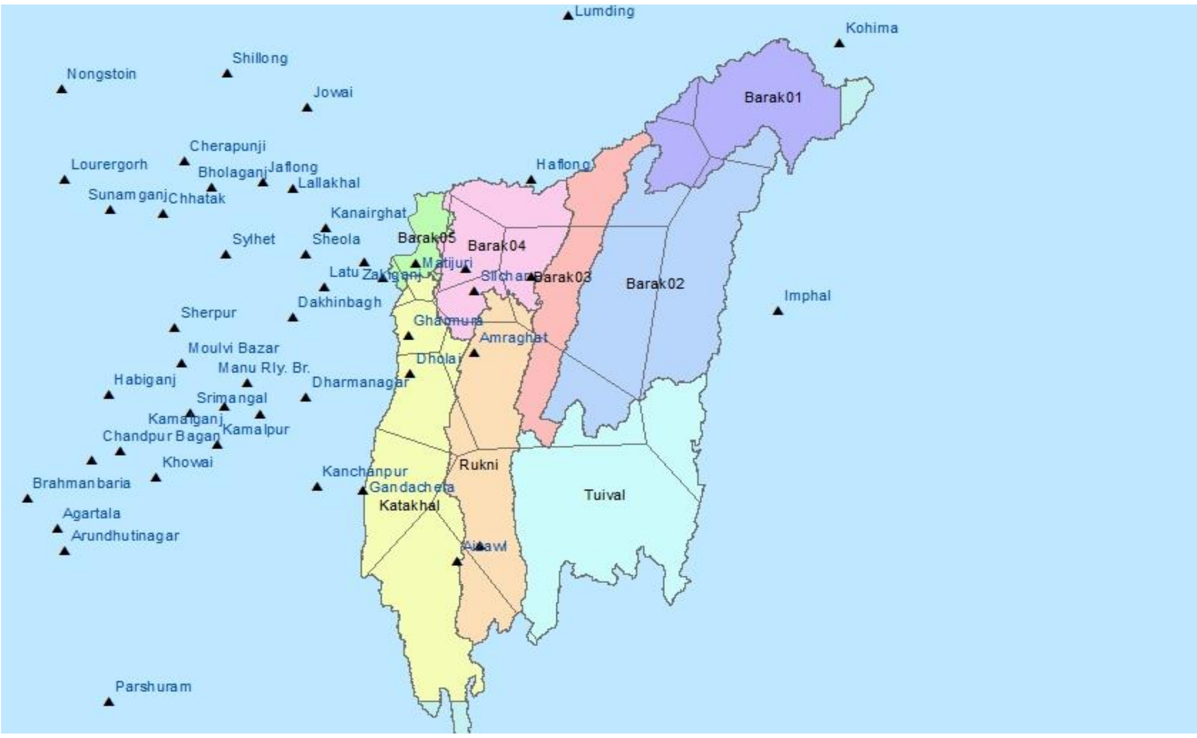
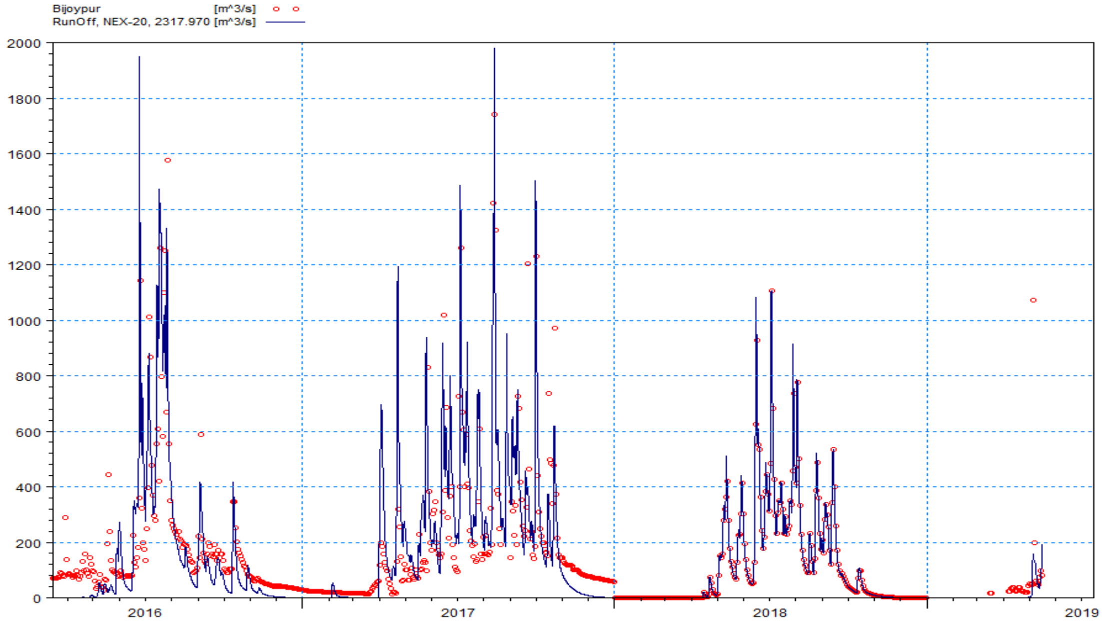


Figure 3-5: Map showing Thiessen Polygons generated based on Real-time Rainfall data collected from Indian websites and FFWC, BWDB for Barak Basin

Parameters of hydrological model (NAM) have been calibrated extensively during 1999-2000 and updated from 2016 to 2018 under this project. Also, refinement of parameters, depending on observed data and information, have been accomplished during various validation projects carried out from 2006 to 2017 at IWM. The developed and updated hydrological model have been checked with observed and rated discharge at various catchment outlets and found satisfactory. Figure 3-6 shows comparison plots at catchment outlet of NEX-20 and 2 at Bijoypur and Sarighat respectively.



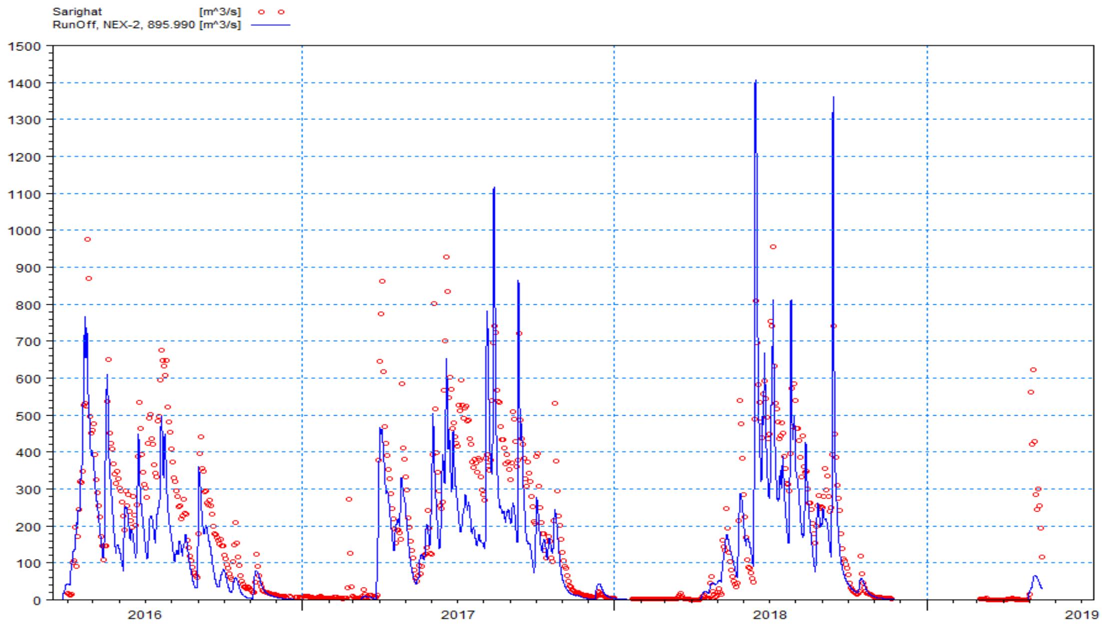


Figure 3-6: NAM Model outputs at Bijoypur and Sarighat at Outlet of Catchment NEX-20 & 2

3.3.2 Hydrodynamic Model of North-East Bangladesh

A detailed hydrodynamic model incorporating rivers and haors of North-East Region computes the water level and discharges at different locations of the region. MIKE 11 HD have been utilized as model tool for developing hydrodynamic river network model for NE Bangladesh. Receiving inflows from Indian catchments (Meghalaya, Barak and Tripura Basins), these runoff passes through Bangladesh and generates flash flood. Figure 3-7 shows the extent of North East Region Model. The northeast region model (NERM) was developed in early 1991 under the Surface Water Simulation Modelling Program Phase-II (SWSMP II), and since then it has been checked for validation for 24 hydrological years (from 1993 up to 2016).

The model comprises an area of about 24,265 sq. km. In addition to its self-area, the region receives external inflows from cross border catchments: the Barak river basin (26,567 sq. km), the Meghalaya river basin (13,466 sq. km.) and the Tripura river basin (6,845 sq. km) located in India. The hydrodynamic component (HD) of the NERM comprises a total of 4200 km river reaches having total river cross sections of around 4180 nos. There are 23 upstream boundaries and one downstream boundary in the model. In addition to the significant rivers, the model also includes representative flood routing channels for significant floodplains and haor areas.

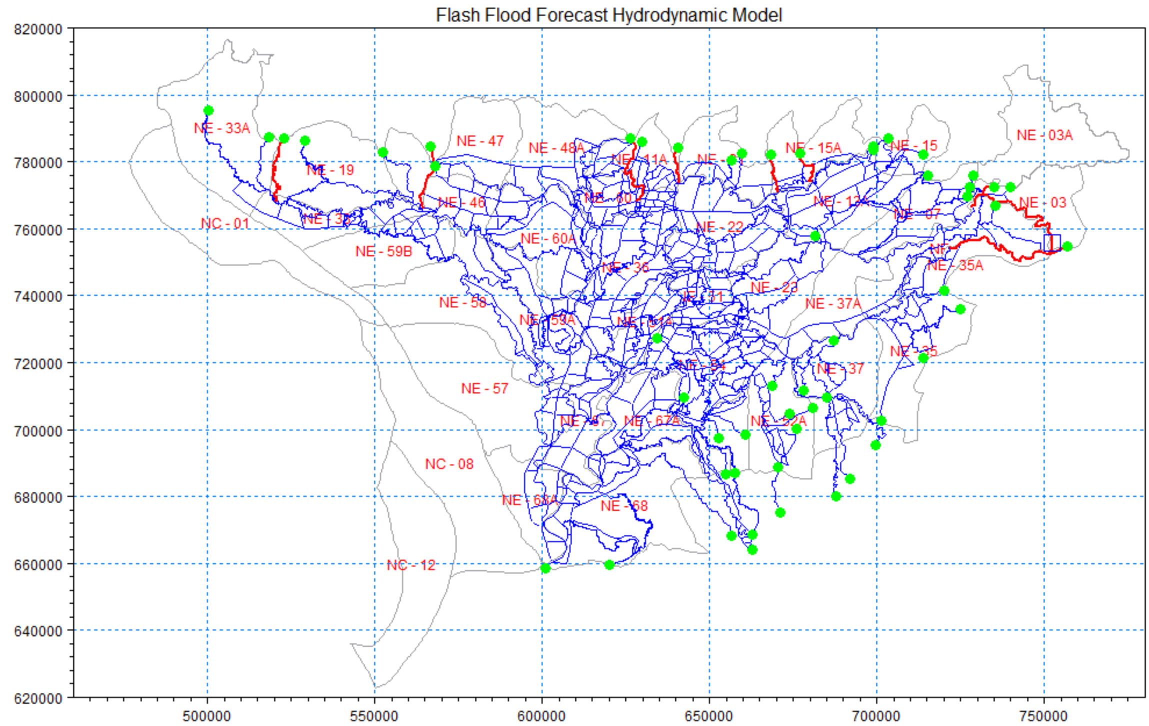
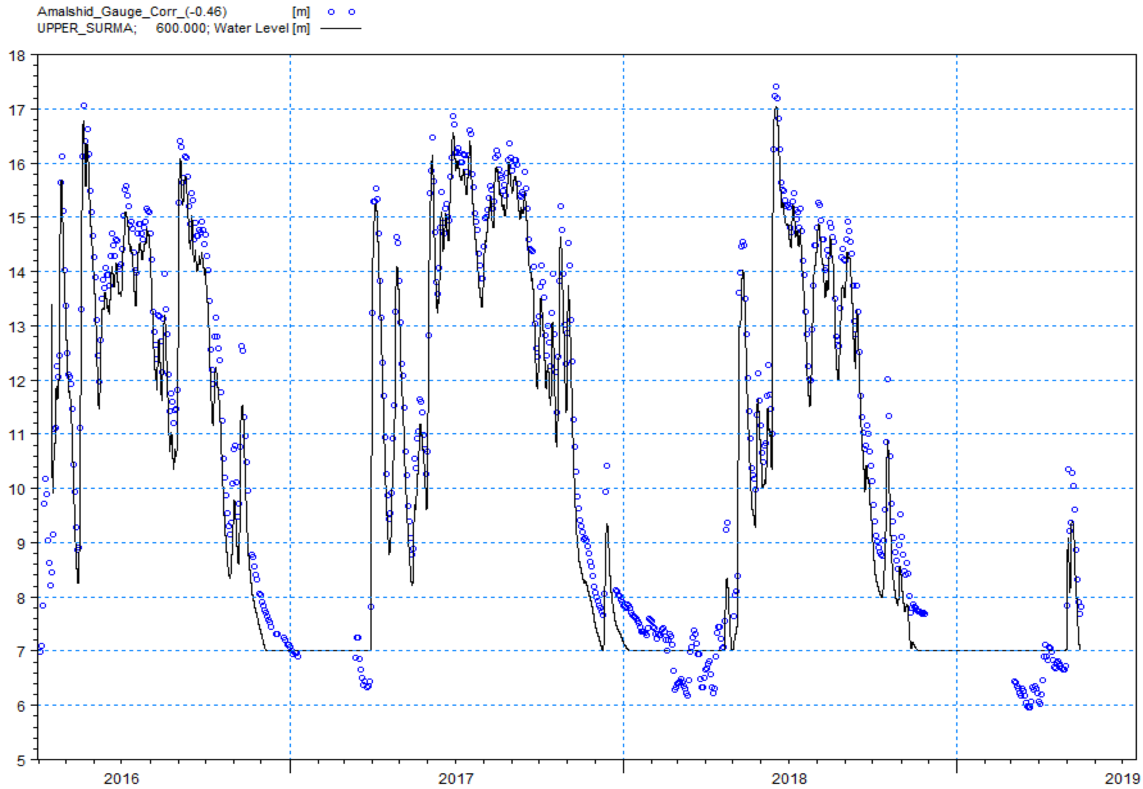
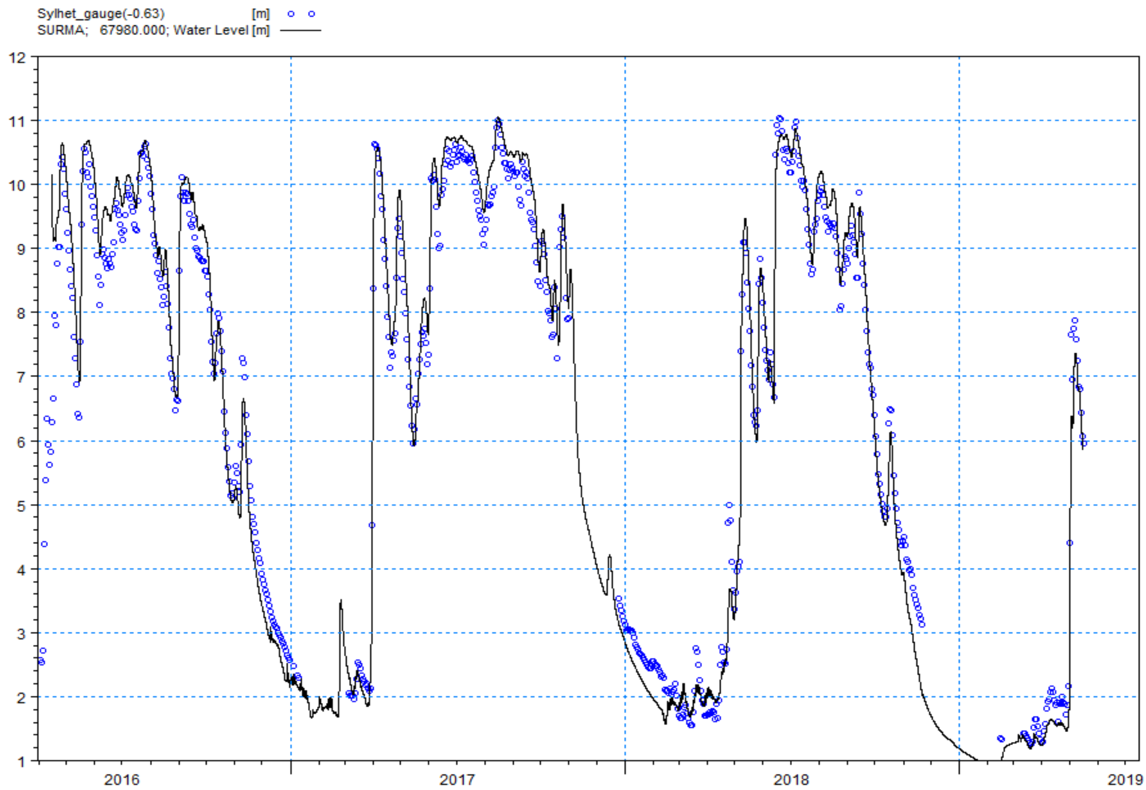
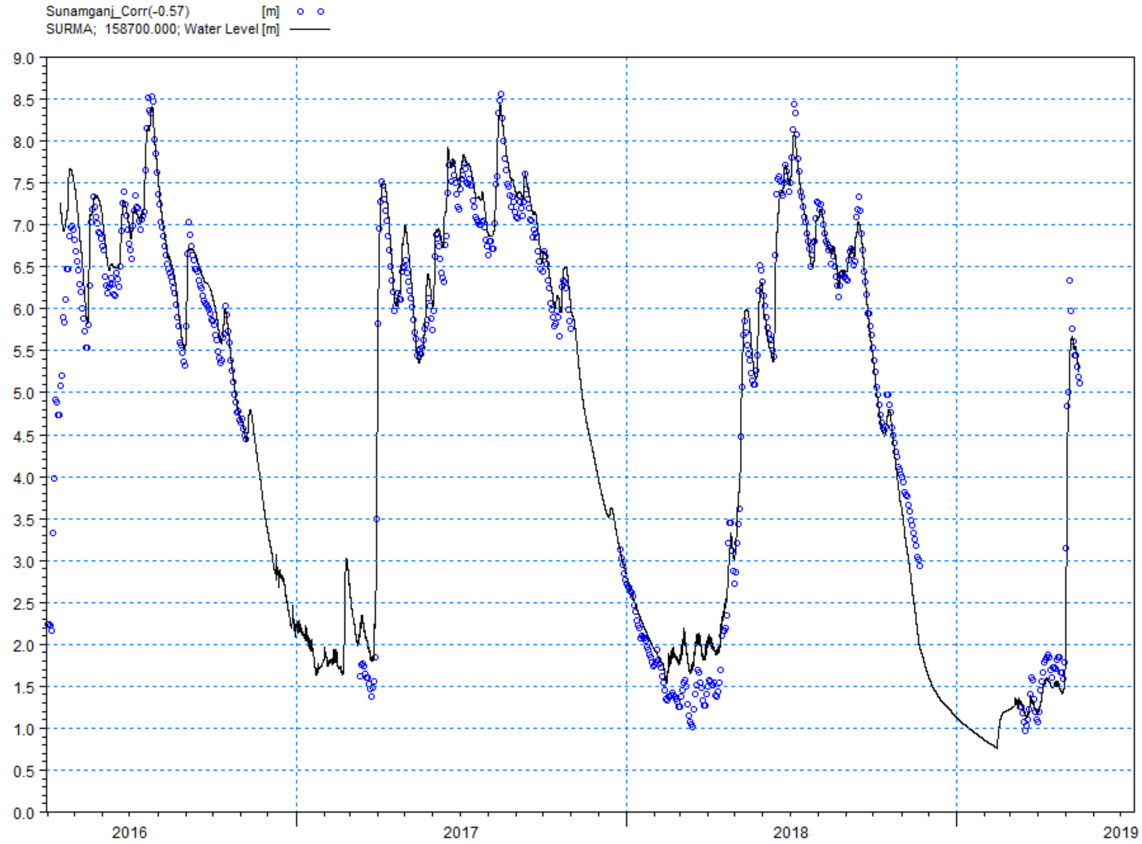


Figure 3-7: Hydrodynamic Network Model of North-East Region

The NE region model is a unique one compared to other region models of Bangladesh. For representation of vast haor areas, around 1400 km reach of floodplains are incorporated in the model where bathymetry is taken from existing Digital Elevation Model (DEM) available in IWM. BWDB haor projects are already incorporated in the model as storage and routing channels taking into account submersible embankments, control structures, bridges and culverts. Link channels are incorporated for allowing spillage through breaches as well as over topping of banks of rivers/khals, and flow over submersible embankments. Figure 3-8 shows hydrodynamic model comparison plots at Amalshid, Sylhet, Sunamganj and Gowainghat.







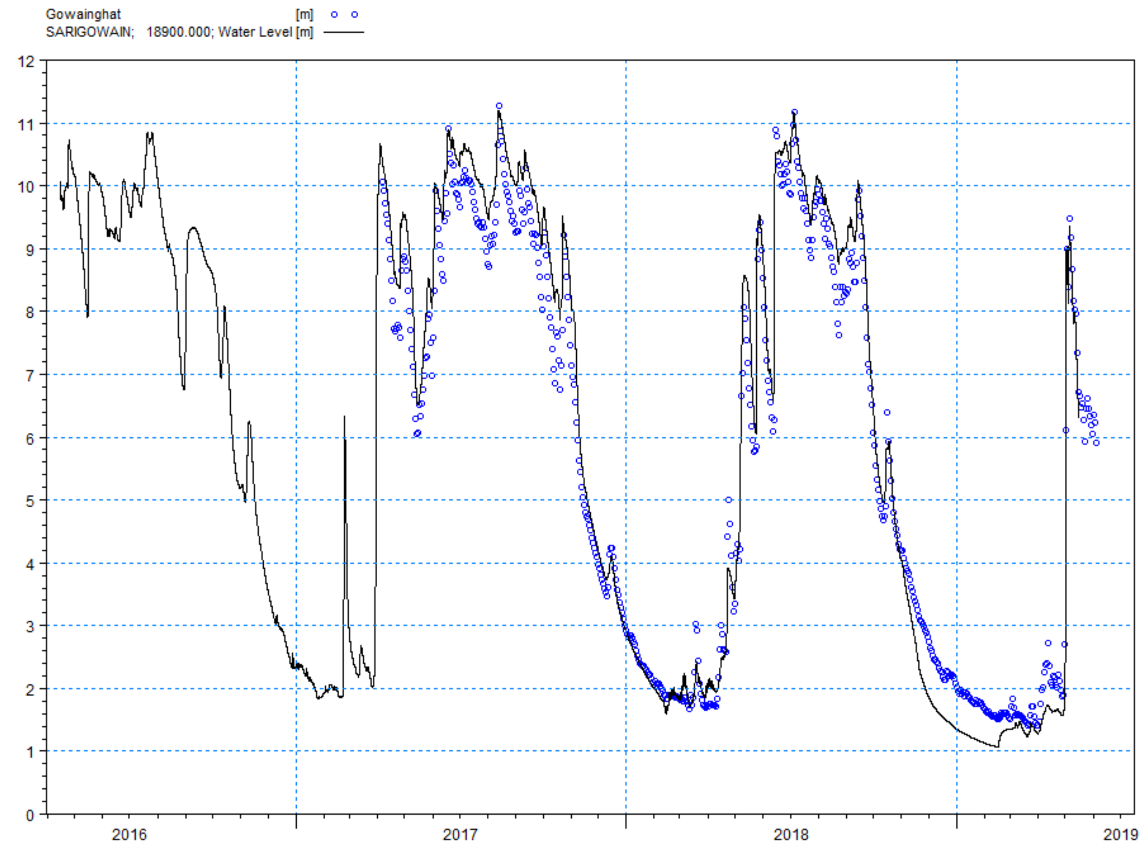


Figure 3-8: Hydrodynamic Model Comparison Plots

3.3.3 Hydrodynamic Model of Barak Basin

One of the major inflow points for the North-East model is Amalshid, through which Barak basin drains runoff to the Meghna river system. Barak Basin itself comprises 26567 sq. km of area and several separate catchments contribute to the Barak River flow. This combined runoff enters Bangladesh border near at Amalshid through hydrological routing. However, separate HD model for Jadukata basin and other small catchments won't be effective as travel time is very short and won't provide any operational lead-time. Thus, separate HD model for only Barak basin has been considered. Under CDMP-II project, a basin model based on MIKE Basin software has been developed for boundary estimation and operational flood forecasting of Barak Basin. However, as FFWC don't poses any Basin Modelling software, thus, a hydrodynamic model considering Barak River system has been developed. MIKE 11 HD have been utilized as model tool. A hydrodynamic model of the Barak River reach extending from its origin to Amalshid (362 Km) has been developed. Around 125 cross-sections of the Barak River have been generated and incorporated in the model due to unavailability of measured cross sections. The cross-sections have been generated based on longitudinal slope, average bed width, available lowest water level, etc. collected from Tipaimukh Dam Study. Table 3-1 shows criteria for generated cross-sections while Figure 3-9 shows a typical assumed cross-section of the Barak River.

Table 3-1: Values of parameters assumed for generating cross-sections of the Barak River

Location	Chainage (Km.)	Average Bed level (meter)	Lowest Water Level (meter)	Top Width (meter)	Bed width (meter)
Tipaimukh	0	19	22	85	50
Amalshid	210	0	6	200	100

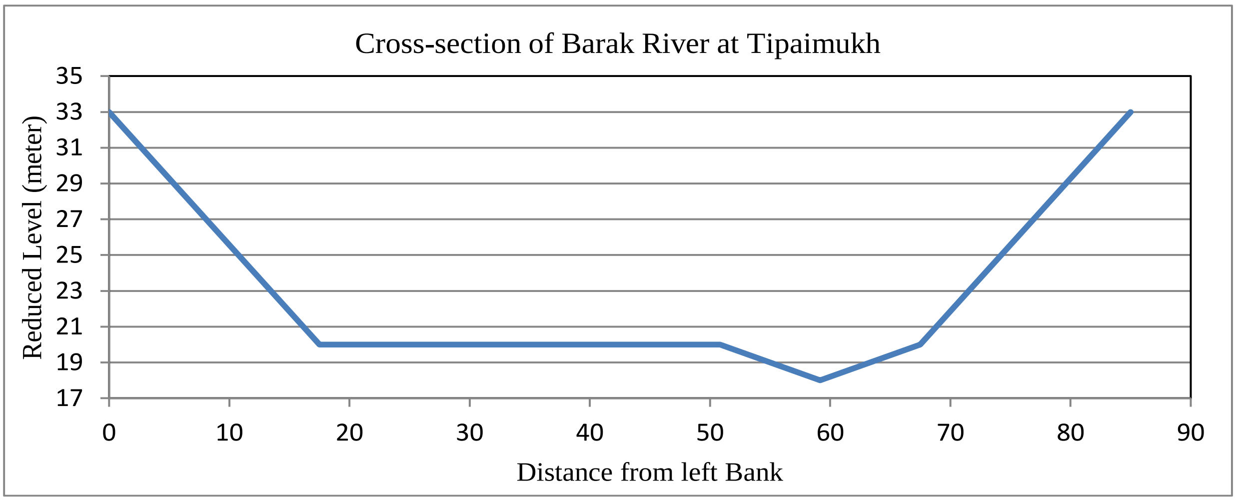


Figure 3-9: A typical assumed cross-section of the Barak River

Barak HD model comprises the entire watershed of the Barak River up to bifurcation of the river at Amalshid of Zakiganj, Sylhet. The Barak Basin (26567 sq. km.) and its sub-catchments (8 nos.) have been delineated using SRTM land terrain data. Gauge observed daily rainfall data at 20 stations of last 4 years (2016-2019) collected from public domain (websites) and month wise mean daily pan evaporation data at three stations: Karimganj, Shillong and Imphal have been used for calibration of the model. Table 3-2 provides the catchment area while Figure 3-10 shows the sub-catchments and network used in the model.

Table 3-2: List of Sub-Catchments of Barak Basin

Catchment Name	Catchment No	Area (Sq. Km)	Catchment Name	Catchment No	Area (Sq. Km)
BARAK-1	6	2721.85	BARAK-5	3	473.49
BARAK-2	5	5345.45	TUIVAL	1	4868.3
BARAK-3	7	1835.76	RUKNI	2	3212.41
BARAK-4	4	2265.87	KATAKHAL	8	5002.82

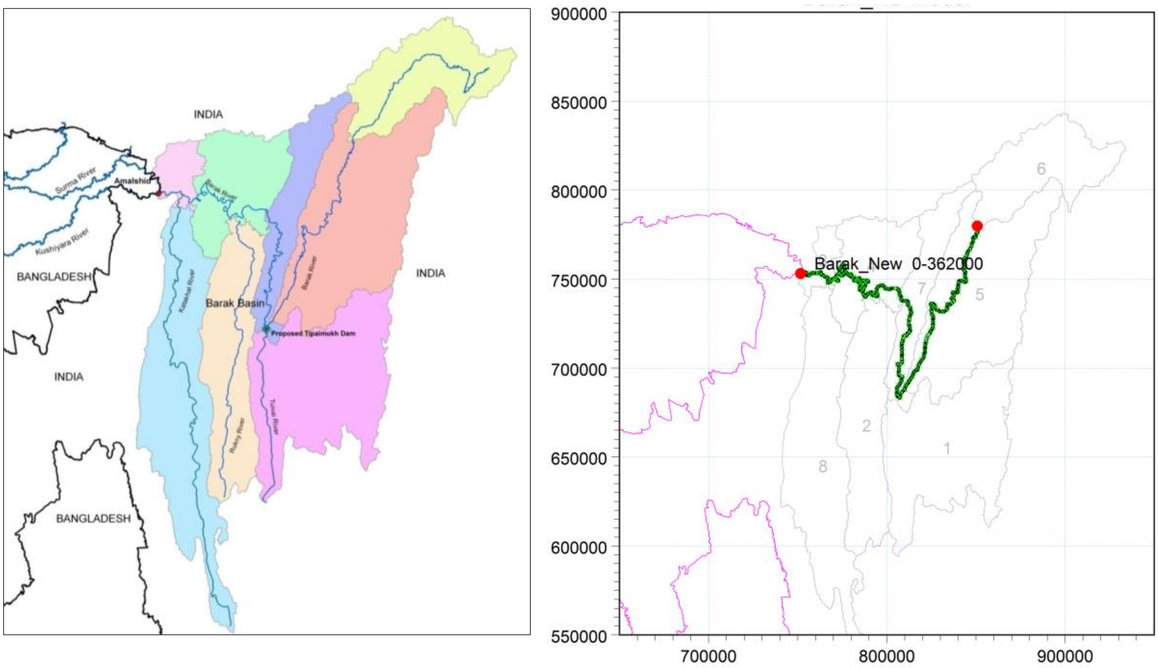


Figure 3-10: Barak Hydrodynamic Model

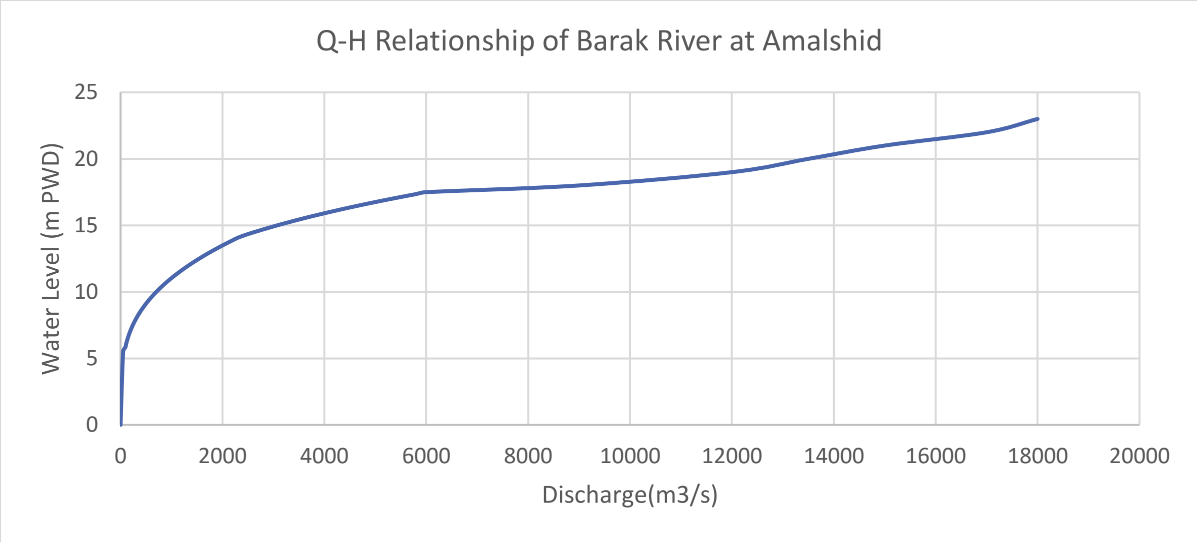
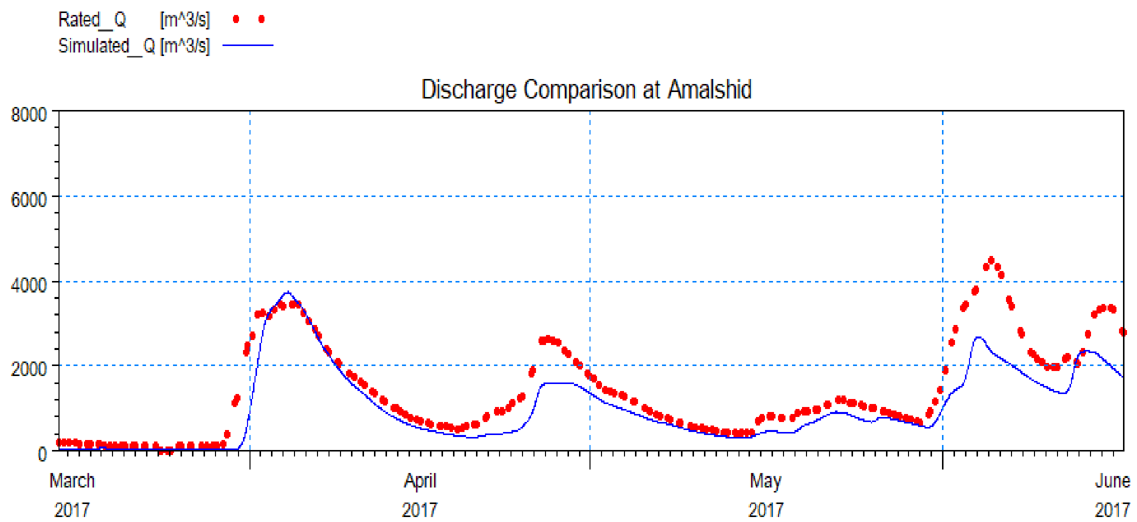


Figure 3-11: Q-H Relationship of Barak River at Amalshid

The Barak HD model uses Q-H relationship at Amalshid and incorporates rainfall generated runoffs as open boundary and point source boundary respectively. Figure 3-11 shows Q-H relationship at Amalshid. The resistance parameters, Manning's M has been assumed to be 30 for the entire river reach. The parameters of the model have been calibrated by comparing the model simulated discharge against available rated discharges at Amalshid. The model would be better calibrated if sufficient hydro-meteorological and topographic data is made available from India. Comparison plots of model simulated and rated discharges as well as water level at Amalshid are given in Figure 3-12.



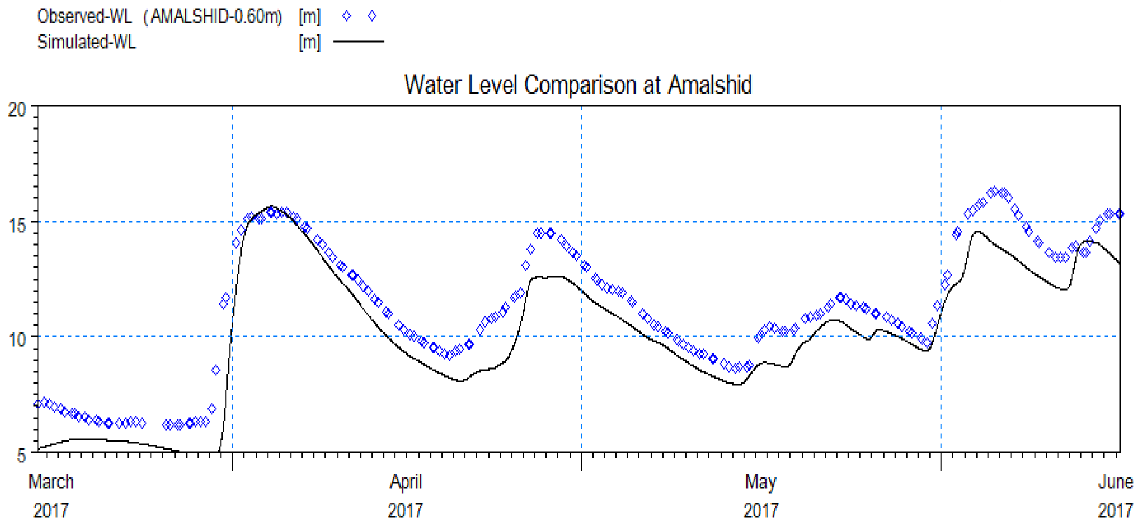


Figure 3-12: Comparison plots at Amalshid

3.3.4 Flood Forecast Module (FF)

The MIKE 11 Flood Forecasting Module (MIKE 11 FF) has been designed to perform the calculations required to predict the variation in water levels and discharges in river systems as a result of catchment rainfall and runoff and inflow / outflow through the model boundaries. Figure 3-13 shows forecast module of the Flash Flood Forecast Model and figure 3-14 shows boundary estimation tab of Forecast Module (FF). The MIKE 11 FF module includes:

- Definition of basic FF parameters
- Definition of boundary conditions in the forecast period (Forecasted boundary conditions)
- Definition of Forecast stations
- An updating routine to improve forecast accuracy. The measured and simulated water levels and discharges are compared and analyzed in the hind cast period and the simulations corrected to minimize the discrepancy between the observations and model simulations

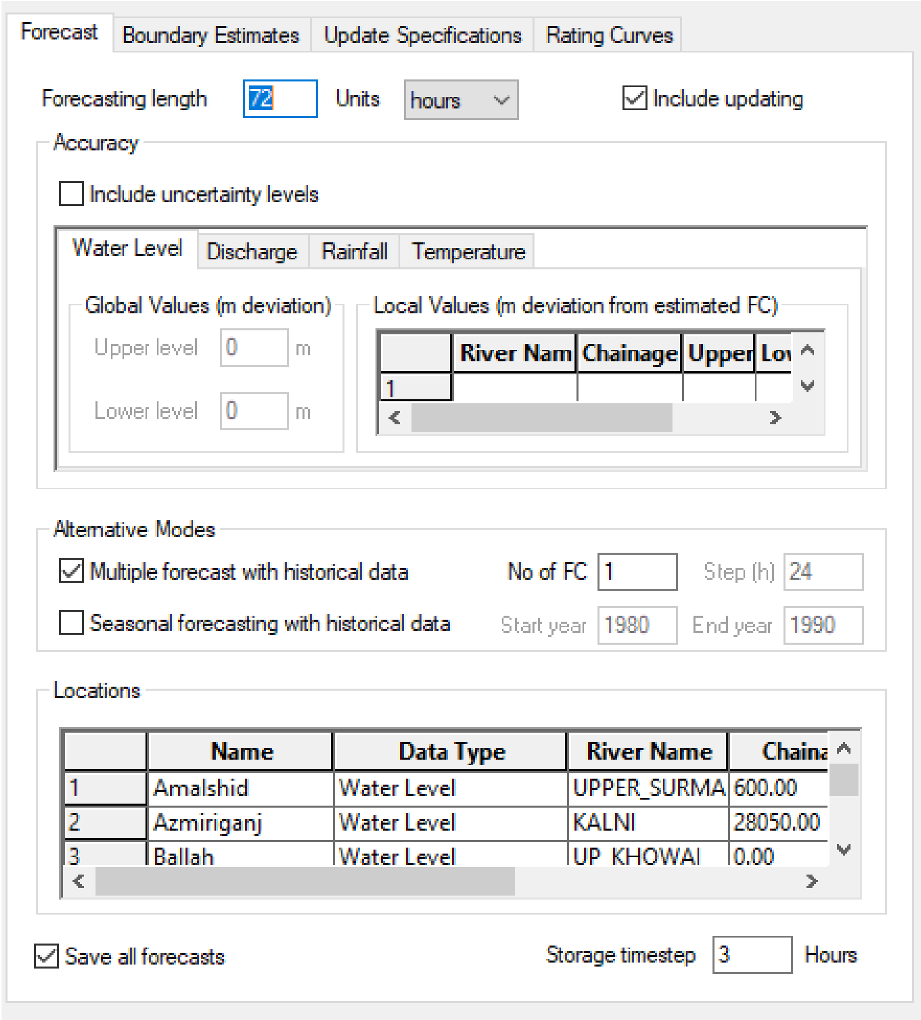


Figure 3-13: Forecast Module of the Flash Flood Forecast Model

The Time of Forecast (ToF) is defined in relation to the Hind cast and the Forecast Period. The Hind Cast Period defines the simulation period up to ToF and is specified in the simulation file or calculated by the system. Under this study, 7 days hind cast and 3 days forecast period is applied. The length of hind cast and forecast periods are defined as hour in this setup.

The Boundary conditions estimated after the Time of Forecast are obviously uncertain. The effect of a specified uncertainty level can be included in the simulations. Simulated water level or discharge at a forecast point is extracted from the MIKE 11 HD result file and stored together with the "Danger level" as individual time series files (dfs0 format), one file for each forecast point (location). The purpose of updating is to evaluate and eliminate deviations between observed and simulated discharges/water levels in the Hind Cast Period to improve the accuracy of the model results in the Forecast Period. Phase and amplitude errors are identified by the updating routine and corrections in the hind cast and the forecast period are subsequently applied. However, under this study, a limited updating is applied only where necessary.

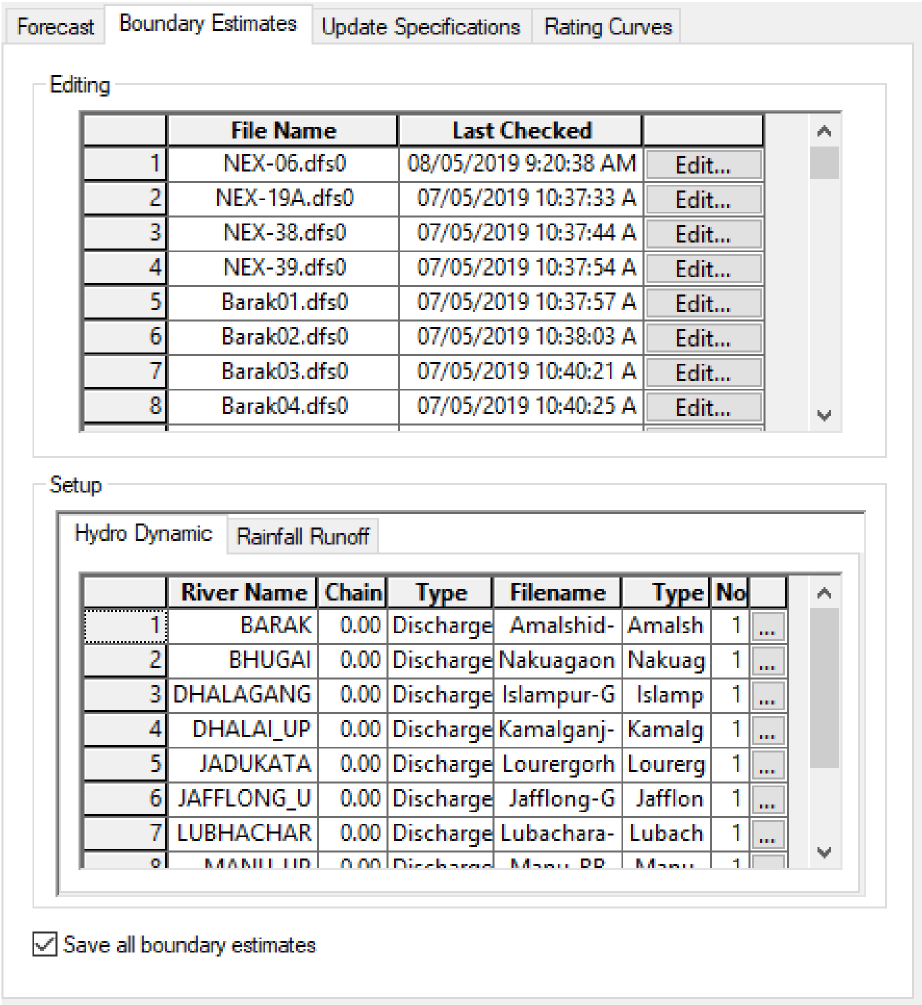


Figure 3-14: Boundary Estimation Tab of Forecast Module (FF)

3.4 Calibration and Validation of FFF Model

Model calibration and validation is a continuous process. The forecast performance largely depends on the calibration of the forecast model. The Flash Flood Forecast model has been calibrated for 2017 flash flood event and validated for 2016 and 2018. After satisfactory calibration and validation, this flash flood forecast model has been made operational to forecast 2019 flash flood event.

Parameters of hydrological model (NAM) have been calibrated extensively during 1999-2000 and updated from 2016 to 2018 under this project. Also, refinement of parameters, depending on observed data and information, have been accomplished during this study. The NAM model has been calibrated based on observed discharge data at the catchment outlet compared with simulated runoff generated from NAM Model. Emphasis on calibration has been given to the external catchments than to internal catchments. NAM calibration in this study largely implies on adding or considering new real-time rainfall stations data in the North-East Region. For example, earlier catchment NEX-2 was simulated using three rainfall stations; one from India and two from Bangladesh and their weightage factors were as follows.

Jowai, India	Kanaighat, Bangladesh	Sheola, Bangladesh	Total Weightage
0.73	0.22	0.05	1

However, due to missing information of rainfall from station Jowai, model generated runoff shows under simulation with large margin. Also, the most significant Lalakhal Rainfall station for this catchment was not included as real-time station and Kanairghat and Sheola are far from this catchment influential area and was not able to capture the total runoff. Hence in this study, Lalakhal rainfall station has been included and considered in the weightage calculation. Two options have been prepared; one with having Indian Rainfall data at Jowai and another having no Indian rainfall data at Jowai.

Option	Jowai, India	Kanaighat, Bangladesh	Lalakhal	Total Weightage
Opt-1 (With Indian data)	0.57	0.04	0.39	1
Opt-2 (Without Indian data)	0.00	0.04	0.96	1

It was then observed that even without Indian data and having real-time data at Lalakhal, the NAM model could capture around 85-90 % of total runoff generated in the catchment NEX-02. Figure 3-15 and 3-16 shows the simulated runoff of catchment NEX-02 without and with lalakhal rainfall data and using revised weightage factors as well as calibrated parameters respectively. The list of parameters is shown in Table 3-3.

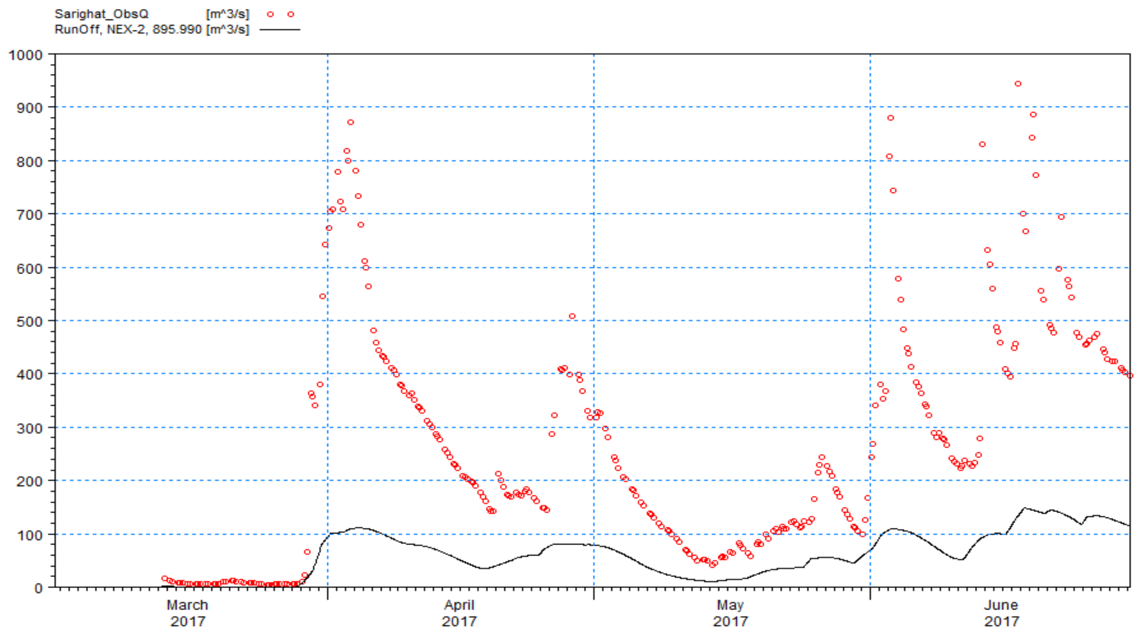


Figure 3-15: Under Simulated Runoff at Catchment NEX-02 with old weightage factor and data

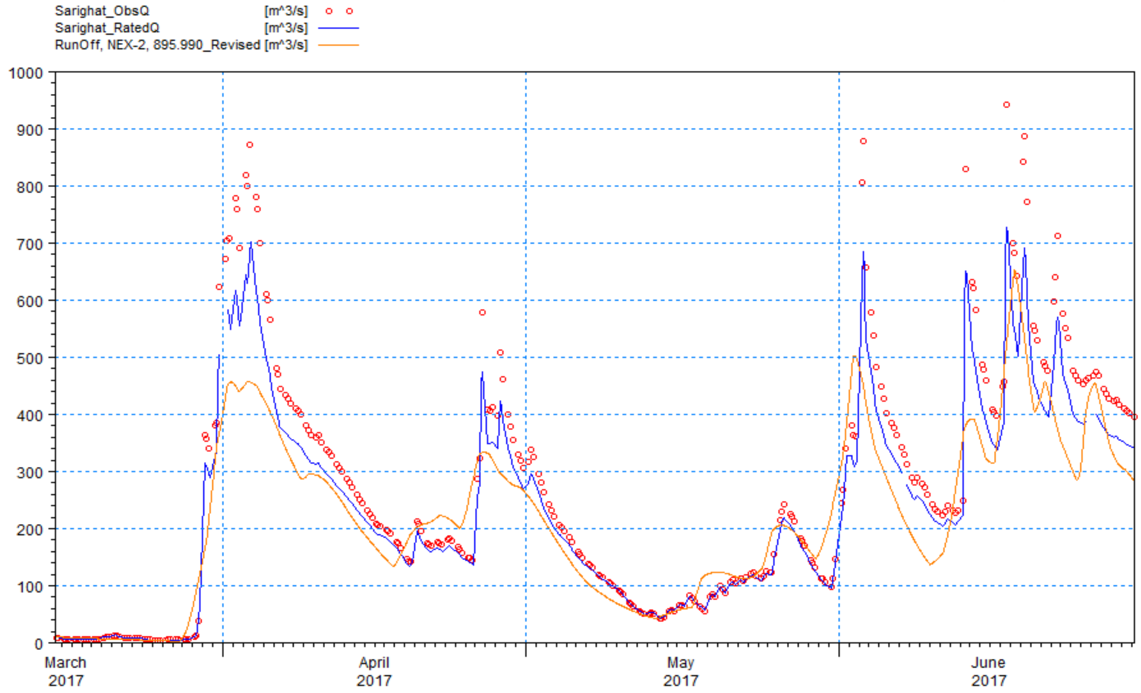


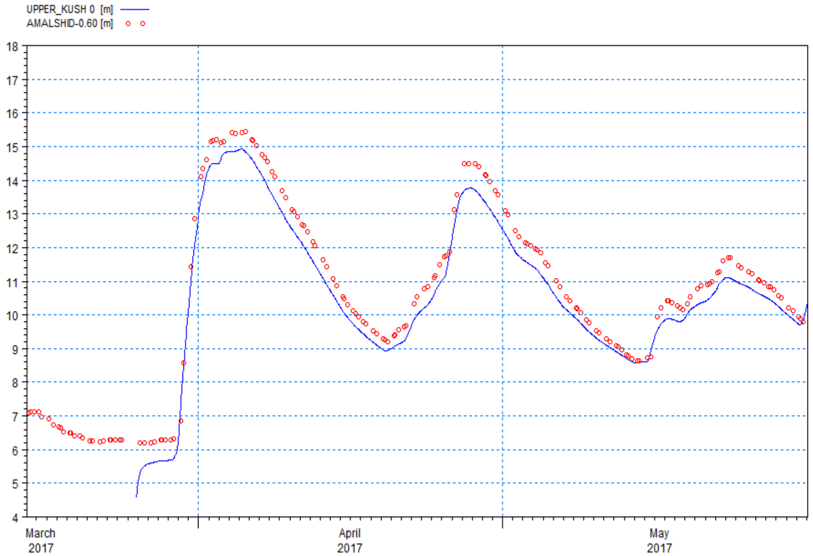
Figure 3-16: Simulated Runoff at Catchment NEX-02 with revised weightage factor and input

Table 3-3: NAM Model Parameters

Name	Range	Sy	KO-inf	TG	GWLBF0	CKIF	CKBF	CKIF	CK1,2
Internal Catchments of North East Region	Min	0.05	0.08	0.5	1.25	12	400	12	24
	Max	0.07	0.25	0.5	4	50	1200	50	400
External Catchments of North East Region Except Barak	Min	0.1	1	0	10	100	300	100	12
	Max	0.1	1	0.99	10	946	3955	946	300
External Catchments of Barak Basin	Min	0.1	1	0.3	10	500	1000	500	12
	Max	0.1	1	0.4	10	500	1700	500	72

On the other hand, Initially the hydrodynamic model of North-East region has been calibrated in 2016 and validated in 2017. However, the validation suggests that the north-east region model requires re-calibration at some stations specially after 2017 devastating flash flood event. Later, the Flash Flood Forecast model has been calibrated for 2017 flash flood event and validated for 2016 and 2018. The model validation shows good agreement in most cases (19 stations namely Amalshid, Azmiriganj, Ballah, Fenchuganj, Kalmakanda, Kanaighat, Khaliajuri, Lourergorh, Manu RB, Markuli, Sarighat, Sherpur, Sunamganj, Sylhet, Moulvibazar, Sheola, Islampur, Jariajanjail and Gowainghat), satisfactory agreement in some cases (Habiganj, Muslimpur and Sutang) while in some cases (Nakuagaon, Durgapur and Kamalganj) the validation founds as poor. The reason behind these mismatches are mostly boundary conditions as developed rating curves often failed to capture the actual discharge due to unstable cross-sections at the border (Abrupt erosion of river bed due to mining in the sand quarry). Also, unavailability of quality discharge data often leads to utilize backdated rating equations. Figure 3-17 shows Calibration Plots of Flash Flood Forecast Model for 2017 at

Amalshid, Fenchuganj, Kalmakanda, Khaliajuri, Lourergorh, Manu Railway bridge, Sunamganj and Sylhey. Figure 3-18 and 3-19 shows validation plots of Flash Flood Forecast Model for 2016 and 2018 respectively at several stations.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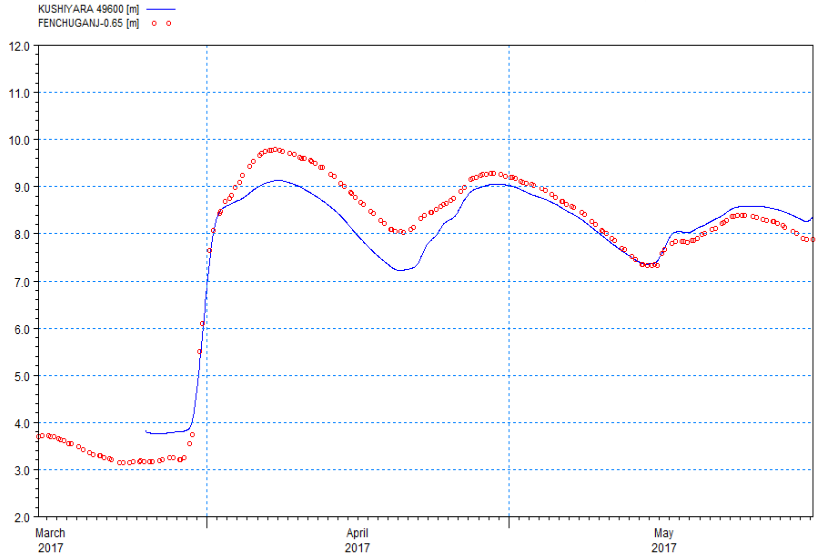
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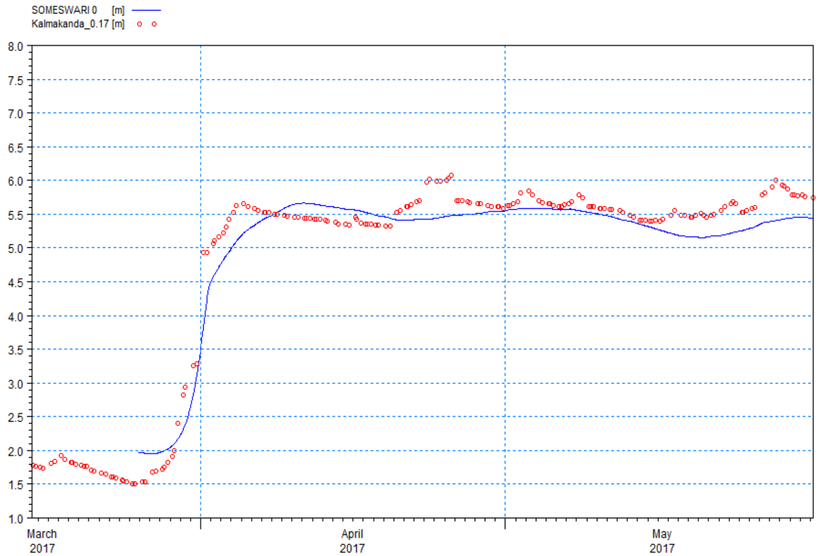
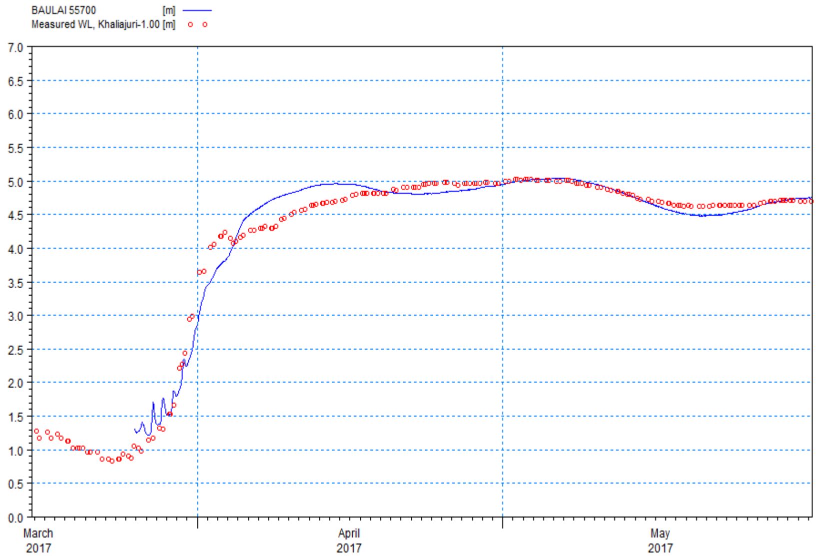
April 2017
May 2017


SOMESWARI 0 [m]
Kalmakanda_0.17 [m]
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
March 2017
April 2017
May 2017


BAULAI 55700 [m]
Measured WL, Khaliajuri-1.00 [m]
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
March 2017
April 2017
May 2017

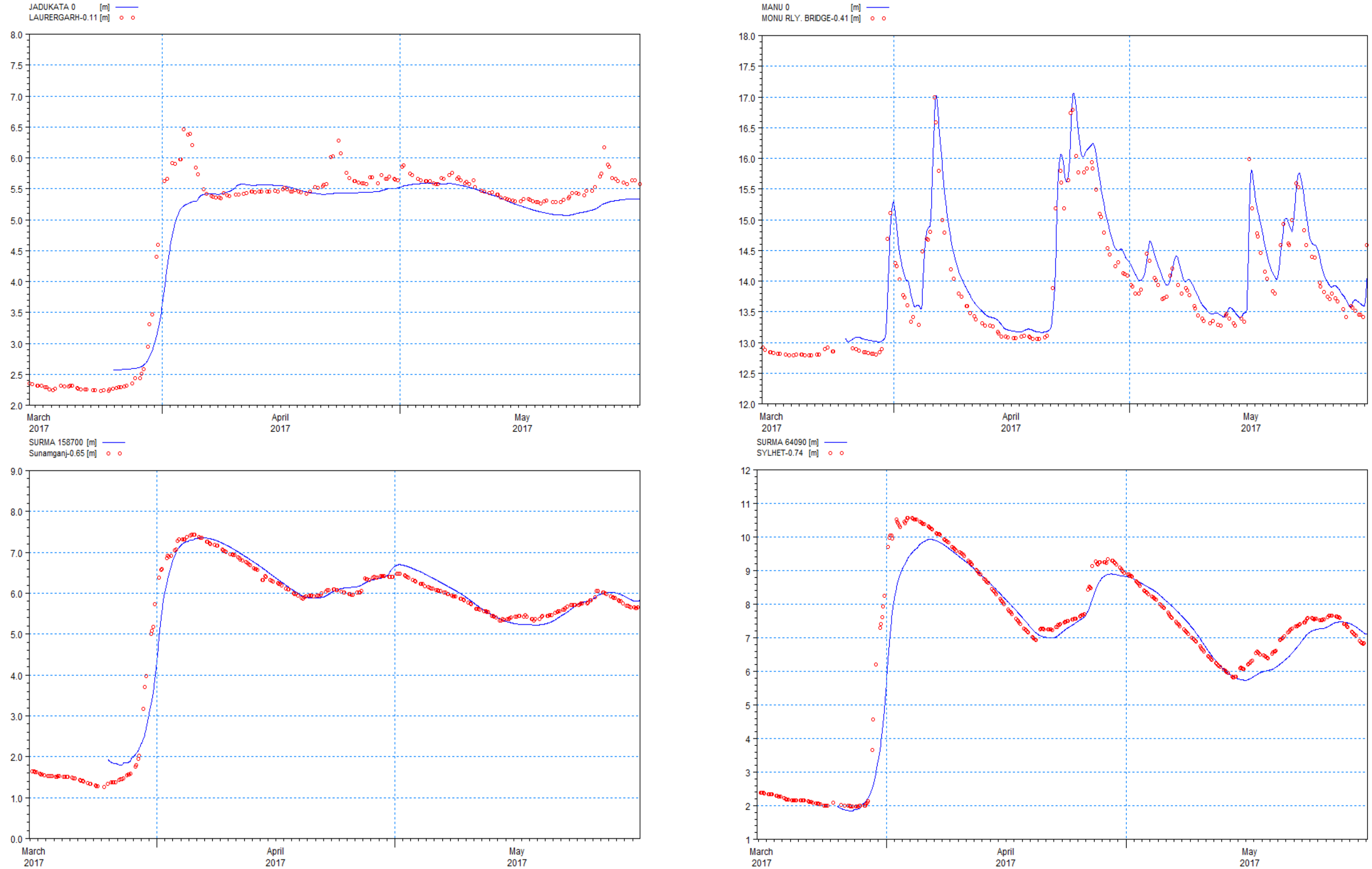
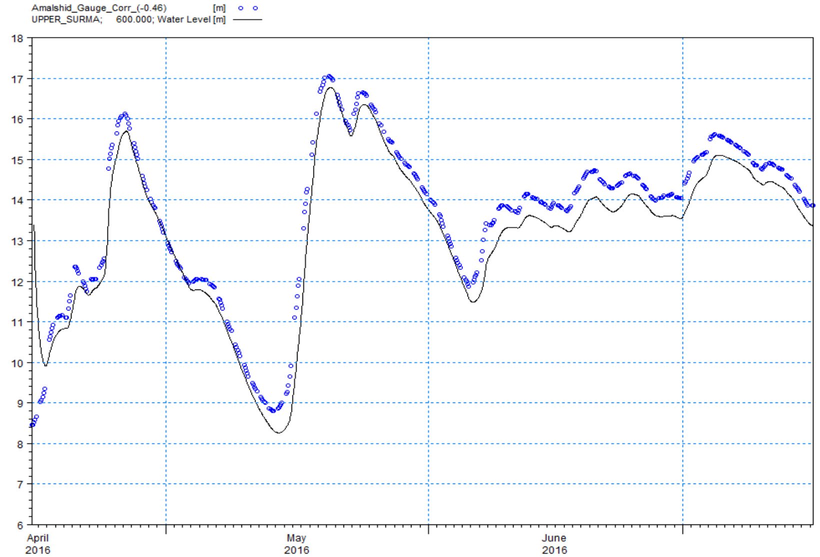
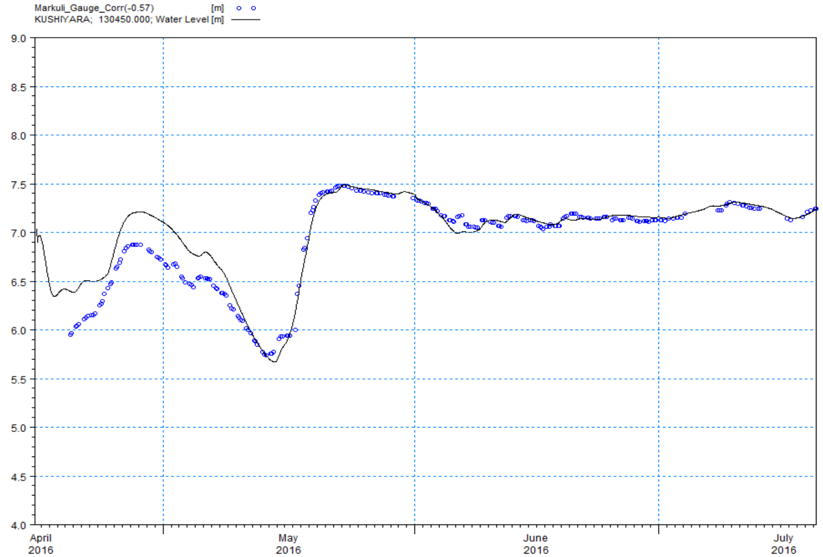
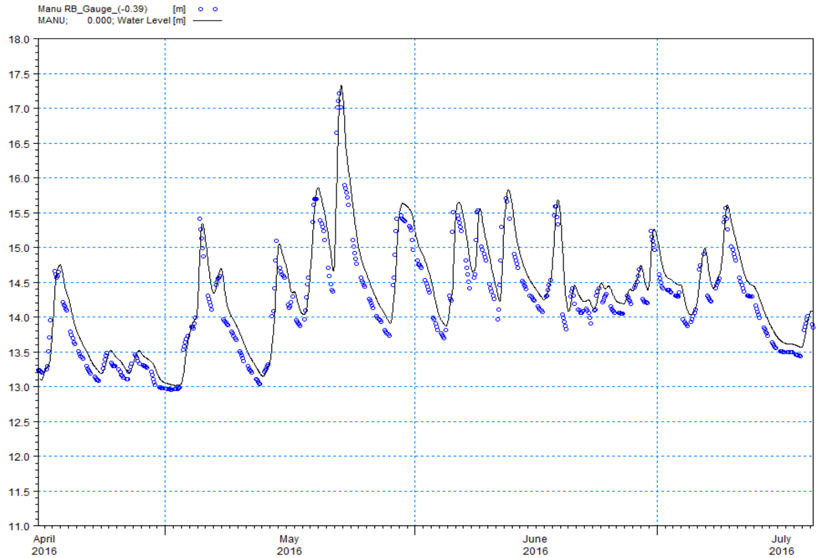
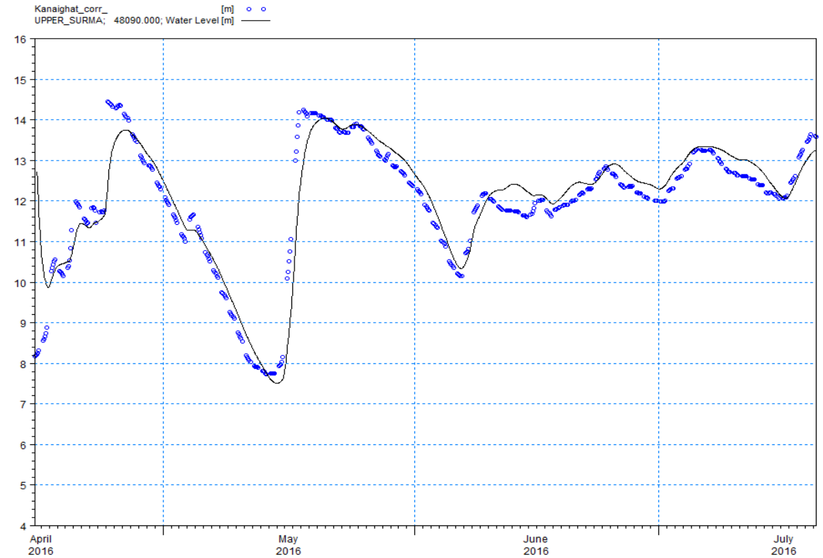


Figure 3-17: Calibration Plots of Flash Flood Forecast Model for 2017


Amalshid_Gauge_Corr_(-0.46) [m]
UPPER_SURMA; 600.000; Water Level [m]
18
17
16
15
14
13
12
11
10
9
8
7
6
April 2016
May 2016
June 2016


Markuli_Gauge_Corr(-0.57) [m]
KUSHIYARA; 130450.000; Water Level [m]
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
April 2016
May 2016
June 2016
July 2016


Manu RB_Gauge_(-0.39) [m]
MANU; 0.000; Water Level [m]
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
April 2016
May 2016
June 2016
July 2016


Kanaighat_corr_ [m]
UPPER_SURMA; 48090.000; Water Level [m]
16
15
14
13
12
11
10
9
8
7
6
5
4
April 2016
May 2016
June 2016
July 2016

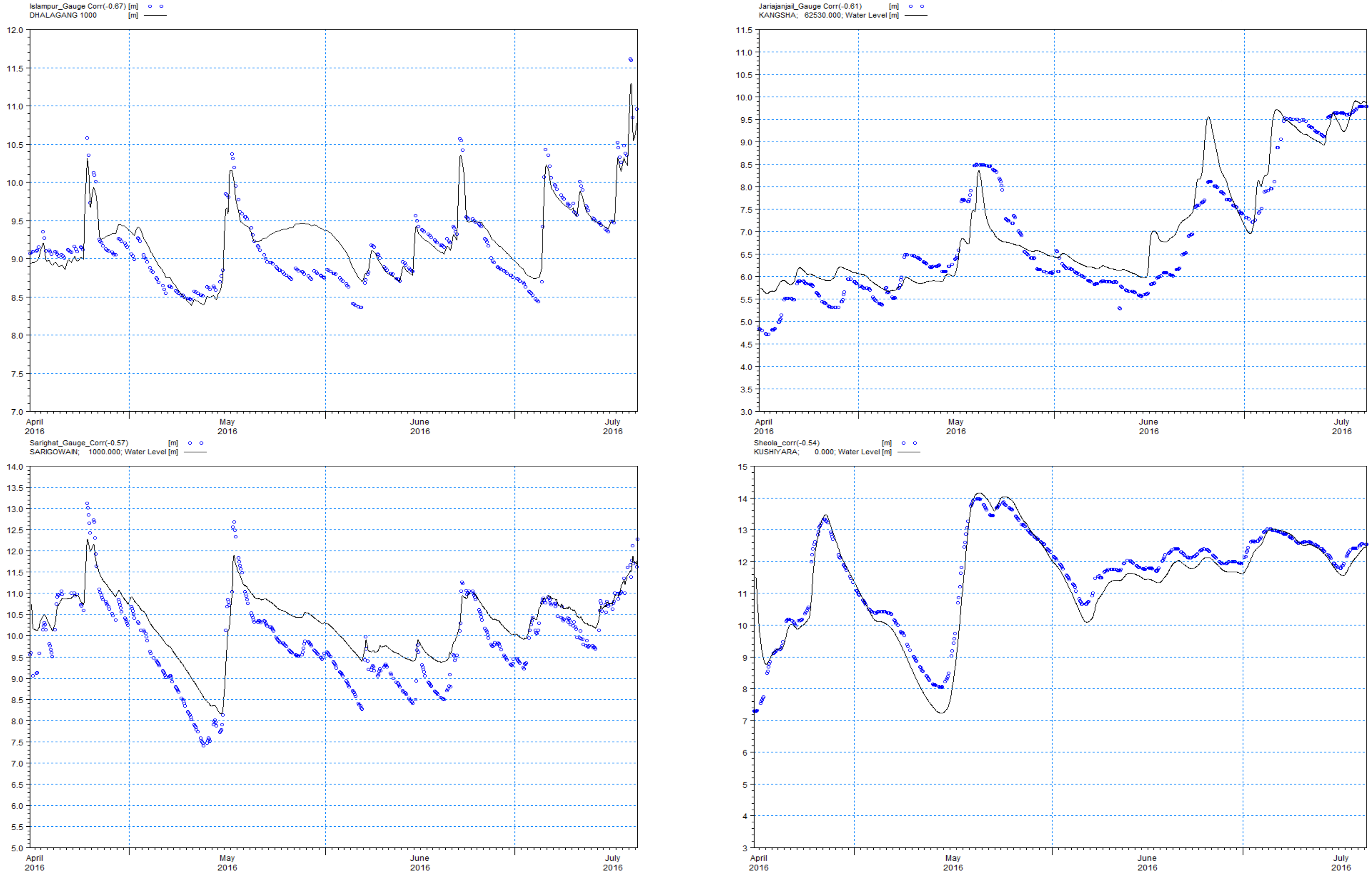
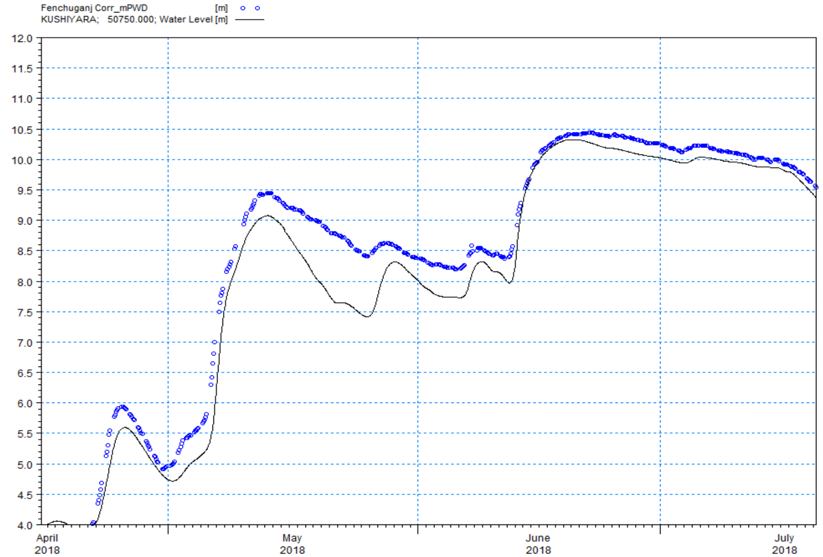
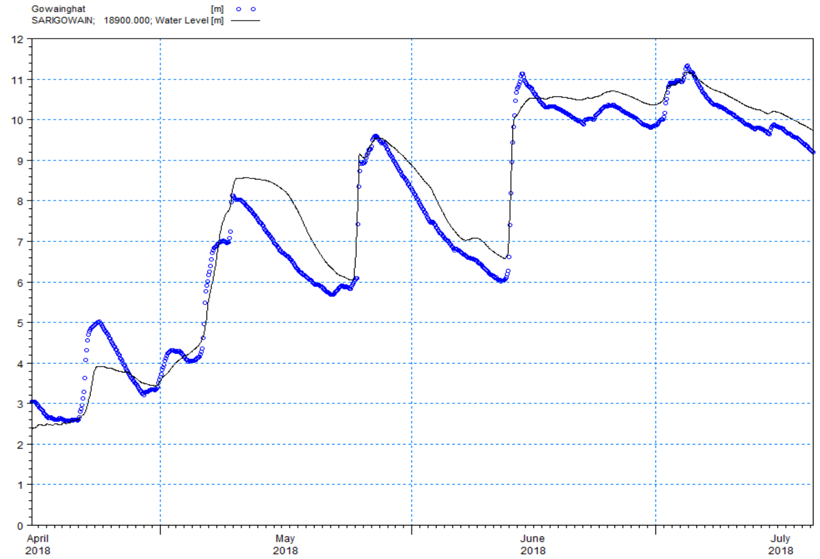
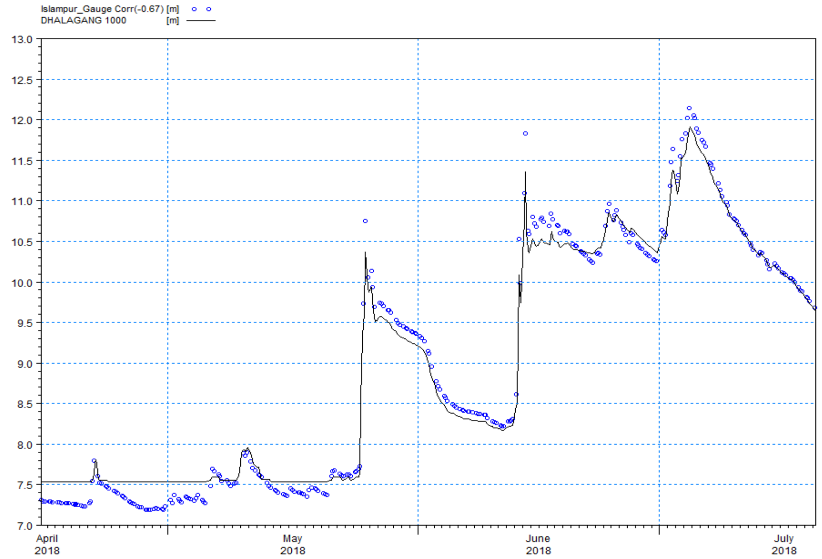


Figure 3-18: Validation Plots of Flash Flood Forecast Model for 2016


Amalshid_Gauge_Corr_(-0.46) [m]
UPPER_SURMA; 600.000; Water Level [m]
April 2018
May 2018
June 2018


Fenchuganj Corr_mPWD [m]
KUSHIYARA; 50750.000; Water Level [m]
April 2018
May 2018
June 2018
July 2018


Gowainghat [m]
SARIGOWAIN; 18900.000; Water Level [m]
April 2018
May 2018
June 2018
July 2018


Islampur_Gauge Corr(-0.67) [m]
DHALAGANG 1000 [m]
April 2018
May 2018
June 2018
July 2018

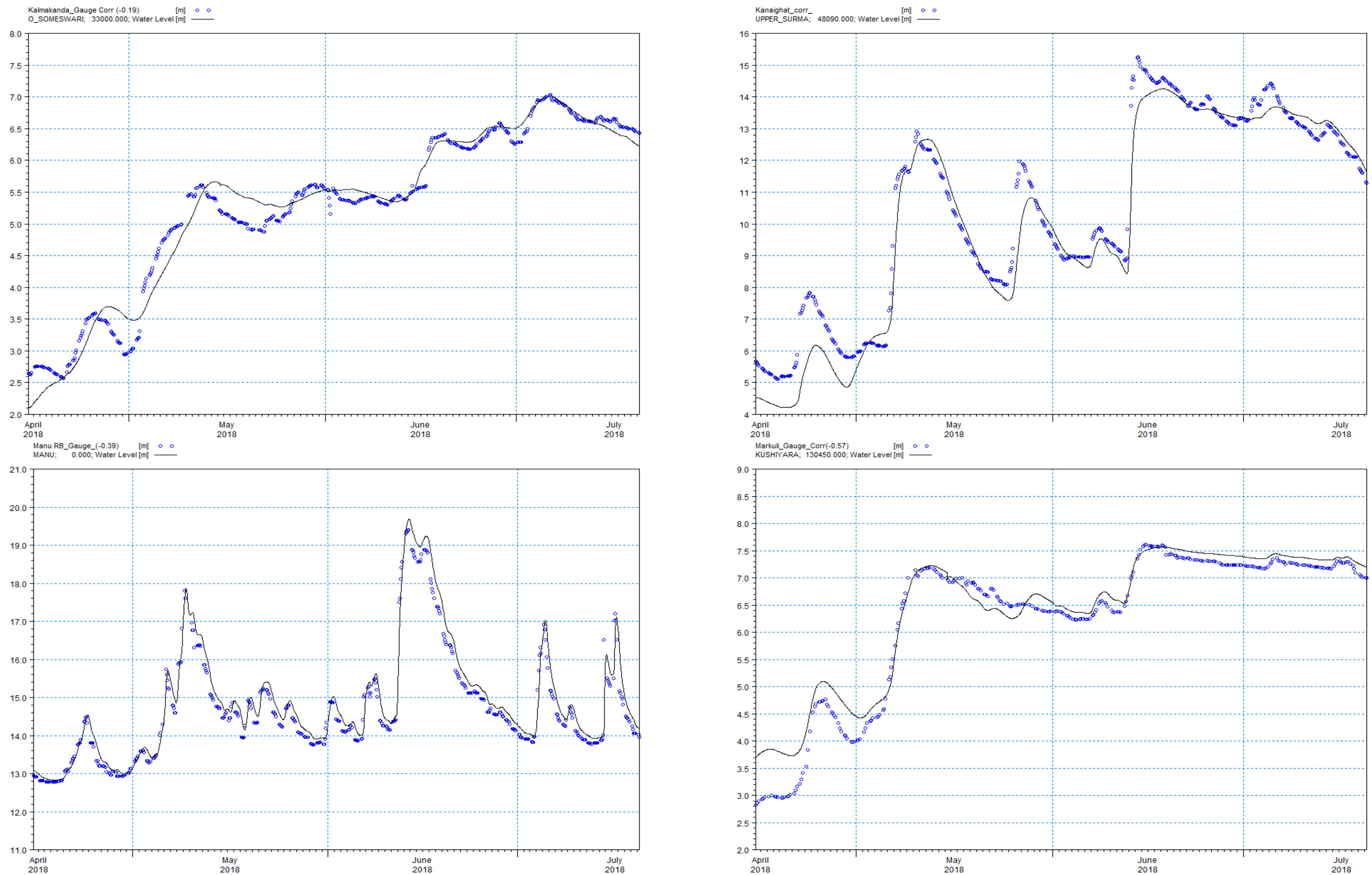


Figure 3-19: Validation Plots of Flash Flood Forecast Model for 2018

3.4 Weather Research and Forecast Model

The Weather Research and Forecasting (WRF) Model is a non-hydrostatic, mesoscale numerical weather prediction system designed to serve both atmospheric research and operational forecasting needs. It was developed by the joint effort of the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centers for Environmental Prediction (NCEP) and the (then) Forecast Systems Laboratory (FSL)), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). WRF-ARW is one of the major components of WRF modeling system which is currently in operational use at NCEP, AFWA, and other centers. The WRF-ARW dynamical core is primarily design for calculating advection, pressure-gradients, Coriolis, buoyancy, filters, diffusion, and time differentiation. It is portable and efficient on available parallel computing platforms. WRF-ARW allows users to generate atmospheric simulations based on real data (observations, analyses) or idealized conditions. The model has various lateral boundary conditions with a full set of physical parameterization data. It can also be set as either a one-way, two-way nesting or moving nest model. WRF-ARW provides advances in physics, numeric, and data assimilation contributed by developers in the broader research community (Janjic et al., 2010; Skamarock et al., 2008).

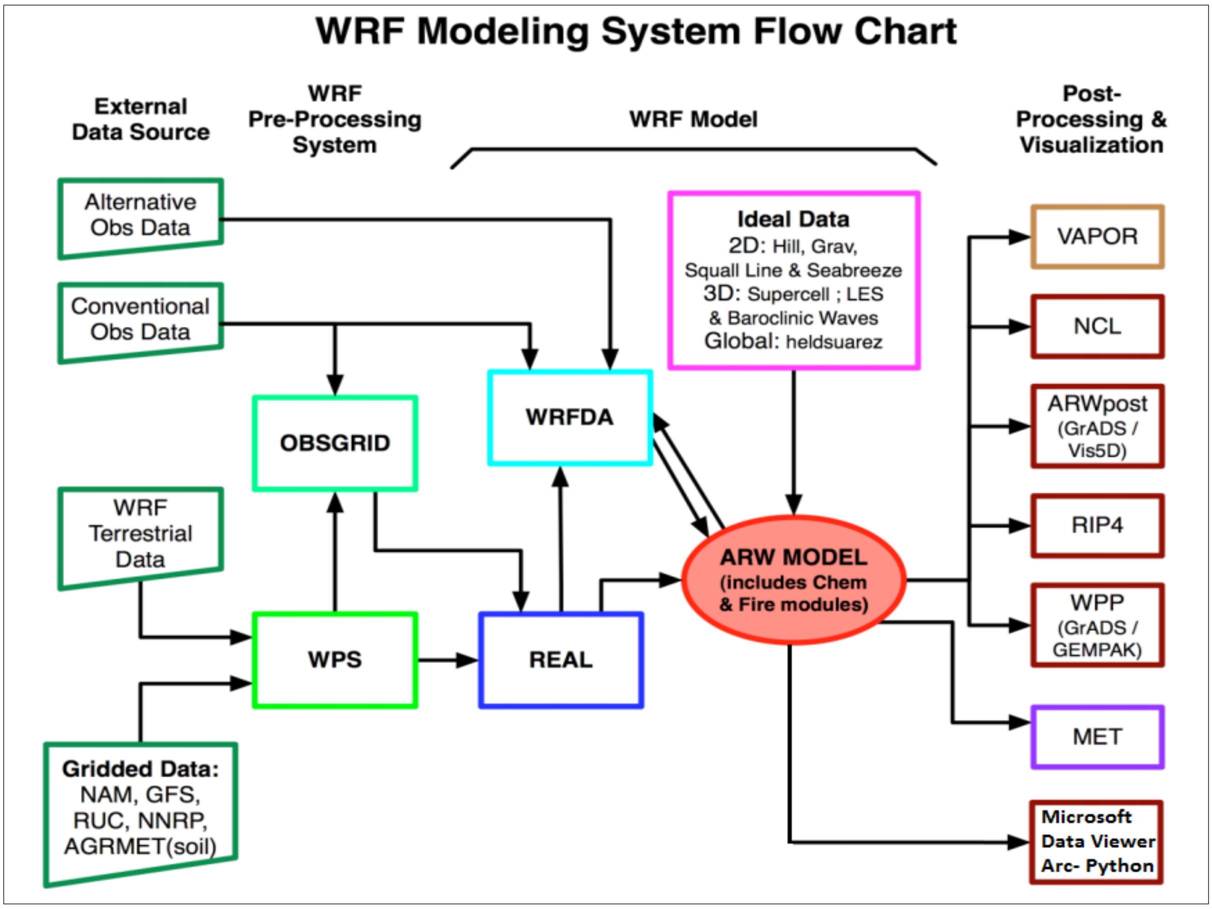


Figure 3-20: WRF Modeling System Flow Chart (Skamarock et al., 2008)

The working mechanism of WRF system is showed in Figure 3-20. Observational data in a specified format is providing into the model as an External Data sources. These data are formatted by OBSGRID and WPS system as a preprocessing mechanism. Generated results from WPS system are then provided into the model processing system. Finally analyzed model outputs are represented by different post-processing tools which are provided with the model installation. Simulation of ARW-WRF requires different variables like topographic information, weather data, terrain data etc. Using these variables, the model can conduct numerical analysis using some fundamental fluid equations.

3.4.1 WRF Model Applied by IWM

IWM has set up the WRF model for the entire GBM river basin system. For this project, a double-nested domain at 27 and 9 km resolutions has been selected. The double nested domains configured in WRF model for this project are showed in Figure 3-21. Domain 1(D1) is the coarse mesh and has 160×160 grid point in the north-south and east-west directions respectively with a horizontal grid spacing of 27km. Within the domain D1, domain 2(D2) is nested with 94×88 grid points at 9km grid spacing. Domain-1 is covered over whole India and Himalayan mountains to represent the regional-scale circulations and to extract the complex meteorological features in the synoptic and subsynaptic scales.

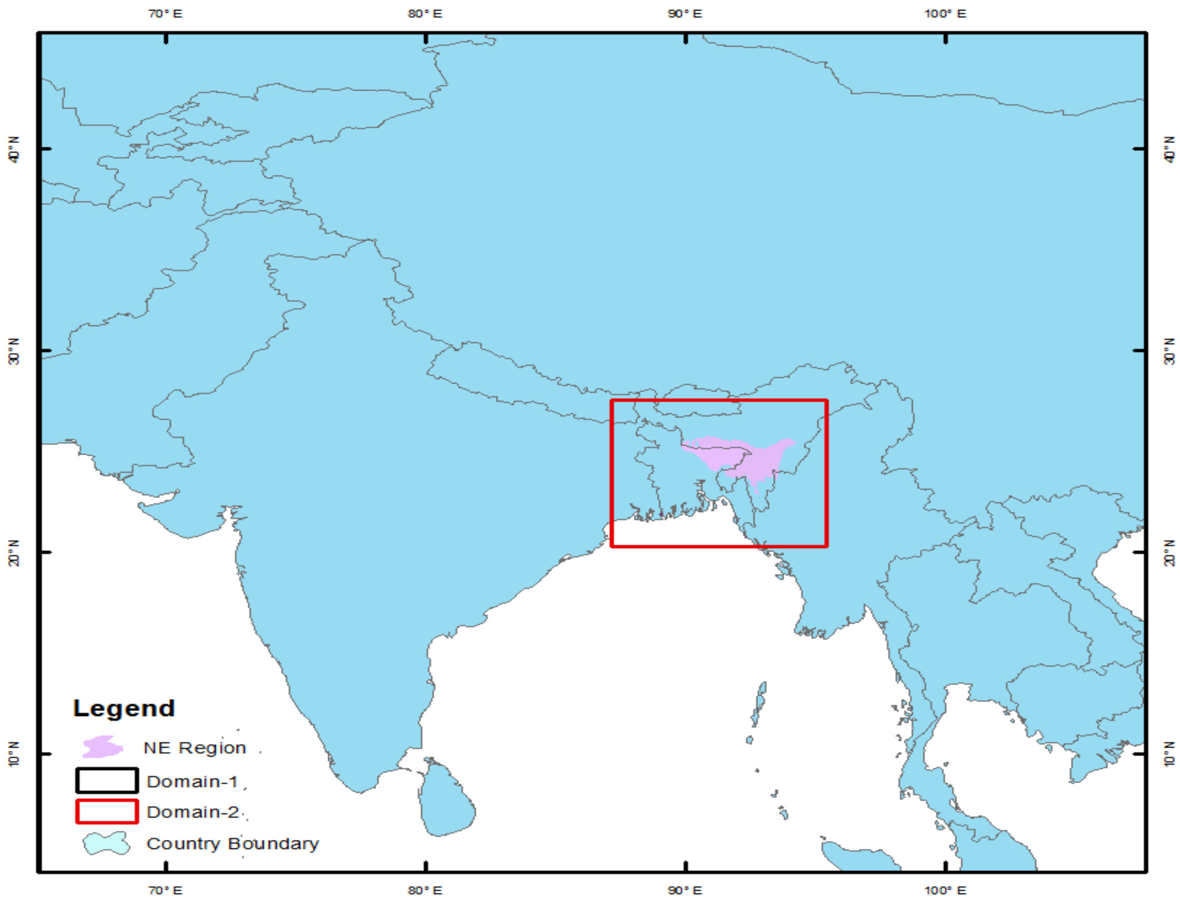


Figure 3-21: WRF model domain. domain-1 is IWM existing WRF model for the GBM basin and nested domain-2 for the North-East Region.

For domain nesting, 3:1 domain ratio must be maintained to preserve model stability. Hence, 27km and 9km resolution has been selected for model simulation. WRF required two kinds of data for model initialization; meteorological data from global model and static topographic data.

Several static topographic data are available in only one resolution, but others are made available in resolutions of 30", 2', 5', and 10'. In this model to compute the latitude, longitude, and map scale factors at every grid point, geogrid will interpolate soil categories, land use category, terrain height, annual mean deep soil temperature, monthly vegetation fraction, monthly albedo, maximum snow albedo, and slope category to the model grids by default as provided in Table 3-4.

Table 3-4: Overview of WRF model configuration

Domain & Dynamics	
WRF core	ARW
Data	GFS (0.5˚ X 0.5˚)
Input data interval	3h
Number of domain	2
Central point of domain	86.462˚E, 24.584˚N for Domain-1 (D1) 91.267˚E, 23.809˚N for Domain-2 (D2)
Resolution	X-direction 160 points, y-direction 160 points (D1) X-direction 94 points, y-direction 88 points (D2)
Gide size	27km X 27km (D1) and 9km X 9km (D2)
Covered area	4.165˚ to 46.472˚N and 65.215 to 107.665˚E (D1) 20.2˚ to 27.3˚N and 87 to 95.4˚E (D2)
Map projection	Mercator
Integration time step	120s (D1), 40s (D2)
Vertical coordinate	Pressure coordinate
Time integration scheme	3rd order Runge-Kutta
Spatial differencing scheme	6th order centered difference
Physics	
Microphysics	WRF Single–moment 3–class and 5–class Schemes
PBL Parameterization	Yonsei University Scheme
Surface layer physics	MM5 Similarity Scheme
Land-surface model	Unified Noah Land Surface Model
Short wave radiation	Dudhia Shortwave Scheme
Long wave radiation	RRTM Longwave Scheme
Cumulus parameterization	Kain–Fritsch Scheme

Meteorological data are assigned as lateral boundary data in domain setup. Here, the NCEP high-resolution global final (GFS) analysis data is employed as lateral boundary data. These NCEP GFS Operational Global Analysis data has 0.5°××0.5° grid resolution grids covering the entire globe in every three hours. The product is from the Global Data Assimilation System (GDAS), which continuously collects observational data from the Global Telecommunications System (GTS), and other sources, for many analyses. The FNLs are made with the same model which NCEP uses in the Global Forecast System (GFS), but the FNLs are prepared about an hour or so after the GFS is initialized. The FNLs are delayed so that more observational data can be used. The GFS is run earlier in support of time critical forecast needs, and uses the FNL from the previous 6-hour cycle as part of its initialization. Parameters of the data include surface pressure, sea level pressure, geopotential height, temperature, sea surface temperature, soil values, ice cover, relative humidity, u- and v- winds, vertical motion, vorticity and ozone. The data are in GRIB1 and GRIB2 format and can be downloaded freely. This data is easily useable by the WRF model. In present study, GFS data has been downloaded for every day. Downloaded data are used as lateral boundary condition for every day weather forecast of North-East Region.

After Model domain setup, model is configured based on 00:00 BDT for every day rainfall events. For model stability, a spin up period of 3 days and 6 hours has been considered in this study. To setup model physics, it was used the Kain–Fritsch cumulus parameterization scheme with WRF Single-Moment 5-class, WRF Single-Moment 6-class, and Thompson microphysics schemes exhibited the most skill in the Ganges-Brahmaputra-Meghna basins (Sikder and Hossain, 2016). Using default parameter settings in earlier, the WRF model was not able to capture the rainfall event accurately. Thus, during pre-monsoon of 2017, the microphysics scheme has been changed and applied as described in Table 3-4. Figure 3-22 and 3-23 shows before and after parameter change effect while figure 3-24 shows the validation of WRF model with changed parameters.

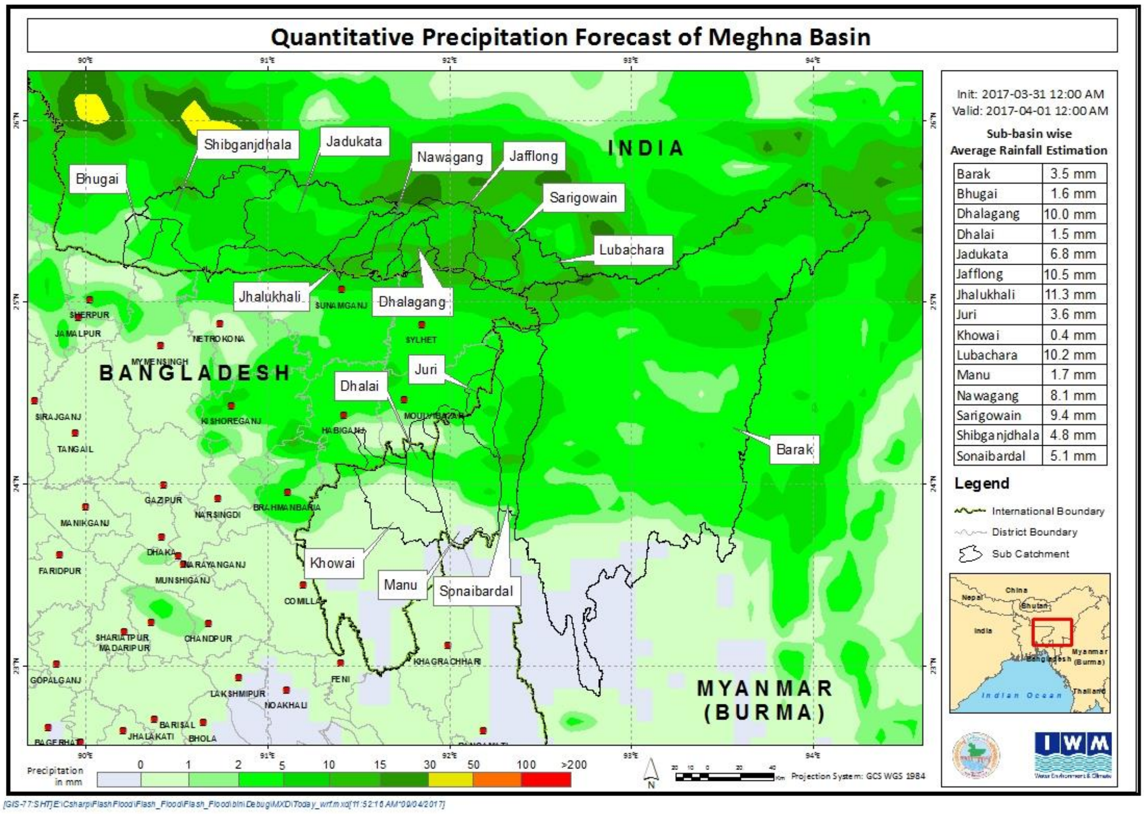


Figure 3-22: Generated QPF on 1st April 2017 using default parameters of WRF Model

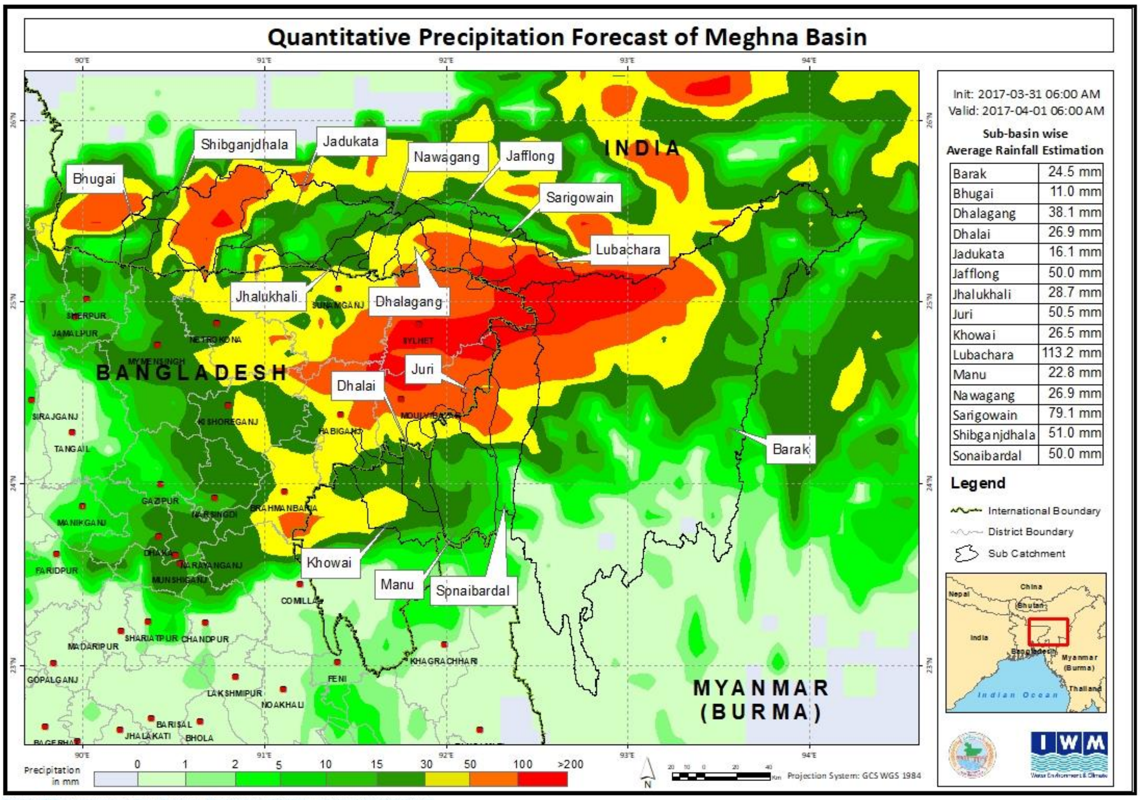


Figure 3-23: Generated QPF on 1st April 2017 using new parameters and updated WRF Model

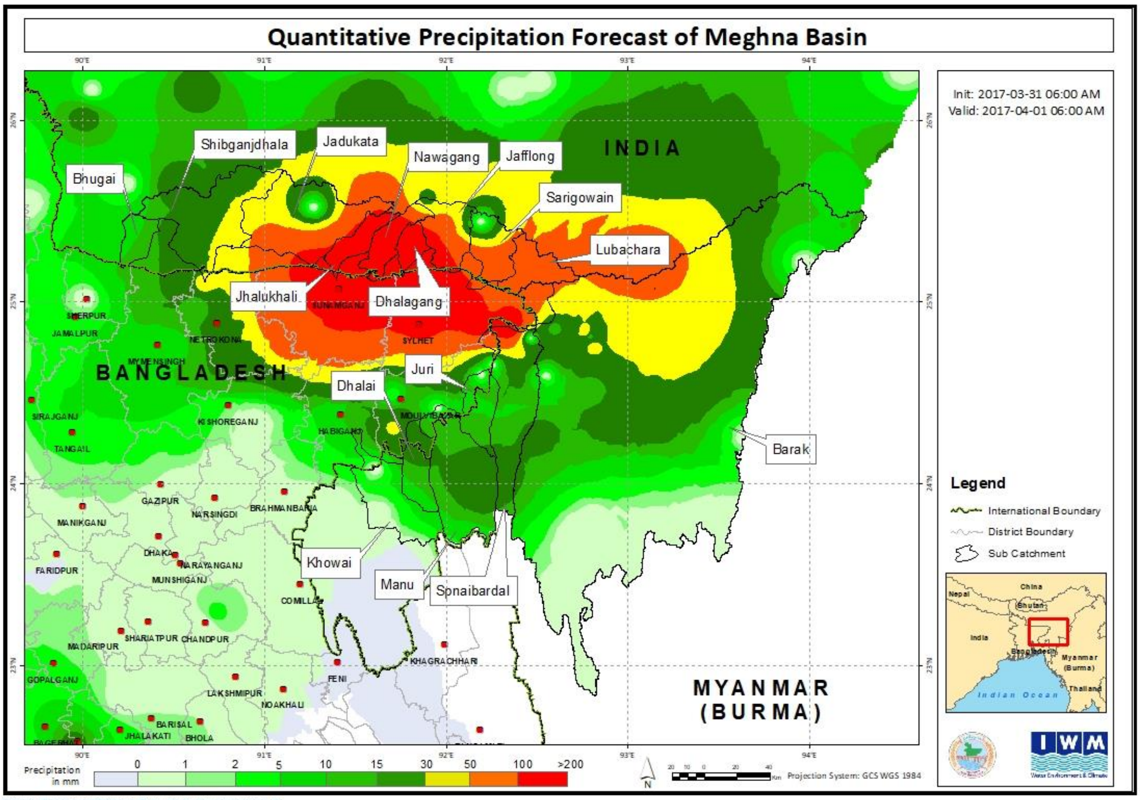


Figure 3-24: Validation of generated QPF on 1st April 2017 using Observed Rainfall from Bangladesh and India

3.4.2 WRF Model Developed by BMD

Bangladesh Meteorological Department (BMD) is the mandated Organization in Bangladesh for weather forecast and its dissemination. On the other hand, BMD is the mandated organization of Bangladesh to provide numerical weather prediction. Using, Weather Research and Forecast (WRF) Model, BMD is providing 3-days lead-time weather forecast for the whole Bangladesh. Figure 3-25 shows the coverage area of 1-day forecast generated by BMD.

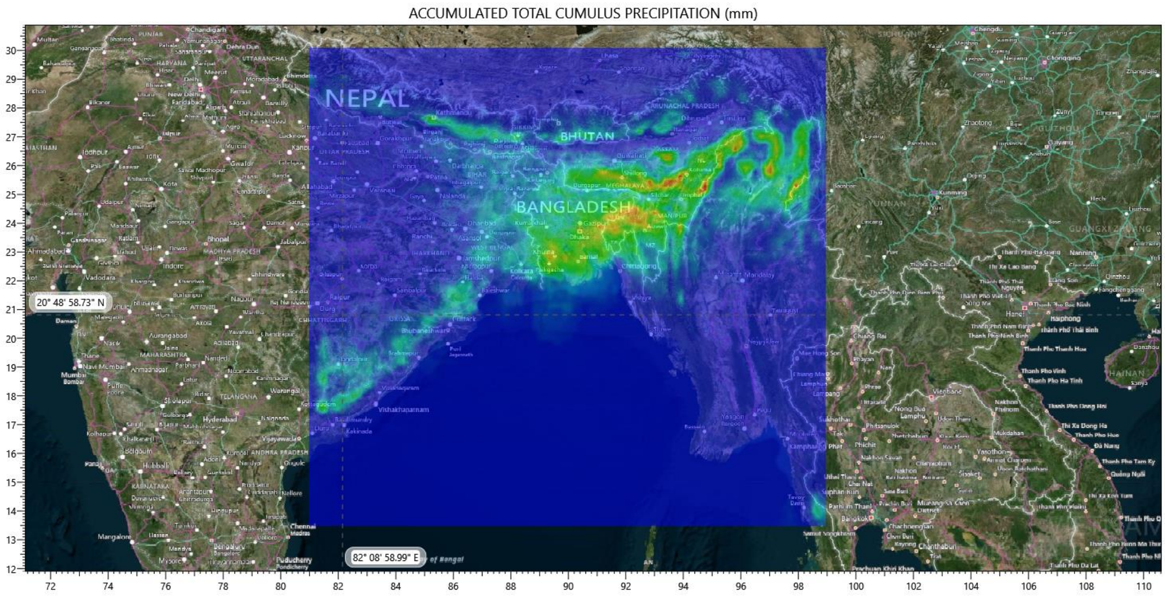


Figure 3-25: BMD Provided WRF Forecast Extent

Under the present study, one of the major idea was to develop flash flood forecasting System for North-Eastern part of Bangladesh where BMD provided weather forecast would be applied. BMD generated WRF Model output was supposed to deliver to project partners like FFWC and IWFM in real-time basis throughout the study. However, due to delay in the data transfer process among government agencies, the BMD generated weather forecast was not applied in the earlier forecast products done by FFWC in 2017 and 2018. After successful data transfer arrangement this year 2019, BMD have agreed to share their Weather Research and Forecast (WRF) model generated forecast as the input in the flash flood forecast model through the following ftp site (url: http://203.159.16.134.xip.io/) to FFWC with password protected arrangements.

Based on the provided forecasted netcdf data, catchment polygons have been overlaid to compute catchment averaged rainfall which then directly linked with Rainfall-Runoff and Hydrodynamic models developed under this study. The color scale indicates the severity of the rainfall event. Figure 3-26 shows the processed output of BMD generated WRF rainfall forecast.

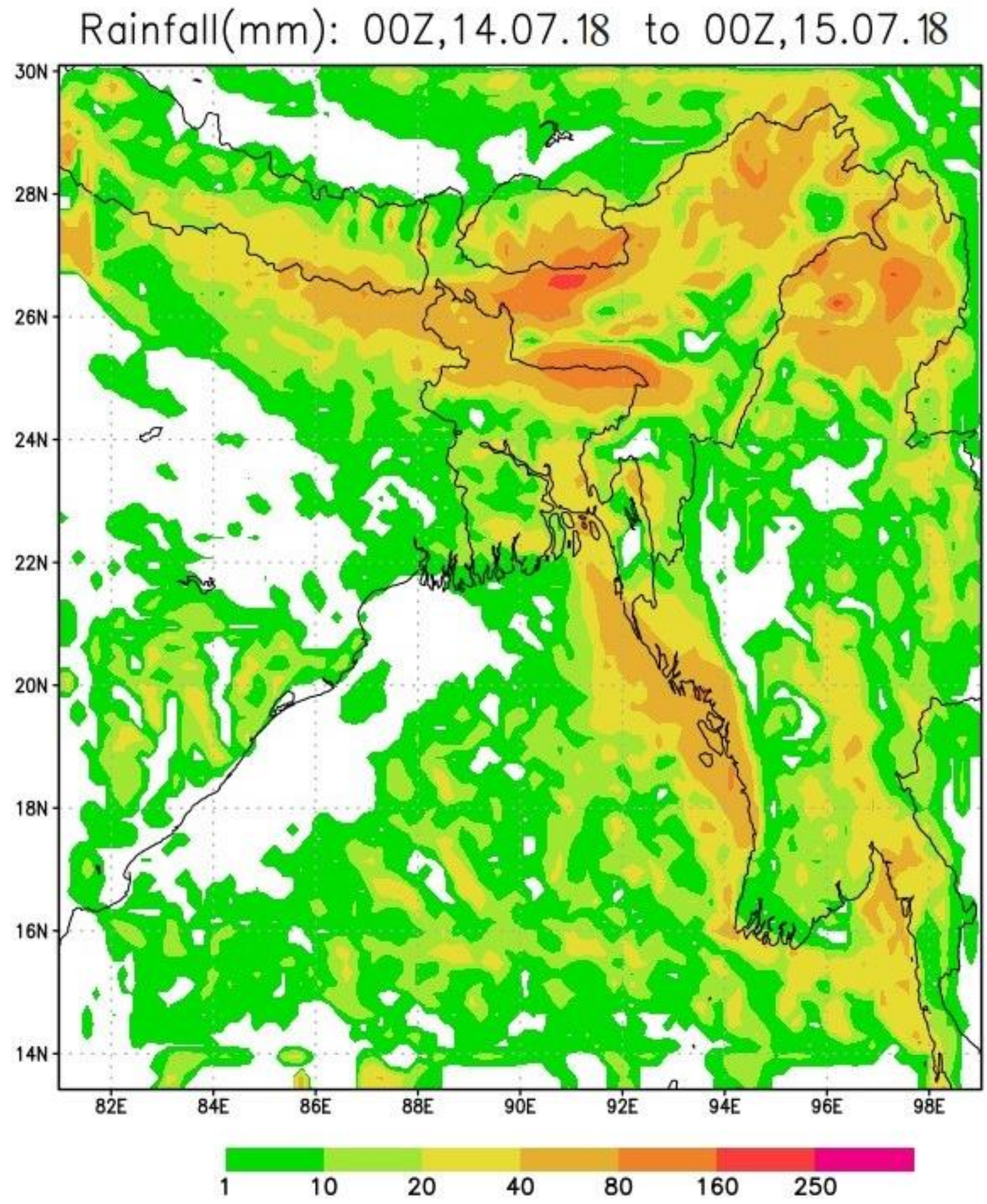


Figure 3-26: BMD generated WRF Rainfall Forecast of 14 July 2018

3.5 Forecast Performance Evaluation

The overall performance of the flash flood forecast outputs has been compared with observed water level at all 25 forecast stations during pre-monsoon of 2017, 2018 and 2019. The performance of the model has been evaluated based on statistical parameters. Performance of forecast has been classified as "Good", "Average", "Not Satisfactory", "Poor", and "Very Poor" as described in the following table 3-5.

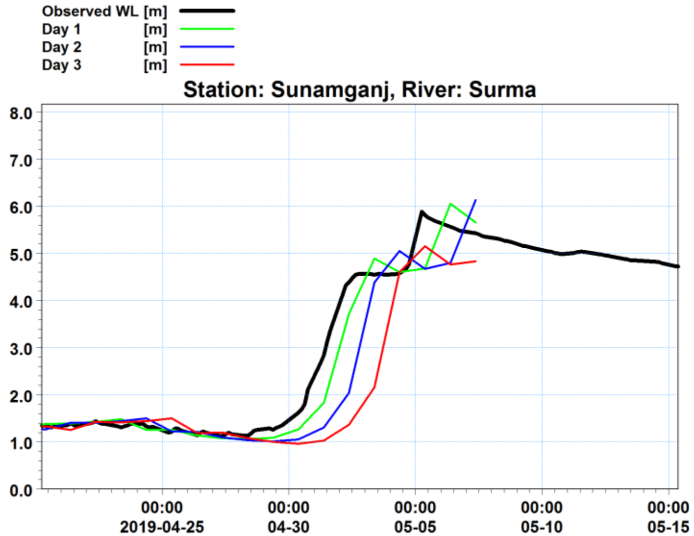
Table 3-5: Performance Scale

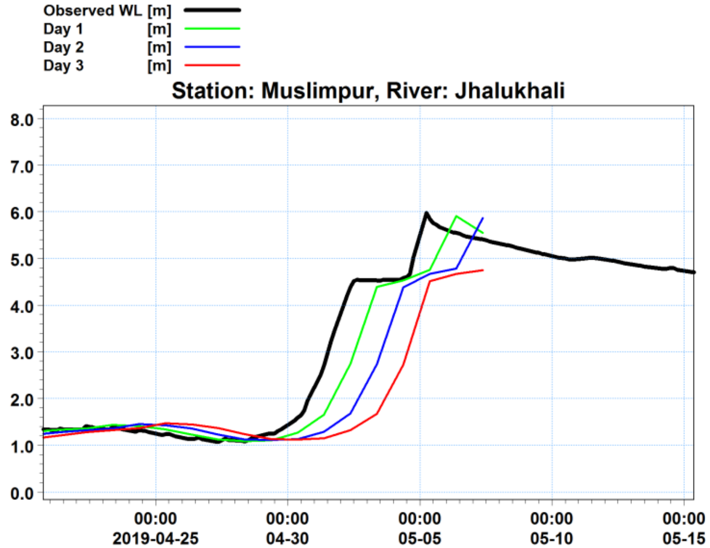
Sl. No.	Scale	Value
1	Good	MAE<= 0.15 meter &r^2>= 0.9
2	Average	MAE<= 0.2 meter &>0.15 meter and r^2>= 0.7 &<0.9
3	Not satisfactory	MAE<= 0.3 meter &>0.2 meter and r^2>= 0.4 &<0.7
4	Poor	MAE<= 0.4 meter&>0.3 meter and r^2>= 0.3 &<0.4
5	Very Poor	MAE> 0.4 meter or r^2< 0.3

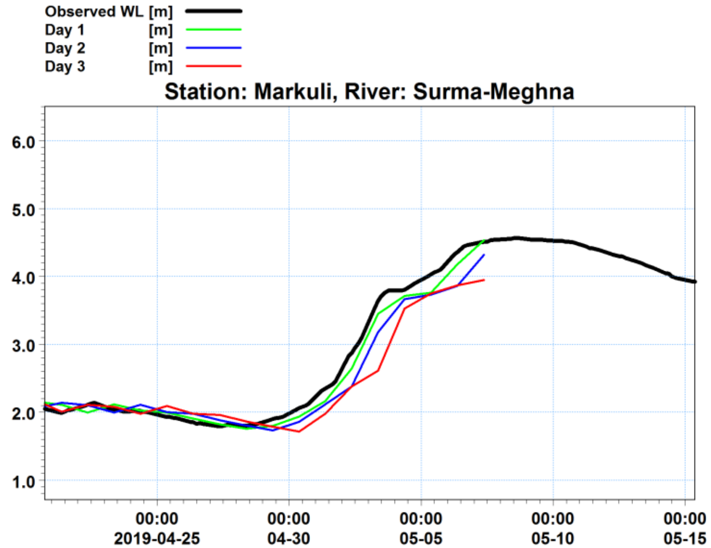
The performance evaluation has been made based on statistical analysis methods such as Correlation Coefficient (R^2) and Mean Absolute Error (MAE). Also, to evaluate the forecast performance, Root Mean Square Error (RMSE), Percent Bias (PBias), Nash-Sutcliffe Efficiency (NSE) are calculated. Table 3-6 and 3-7 shows the performance in numerical values and status in terms of above specified scale for the operational forecast made at FFWC during 2019 respectively. It is remarkable to mention that cyclone event “Fani” hit India and Bangladesh coast on 5th May, 2019 and caused heavy downpours in the North-East Region and consequently caused a flash flood in the North-Eastern part of Bangladesh. The developed flash flood forecast model has successfully captured this flash flood event. Figure 3-27 shows the forecast performance during cyclone event “Fani” in 2019. Map of forecast performance in 2019 in the North-East Region of Bangladesh is shown in Figure 3-28.

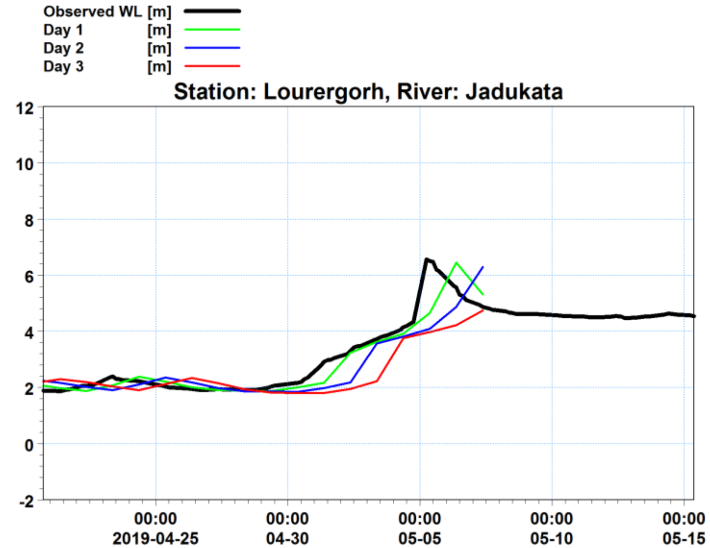
Table 3-6: Forecast Performance for 2019 Flash Flood Event

		1-Day Forecast					2-Day Forecast					3-Day Forecast				
SL	Station	RMSE	R2	MAE	PBAIS	NSE	RMSE	R2	MAE	PBAIS	NSE	RMSE	R2	MAE	PBAIS	NSE
1	Amalshid	0.26	0.96	0.13	-0.07	0.96	0.53	0.84	0.28	-0.02	0.82	1.08	0.52	0.52	-1.46	0.26
2	Azmiriganj	0.08	0.99	0.07	0.48	0.99	0.17	0.97	0.13	1.47	0.96	0.25	0.93	0.20	1.93	0.92
3	Ballah	0.25	0.46	0.16	-0.17	-0.17	0.40	0.34	0.26	-0.45	-1.84	0.45	0.36	0.30	-0.46	-2.74
4	Durgapur	0.39	0.66	0.17	-0.07	0.64	0.40	0.64	0.21	-0.22	0.64	0.46	0.51	0.25	-0.17	0.50
5	Fenchuganj	0.21	0.97	0.11	0.30	0.97	0.30	0.94	0.18	0.86	0.94	0.46	0.87	0.30	0.85	0.86
6	Habiganj	0.24	0.53	0.14	1.14	0.38	0.43	0.36	0.30	-0.59	-1.00	0.59	0.30	0.43	-2.00	-2.98
7	Islampur	0.37	0.83	0.15	0.30	0.82	0.55	0.65	0.24	0.81	0.62	0.54	0.67	0.24	1.31	0.65
8	Jariajanjail	0.36	0.92	0.19	-0.46	0.92	0.63	0.78	0.40	-0.95	0.77	0.78	0.67	0.53	-1.96	0.64
9	Kalmakanda	0.28	0.98	0.17	1.54	0.98	0.47	0.94	0.33	3.46	0.94	0.71	0.87	0.49	5.45	0.86
10	Kamalganj	0.30	0.49	0.16	0.11	-0.10	0.46	0.37	0.28	-0.29	-2.00	0.55	0.43	0.32	-0.97	-4.04
11	Kanaighat	0.46	0.95	0.23	-0.16	0.95	0.82	0.86	0.43	0.59	0.83	1.13	0.74	0.55	1.03	0.69
12	Khaliajuri	0.18	0.97	0.13	-0.42	0.97	0.29	0.93	0.18	0.32	0.93	0.42	0.86	0.27	1.16	0.85
13	Lourergorh	0.33	0.93	0.17	0.67	0.93	0.52	0.82	0.31	0.63	0.82	0.67	0.71	0.43	0.59	0.70
14	Manu-RB	0.19	0.80	0.11	0.08	0.74	0.33	0.51	0.21	-0.27	0.22	0.44	0.29	0.28	-0.64	-0.46
15	Markuli	0.11	0.99	0.08	0.63	0.99	0.19	0.97	0.14	1.21	0.96	0.30	0.93	0.21	1.95	0.92
16	Moulvi-Bazar	0.36	0.59	0.23	0.25	0.51	0.48	0.42	0.34	-0.09	0.19	0.56	0.37	0.40	-1.66	-0.31
17	Muslimpur	0.34	0.96	0.15	2.16	0.96	0.59	0.90	0.29	4.61	0.89	0.80	0.81	0.42	7.14	0.80
18	Nakuagaon	0.28	0.33	0.14	-0.08	0.06	0.35	0.12	0.18	-0.02	-0.31	0.38	0.06	0.21	0.04	-0.49
19	Sarighat	0.59	0.94	0.21	0.86	0.94	0.94	0.86	0.38	1.93	0.85	1.21	0.77	0.51	3.76	0.76
20	Sheola	0.21	0.98	0.11	0.28	0.98	0.37	0.94	0.19	0.55	0.93	0.78	0.75	0.41	-0.28	0.70
21	Sherpur	0.18	0.98	0.11	1.13	0.98	0.29	0.95	0.19	2.30	0.95	0.39	0.91	0.28	2.65	0.90
22	Sunamganj	0.25	0.98	0.12	0.82	0.98	0.46	0.93	0.22	2.27	0.93	0.65	0.86	0.33	4.10	0.86
23	Sutang_RB	0.24	0.85	0.14	-0.32	0.83	0.37	0.68	0.25	-0.91	0.58	0.44	0.61	0.32	-3.02	0.35
24	Sylhet	0.33	0.98	0.18	0.45	0.98	0.72	0.91	0.34	1.78	0.91	0.99	0.83	0.46	3.63	0.82


Observed WL [m]
Day 1 [m]
Day 2 [m]
Day 3 [m]
Station: Sunamganj, River: Surma
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
00:00 2019-04-25
00:00 04-30
00:00 05-05
00:00 05-10
00:00 05-15


Observed WL [m]
Day 1 [m]
Day 2 [m]
Day 3 [m]
Station: Muslimpur, River: Jhalukhali
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
00:00 2019-04-25
00:00 04-30
00:00 05-05
00:00 05-10
00:00 05-15


Observed WL [m]
Day 1 [m]
Day 2 [m]
Day 3 [m]
Station: Markuli, River: Surma-Meghna
6.0
5.0
4.0
3.0
2.0
1.0
00:00 2019-04-25
00:00 04-30
00:00 05-05
00:00 05-10
00:00 05-15


Observed WL [m]
Day 1 [m]
Day 2 [m]
Day 3 [m]
Station: Lourergorh, River: Jadukata
12
10
8
6
4
2
0
-2
00:00 2019-04-25
00:00 04-30
00:00 05-05
00:00 05-10
00:00 05-15

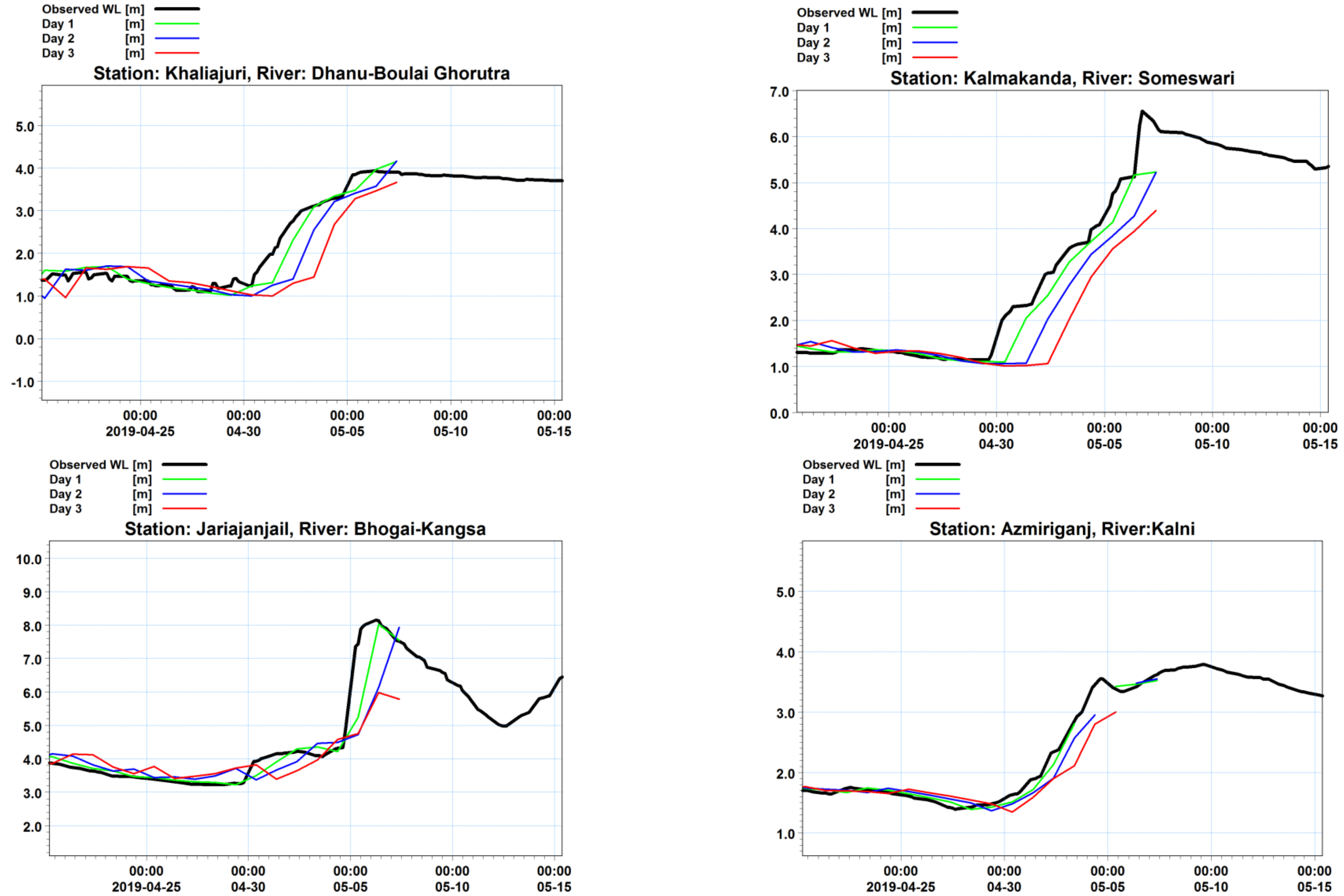


Figure 3-27: Forecast Performance in 2019

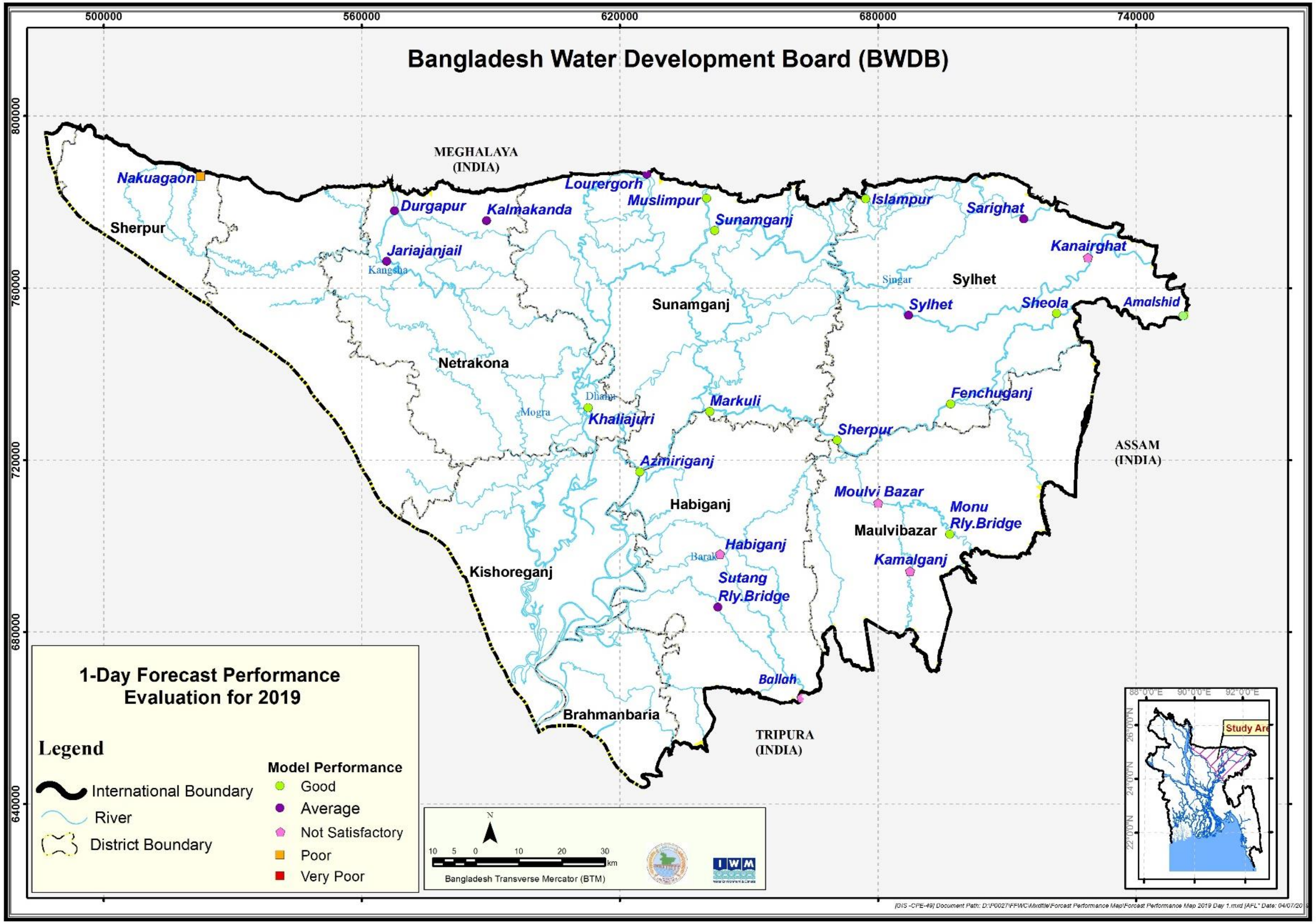


Figure 3-28: Map showing station wise forecast performance in 2019

Table 3-7: Forecast Performance Status in 2019

SL	Station	Day 1	Day 2	Day 3
1	Amalshid	Good	Not Satisfactory	Very Poor
2	Azmiriganj	Good	Good	Average
3	Fenchuganj	Good	Average	Not Satisfactory
4	Islampur	Good	Not Satisfactory	Not Satisfactory
5	Khaliajuri	Good	Average	Not Satisfactory
6	Manu-RB	Good	Not Satisfactory	Poor
7	Markuli	Good	Good	Average
8	Muslimpur	Good	Not Satisfactory	Very Poor
9	Sheola	Good	Average	Very Poor
10	Sherpur	Good	Average	Not Satisfactory
11	Sunamganj	Good	Not Satisfactory	Poor
12	Durgapur	Average	Not Satisfactory	Not Satisfactory
13	Jariajanjail	Average	Poor	Very Poor
14	Kalmakanda	Average	Poor	Very Poor
15	Lourergorh	Average	Poor	Very Poor
16	Sarighat	Average	Poor	Very Poor
17	Sutang_RB	Average	Not Satisfactory	Poor
18	Sylhet	Average	Poor	Very Poor
19	Ballah	Not Satisfactory	Not satisfactory	Not satisfactory
20	Habiganj	Not satisfactory	Not satisfactory	Very Poor
21	Kamalganj	Not Satisfactory	Not satisfactory	Poor
22	Kanaighat	Not Satisfactory	Very Poor	Very Poor
23	Moulvi-Bazar	Not Satisfactory	Poor	Poor
24	Nakuagaon	Poor	Very Poor	Very Poor

During 2017, a severe flash flood hit North-Eastern part of Bangladesh and caused catastrophic damage of Boro rice occurred during End of March and Early April in 2017. Flood started on 28th March,2017 affecting six districts (Sylhet, Moulavibazar, Sunamganj, Habiganj, Netrokona and Kishoreganj) in the north-east region. Rising water overflow and breeched embankment in many places, inundated vast areas of croplands. From hydrological point of view, this year flash flood seems unusual as the flood hits quite early than any historical flash flood event occurred in this region.

The developed flash flood forecast model based on FFWC generated WRF model outputs has been applied in real-time during pre-monsoon 2017 and found some discrepancies with the observed data. The main reason behind the failure was mainly data unavailability from Indian sites as well as real-time data from BWDB gauges. Also, BMD generated WRF forecast was not available that time. Moreover, the flood comes too early which the system could not captured properly. Later, the same flash flood event of 2017 has been simulated with updated forecast model and found very good agreement between observed and simulated water levels at most of the forecast stations. However, due to sharp and sudden up rise, flash flood event was not captured numerically but the trend was matched very well. Table 3-8 and 3-9 shows status and performance in numerical values in terms of above specified scale for the forecast using WRF model operated at FFWC during 2017 respectively. Forecast performance in 2017 in the North-East Region of Bangladesh is shown in Figure 3-29 and map showing station wise forecast performance in Figure 3-30.

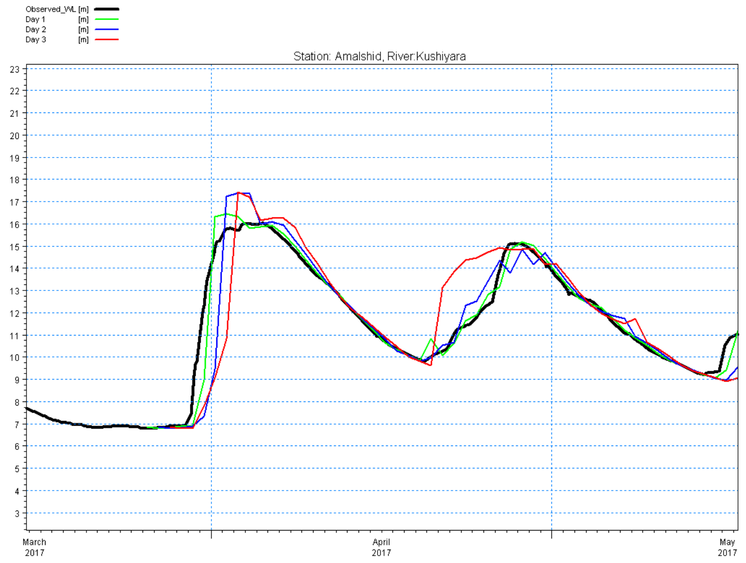
Table 3-8: Forecast Performance Status in 2017

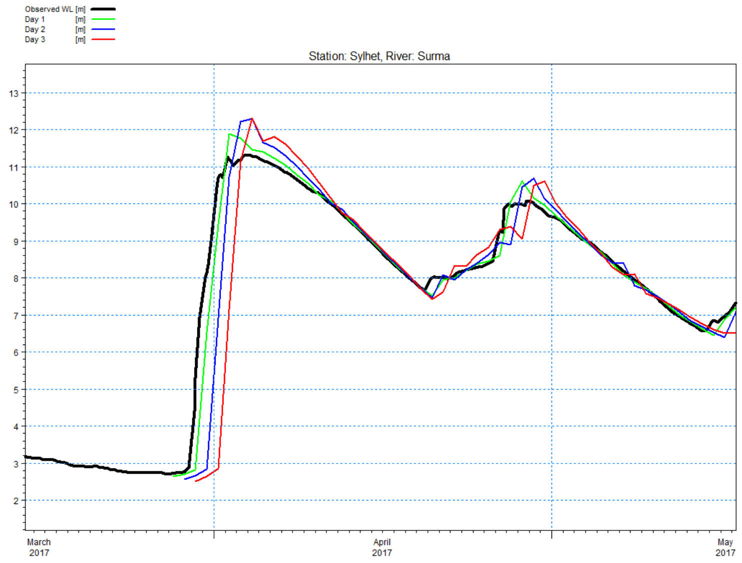
SL	Station	Day 1	Day 2	Day 3
1	Lourergorh	Good	Not Satisfactory	Poor
2	Markuli	Good	Good	Average
3	Sherpur	Good	Not Satisfactory	Poor
4	Sunamganj	Good	Not Satisfactory	Poor
5	Durgapur	Average	Not Satisfactory	Not Satisfactory
6	Islampur	Average	Poor	Very Poor
7	Amalshid	Not Satisfactory	Very Poor	Very Poor
8	Ballah	Not Satisfactory	Poor	Very Poor
9	Jariajanjail	Not Satisfactory	Very Poor	Very Poor
10	Kanaighat	Not Satisfactory	Very Poor	Very Poor
11	Muslimpur	Not Satisfactory	Very Poor	Very Poor
12	Sheola	Not Satisfactory	Very Poor	Very Poor
13	Sylhet	Not Satisfactory	Very Poor	Very Poor
14	Kamalganj	Poor	Very Poor	Very Poor
15	Moulvi-Bazar	Poor	Very Poor	Very Poor
16	Nakuagaon	Poor	Very Poor	Very Poor
17	Sarighat	Poor	Very Poor	Very Poor
18	Habiganj	Very Poor	Very Poor	Very Poor
19	Manu-RB	Very Poor	Very Poor	Very Poor

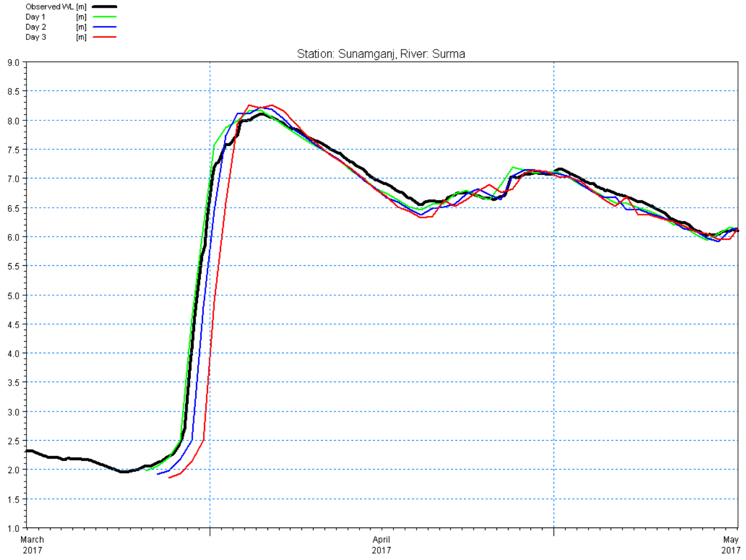
Forecast performance in 2018 in the North-East Region of Bangladesh is shown in Figure 3-31 while performance in numerical values in terms of above specified scale is provided in table 3-10. Map showing station wise forecast performance for 2018 is in Figure 3-32.

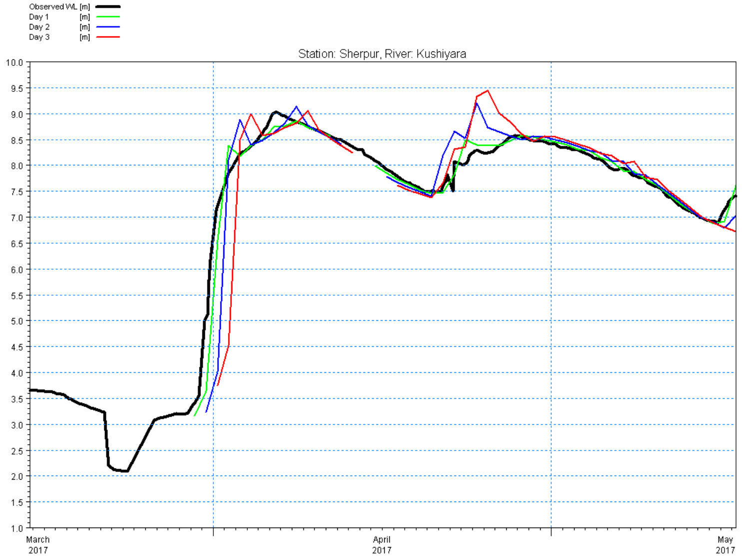
Table 3-9: Forecast Performance for 2017 Flash Flood Event

		1-Day Forecast					2-Day Forecast					3-Day Forecast				
SL	Station	RMSE	R2	MAE	PBAIS	NSE	RMSE2	R_square2	MAE2	PBAIS2	NSE2	RMSE3	R_square3	MAE3	PBAIS3	NSE3
1	Amalshid	0.63	0.95	0.30	-0.07	0.94	1.37	0.77	0.68	-0.71	0.69	2.04	0.56	1.15	-2.90	0.27
2	Ballah	0.55	0.50	0.32	0.18	0.45	0.67	0.30	0.43	0.31	0.19	0.76	0.15	0.54	0.54	-0.02
3	Durgapur	0.23	0.76	0.15	0.32	0.75	0.34	0.51	0.22	0.71	0.46	0.40	0.38	0.24	1.08	0.27
4	Habiganj	0.97	0.49	0.51	0.64	0.40	1.19	0.26	0.76	1.42	0.10	1.32	0.14	0.83	2.01	-0.08
5	Islampur	0.40	0.68	0.20	1.14	0.63	0.60	0.40	0.34	2.15	0.16	0.68	0.27	0.42	2.75	-0.19
6	Jariajanjail	0.31	0.93	0.22	0.95	0.92	0.63	0.73	0.44	2.26	0.58	0.94	0.45	0.66	4.03	-0.21
7	Kamalganj	0.67	0.61	0.36	-0.25	0.43	1.01	0.56	0.52	-1.05	-0.32	1.21	0.27	0.64	-0.82	-0.92
8	Kanaighat	0.60	0.95	0.28	0.26	0.93	1.34	0.77	0.69	0.29	0.63	2.13	0.47	1.18	-0.22	-0.08
9	Lourergorh	0.29	0.93	0.16	0.52	0.90	0.56	0.76	0.31	0.76	0.57	0.83	0.54	0.47	0.66	-0.26
10	Manu-RB	0.71	0.69	0.39	-0.38	0.44	1.18	0.52	0.71	-1.34	-0.55	1.34	0.49	0.80	-1.57	-1.00
11	Markuli	0.11	0.94	0.07	-0.25	0.93	0.20	0.83	0.14	-0.85	0.79	0.29	0.74	0.19	-1.61	0.59
12	Moulvi-Bazar	0.65	0.71	0.35	-0.52	0.54	1.08	0.51	0.59	-2.99	-0.27	1.33	0.48	0.72	-3.93	-0.88
13	Muslimpur	0.49	0.94	0.21	2.90	0.92	0.92	0.79	0.42	5.84	0.66	1.29	0.58	0.61	8.36	0.09
14	Nakuagaon	0.36	0.45	0.24	0.22	0.28	0.52	0.10	0.38	0.48	-0.52	0.57	0.04	0.41	0.68	-0.85
15	Sarighat	0.84	0.83	0.36	2.14	0.80	1.26	0.62	0.67	3.34	0.50	1.70	0.35	0.94	4.58	0.00
16	Sheola	0.64	0.93	0.25	0.10	0.91	1.29	0.73	0.60	-0.32	0.57	1.83	0.47	1.00	-1.81	-0.04
17	Sherpur	0.28	0.95	0.14	0.44	0.92	0.61	0.81	0.28	0.49	0.62	0.85	0.61	0.41	0.12	0.07
18	Sunamganj	0.32	0.96	0.13	1.31	0.94	0.67	0.82	0.27	2.96	0.65	1.02	0.59	0.42	4.69	-0.18
19	Sylhet	0.51	0.95	0.24	0.79	0.92	1.08	0.76	0.48	1.78	0.57	1.65	0.43	0.77	2.58	-0.37


Observed_WL [m]
Day 1 [m]
Day 2 [m]
Day 3 [m]
Station: Amalshid, River:Kushiyara
March 2017
April 2017
May 2017


Observed WL [m]
Day 1 [m]
Day 2 [m]
Day 3 [m]
Station: Sylhet, River: Surma
March 2017
April 2017
May 2017


Observed WL [m]
Day 1 [m]
Day 2 [m]
Day 3 [m]
Station: Sunamganj, River: Surma
March 2017
April 2017
May 2017


Observed WL [m]
Day 1 [m]
Day 2 [m]
Day 3 [m]
Station: Sherpur, River: Kushiyara
March 2017
April 2017
May 2017

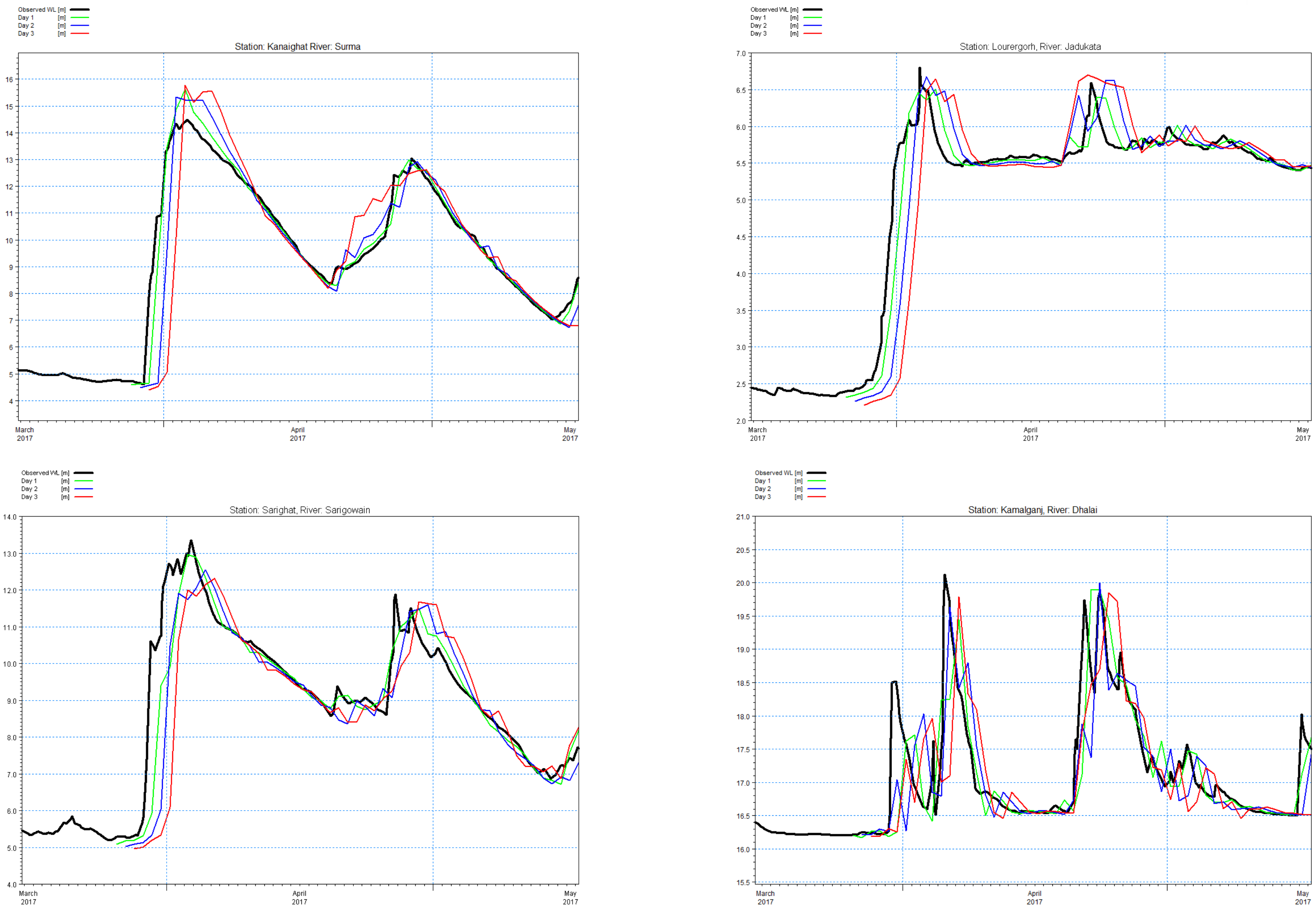


Figure 3-29: Forecast Performance in 2017

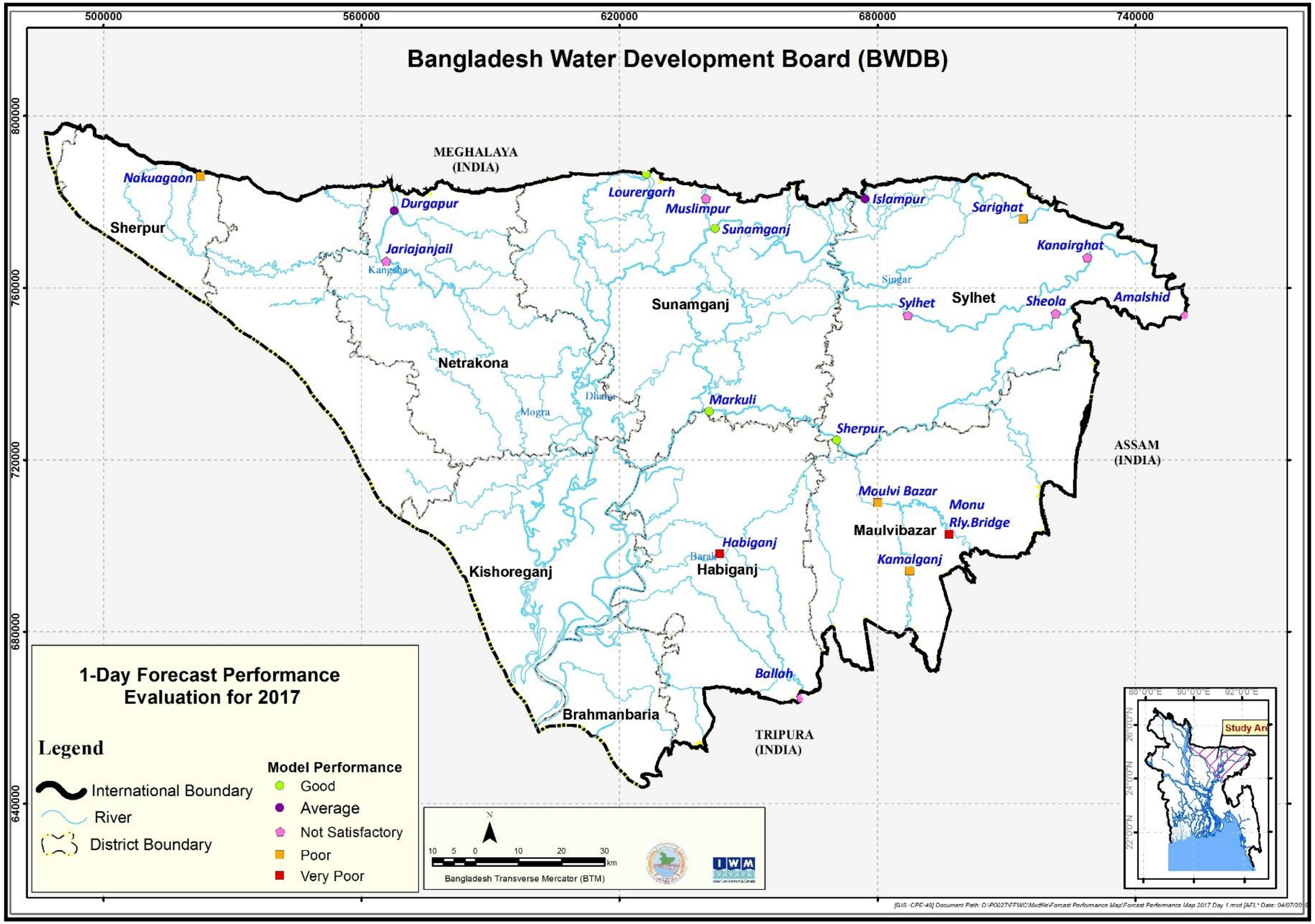
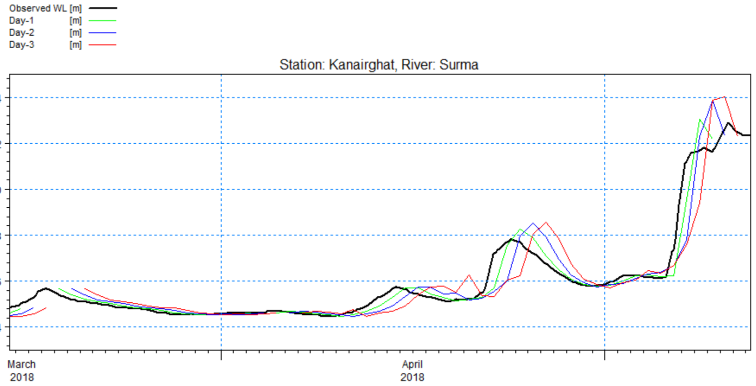
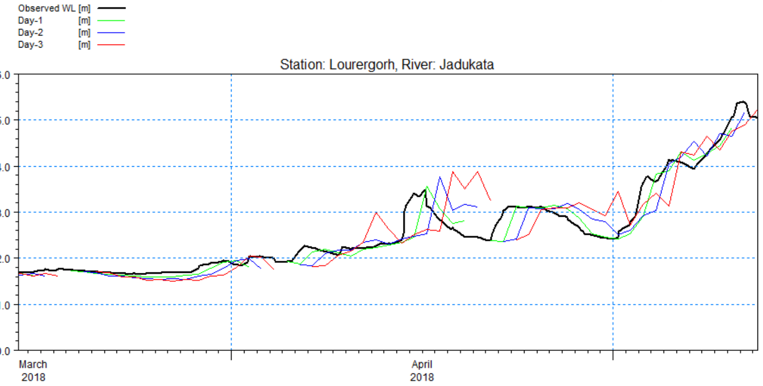
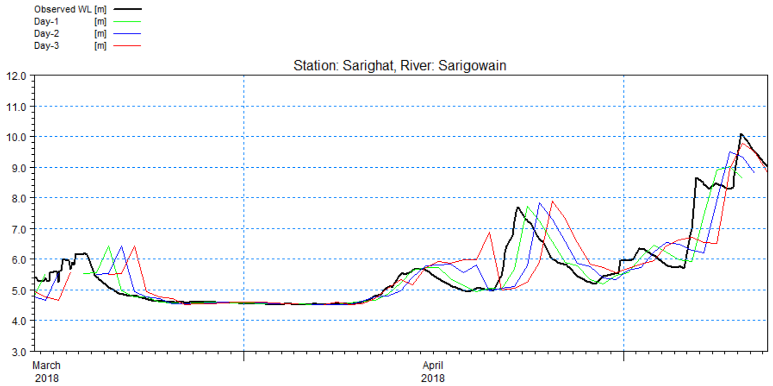
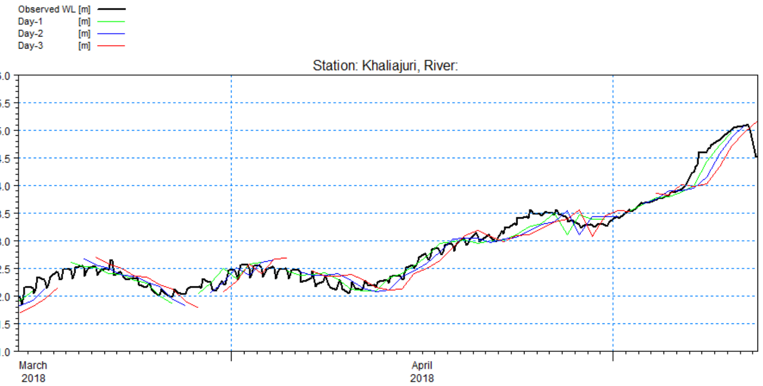


Figure 3-30: Map showing station wise forecast performance in 2017


Observed WL [m]
Day-1 [m]
Day-2 [m]
Day-3 [m]
Station: Kanairghat, River: Surma
14
12
10
8
6
4
March
2018
April
2018


Observed WL [m]
Day-1 [m]
Day-2 [m]
Day-3 [m]
Station: Lourergorh, River: Jadukata
6.0
5.0
4.0
3.0
2.0
1.0
0.0
March
2018
April
2018


Observed WL [m]
Day-1 [m]
Day-2 [m]
Day-3 [m]
Station: Sarighat, River: Sarigowain
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
March
2018
April
2018


Observed WL [m]
Day-1 [m]
Day-2 [m]
Day-3 [m]
Station: Khaliajuri, River:
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
March
2018
April
2018

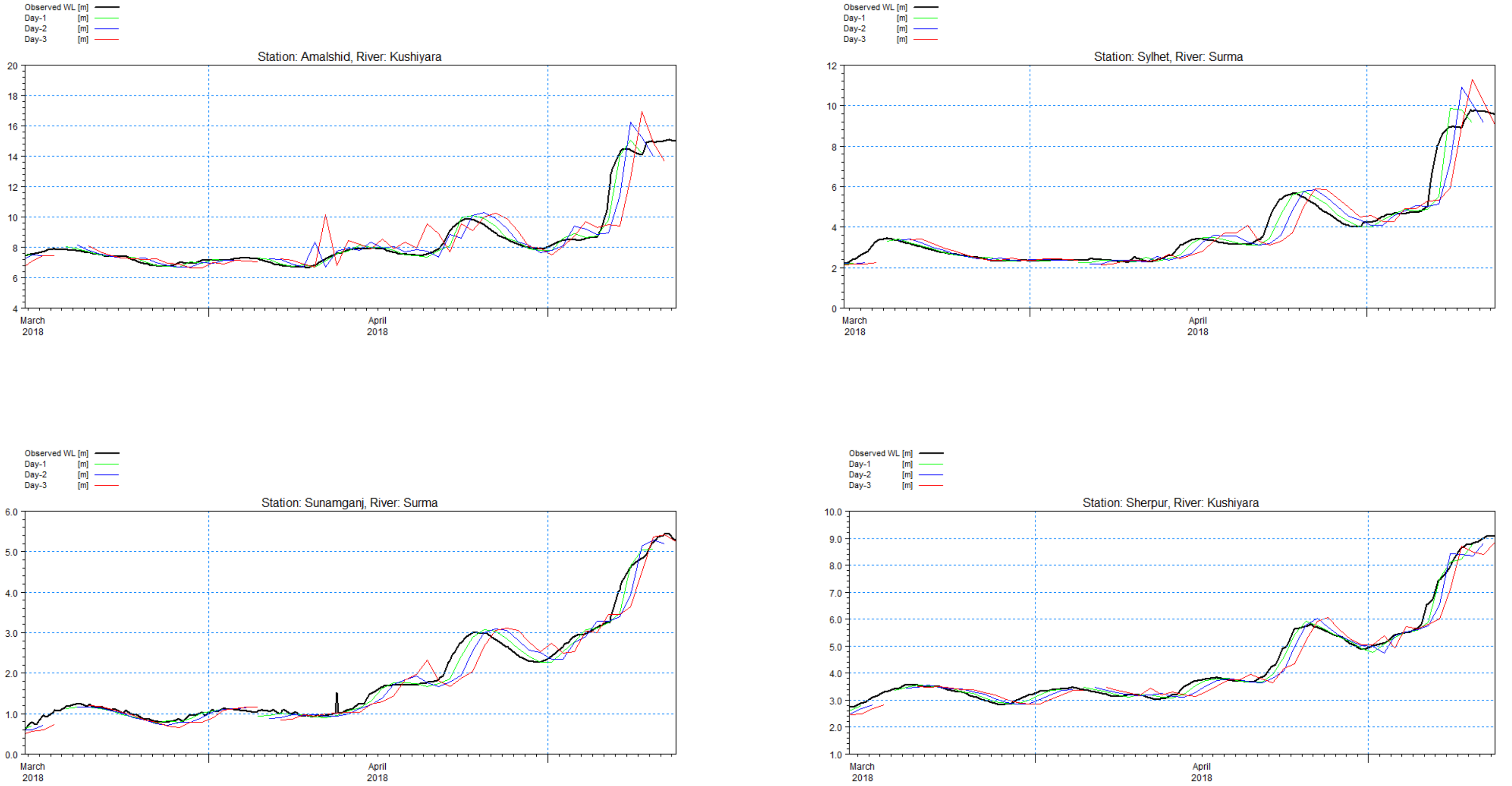


Figure 3-31: Forecast Performance in 2018

Table 3-10: Forecast Performance for 2018

		1-Day Forecast					2-Day Forecast					3-Day Forecast				
SL	Station	RMSE	R2	MAE	PBAIS	NSE	RMSE	R2	MAE	PBAIS	NSE	RMSE	R2	MAE	PBAIS	NSE
1	Amalshid	0.38	0.98	0.23	0.50	0.98	0.81	0.90	0.53	0.61	0.90	1.17	0.79	0.77	0.36	0.79
2	Azmiriganj	0.10	0.99	0.08	0.71	0.99	0.19	0.98	0.15	1.35	0.98	0.29	0.96	0.22	1.86	0.95
3	Ballah	0.42	0.52	0.24	0.17	0.40	0.48	0.47	0.30	0.02	0.22	0.49	0.46	0.30	0.05	0.22
4	Durgapur	0.18	0.73	0.09	0.20	0.73	0.21	0.64	0.12	0.28	0.63	0.26	0.43	0.16	0.32	0.41
5	Fenchuganj	0.14	1.00	0.11	0.73	1.00	0.31	0.98	0.22	1.36	0.98	0.47	0.95	0.35	1.90	0.95
6	Gowainghat	0.51	0.92	0.43	-1.21	0.91	0.82	0.79	0.66	-1.63	0.75	0.93	0.73	0.76	-1.41	0.66
7	Habiganj	0.49	0.69	0.22	1.64	0.67	0.54	0.60	0.31	1.37	0.59	0.59	0.57	0.36	1.20	0.55
8	Islampur	0.10	0.77	0.07	-0.22	0.74	0.15	0.55	0.11	-0.68	0.40	0.22	0.30	0.15	-1.07	-0.17
9	Jariajanjail	0.26	0.97	0.16	-0.17	0.97	0.43	0.91	0.27	-0.48	0.91	0.54	0.86	0.36	-0.21	0.86
10	Kalmakanda	0.19	0.98	0.14	0.30	0.98	0.28	0.96	0.23	0.70	0.95	0.34	0.94	0.28	0.75	0.93
11	Kamalganj	0.03	0.65	0.02	0.01	0.62	0.05	0.43	0.03	0.03	0.31	0.05	0.29	0.04	0.07	0.04
12	Kanaighat	0.44	0.97	0.24	0.35	0.97	0.73	0.91	0.42	0.69	0.91	0.93	0.86	0.61	1.04	0.86
13	Khaliajuri	0.11	0.98	0.09	0.47	0.98	0.15	0.97	0.12	0.71	0.97	0.20	0.96	0.17	0.73	0.95
14	Lourergorh	0.61	0.95	0.56	16.98	0.67	0.65	0.90	0.58	16.43	0.62	0.69	0.81	0.60	14.48	0.58
15	Manu-RB	0.41	0.87	0.24	0.13	0.87	0.63	0.70	0.33	0.45	0.68	0.75	0.59	0.43	0.77	0.56
16	Markuli	0.18	0.99	0.12	1.67	0.99	0.27	0.98	0.20	2.68	0.98	0.40	0.96	0.30	4.13	0.95
17	Moulvi-Bazar	0.48	0.92	0.33	0.69	0.92	0.72	0.82	0.48	1.15	0.81	0.86	0.75	0.62	1.57	0.74
18	Muslimpur	1.10	0.98	1.08	31.39	0.43	1.20	0.94	1.14	32.71	0.32	1.31	0.88	1.20	34.06	0.19
19	Nakuagaon	0.25	0.36	0.12	0.04	0.19	0.28	0.24	0.14	0.11	-0.01	0.25	0.36	0.14	0.20	0.21
20	Sarighat	0.47	0.90	0.30	-0.45	0.89	0.72	0.79	0.48	-1.45	0.76	0.87	0.70	0.58	-2.53	0.65
21	Sheola	0.28	0.99	0.17	0.67	0.99	0.58	0.95	0.38	1.18	0.95	0.89	0.88	0.58	1.21	0.88
22	Sherpur	0.16	0.99	0.11	1.00	0.99	0.29	0.98	0.20	1.90	0.98	0.42	0.96	0.30	2.74	0.95
23	Sunamganj	1.07	0.99	1.06	33.20	0.43	1.11	0.97	1.08	33.66	0.39	1.14	0.95	1.09	33.74	0.36
24	Sutang_RB	0.25	0.64	0.22	-1.24	0.57	0.36	0.49	0.28	-3.07	0.17	0.50	0.22	0.36	-3.47	-0.51
25	Sylhet	0.45	0.96	0.24	0.66	0.96	0.68	0.92	0.40	1.40	0.91	0.84	0.88	0.51	1.87	0.87

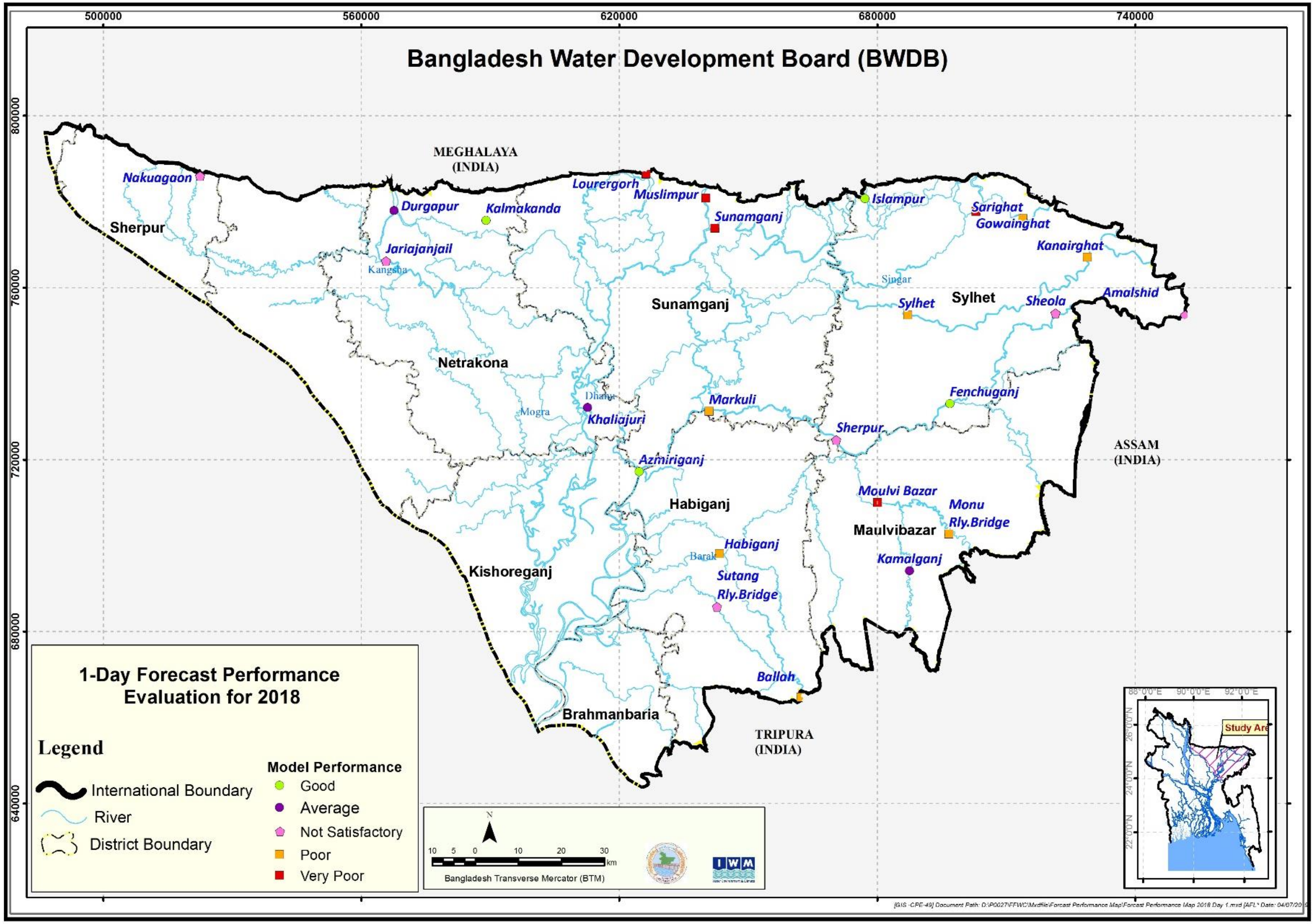


Figure 3-32: Map showing station wise forecast performance in 2018

4. FLASH FLOOD FORECAST PRODUCTS & DISSEMINATION

4.1 General

As per ToR of the study, IWM has been involved in developing the forecasting model and operational forecast system for the flash flood prone North-East Region. The major outputs of this forecasting system are station wise forecast hydrograph, observed bulletin, forecast bulletin and summary bulletin produced on daily basis. Also, Quantitative Precipitation Forecast (QPF) and Embankment based forecast are also significant outputs in this study. To ease this forecast products, an automatic forecasting system, dedicated website and mobile apps have been developed under this project.

4.2 Automatic Flash Flood Forecast System

Flash Flood occurs within 6 to 12 hours of any rainfall event. Hence fast data collection and processing is very important for operational flash flood forecasting system. To receive and to process rainfall data from Indian part and Bangladesh part, to simulate the weather forecast model and hydrological, hydrodynamic and forecast module and to process the model outputs in a quick and efficient manner, a software tool has been developed under this study. The automatic forecast system has been developed to ease the process.

The automatic forecast system is comprised with four modules described as a) Data Processing Module, b) Weather Model Data Processing Module, c) MIKE Packages and d) Post-Processing Modules. All modules are described in the subsequent sections.

a) Data Processing Module:

Data analysis and processing is very significant part of flood forecasting system. Rainfall, water level, discharge and weather forecast data are the main input of flood forecasting modeling. This module allows the user to prepare all type of data for modelling as well as checking the consistency of the input data to run the forecast model twice in a day. Figure 4-1 shows the data processing module while figure 4-2 and 4-3 shows the rainfall and water level data processing interfaces respectively.

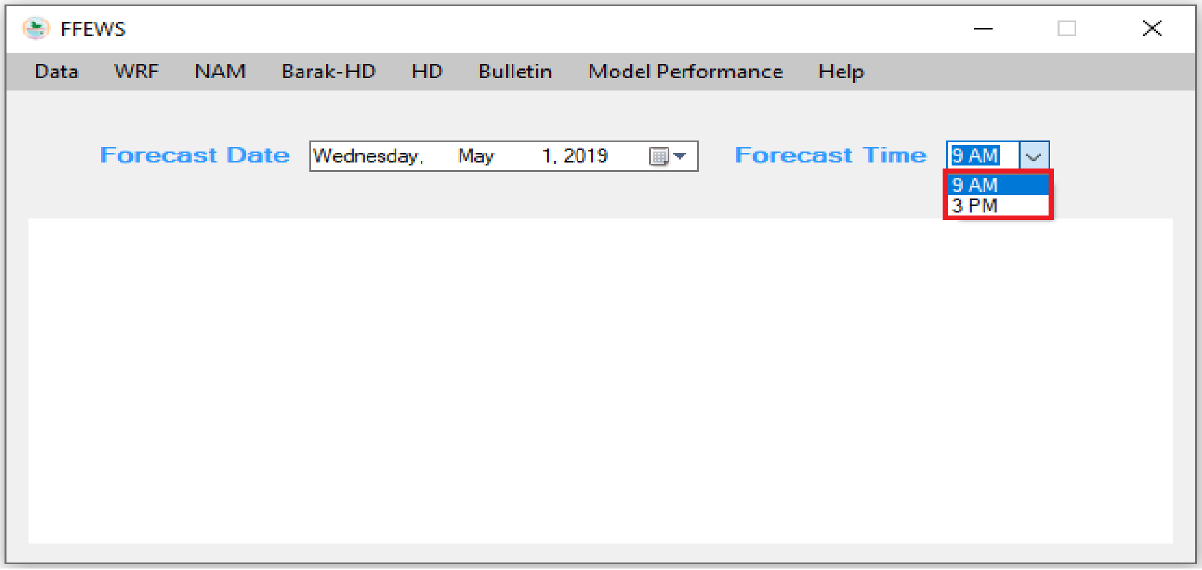
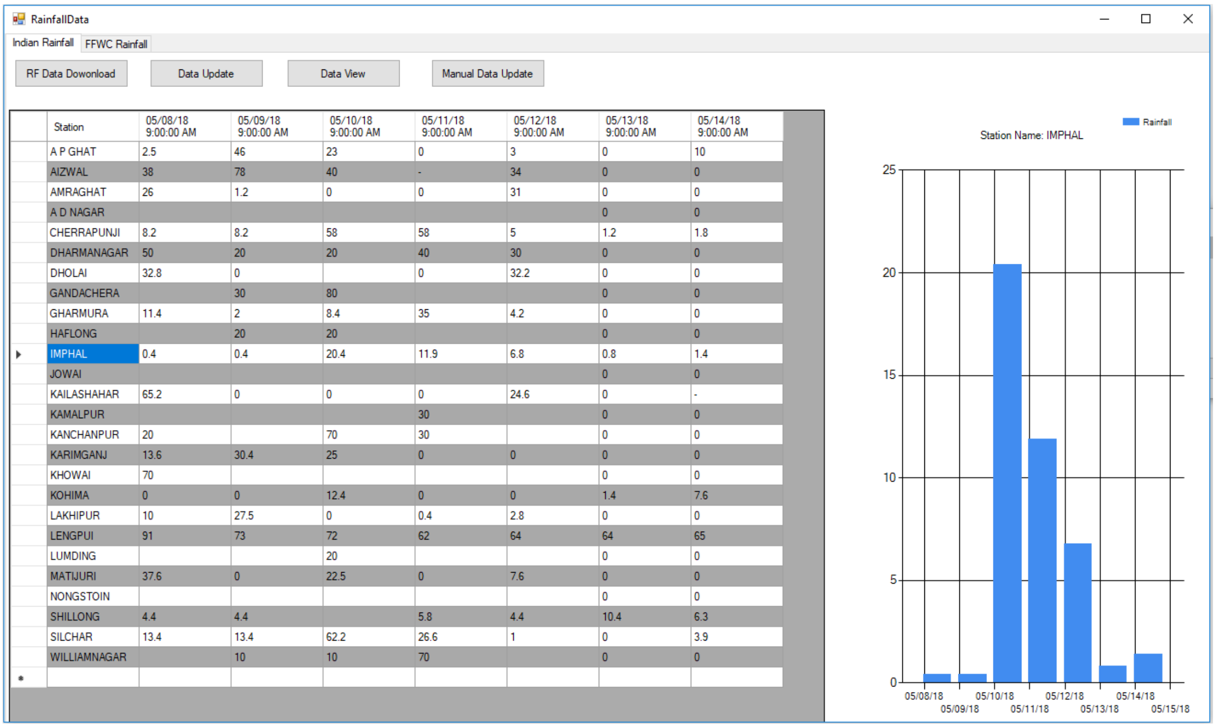


Figure 4-1: Data processing module

Rainfall data processing module process two types of rainfall data, one is collected from Indian websites and other one is collected from FFWC server. This interface gives the user a lot of opportunities to download the rainfall data, edit data, data checking and data updating etc. On the other hand, water level data processing module gives the user a lot of freedom. User can update any inconsistent data and add new data in model database. To receive real-time rainfall and water level data from gauges, a SMS data handling software titled as “SMS Solution” has been enriched with new stations and applied in this process to get input for this data processing module. The details of the tool are described in section 4.2 of this report.



Station	05/08/18 9:00:00 AM	05/09/18 9:00:00 AM	05/10/18 9:00:00 AM	05/11/18 9:00:00 AM	05/12/18 9:00:00 AM	05/13/18 9:00:00 AM	05/14/18 9:00:00 AM
A P GHAT	2.5	46	23	0	3	0	10
AIZWAL	38	78	40	-	34	0	0
AMRAGHAT	26	1.2	0	0	31	0	0
A D NAGAR						0	0
CHERRAPUNJI	8.2	8.2	58	58	5	1.2	1.8
DHARMANAGAR	50	20	20	40	30	0	0
DHOLAI	32.8	0		0	32.2	0	0
GANDACHERA		30	80			0	0
GHARMURA	11.4	2	8.4	35	4.2	0	0
HAFLONG		20	20			0	0
IMPHAL	0.4	0.4	20.4	11.9	6.8	0.8	1.4
JOWAI						0	0
KAILASHAHAR	65.2	0	0	0	24.6	0	-
KAMALPUR				30		0	0
KANCHANPUR	20		70	30		0	0
KARIMGANJ	13.6	30.4	25	0	0	0	0
KHOWAI	70					0	0
KOHIMA	0	0	12.4	0	0	1.4	7.6
LAKHIPUR	10	27.5	0	0.4	2.8	0	0
LENGPUI	91	73	72	62	64	64	65
LUMDING			20			0	0
MATIJURI	37.6	0	22.5	0	7.6	0	0
NONGSTOIN						0	0
SHILLONG	4.4	4.4		5.8	4.4	10.4	6.3
SILCHAR	13.4	13.4	62.2	26.6	1	0	3.9
WILLIAMNAGAR		10	10	70		0	0

Figure 4-2: Rainfall data processing and checking interface

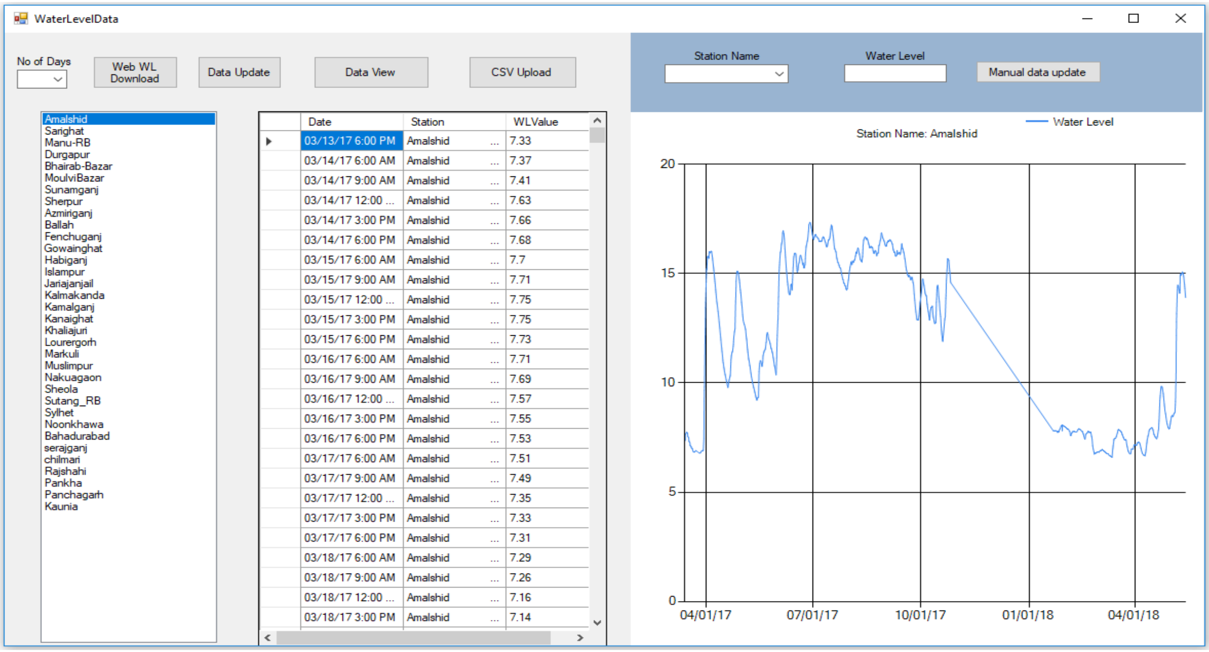


Figure 4-3: Water Level data processing and checking interface

b) Weather Model Data Processing

In this system, weather forecast model (WRF) is running in Linux operating system in separate computer but connected with the "Flash Flood Early Warning System Automation" tool by Lan. WRF model is fully automated and run on daily basis. Once the WRF model simulation is done, user can process the forecast outputs in map format and prepare the forecast for the hydrological simulation in model compatible format. Figure 4-4 shows the weather model data processing module. Also, this module is connected with the BMD's ftp server where BMD updates ten days WRF's forecasted rainfall regularly. User can use either FFWC or BMD predicted rainfall and map viewer option gives the flexibility to compare the two products.

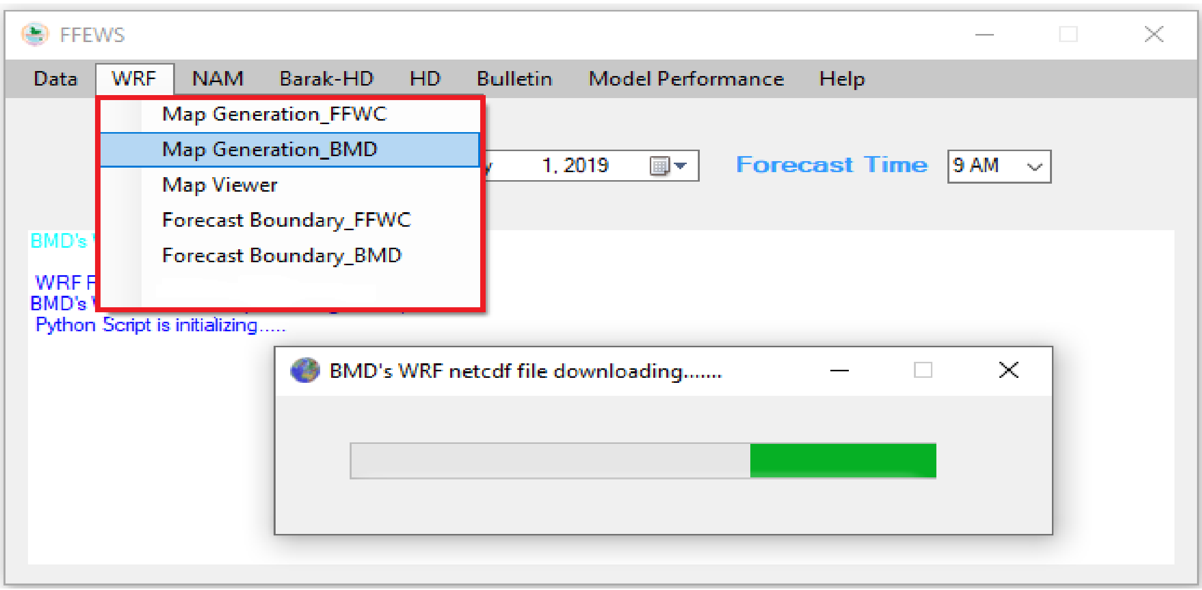


Figure 4-4: Weather model data processing module

Weather model data processing module is consisted with python script and Arc-GIS .dll file. This module completes two jobs, one is rainfall map processing by clicking on 'Map Generation' and other one is created forecasted boundary for hydrological model using WRF forecasted rainfall data by clicking on 'Forecast Boundary'.

c) Mike Packages

This automation tool provides facility to simulate the forecast models in a single platform. One hydrological and two hydrodynamic models are incorporated in here. Figure 4-5 shows the interface of the mike package module. The package is described below.

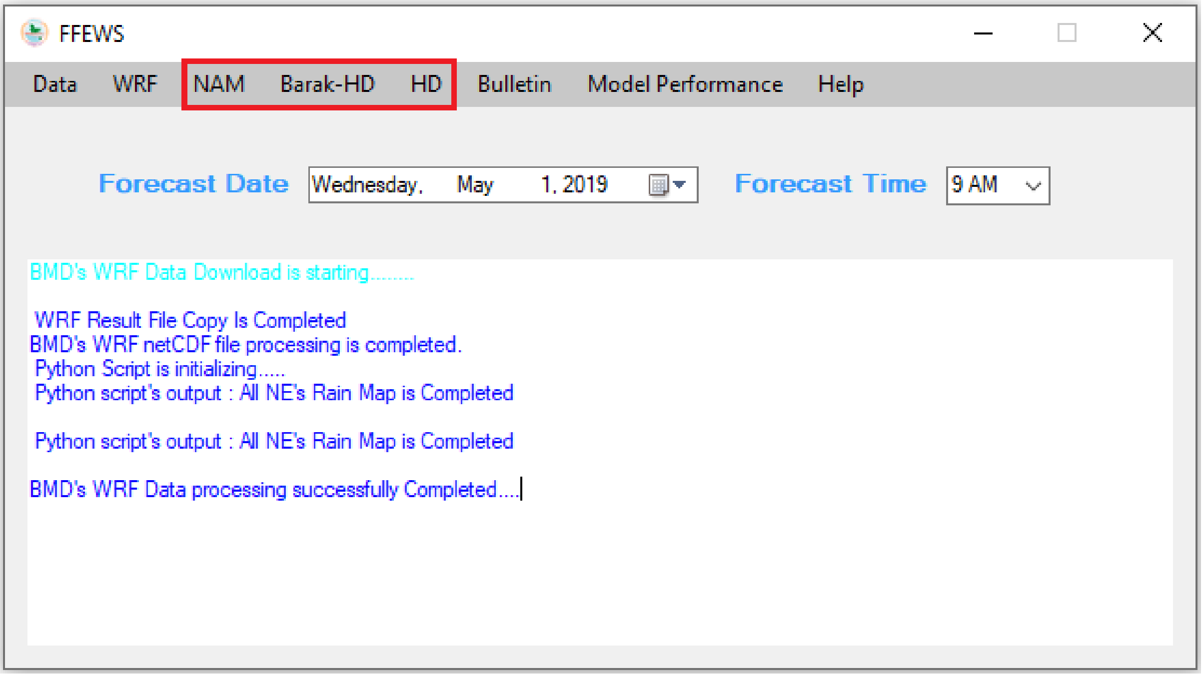


Figure 4-5: Mike package module

Step 1: Rainfall Runoff Model (NAM) Tab:

To simulate the Rainfall-Runoff Model (NAM), it has three steps such as boundary generation from observed data, run /simulate NAM model and NAM result processing. And user should follow it step by step. Figure 4-6 shows the NAM Tab of the automation tool.

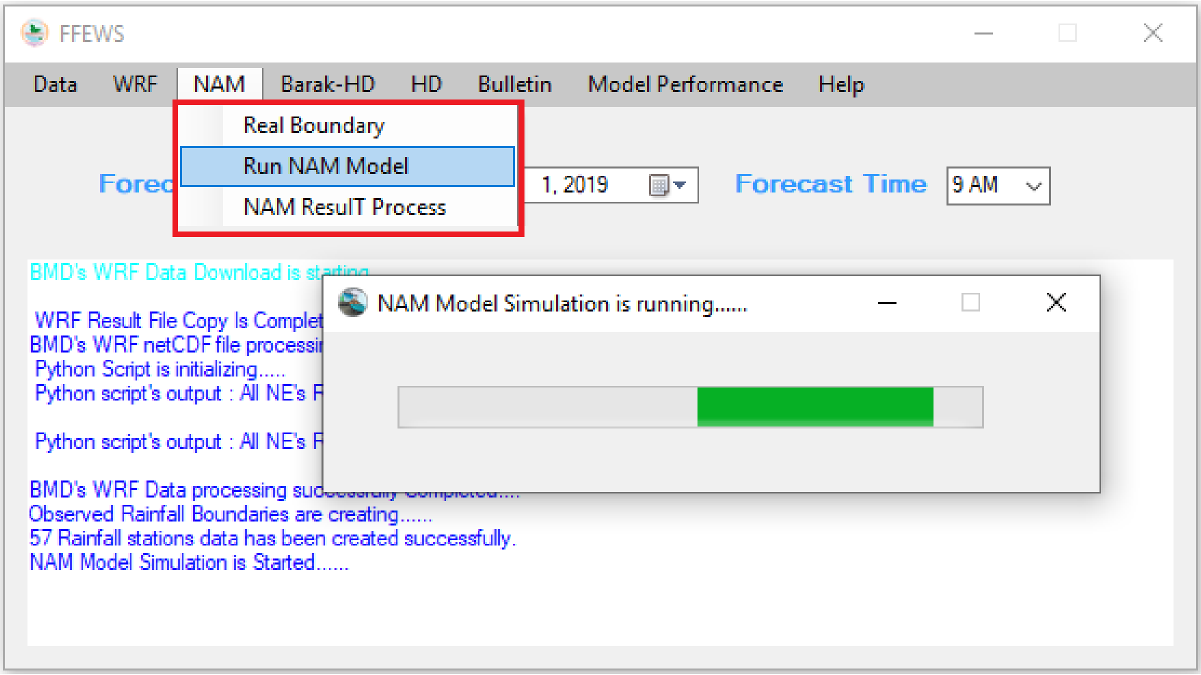


Figure 4-6: Automation of hydrological model

Step 2: Barak Hydrodynamic Model (Barak-HD):

Barak basin is comprised by eight sub-basins. This basin is dominating force for flooding in North-East Region as this basin has the largest catchments coverage and Barak River carry water from nearly 140 km river reach to Bangladesh border at Amalshid. To predict flow at Amalshid, Barak hydrodynamic model simulates flow at the outlet of Barak Basin. User can simulate the model by clicking on 'Run Barak Model'. Figure 4-7 shows the interface for this purpose.

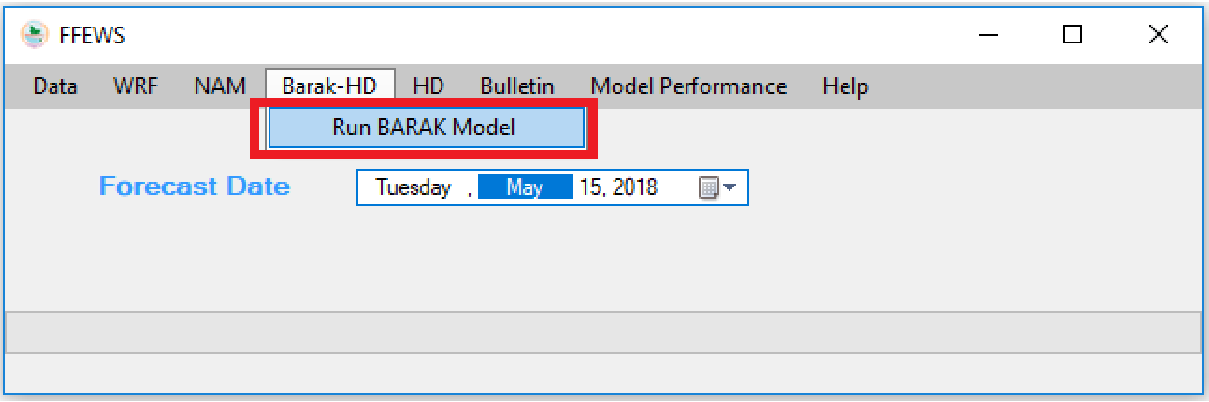


Figure 4-7: Automation of Barak-HD model

Step 3: North-East Hydrodynamic Model (HD):

North-East hydrodynamic model is consisted by all major and influential river and khals of the North-East Region. This module has three steps such as boundary generation, model run and forecast generation. User can simulate the model by following the sequence of the Tab. Figure 4-8 shows the screenshot of the interface.

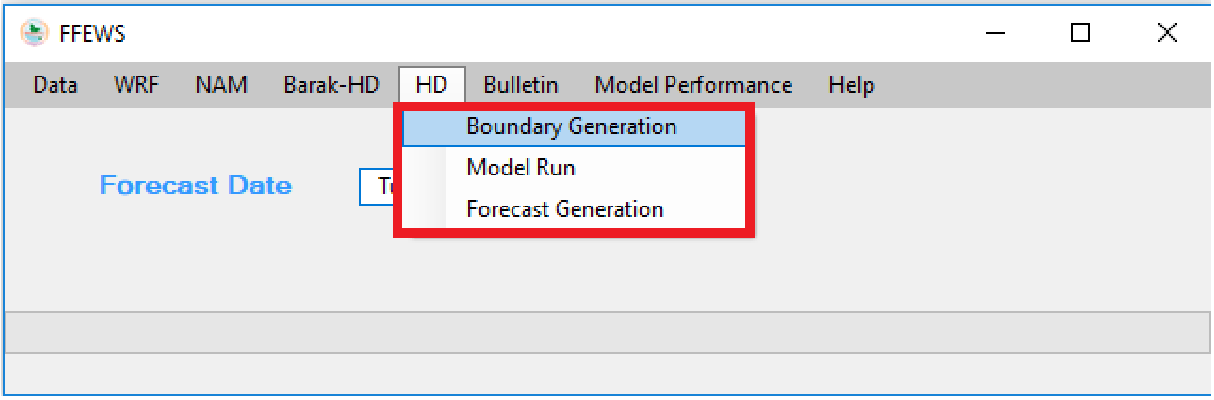


Figure 4-8: Automation of North-East-HD model

In "Boundary Generation" button, system creates all boundary condition for HD Model using rating curves and necessary correction. This popup window also gives the freedom to check data consistency of forecasted boundary condition and user can apply his own judgement for boundary correction (Figure 4-9). If user change water level data, this module calculates the discharge data according to water level and vice-versa.

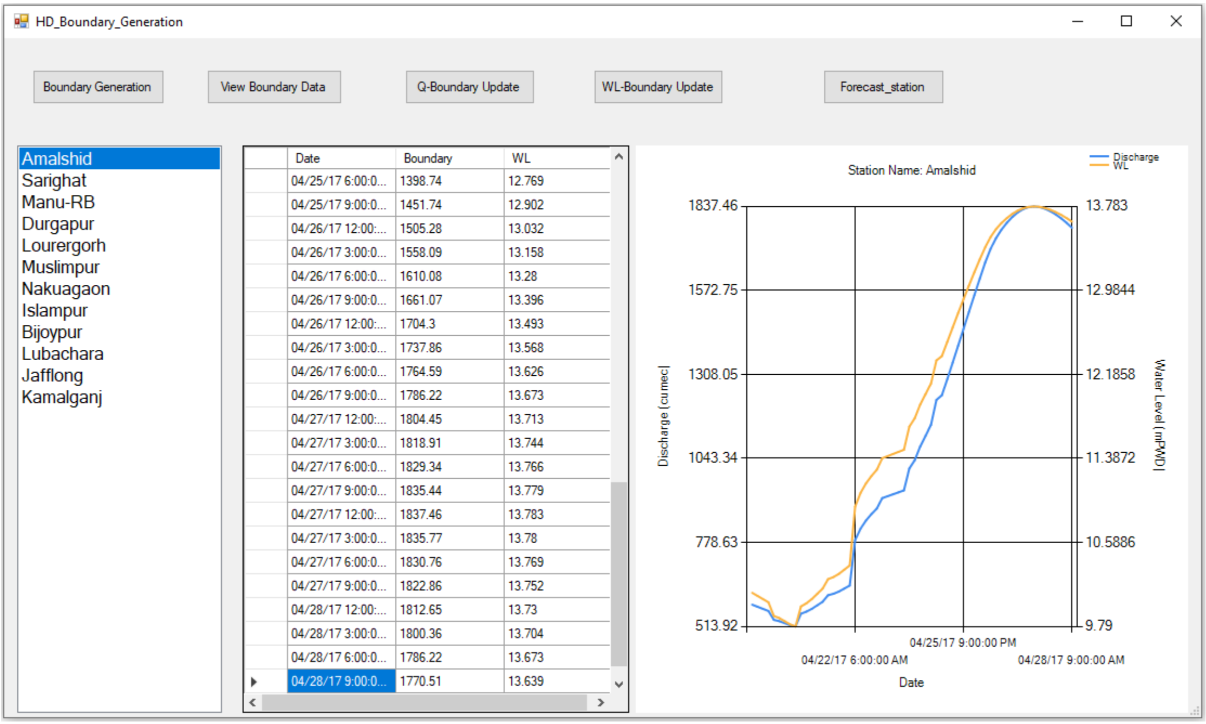


Figure 4-9: Boundary Generation for HD model

SMS Solutions

This software has been proved as an efficient tool for collecting real-time water level and rainfall data from more than 100 nos. real-time monitoring stations spread all over Bangladesh developed by IWM for FFWC since 2015. The main objective of the system is acquisition of water level and rainfall data from observation stations through SMS (through GSM network) and pre-process for Flood Forecast Model input. It provides quality data in less time and eliminate the redundant jobs for parsing and processing. Data pre-processing for flood model has been achieved through a few clicks. This software has been used with necessary updating and customization for this study. The tools work through a conceptual framework as shown in figure 4-10.

Figure 4-10: Conceptual design of the System

The methodology of the tool has been described and shown in figure 4-11. As a process, gauge reader creates SMS as per defined SMS specification and send SMS to specific FFWC's cell phone number. Then, FFWC Android Apps (developed using Java) create files (text format) containing SMS(s) which are to be imported by application software running on Windows operating system, then clear all SMS (by delete operation) from inbox of the cell phone to make it ready for next operation. Later, an SMS software (developed using C#, SQL Server 2008, RDLC) Store all raw SMS in the database server. Features and functionalities are also there to view raw SMS(s), filter out all irrelevant SMS from the SMS(s), sorting and parsing SMS(s) to store in databases in appropriate data format as well as to pre-process data and export data in csv/text format.

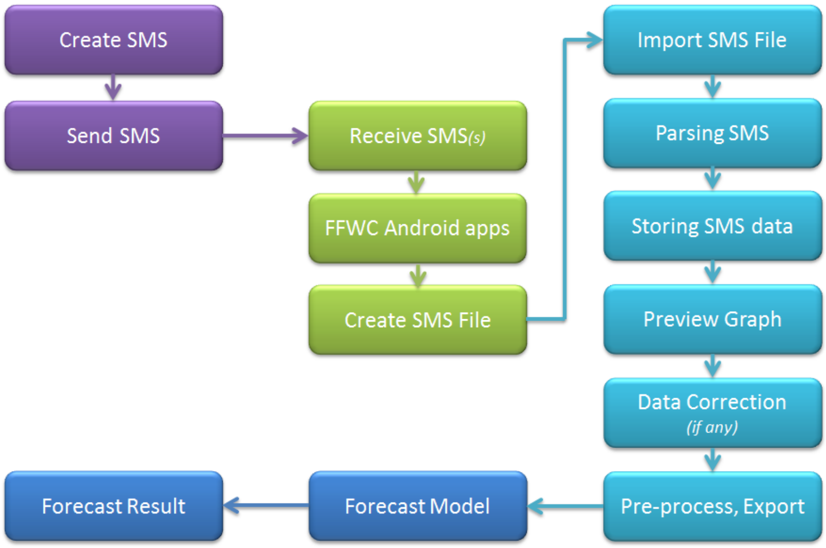


Figure 4-11: Detail design of the System through activity

d) Post Processing Module

Once the model simulation is done, forecast products can be automatically processed using 'POST PROCESSING MODULE' of the automation tools developed in IWM under this study. Post processing module creates different types of forecast output like observed bulletin, forecast bulletin, web data etc. Figure 4-12 shows the screenshot of the post processing module. Once the pre-monsoon season is over, user can estimate statistical values and evaluate the forecast performance for any desired forecast stations using "Model Performance "Tab shown in Figure 4-13.

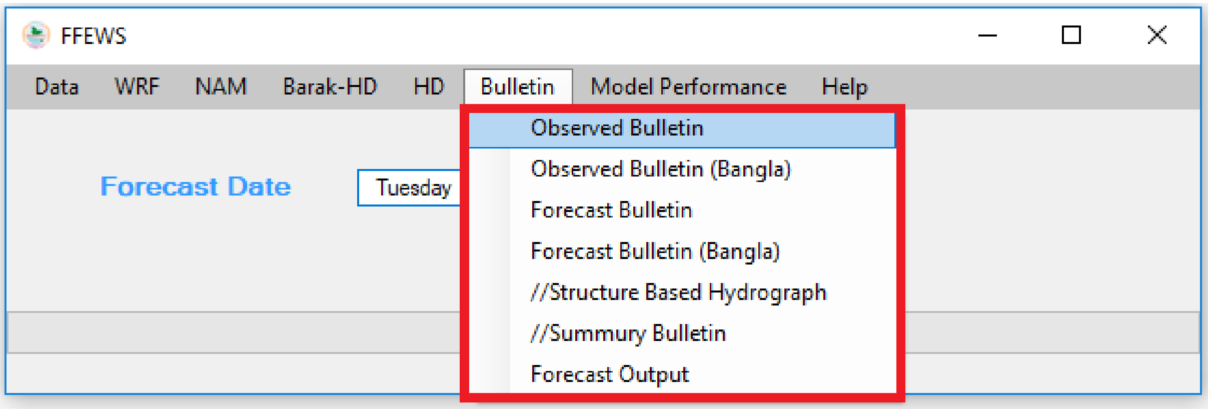


Figure 4-12: Post processing module

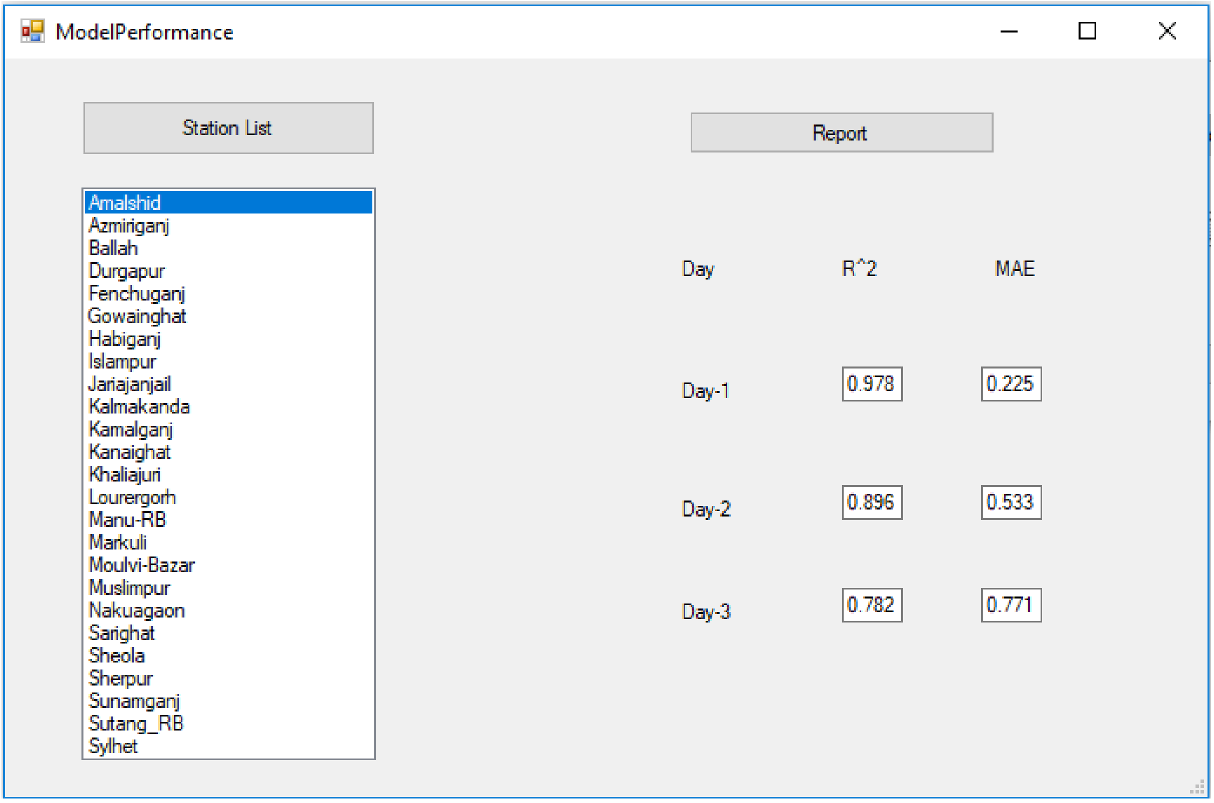


Figure 4-13: Model performance checking performance.

4.3 Forecast Hydrograph and Bulletin

The flash flood forecasting system of FFWC has been made operational this year since March 15, 2019 as per the agreed timeline taken by Technical Committee for covering flash flood from its very beginning. In this response, IWM and FFWC have jointly started the data collection process from 1st March through alerting all the concern Section Officers (SO) of North Eastern Measurement Division and gauge readers and based on the available data, simulated the models from March 1 to March 15 as warm up periods. After successfully simulated the models for the warm-up periods, the flash flood forecasting system have been made operational from March 15 and onwards. As per ToR, the forecast system has to be made fully operational in its third year, thus "Experimental" terms have been omitted from the website and all associated pages or tables.

Flood Forecasting and Warning Center (FFWC) have been involved and uploading all the routine forecast products such as Summary Bulletin, Observed Bulletin both in Bangla and English, Forecast Bulletin both in Bangla and English and special outlook bulletin in case of severe or emergency flood events in their websites from the very first day of this season. The flash flood forecast products as of 15th April 2019 is provided in the following figure 4-14. It is necessary to mention here that in the last technical committee meeting; a decision was made that the flash flood forecast bulletin should reflect the forecast for 6 or 12 hours interval instead of 24-hr interval as flash flood event changes very rapidly. In this response, the forecast bulletin format has been modified into 12-hr interval and made available in the website since March 2019.

FLOOD INFORMATION CENTRE, FLOOD FORECASTING & WARNING CENTRE
BANGLADESH WATER DEVELOPMENT BOARD, WAPDA BUILDING, 8TH FLOOR, DHAKA
E-mail: ffwcbwdb@gmail.com, ffwc05@yahoo.com, Website: http://www.ffwc.gov.bd Tel: 9553118, 9550755 Fax: 9557386
Flash Flood Forecast Bulletin for North East Region as on 15-April-2019 (Morning)

Station Name	River Name	Experimental		15-April-2019			16-April-2019				17-April-2019				18-April-2019	
		DL (PM) (mMSL)	RHWL (PM) (mMSL)	Observed 9:00 AM (mMSL)	Forecast 9:00 PM (mMSL)	12-Hr R/F (cm)	Forecast 9:00 AM (mMSL)	24-Hr R/F (cm)	Forecast 9:00 PM (mMSL)	36-Hr R/F (cm)	Forecast 9:00 AM (mMSL)	48-Hr R/F (cm)	Forecast 9:00 PM (mMSL)	60-Hr R/F (cm)	Forecast 9:00 AM (mMSL)	72-Hr R/F (cm)
Kanaighat	Surma	10.89	14.8	3.73	3.70	-3	3.68	-5	3.65	-8	3.63	-10	3.61	-12	3.59	-14
Sylhet	Surma	8.29	10.31	1.38	1.37	-1	1.37	-1	1.37	-1	1.36	-2	1.36	-2	1.35	-3
Sunamganj	Surma	6.04	7.89	1.13	1.13	0	1.13	0	1.13	0	1.13	0	1.13	0	1.12	-1
Amalshid	Kushiyara	13.04	15.82	6.38	6.32	-6	6.28	-10	6.23	-15	6.18	-20	6.12	-26	6.07	-31
Sheola	Kushiyara	10.69	13.76	4.38	4.34	-4	4.31	-7	4.27	-11	4.24	-14	4.21	-17	4.17	-21
Sherpur	Kushiyara	7.79	8.44	2.84	2.82	-2	2.80	-4	2.79	-5	2.77	-7	2.75	-9	2.73	-11
Markuli	Surma-Meghna	5.94	7.36	2.40	2.38	-2	2.37	-3	2.35	-5	2.34	-6	2.32	-8	2.31	-9
Sarighat	Sarigowain	10.69	13.61	3.51	3.51	0	3.50	-1	3.50	-1	3.49	-2	3.49	-2	3.48	-3
Manu-RB	Manu	16.44	19.96	12.35	12.31	-4	12.30	-5	12.29	-6	12.28	-7	12.28	-7	12.27	-8
Moulvi-Bazar	Manu	9.54	12.5	5.23	5.14	-10	5.17	-7	5.09	-14	5.09	-14	4.96	-27	4.99	-24
Ballah	Khowai	21.34	24.82	19.41	19.32	-9	19.24	-17	19.18	-23	19.13	-28	19.10	-31	19.07	-34
Habiganj	Khowai	8.64	11.04	4.20	4.08	-12	3.96	-24	3.86	-34	3.77	-43	3.71	-49	3.66	-54
Kamalganj	Dhalai	19.04	20.72	15.19	15.08	-11	14.99	-20	14.90	-29	14.83	-36	14.78	-41	14.73	-46
Khaliajuri	Baulai	4.14	5.31	1.12	1.17	+5	1.18	+6	1.19	+7	1.21	+9	1.22	+10	1.23	+11
Nakuagaon	Bhogai-Kangsa	20.79	22.6	17.67	17.68	+1	17.68	+1	17.69	+2	17.69	+2	17.69	+2	17.68	+1
Lourergorh	Jadukata	5.94	7.15	1.94	1.96	+2	1.96	+2	1.96	+2	1.95	+1	1.94	0	1.93	-1
Durgapur	Someswari	10.79	13.38	8.04	8.04	0	8.04	0	8.03	-1	8.03	-1	8.03	-1	8.03	-1
Jariajanjail	Bhogai-Kangsa	6.34	8.97	4.05	4.08	+3	4.10	+5	4.12	+7	4.14	+9	4.14	+9	4.13	+8
Azmiriganj	Kalni	4.54	7.17	1.95	1.94	-1	1.92	-3	1.91	-4	1.89	-6	1.88	-7	1.86	-9
Fenchuganj	Kushiyara	7.74	10.84	3.52	3.50	-2	3.48	-4	3.46	-6	3.44	-8	3.42	-10	3.40	-12
Gowainghat	Sari-Gowain	8.64	11	-	-	-	-	-	-	-	-	-	-	-	-	-
Islampur	Dhalagang	10.24	12.79	5.80	5.79	-1	5.78	-2	5.76	-4	5.75	-5	5.73	-7	5.72	-8
Kalmakanda	Someswari	4.89	5.61	1.36	1.39	+3	1.41	+5	1.43	+7	1.45	+9	1.47	+11	1.48	+12
Muslimpur	Jhalukhali	6.44	9.44	1.11	1.11	0	1.10	-1	1.10	-1	1.09	-2	1.08	-3	1.07	-4
Sutang_RB	Sutang	4.94	7.05	3.99	3.91	-8	3.82	-17	3.74	-25	3.67	-32	3.61	-38	3.55	-44

Note :- *(PM)* *: Pre-Monsoon*
R/F *: Rise/Fall*
mMSL *: metre Mean Sea Level*

Figure 4-14: Forecast Bulletin as of 15 April 2019

The forecast products also include pre-monsoon hydrograph and pre-monsoon historical hydrographs as shown in figure 4-15 and 4-18. Sample observed bulletin in English and Bangla are shown in figure 4-16 and 4-17.

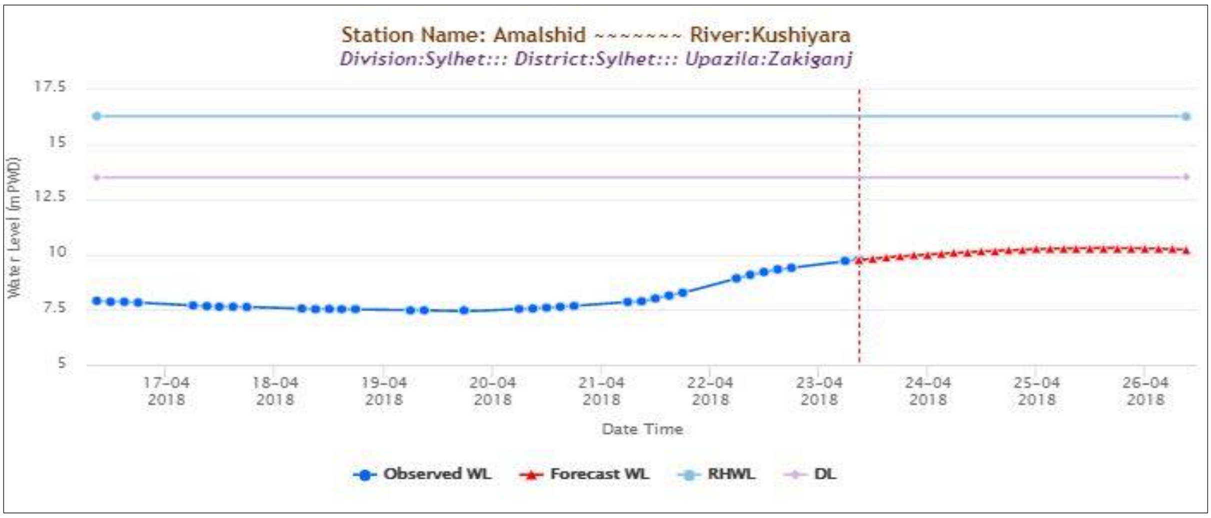


Figure 4-15: Pre-monsoon Forecast hydrograph at Amalshid on Kushiyara River during April 2018

FLOOD FORECASTING AND WARNING CENTER, BWDB
RIVER SITUATION AS ON 2019-04-15 AT 09:00 HOURS

SL NO.	RIVER	STATION NAME	RHWL (m)	D.L. (m).	WATER LEVEL 14-04-2019	WATER LEVEL 15-04-2019	+ Rise -Fall in cm	Above D.L. in cm
	MEGHNA BASIN							
1	SURMA	KANAIGHAT	14.80	10.89	3.79	3.73	- 6	- 621
2	SURMA	SYLHET	10.31	8.29	1.47	1.38	- 9	- 582
3	SURMA	SUNAMGANJ	7.89	6.04	1.23	1.13	- 10	- 388
4	KUSHIYARA	AMALSHID	15.82	13.04	6.52	6.38	- 14	- 574
5	KUSHIYARA	SHEOLA	13.76	10.69	4.50	4.38	- 12	- 531
6	KUSHIYARA	SHERPUR	8.44	7.79	3.03	2.84	- 19	- 399
7	KUSHIYARA	MARKULI	7.36	5.94	2.54	2.40	- 14	- 251
8	SARIGOWAIN	SARIGHAT	13.61	10.69	3.65	3.51	- 14	- 615
9	MANU	MANU-RB	19.96	16.44	12.43	12.35	- 8	- 324
10	MANU	MOULVIBAZAR	12.50	9.54	5.22	5.23	+ 1	- 326
11	KHOWAI	BALLAH	24.82	21.34	19.45	19.41	- 4	- 155
12	KHOWAI	HABIGANJ	11.04	8.64	4.28	4.20	- 8	- 397
13	DHALAI	KAMALGANJ	20.72	19.04	15.21	15.19	- 2	- 292
14	BAULAI	KHALIAJURI	5.31	4.14	1.19	1.12	- 7	- 157
15	BHUGAI	NAKUAGAON	22.60	20.79	17.62	17.67	+ 5	- 262
16	JADUKATA	LOURERGORH	7.15	5.94	1.93	1.94	+ 1	- 348
17	SOMESWARI	DURGAPUR	13.38	10.79	8.03	8.04	+ 1	- 215
18	KANGSHA	JARIAJANJAIL	8.97	6.34	4.08	4.05	- 3	- 122
19	TITAS	B.BARIA	6.50	5.50	-	-	-	-
20	MEGHNA	BHAIRAB BAZAR	7.78	6.25	-	-	-	-
21	MEGHNA	NARSINGDI	7.01	5.70	0.59	0.68	+ 9	- 502
22	MEGHNA	MEGHNA BRIDGE	5.03	4.00	-	-	-	-
23	GUMTI	COMILLA	13.56	11.75	4.94	4.74	- 20	- 701
24	GUMTI	DEBIDDAR	-	5.34	-	-	-	-
25	SARI-GOWAIN	GOWAINGHAT	11.00	8.64	-	-	-	-
26	KALNI	AZMIRIGANJ	7.17	4.54	2.07	1.95	- 12	- 139
27	KUSHIYARA	FENCHUGANJ	10.84	7.74	3.79	3.52	- 27	- 422
28	DHALAGANG	ISLAMPUR	12.79	10.24	5.82	5.80	- 2	- 344
29	SOMESWARI	KALMAKANDA	5.61	4.89	1.36	1.36	- 0	- 288
30	JHALUKHALI	MUSLIMPUR	9.44	6.44	1.19	1.11	- 8	- 432
31	SUTANG	SUTANG_RB	7.05	4.94	4.17	3.99	- 18	- 95

RAINFALL SITUATION AS ON 2019-04-15 (IN MM)

SL NO.	STATION NAME	MAXIMUM FOR APRIL	NORMAL FOR APRIL	RAINFALL FOR 2019 13-04	RAINFALL FOR 2019 14-04	RAINFALL FOR 2019 15-04	MONTHLY CUMULATIVE (UPTO 15-04-2019)
	MEGHNA BASIN						
1	KANAIGHAT	1096	443	0.00	0.00	0.00	110.00
2	SYLHET	1003	418	0.00	0.00	34.00	174.00
3	SUNAMGANJ	700	361	0.00	0.00	13.00	170.00
4	SHEOLA	867	397	0.00	0.00	2.00	102.00
5	MOULVI-BAZAR	527	222	0.00	0.00	-	123.00
6	MANU-RLY-BR.	401	246	0.00	0.00	0.00	160.00
7	HABIGANJ	509	194	0.00	0.00	0.00	169.00
8	SHERPUR-SYLHET	414	134	-	-	-	0.00
9	DURGAPUR	415	181	0.00	0.00	16.00	55.00
10	LOURERGORH	589	209	0.00	0.00	5.00	80.00
11	NAKUAGAON	416	154	0.00	0.00	17.00	125.00
12	JARIAJANJAIL	752	156	0.00	0.00	26.00	84.00
13	BHAIRAB-BAZAR	458	145	0.00	0.00	0.00	95.00
14	ZAKIGANJ	1252	455	0.00	0.00	-	33.00
15	LALLAKHAL	1650	571	0.00	0.00	-	0.00
16	JAFFLONG	-	-	0.00	0.00	10.00	86.00
17	BHOLAGANJ	1710	499	0.00	0.00	-	0.00
18	CHATTAK	765	373	0.00	0.00	-	9.00
19	MOHESHKHOLA	735	136	0.00	0.00	15.50	41.20
20	CHANDPUR BAGAN	1237	220	0.00	0.00	-	0.00
21	KAMALGANJ	744	248	0.00	0.00	0.00	180.00
22	DAKHSINBAG	670	312	-	-	-	0.00
23	SREEMONGAL	784	241	0.00	0.00	0.00	117.00
24	LATU	1131	415	0.00	0.00	-	61.00
25	ITAKHOLA	494	177	0.00	0.00	0.00	93.50

NOTE : WATER LEVEL AT STATION ABOVE DANGER LEVEL UNDERLINED.

- DATA NOT AVAILABLE.

RHWL : Recorded Highest Water Level.

D.L. : Danger Level.

RAINFALL AT STATIONS ABOVE 50 MM UNDERLINED.

In General, 50 mm or above rainfall in one day causes stress on local drainage system leading to localised flood.

300 mm or more rainfall in consecutive 10 days impedes the drainage and likely to cause rain-fed flood in the area.

DUTY OFFICER
FLOOD INFORMATION CENTER
BWDB, DHAKA

Figure 4-16: Observed Bulletin (English)

বন্যা পূর্বাভাস ও সতর্কীকরণ কেন্দ্র, বাপাউবো

নদ-নদীর অবস্থা যথাঃ ২০১৮-০৪-২৩ এ ০৯.০০ ঘন্টায়

ক্রমিক নং	নদীর নাম	পানি সমতল স্টেশন	সর্বোচ্চ পানি সমতল	বিপদসীমা	পানি সমতল		+বৃদ্ধি -হ্রাস সে.মি.	বিপদসীমার উপরে সে.মি.
					২২-০৪-২০১৮	২৩-০৪-২০১৮		
	মেঘনা বেসিন							
১	সুরমা	কানাইঘাট	১৫.২৬	১১.৩৭	৭.২০	৭.৭০	+ ৫০	- ৩৬৭
২	সুরমা	সিলেট	১০.৭৭	৮.৭৫	৪.৪৫	৫.৩৭	+ ৯২	- ৩৩৮
৩	সুরমা	সুনামগঞ্জ	৮.৩৫	৬.৪৯	২.৩০	২.৭৬	+ ৪৬	- ৩৭৩
৪	কুশিয়ারা	অমলশীদ	১৬.২৮	১৩.৪৯	৯.০৮	৯.৭৫	+ ৬৭	- ৩৭৪
৫	কুশিয়ারা	শেওলা	১৪.২২	১১.১৫	৬.৬৬	৭.৬১	+ ৯৫	- ৩৫৪
৬	কুশিয়ারা	শেরপুর-সিলেট	৮.৯০	৮.২৭	৪.২৬	৪.৯৪	+ ৬৮	- ৩৩৩
৭	কুশিয়ারা	মারকুলি	৭.৮২	৬.৪১	৩.৮৭	৪.৪১	+ ৫৪	- ২০০
৮	সারিগোয়াইন	সারিঘাট	১৪.০৭	১১.১৬	৭.২৩	৭.২৭	+ ৪	- ৩৮৯
৯	মনু	মনু রেলওয়ে ব্রিজ	২০.৪২	১৬.৯২	১৪.১৭	১৪.৭৭	+ ৬০	- ২১৫
১০	মনু	মৌলভীবাজার	১২.৯৬	৯.৯৬	৭.৪২	৭.৭৯	+ ৩৭	- ২১৭
১১	খোয়াই	বাল্লা	২৫.২৮	২১.৮১	২০.৭৫	২০.৭৫	- ০	- ১০৬
১২	খোয়াই	হবিগঞ্জ	১১.৫০	৯.০৭	৫.৯৫	৬.২৫	+ ৩০	- ২৮২
১৩	ধলাই	কমলগঞ্জ	২১.১৮	১৯.৫৫	-	-	-	-
১৪	বাউলাই	খালিয়াজুরি	৫.৭৭	৪.৫৯	৩.১৩	৩.২৮	+ ১৫	- ১৩১
১৫	ভুগাই	নাকুয়াগাঁও	২৩.০৬	২১.২৫	১৮.৪৭	১৮.৪৫	- ২	- ২৮০
১৬	যদুকাটা	লরেরগড়	৭.৬১	৬.৩৮	৩.০৩	৩.১২	+ ৯	- ৩২৬
১৭	সোমেশ্বরী	দুর্গাপুর	১৩.৮৪	১১.২৩	৯.৭৩	৯.৬৩	- ১০	- ১৬০
১৮	কংস	জারিয়াজঞ্জাইল	৯.৪৩	৬.৮৩	৬.০০	৬.০৮	+ ৮	- ৭৫
১৯	তিতাস	ব্রাহ্মণবাড়িয়া	৬.৫০	৫.৫০	-	-	-	-
২০	মেঘনা	ভৈরববাজার	৭.৭৮	৬.২৫	-	-	-	-
২১	মেঘনা	নরসিংদী	৭.০১	৫.৭০	১.৭২	১.৭২	- ০	- ৩৯৮
২২	মেঘনা	মেঘনা ব্রিজ	৫.০৩	৪.০০	-	-	-	-
২৩	গোমতী	কুমিল্লা	১৩.৫৬	১১.৭৫	৭.১৯	৭.৫৩	+ ৩৪	- ৪২২
২৪	গোমতী	দেবীদ্বার	-	৫.৩৪	৩.৮৫	৪.৭৭	+ ৯২	- ৫৭
২৫	সারি-গোয়াইন	গোয়াইনঘাট	১১.৪৬	৯.১১	৪.৮৩	-	-	-
২৬	কালনি	আজমিরিগঞ্জ	৭.৬৩	৫.০৪	৪.১১	৪.৫৩	+ ৪২	- ৫১
২৭	কুশিয়ারা	ফেঞ্চুগঞ্জ	১১.৩০	৮.২২	৫.০৮	৫.৮৭	+ ৭৯	- ২৩৫
২৮	ধলাগাঙ্গ	ইসলামপুর	১৩.২৫	১০.৭০	৭.২১	৭.১৪	- ৭	- ৩৫৬
২৯	সমেশ্বরী	কলমাকান্দা	৬.০৭	৫.৩৪	৩.০৫	৩.৪০	+ ৩৫	- ১৯৪
৩০	ঝালুখালি	মুসলিমপুর	৯.৯০	৬.৯১	২.২৯	২.৭১	+ ৪২	- ৪২০
৩১	সুতাং	সুতাং রেলওয়ে ব্রিজ	৭.৫১	৫.৪২	-	-	-	-

বন্যা পূর্বাভাস ও সতর্কীকরণ কেন্দ্র, বাপাউবো

বৃষ্টিপাতের অবস্থা ২০১৮-০৪-২৩ এ (মিমি-এ)

ক্রমিক নং	স্টেশন	এপ্রিল - এ সর্বোচ্চ	এপ্রিল -এ স্বাভাবিক	বৃষ্টিপাত ২০১৮			মাসিক কিউমুলেটিভ (২৩-০৪-২০১৮)
				২১-০৪	২২-০৪	২৩-০৪	
	মেঘনা বেসিন						
১	কানাইঘাট	১০৯৬	৪৪৩	৭৬.০০	৩৫.০০	৬৩.০০	৩২২.০০
২	সিলেট	১০০৩	৪১৮	৭০.০০	৩২.০০	১.০০	২৮৯.০০
৩	সুনামগঞ্জ	৭০০	৩৬১	১৯.০০	২৩.০০	০.০০	১৬২.০০
৪	শেওলা	৮৬৭	৩৯৭	৮০.০০	৪২.০০	২.০০	২৩৭.০০
৫	মৌলভীবাজার	৫২৭	২২২	২৫.০০	২৬.০০	০.০০	১১৮.০০
৬	মনু রেলওয়ে ব্রিজ	৪০১	২৪৬	২৯.০০	৩৩.০০	৫.০০	১৮৫.০০
৭	হবিগঞ্জ	৫০৯	১৯৪	৯.৫০	৯.০০	৭.০০	১২০.০০
৮	শেরপুর-সিলেট	৪১৪	১৩৪	১৪.০০	২৬.০০	৮.০০	১৩৩.০০
৯	দুর্গাপুর	৪১৫	১৮১	০.০০	৯.০০	০.০০	৯৫.০০
১০	লরেরগড়	৫৮৯	২০৯	১৫.০০	১৬.০০	০.০০	১০২.০০
১১	নাকুয়াগাঁও	৪১৬	১৫৪	১০.০০	১৬.৫০	০.০০	২৩৩.০০
১২	জারিয়াজঞ্জাইল	৭৫২	১৫৬	০.০০	১৫.০০	০.০০	১১৯.০০
১৩	ভৈরববাজার	৪৫৮	১৪৫	৯.০০	৫৫.০০	০.০০	১০৯.০০
১৪	জকিগঞ্জ	১২৫২	৪৫৫	৭৮.০০	৩৭.০০	২৩.০০	৩১০.০০
১৫	লালাখাল	১৬৫০	৫৭১	৩৮.০০	৩০.০০	৩০.০০	২৩৩.০০
১৬	জাফলং	-	-	৩৪.০০	২১.০০	৩.০০	২১৭.০০
১৭	ভোলাগঞ্জ	১৭১০	৪৯৯	-	-	-	০.০০
১৮	ছাতক	৭৬৫	৩৭৩	২৪.০০	৩৭.০০	৩০.০০	১৭৩.০০
১৯	মহেশখোলা	৭৩৫	১৩৬	-	-	-	০.০০
২০	চাঁদপুর বাগান	১২৩৭	২২০	-	-	-	০.০০
২১	কমলগঞ্জ	৭৪৪	২৪৮	৮.০০	৫৫.০০	১২.০০	১৫৩.০০
২২	দক্ষিণবাগ	৬৭০	৩১২	-	-	-	০.০০
২৩	শ্রীমঙ্গল	৭৮৪	২৪১	-	-	-	০.০০
২৪	লাতু	১১৩১	৪১৫	১১০.০০	৭৫.০০	-	২৯৪.০০
২৫	ইঁটাখোলা	৪৯৪	১৭৭	-	-	-	০.০০

দ্রষ্টব্যঃ বিপদসীমার উপরের প্রবাহিত ষ্টেশন সমূহের নাম নিম্ন রেখাঙ্কিত করে চিহ্নিত করা হলো।

- উপাত্ত অনুপস্থিত।

৫০ মি মি উপরের বেশি বৃষ্টিপাত নিম্ন রেখাঙ্কিত।

সাধারণত একদিনে ৫০ মি মি উপরের বৃষ্টিপাত এলাকা ভিত্তিক বন্যা তৈরি করে।

১০ দিন ধরে বৃষ্টিপাতের পরিমাণ ৩০০ মি মি এর উপর হলে পানি নিষ্কাশন ব্যবস্থা বাধাগ্রস্থ হয়ে বন্যা দেখা দেয়।

কর্তব্যরত কর্মকর্তা

বন্যা পূর্বাভাস ও সতর্কীকরণ কেন্দ্র

বাপাউবো

Figure 4-17: Sample Observed Bulletin (Bangla)

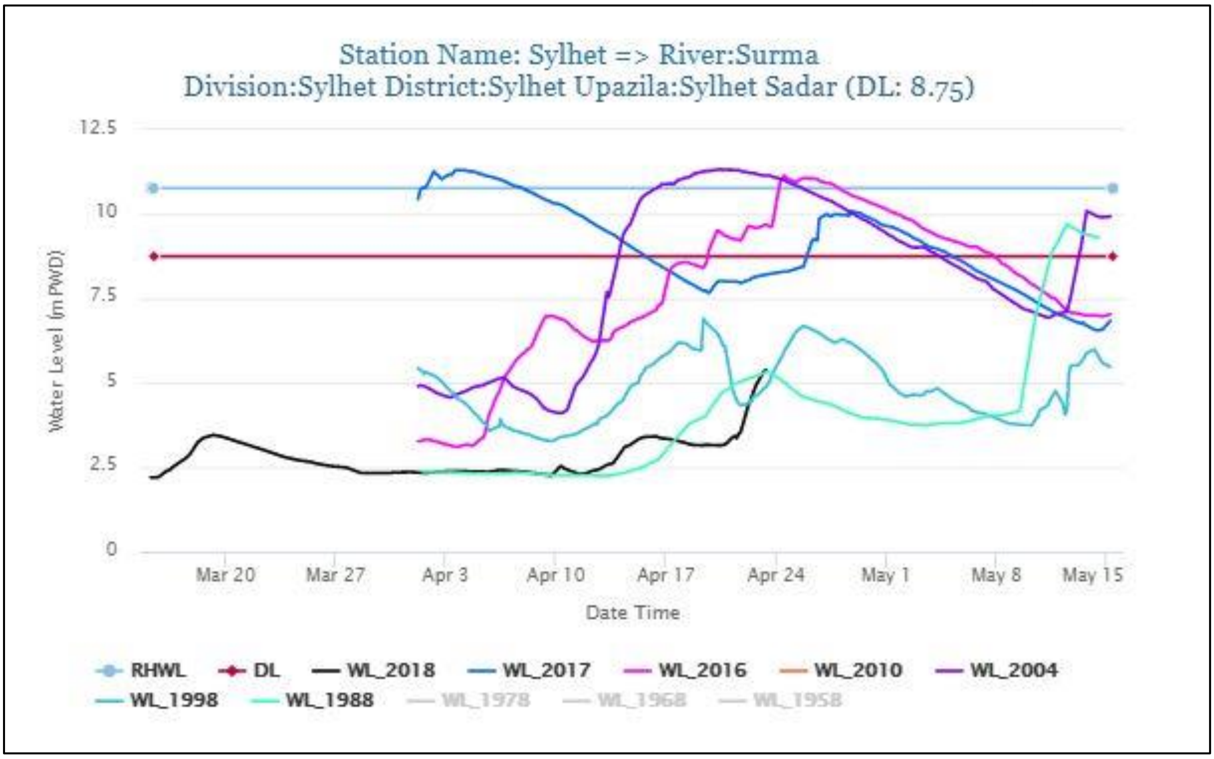
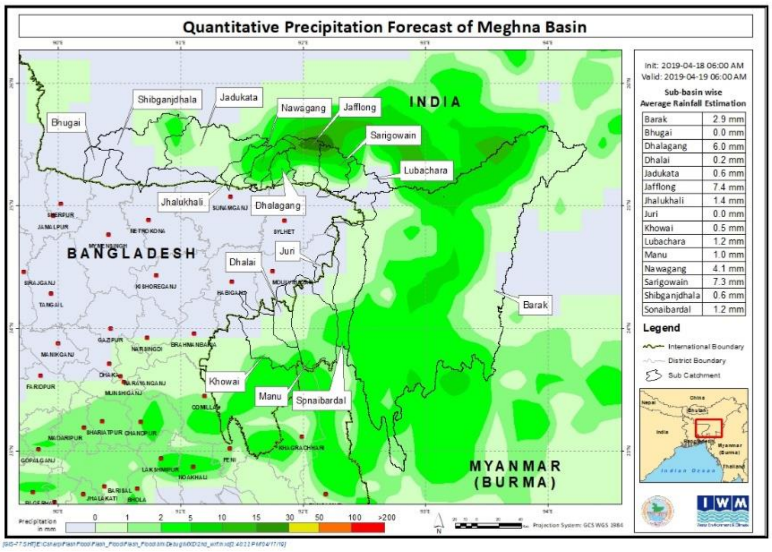
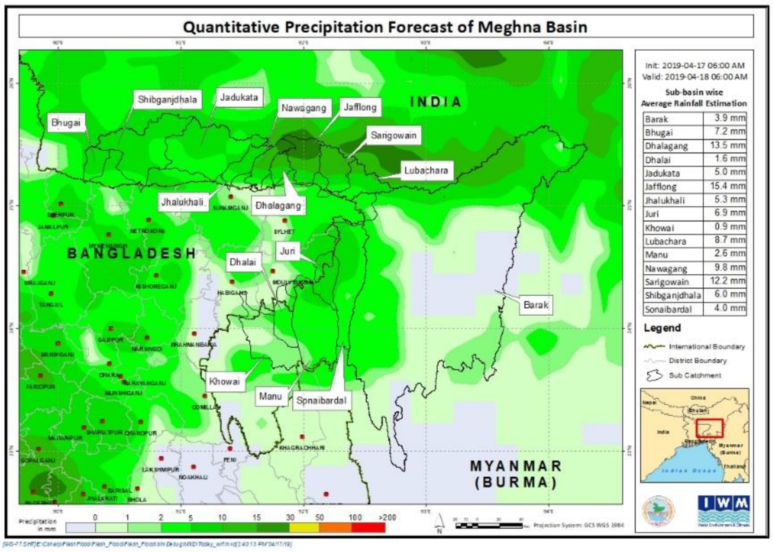


Figure 4-18: Historical Forecast Hydrograph at Sylhet on Surma River

4.3 Quantitative Precipitation Forecast (QPF), Outlook and Summary Bulletin

Quantification of forecasted precipitation in the different basins also helps the forecaster to estimate the amount of total volume in the sub-basins level or even in the river boundaries. Thus, using the forecasted rainfall provided by BMD, basin wise average rainfall estimates have been made for 1day, 2day and 3day events. Figure 4-19 shows the QPF based on BMD provided WRF model outputs earlier this QPF was done and supplied from WRF model maintained at FFWC. Sample Outlook Bulletin disseminated during Flash Flood event is showed in figure 4-20 and Sample Summary Bulletin is showed in figure 4-21.





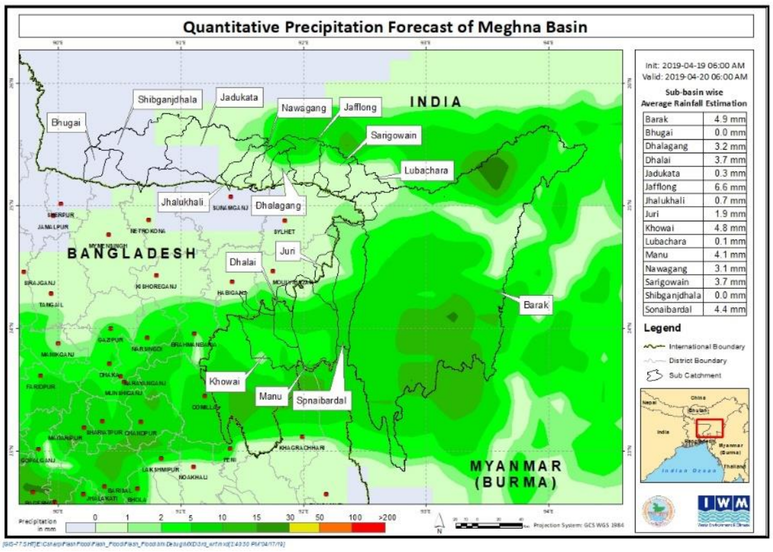


Figure 4-19: Qualitative Precipitation Forecast based on BMD provided WRF model outputs

বন্যা তথ্য কেন্দ্র
বন্যা পূর্বাভাস ও সতর্কীকরণ কেন্দ্র
বাংলাদেশ পানি উন্নয়ন বোর্ড
ওয়াপদা ভবন (৯ম তলা) মতিঝিল বা/এ, ঢাকা-১০০০

ই-মেইলঃ ffwcbwdb@gmail.com, ffwc05@yahoo.com; ওয়েবসাইট : www.ffwc.gov.bd, দূরালাপনি : ৯৫৫৩১১৮, ৯৫৫০৭৫৫; ফ্যাক্স :৯৫৫৭৩৮৬

১০ বৈশাখ ১৪২৫ বং/ ২৩ এপ্রিল ২০১৮ খৃঃ

উত্তর পূর্বাঞ্চলের আকস্মিক বন্যা পরিস্থিতির সংক্ষিপ্ত প্রতিবেদন ও পূর্বাভাস

বিগত দুইদিনে বাংলাদেশের উত্তর পূর্বাঞ্চল ও তৎসংলগ্ন ভারতের উত্তর পূর্বাঞ্চলের প্রদেশ আসাম, মেঘালয় ও ত্রিপুরার অনেক স্থানে মাঝারী থেকে ভারী বৃষ্টিপাত পরিলক্ষিত হয়েছে। উল্লেখযোগ্য রেকর্ডকৃত বৃষ্টিপাত নিম্নরূপঃ

ছক: ভারতের উত্তর পূর্বাঞ্চলের প্রদেশ মেঘালয়, আসাম ও ত্রিপুরা অঞ্চলের বৃষ্টিপাতের পরিমাণ (বৃষ্টিপাত: মি.মি.)

Date	Silchar	Kailasahar/Manu	Cherrapunjee	Aizwal	Shillong
22/04/2018	36	53	59	23	3
23/04/2018	2	1	3	0	0
Total	38	54	62	23	3

ছক: বাংলাদেশের উত্তর পূর্বাঞ্চলের উল্লেখযোগ্য বৃষ্টিপাতের পরিমাণ (বৃষ্টিপাত: মি.মি.)

Date	Kanaighat	Sylhet	Sheola	Manu Rly Br	Chandpur
21/04/2018	76	70	80	29	0
22/04/2018	35	32	42	33	0
23/04/2018	63	1	2	5	38
Total	174	103	124	67	38

নদ-নদীর অবস্থাঃ

পানি সমতল স্টেশন	নদীর নাম	বিগত ২৪ ঘন্টায় বৃদ্ধি(+)/হ্রাস(-) (সে.মি.)	বিপদসীমার উপরে (+)/নিচে(-) (সে.মি.)
কানাইঘাট	সুরমা	+৫০	-৩৬৫
সিলেট	সুরমা	+৯২	-৩৩৮
সুনামগঞ্জ	সুরমা	+৪৬	-৩৭৪
অমলশীদ	কুশিয়ারা	+৬৭	-৩৭৫
শেওলা	কুশিয়ারা	+৯৫	-৩৫৪
মৌলভীবাজার	মনু	+৩৭	-২২১
কংস	জারিয়াজঞ্জাইল	+৮	-৭২
সারিগোয়াইন	সারিঘাট	+8	-৩৮৮

বিদ্যমান আবহাওয়ার পূর্বাভাসে ভারী বৃষ্টিপাতঃ

বাংলাদেশ আবহাওয়া অধিদপ্তর ও ভারতের আবহাওয়া অধিদপ্তর হতে সরবরাহকৃত আবহাওয়ার গাণিতিক মডেলের পূর্বাভাস হতে দেখা যাচ্ছে যে, আগামী ৪৮ ঘন্টায় বাংলাদেশের উত্তর পূর্বাঞ্চলের জেলাসমূহের এবং তৎসংলগ্ন ভারতের উত্তর পূর্বাঞ্চলের প্রদেশ আসাম, মেঘালয় ও ত্রিপুরায় ভারী বৃষ্টিপাতের পূর্বাভাস নেই ।

বন্যার পূর্বাভাসঃ

এমতাবস্থায়, বর্তমানে আবহাওয়ার পূর্বাভাস ও নদ-নদীর পরিস্থিতি বিবেচনায় বাংলাদেশের উত্তর পূর্বাঞ্চলের জেলাসমূহের প্রধান নদীসমূহের পানি সমতল আগামী ২৪ ঘন্টায় স্থিতিশীল থাকতে পারে।

সংযুক্তিঃ

১. বাংলাদেশ আবহাওয়া অধিদপ্তর থেকে প্রাপ্ত গাণিতিক মডেলের পূর্বাভাস।
২. ভারতীয় আবহাওয়া অধিদপ্তরের গাণিতিক মডেলের পূর্বাভাস।

যোগাযোগঃ ১। মোঃ আরিফুজ্জামান ভূঁইয়া, নির্বাহী প্রকৌশলী (মোবাইল নম্বর ০১৭১৫-০৪০১৪৪)
২। সরদার উদয় রায়হান, উপবিভাগীয় প্রকৌশলী (মোবাইল নম্বর ০১৫৫২৩৫৩৪৩৩)
৩। জুয়েল আহমেদ, সহকারী প্রকৌশলী (মোবাইল নম্বর ০১৭৪১৪২২২৩৮)
৪। মোঃ আলরাজী লিয়ন, সহকারী প্রকৌশলী (মোবাইল নম্বর ০১৯১৫৯৭৭৭৩৮)

Figure 4-20: Sample Outlook Bulletin disseminated during Flash Flood event

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Website: http://www.ffwc.gov.bd
Tel: 9553118, 9550755 Fax: 9557386

Flash Flood Early Warning Bulletin for North East Region as on April 23,2018

Rainfall:

Significant rainfalls recorded during last 24 hours within Bangladesh:

Station	Rainfall (mm)
Kanaighat	63
Chandpur	38
Lalakhal	30
Chattak	30

General River Condition:

Monitored WL Stations	Rise	Fall	Steady	Not Reported	Stations above DL
33	24	05	02	02	0

Flood Condition:

- ***The Surma-Kushiyara, Sarigowain and Manu rivers of North-Eastern region are in rising trend.***
- ***All the rivers of North-Eastern zone are flowing below danger level.***

1

Figure 4-21: Sample Summary Bulletin

4.4 Embankment Based Forecast

One of the major tasks of the present study is to develop structure/embankment based forecast for the nationally important structures in the North-East region of Bangladesh. From historical flash flood damage point of view, Haors located in Sunamganj are most important. Thus, to identify the significant Haor for embankment based forecast system, several haors have been reviewed from observed data availability point of view. BWDB have introduced some water level monitoring stations (Solemanpur, Madhyanagar, Durlavpur and Lourergorh) as a real-time water level station around these Haors which helps to relate both the Haors during embankment based forecast.

The main idea behind embankment based forecast is to alert the local people living in and around the said embankment and to whom the flash flood forecast information is most important as upcoming flood information prior to 3 days related to their portion of Haor embankments will certainly provide them some time to take decisions on upcoming flood events. The Embankment based forecast actually compares the existing crest level of the polder or circular embankment and the adjacent river water levels in next 1day, 2day and 3day. The embankment based forecast for Shanir Haor and Matian Haor are provided in the website under "Forecast" tab where one can identify the Shanir Haor as green polygon while Matian Haor as yellow polygon. Clicking on any of the polygons will lead one to the profile of the Haor. Figure 4-22 shows the webpage which demonstrates the embankment based forecast outputs.

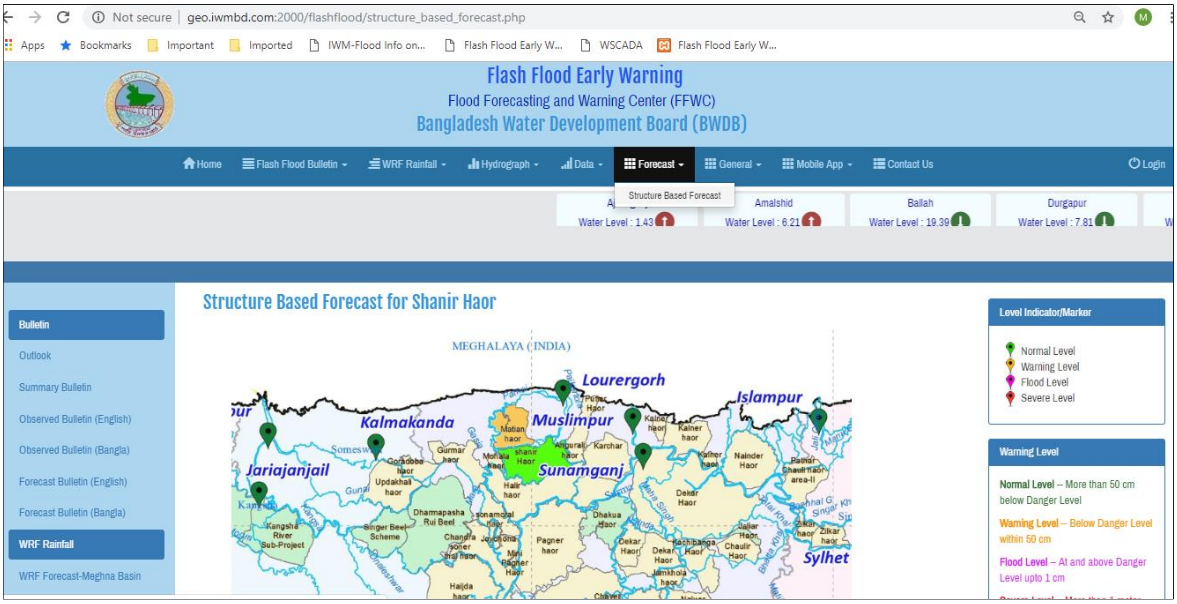


Figure 4-22: Embankment Based Forecast as on webpage

The Shanir Haor is situated on the southern side of Tahirpur Upazila Headquarter of Sunamganj district. Four rivers define the boundary of this Haor namely Jadukata on the east, Nandaigang on the south, Patnaigang on the west and Baulai on the north. The project covers a gross area of 7761 ha and a net area of 6721 ha. Floodwater enters from the Baulai and the Jadukata rivers from the northeastern side by overtopping and breaching the embankments. The main drainage of the Haor occurs through the regulators situated in the southwestern side of the Project namely, Ahmakkhali, Bogiani and Beheli. In addition, water also drains through number of cut/breach locations situated on this side of the Haor. Figure 4-23 shows Shanir Haor.

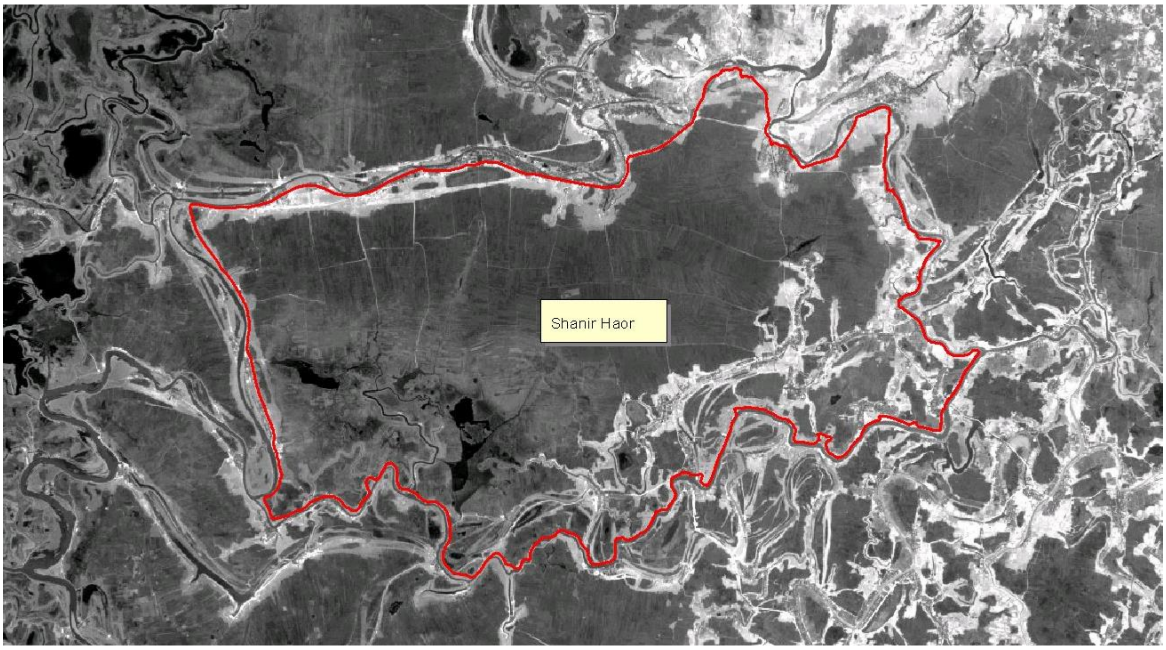


Figure 4-23: Shanir Haor boundary and adjoining rivers

Figure 4-24 shows the real-time embankment based forecast of Shanir Haor as of 28th April 2019. The legend in the graph indicates that blue line, orange line, yellow line and green line represents simulated water level on 28th April and 1-day, 2-day and 3-day forecasted water level respectively.

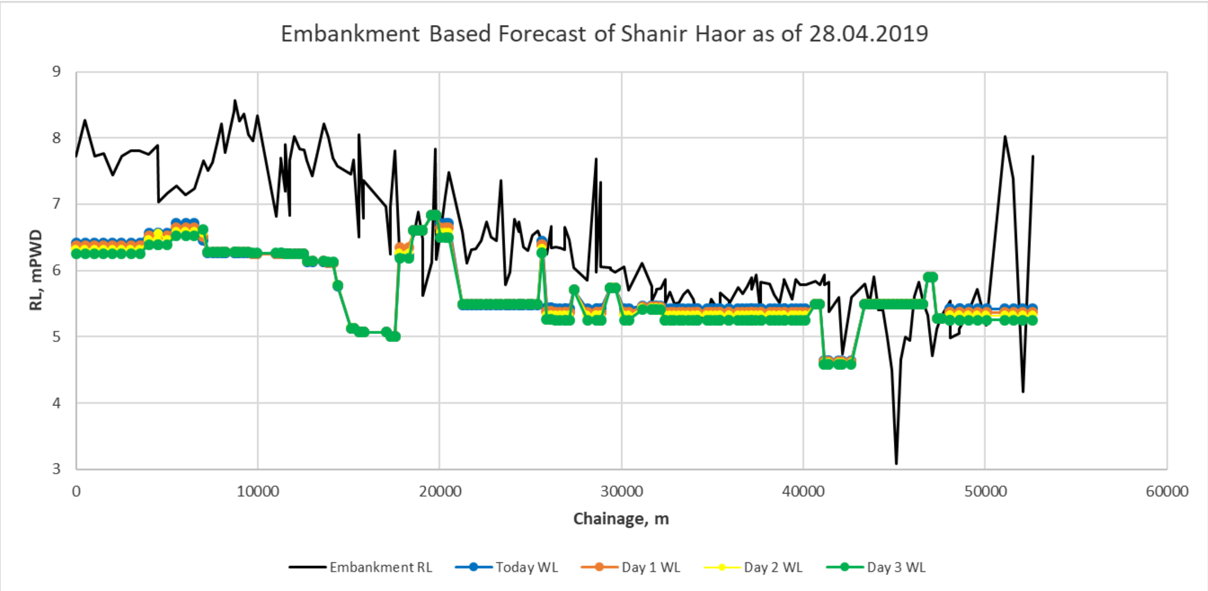


Figure 4-24: Embankment based Forecast for Shanir Haor as of 28 April 2019

The Matian Haor is situated on the northwest corner of Sunamganj district under Tahirpur Upazila. Patnaigang and Baulai are the main rivers controlling the flooding and drainage of this Haor. Patnaigang River flows along the northwestern boundary and Baulai along the southern side of the Haor. The project covers a gross area of 7761 ha and a net area of 6721 ha. The Haor is situated very close to the Meghalaya hills and always remains under threat of flash floods. Rainwater from the upstream catchments accumulates in the rivers and creates pressure on the surrounding embankments. Floodwater enters through the vulnerable part of the surrounding embankments. Drainage congestion is one of the major problems of the Haor specially, in the southwestern low-lying part of the Haor. The main drainage of the Haor occurs through the Boalmari regulator situated in the southwestern side of the Project. In addition, water also drains through number of cut/breach locations situated on this side of the Haor. Figure 4-25 shows Matian Haor. Figure 4-26 shows the real-time embankment based forecast of Matian Haor as of 28th April 2019. The legend in the graph indicates that blue line, orange line, yellow line and green line represents simulated water level on 28th April and 1-day, 2-day and 3-day forecasted water level respectively.

Although, the embankment based forecasting system have been piloting in this study for two major haors, a thorough study involving local stakeholders need to be conducted before implementing operationally in the field which is beyond the scope of this study.

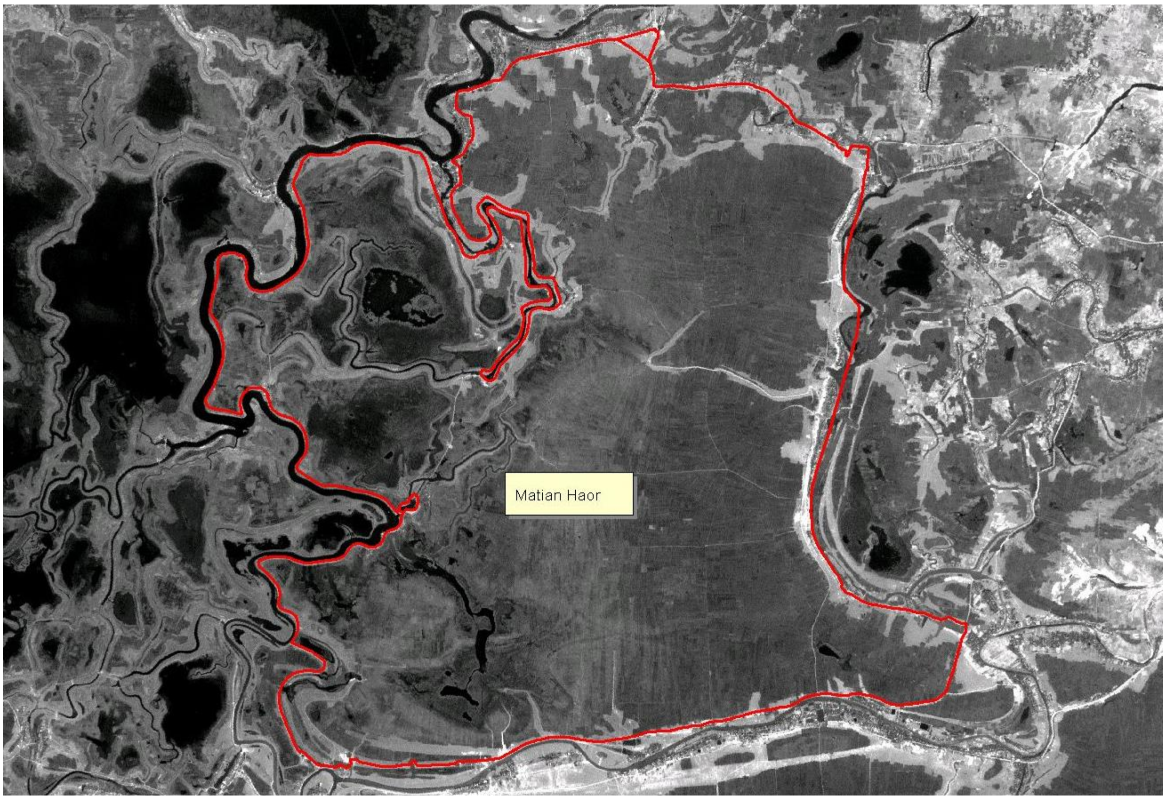


Figure 4-25: Matian Haor boundary and adjoining rivers

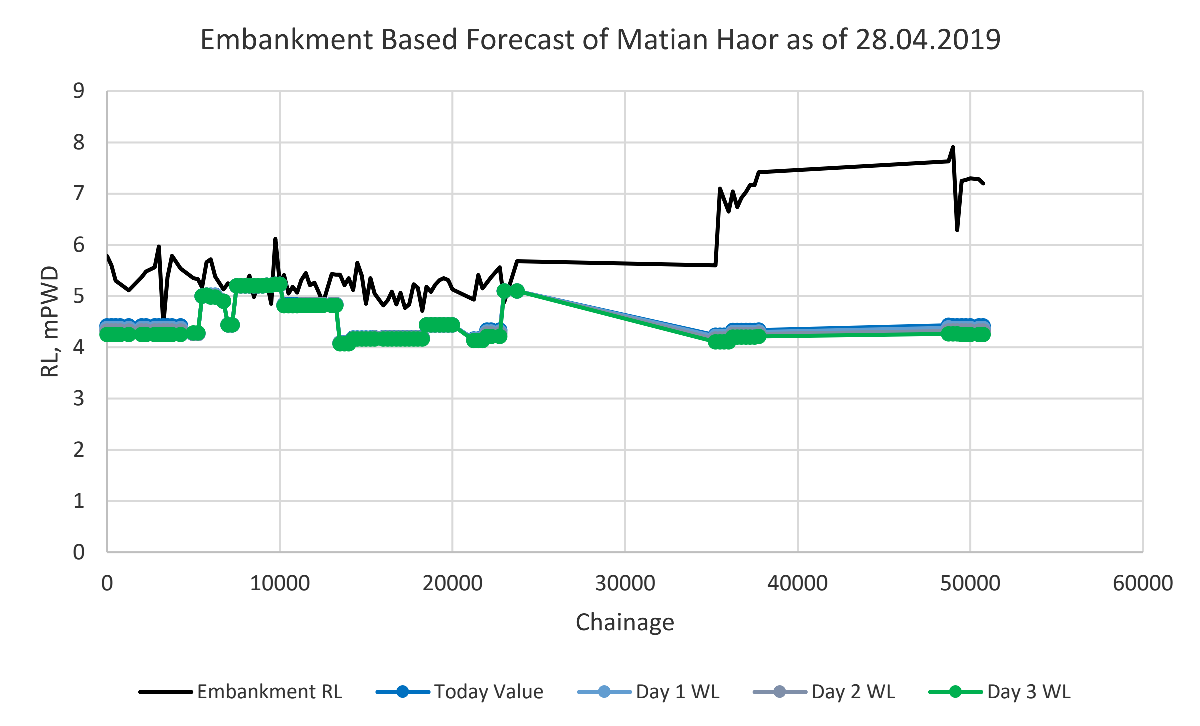


Figure 4-26: Embankment based Forecast for Matian Haor as of 28 April 2019

4.5 Website and Mobile Apps for Forecast Dissemination

Under this study, all the forecast products have been successfully uploaded and disseminated through the dedicated websites developed and hosted in FFWC main webpage as link. One can access the webpage and can explore the webpage by visiting the following address link as (www.ffwc.gov.bd) then to http://www.geo.iwmbd.com:2000/flashflood/

The system has been developed based on LAMP (Linux server, Apache, MySQL, PHP). Data stored in MySQL database that is installed in Linux server and the web application has been developed using PHP to take input and generate output. The application has been hosted in Apache and Apache is installed in Linux server. System administrator keep the input data in the system and the system then process input data. The end user of this web application needs a web browser to operate.

The web application has been developed to incorporating all features and functionalities. The system is hosted on IWM Server. The web application has been tested by following Software Engineering methods those are black box testing, white box testing, gray box testing, agile testing, ad hoc testing etc. In all test cases the system passes the tests and QA team releases the system. System may fail in some cases those are not appeared before. To handle those occurrences system may need to modify. The system is quite user friendly so that end users can operate the system easily. The system is fully responsive and device independent so the users can operate from any web browsers such as Mozilla Firefox, google chrome, internet explorer, opera etc. from any operating system such as Windows, Linux, Mac, Android, IOS etc. Figure 4-27 shows the operational forecast website page.

Figure 4-27: Screenshot shows the operational forecast website pages

To enhance the dissemination of forecast products to the end users, a mobile apps has been developed under this study. The application is open for publicly use. No authentication is required to use this application. User needs an Android device with version Android 5.1 (Lollipop) or higher, internet to use this application. User needs to download the application using Android device from the URL:

http://geo.iwmbd.com:2000/flashflood/mobile_apps.php

The application comprises several numbers of modules such as:

1) **Home** module contains two types of view for gauges such as map view and list view. On map view users will find gauges on google map and in list view they find gauges in a list. Users will find pre-monsoon hydrograph and pre-monsoon historical hydrograph from map view and pre-monsoon hydrograph from list view.

2) **Flash Flood Bulletin** shows information about summary bulletin, observed bulletin (English/Bengali), Forecast bulletin (English/Bengali).

3) **WRF Rainfall** contains information about WRF forecast-Meghna basin, WRF forecast-GBM basin and linked with BMD weather forecast website, IMD weather forecast website, NOAA/National Weather Service forecast website.

4) **Data** contains rainfall data, water level data and linked with Gowainghat auto gauge and Lourergorh auto gauge data.

5) **Forecast** contains information about structure-based forecast for Shanir Haor, Sunamganj.

6) **General** focuses on administrative unit, topography, physiography, major river system, hydrology, haor and water management projects.

7) **Important Links** are linked with Bangladesh Government, Bangladesh Water Development Board (BWDB), Bangladesh Water Resources Planning Organization (WARPO), Bangladesh Meteorological Department (BMD) and India Meteorological Department (IMD).

8) **Feedback** module send feedback by mail to another recipient. To send a feedback user needs his own email address and the receiver email address. User has to fill subject and message as mail body.

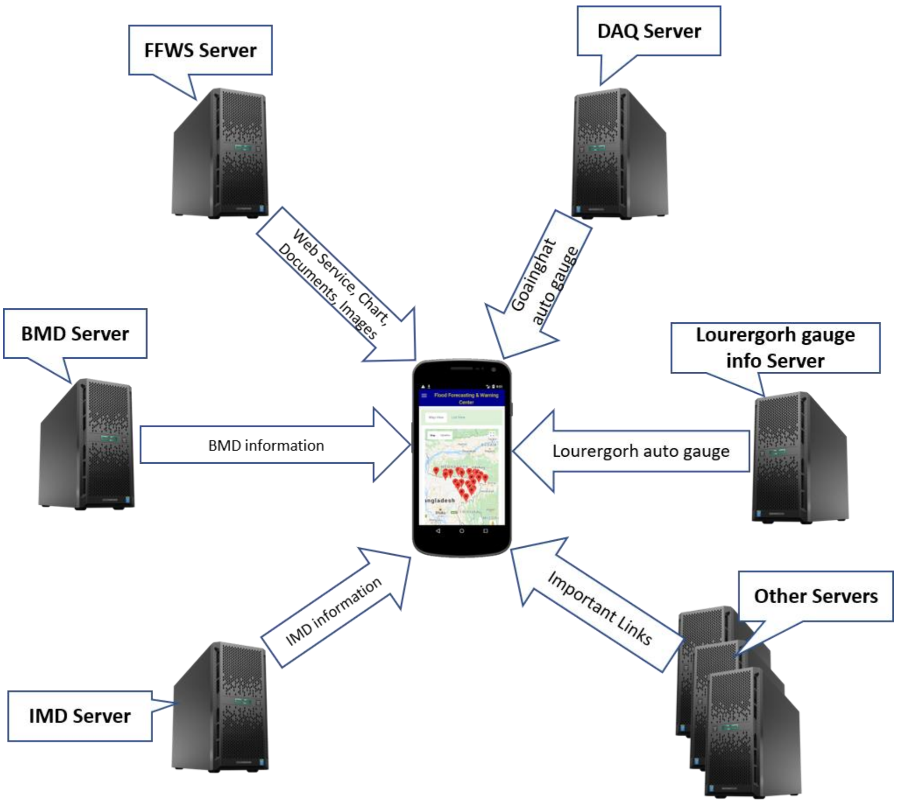


Figure 4-28: Conceptual design of the System

FFWS server provides web services and the mobile application generates points on google map and list view of stations with basic information. FFWS server also provides charts, images and documents for different features. This application is also linked with DAQ server, BMD, IMD and other important links. A feedback system is included with this application. The feedback is sent through FFWS mail server. The application has been developed using Apache Cordova (Hybrid) so that the application can be generated for Android, IOS and Windows (mobile) operating system. The major modules are developed and some minor modification/update might be needed. Feedback system is under development. Figure 4-28 shows conceptual design of the system.

The mobile apps contain a home tab, application menu, general tab and feedback tab. The details of the apps are illustrated in the following section.

Install Application

The following steps to be followed to install the application as shown in figure 4-29.

Step 1. Tap on 'ffwc-new.apk' from download folder

Step 2. Tap on 'Install' button to install the application

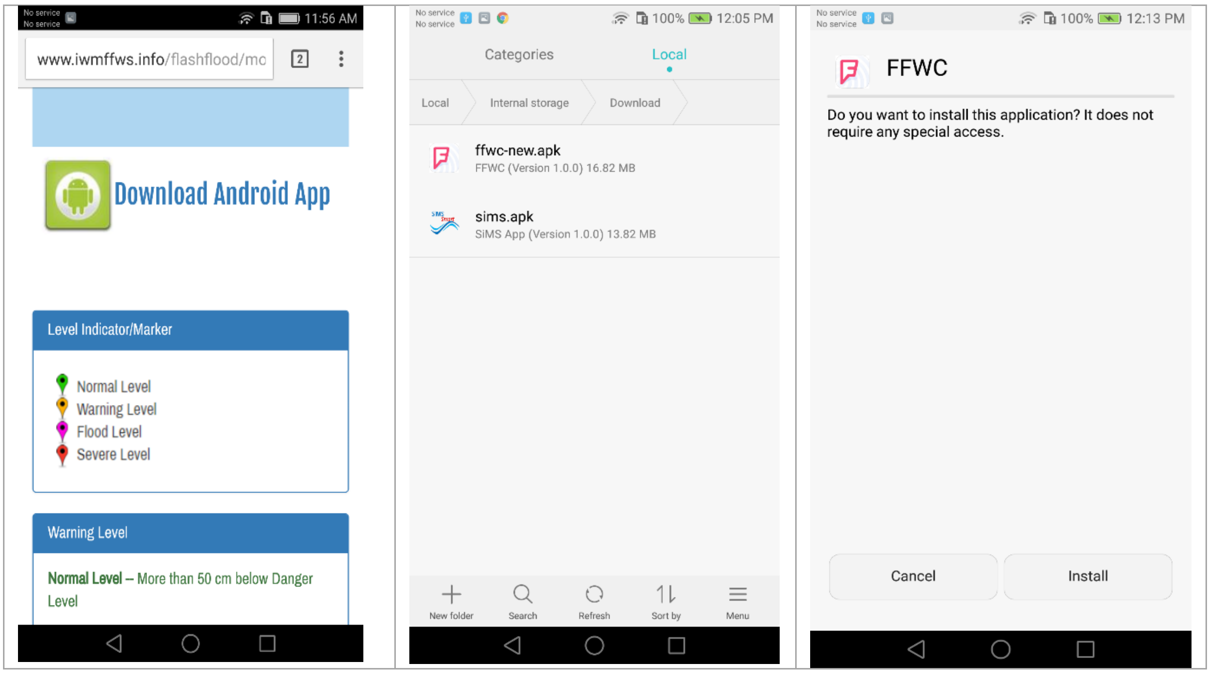


Figure 4-29: Application installation

Open Application

Click on FFWC icon from application menu and application home page will appear on the screen as shown in Figure 4-30.

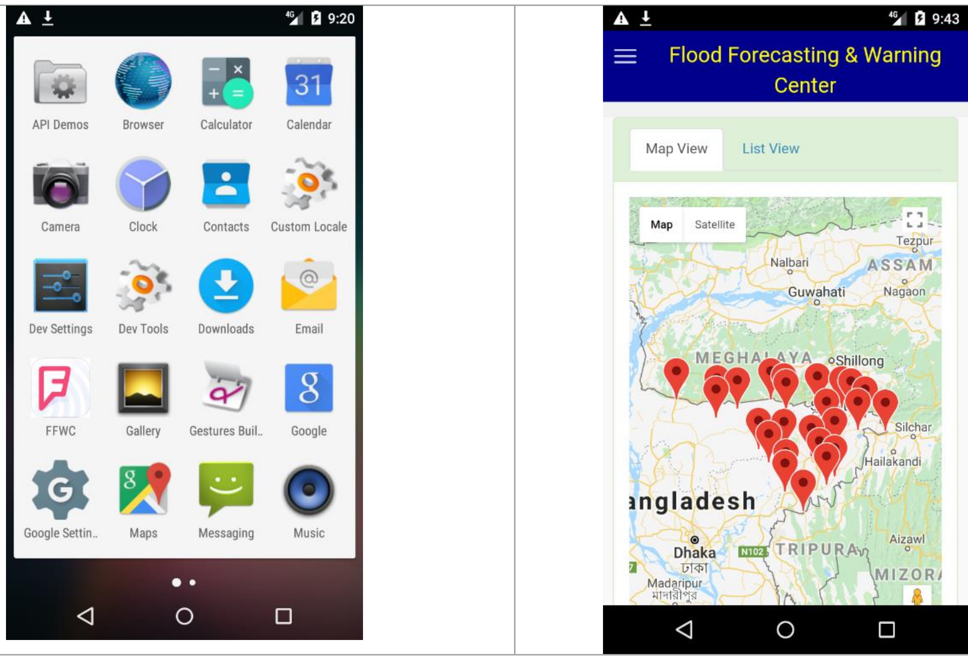
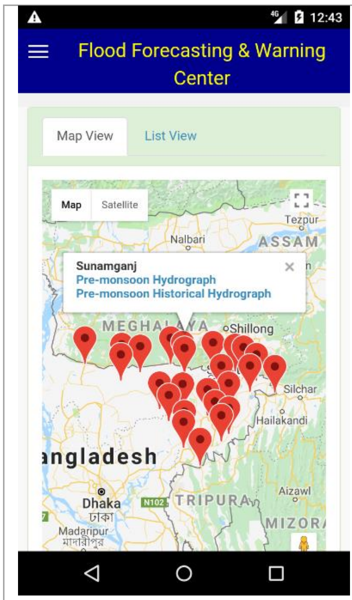


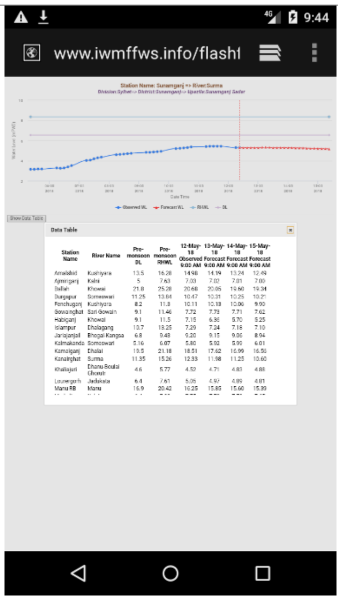
Figure 4-30: Open Application

Application Menu

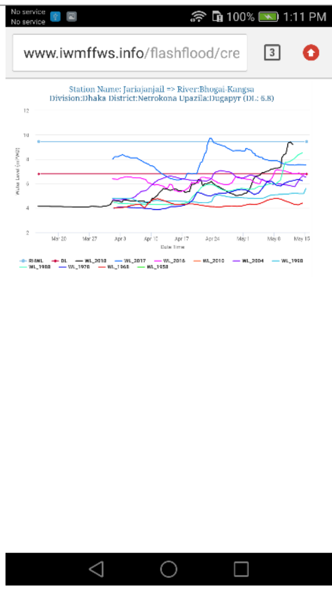
Tap on the icon ☰ to view/close menu as shown in figure 4-31. Home has two types of view such as map view and list view. By default, it appears with map view as shown Figure 4-31. Tap on red marker to view pre-monsoon hydrograph or pre-monsoon historical hydrograph. Tap List view to see the gauge station list and tap on station to view pre-monsoon hydrograph.



Pre-monsoon hydrograph



Pre-monsoon hydrograph chart



Pre-monsoon historical hydrology chart

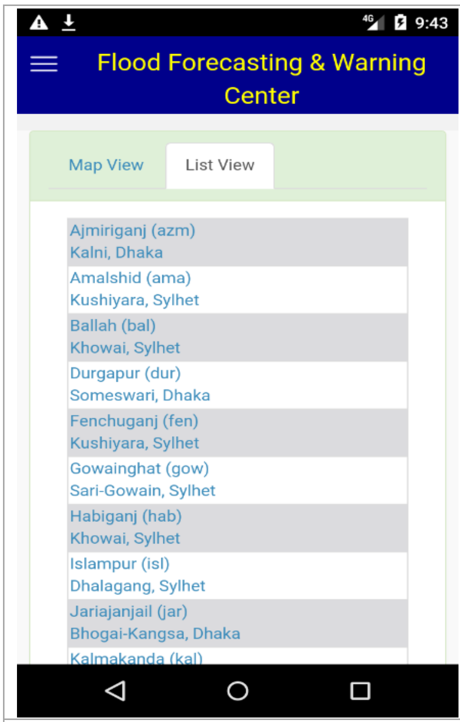
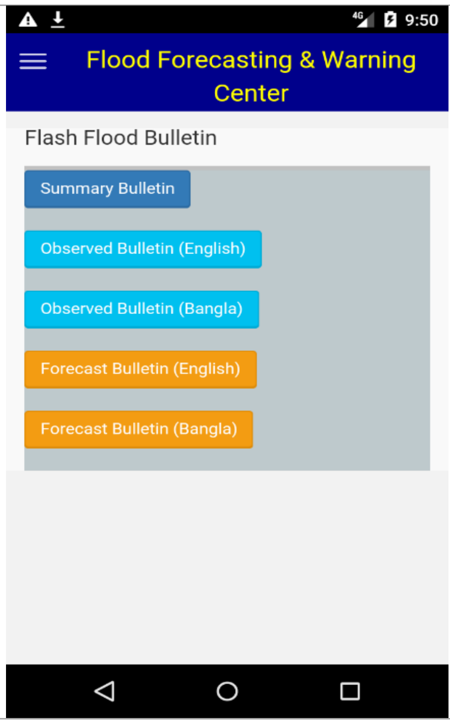
	
List View	Bulletin List

Figure 4-31: Application Menu

Flash Flood Bulletin

Tap on Flash Flood Bulletin to view Summary Bulletin, Observed Bulletin (English), Observed Bulletin (Bangla), Forecast Bulletin (English) and Forecast Bulletin (Bangla). User can tap on WRF Rainfall from menu to view WRF Forecast-Meghna Basin, WRF Forecast-GBM Basin and BMD Weather Forecast, IMD Weather Forecast and NOAA/National Weather Service as shown in Figure 4-32. Tap on forecast from menu to view structure based forecast for Shanir haor and Matian Haor.

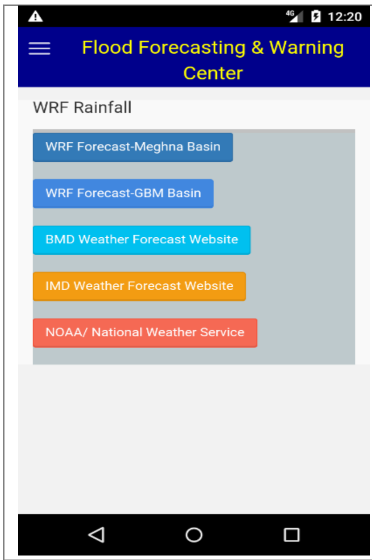
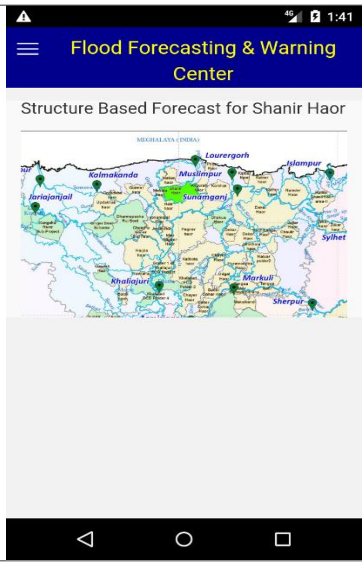
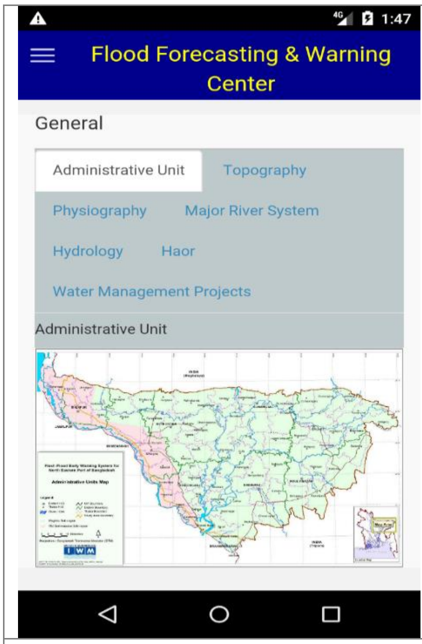
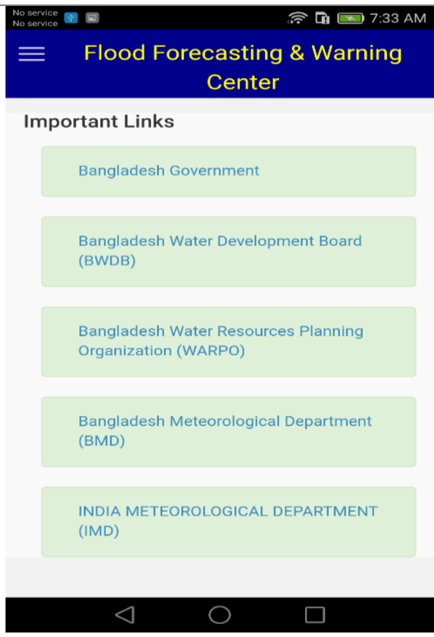
		
WRF Rainfall	WRF Forecast-Meghna Basin	Forecast for Shanir Haor

Figure 4-32: Forecast Product Menu

User can tap on general to view administrative unit, topography, physiography, major river system, hydrology, haor and water management projects as shown in figure 4-33.





General information for Administrative Unit	Important Links

Figure 4-33: General Information and Links

Important Links

Tap on important links to view Bangladesh Government, BWDB, WARPO, BMD, IMD information from their website.

Feedback

User can send feedback from feedback module. Tap on Feedback from menu. User must fill recipient email address, sender/own email address, subject, message and finally tap on send mail as shown on Figure 4-34. After necessary feedback from different users and suggestion, the mobile apps would be finalized within project tenure.

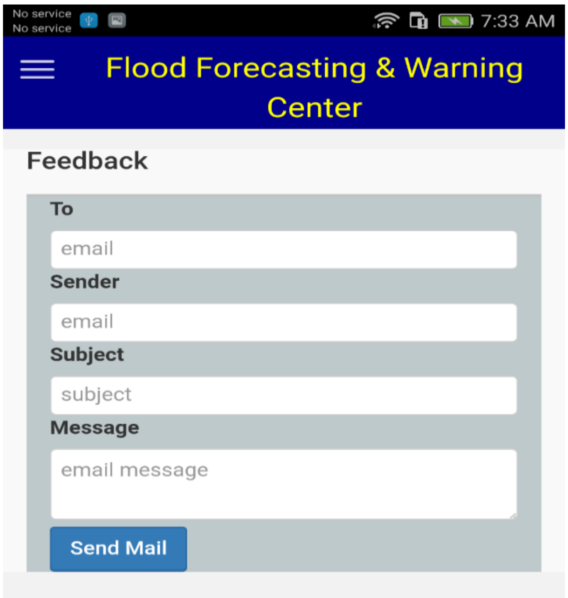
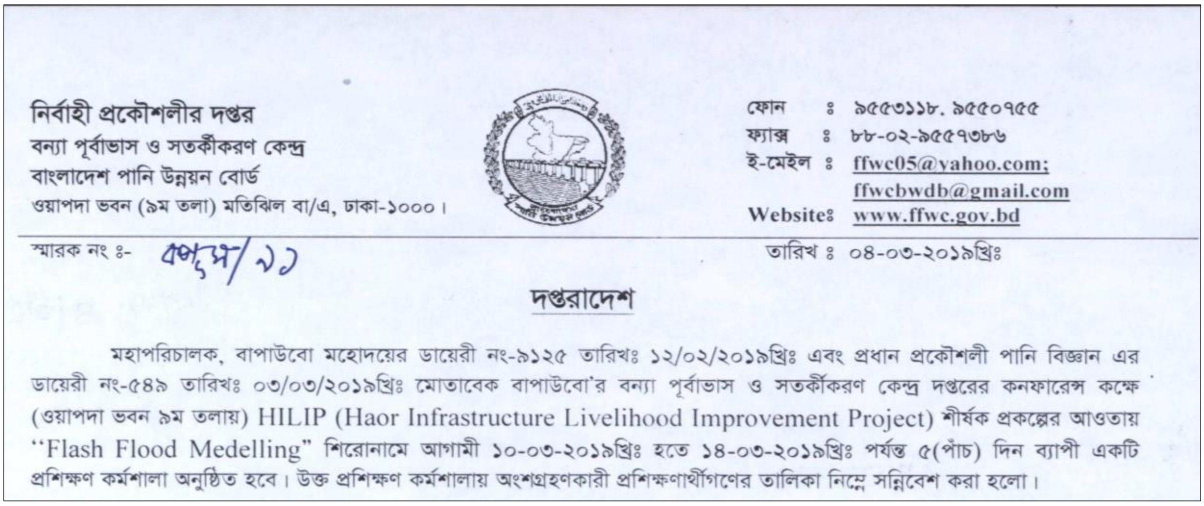


Figure 4-34: Feedback module

5. TRAINING AND TECHNOLOGY TRANSFER, WORKSHOPS AND FIELD VISITS

5.1 Intensive Training on Developed System

A week-long formal training program has been arranged at FFWC, BWDB during March 31 to April 4, 2019 with several shifts from original plan to transfer the developed flash flood forecast models and associated systems to the professionals of Flood Forecasting and Warning Center, Processing and Flood Forecasting Circle and Hydrology, BWDB. Also, observer from LGED and IWFM were participated in the program. Figure 5-1 shows the screenshot of the office order for the training program while figure 5-2 shows the glimpse of the opening ceremony.



নির্বাহী প্রকৌশলীর দপ্তর
বন্যা পূর্বাভাস ও সতর্কীকরণ কেন্দ্র
বাংলাদেশ পানি উন্নয়ন বোর্ড
ওয়াপদা ভবন (৯ম তলা) মতিঝিল বা/এ, ঢাকা-১০০০।

ফোন ঃ ৯৫৫৩১১৮, ৯৫৫০৭৫৫
ফ্যাক্স ঃ ৮৮-০২-৯৫৫৭৩৮৬
ই-মেইল ঃ ffwc05@yahoo.com; ffwcbwdb@gmail.com
Website: www.ffwc.gov.bd

স্মারক নং ঃ- [illegible]

তারিখ ঃ ০৪-০৩-২০১৯খ্রিঃ

দপ্তরাদেশ

মহাপরিচালক, বাপাউবো মহোদয়ের ডায়েরী নং-৯১২৫ তারিখঃ ১২/০২/২০১৯খ্রিঃ এবং প্রধান প্রকৌশলী পানি বিজ্ঞান এর ডায়েরী নং-৫৪৯ তারিখঃ ০৩/০৩/২০১৯খ্রিঃ মোতাবেক বাপাউবো'র বন্যা পূর্বাভাস ও সতর্কীকরণ কেন্দ্র দপ্তরের কনফারেন্স কক্ষে (ওয়াপদা ভবন ৯ম তলায়) HILIP (Haor Infrastructure Livelihood Improvement Project) শীর্ষক প্রকল্পের আওতায় "Flash Flood Medelling" শিরোনামে আগামী ১০-০৩-২০১৯খ্রিঃ হতে ১৪-০৩-২০১৯খ্রিঃ পর্যন্ত ৫(পাঁচ) দিন ব্যাপী একটি প্রশিক্ষণ কর্মশালা অনুষ্ঠিত হবে। উক্ত প্রশিক্ষণ কর্মশালায় অংশগ্রহণকারী প্রশিক্ষণার্থীগণের তালিকা নিম্নে সন্নিবেশ করা হলো।

Figure 5-1: Training order

Figure 5-2: Glimpse of the opening ceremony of the Training Program

The training program was inaugurated by the Mr. A.K. Manzur Hasan, Chief Engineer, Hydrology, BWDB where Mr. Md. Saiful Hossain, Superintending Engineer, Processing and Flood Forecasting Circle, BWDB and Executive Engineer, Flood Forecasting and Warning Center, BWDB and Director, Flood Management Division, Institute of Water Modelling were also present. The list of participants is provided in Table 5-1 while the training banner is provided in figure 5-3.

Table 5-1: List of Participants

Serial	Participant's Name	Designation
1	Sarder Udoy Raihan	Sub-division Engineer, FFWC, BWDB
2	Partho Protim Barua	Assistant Engineer, FFWC, BWDB
3	Preetom Kumar Sarker	Assistant Engineer, FFWC, BWDB
4	Md. Alraji Leon	Assistant Engineer, FFWC, BWDB
5	Sudipto Chowdhury	Assistant Engineer, PFFC, BWDB
6	Md. Salehin Sharif	Assistant Engineer, RMPB, BWDB
7	Tahiya Tarannum	Assistant Engineer, RMPB, BWDB
8	Sirazhum Monera Asha	Assistant Engineer, BWDB
9	A.N.M. Tareq Siddiquee	Assistant Programmer, FFWC, BWDB
10	Md. Shibbir Hossain	Assistant Engineer, SHEWS, BWDB
11	Shammi Haque	Assistant Professor, IWFM, BUET
12	Sadequr Rahman Bhuiyan	Climate Change Specialist, HILIP, LGED

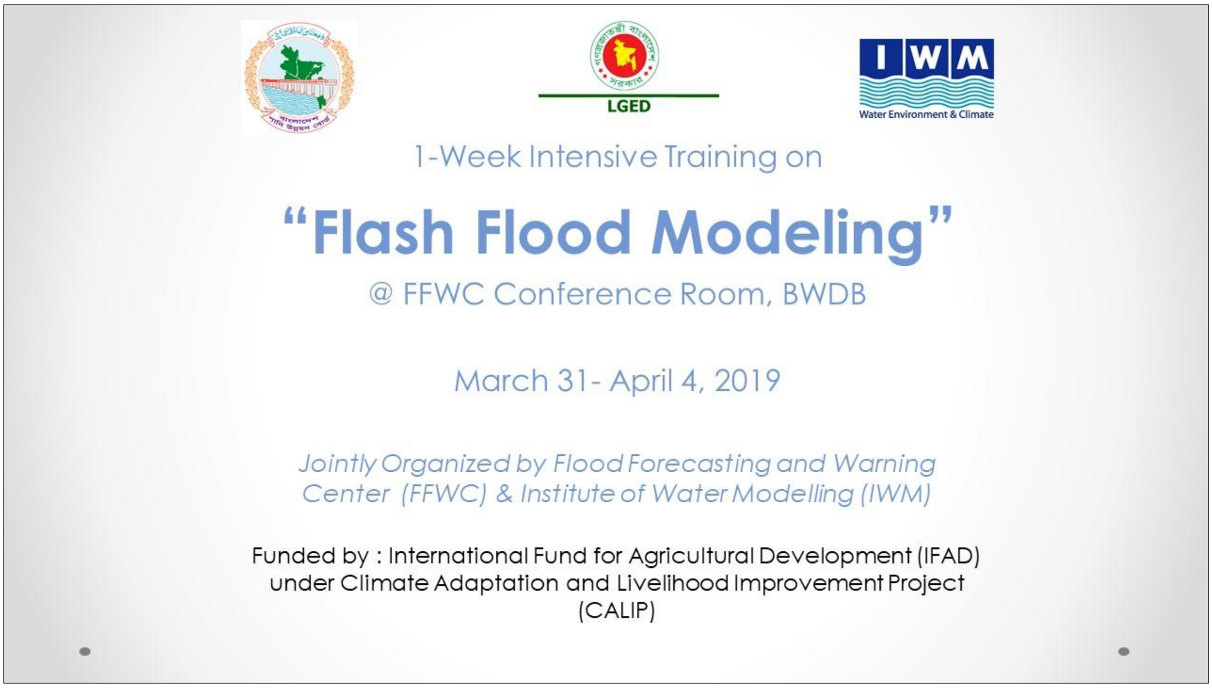
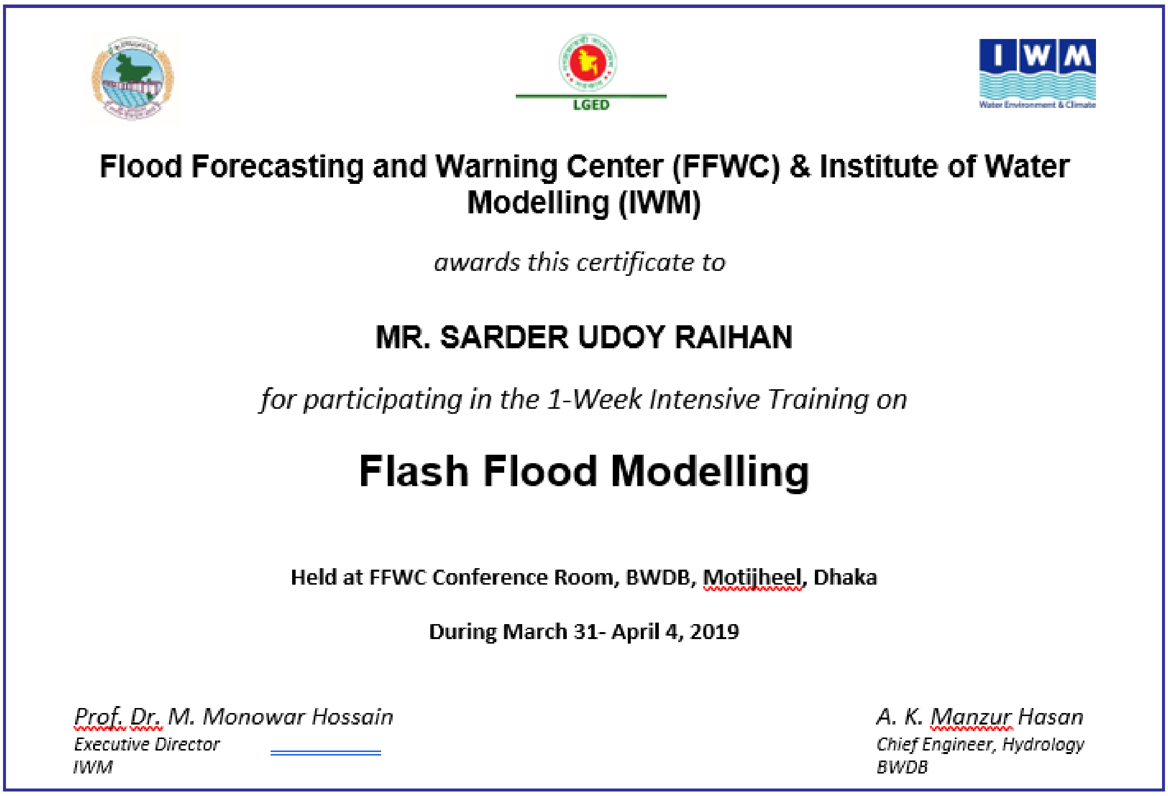


Figure 5-3: Training Banner

The training was comprised of three parts. Mr. Md. Saiful Hossain, Superintending Engineer, Processing and Flood Forecasting Circle, BWDB provided scientific background and theoretical hypothesis of riverine flood forecasting and flash flood forecasting system. In the second part, technical demonstration on mathematical models specially on Rainfall-Runoff and Hydrodynamic Modelling was conducted and in the third part, hands on training on mathematical models solving worked done example was carried out. The training was more informal and interactive than any formal presentation. Figure 5-4 and 5-5 shows training moments and sample certificates of the training program.

Figure 5-4: Some moments from Training Program


LGED

IWM
Water Environment & Climate

Flood Forecasting and Warning Center (FFWC) & Institute of Water Modelling (IWM)

awards this certificate to

MR. SARDER UDOY RAIHAN

for participating in the 1-Week Intensive Training on

Flash Flood Modelling

Held at FFWC Conference Room, BWDB, Motijheel, Dhaka

During March 31- April 4, 2019

Prof. Dr. M. Monowar Hossain
Executive Director
IWM

A. K. Manzur Hasan
Chief Engineer, Hydrology
BWDB

Figure 5-5: Sample Training Certificate of the Training Program

5.2 Training on WRF Model

The essential element of flash flood forecasting is to improve accuracy of rainfall forecasting. The Weather Research and Forecasting (WRF), a mesoscale community model which has been widely used for rainfall forecasting around the world and also used in Flash Flood Early Warning

System (FFEWS) project. A training on the next-generation mesoscale numerical weather prediction system; the WRF model was held during **November 5-9, 2017** for the benefit of its professionals aiming to provide necessary support to FFWC for this flash flood project. The contents and schedule that covered the whole training program is provided in Table 5-2.

Table 5-2: Training Schedule of WRG Training

	Day-1		
Morning	• Introduction to Unix/Linux • Building the WRF system on the machines	• WRF Overview • WPS - Description of General Functions • WPS - Set up and Run • WRF - Set up and Run	**Afternoon**
	Day-2		
Morning	• Hands-on WRF setup	• Introduction to GBM Basin and associated physics • Rainfall forecasting with WRF parameterization	**Afternoon**
	Day-3		
Morning	• Modeling Bay of Bengal Cyclones with WRF • Hands-on Bay of Bengal Cyclones	• Introduction to GrADS • Post-processing with GrADS	**Afternoon**
	Day-4		
Morning	• Setting up a real-time system with WRF • Hands-on	• Hands-on WRF with real-time data and coupling with SST	**Afternoon**
	Day-5		

The training consisted of lectures on the components of the WRF modeling system, WRF Preprocessing System (WPS), Post-processing software and graphical tools as well as practical sessions providing hands-on experience using the software. Mr. Susantha Jayasinghe, A professional from Asian Disaster Preparedness Center (ADPC), Thailand provided the training while Junior Professional from Flood Management Division, IWM received the training.

5.3 On-the-Job Training of FFWC Professionals

Technology transfer through formal training program is the most convenient way to train people on developed system. On the other hand, on-the-job training program is the best way to exchange views of the developed system within trainer and trainee. Thus, during this period, hands on training on the developed forecast system, WRF model and output preparation such as Observed Bulletin, Forecast Bulletin, Hydrographs, Summary Bulletin and Outlook bulletin have been done. The FFWC professionals have taken this informal training during March 2018 on the pre-monsoon flash flood forecast system. Figure 5-6 shows a glimpse of the training program at FFWC, BWDB on Mobile Apps developed for disseminating flash flood forecast outputs.

Figure 5-6: Glimpse of on-the-job training at FFWC, BWDB

5.3 Gauge Readers Training

Training to the gauge readers who provide real-time data to Flood Forecasting and Warning Center during pre-monsoon season requires proper training so that they can send data properly. Thus, to train the gauge readers of the North-East Region, a formal gauge readers' training program on data collection and sending through mobile SMS to FFWC was organized on 28th April 2018 at Sylhet BWDB O&M Office. The list of participants is provided in Table 5-3 and Figure 5-7 shows a glimpse of the training program.

Table 5-3: Gauge Readers List

SL	Name &	Station	Station No.	Station Type	Email/Mobile
1.	মোঃ হাছান আলী	বিজয়পুর	২৬২	পানি সমতল	-
2.	মোবারক হোসেন	কলমাকান্দা	২৬৩.১	পানি সমতল	-
3.	সুমিত্রা রানী	লুভা ছড়া	৩২৬	পানি সমতল	০১৭৪৬২৪৩২০১
4.	মোঃ মশিউর রহমান	ইসলামপুর	৩৩২	পানি সমতল	০১৭৮৯৪৩৭১০২

SL	Name &	Station	Station No.	Station Type	Email/Mobile
5.	মোঃ আবুল বাসার	মুসলিমপুর	৩৩৩	পানি সমতল	০১৭৯৫০০৮১৪৪
6.	মো: শিপলু	সুতং রেলওয়ে ব্রিজ	২৮০	পানি সমতল	-
7.	গিয়াস উদ্দিন মোলৰা	ফেঞ্চুগঞ্জ	১৭৪	পানি সমতল	০১৭২৪৫৫৫১৫২
8.	উগ্রকণ্ঠ রায়	আজমিরিগঞ্জ	২৭১	পানি সমতল	
9.	মো: দেলোয়ার হোসেন	জাফলং	২৩৩ এ ও আর-৪৮	পানি সমতল ও বৃষ্টিপাত	০১৮৩২১০৯৭৪৪
10.	মো: আবদুর রশিদ	জকিগঞ্জ	আর-১৩০	বৃষ্টিপাত	০১৭৬৪৩৭৫৩২৩
11.	মো: জাহাঙ্গীর আলম	লালাখাল	আর-১১৬	বৃষ্টিপাত	০১৬৩৬১১৬১৯০
12.	ফরিদ আহমদ	ছাতক	আর-১০৭	বৃষ্টিপাত	০১৭৪০৫৪৯০৩৫
13.	এম এ কাশেম	দক্ষিণাবাগ	আর-১০৮	বৃষ্টিপাত	০১৮১৭৩১২৬০৭
14.	মোঃ দুলাল	শ্রীমঙ্গল	আর-১২৬	বৃষ্টিপাত	০১৭৫৪৮৮৮১৩০
15.	শাহিদা মুমিত চৌধুরী	লাতু	আর-১১৮	বৃষ্টিপাত	০১৭১৫৭৪৪৪০
16.	মো: ইউসুফ আলী	মহেশখোলা	৪৪	বৃষ্টিপাত	-
17.	পিযুষ কান্তি রায়	চাঁদপুর বাগান	১০৫	বৃষ্টিপাত	০১৭১৬২৯৫৬৯৫
18.	রওশন আলী	ইটাখোলা	১১১	বৃষ্টিপাত	-

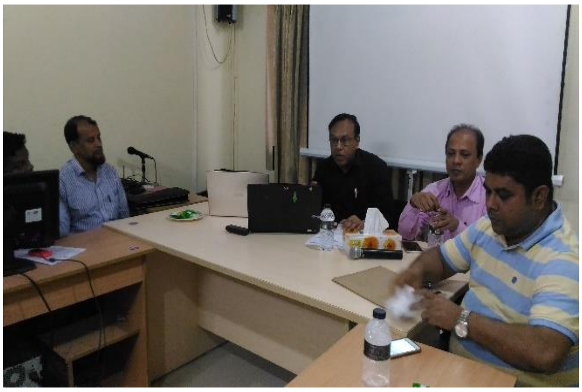



Figure 5-7 Gauge Readers Training Program at BWDB O&M office, Sylhet on 28th April 2018

5.5 Dissemination Workshop

Several workshops have been arranged throughout this study to disseminate its purpose, activities and benefits to various stakeholders in the field. The first dissemination workshop was arranged at Netrokona in the first year in 2016, second workshop in Habiganj in the second year in 2017, third workshop in Sunamganj in 2018 and fourth workshop in Brahmanbaria in 2019. The workshops have been arranged at LGED office premises and district commissioner's office respectively.

5.5.1 Netrokona Workshop

A Stakeholder consultation workshop was held on 15th May, 2016 at LGED Office, Netrokona to discuss the need of the local stakeholders and expectations from this project as well as to get their feedback and suggestions and comments to formulate the project in more realistic and effective manner. The event was successful. Figure 5-8 shows the glimpse of the event.

Figure 5-8: Netrokona Workshop glimpse

The workshop was first of its kind under this project and discussant from various government agencies including Upazila Nirbahi Officer, Department of Disaster Management, Department of Agriculture Extension working in Netrokona area and mainly deals with flash flood affected people, asked more about project benefits and how to involve more stakeholders in this project. Superintending Engineer, Processing and Flood Forecasting Circle, BWDB, Executive Engineer, Flood Forecasting and Warning Center of BWDB, Executive Engineer, BWDB O & M office, Netrokona, Executive Engineer, LGED, Netrokona and professionals from IWM were also present in this workshop.

5.5.2 Habiganj Workshop

A half-day stakeholder consultation workshop at LGED office, Habiganj was held on 19th December 2016 where guests and participants from District administration, Department of Agriculture Extension, Bangladesh Water Development Board (BWDB), Local Government Engineering Department (LGED) were present. Chief Engineer, Hydrology, BWDB Mr. A.K. Manzur Hasan attended the program as Chief Guest. Md. Saiful Hossain, Superintending Engineer, Processing and Flood Forecasting, Hydrology, BWDB, Mr. Abu Saleh Khan, Deputy Executive Director, IWM were also present in the workshop. The participants were briefed about the project progress, flash flood forecast outputs, dissemination techniques etc. On the other hand, participants were interested to learn about very local gauges of Habiganj, how they will receive and what should be done to make this project more fruitful. Figure 5-9 shows the glimpse of the workshop and figure 5-10 shows the invitation card of that program.

Figure 5-9: Moments from Habiganj Workshop

Stakeholder Consultation Workshop on Flash Flood Early Warning System for North East Region

It is our pleasure to inform you that a workshop on "Flash Flood Early Warning System for North East Region" will be held on 19 December 2016 (Monday), 11:00 AM at LGED Conference Room, LGED, Habiganj.

A.K. Manzur Hasan, Chief Engineer, Hydrology, BWDB will attend the workshop as Chief Guest, Gopal Chandra Sarker, Project Director, HILIP, LGED and Md. Saiful Hossain, Superintending Engineer, Processing & Flood Forecasting Circle, BWDB will be present as Special guest, Sabina Alam, District Commissioner, Habiganj will grace the workshop as Guest of Honor and Abu Saleh Khan, Deputy Executive Director, Institute of Water Modelling will preside over the event.

You are cordially invited to attend the workshop

Md. Arifuzzaman Bhuyan
Executive Engineer, & Project Director, (in-charge), CALIP
Flood Forecasting & Warning Center (FFWC),
Bangladesh Water Development Board

Program Schedule

TIME	EVENT
11:00	Registration
11:30	Recitation from the Holy Quran
11:35	Address of the Participants
11:45	Welcome Speech and Project Introduction by Mr. Saiful Hossain, SE, P& FFC, BWDB
12:00	Tea Break
12:15	Presentation on "Flash Flood Early Warning System for NE region under HILIP" by IWM
12:30	Open Discussions
13:10	Speech by Executive Engineer, BWDB, Habiganj
13:20	Speech by Executive Engineer, LGED, Habiganj
13:30	Speech by participants from DAE/DDM/NGO
13:45	Speech by Special Guest, Gopal Chandra Sarker, PD, HILIP, LGED
13:55	Speech by Guest of Honor, DC, Habiganj
14:05	Speech by Chief Guest A.K. Manzur Hasan, CE, Hydrology, BWDB
14:15	Vote of Thanks by Md. Arifuzzaman Bhuyan, Executive Engineer & Project Director, (in-charge), CALIP, BWDB
14:20	Close and Lunch

Figure 5-10: Habiganj Workshop Schedule

5.5.3 Sunamganj Workshop

Another stakeholder consultation workshop was arranged at Sunamganj on 29h April 2018 to disseminate the project outputs and to inform the representatives of the combat agencies working in the Haor area in Sunamganj. A.K. Manzur Hasan, Chief Engineer, Hydrology, BWDB graced the workshop as Chief Guest. Gopal Chandra Sarker, Project Director, HILIP, LGED and Md. Saiful Hossain, Superintending Engineer, Processing and Flood Forecasting Circle were present as Special Guest during the event. The workshop had been chaired by Md. Sabirul

Islam, District Commissioner of Sunamganj, Govt. of the Peoples Republic of Bangladesh. Figure 5-11 and 5-12 shows the glimpse of the workshop.

Figure 5-11: Dissemination workshop at Sunamganj on 29th April 2018

The major outcomes of the workshop can be summarized as follows:

- District Commissioner, Sunamganj was happy to attend the workshop and learned about the ongoing project outcomes. He suggested to invite red crescent and disaster ministry personnel for similar workshop next time. He asked the team to find a way to get haor based forecast and how DC office can warn different UNOs ahead of time.
- Additional District Commissioner, Sunamganj suggested to follow LGED methodology for data/forecast dissemination.
- Representative from Shouhardo Project, Care, Sunamganj suggested to include local level flood forecasting specially haor wise forecast system, involve union digital center and mobile operators for better dissemination.
- Sub-divisional Engineer, BWDB, Sunamganj showed his concern whether he can disseminate the findings of the study and team assured him that he can.
- UNO, Sunamgnaj was not convinced with the mobile apps rather he suggested to improve its features. He suggested to include effective message through mail, have a good coordination among BMD and FFWC, try to increase accuracy involving flood response team.
- DPC, Sunamganj, HILIP project interested to make the already developed forecast products to effective.
- AC, Land, Doarabazar, Sunamganj suggested to focus on target group for dissemination of forecast such as Rubber Dam Management Group.

- PD, HILIP explained his role in this project. He also mentioned some of their initiatives in the Sunamganj Haor area and emphasized on haor based forecasting with correlation from Upstream India.
- Deputy Director, Department of Agriculture Extension, suggested to disseminate the forecast to the farmers using mobile SMS and gather information from Zila Krishibatayon.
- Executive Engineer, Sunamganj BWDB explained their field level preparation, activities taken to combat flash flood and finally asked the forecast team to circulate the forecast to more recipients and in a structured manner.
- Executive Engineer, Local Government & Engineering Department, Sunamganj suggested to follow some guidelines while disseminating flood forecast and he acknowledged the pre-monsoon danger levels applied in this project.
- Superintending Engineer, P&FFC and Chief Engineer, Hydrology, BWDB along with IWM team acknowledged and thanked the participants and tried to explain the project outcomes to the audience.

In brief, the following points were noted from the workshop at Sunamganj:

- Involvement of people in union level for maximize benefit to the stakeholder.
- Publishing more generalized information rather than technical terms in the website
- Publishing haor based forecast products and vulnerability level
- GPS position based customized forecast output to the user via app.
- Sending forecast info to the farmers or farmer group directly from farmer database.
- NGO involvement suggested as information dissemination media.
- 5 to 7 days early forecast demanded as it takes time to harvest crops.
- Some haor can be used as temporary reservoir during high flood flow.
- Involving BADC and Water Management Samete to this project.

Figure 5-12: Participants attending Workshop

5.6 Field Visits

Several Field Visits have been made throughout the study. An important field visit at Tahirpur, Sunamganj was conducted during February 10 to 12, 2019 comprising of two members; Md. Arifuzzaman Bhuyan, Executive Engineer, FFWC, BWDB and Md. Tohidul Islam, Associate Specialist (FMG), IWM to monitor the existing embankment condition and discuss with local people of the Shanir Haor and Matian Haor area. The main purpose of the field visit was to visit Shanir Haor and surrounding water level gauges maintained by BWDB for Flash Flood, to check Lourergorh Auto-gauge site and meet BWDB officials of Sunamganj and discuss. The tour program is provided in table 5-4. The visit was successful one as Executive Engineer, FFWC identified the Solemanpur water level gauge was very relevant one for embankment based forecast system and well maintained by gauge reader which gave him confidence on the project outputs. Small discussion among local stakeholders and concerned Executive Engineer, Sunamganj O&M also revealed that embankment-based forecast is a significant step taken by FFWC for disseminating its outputs to local people of the flood affected area. Figure 5-13 shows some moments from field visits.

Table 5-4: Tour Program

February 10, 2019 (Sunday)	• Leave Dhaka for Sylhet by hired vehicle. • Reach Sylhet and visit BWDB office • Night halt at Sylhet IWM rest House
February 11, 2019 (Monday)	• Leave Sylhet for Sunamganj • Visit to Shanir Haor and Solemanpur gauge at Tahirpur, Sunamganj related to Embankment based Forecast • Visit Lourergorh and check the auto-gauge site • Return to Sunamganj • Night halt at Sunamganj
February 12, 2019 (Tuesday)	• Visit to Sukdevpur and Derai gauges of Sunamganj • Return to Sunamganj and leave for Dhaka • Reached Dhaka

Figure 5-13: Solemanpur Gauge on Patnagang River (top left); Relates Solemanpur gauge with Shanir Haor (top right); Gauge monitoring at Sukdevpur (Bottom left) and Rainfall gauge monitoring at Tahirpur

A field visit to Gowainghat, Sylhet and Lourergorh, Sunamganj was conducted comprising the following personnel from BWDB and IWM to confirm the auto-gauge during 17 to 19 December 2017. Figure 5-14 and 5-15 show some glimpse of the field visits.

BWDB Team		IWM Team	
1.	A. K. Manzur Hasan, CE, Hydrology	1.	Abu Saleh Khan, DED (Opn.),
2.	Md. Saiful Hossain, SE, P&FFC	2.	Md. Sohel Masud, Director, FMG
3.	Md. Arifuzzaman Bhuyan, EE, River Morphology	3.	Md. Tohidul Islam, AS, FMG

The main purpose of the tour was as following;

- To attend a stakeholder consultation workshop at Habiganj
- To check existing facility & suitability of installing two auto-gauges i.e. one at Lourergorh, Sunamganj and another at Gowainghat, Sylhet.
- To visit some selected BWDB gauges of North East Region to convert them from non-real-time to FFWC real-time station


Figure 5-14: Lourergorh Site Visit

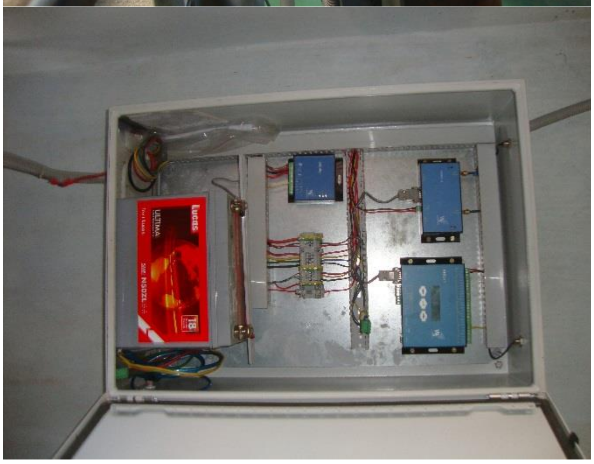

Figure 5-15: Gowainghat Site Visit

Earlier, another field visit to Sherpur, Sylhet, Fenchuganj, Jafflong and Moulvibazar was carried out during November 01 to November 04, 2016. IWM study team completed the visit to check the physical conditions of the gauges and data collection system in this area.

The team started their visit from IWM office premises at 9. 00 AM on Day 1 (November 01, 2016) using hired microbus and on the way to Sylhet, the team visited the Sherpur water level gauge and found the gauge location is found to be disturbed with boat ghat; the team reached Sylhet at about 5.00 PM. The team then reached BWDB office, Sylhet to meet Executive Engineer, Md. Sirajul Islam and explained him the plan of the visit. The team also meet Chief Engineer, Northern measurement division, Md. Abdul Hye and received his valuable suggestions. Section Officer, Md. Zahirul Islam, Gowainghat Section, was introduced with the team. The team then visited Habibnagar Tea Estate, near Chiknagool, Sylhet to collect rainfall measurement data solely measured at each tea estate to supplement rainfall measurement done by BWDB and BMD. Night halt at IWM rest house, Sylhet. Figure 5-16 and 5-17 shows some photos of the field visit.

Figure 5-16: (Left) Meeting with CE, NEMD, Sylhet; (Right) Rain gauge at Habibnagar Tea Estate

The team started their journey at 7.00 AM on Day 2 (November 02, 2016) from Sylhet and reached Jafflong river close to border to find a suitable location for installing auto-gauge. It was found that the Jafflong river is a potential stone quarry and boat movement, stone collection hampers almost full reach length of the river and leave a very few locations to install auto-gauge. However, the present manual gauge location found most suitable for installing auto gauge but lacking other setup facilities like machine room, electric supply etc. An under-construction bridge is found close to the manual gauge location which could be suitable for shifting the auto-gauge to the bridge deck in later 2017. A nearby school “Amir Mia High School”, Jafflong, Sylhet could be used as temporary installation point. The team also discussed the issue with head master of the school and he assured that if BWDB approach to them through school committee, the school will allow a piece of land for any facility installation. The team then moved to Jafflong zero point and found that the Piyain River is totally silted up and the catchment runoff is completely passed through the possible site for auto-gauge installation at Jafflong. On the way to Lallakhal, the team visited the existing Sarighat Auto-gauge installation point, talked with gauge reader and observed the operational facility to understand the ongoing installation. The team then moved to Lallakhal Tea Estate to collect rainfall measurement data solely collected at Lallakhal. The team also discussed with tea garden manager to find the way how to collect other tea estate rainfall data which could be a very effective source of rainfall data to simulate and forecast flash flood in the North-East region. The team then returned to IWM rest house and night halt at Sylhet.



(Top) Existing manual water Level gauge at Jafflong; (Middle) Sarighat Gauge Reader is monitoring auto-gauge sensor set at the bottom of the bridge deck; (Bottom) Equipments of autogauge sensors installed inside the room

(Top) Silted up and disturbed Jafflong river near indian border; (Middle) Sarighat instrument room for auto-gauge sensor; (Bottom) Autogauge data transmitter shows error in data sending


Figure 5-17: (Left) Rain Gauge at Lallakhal Tea Estate; (Right) Poor condition of Sherpur Water Level Gauge

The team started their third day journey at 7 am on Day 3 (November 3, 2016) and reached proposed Gowainghat FCD project area and visited several locations. The team then reached Gowainghat and contacted with BWDB gauge reader and informed that BWDB is not maintaining the gauge at this moment. However, he maintained the gauge last year and if required, he would be able to provide service in future. The Gowainghat Bridge is a permanent structure and suitable for installing auto-gauge sensor over there. A close by T&T office can be used for equipment room if permission is received. The Sarigowain river at Gowainghat captures flow both from Jafflong river and Sarigowain river and some other hilly streams and thus could be most suitable location for auto-gauge installation.

Also, during June 10 -11, 2019, Executive Engineer of Flood Forecasting and Warning Center (FFWC) of BWDB visited Brahmanbaria and meet with District Commissioner to brief him about the study outputs and other associated activities. During his visit, he also visited B.Baria water level gauge over Titas river. Figure 5-18 and 5-19 shows gauge condition and meeting with District Commissioner of B.Baria respectively.


Figure 5-18: B.Baria Water Level Gauge Visit

Figure 5-19: Meeting with DC, B.Baria

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Flood Forecasting and Warning Services (FFWS) in Bangladesh is the mandate of Bangladesh Water Development Board (BWDB) under Ministry of Water Resources. Flood Forecasting and Warning Center (FFWC) of BWDB is carrying out this responsibility on behalf of BWDB. Significant improvement has been made in the area of riverine monsoon flood forecast in Bangladesh up to 5-days deterministic forecast and 10-days lead time probabilistic forecast in the recent past. But in the area of flash flood especially for the North-East region, need of further expansion and advancement was felt necessary. In this regard, Bangladesh Water Development Board (BWDB) signed a MoU with Local Government Engineering Department (LGED) as Partner institute to conduct a study titled as" Flash Flood Early Warning System for North Eastern Part of Bangladesh" and Bangladesh Water Development Board has engaged Institute of Water Modelling in March 2016 to conduct the study funded by International Fund for Agricultural Development (IFAD). As per contract, IWM have successfully completed this tasks during 2016-19 period. The overall objective of the study was to develop a dedicated Early Warning System of Flash Flood in the NE region of Bangladesh for saving Boro rice cultivated both in protected and non-protected areas. The other objectives were

g) Increase number of flash flood forecast stations up to 25 locations;
h) Produce diversified forecast outputs and make operational of the Flash Flood Early Warning System at FFWC of BWDB;
i) Update website of FFWC, BWDB (Flash flood forecasting page) for wide spread dissemination of flash flood forecast;
j) Capacity building of FFWC professionals in flash flood forecasting.

To comply with these objectives of the study, the major tasks that have been carried out are as follows;

- Data collection and monitoring of real-time rainfall and water level gauges
- Update of flash flood forecast model for northeastern part of Bangladesh
- Increase 17 nos. forecast stations and expand forecast coverage area towards Brahmanbaria, Sherpur, Netrokona and further area of Sylhet, Sunamganj, Habiganj and Moulvibazar.
- Produce various flash flood forecast outputs (Hydrograph, Bulletin, Embankment based forecast)
- Develop dedicated flash flood forecast website and mobile apps for dissemination
- Technology transfer through intensive training and on-the-job training
- Writing Reports, arranging field visits and organizing workshops

Data Collection and monitoring:

Two Radar Level Sensor based auto-gauges have been installed at Gowainghat on Sarigowain River during April 2017 and at Lourergorh on Jadukata River during December 2017 to collect real-time water level data and to supplement automatic real-time data collection system of FFWC. Both the gauges have been made operational since its installation. To update the rating equations of the border locations, discharge measurement campaign has been carried out during 2016 and 2018 and discharge data were applied to validate the rating equations for Bijoypur and Lourergorh. However, due to limited budget provision, not all rating curves have been updated with observed discharge data. To update the existing North-East Region Model using recent cross-sections by replacing most old sections of some selected rivers of North East region, a cross-section survey campaign has been carried out during 2016-17. Around 200 nos. cross-sections have been surveyed, processed and incorporated in the Flash Flood Forecast Model. To enhance the rainfall-runoff model through rainfall distribution within the North-East Region particularly at the border locations, additional 12 nos. rainfall stations maintained by Hydrology, BWDB have been identified and incorporated in the real-time data collection system under this project. A total 17 number of water Level monitoring stations have been made real-time and incorporated into the Forecast System under this study. These stations are now providing real-time water level data to FFWC through mobile SMS technology.

Updating of Flash Flood Forecast Model:

The Flash Flood Forecast Model developed in the CDMP-II of MoDMR study has been utilized in this project with necessary updating, adjustment and expansion. Three separate modules of one-dimensional mathematical modelling tool developed by DHI Water and Environment, Denmark have been utilized in carrying out this study. The modules are Rainfall-Runoff (MIKE11 NAM) for hydrological modelling, One-dimensional River Model (MIKE 11 HD) for hydraulic modelling of North-East Region, Bangladesh and Barak Basin, India coupled with flood forecast module (MIKE 11 FF) for flood forecasting. The Rainfall-Runoff model coupled with Hydrodynamic model for North-East Region operated with flood forecast module is combinedly called as "Flash Flood Forecast Model". Flash flood in the Northeast Bangladesh occurs from the inflow coming from the cross-border catchments. The hydrological component (NAM) of the NERM comprises 39 sub catchments inside Bangladesh and 18 cross-border sub catchments within India except the Barak river basin. The Barak Basin itself comprises of 8 catchments and combined runoff enters Bangladesh border near at Amalshid through hydrological routing. Total 71 nos. station rainfall data collected from FFWC, BWDB and Indian Meteorological Department (IMD) websites are utilized for this rainfall-runoff model with necessary weightage distribution applying Thiessen-Polygon method. Parameters of hydrological model (NAM) have been calibrated extensively during 1999-200 and updated during 2016 to 2018 under this project. The hydrodynamic model has been updated through incorporating surveyed cross-sections, updated link channels and updated boundary discharges. Barak HD model comprises the entire watershed of the Barak River up to bifurcation of the river at Amalshid of Zakiganj, Sylhet. Gauge observed daily rainfall data at 20 stations of last 4 years (2016-2019) collected from public domain (websites) have been used for calibration of the model The Flash Flood Forecast model has been calibrated for 2017 flash flood event and validated for 2016 and 2018. After satisfactory calibration and validation, this flash flood forecast model has been made operational to forecast 2019 flash flood event. The model validation shows good agreement in most cases (19 stations namely Amalshid, Azmiriganj, Ballah, Fenchuganj, Kalmakanda, Kanaighat, Khaliajuri, Lourergorh, Manu RB, Markuli, Sarighat, Sherpur, Sunamganj, Sylhet, Moulvibazar, Sheola, Islampur, Jariajanjail and Gowainghat), satisfactory agreement in some cases (Habiganj, Muslimpur and Sutang) while in some cases (Nakuagaon, Durgapur and Kamalganj) the validation founds as poor.

Increase Forecast Stations:

A total 17 number of water level forecast stations have been incorporated into the Forecast System under this study. Thus, including past 8 nos. forecast stations (Amalshid, Sheola, Sherpur, Kanairghat, Sylhet, Sunamganj, Lourergorh, Jariajanjail) initiated in the MoDMR study period, the total no. of Flash Flood Forecast stations has been increased up to 25 nos.

Produce various flash flood forecast outputs:

IWM has been involved in developing the forecasting model and operational forecast system for the flash flood prone North-East Region. The major outputs of this forecasting system are station wise forecast hydrograph, observed bulletin, forecast bulletin and summary bulletin produced on daily basis. Also, Quantitative Precipitation Forecast (QPF) and Embankment based forecast are also significant outputs in this study. To ease this forecast products, an automatic forecasting system has been developed under this project.

Develop dedicated flash flood forecast website and mobile Apps

All the forecast products have been successfully uploaded and disseminated through a dedicated website developed under this study and hosted in FFWC main webpage as link. One can access the webpage and can explore by visiting the following address link as (www.ffwc.gov.bd) then to http://www.geo.iwmbd.com:2000/flashflood/

To enhance the dissemination of forecast products to the end users, a mobile apps has been developed under this study. The application is open for publicly use. No authentication is required to use this application. One can download the application using Android device from http://geo.iwmbd.com:2000/flashflood/mobile_apps.php. The mobile apps contain a home tab, application menu, general tab and feedback tab.

Training and Technology Transfer

Several on-the job trainings to the FFWC professionals have been carried out throughout the project tenure. Also, one week-long intensive training has been arranged at FFWC two times within this time. Gauge readers training, training on WRF model and developed Flash Flood Forecast Model have been discussed in these training program. The fully operational flash flood forecast system has also been successfully handed over to FFWC and demonstrated them on the developed system. A user manual is also have been provided.

Reports, Workshops and Field Visits

Several reports have been submitted throughout the study. Starting with Inception report, 3 nos. Annual Progress Reports, around 12 nos. Quarterly Progress Reports and one Draft Final Report have been submitted. This is the Final report submitted incorporating compliance of the comments made on DFR.

Four nos. Stakeholder consultation workshops have been arranged at Netrokona, Habiganj, Sunamganj and B.Baria. Workshop scheduled to be held at Kishoreganj was later postponed due to National Election Program. Several field visits have been made in the study area to understand the peoples demand, check the gauge conditions and verify pre-monsoon danger levels and for installing two nos. Automatic Water Level measurement gauges.

6.2 Recommendations

The following recommendations have been made for better performance of the developed flash flood forecasting system with a lead time of up to 3 days:

1. Short duration rainfall data of higher frequency should be made available to simulate flash flood event during pre-monsoon.
2. Probabilistic flash flood forecast techniques using satellite based rainfall information should be adopted in future for relatively accurate forecast product instead of deterministic forecast product.
3. Installation of automatic discharge measurement system at the entry point of border rivers in the NE Region should be initiated
4. Regular updating of hydrological and hydrodynamic models is necessary
5. Flood forecast is the mandate of BWDB; thus, in any future flood forecasting project, development partners should engage BWDB directly so that BWDB can lead the project.
6. Increased man power and capacity building process of FFWC should be taken good care of.
7. Alongside the present Mike 11 software based model, open source modelling software performances should be evaluated and compared with Mike based system in future studies.

8. Flood Forecasting and Warning Center of BWDB will disseminate the forecast according to the mandate of FFWC and go with Government Initiative to disseminate flash flood forecast warning through Union Information Center under A2i project.

9. Haor based flash flood forecast system experimentally developed under this study can be scaled up and adopted as a means of community based early warning system in NE region of Bangladesh.

6.3 Constraints and limitation of the Study

The following constraints and limitations have been identified in this project and as per ToR, the following remarks can be made on the completed project.

1. The joint evaluation of IWM developed system and IWFM developed system has not been conducted so far.

2. The WRF forecast generated by IWFM, BMD and FFWC-IWM is not yet compared and thus which product is most suitable for pre-monsoon flash flood forecasting done by FFWC is not yet evaluated.

3. The real-time exchange or data sharing between FFWC and BMD has made functional using an ftp site, however the continuity of this data sharing has not been ensured by any formal agreement.

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