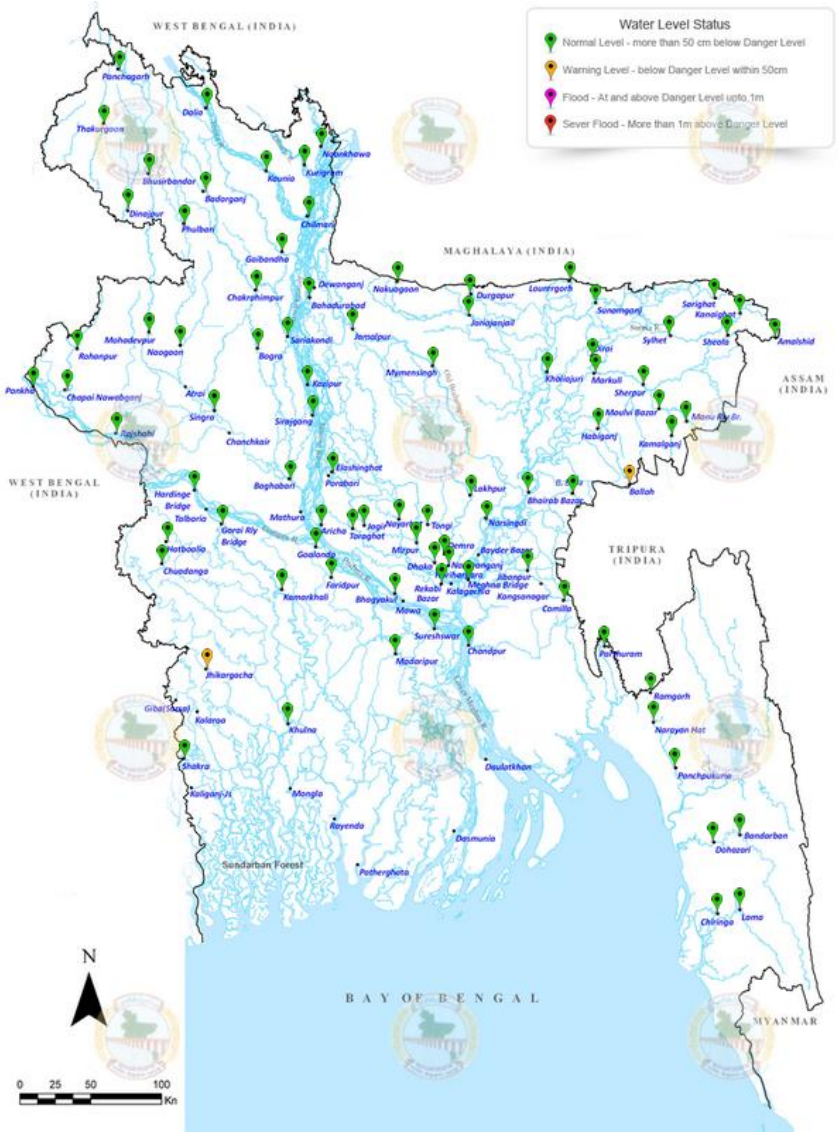
ANNUAL FLOOD REPORT 2016



FLOOD FORECASTING & WARNING CENTER

PROCESSING & FLOOD FORECASTING CIRCLE

BANGLADESH WATER DEVELOPMENT BOARD

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PREFACE

Bangladesh is the part of world's most dynamic hydrological and the biggest active delta system. The topography, location and outfall of the three great rivers system (The Ganges-Brahmaputra-Meghna) shape the annual hydrological cycle of the country. Too much and too little water in a hydrological cycle is the annual phenomenon. Flood is a regular monsoon event whose depth and duration are the deciding factors whether it affecting beneficially or adversely. Monsoon inflow along with rainfall historically shapes the civilization, development, environment, ecology and the economy of the country. Extreme events of flood adversely affect the development, economy, food security, poverty and almost every sector. In flood management, Bangladesh has been taken structural and non-structural measures. One of the main non-structural measures is the flood forecasting and warning service.

As stated in the BWDB Act-2000, Flood Forecasting in Bangladesh is the mandate and responsibility of Bangladesh Water Development Board (BWDB). Flood Forecasting and Warning Center (FFWC) of BWDB is carring out this duty. The FFWC was established in 1972 and is fully operative in the flood season, from April to October every year, following the Standing Orders for Disaster (SOD) of the Government of Bangladesh. The FFWC is acting as the focal point on flood forecasting and warning services in co-ordination with concerned ministries and agencies like Ministry of Disaster Managment and Relief, BMD, DDM, DAE etc. during the monsoon for flood disaster management.

The objectives of flood forecasting and warning services are to enable and persuade people, community, agencies and organizations to be prepared for the flood and take necessary actions to increase safety and reduce or protect damages of lives and properties. Its goal is to alert the agencies, departments, communities and people to enhance their preparedness and to motivate vulnerable communities to undertake preparedness and protective measures.

The professionals of FFWC gratefully acknowledge the valuable advice, guidence, leadership of Director General, BWDB for his interest, continuous drive and suggestion. The valuable suggestions and encouragement provided by the ADG (Planning), Chief Engineer, Hydrology and Superintending Engineer, Processing & Flood Forecasting Circle, Hydrology, BWDB to improve the quality of works of the center.

The services of Flood Information Centers (FICs) established at the Division Offices of BWDB, Gauge Reader's, Wireless operators, local communities and other support service providers are gratefully acknowledged. The FFWC is also grateful both to the print and electronic news media and those who helped in disseminating the flood information and warning messages during flood 2016. A number of NGOs have been working in different areas for dissemination of the flood warning message generated by the FFWC at community (Union and Village), this enables flood preparedness at local level. FFWC disseminate flood forecating information through the user friendly web-site (www.ffwc.gov.bd) with bangle flood warning message. Flood warning message also is

being disseminated through Interactive Voice Response (IVR) method using mobile phone(number 1090). A Collaborative programme is underway with Regional Integrated Multi-hazard Early Warning System (RIMES) to increase the forecst leadtime using probabilistic approach.

It is great pleasure that the regular observer of the FFWC web-site, noted by distinguished personalities at home and abroad is source of inspiration for improving the quality of services. Suggestion, feed-back and appreciation from policy level, ministries, different levels of GOs and NGOs is great encouragement of the professionals working in FFWC. This is indeed a struggle and commitment to continue the services from April to October continuously, without week-ends and holidays. FFWC with its limited resources is working hard to carry out the responsibility during the monsoon. FFWC is trying to develop further the process and system to cope-up with the technological and computational development. One of the main struggle and demand is to increase flood forecasting and warning lead time and its forecast coverage.

The FFWC hopes that this report might be a point of interest to the planners, designers, administrators, working in the water sector, disaster managers/flood fighters and various activities of formulating measures for flood mitigation/management in Bangladesh. FFWC warmly welcomes comments and suggestions, and these would certainly improve the services, activities and output of the FFWC in the coming days.

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Executive Summary

The characteristics of flood of 2016 represent a moderate flooding year for Bangladesh. The northern region of Bangladesh especially the river basins of Brahmaputra-Jamuna, Teesta, Darla and Dudkumar experienced flooding during the monsoon in 2016. Some places in the North Eastern part of the country experienced short duration flooding end of April. Flood also occured in districts along the Padma river mainly- Rajbari, Shariyetpur, Munshiganj. Duration of flooding in the south west, in the part of Jessore and Satkhira districts was moderate. Flood in this region dominates primarily due to tidal influence as well as local rainfall. Water Level of Kobodak River at Jhikorgacha flowed above danger level for 22 days. The duration, inundation status and timing of flooding indicate medium range flood.

The country as a whole received 24.43% less rainfall than normal during the monsoon-2016 (May to October). The Brahmaputra, Ganges, Meghna, South-Eastern Hill received 32.14%, 6.90%, 29.48%, 23.81% less rainfall than the normal value respectively in the year of 2016. During the monsoon-2016 all the basins recorded more rainfall than their respective normal during August month. Basin wise monthly percent less(-) or more(+) rainfall than the normal is presented in the following table.

Month	Brahmaputra basin	Ganges basin	Meghna basin	South East Hill basin
May	-23.52	23	1.72	-11.91
June	-32.23	-30.18	-48.50	-36.04
July	-9.97	16.16	-7.71	-5.82
August	-67.74	6.16	-54.90	-14.29
September	-30.51	-25.08	-47.74	-13.37
October	-22.07	-18.76	-40.22	36.55

[BWDB Data 2016]

Professionals of FFWC has been fully dedicated and committed to generate and disseminate flood forecasting and warning services on daily basis during the monsoon.

During the monsoon-2016, maximum flooded area was 33% of the whole country (48,675 sq-km approximately).

List of Abbreviations

ADG	Additional Director General
ADPC	Asian Disaster Preparedness Centre
BWDB	Bangladesh Water development Board
BMD	Bangladesh Meteorological Department
CB	Cell Broadcast
CDMP	Comprehensive Disaster Management Programme
CEGIS	Centre for Environmental Geographical Information Services
CFAB	Climate Forecast Application Bangladesh
CARE	Cooperative for American Relief Everywhere
CFAN	Climate Forecast Application Network
DG	Director General
DL	Danger Level
DDM	Department of Disaster Management
DHI	Danish Hydraulic Institute
ECMWF	European Centre for Medium-Range Weather Forecasts
DEM	Digital Elevation Model
DAE	Department of Agriculture Extension
FFWC	Flood Forecasting and Warning Centre
GM	General Model
GBM	Ganges Brahmaputra Meghna
IWM	Institute of Water Modelling
IVR	Interactive Voice Response
MAE	Mean Absolute Error
MoFDM	Ministry of Food and Disaster Management
MoWR	Ministry of Food Water Resources
NGO	Non-Government Organization
MSL	Mean Sea Level
RIMES	Regional Integrated Multi-hazard Early Warning System
SOD	Standing Order on Disaster
SSB	Single Site Band
SPARRSO	Space Research and Remote Sensing Organization
UNDP	United Nations Development Porgramme
USAID	United States Agency for International Development
WL	Water Level

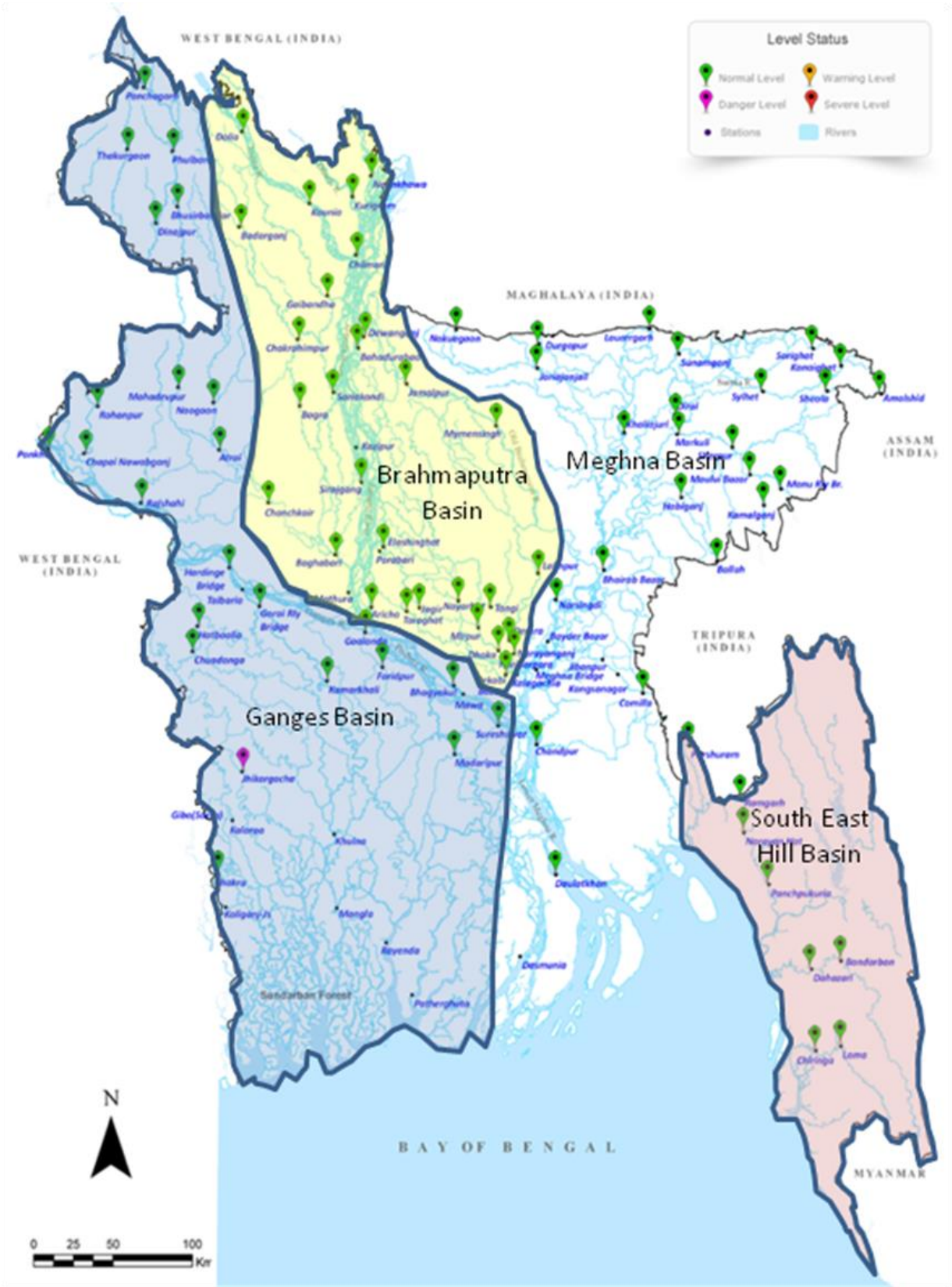


Figure 1 : Basin Map of Bangladesh with Water Level Gauge Stations

CHAPTER 1: INTRODUCTION

1.1. THE PHYSICAL SETTING

Bangladesh lies approximately between 20°30' and 26°40' north latitude and 88°03' and 92°40' east longitude. It is one of the biggest active deltas in the world with an area of about 1,47,570 sq-km. The country is under sub-tropical monsoon climate, annual average precipitation is 2,300 mm, varying from 1,200 mm in the north-west to over 5,000 mm in the north-east. India borders the country in west, north and most part of east. The Bay of Bengal is in the south, Myanmar borders part of the south-eastern area. It has 405 rivers including 57 transboundary rivers, among them 54 originated from India including three major rivers the Ganges, the Brahmaputra and the Meghna (*Ref. Bangladesher Nod Nodi, BWDB, August 2011*). Three rivers originated from Myanmar. Monsoon flood inundation of about 20% to 25% area of the country is assumed beneficial for crops, ecology and environment. But flood more than that causing direct and indirect damages and considerable inconveniences to the population.

The country is mostly flat with few hills in the southeast and the northeast part. Generally ground slopes of the country extend from the north to the south and the elevation ranging from 60 meters to one meter above Mean Sea Level (MSL) at the Northwest boundary of the country and at the coastal areas in the south. The land in the west of the Brahmaputra is higher than the eastern part. Several large depressions have been formed, particularly in greater Mymensingh, Sylhet, Sunamgonj and part of Pabna-Rajshahi districts. The country consists of the flood plains of the Ganges, the Brahmaputra and the Meghna rivers and their numerous tributaries and distributaries. The Ganges and the Brahmaputra join together at Aricha-Goalundo and is known as the Padma River. The river Meghna joining the Padma near Chandpur flows to the Bay of Bengal as the Meghna River.

1.2. THE RIVER SYSTEM

The Ganges, Brahmaputra and Meghna river systems together, drain the huge runoff generated from large area with the highest rainfall areas in the world. Their total catchment area is approximately 1.6 million sq-km of which only about 7.5% lies in Bangladesh and the rest, 92.5% lies outside the territory. It is assumed that an average flow of 1,009,000 Million cubic meters passes through these river systems during the monsoon season. Most of the rivers are characterized by having sandy bottoms, flat slopes, substantial meandering, banks susceptible to erosion and channel shifting. The river system of Bangladesh is one of the most extensive in the world, and the Ganges and the Brahmaputra are amongst the largest rivers on earth in terms of catchment size, river length and discharge.

The Brahmaputra (Jamuna) river above Bahadurabad has a length of approximately 2,900 km and a catchment area about 5,83,000 sq-km. Started from the glaciers in the

northernmost range of the Himalayas and flows east far above half its length across the Tibetan plateau. In the complex mountain terrain bordering north-east India and China it bends through a series of gorges and is joined by a number of major tributaries, e.g., the Dihang and the Luhit before entering its broad valley section in Assam. This stretch is about 720 km long to the border of Bangladesh and throughout most of this, the course is braided. This braided channel is continued to the confluence with the Ganges.

Within Bangladesh, the Brahmaputra receives four major Right Bank tributaries - the Dudkumar, the Dharla, the Teesta and the Hurasagar. The first three are flashy rivers, rising in steep catchments on the southern side of the Himalayan between Darjeeling and Bhutan. The Hurasagar River is the outlet to the Karatoya-Atrai river system, which comprises much of the internal drainage of northwest of Bangladesh.

The Old Brahmaputra is the main left-bank distributaries of the Brahmaputra river presently known as the Jamuna. The shift of river course appears to have been taken place after a major earthquake and catastrophic flood in 1787. It is now a high flow spill river contributing largely to flood, as in the Dhaleswari, and their behavior is highly dependent on the variations of siltation at their entries.

Total length of the Ganges River is about 2,600 km to its confluence with the Brahmaputra -Jamuna at Aricha-Goalondo and a catchment area of approximately 9,07,000 sq-km. Started from the high western Himalayans glaciers, the Ganges has a short mountain course of about 160 km. From there it flows south easterly in a vast plain with major tributaries from the southern Himalayans in Nepal and smaller rivers from the central Indian Plateau to the south. With deep-water channel with numerous bar formations (chars), the Ganges is not braided. After its confluence with the Jamuna at Goalondo, the river, known as the Padma, flows in a wide and straight. At Chandpur, the Padma is joined to the Meghna from where it flows to the sea with tidal influence.

The Meghna system originates in the hills of Shillong and Meghalaya of India. The main source is the Barak River, which has a considerable catchment in the ridge and valley terrain of eastern Assam bordering Myanmar. On reaching the border with Bangladesh at Amalshid in Sylhet district, it bifurcates into Surma and the Kushiyara rivers. The Surma, flowing on the north of the Sylhet basin receives Right Bank tributaries from Khasia and Jaintia Hills of Shillong. These are steep, highly flashy rivers, originating in one of the wettest area of the world, the average annual rainfall at Cherrapunji at Meghalay being about 11,755 mm. The Kushiyara receives left bank tributaries from the Tripura Hills, the principal ones being the Manu. Also, flashy in nature with less elevations and rainfall of Tripura makes these rivers less violent than the northern streams.

Between the Surma and Kushiyara, there are many internal draining depressions (haors), meandering flood channels and abandoned river courses, which are widely flooded every monsoon season. The two rivers rejoined at Markuli and flow via Bhairab as the Meghna to join the Padma at Chandpur. The major tributaries of any size outside the Sylhet basin

are the Gumti and the Khowai River, which rises in Tripura and other hilly streams from Meghalaya and Assam of India to join the Meghna.

The streams of the southeast region are all short and of a flashy nature, rising in the Chittagong Hill Tracts or adjacent parts of eastern India. The main streams are the Muhuri, Halda, Sangu, Matamuhuri, etc.

1.3. ACTIVITIES OF FFWC

The importance of the flood forecasting and warning is recognized as a vital non-structural measures to aid the mitigating the loss of lives, crops and properties caused by the annual flood occurrence. The Flood Forecasting and Warning Centre, under the Directorate of Processing and Flood Forecasting Circle, Hydrology, BWDB takes hydrological monitoring data of 90 representative water level stations and 59 rainfall stations throughout the country. The principal outputs are the daily statistical bulletin of floods, river situation, a descriptive flood bulletin, forecast for 24, 48, 72, 96 and 120 hours at 54 monitoring points on the major rivers, special flood report along with different graphical and statistical presentation during the monsoon season. The Centre is also involved in preparation of flood status report at national level, weekly bulletin during dry season bulletin, monthly and annual flood reports. The Centre is responsible as a focal point in respect of flood from the month of April to November as per Government order for generating flood forecast & warning that are issued with the flood bulletin and also provide support services to DDM other relevant organization.

OUTPUTS of the FFWC

- **Rainfall Distribution Map.**
- **Daily Flood Bulletin & River situation summary**
- **Forecast bulletin & Hydrograph**
- **Warning message**
- **River situation map**
- **Special outlook**
- **Structure based flood forecast**
- **Countrywide coarse flood inundation map**
- **Comparison Hydrographs for various years**

Step by step development has been made in the flood forecasting and warning services in Bangladesh, started from 1972. Before 1990, forecast for six locations viz. Bahadurabad, Serajgonj, Aricha, Goalondo, Bhagyakul and Hardinge Bridge on the Padma – Brahmaputra –Jamuna river system were issued by Co-axial correlation, Gauge to Gauge relation and Muskingum-Cunge Routing Model. After the devastating flood of 1987 and catastrophic flood of 1988, it was deeply realized that the forecast formulation should be introduced in the process of river modelling. In view of the above, the simulation model MIKE11 developed by Danish Hydraulic Institute (DHI) was installed at FFWC and a special version of MIKE11 FF conceptual Hydrodynamic model is in operation for forecast formulation.

The General Model (GM) developed under MIKE11 was adapted to real time operation in which boundary extended near to the Indian border on all main rivers. A supermodel now is in operational at FFWC covering entire flood affected area of Bangladesh, except coastal zone, the southern part. The Supermodel covers about 82,000 km^2 of entire country, except the coastal zone of the country. The area covered under the supermodel is divided into 107 numbers of sub-catchments. It includes 195 river branches, 207 link channels, 40 Broad Crested Weirs. The total river length modeled is about 7300 km. Model operation and data base management is being done with a well-managed server based (Widows 2000) LAN–Operating System installed with desk top PCs at the FFWC.

Flood Forecasting & Warning Services: Brief History

1972 - FFWC Established under BWDB
- Real Time Flood Monitoring at 10 Stations/Points along the Brahmaputra, Ganges and Padma rivers
- Flood Forecast (FF) with few hours lead time at 6 points by Gauge Correlation along Brahmaputra and Padma rivers

1992 - MIKE11-FF Model Introduced
- FF with one day lead time at 16 points/locations

1995-96 - MIKE11 Super Model with GIS
- FF at 30 locations with lead time upto 2-days

2000-04 - Strengthening FFWS
- Expansion of FF areas coverage
- Flood monitoring covers entire country
- Improved accuracy and extend Lead Time upto 3-days
- Improved dissemination

2005-07 - Probabilistic medium range FF with lead time upto 10-days initiated at 18 points/locations

2007-09 - Further extension of FFWS
- Mike 11 Super Model with GIS introduced with flood ma generation facility
- FF at 38 locations on 21 Rivers upto 3-days Lead Time
- Flood Inundation Mapping
- Improvement of probabilistic medium range FF upto 10-days at 18 points

From 2012 - Strengthening and Improvement of FFWS
- FF at 54 locations on 29 rivers with Extended Lead Time upto 5-days
- Structure based FF for 4-selected projects upto 5-days lead time
- Improved and more user friendly web-site with Bangla language
- IVR system for dissemination based on mobile phone introduced
- Improved LAN and display.

1.4. OPERATIONAL STAGES BEFORE FORECAST MODEL RUN

Data Collection: The real time hydrological data (90 WL stations and 59 rainfall stations) is collected by SSB wireless, fixed & mobile telephone from the BWDB hydrological network. WL for non-tidal stations are collected five times daily at 3 hourly intervals during day time from 6:00 AM to 6:00 PM, and for tidal stations collected hourly. Rainfall is collected daily basis at 9 AM. The data collections at FFWC are usually

completed within 9.30 A.M. using mobile sms. Limited WL, rainfall and forecasts of upper catchments from Indian stations are also collected through internet, e-mail, and from BMD.

Essential Information's: Estimation of WL at the model boundaries and rainfall for the catchments are required input to the model upto the time of Forecast (24, 48, 72, 96 & 120hrs). For the rainfall estimation, satellite images from NOAA and IMD is used.

Forecast Calculation: Collected/observed WL and rainfall data are given input to the computer database and checked. The WL and rainfall estimation has to be prepared. During monsoon (June to October) WL of few stations of upper catchments of Ganges, Brahmaputra, Teesta, Dharala and Barak rives has been received since 2010 from Central Water Comission(CWC) India through e-mail. The basis for WL estimation is considering trend Hydrograph extrapolated upto the period of forecast from previous few days data, response characteristics of rivers, effect of rainfall on WL and Indian available WL & forecasts data. Rainfall estimation based on previous 2-day's rainfall and analysis of information collected. After input required data and boundary-estimated data to the model, model run started. It takes about 30 to 40 minutes time to complete the calculations.

Daily forecast bulletin is prepared upto 5 days for important locations and region-wise flood warning messages. The bulletins are disseminated to more than 600 recipients including different ministries, offices (central & district level), individuals, print & electronic news media, development partners, research organizations, NGO's etc. including President's & Prime Minister's Secretariat. Whenever, the forecast river stage cross the DL, the concern field offices and limited key officials are informed through mobile SMS. Interactive Voice Response (IVR) through mobile has been initiated since July 2011 through Teletalk. Now, all the mobile operators have started the IVR since 2015.

The flood forecast is intended to alert the people of the locality about the predicted WL of floodwater 3-days ahead of its occurrence. An accurate forecast would be one where the forecast level and corresponding observed level at the stipulated time are within a small range of variation.

Mode of Dissemination

- E-mail
- Website
- Media, print & electronic
- Telephone, Mobile, Fax
- Hard/print copy
- Lobby display
- (IVR) through mobile (No. 1090)

1.5. NATURE AND CAUSES OF FLOODING

1.5.1. Causative Factors

There are for climatic distinct seasons(i) Winter -December to February (ii) Premonsoon March to May, (iii) Monsoon- June to September (iv) Post monsoon- October to November. Over 80% of the rainfall occurs during the monsoon or rainy season also

known as flood season. The normal annual rainfall of the country varies approximately from 1,200 mm in the west to over 5,000 mm in the east. Long periods of steady rainfall persisting over several days are common during the monsoon, but sometimes local high intensity rainfall of short duration also occurs.

Floods in Bangladesh occur for number of reasons. The main causes are excessive precipitation, low topography and flat slope of the country; but others include:

- *The geographic location and climatic pattern:* Bangladesh is located at the foot of the highest mountain range in the world, the Himalayas, which is also the highest precipitation zone in the world. This rainfall is caused by the influence of the south-west monsoon. Cherapunji, highest rainfall in the world, is located a few kilometers north east of the Bangladesh border.
- *The confluence of three major rivers, the Ganges, the Brahmaputra and the Meghna:* the runoff from their vast catchment (about 1.72 million km^2) passes through a small area, only 7% of these catchments lie within Bangladesh. During the monsoon season the amount of water entering Bangladesh from upstream is greater than the capacity of the rivers to discharge in to the sea.
- *Bangladesh is a land of rivers:* there are about 405 major and minor rivers in the country. The total annual runoff of surface water flowing through the rivers of Bangladesh is about 12,000 billion cubic meters.
- *Man-made environment:* the construction of embankments in the upstream catchments reduces the capacity of the flood plains to store water. The unplanned and unregulated construction of roads and highways in the flood plain without adequate opening creates obstructions to flow.
- *The influence of tides and cyclones*: the frequent development of low pressure areas and spring tide as well as storm surges in the Bay of Bengal can impede drainage. The severity of flooding is greatest when the peak floods of the major rivers coincide with these effects.
- *Long term environmental changes:* climate changes could influence the frequency and magnitude of flooding. A higher sea level will inhibit the drainage from the rivers to the sea and increase the impact of tidal surges. Deforestation in hilly catchments causes more rapid and higher runoff, and hence more intense flooding.

The springtides of the Bay of Bengal retard the drainage of flood water into the sea and locally increase monsoon flooding. A rise of MSL at times during the monsoon period due to effect of monsoon winds also adversely affect the drainage and raise the flood level along the coastal belt.

1.5.2. Statistics of Flooding

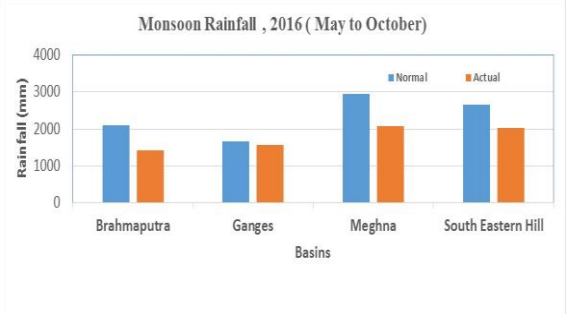
Many parts of the Asia during monsoon frequently suffer from severe floods. Some parts of India and Bangladesh experience floods almost every year with considerable damage. The floods of 1954, 1955, 1974, 1987, 1988, 1998, 2004 and 2007 all caused enormous damages to properties and considerable loss of life. The floods of 1987, 1988 1998, 2004 and 2007 flood caused heavy damage. During the monsoon 2016, the flood was not a

severe one except for the Brahmaputra Basin. Normal flooding condition prevails over the Ganges, the Meghna and South Eastern Hill Basin. During the monsoon-2016 flood affected districts (part of full, on the low-lying areas) are of Kurigram, Lalminiorhat, Gaibandha, Bogra, Rangpur, Serajgonj, Tangail, Jamalpur and Narayangonj, Munshigonj, Madaripur, Sariatpur, Sylhet, Sunamgonj, Netrokona, Sherpur, Moulvi Bazar, Brahmmanbaria, Habigonj. Percent of total area of Bangladesh affected by the flood are available since 1954 is presented in Table 1.1.

Table 1. 1 :Year-wise Flood Affected Area in Bangladesh

Year	Flood Affected area		Year	Flood affected area		Year	Flood affected area	
	Sq-Km	%		Sq-Km	%		Sq-Km	%
1954	36,800	25	1976	28,300	19	**1998**	**1,00,250**	**68**
1955	50,500	34	1977	12,500	8	1999	32,000	22
1956	35,400	24	1978	10,800	7	2000	35,700	24
1960	28,400	19	1980	33,000	22	2001	4,000	2.8
1961	28,800	20	1982	3,140	2	2002	15,000	10
1962	37,200	25	1983	11,100	7.5	2003	21,500	14
1963	43,100	29	1984	28,200	19	2004	55,000	38
1964	31,000	21	1985	11,400	8	2005	17,850	12
1965	28,400	19	1986	6,600	4	2006	16,175	11
1966	33,400	23	1987	57,300	39	**2007**	**62,300**	**42**
1967	25,700	17	**1988**	**89,970**	**61**	2008	33,655	23
1968	37,200	25	1989	6,100	4	2009	28,593	19
1969	41,400	28	1990	3,500	2.4	2010	26,530	18
1970	42,400	29	1991	28,600	19	2011	29,800	20
1971	36,300	25	1992	2,000	1.4	2012	17,700	12
1972	20,800	14	1993	28,742	20	2013	15,650	10.6
1973	29,800	20	1994	419	0.2	2014	36,895	25
1974	52,600	36	1995	32,000	22	2015	47,200	32
1975	16,600	11	1996	35,800	24	2016	48,675	33

CHAPTER 2 : RAINFALL SITUATION



During the monsoon-2016 (May to Oct), the country experienced as a whole 24.43% less rainfall than normal. The Brahmaputra, Ganges , Meghna South Eastern Hill Basin received 32.14%, 6.90 %, 29.48%, 23.81 % less rainfall than the normal value respectively, in the year of 2016. Comparison of the basin and country average of normal and actual rainfall for the monsoon-2016 (May to October) is presented in the bar chart. Considering monthly value, all the basins recorded less rainfall than their respective normal during May-October period except the South-Eastern Hill Region. The. Monthly normal and actual rainfall of all the basins and the country average are shown in Table 2.1.

Table 2.1: Rainfall statistics for the monsoon 2016 over the four Basins

Month	Brahmaputra Basin(mm)		Ganges Basin(mm)		Meghna Basin(mm)		South Eastern Hill Basin(mm)		Monsoon average (mm)	
	Nor	Act	Nor	Act	Nor	Act	Nor	Act	Normal	Actual
May	315.4	238.66	191.8	233.01	491	461.25	290.4	242.44	2342.0	1769.85
June	433.5	288.11	327	215.74	621	402.59	599.8	364.87		
July	496.1	436.60	397.8	466.24	650.5	597.47	728.5	437.74		
Aug	339.7	109.56	337.8	332.96	537.9	233.68	536.9	441.98		
Sept	353.4	245.56	298.7	205.76	449.2	277.54	317.9	302.28		
Oct	155.6	102.44	120.1	103.91	194.7	103.82	183.4	235.23		
Total	2094	1420.93	1673.2	1557.62	2944.3	2076.32	2656.9	2024.54		
%More / Less	32.14% less		6.90% less		29.48% less		23.81% Less		24.43% less	

Rainfall situation of the country for the monsoon-2016 (May to October) is described in the following sections.

2.1 MAY

The country, as a whole, experienced rainfall less than normal during the month of May 2016. All four basins, namely the Brahmaputra, the Ganges, the Meghna and the South-Eastern Hill Basin received 28.52%, 51.91%, 9.16% and 77.28% less rainfall than their monthly normal rainfall respectively. The summery of rainfall situation of the country during May 2016 is shown in the Table 2.2.

Important Rainfall Information for May 2016

Monthly Maximum at Kanaighat 753 mm

1 day maximum at Sherpur: 275.0 mm

10 day maximum at Sherpur: 557.0 mm

Table 2. 2 : **Summary of the rainfall situation during the month of May 2016**

Basin:	**Brahmaputra**	**Ganges**	**Meghna**	**South Eastern Hill**
No of Stations:	13	18	17	11
Average Rainfall (mm) of the basin:	238.65	233.01	461.25	242.44
%More(+)/Less(-) than the Normal	-23.52%	23.00%	1.72%	-11.91%
Number of Stations above Normal Rainfall	4	11	8	5
Highest 1-day Maximum Rainfall with Stations	Serajganj	Patuakhali	Sherpur	Cox's Bazar
	125.3 mm	189.2 mm	275 mm	103.6 mm
Number of Rain Fed Flood* Stations	0	1	8	1

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

In Brahmaputra basin, out of 13 rainfall monitoring stations, all the stations except Kurigram, Rangpur, Dalia, Sirajganj received less rainfall than their normal. The Basin received 23.52% less rainfall than their normal during the month May 2016 (Table-2.2).

In Ganges basin, out of 18 rainfall monitoring stations and 11 stations which are Panchagarh, Rajshahi, Rohanpur, Bhagyakul, Jessore, Khulna, Satkhira, Madaripur, Barisal, Patuakhali, Barguna received above rainfall than their normal value during the month of May in 2016. The basin as a whole received 23% more rainfall than the normal during the month of May-2016 (Table-2.2).

In the Meghna basin, out of 17 rainfall monitoring stations and half of the monitoring stations received above normal rainfall. The stations received above normal rainfall are Kanaighat, Sylhet, Sheola, Moulvi Bazar, Sherpur, Jariajanjail, Comilla and Chadpur. The Basin received only 1.72% more rainfall than their monthly normal during the month of May in 2016 (Table-2.2).

In the South Eastern Hill basin, out of 11 rainfall monitoring stations, except Noakhali, Lama, Ramgarh , Cox's Bazar and Teknaf received less rainfall than their normal value of the month. The Basin received 11.91% less rainfall than their monthly normal in may 2016.

Summary of the rainfall situation of the country is presented in Table 2.2. Considering 10-day maximum rainfall of 300 mm as a rain-fed flood index, as many as 8 stations were crossed the threshold value in this month in Meghna Basin. Those stations are Kanaighat, Sylhet, Sheola, Sunamganj, Sherpur, Moulvibazar, Comilla and Chandpur.

The Isohyets of the actual rainfall of the month of May-2016 is shown in the Figures 2.1.

2.2 JUNE

Important Rainfall Information for June, 2016

Maximum, at Sunamganj : 1176 mm

1 day maximum, Kurigram : 299 mm

10 day maximum at Lorergarh: 662 mm

The country, as a whole, recorded less rainfall than normal during the month of June-2016. the Brahmaputra basin, the Ganges basin the Meghna basin and the South Eastern Hill basins received 32.23%, 30.18%, 48.50%, and 36.04% less rainfall than their respective monthly normal rainfall in the month of June 2016. The summery of the rainfall situation for June 2016 is shown in the Table 2.3.

Table 2. 3: Summary of the rainfall situation during the month of June 2016

Basin:	Brahmaputra	Ganges	Meghna	South Eastern Hill
No of Stations:	13	18	17	11
Average Rainfall (mm) of the basin:	288.16	221.98	402.59	364.87
%More(+)/Less(-) than the Normal:	-32.23%	-30.18%	-48.50%	-36.04%
Number of Stations above Normal Rainfall:	02	02	02	02
Highest 1-day Maximum Rainfall with Stations:	**Kurigram 299mm**	**Barisal 155 mm**	**Lorergarh 175 mm**	**Teknaf 253 mm**
Number of Rain Fed Flood* Stations:	04	02	05	04

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

In Brahmaputra basin, out of 13 rainfall monitoring stations, 2 stations were recorded more rainfall than the monthly normal. The Basin received 8.65% more rainfall than their normal during the month of June 2016. Kurigram received one day highest rainfall which is 299 mm in June.

2 out of 18 monitoring stations in the Ganges Basin were recorded rainfall above their monthly normal. One-day maximum rainfall of 155 mm was recorded at Barisal. Ten days consecutive maximum rainfall of 359 mm was recorded at Panchagarh and 301 mm in Barguna. The Basin received 30.18% less rainfall than their monthly normal rainfall during the month of June 2016.

In the Meghna basin, out of 16 rainfall monitoring stations, 2 stations were recorded more rainfall than the normal. One-day maximum of 175 mm at Lorergarh and the 10-day consecutive maximum rainfall of 846 mm at Sunamganj was recorded in the month of June 2016. The Meghna basin as a whole received 48.5% less rainfall than the normal rainfall during the month of June-2016.

In the South-Eastern Hill basin, all rainfall monitoring stations received less rainfall than their normal rainfall for the month of June-2016 except Bandarban and Teknaf. One day maximum of 253 mm was recorded at Teknaf and the 10-day consecutive maximum rainfall was recorded at Lama (578.7 mm), Teknaf (531.6mm) and Bandarban(314.4mm).

The basin as a whole recorded 36.04% less rainfall than the normal rainfall during the month of June 2016.

Summary of the rainfall situation of the country is presented in the Table 2.3. Total 10 stations in the country recorded 10-day consecutive rainfall more than 300mm. The maximum 1-day rainfall of 420 mm and the 10-day consecutive maximum rainfall of 578.7 mm was recorded at Lama.

The Isohyets of the actual rainfall of the month of June-2016 are shown in the Figure 2.2.

2.3 JULY

Important Rainfall Information for July 2016
Monthly Maximum at Lorergarh: 1519.0 mm
1 day maximum at Loregarh: 175.0 mm
10 day maximum at Lorergarh: 825 mm

The country, as a whole, experienced rainfall less than normal during the month of July 2016. Only the Ganges Basin received excess rainfall. The Brahmaputra, Meghna, South Eastern Hill basins received 9.97%, 7.71%, and 5.82% less rainfall while the Ganges basin received 16.16% more rainfall than monthly normal value. The summery of the rainfall situation of the country during the month of July 2016 is shown in the Table 2.4.

Table 2.4: Summary of the rainfall situation during the month of July 2016

Basin:	Brahmaputra	Ganges	Meghna	South Eastern Hill
No of Stations:	13	18	17	12
%More(+)/Less(-) than the Normal:	**-9.97%**	**+16.16%**	**-7.71%**	**-5.82%**
Number of Stations above Normal Rainfall:	3	13	6	3
Highest 1-day Maximum Rainfall with Stations:	Rangpur 125 mm	Barguna 135.05 mm	Loregarh 175 mm	Narayanhat 155.5 mm
Number of Rain Fed Flood* Stations:	3	3	8	8

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

In Brahmaputra basin, most of the stations received less rainfall than their normal rainfall except Dhaka, Gaibandha and Rangpur station. The Basin received 9.97% less rainfall than their normal during the month of July 2016. Monthly 1-day maximum rainfall of 125 mm and 10-day max of 398 mm was recorded at Rangpur.

In Ganges basin, 13 of 18 stations received more rainfall than their normal. The basin as a whole received 16.16% more rainfall than its normal during the month of July in 2016. One day maximum rainfall of 135.05 mm at Barguna and 10-day consecutive maximum rainfall of 465.21 mm was recorded at Barguna.

In Meghna basin, 7 stations were recorded more rainfall than their normal value of the month. The Basin recorded 7.71% less rainfall than their normal during the month of July in 2016. One day maximum rainfall of 175 mm and 10-day consecutive maximum rainfall of 825 mm were recorded at Lorergarh.

In South Eastern Hill basin, only 8 stations received more rainfall than their normal rainfall. The basin as a whole received 5.82% less rainfall than its normal rainfall during the month of July 2016. One day maximum rainfall of 163 mm and 10-day consecutive maximum rainfall of 720 mm was recorded at Cox's Bazar. This rainfall caused water logging and local flood at the area.

Summary of the country's rainfall situation is presented in Table 2.4 . Total 22 out of 59 stations recorded more than 300 mm rainfall for 10-day consecutive maximum rainfall. Maximum 10-day rainfall recorded at Teknaf of 615.8 mm. 1-day maximum rainfall recorded 175 mm in Lorergarh.
A map with isohyets of the actual rainfall of July-2016 is shown in the Figure 2.3.

2.4 AUGUST

Important Rainfall Information for August 2016
Maximum at Jessore :705.7 mm
One day maximum at Jessore : 265.0 mm
10-day maximum at Teknaf : 673.9 mm

The intensity of rainfall in the Brahmaputra, the Meghna and the South Eastern Hill basin was moderately low at most of the places during the month of August 2016. The three hydrological basins Brahmaputra, Meghna and South Eastern Hill basins received less rainfall than their respective monthly normal rainfall in the month of August. The Brahmaputra, the Meghna and the South Eastern Hill basin received 67.74%, 54.90%, 14.29% less rainfall and the Ganges basin received 6.16% more rainfall than their respective normal rainfall of the month. Table 2.5 represents the summary of rainfall situation all through the country.

Table 2.5: Summary of the rainfall situation during the month of August 2016

Basin	Brahmaputra	Ganges	Meghna	South Eastern Hill
No of Stations:	13	18	17	11
Basin average rainfall at August, 2016(mm):	109.56	332.96	233.68	441.98
%More(+)/Less(-) than Normal:	-67.74%	6.16%	-54.90%	-14.29%
No. of Stations above Normal Rainfall:	-	9	1	3
Highest 1-day Maximum Rainfall Stations:	Tangail	Jessore	Chandpur	Teknaf
	(120 mm)	(265 mm)	(169 mm)	(219 mm)
No of Rain Fed Flood* Stations:	-	5	1	1

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

The above table shows that all the rainfall monitoring stations in the Brahmaputra basin received monthly rainfall below their respective monthly normal rainfall; 9 out of 18 rainfall stations in the Ganges basin; 1 out of 16 rainfall stations in the Meghna basin and

3 out 12 stations in South Eastern Hill the basin received more rainfall than their monthly normal rainfall. Among all monitoring stations, Jessore in the Ganges Basin is the daily highest rainfall recorded station.

The Isohyets of the actual rainfall of the month of August-2016 is shown in the Figure 2.4.

2.5 SEPTEMBER

The country, as a whole, experienced less rainfall than normal during the month of September.

Important Rainfall Information for September 2016

Maximum at Lorergarh : 718 mm

1-day maximum at Lorergarh : 260 mm

10-day maximum at Lorergarh : 558 mm

Among the four hydrological basins, the Brahmaputra, the Ganges and the Meghna basin received 30.51 %, 25.08% and 47.74% less rainfall and the South Eastern Hill Basin received 13.37% less rainfall in the month of September 2016. Table 2.6 represents the summary of rainfall situation all through the country.

Table 2.6: Summary of the rainfall situation during the month of September 2016

Basin	Brahmaputra	Ganges	Meghna	South Eastern Hill
No of Stations:	13	18	17	11
Basin average rainfall at September,2016(mm):	245.56	205.76	277.54	302.28
%More(+)/Less(-) than Normal:	-30.51%	-25.08%	-47.74%	-13.37%
No. of Stations above Normal Rainfall:	1	5	2	4
Highest 1-day Maximum Rainfall Stations:	Serajganj (79.5mm)	Barisal (135mm)	Lorergarh (260 mm)	Chittagong (118 mm)
No of Rain Fed Flood*Stations:	0	1	1	1

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

The above table shows that 1 out of 13 stations in the Brahmaputra, 5 out of 18 stations in the Ganges basin, 2 out of 16 stations in the Meghna and 4 out of 11 stations in South Eastern Hill the basin received more rainfall than their monthly normal rainfall. Among all monitoring stations, Lorergarh in the Meghna basin is the daily highest (260mm) rainfall recipient station.

The table also shows that one station in the Ganegs, Meghna, SouthEastern Hill basin received more than 300 mm rainfall in 10-day period.

The Isohyets of actual rainfall for September-2016 is shown in the Figure 2.5.

2.6 OCTOBER

The country, as a whole, also received rainfall less than normal during the month of October 2016. The Brahmaputra, the Ganges and the Meghna basin received 22.07%, 18.76%, 40.22% less rainfall while South Eastern Hill Basin received 36.55% more rainfall than their monthly normal rainfall respectively.

Important Rainfall Information for October 2016

Monthly Maximum at Cox's Bazar:- 513 mm

1 day maximum at Bogra: 176 mm

10 day maximum at Cox's Bazar: 496 mm

Table 2.7: Summary of Rainfall for the month of October-2016

Basin:	Brahmaputra	Ganges	Meghna	South Eastern Hill
No of Stations:	13	18	17	12
Average Rainfall (mm) of the basin:	120.42	103.91	103.82	235.23
%More(+)/Less(-) than the Normal:	-22.07 % less	-18.76 % less	-40.22 % less	+36.55 % more
Number of Stations above Normal Rainfall:	04	06	02	08
Highest 1-day Maximum Rainfall with Stations:	Bogra 176 mm	Satkhira 85.5 mm	Durgapur 105 mm	Cox's Bazar 171 mm
Number of Rain Fed Flood* Stations:	0	0	0	2

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

In Brahmaputra basin, out of 13 rainfall monitoring stations, 4 stations recorded more rainfall than the normal and the basin received 22.07% less rainfall than their normal during the month of October in 2016. Highest 1day maximum rainfall of 176 mm was recorded at Bogra.

In Ganges basin, out of 18 rainfall monitoring stations, 6 stations recorded less rainfall than the normal rainfall in October. The basin as a whole received 18.76% less rainfall than the normal in the same period.

In the Meghna basin, out of 17 rainfall monitoring stations, 2 stations were recorded more rainfall than the normal value of the month. The Basin received 40.22% less rainfall than their monthly normal during the month of October 2016.

In the South-Eastern Hill basin, monitoring stations Bandarban, Lama, Swandip, Cox's Bazar, Teknaf, Noakhali, Parsuram,Noakhali received more rainfall than their normal rainfall. The Basin as a whole recorded 36.55% more rainfall than the normal rainfall during the month October 2016.

A map with the Isohyets of actual rainfall for the month of October-2016 is shown in the Figure 2.6.

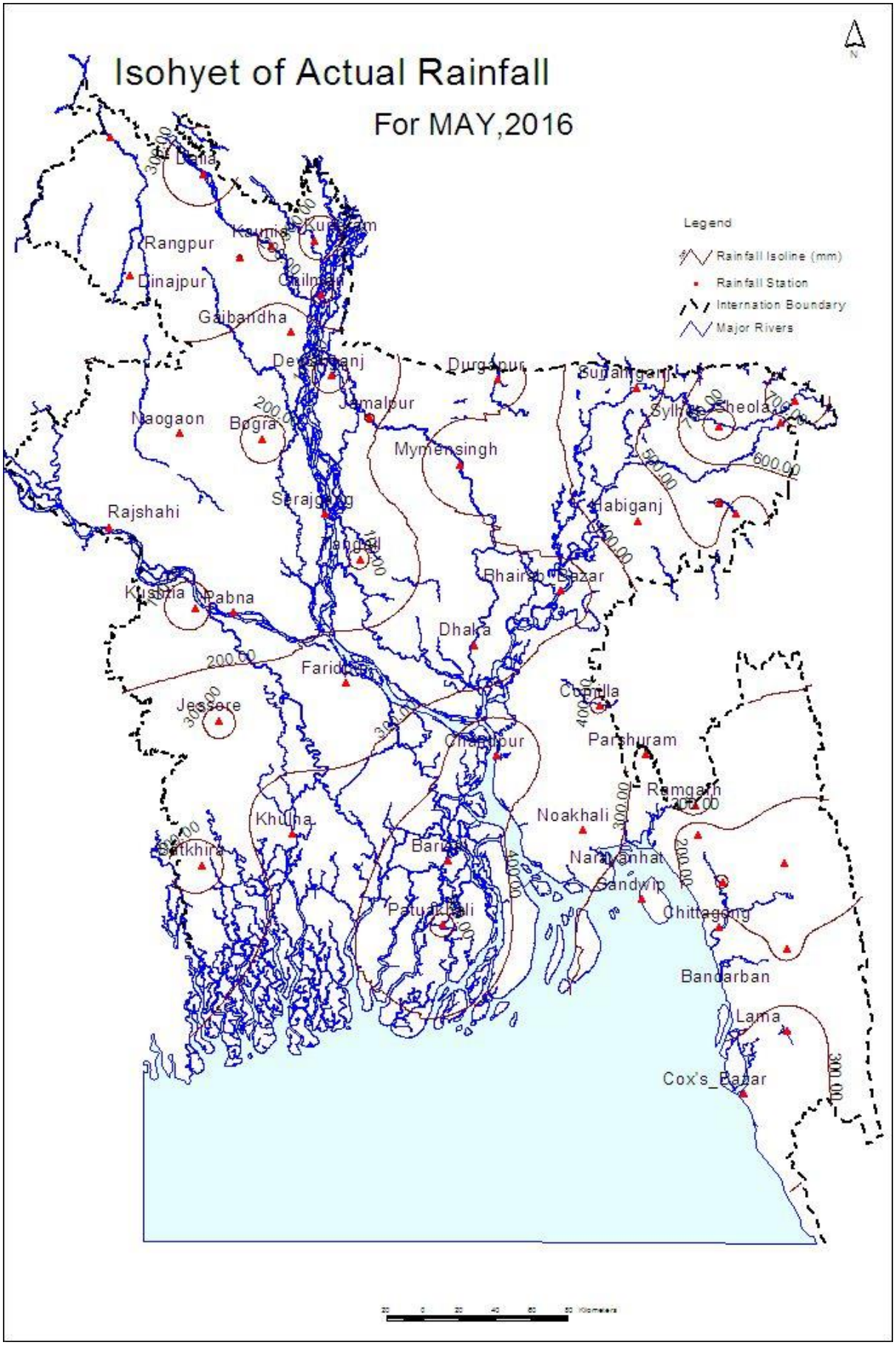


Figure 2.1 : Isohyets of Actual Rainfall (May 2016)

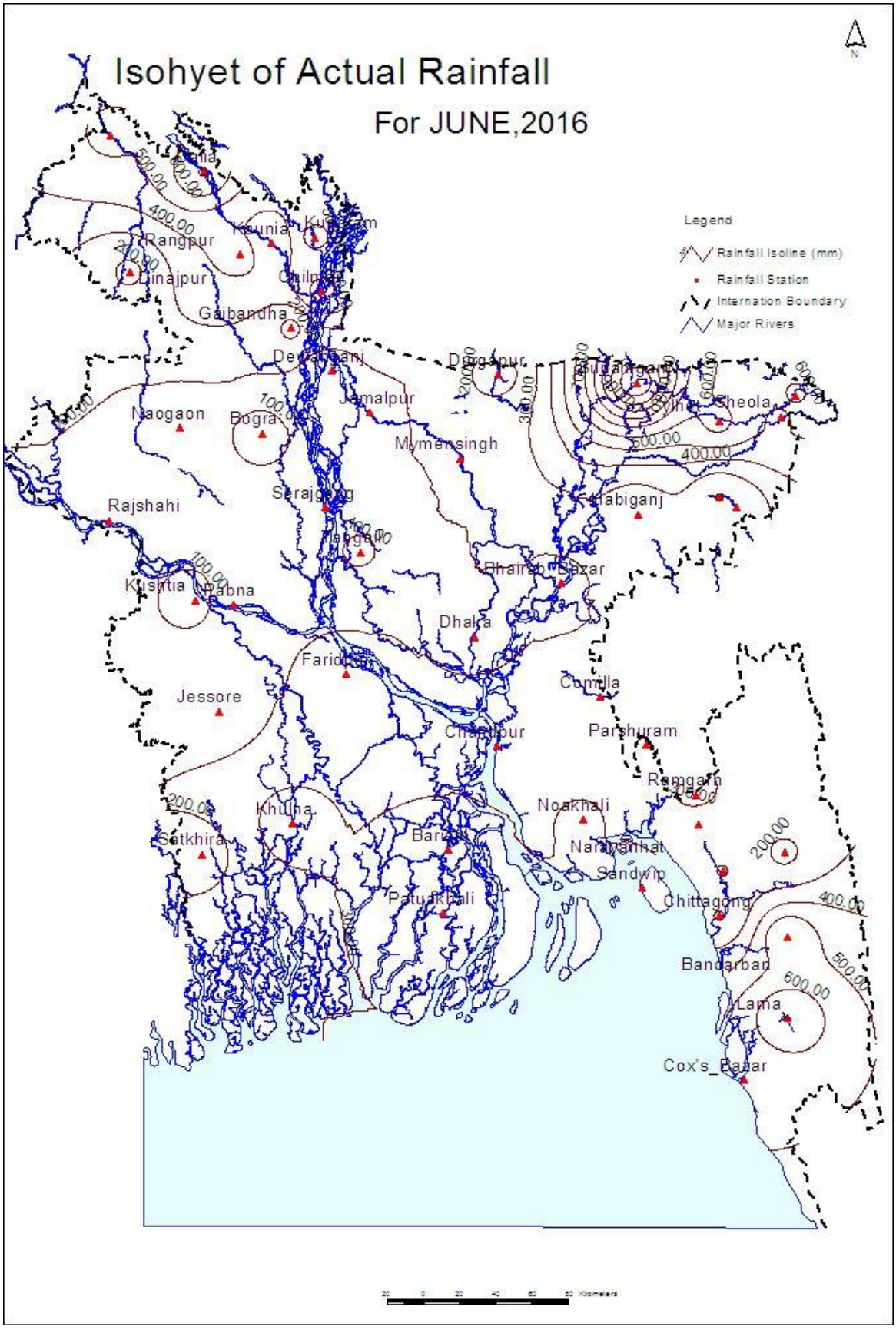


Figure 2.2 : Isohyets of Actual Rainfall (June 2016)

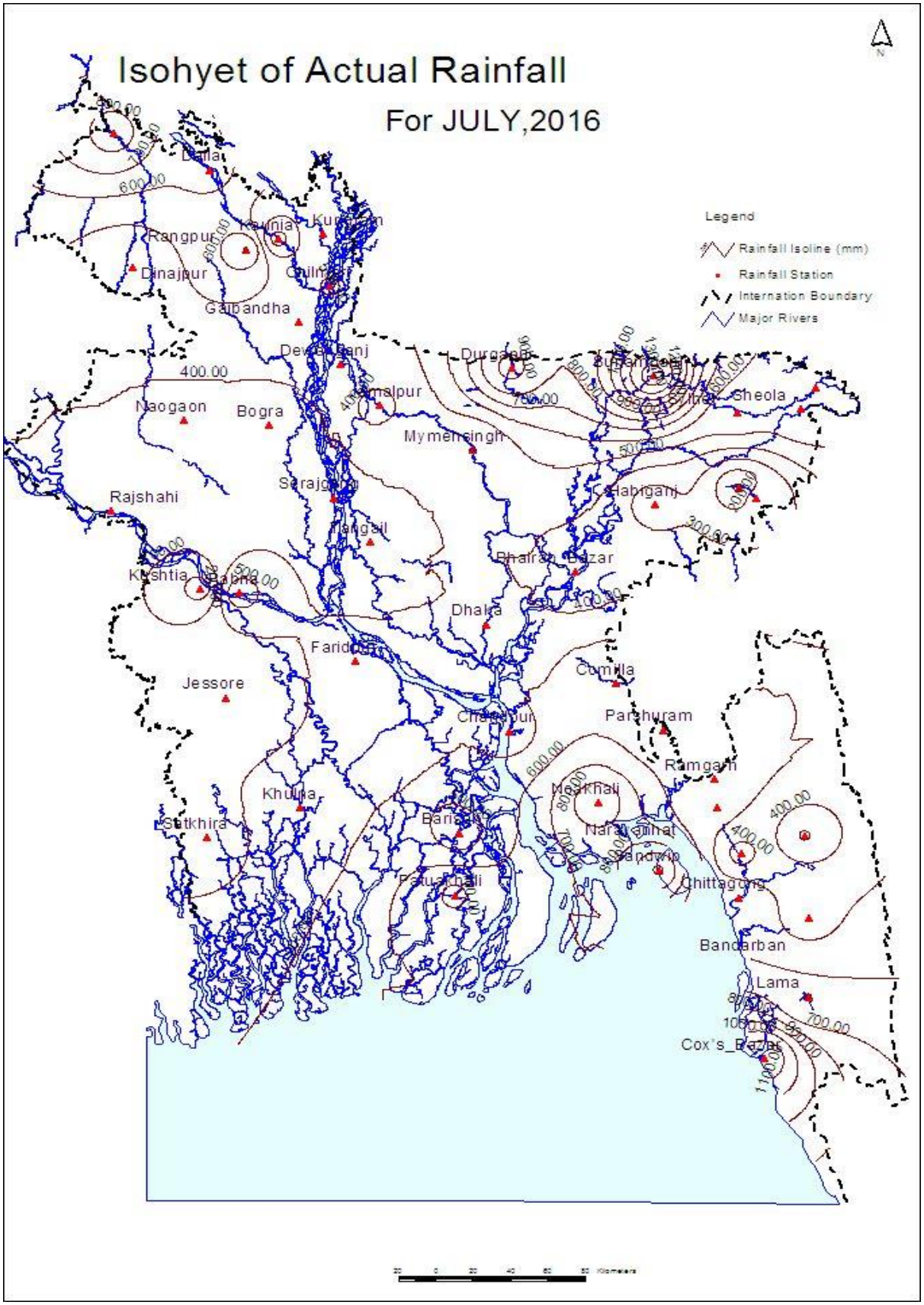


Figure 2.3 : Isohyets of Actual Rainfall (July 2016)

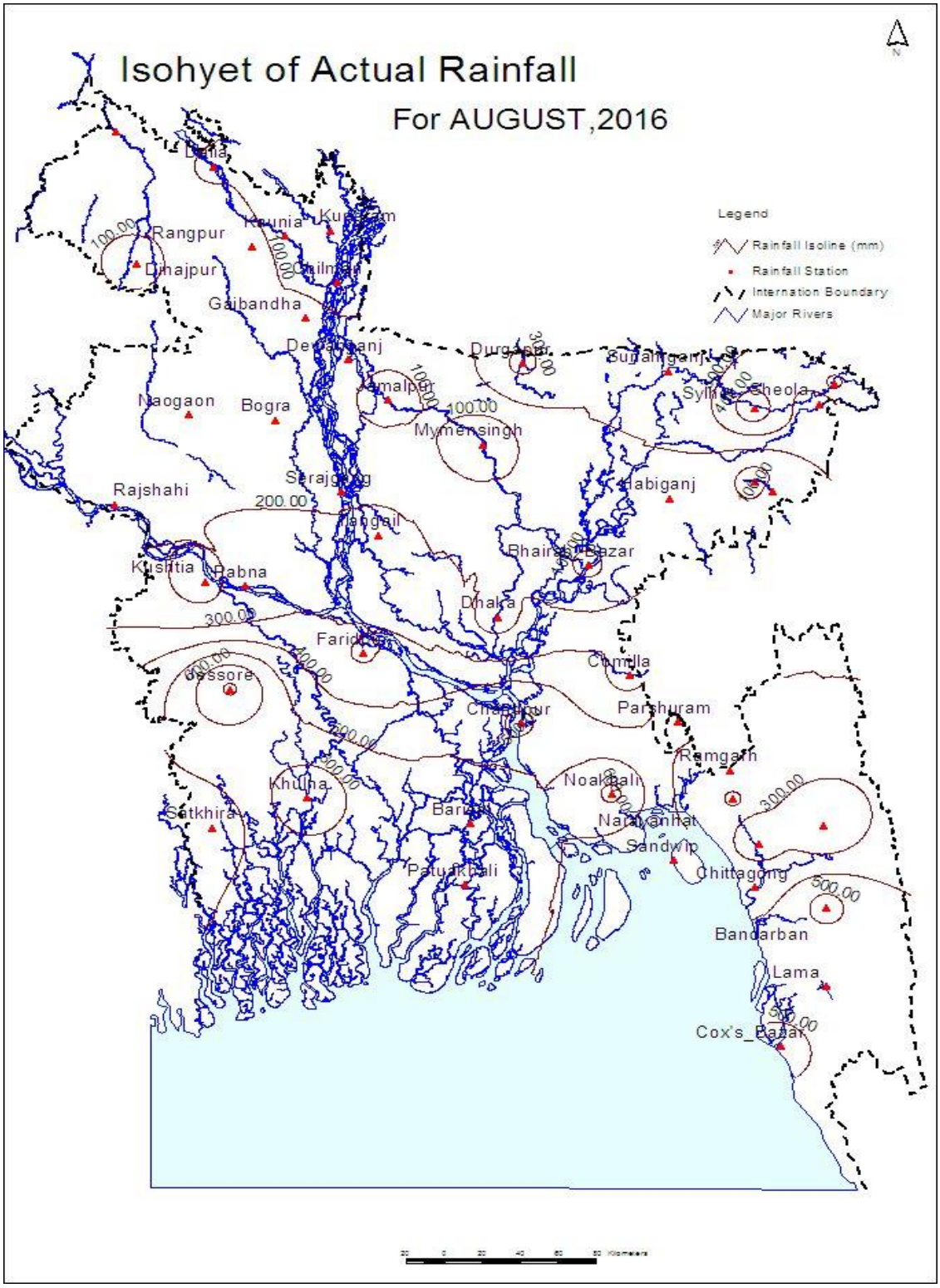


Figure 2.4 : Isohyets of Actual Rainfall (August 2016)

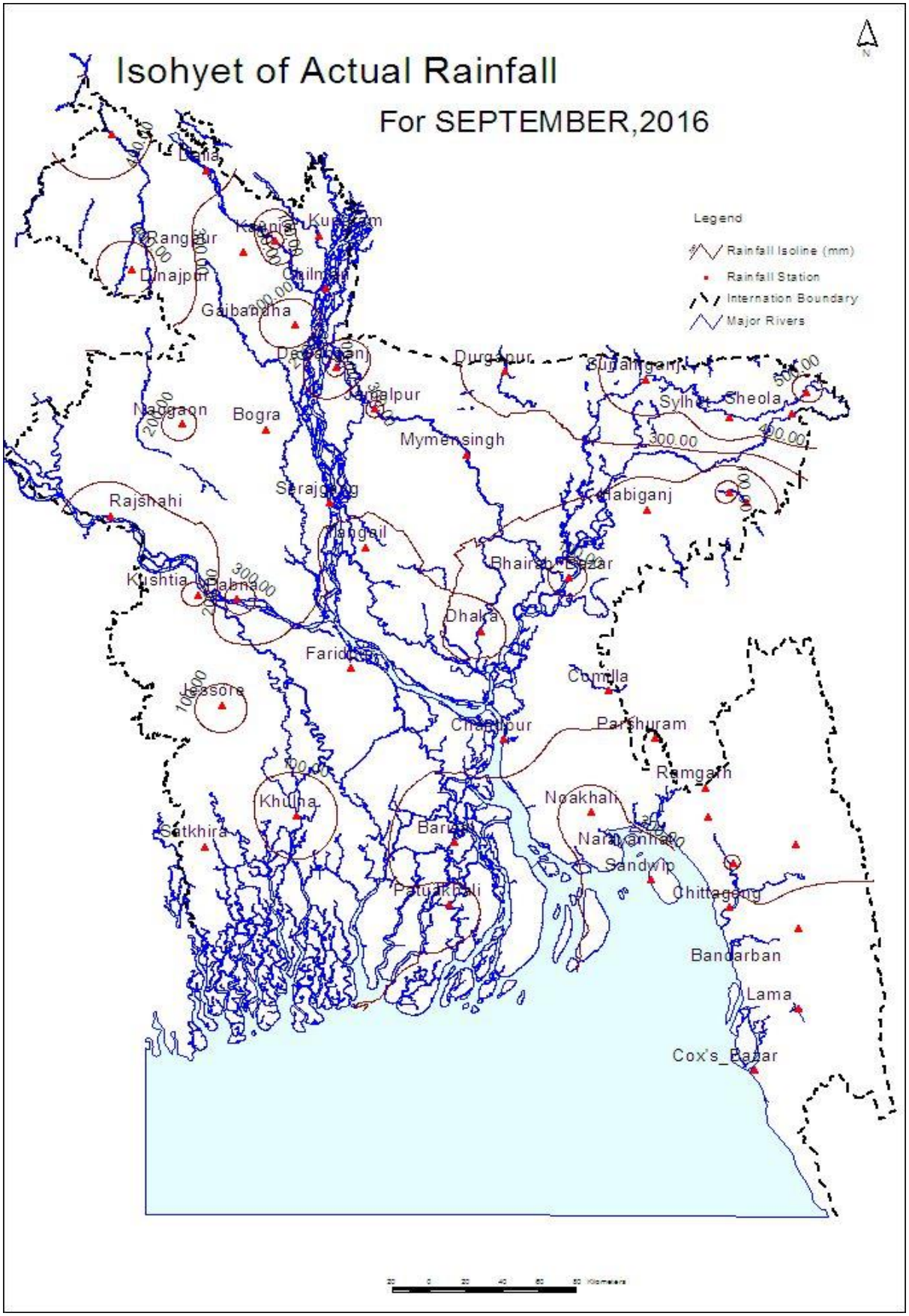


Figure 2.5 : Isohyets of Actual Rainfall (September 2016)

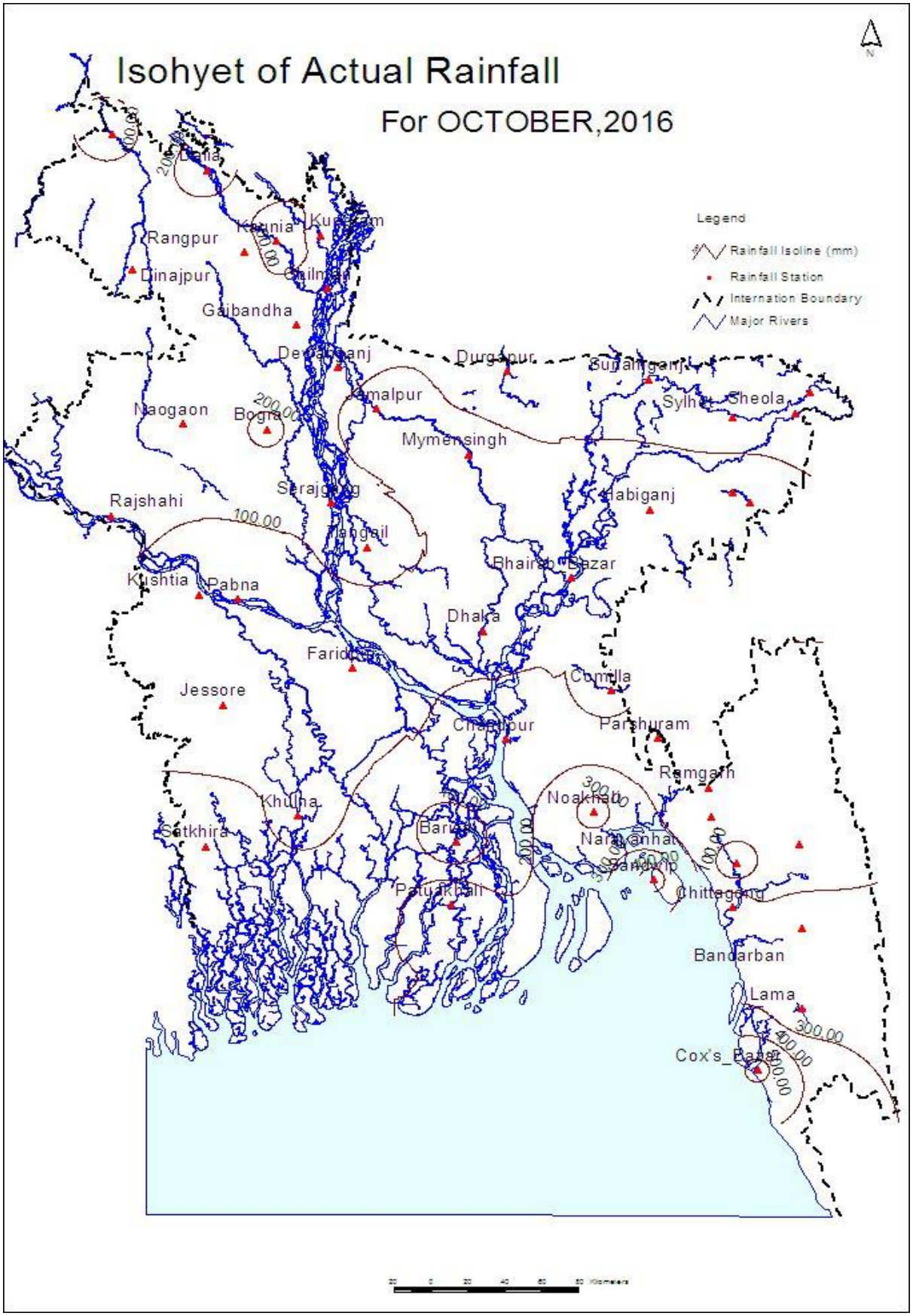


Figure 2.6 : Isohyets of Actual Rainfall (October 2016)

CHAPTER 3: RIVER SITUATION

During the monsoon 2016, the flood was a moderate flooding year and stayed for medium duration in all the four basins, the Brahmaputra, the Ganges, the Meghna and South Eastern Hill Basin. The Brahmaputra and Meghna Basin first experienced the monsoon flood from the third week of July 2016. The upper portion of Ganges Basin was recorded rise of water level in mid of August. Basin wise WL situation is described in the following sections.

3.1 THE BRAHMAPUTRA BASIN

Out of 30 Water Level (WL) monitoring stations in this basin, at 9 stations river WL was crossed their respective Danger Levels (DL). Water Level of Brhamaputra Basin started to rise from the second week of June 2016 for the first time in the monsoon and caused a medium duration of flood for this basin. In this monsoon Brahmaputra basin had experienced several peaks with one highest peak, which caused flood in the northern part country in 2016. This flood situation lasted 2 to 23 days for the basin. As a result, low-lying areas of Kurigram, Lalminiorhat, Gaibandha, Bogra, Rangpur, Serajgonj, Jamalpur and Narayanganj districts were flooded for short to medium period of flooding. A comparative statement of WL for current year 2016 and historical events of 1988 and 1998 for the Brahmaputra Basin is shown in the Table 3.1. The details of the river situation in this basin are described in the following sections:

The Dharla at Kurigram

The WL of Dharla river at Kurigram registered its monsoon peak during the monsoon 2016, in 3rd week of July. It crossed the DL three times during the monsoon 2016 at the last week of June and then again 3rd week of July and 1st of August and flowed above DL for total 16 days. WL at Kurigram attained peak of 27.56 mPWD on 27 July which was 49 cm above the DL (26.50 m).

The Teesta at Dalia and Kaunia

The Teesta river is flashy in nature. The WL of river Teesta showed several peaks during the monsoon both at Dalia and Kaunia. At Dalia, WL crossed its DL mark for 5 times during the monsoon (June and July), highest peak on 2nd July with peak of 52.89 mPWD, which was 49cm above its DL (52.40m). At Dalia, it flowed above DL for 8 days throughout the monsoon period. At Kaunia, WL of the river Teesta did not cross the DL during the mosoon-2016, attained the peak of 28.90 m on 3rd week of July which was 110 cm below the DL(30.0m) at this point.

The Jamuneswari at Badargonj

The Jamuneswari at Badargonj did not crossed the DL in 2016 monsoon and attained the peak of 30.40 mPWD (DL 32.16m) on 21st July. During the whole monsoon this station was recorded with small peaks.

The Ghagot at Gaibandha

The WL of Ghagot river at Gaibandha did not crossed DL (21.70m) during the monsoon 2016. It attained peak water level 22.61 m which was 9 cm below DL (21.70m)

The Korotoa at Chakrahimpur and Bogra

The WL of Korotoa river at Gaibandha and Bogra stations did not crossed DL during the monsoon 2016. At Chakrahim, the korotoa reached peak water level 19.55m and flowed 60cm below its DL(20.15m). At Bogra point the Korotoa river also did not cross its DL and attained a peak level of 14.09m on 13th October which was 223cm below the DL(16.32mPWD).

The Brahmaputra at Noonkhawa and Chilmari

The river Brahmaputra at Noonkhawa and Chilmari observed rise and fall at several times. At Noonkhawa, WL of the Brhamaputra river attained the peak of 27.31mPWD on 28th July, which was 6cm above the DL (27.25m) at this point. Water level flowed above danger level for 2 days.

Brahmaputra at Chilmari flowed above its DL for 21 days from end of first week of July 2016 (7th July) to end of 2nd week of July (13th July) & it also crossed the danger level again from middle of 3rd week of July (18th July) to last week of the month (31st July). It recorded its monthly highest peak water level of 24.99 m which was 54cm above its DL (24.45m). Brahmaputra at Chilmari flowed above its DL for 23 days in 2016 monsoon.

The Jamuna at Bahadurabad, Sariakandi, Serajgonj and Aricha

The WL of river Jamuna at Bahadurabad, Sariakandi, Serajgonj & Aricha demonstrated similar trend like Brahmaputra at Noonkhawa and Chilmari. At Bahadurabad the Jamuna flowed above DL for 17 days with the peak of 20.71mPWD on 29th July, which is 121cm above the DL(19.50m) at this point. At this point Jamuna crossed its DL on 8th July for two days, then again crossed the DL on 21st July and continued till 4th August, 2016. Water Level of Jamuna at Bahadurabad also showed slight rise end of September but it did not crossed DL. Sariakandi the Jamuna crossed the respective DL twice in this monsoon like Bahadubad station. At first, it crossed the DL on 9th July and flowed for 2 days till 10th July. Again, it crossed DL on 22nd July and flowed above the DL for 15 days till 5th August. It flowed above DL for total 17 days, with a peak of 17.69mPWD on 29th July which was 99 cm above the DL (16.70 m). At Serajgonj the Jamuna flowed above DL from 24th July to 4th August for 12 days with peak of 14.24mPWD, on 29th July, which is 89cm above the DL (13.35m).

At Aricha the WL of the Jamuna river crossed the DL on 26th July and reached peak WL of 9.97mPWD on 30th July, which was 57cm above the DL (9.40m) and remained above DL for 10 days from 26th July to 4th August.

The Gur at Singra

The WL of river Atrai at Baghabari flowed above DL for 11 days from 25th July to 04th August 2016, with the peak of 12.83mPWD on 30th July, which is 18cm above the DL(12.65m) at this point.

The Atrai at Baghabari

The WL of river Atrai at Baghabari flowed above DL for18 days, 24th July and 8th July and from 21st 2016, with the peak of 11.49mPWD on 31st July, which is 109cm above the DL(10.40m) at this point.

The Dhaleswari at Elashin

The WL of river Dhaleswari at Elashin flowed above DL for 35 days starting from 9th July to 13th August 2016, with the peak of 12.80mPWD on 31th July, which is 140cm above the DL (11.40m) at this point.

The Old Brahmaputra at Jamalpur and Mymensingh

The WL of the Old Brahmaputra river at Jamalpur and Mymensingh showed rise and fall during the monsoon, but remained below the respective DLs at both the stations. At Jamalpur, the peak WL recorded of 16.76mPWD on 1st August which is 24cm below the DL at this point (DL 17.0m). At Mymensingh the peak WL recorded was 11.66mPWD on 04th August, which was 84cm below the DL (12.5m) at this point.

The Lakhya at Lakhpur and Narayanganj

The Lakhya river at Lakhpur crossed during August 2016. It attained its monsoon peak of 5.70mPWD 6th August, which is 10cm below the DL (DL 5.8m). Lakhya River at Narayanganj crossed its respective DL at 30th July 18:00 hours and continued to flow above DL up to 8th August for 9 days. It attained its monsoon peak of 5.82mPWD 4th August, which 32cm above the DL (DL 5.5m).

The Rivers around Dhaka

Stations near or around Dhaka city like Buriganga at Dhaka and the Turag at Mirpur attained the peak of the monsoon during the August in this year. All the rivers around Dhaka city flowed below their respective DLs. The Buriganga at Dhaka, and the Balu at Demra recoded their highest peak of 5.21 mPWD (DL 6.0m) on 4th August, 5.64m (DL 5.75m) on 5th August 2016 respectively. The Turag at Mirpur aslo did not cross its respective DL and flowed with a peak of 5.82 mPWD which is 12 cm below the DL (5.94 mPWD).

The Kaliganga at Taraghat

The WL of Kaliganga river at Taraghat showed a trend similar to that of the Buriganga at Dhaka. The river at this station crossed the DL at 29th July and continued to flow above DL up to 10th August for 13 days with peak of 9.44 mPWD on 10th August, which was 106 cm above its DL(8.38 m) at Taraghat.

Comparative hydrographs for the year of 2016, 2007 & 2004 of few stations of the Brahmaputra basin are shown in Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, 3.12 and 3.13.

Table 3. 1 : Comparison of Water Level of 2016 and Historical Events of 1988 & 1998 of Some Important Stations in the Brahmaputra Basin.

Sl. No	River	Station	Recorded Maximum (m)	Danger Level (m)	Peak of the year (m)			Days above Danger level		
					2016	1998	1988	2016	98	88
1	Dharla	Kurigram	27.66	26.50	27.56	27.22	27.25	16	30	16
2	Teesta	Dalia	52.97	52.40	52.65	52.20	52.89	8	-	8
3	Teesta	Kaunia	30.52	30.00	28.98	29.91	30.43	2	-	38
4	Jamuneswari	Badargonj	33.00	32.16	30.40	33.00	32.80	-	6	5
5	Brahmaputra	Noonkhawa	28.10	27.25	27.31	27.35	NA	2	-	NA
6	Brahmaputra	Chilmari	25.06	24.00	24.99	24.77	25.04	23	22	15
7	Ghagot	Gaibandha	22.81	21.70	22.61	22.30	22.20		51	17
8	Jamuna	Bahadurabad	20.62	19.50	20.71	20.37	20.62	17	66	27
9	Jamuna	Serajgonj	15.12	13.35	14.24	14.76	15.12	12	48	44
10	Jamuna	Aricha	10.76	9.40	9.97	10.76	10.58	10	68	31
11	Old Brahmaputra	Jamalpur	18.00	17.00	16.76	17.47	17.83	-	31	8
12	Old Brahmaputra	Mymensingh	14.02	12.50	11.66	13.04	13.69	-	33	10
13	Buriganga	Dhaka	7.58	6.00	5.21	7.24	7.58	-	57	23
14	Lakhya	Narayangonj	6.71	5.50	5.82	6.93	6.71	12	71	36
15	Turag	Mirpur	8.35	5.94	5.89	7.97	NA	-	70	NA
16	Tongi Khal	Tongi	7.84	6.08	5.84	7.54	NA	-	66	NA

3.2 THE GANGES BASIN

In this basin out of 25 WL monitoring stations, 4 stations exceeded their respective DLs, during the monsoon 2016. The rivers flowed above DL are Padma at Goalondo for 17 days, at Bhagyakul for 17 days and at Sureswar for 22 days and the Kobadak River at Jhikargacha for 22 days. Some places of low lying areas of Rajbari, Faridpur, Munshigonj, Sariatpur districts were affected by normal flooding during the end of July and first week of August for short period. A comparative statement of WL for 2016 and historical events of 1998 & 1988 for the Ganges Basin is shown in the Table 3.2. The details of the river WL situation in this basin are described below:

The Karatoa at Panchagarh

The karatoa river at Panchgarh showed a sharp rise and fall during the monsoon and didn't cross the DL. It attained the peak WL 69.81 mPWD at 25th July, which was 94 cm below the respective DL (70.75 m)

The Punarbhaba at Dinajpur

The WL of river Punarbhaba at Dinajpur showed rise and fall during the monsoon, but flowed well below the DL during the flood season of 2016. The peak WL of 30.28mPWD was recorded on 27th July, which was 322cm below of its DL (33.50m).

The Tangon at Thakurgaon

The Tangon river is flashy in nature and showed various small peaks during the monsoon but did not crossed its respective DL. The highest peak was 50.10mPWD on 25th June , which was 30 cm below the Danger level (50.40 m).

The Upper Atrai at Bhusirbandar and Atrai at Modevpur

The WL of river Upper Atrai at Bhusirbandar also showed similar trend of Punarbhaba, and did not cross the DL. It had a peak value of WL 39.37mPWD on 38.67th July, which was 95cm below the DL(39.62m). The Atrai at Mohadevpur also flowed below the DL with peak of 17.26mPWD on 28th July, which is 133cm below the DL(18.59m).

The Mohananda at Chapai-Nawabgonj

This river showed a gradual rise and fall in water level throughout the monsoon and did not cross the DL. The water level of Mahanada rose It attained its peak of 20.90m on 29th July, which was 10cm below its DL (DL21.00m) at Chapai-Nawabgonj.

The Little Jamuna at Naogaon

The Little Jamuna river at Nagon did not cross its danger level and it attained monsoon peak 14.63mPWD on 24th July, which was 61 cm below the Danger level (15.24 m).

The Ganges/Padma at Pankha, Rajshahi and at Hardinge Bridge

The Ganges River at Pankha showed a gradual rise in July as well as in mid of August to the end of August 2016 but did not cross the respective DL. At Pankha the peak of 22.44mPWD was recorded during the day of 28th August, which was only 6 cm below the DL (22.50m) at this point. At Rajshahi, the Ganges showed nearly similar trend as at Pankha and also flowed below its respective DL. It attained its peak of 18.46mPWD on 28th August, which was just 4cm below its DL (DL18.50m) at Rajshahi. At Hardinge Bridge, water level did not cross the respective DL and it attained its peak of 14.19mPWD on 27th August, which was 6 cm below its DL (14.25m) at this point.

The Ganges/ Padma at Goalundo

At Goalondo river WL started to rise in month of August, crossed its respective DL on 24th August and it flowed above the DL for 17 days from 24th July to 7th August 2017. The WL of the river Padma at Goalondo attained its yearly peak of 9.66mPWD on the 31st July, which was 101 cm above its DL (8.65m) at this point.

The Padma at Bhagyakul and Sureswar

The river Padma has tidal influence at this point. At Bhagyakul, the WL of river Padma crossed the DL on 25th July to 7th July for 17 days. The WL of the river attained its

highest yearly peak water level of 6.90 mPWD on 1th August, which was 60cm above the DL (6.30m) at Bhagyakul. The Padnma at Sureswar crossed the DL for 7 days in the month of August and September 2016. At sureswar point, the WL crossed the DL from 23th July to 9th August for 7 days. The WL of the river attained its highest yearly peak water level of 5.16 mPWD on 03th August, which was 71cm above the DL (4.45m) at Sureswar.

The Gorai at Gorai Railway Bridge and Kamarkhali

The WL of river Gorai at Gorai Railway Bridge and Kamarkhali showed steady rise during July and rise and fall in August during the monsoon in 2016. The WL of river Gorai did not cross the DL at Gorai Railway Bridge. The WL of the river attained its highest yearly peak of 12.37 mPWD on 28th of August, which was 38cm below the DL (12.75m) at Gorai Rail Bridge. Gorai river at Kamarkhali crossed Danger Level on 25th August and continue to 1st September in 2016. The WL of the river attained its highest yearly peak of 8.31 mPWD on 29th of August, which was 11cm below the DL (8.20m) at Kamarkhali station.

The Arialkhan at Madaripur

At Madaripur the WL of the river Arialkhan showed similar trend of rise and fall of the river Padma. The WL of Arialkhan at Madaripur flowed below the DL. The WL attained its highest peak of 3.87 m on the 5th of August, which was 24cm below the DL (4.17m) at Madaripur.

Kobodak at Jhikorgacha

Water Level at Jikorgaha crossed DL on 10th August and continue upto September16,2016 and drainage congestion is the main reasons to proong the flooding sitaution . At Jhikorgacha, the WL flowed above the DL for continuous 37 days with a peak of 5.30 mPWD on 25th August, which was 119cm above the DL(4.11m) at this point.

Comparative hydrographs for few important stations for the year of 2016, 2007 & 2004 of the Ganges basin are shown in figures 3.14 to 3.20.

Table 3.2 : Comparison of Water Level of 2016 and Historical Events of 1988 & 1998 of Some Important Stations in Ganges Basin

Sl. No	River	Station	Recorded Maximum (m)	Danger Level (m)	Peak of the year (m)			Days above Danger Level		
					2016	1998	1988	2016	98	88
1	Punarbhaba	Dinajpur	34.40	33.50	30.28	34.09	34.25	0	3	4
2	Ganges	Pankha	22.97	22.50	22.44	24.14	NA	0	66	NA
3	Ganges	Rajshahi	20.00	18.50	18.46	19.68	19.00	0	28	24
4	Ganges	Hardinge Bridge	15.04	14.25	14.19	15.19	14.87	0	27	23
5	Padma	Goalundo	10.01	8.50	9.66	10.21	9.83	17	68	41
6	Padma	Bhagyakul	7.58	6.00	6.90	7.50	7.43	17	72	47
7	Padma	Sureswar	7.50	4.45	5.16			22		
8	Gorai	Gorai Rail Bridge	13.65	12.75	12.37	13.45	13.65	0	25	25
9	Gorai	Kamarkhali	9.48	8.20	8.31	NA	NA		NA	NA
10	Arialkhan	Madaripur	5.80	4.17	3.87	NA	NA	0	NA	NA
11	Kobodak	Jhikorgacha	5.59	4.11	5.30	NA	NA	22	NA	NA

3.3 THE MEGHNA BASIN

Most of the rivers of this basin entered from the hilly catchment of India (Barak Basin, Tripura and Meghalaya) and are flashy in nature. Out of 26 WL monitoring stations in the Meghna basin, 18 stations flowed above their respective DLs, these are Surma River at Kanaighat, Sylhet and Sunamganj, Kushyara River at Amalshid, Sheola and Sherpur, Sarigowain river at Sarighat, Khowai river at Habigonj and Ballah, Bhugai river at Nakuagaon, Jadukata river at Lorergarh, Someswari river at Durgapur, Kangsha River at Jariajanjail and Titas river at Brahmanbaria. The period of above Danger Level varies from 2 days to 29 days. As a result, floods of short to moderate duration was experienced in the districts of Sylhet, Sunamgonj, Netrokona, Sherpur, Moulvi Bazar, and Habigonj during the monsoon 2016.

Comparative statement of WL and days flowed above the DL for 2016 and historical events of 1998 and 1988 for this basin for selected stations are shown in Table 3.3.

The Surma

Water Level in the Surma river started to rise from mid of April and it showed rapid rise and fall in several times. FFWC monitors 3 stations on the Surma River.

The Surma at Kanaighat

As a flashy river, WL of the river Surma at Kanaighat in Sylhet district showed several peaks during the monsoon-2016. First it flowed above its DL at Kanaighat from 24 April to 27 April,216 for 4 days. Secondly, its crossed danger level from 17th May to 26th May and finally, it again crossed its danger level on 19th July, 2017 and continued to 21st July. It attained its highest peak of 14.45mPWD on 24th April at 18:00 hours, which was 125cm above the DL (13.20 m) at Kanaighat.

The Surma at Sylhet

The WL of river Surma at Sylhet showed similar trend like Kanaighat. However, it did not cross danger level in April and May. The Surma at Sylhet flowed above its danger level for two days from 25th July and 26 July. It attained the peak WL of 11.27mPWD on 26th July which was just 2cm above its DL (11.25m).

The Surma at Sunamgonj

The Surma at Sumangnaj showed rapid rise from mid-April in 2016 with sharp fall in sometimes in May and June. The WL of the river Surma at Sunamgonj crossed the DL on 21st July and continue to end of July. The WL of Surma at Sunamgonj recorded its highest peak of 9.15 mPWD on 21th July, which was 90cm above its DL (8.25m).

The Kushiyara at Amalshid, Sheola and Sherpur

The Kushiyara river at Amalshid, Sheola and Sherpur (Sylhet district) observed similar rise and fall trend throughout the monsoon 2016. At Amalshid water level of Kushiyara crossed the DL four times, firstly 24th April July to 27th April for 4 days. Third time in July 4th to 7th and finally September 1 to 11 . It flowed abve DL for 25 days.

At Amalshid, Kushiyara attained the peak flow of 17.52 mPWD on 20th May which was 167cm above the DL (15.85 mPWD).

At Sheola it also crossed the DL three times, First on May it crossed danger level 18th May to 28th May for 11 days and on 4th July to 6th July for 2 days , thirdly, Septmebr 1 to 11 in total 27 days in this monsoon and. It attained its highest peak of 14.51 mPWD on 20th May which was 101 cm above its DL (13.50 m).

At Sherpur the river flowed similar trend like Sheola and it also crossed the DL three times. First on May it crossed danger level between 18th May to 28th May for 11 days and on 9th July for 1 days and thirdly, Septmebr 15 to 16 in total 18 days in this monsoon and. It attained its highest peak of 9.29 mPWD on 22th May which was 29 cm above its DL (9.0 m).

The Sarigowain at Sarighat

As the flashy river the Sarighat on Saigowain river in Sylhet district, showed several peaks during the monsoon 2016 and crossed the respective DL for 5 times in monsoon period. First peak 24th April to 25th April for 2 days , second time on 20 th July for one day. It attained monsoon highest peak of 13.70 mPWD on 24th April which was 90cm above its DL (12.80 m).

The Manu at Manu Railway Bridge and Moulvi Bazar

As a flashy river, the WL of the river Manu at Manu Railway Bridge and at Moulvibazar observed several sharp peaks during the monsoon-2016. The WL of Manu river did not cross the DL at Manu Railway Bridge until August. It crossed DL with a peak flow of 18.76mPWD on 15th September, which is 76 cm above the DL(18.0mPWD). At Moulvibazar the WL of Manu crossed the DL once in 2016 monsoon. It attained with highest peak of 12.07mPWD on 15th which was 32 cm above its DL(11.75m) at this point.

The Khowai at Habigonj and Bullah

The Khowai at Habigonj showed several peaks during the monsoon 2016. The WL recorded its yearly highest peak of 22.37 m on 18th August, which was 73 cm above its DL (21.64m). At Habiganj, the WL of Khowai crossed the DL once in the month of May and for other times it flowed DL. The highest peak was 10 mPWD which attainted on 22th May.

The Dhalai at Kamalgonj

The WL of the flashy river Dhalai at Kamalganj flowed above its DL for a single day in this monsoon. The peak water level was 20.15mPWD on 16th August, which was 33cm above its DL(19.82m).

The Bhugai at Nakuagaon

As flashy river the Bhugai at Nakuagaon in Sherpur district recorded sharp rise & fall with several peaks during the monsoon. It has just flowed above its DL for one day only during monsoon 2016. It attained monsoon highest peak of 22.48mPWD at 4th July, which was 8cm above its DL (22.40m) at this point.

The Jadukata at Lorergarh

Like other flashy rivers in the North-east region, the Jadukata showed several peaks during the monsoon 2016, crossed its DL for three times, twice in July and once in early September. First it crossed the DL from 20th July to 21th July for 2 days, then 25th July for one day and on 2rd September for one day, in total 4 days in this monsoon. It attained monsoon highest peak of 9.71mPWD on 21st July, which was 118 cm above its DL (8.53 m).

The Someswari at Durgapur

As the flashy river the Durgapur in Netrokona district, showed rise and fall during the monsoon 2016, crossed its DL once in July. It crossed the DL from 25th July for one day only. It attained monsoon highest peak of 13.28mPWD on 25th August, which was 28 cm above its DL (13.0 m).

The Kangsha at Jariajanjail

As flashy river the Kangsha at Jariajanjail in Netrokona district showed rise and fall during the monsoon 2016, crossed the DL four times and remained above DL for total 29 days in the monsoon period. It started to cross DL from 7th June to 4th August . It attained its yearly highest peak of 10.95 mPWD on 26th July, which was 120 cm above its DL (9.75m).

The Titas at Brahmanbaria

The Titas River at Brahmanbaria point started to flow at above its DL for 17 days from 25th July to 10th August with monsoon peak of 5.93 mPWD on 3rd August, which was 43 cm above its DL (5.5 m) at this point.

Comparative hydrographs for few stations the year of 2016, 2007 & 2004 of rivers of the Meghna basin are shown in figures 3.21 to 3.36.

Table 3.3: Comparison of Water Level of 2016 and Historical Events of 1988 & 1998 of Some Important Stations in Meghna Basin.

Sl. No	River	Station	Recorded Maximum (m)	Danger Level (m)	Peak of the year (m)			Days above Danger level		
					2016	1998	1988	16	98	88
1	Surma	Kanaighat	15.58	13.20	14.45	15.00	15.10	31	73	75
2	Surma	Sylhet	11.95	11.25	11.27	11.72	11.95	2	14	21
3	Surma	Sunamgonj	9.46	8.25	9.15	8.90	9.03	9	56	62
4	Kushiyara	Amalshid	18.28	15.85	17.52	17.60	17.50	25	54	65
5	Kushiyara	Sheola	14.60	13.50	14.51	14.14	14.09	27	37	80
6	Kushiyara	Sherpur	9.68	9.00	9.29	NA	NA	18	NA	NA
7	Jariajanjail	Kangsha	13.37	9.75	10.95	NA	NA	29	NA	NA
8	Manu	Manu RB	20.42	18.0	18.76	18.63	18.95	1	6	66
10	Manu	Moulvi Bazar	15.50	11.75	12.07	11.68	13.01	2	-	25
11	Khowai	Habiganj	12.00	9.50	10	11.44	11.06	1	8	14
12	Upper Meghna	Bhairab Bazar	7.66	6.25	6	7.33	7.66	0	68	68
13	Gumti	Comilla	13.56	11.75	9.69	12.79	11.80	0	17	17

3.4 THE SOUTH EASTERN HILL BASIN

The South Eastern Hill basin is constituted with the basin areas of the hilly rivers like the Muhuri, the Halda, the Sangu, the Matamuhuri and the Feni in the South Eastern Part of the country and most of the rivers show similar behavior during monsoon flood. The WL of the monitoring rivers except Feni crossed their respective DLs several times throughout the monsoon-2016. Due to flashy in nature, a short duration flood occurred at some places of Chittagong, Feni, Bandarban, Khagrachari, Cox's Bazar during the monsoon 2016 and low lying areas of Chittagong, Bandarban and Cox's Bazar were slightly affected by the flood for very short duration. The details of WL of different river are described in following sections. A comparative statement of water level and days flowed above the DLs for the monsoon-2016 and historical events of 1998 and 1988 for this basin are shown in the Table 3.4.

The Muhuri at Parshuram

The Muhuri river in Feni, Noakhali district is a flashy one flowed above the DL for 3 days on 16th July, 21st, August and 1st September. It attained its highest peak 14.50 mPWD on 21st August, which was 150cm above its DL (13.00 m).

The Halda at Narayanhat

As it is a flashy river, the WL of the river Halda (a flashy river) at Narayanhat under Hathazari upzilla also showed several peaks during this monsoon. It crossed danger mark

during the monsoon-2016, for 3 days from 4th July to 6th July in 2016 with peak 5.82mPWD which was 57 cm above the DL(15.25 m) at Narayanhat.

The Halda at Panchpukuria

The river here observed several peaks like Narayanhat, but flowed below its DL during the monsoon 2016. At Panchpukuria it attained its highest peak of 7.61mPWD on 4th July , which was 189 cm below its DL (9.50 m).

The Sangu at Bandarban and Dohazari

The Sangu is also a flashy river, showed several peaks during flood period. The river crossed the DL at Banarban for once in this monsoon. At Bandarban the peak recorded was 15.30 mPWD on 5th July, which was only 5 cm above its DL (15.25m). At Dohazari, the Sangu river crossed its DL times, for 3 days from 5th July to 7th July in this monsoon. At Dohazari the highest peak was recorded 7.60m on 6th July which was 60 cm above its danger mark (7.00 m) at this point.

The Matamuhuri at Lama and Chiringa

The river observed several peaks DL in the monsoon-2016 like Sangu River. At Lama, the Matamuhuri River did not crossed the DL while it had just touched danger level at Chiringa point. At Lama the peak recorded was 12.24 mPWD on 5th July, which was 1cm below its DL (12.25m). At Chiringa station the matamuhuri river touched DL on 5th July which was 7mPWD and it flowed above DL for 3 days.

The Feni at Ramgarh

The WL of river Feni at this point observed several peaks and flowed below its DL during the monsoon-2016. The highest peak WL attained by the river was 16.32 m on 5th July, which was 105cm below its DL (17.37m) at this point.

Table 3.4 : Comparison of Water Level of 2016 and Historical Events of 1988 and 1998 of Some Important Station in South Eastern Hill Basin.

Sl. No	River	Station	Recorded Maximum (m)	Danger Level (m)	Peak of the year (m)			Days above Danger level		
					2016	98	88	2016	98	88
1	Muhuri	Parshuram	15.03	13.00	14.50	14.60	12.42	3	9	48
2	Halda	Narayanhat	18.05	15.25	15.82	16.57	NA	3	21	NA
3	Halda	Panchpukuria	11.55	9.50	7.61	10.44	10.05	0	4	6
4	Sangu	Bandarban	20.38	15.25	15.30	15.25	16.80	1	1	3
5	Sangu	Dohazari	9.05	7.00	7.60	7.42	NA	3	2	NA
6	Matamuhuri	Lama	15.45	12.25	12.24	13.05	12.18	0	2	-
7	Matamuhuri	Chiringa	6.83	5.75	7	6.85	NA	0	5	NA
8	Feni	Ramgarh	21.41	17.37	16.32	17.50	NA	0	1	NA

Comparative hydrographs for the year of 2016, 2007 and 2004 of few stations of the South Eastern Hill Basin are shown in Figures 3.37 to 3.42.

3.5 RECORDED HIGHEST WATER LEVEL

The peak water level of all the water level monitoring stations under FFWC with the date during the monsoon 2016 is shown in the following table.

Table 3.5: Recorded Peak Water Level with Date during the monsoon 2016

SL No	River name	Station	Peak WL-2016 (m)	Date
	BRAHMAPUTRA BASIN			
1	DHARLA	KURIGRAM	27.56	27/07/16
2	TEESTA	DALIA	52.65	22/06/16
3	TEESTA	KAUNIA	28.98	10/10/16
4	JAMUNESWARI	BADARGANJ	30.40	21/07/16
5	GHAGOT	GAIBANDHA	22.61	28/07/16
6	KARATOA	CHAK RAHIMPUR	19.55	25/07/16
7	KARATOA	BOGRA	14.09	13/10/16
8	BRAHMAPUTRA	NOONKHAWA	27.31	28/07/16
9	BRAHMAPUTRA	CHILMARI	24.99	28/07/16
10	JAMUNA	FULCHORI	21.13	28/07/16
11	JAMUNA	BAHADURABAD	20.71	29/07/16
12	JAMUNA	SARIAKANDI	17.69	29/07/16
13	JAMUNA	KAZIPUR	16.07	29/07/16
14	JAMUNA	SERAJGONJ	14.24	29/07/16
15	JAMUNA	ARICHA	9.97	31/07/16
16	GUR	SINGRA	12.83	30/07/16
17	ATRAI	BAGHABARI	11.49	31/07/16
18	DHALESWARI	ELASIN	12.80	31/07/16
19	OLD BRAHMAPUTRA	JAMALPUR	16.76	01/08/16
20	OLD BRAHMAPUTRA	MYMENSINGH	11.66	04/08/16
21	LAKHYA	LAKHPUR	5.70	06/08/16
22	BURIGANGA	DHAKA	5.21	04/08/16
23	BALU	DEMRA	5.64	05/08/16
24	LAKHYA	NARAYANGONJ	5.82	04/08/16
25	TURAG	MIRPUR	5.89	04/08/16
26	TONGI KHAL	TONGI	5.84	06/08/16
27	KALIGANGA	TARAGHAT	9.44	02/08/16
28	DHALESWARI	JAGIR	9.07	03/08/16
29	DHALESWARI	REKABI BAZAR	5.12	04/08/16
30	BANSHI	NAYARHAT	6.48	07/08/16
GANGES BASIN				
29	KARATOA	PANCHAGARH	69.81	25/07/16
30	PUNARBHABA	DINAJPUR	30.28	27/09/16
31	ICH-JAMUNA	PHULBARI	28.37	23/07/16
32	TANGON	THAKURGAON	50.10	25/06/16
33	UPPER ATRAI	BHUSIRBANDAR	38.67	27/07/16
34	MOHANANDA	ROHANPUR	20.89	28/08/16
35	MOHANANDA	CHAPAI-NAWABGANJ	20.90	28/08/16
36	LITTLE JAMUNA	NAOGAON	14.63	24/07/16
37	ATRAI	MOHADEBPUR	17.26	28/07/16
38	GANGES	PANKHA	22.44	28/08/16
39	GANGES	RAJSHAHI	18.46	28/08/16
40	GANGES	HARDINGE BRIDGE	14.19	27/08/16
41	PADMA	GOALONDO	9.66	31/07/16
42	PADMA	BHAGYAKUL	6.90	01/08/16

SL No	River name	Station	Peak WL-2016 (m)	Date
43	PADMA	SURESWAR	5.16	03/08/16
44	GORAI	GORAI RAIL BRIDGE	12.37	28/08/16
45	GORAI	KAMARKHALI	8.31	29/08/16
46	ICHAMATI	SAKRA	3.69	18/08/16
47	MATHABHANGA	CHUADANGA	9.36	28/08/16
48	MATHABHANGA	HATBOALIA	11.27	29/08/16
49	KOBADAK	JHIKORGACHA	5.30	25/08/16
50	KUMAR	FARIDPUR	4.75	22/08/16
51	ARIALKHAN	MADARIPUR	3.87	05/08/16
52	KIRTONKHOLA	BARISAL	2.62	05/08/16
MEGHNA BASIN				
53	SURMA	KANAIGHAT	14.45	24/04/16
54	SURMA	SYLHET	11.27	26/07/16
55	SURMA	SUNAMGONJ	9.15	21/07/16
56	KUSHIYARA	AMALSHID	17.52	20/05/16
57	KUSHIYARA	SHEOLA	14.51	20/05/16
58	KUSHIYARA	SHERPUR	9.29	22/05/16
59	KUSHIYARA	MARKULI	8.06	22/05/16
60	SARIGOWAIN	SARIGHAT	13.70	24/04/16
61	MANU	MANU RAILY BRIDGE	18.76	15/09/16
62	MANU	MOULVI BAZAR	12.07	15/09/16
63	KHOWAI	BALLAH	22.37	18/07/16
64	KHOWAI	HABIGONJ	10	22/05/16
65	DHALAI	KAMALGONJ	20.15	16/08/16
66	BAULAI	KHALIAJURI	8.87	10/09/16
67	BHUGAI	NAKUAGAON	22.48	04/07/16
68	JADUKATA	LORERGARH	9.71	21/07/16
69	SOMESWARI	DURGAPUR	13.28	26/07/16
70	KANGSHA	JARIAJANJAIL	10.95	26/07/16
71	TITAS	B. BARIA	5.93	03/08/16
72	MEGHNA	BHAIRAB BAZAR	6	03/08/16
73	MEGHNA	NARSINGDI	5.36	03/08/16
74	GUMTI	COMILLA	9.69	19/07/16
75	GUMTI	DEBIDDAR	6.97	02/09/16
76	MEGHNA	CHANDPUR	4.63	02/08/16
	SOUTH EASTERN HILL BASIN			
77	MUHURI	PARSHURAM	14.50	21/08/16
78	HALDA	NARAYAN HAT	5.82	04/08/16
79	HALDA	PANCHPUKURIA	7.61	04/07/16
80	SANGU	BANDARBAN	15.30	05/07/16
81	SANGU	DOHAZARI	7.60	06/07/16
82	MATAMUHURI	LAMA	12.24	05/07/16
83	MATAMUHURI	CHIRINGA	7	05/07/16
84	FENI	RAMGARH	16.32	05/07/16

Table 3.6: Recorded Historical Highest Water Level with Date

Sl. No.	River	Station	Danger Level (m)	Recorded highest WL (m) before 2016 flood (date)	WL (Date) Exceeding previous Highest WL (m)
1	Dharla	Kurigram	26.50	27.66 (14.07.96)	-
2	Teesta	Dalia	52.40	52.97 (29.07.72)	-
3	Teesta	Kaunia	30.00	30.52 (06.01.68)	-
4	Brahmaputra	Noonkhawa	27.25	28.10(22.08.1962)	-

5	Brahmaputra	Chilmari	24.00	25.07 (23.08.62)	-
6	Jamuna	Bahadurabad	19.50	20.62 (30.08.88)	-
7	Jamuna	Serajgonj	13.35	15.12 (30.08.88)	-
8	Jamuna	Aricha	9. 40	10.76 (02.09.88)	-
9	Old Brhamaputra	Jamalpur	17.00	18.00 (31.07.54)	-
10	Old Brhamaputra	Mymensingh	12.50	13.71(1.09.88)	-
11	Buriganga	Dhaka	6.00	7.58 (04.09.68)	-
12	Lakhya	Narayangonj	5.50	6.93 (10.09.98)	-
13	Turag	Mirpur	5.94	8.35 (10.09.88)	-
14	Tongi Khal	Tongi	6.08	7.84 (01.09.62)	-
15	Kaliganga	Taraghat	8.38	10.37(2.09.88)	-
16	Punarbhaba	Dinajpur	33.50	34.09 (05.09.98)	-
17	Padma	Pankha	21.50	24.14 (07.09.97)	-
18	Padma	Rajshahi	18.50	20.00(13.09.1910)	-
19	Padma	H- Bridge	14.25	15.19 (10.09.98)	-
20	Padma	Goalundo	8.50	10.21 (03.08.08)	-
21	Padma	Bhagyakul	6.00	7.50 (10.09.1998)	-
22	Gorai	Gorai Rly Br	12.75	13.65 (02.09.98)	-
23	Surma	Kanaighat	13.20	15.58(26.06.12)	-
24	Surma	Sylhet	11.25	12.44 (19.07.04)	-
25	Surma	Sunamgonj	8.25	9.75 (20.07.04)	-
26	Kushiyara	Amalshid	15.85	18.28 (08.06.74)	-
27	Kushiyara	Sheola	13.50	14.60 (09.09.08)	-
28	Manu	Manu Rly Br	18.00	20.42 (23.05.02)	-
29	Manu	Moulvi Bazar	11.75	13.25 (8.06.93)	-
30	Khowai	Habigonj	9.50	12.00 (18.06.07)	-
31	Someswari	Durgapur	13.00	15.5(23.09.2014)	-
32	Upper Meghna	Bhairab Bazar	6.25	7.78 (24.07.04)	-
33	Gumti	Comilla	11.75	13.56 (23.07.93)	-
34	Muhuri	Parshuram	13.00	16.33 (13.09.04)	-
35	Halda	Narayanhat	15.25	19.30 (13.08.99)	-
36	Halda	Panchpukuria	7.00	12.54(27.06.03)	-
37	Sangu	Bandarban	15.25	20.7 (12.07.97)	-
38	Sangu	Dohazari	7.00	8.37(12.07.1997)	-
39	Matamuhuri	Lama	12.25	15.46 (12.08.99)	-
40	Matamuhuri	Chiringa	5.75	7.03 (10.07.97)	-
41	Feni	Ramgarh	17.37	21.42 (11.07.68)	-

WL - Water Level

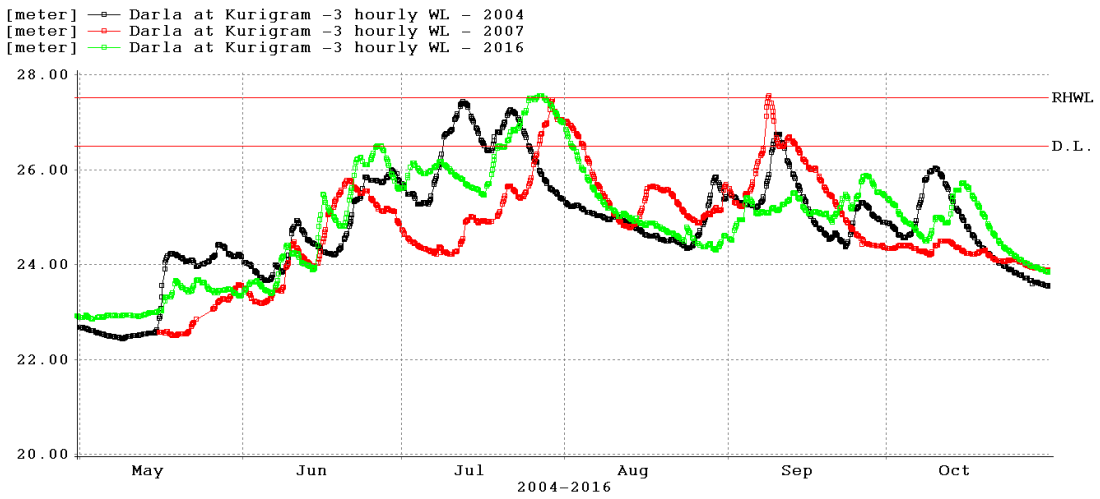


Figure 3.1: Comparison of Hydrograph on Dharla at Kurigram

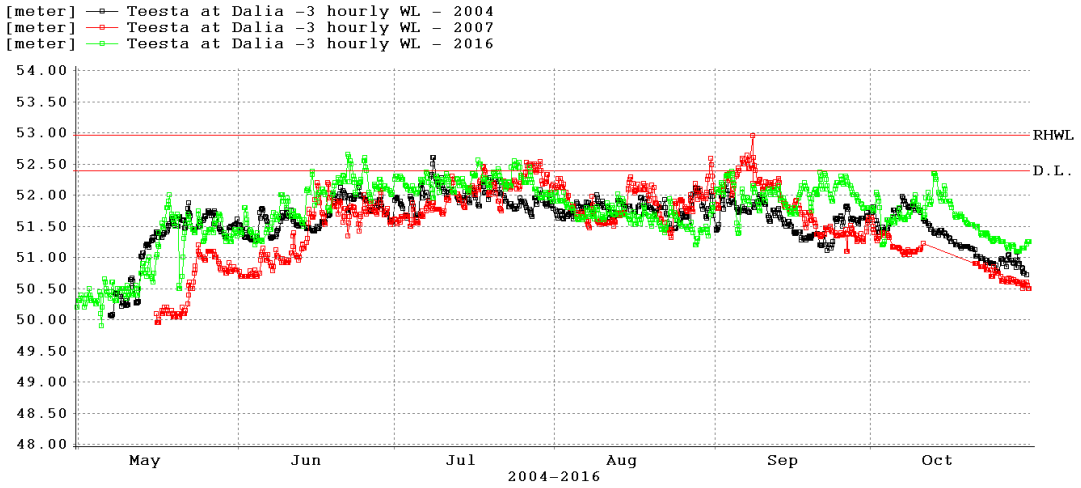


Figure 3.2: Comparison of Hydrograph on Teesta at Dalia

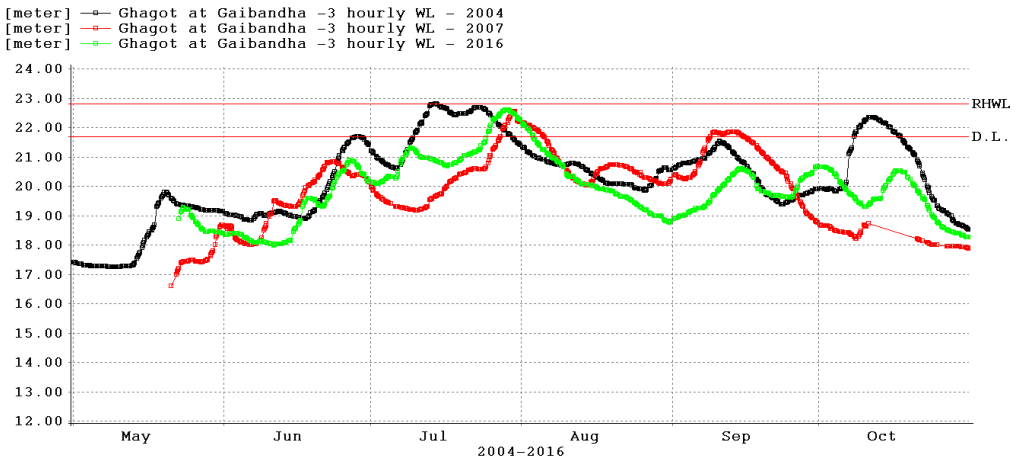


Figure 3.3: Comparison of Hydrograph on Ghagot at Gaibandha

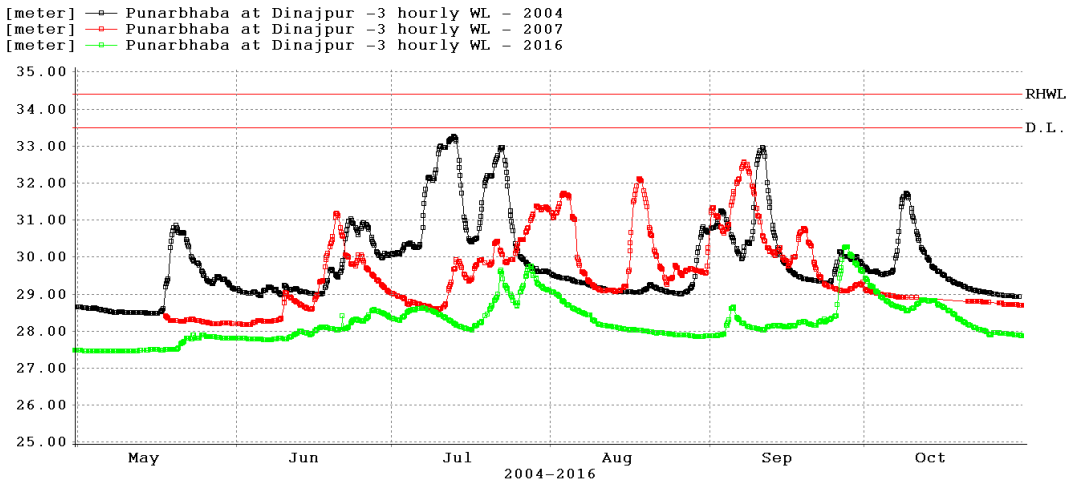


Figure 3.4: Comparison of Hydrograph on Punurbhoba at Dinajpur

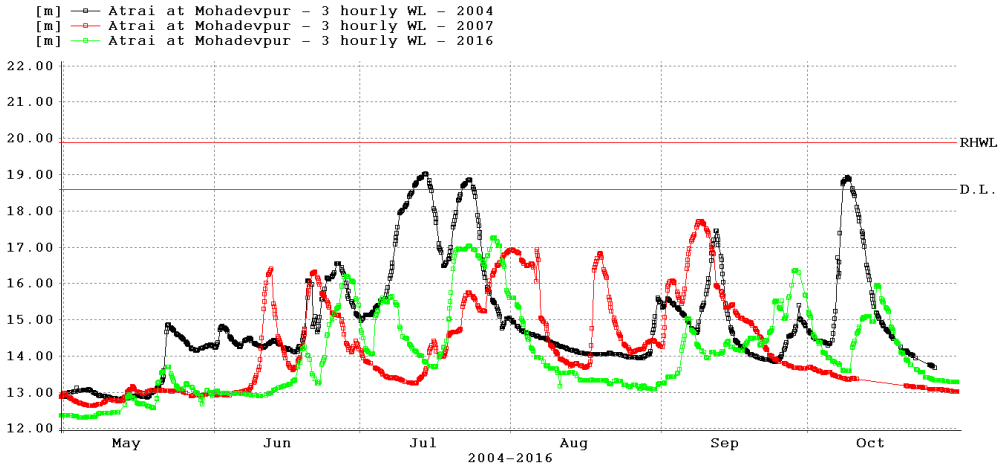


Figure 3.5: Comparison of Hydrograph on Atrai at Mohadevpur

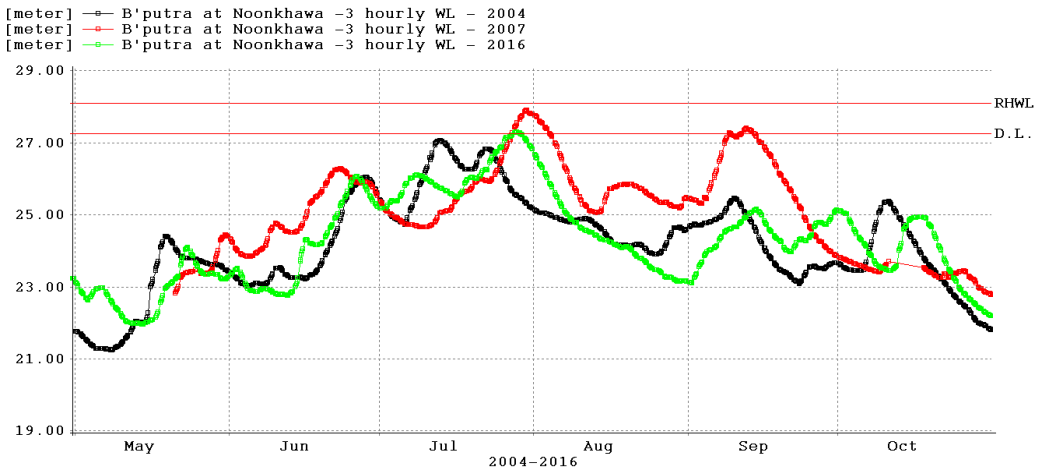


Figure 3.6: Comparison of Hydrograph on Brahmaputra at Noonkhawa

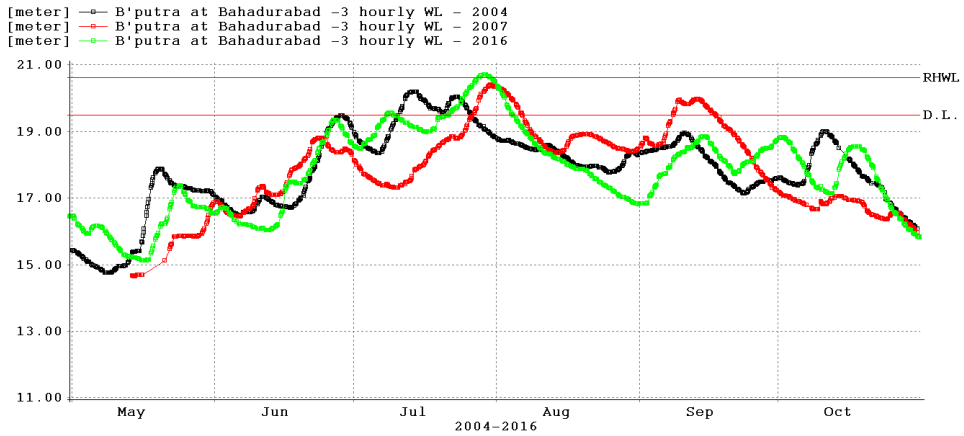


Figure 3.7: Comparison of Hydrograph on Brahmaputra at Bahadurabad

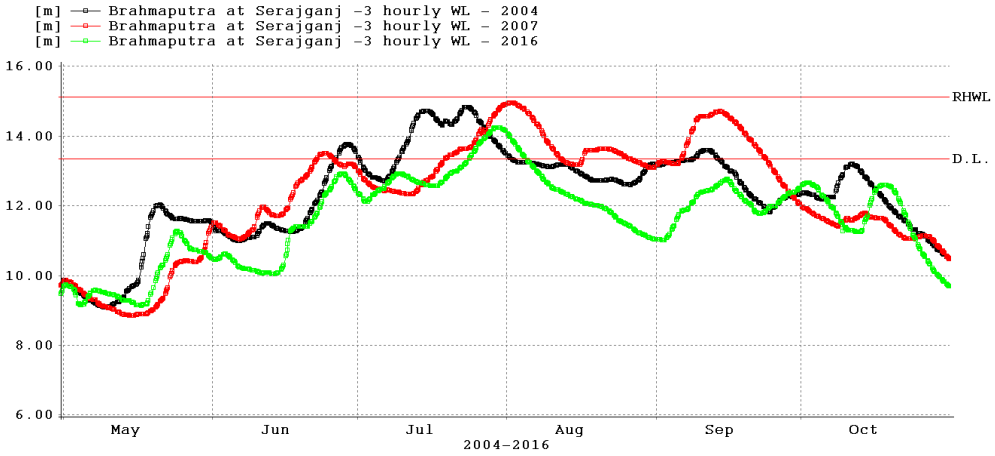


Figure 3.8: Comparison of Hydrograph on Jamuna at Serajgonj

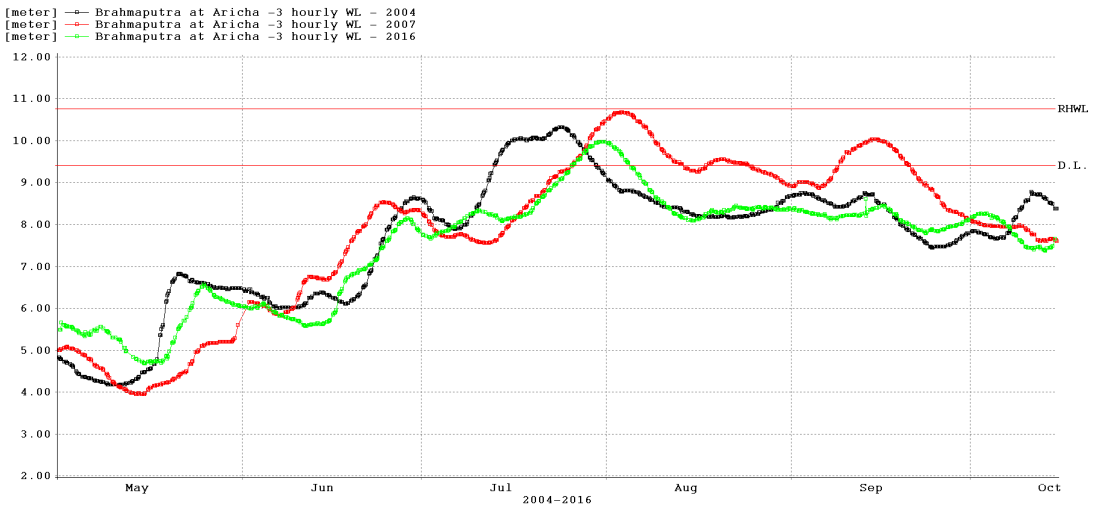


Figure 3.9: Comparison of Hydrograph on Jamuna at Aricha

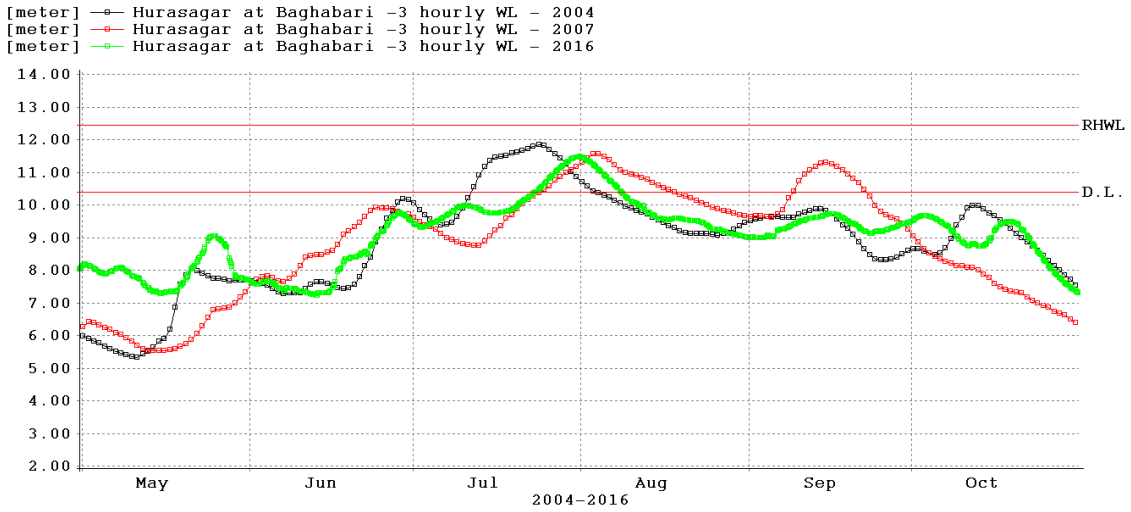


Figure 3.10: Comparison of Hydrograph on Atrai at Baghabari

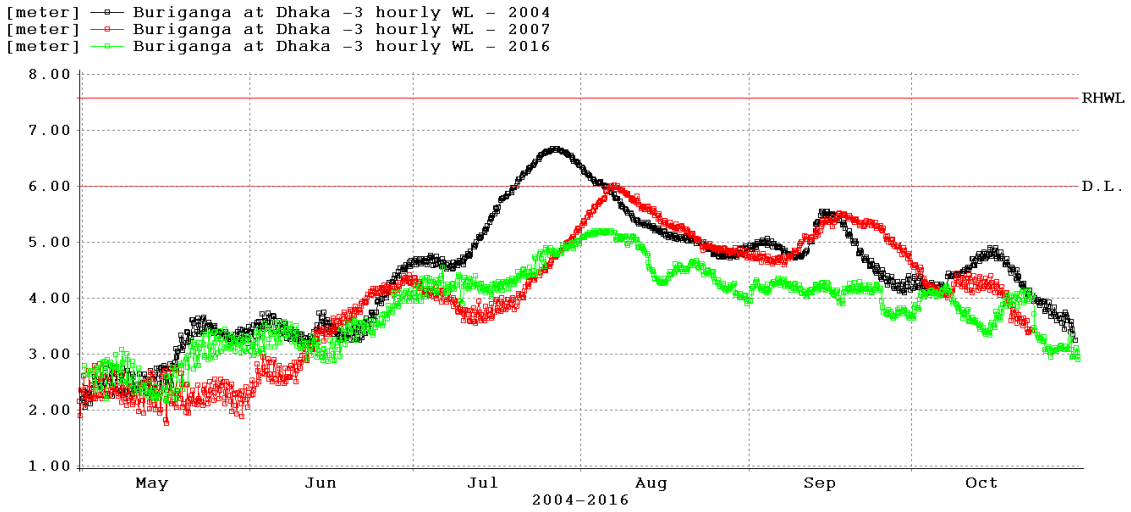


Figure 3.11: Comparison of Hydrograph on Buriganga at Dhaka (Milbarak)

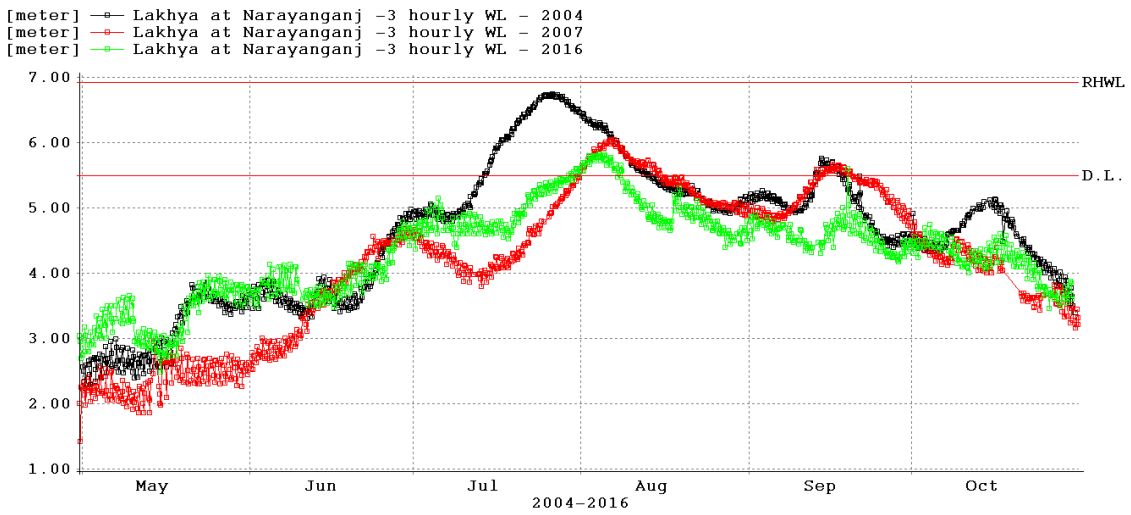


Figure 3.12: Comparison of Hydrograph on Lakhya at Narayangonj

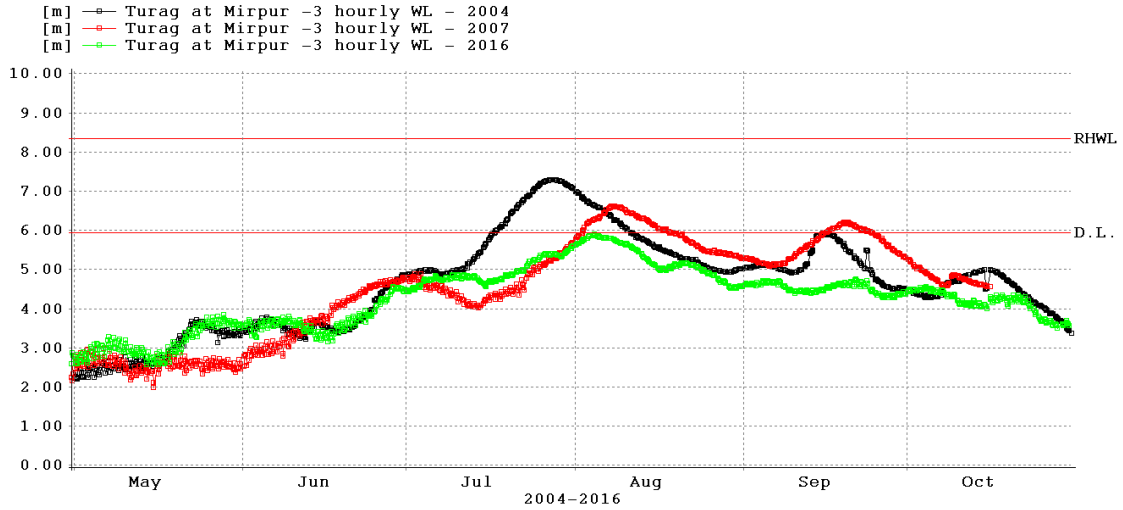


Figure 3.13 : Comparison of Hydrograph on Turag at Mirpur

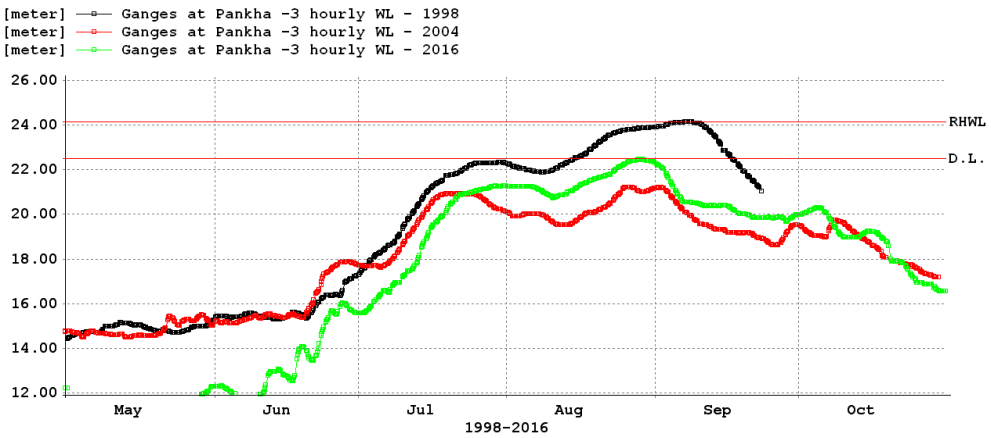


Figure 3.14: Comparison of Hydrograph on Ganges at Pankha

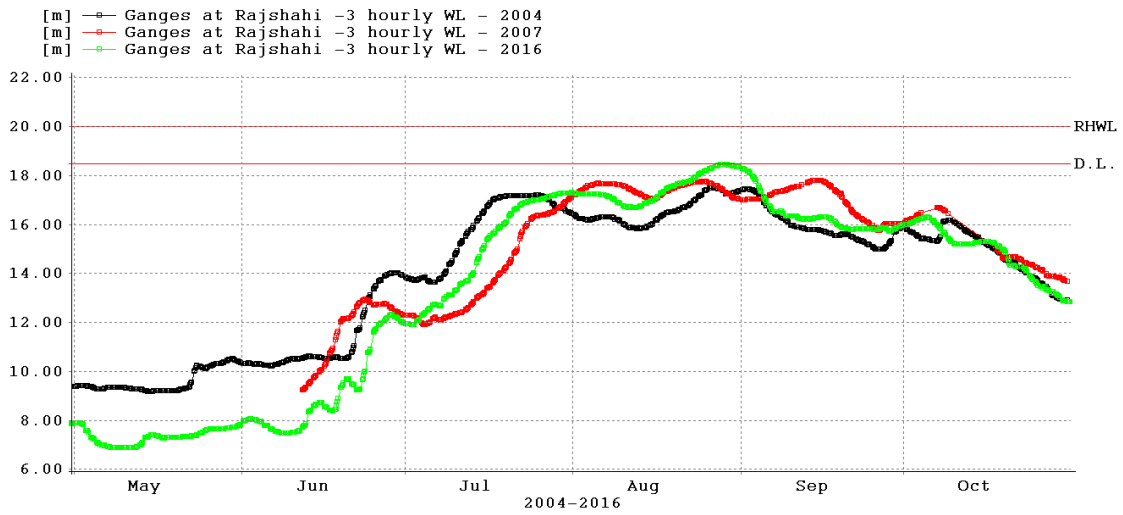


Figure 3.15: Comparison of Hydrograph on Ganges at Rajshahi

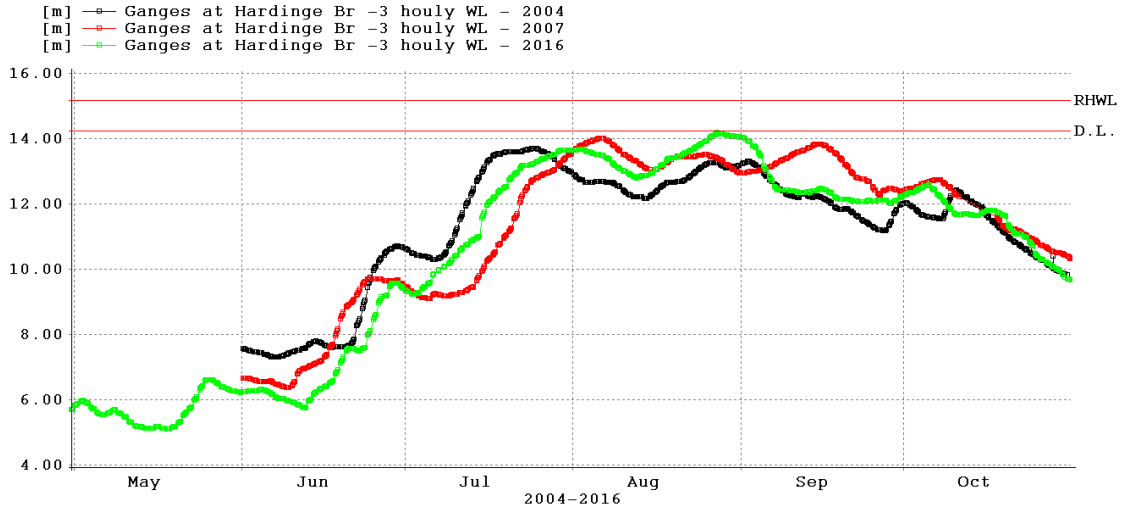


Figure 3.16: Comparison of Hydrograph on Ganges at Hardinge Bridge

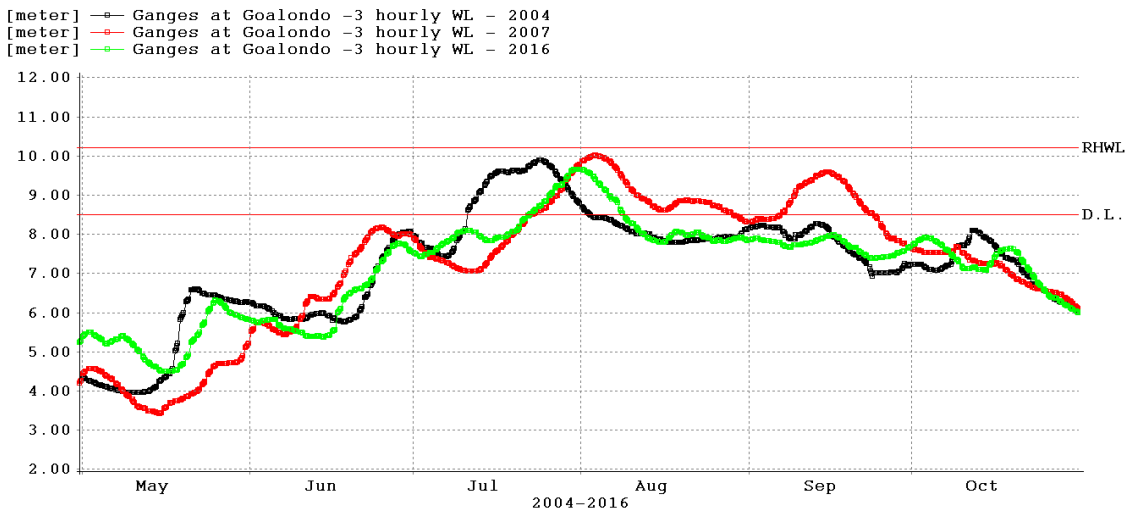


Figure 3.17: Comparison of Hydrograph on Padma at Goalondo

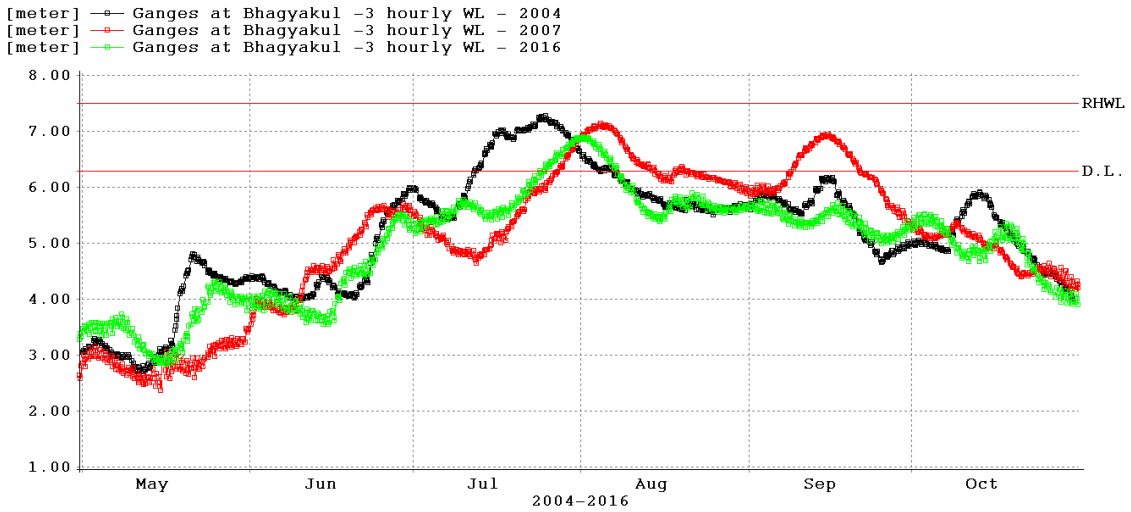


Figure 3.18: Comparison of Hydrograph on Padma at Bhagyakul

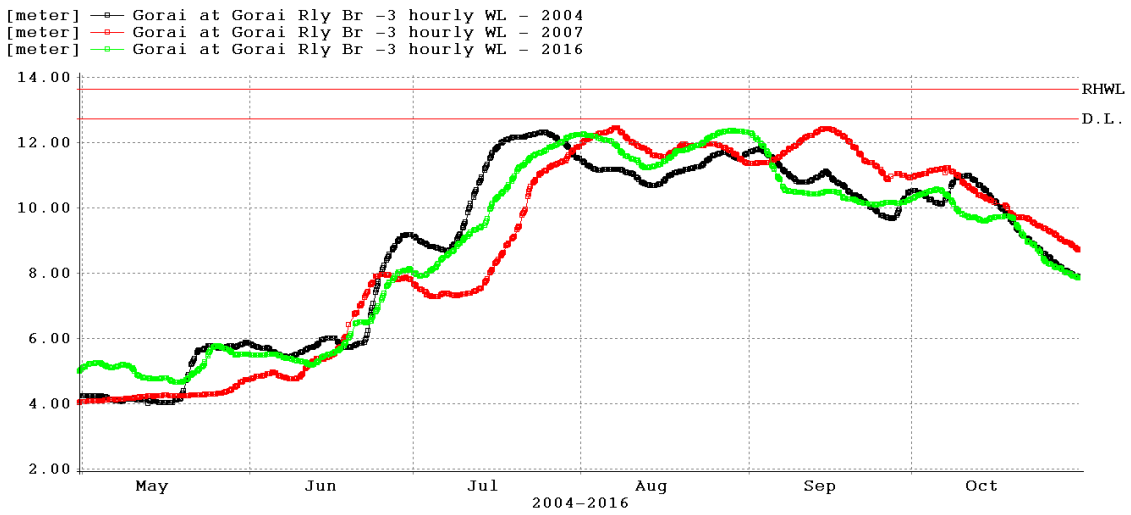


Figure 3.19: Comparison of Hydrograph on Gorai at Gorai Railway Bridge

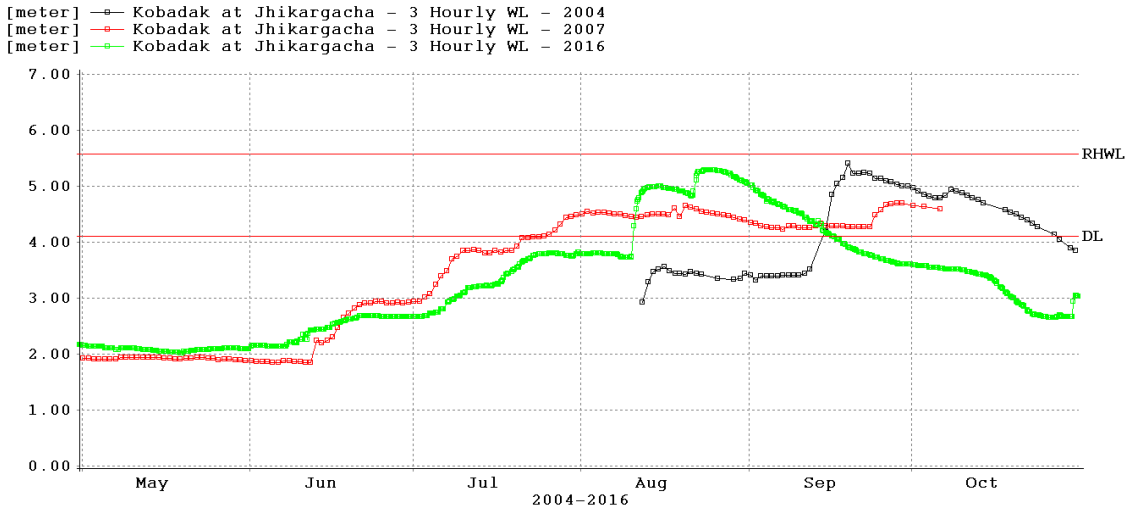


Figure 3.20: Comparison of Hydrograph on Kobodak at Jhikorgacha

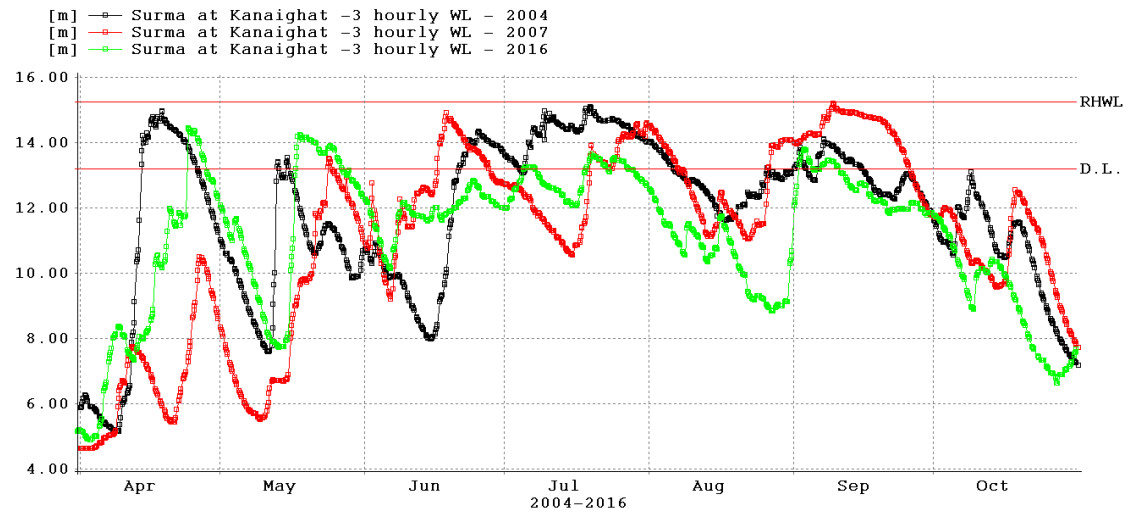


Figure 3.21: Comparison of Hydrograph on Surma at Kanaighat

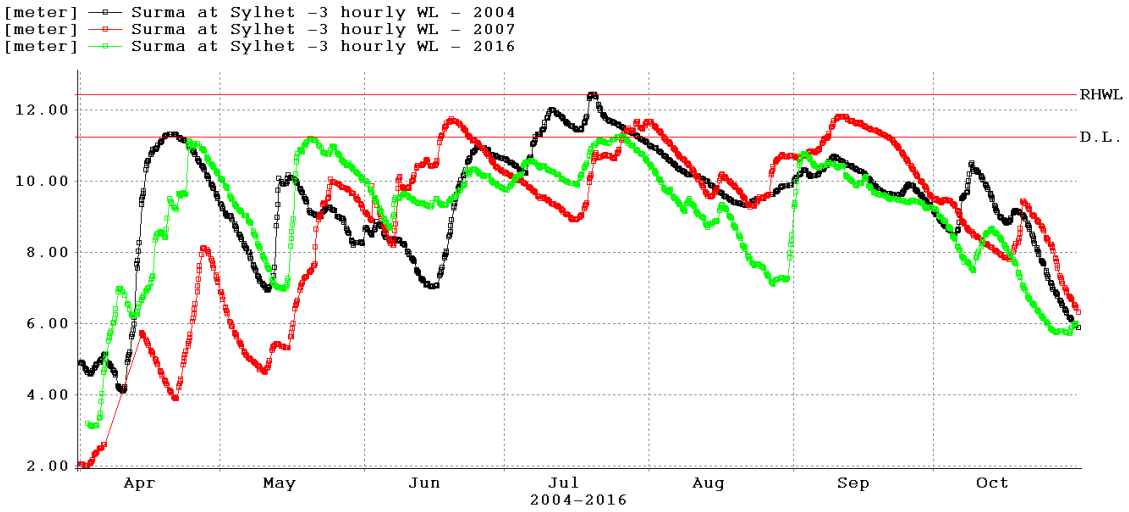


Figure 3.22: Comparison of Hydrograph on Surma at Sylhet

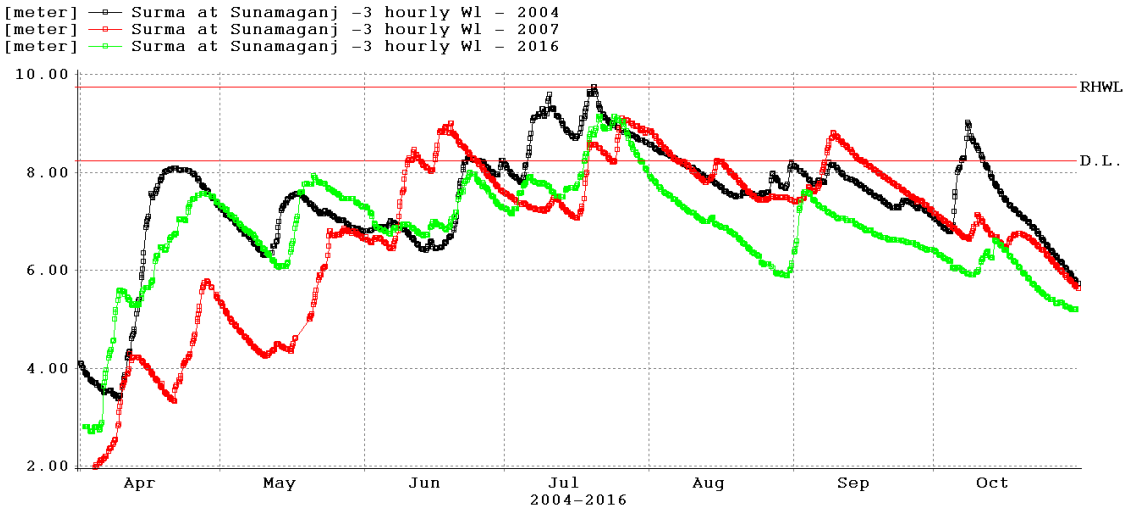


Figure 3.23: Comparison of Hydrograph on Surma at Sunamganj

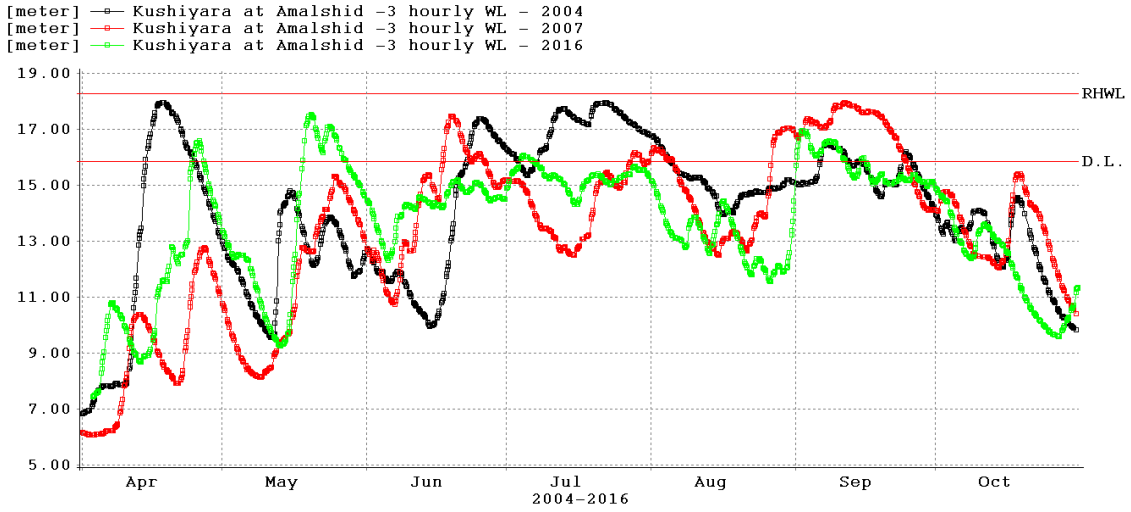


Figure 3.24: Comparison of Hydrograph on Kushiyara at Amalshid

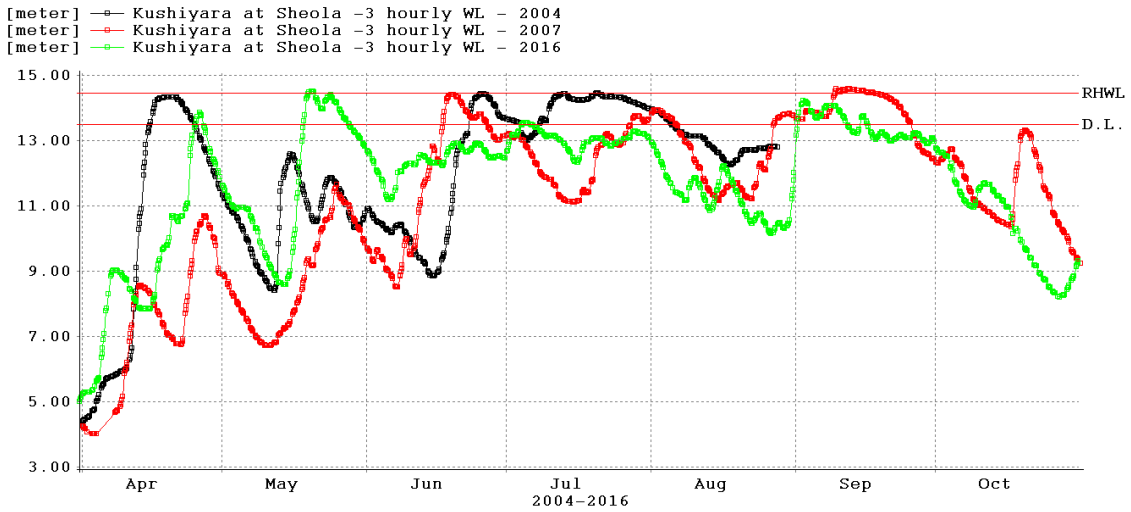


Figure 3.25: Comparison of Hydrograph on Kushiyara at Sheola

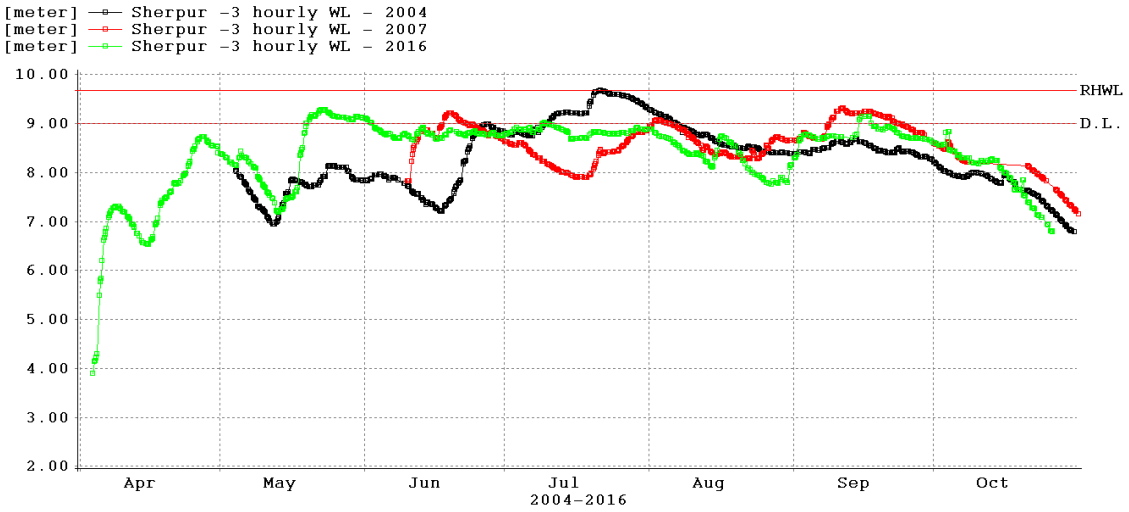


Figure 3.26: Comparison of Hydrograph on Kushiyara at Sherpur

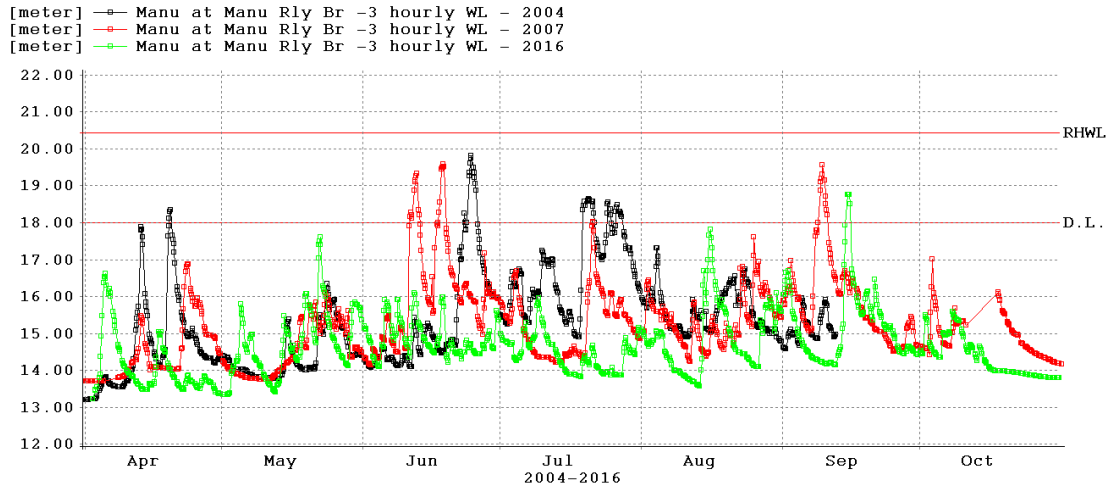


Figure 3.27: Comparison of Hydrograph on Manu at Manu Rail Bridge

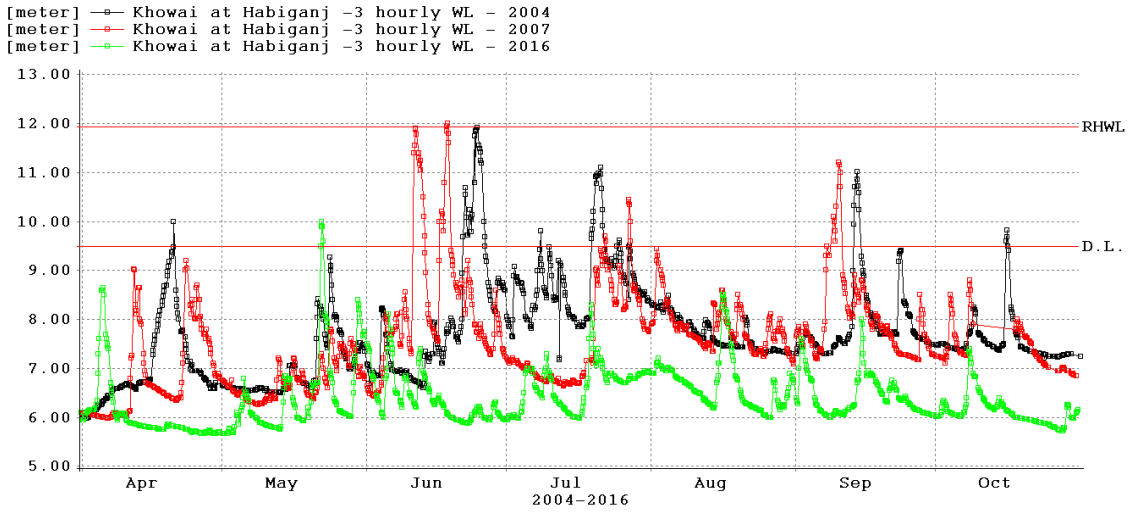


Figure 3.28: Comparison of Hydrograph on Khowai at Habigonj

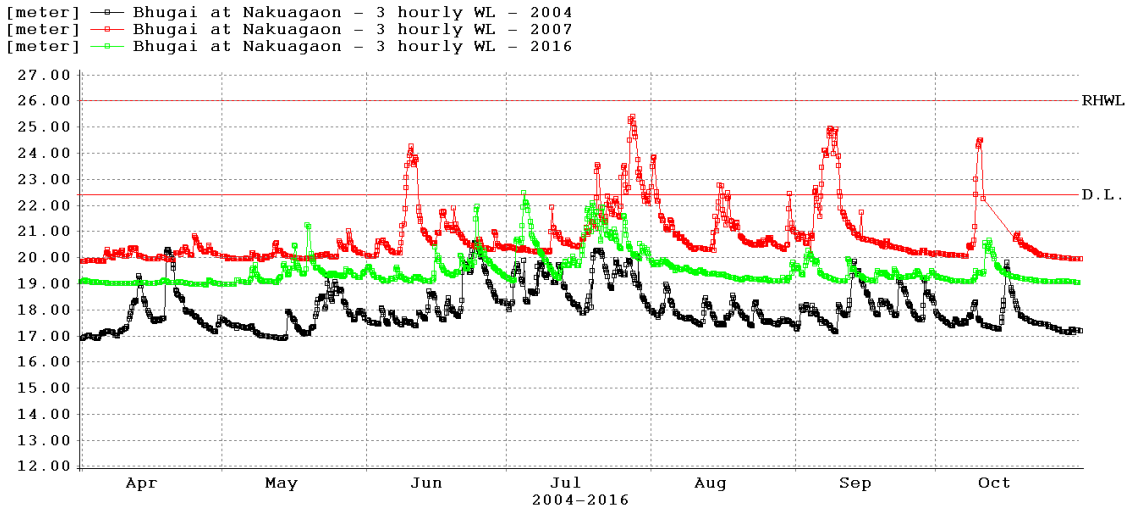


Figure 3.29: Comparison of Hydrograph on Bhugai at Nokuagaon

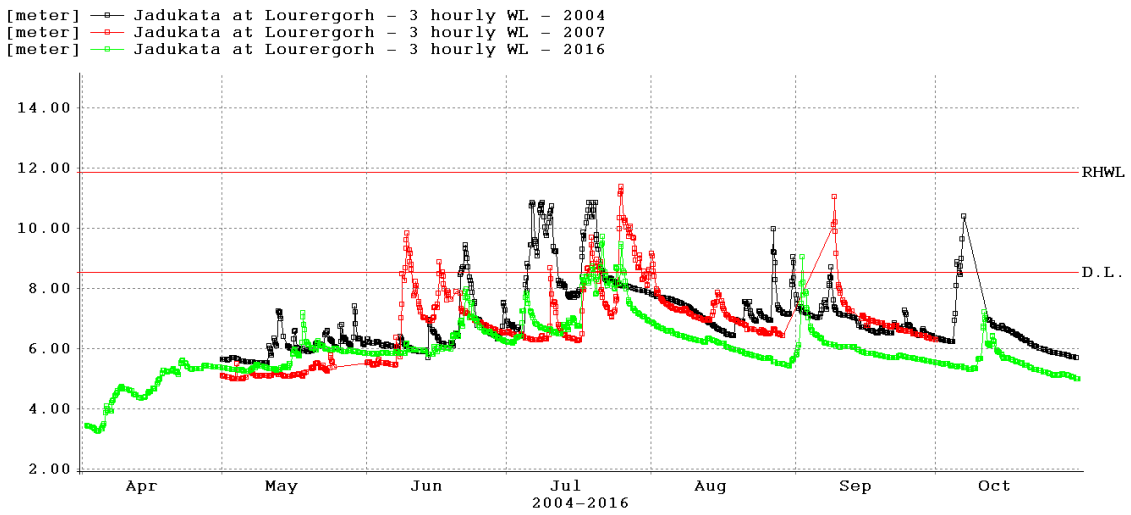


Figure 3.30: Comparison of Hydrograph on Jadukata at Lorergarh

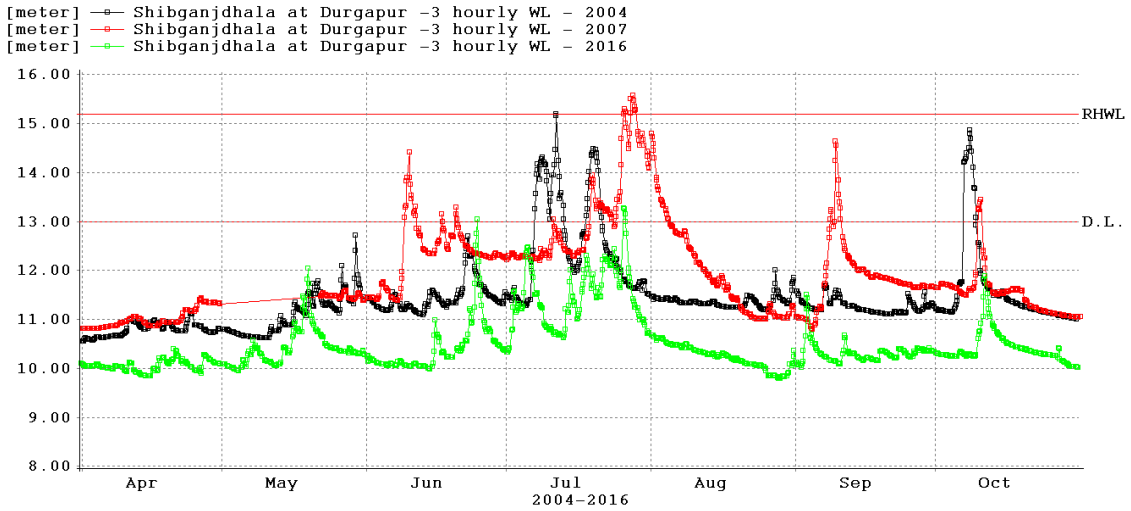


Figure 3.31: Comparison of Hydrograph on Someswari at Durgapur

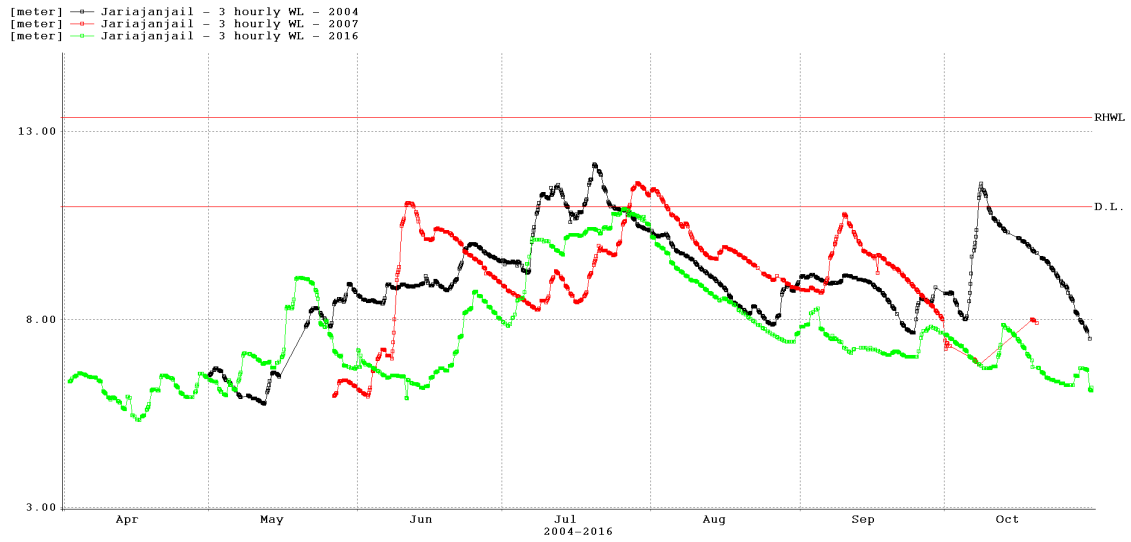


Figure 3.32: Comparison of Hydrograph on Kangsha at Jariajanjail

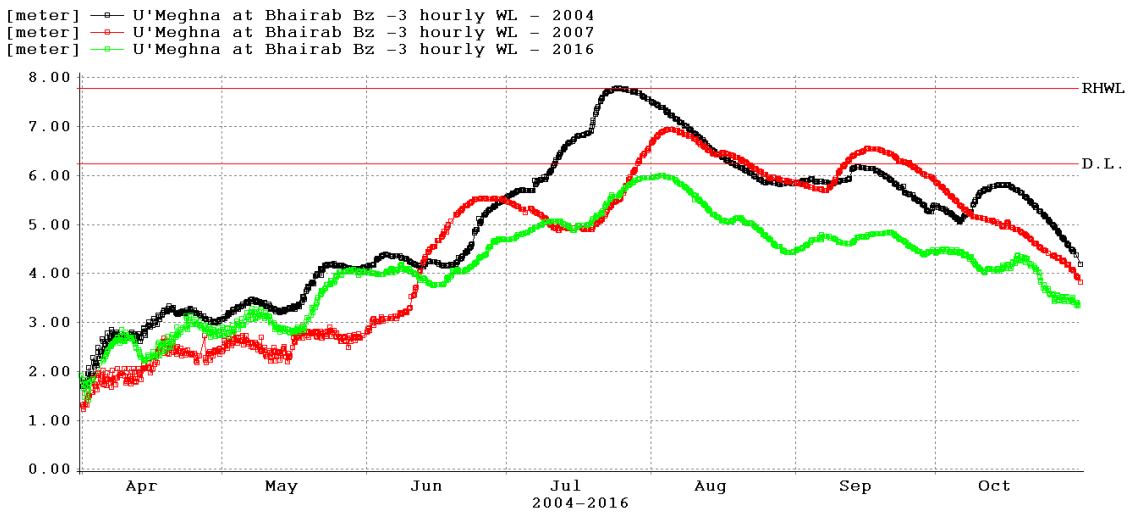


Figure 3.33: Comparison of Hydrograph on Upper Meghna at Bhairab Bazar

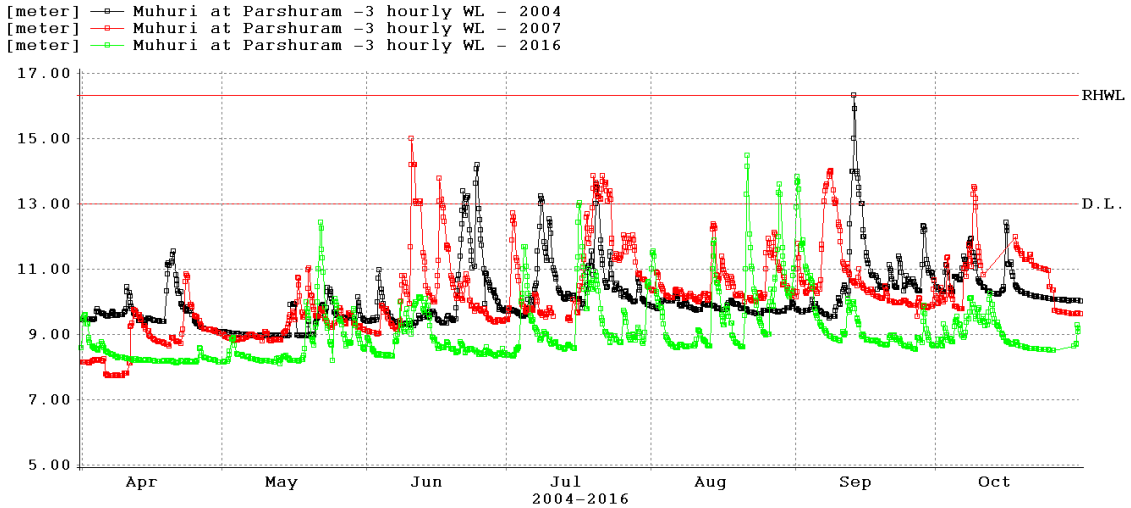


Figure 3.34: Comparison of Hydrograph on Muhuri at Parshuram

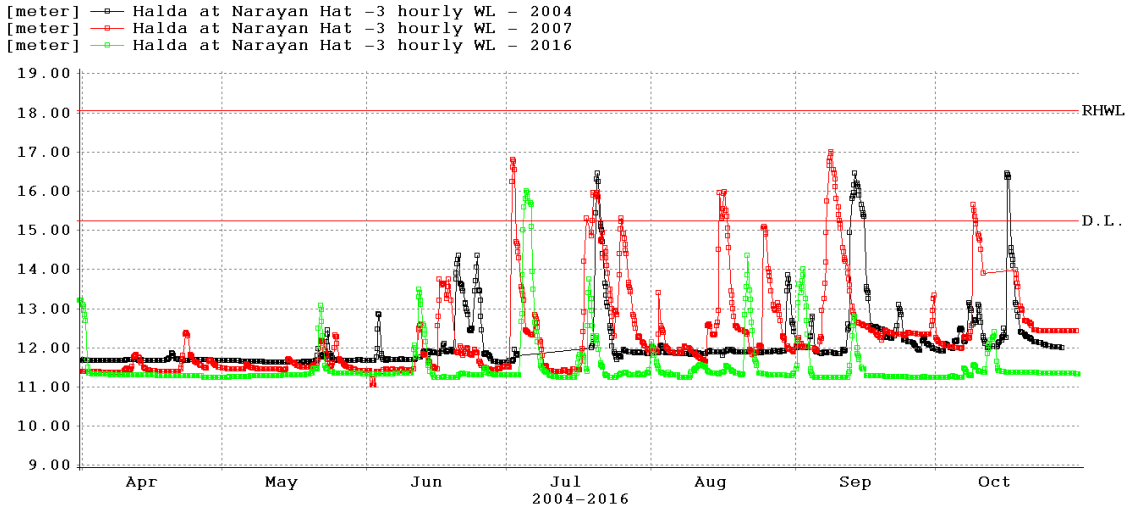


Figure 3.35 : Comparison of Hydrograph on Halda at Narayanhat

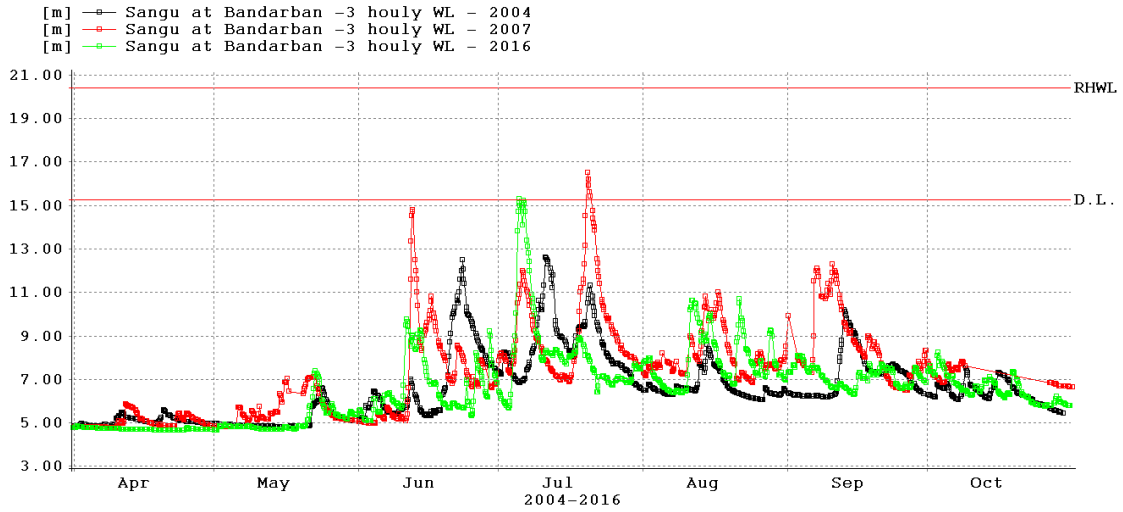


Figure 3.36: Comparison of Hydrograph on Sangu at Bandarban

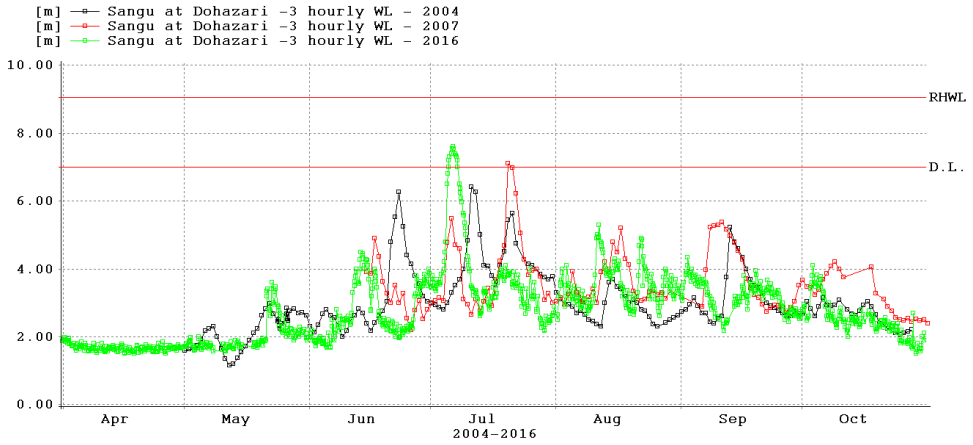


Figure 3.37: Comparison of Hydrograph on Sangu at Dohazari

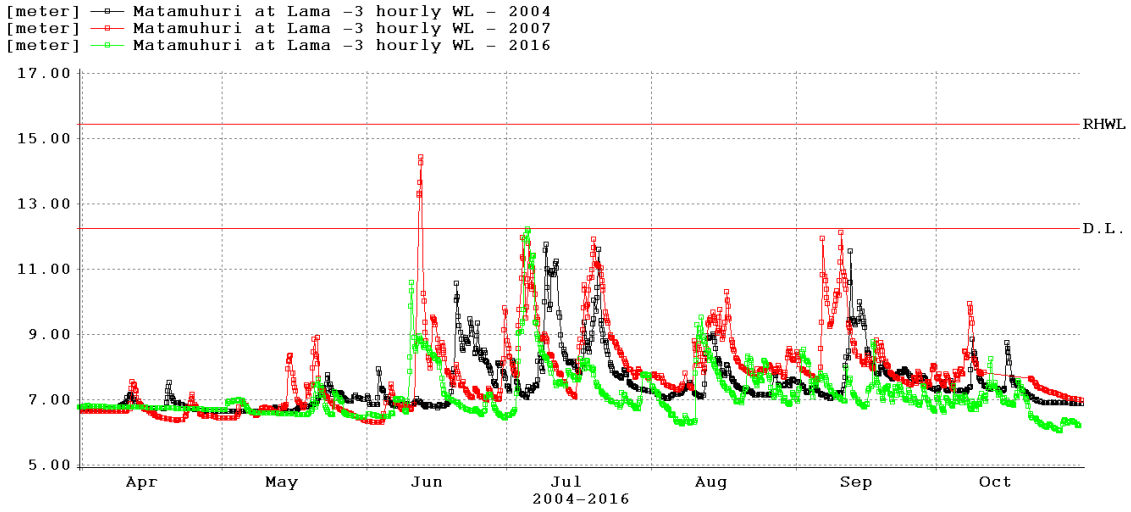


Figure 3.38: Comparison of Hydrograph on Matamuhuri at Lama

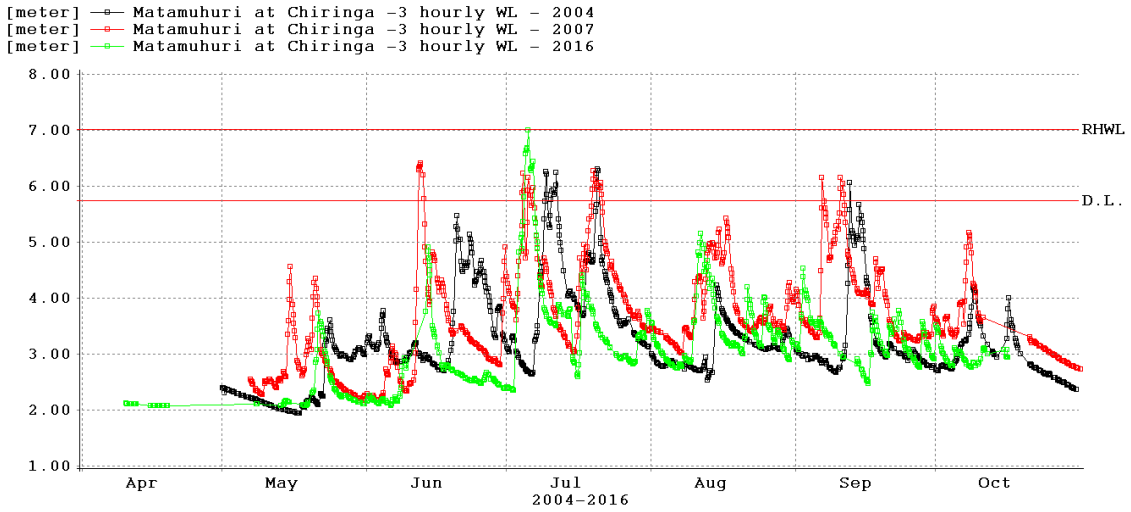


Figure 3.39: Comparison of Hydrograph on Matamuhuri at Chiringa

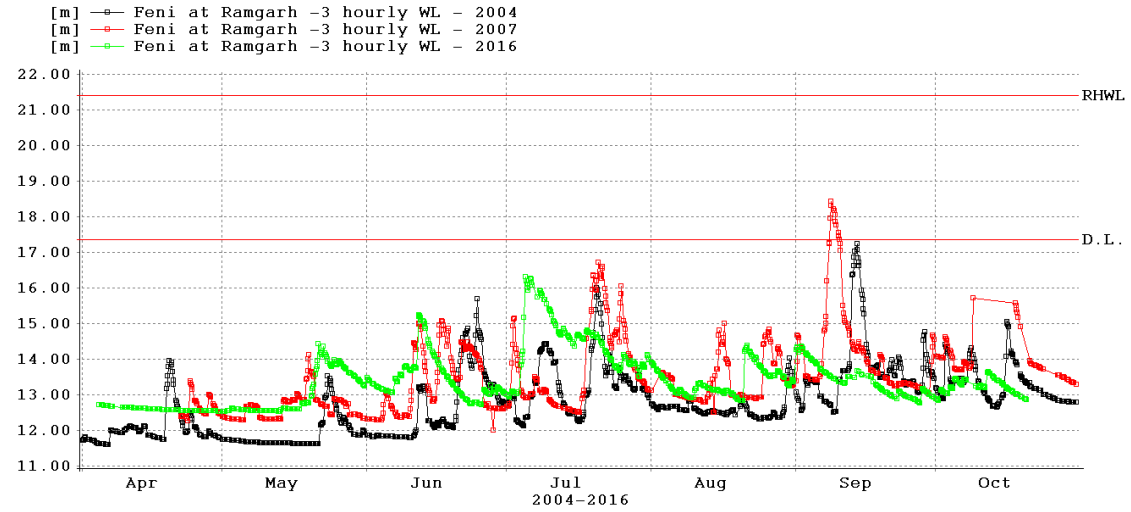


Figure 3.40: Comparison of Hydrograph on Feni at Ramgarh

CHAPTER 4: FORECAST EVALUATION- 2016

4.1 GENERAL

BWDB is the mandated organization for flood forecasting and warning services in Bangladesh as par the BWDB Act-2000. FFWC under BWDB has been carrying out this task through preparation of flood forecasting and early warning messages and its dissemination. Flood forecasting system of FFWC is developed using MIKE 11, a one-dimensional water modeling software used for the simulation of WLs and discharges in river networks and flood plains. The existing early warning system of floods provides a lead time of 120 hours, previously which was 72 hours. In order to meet the needs and expectations of flood forecast with increased lead times for cropping decisions, such as early harvesting, or to implement a contingency crop plan or protect infrastructure and preserve livelihoods, a research initiative was taken in July 2011 with support from CDMP-II under Ministry of Food and Disaster Management (MoFDM) (from middle of 2012 renamed as Ministry of Disaster Management and Relief) to increase lead time for deterministic flood forecast up to 5 days (120 hours) from then existing 3-days (72 hours) forecast and also to extend the flood forecast to few selected BWDB projects. Since June 2015, FFWC is generating and disseminating 5-days deterministic flood forecast with experimental 4th and 5th day forecast in 54 stations during monsoon on operational basis.

The Climate Forecast Applications in Bangladesh (CFAB) project was supported by USAID/OFDA to develop and evaluate three tire overlapping forecast systems with improved lead time during monsoon seasons of 2003 and 2004. It showed a success in forecasting the discharges at Hardinge Bridge station of Ganges and Bahadurabad station of Brahmaputra river of Bangladesh. From March 2006– June 2009, CARE-Bangladesh and United States Agency for International Development (USAID), Dhaka supported the program with an objective to technology transfer and capacity building for sustainable end-to-end generation and application of flood forecasts through pilot projects at selected sites.

Under the project, the medium range probabilistic flood forecast with 10-days lead time was initiated to a limited number of places (18 stations) on experimental basis. After the termination of the support from the USAID-CARE, this has been continued with technical support from RIMES. Another initiative was started in July 2012 to expand the number of points for medium range 10-days probabilistic flood forecast with a view to increase the areal coverage, along with a long range seasonal flood forecast at 5 places on experimental basis with support from USAID through CARE-Bangladesh under SHOURHARDO-II programme with technical support from RIMES. Currently FFWC is experimentally generating medium range 10-days probabilistic flood forecast in 37 stations during monsoon and disseminating on a limited basis.

4.2 EVALUATION CRITERIA OF FORECAST PERFORMANCE

Two statistical criteria considered for the performance evaluation of the model are as follows:

- Mean Absolute Error, MAE
- Co-efficient of Determination, r^2

4.2.1. Mean Absolute Error (MAE)

MAE is the mean of the absolute difference between *Observed* and *Forecast* levels as shown in the following equation:

$$MAE = \frac{\sum_{i=1}^{n} |x_i - y_i|}{n}$$

Where,

$x_1, x_2 \ldots\ldots x_n$ are *Observed* water levels

$y_1, y_2 \ldots\ldots y_n$ are *Forecast* water levels

n is the number of *Observed/Forecast* levels

4.2.2. Co-efficient of Determination, r^2

r^2 is the *Co-efficient of Determination* for the correlation of *Observed* and *Forecast* water levels and is given by the relation as show in the equation below:

$$r^2 = \frac{\left[\sum_{i=1}^{n} \left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)\right]^2}{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n} \left(y_i - \bar{y}\right)^2}$$

Where,

$x_1, x_2 \ldots\ldots x_n$ are *Observed* water levels

$\bar{x}$ is the average of *Observed* water levels

$y_1, y_2 \ldots\ldots y_n$ are *Forecast* water levels

$\bar{y}$ is the average of *Forecast* water levels

n is the number of *Observed/Forecast* levels

4.3 PRE-DEFINED SCALES TO EVALUATE FORECAST PERFORMANCE

The forecast performances for the monsoon-2016 have been evaluated from the statistical components r^2 (*Co-efficient of Determination*) and *MAE* (*Mean Absolute Error*). Values of the above two components in their ideal case are generally assumed to be in the order of $MAE = 0$

$r^2 = 1$

Utilizing above two indicators, 5 category scales have been used to describe forecast performances. Stations having a minimum value of 0.9 for r^2 and a maximum value of 15 centimeter for *MAE* have been considered as "*Good*" performance. Table 4.1 presents the definition of scales used in the evaluation:

Table 4.1: Scales used for performance evaluation

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

Simulations were made for maximum 120 hours in the forecast period and forecasts were saved in the database at 24-hour and 48-hour, 72-hour, 96-hour and 120-hour intervals. Usually, the forecast quality gradually deteriorated with higher forecast intervals from the time of forecast. As lead time increases the forecast accuracy decreases. Figures from 4.1 to 4.5 are shown the comparison of observed and forecasted WL for 24, 48, 72, 96 and 120 hours. Result of the statistical analysis and performance on the basis of the aforesaid scale are presented in Table 4.2, Table 4.3, Table 4.4, Table 4.5 and Table 4.6.

4.4 FORECAST STATISTICS AND MODEL PERFORMANCE, 2016

4.4.1. Deterministic forecast performance

For deterministic forecast, simulations were made up to 120 hours in the forecast period. Total 45 stations located within the model area (including some boundary stations) are evaluated. The deterministic forecast statistics along with performance based on the aforementioned scale are provided in Tables 4.2 to 4.6 and in Figures 4.1 to 4.5. From Table 4.2 and Table 4.6 it may be seen that for 1-day forecast 64.45% stations are within the range of Good and Average, while for 5-days forecast only 2.23% stations are in the range of Good and Average. A number of stations near boundary showed poor to very poor performance for increased lead time, most of which were of flashy characteristics or under regulated flow condition from upstream. From the following tables it may also be seen that based on the average statistics of co-efficient of determination of all stations the forecasts were 78% (Mean Absolute Error 0.17m), 71% (MAE 0.27m), 65% (MAE 0.34m), 59% (MAE 0.40m) and 54% (MAE 0.46m) accurate for 24 hours, 48 hours, 72 hours, 96 hours and 120 hours respectively for the monsoon of 2016.

Table 4.2: Statistics for 24- hour forecast performance

Sl. No.	Station	MAE (m)	r^2	Performance-24hr
1	Aricha	0.08	0.92	Good
2	Baghabari	0.08	0.92	Good
3	Bahadurabad	0.10	0.93	Good
4	Bhagyakul	0.08	0.93	Good
5	Bhairab Bazar	0.10	0.68	Not Satisfactory
6	Bogra	0.11	0.94	Good
7	Chakrahimpur	0.13	0.98	Good
8	Chapai Nawabganj	0.18	0.93	Average
9	Chilmari	0.10	0.94	Good
10	Demra	0.07	0.96	Good
11	Dhaka (Mill Barrack)	0.19	0.38	Poor
12	Elashinghat	0.08	0.93	Good
13	Gaibandha	0.14	0.92	Good
14	Goalondo	0.08	0.93	Good
15	Gorai Rly Bridge	0.15	0.93	Good
16	Hardinge Br	0.16	0.91	Average
17	Jagir	0.05	1.00	Good
18	Jamalpur	0.17	0.95	Average
19	Kamarkhali	0.11	0.94	Good
20	Kaunia	0.32	0.21	Very Poor
21	Kazipur	0.05	0.99	Good
22	Khaliajuri	0.66	0.05	Very Poor
23	Kurigram	0.16	0.90	Average
24	Lakhpur	0.21	0.52	Not Satisfactory
25	Markuli	1.08	0.05	Very Poor
26	Meghna Bridge	0.18	0.23	Very Poor
27	Mirpur	0.14	0.56	Not Satisfactory
28	Mohadevpur	0.22	0.93	Not Satisfactory
29	Moulvi Bazar	0.33	0.20	Very Poor
30	Mymensingh	0.18	0.95	Average
31	Naogaon	0.17	0.94	Average
32	Narayanganj	0.15	0.61	Not Satisfactory
33	Narsingdi	0.10	0.69	Not Satisfactory
34	Nayerhat	0.20	0.55	Not Satisfactory
35	Rajshahi	0.23	0.90	Not Satisfactory
36	Sariakandi	0.08	0.93	Good
37	Serajganj	0.08	0.92	Good
38	Sheola	0.19	0.90	Average
39	Sherpur-Sylhet	0.09	0.63	Not Satisfactory
40	Singra	0.10	0.93	Good
41	Sunamganj	0.08	0.98	Good
42	Sureswar	0.16	0.62	Not Satisfactory
43	Sylhet	0.11	0.97	Good
44	Taraghat	0.12	0.94	Good
45	Tongi	0.07	0.97	Good

Table 4.3: Statistics for 48- hour forecast performance

Sl. No.	Station	MAE (m)	r^2	Performance-48hr
1	Aricha	0.15	0.82	Average
2	Baghabari	0.14	0.84	Average
3	Bahadurabad	0.20	0.84	Average
4	Bhagyakul	0.14	0.85	Average
5	Bhairab Bazar	0.18	0.44	Not Satisfactory
6	Bogra	0.21	0.77	Not Satisfactory
7	Chakrahimpur	0.26	0.92	Not Satisfactory
8	Chapai Nawabganj	0.35	0.85	Poor
9	Chilmari	0.20	0.87	Average
10	Demra	0.13	0.89	Average
11	Dhaka (Mill Barrack)	0.18	0.74	Average
12	Elashinghat	0.14	0.86	Average
13	Gaibandha	0.27	0.83	Not Satisfactory
14	Goalondo	0.15	0.84	Average
15	Gorai Rly Bridge	0.28	0.85	Not Satisfactory
16	Hardinge Br	0.31	0.82	Poor
17	Jagir	0.09	0.99	Good
18	Jamalpur	0.28	0.89	Not Satisfactory
19	Kamarkhali	0.20	0.87	Average
20	Kaunia	0.41	0.15	Very Poor
21	Kazipur	0.10	0.94	Good
22	Khaliajuri	0.85	0.05	Very Poor
23	Kurigram	0.28	0.78	Not Satisfactory
24	Lakhpur	0.29	0.41	Not Satisfactory
25	Markuli	1.38	0.06	Very Poor
26	Meghna Bridge	0.34	0.11	Very Poor
27	Mirpur	0.20	0.53	Not Satisfactory
28	Mohadevpur	0.37	0.82	Poor
29	Moulvi Bazar	0.44	0.13	Very Poor
30	Mymensingh	0.33	0.87	Poor
31	Naogaon	0.33	0.86	Poor
32	Narayanganj	0.18	0.78	Average
33	Narsingdi	0.16	0.62	Not Satisfactory
34	Nayerhat	0.30	0.44	Not Satisfactory
35	Rajshahi	0.46	0.80	Very Poor
36	Sariakandi	0.16	0.85	Average
37	Serajganj	0.15	0.82	Average
38	Sheola	0.38	0.71	Poor
39	Sherpur-Sylhet	0.12	0.58	Not Satisfactory
40	Singra	0.17	0.88	Average
41	Sunamganj	0.14	0.94	Good
42	Sureswar	0.25	0.49	Not Satisfactory
43	Sylhet	0.22	0.89	Not Satisfactory
44	Taraghat	0.22	0.86	Not Satisfactory
45	Tongi	0.13	0.90	Good

Table 4.4: Statistics for 72- hour forecast performance

Sl. No.	Station	MAE (m)	r^2	Performance-72hr
1	Aricha	0.18	0.81	Average
2	Baghabari	0.17	0.83	Average
3	Bahadurabad	0.28	0.81	Not Satisfactory
4	Bhagyakul	0.20	0.65	Not Satisfactory
5	Bhairab Bazar	0.22	0.39	Poor
6	Bogra	0.32	0.58	Poor
7	Chakrahimpur	0.39	0.82	Poor
8	Chapai Nawabganj	0.44	0.85	Very Poor
9	Chilmari	0.29	0.84	Not Satisfactory
10	Demra	0.17	0.83	Average
11	Dhaka (Mill Barrack)	0.33	0.32	Poor
12	Elashinghat	0.17	0.84	Average
13	Gaibandha	0.36	0.78	Poor
14	Goalondo	0.18	0.83	Average
15	Gorai Rly Bridge	0.34	0.83	Poor
16	Hardinge Br	0.38	0.80	Poor
17	Jagir	0.13	0.97	Good
18	Jamalpur	0.35	0.86	Poor
19	Kamarkhali	0.24	0.86	Not Satisfactory
20	Kaunia	0.46	0.13	Very Poor
21	Kazipur	0.15	0.87	Average
22	Khaliajuri	0.94	0.04	Very Poor
23	Kurigram	0.36	0.72	Poor
24	Lakhpur	0.34	0.36	Poor
25	Markuli	1.47	0.05	Very Poor
26	Meghna Bridge	0.44	0.08	Very Poor
27	Mirpur	0.24	0.50	Not Satisfactory
28	Mohadevpur	0.46	0.74	Very Poor
29	Moulvi Bazar	0.53	0.05	Very Poor
30	Mymensingh	0.41	0.82	Very Poor
31	Naogaon	0.44	0.79	Very Poor
32	Narayanganj	0.27	0.38	Poor
33	Narsingdi	0.20	0.56	Not Satisfactory
34	Nayerhat	0.36	0.39	Poor
35	Rajshahi	0.56	0.79	Very Poor
36	Sariakandi	0.23	0.83	Not Satisfactory
37	Serajganj	0.21	0.81	Not Satisfactory
38	Sheola	0.52	0.57	Very Poor
39	Sherpur-Sylhet	0.16	0.52	Not Satisfactory
40	Singra	0.21	0.86	Not Satisfactory
41	Sunamganj	0.20	0.87	Average
42	Sureswar	0.33	0.37	Poor
43	Sylhet	0.32	0.80	Poor
44	Taraghat	0.28	0.83	Not Satisfactory
45	Tongi	0.17	0.84	Average

Table 4.5: Statistics for 96- hour forecast performance

Sl. No.	Station	MAE (m)	r^2	Performance-96hr
1	Aricha	0.21	0.79	Not Satisfactory
2	Baghabari	0.21	0.81	Not Satisfactory
3	Bahadurabad	0.36	0.78	Poor
4	Bhagyakul	0.23	0.62	Not Satisfactory
5	Bhairab Bazar	0.29	0.23	Very Poor
6	Bogra	0.42	0.40	Very Poor
7	Chakrahimpur	0.53	0.70	Very Poor
8	Chapai Nawabganj	0.53	0.84	Very Poor
9	Chilmari	0.37	0.80	Poor
10	Demra	0.21	0.76	Not Satisfactory
11	Dhaka (Mill Barrack)	0.38	0.22	Very Poor
12	Elashinghat	0.22	0.82	Not Satisfactory
13	Gaibandha	0.42	0.74	Very Poor
14	Goalondo	0.22	0.81	Not Satisfactory
15	Gorai Rly Bridge	0.41	0.82	Very Poor
16	Hardinge Br	0.45	0.79	Very Poor
17	Jagir	0.17	0.94	Average
18	Jamalpur	0.41	0.84	Very Poor
19	Kamarkhali	0.28	0.86	Not Satisfactory
20	Kaunia	0.45	0.12	Very Poor
21	Kazipur	0.20	0.75	Average
22	Khaliajuri	0.94	0.03	Very Poor
23	Kurigram	0.43	0.68	Very Poor
24	Lakhpur	0.41	0.30	Very Poor
25	Markuli	1.62	0.02	Very Poor
26	Meghna Bridge	0.53	0.05	Very Poor
27	Mirpur	0.28	0.46	Not Satisfactory
28	Mohadevpur	0.54	0.64	Very Poor
29	Moulvi Bazar	0.58	0.02	Very Poor
30	Mymensingh	0.46	0.78	Very Poor
31	Naogaon	0.52	0.70	Very Poor
32	Narayanganj	0.33	0.28	Very Poor
33	Narsingdi	0.24	0.49	Not Satisfactory
34	Nayerhat	0.46	0.29	Very Poor
35	Rajshahi	0.67	0.78	Very Poor
36	Sariakandi	0.30	0.79	Not Satisfactory
37	Serajganj	0.27	0.77	Not Satisfactory
38	Sheola	0.62	0.47	Very Poor
39	Sherpur-Sylhet	0.18	0.46	Not Satisfactory
40	Singra	0.26	0.80	Not Satisfactory
41	Sunamganj	0.24	0.81	Not Satisfactory
42	Sureswar	0.41	0.23	Very Poor
43	Sylhet	0.41	0.71	Very Poor
44	Taraghat	0.33	0.80	Poor
45	Tongi	0.21	0.76	Not Satisfactory

Table 4.6: Statistics for 120- hour forecast performance

Sl. No.	Station	MAE (m)	r^2	Performance-120hr
1	Aricha	0.25	0.76	Not Satisfactory
2	Baghabari	0.25	0.79	Not Satisfactory
3	Bahadurabad	0.44	0.72	Very Poor
4	Bhagyakul	0.26	0.58	Not Satisfactory
5	Bhairab Bazar	0.36	0.12	Very Poor
6	Bogra	0.52	0.27	Very Poor
7	Chakrahimpur	0.64	0.57	Very Poor
8	Chapai Nawabganj	0.64	0.82	Very Poor
9	Chilmari	0.46	0.75	Very Poor
10	Demra	0.24	0.68	Not Satisfactory
11	Dhaka (Mill Barrack)	0.44	0.16	Very Poor
12	Elashinghat	0.27	0.79	Not Satisfactory
13	Gaibandha	0.49	0.69	Very Poor
14	Goalondo	0.25	0.78	Not Satisfactory
15	Gorai Rly Bridge	0.48	0.80	Very Poor
16	Hardinge Br	0.51	0.78	Very Poor
17	Jagir	0.20	0.90	Average
18	Jamalpur	0.49	0.80	Very Poor
19	Kamarkhali	0.33	0.85	Poor
20	Kaunia	0.46	0.10	Very Poor
21	Kazipur	0.27	0.60	Not Satisfactory
22	Khaliajuri	0.85	0.01	Very Poor
23	Kurigram	0.51	0.63	Very Poor
24	Lakhpur	0.45	0.28	Very Poor
25	Markuli	1.68	0.01	Very Poor
26	Meghna Bridge	0.61	0.06	Very Poor
27	Mirpur	0.32	0.38	Poor
28	Mohadevpur	0.64	0.51	Very Poor
29	Moulvi Bazar	0.63	0.01	Very Poor
30	Mymensingh	0.52	0.74	Very Poor
31	Naogaon	0.61	0.62	Very Poor
32	Narayanganj	0.40	0.13	Very Poor
33	Narsingdi	0.28	0.41	Not Satisfactory
34	Nayerhat	0.50	0.25	Very Poor
35	Rajshahi	0.78	0.76	Very Poor
36	Sariakandi	0.38	0.73	Poor
37	Serajganj	0.35	0.72	Poor
38	Sheola	0.69	0.39	Very Poor
39	Sherpur-Sylhet	0.20	0.44	Not Satisfactory
40	Singra	0.29	0.78	Not Satisfactory
41	Sunamganj	0.29	0.74	Not Satisfactory
42	Sureswar	0.49	0.10	Very Poor
43	Sylhet	0.48	0.63	Very Poor
44	Taraghat	0.37	0.77	Poor
45	Tongi	0.25	0.68	Not Satisfactory

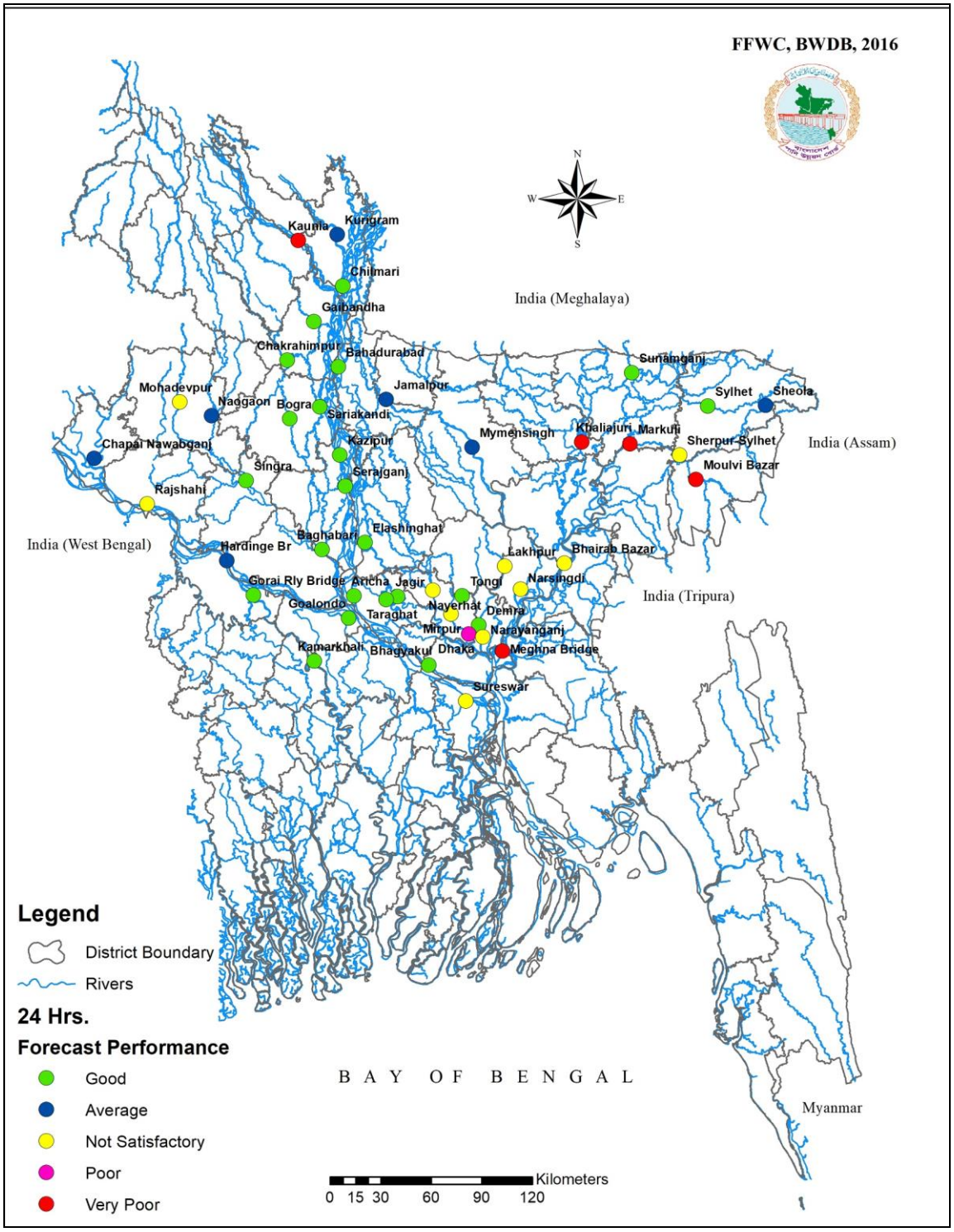


Figure 4.1 : 24 hr Forecast Evaluation (Year, 2016)

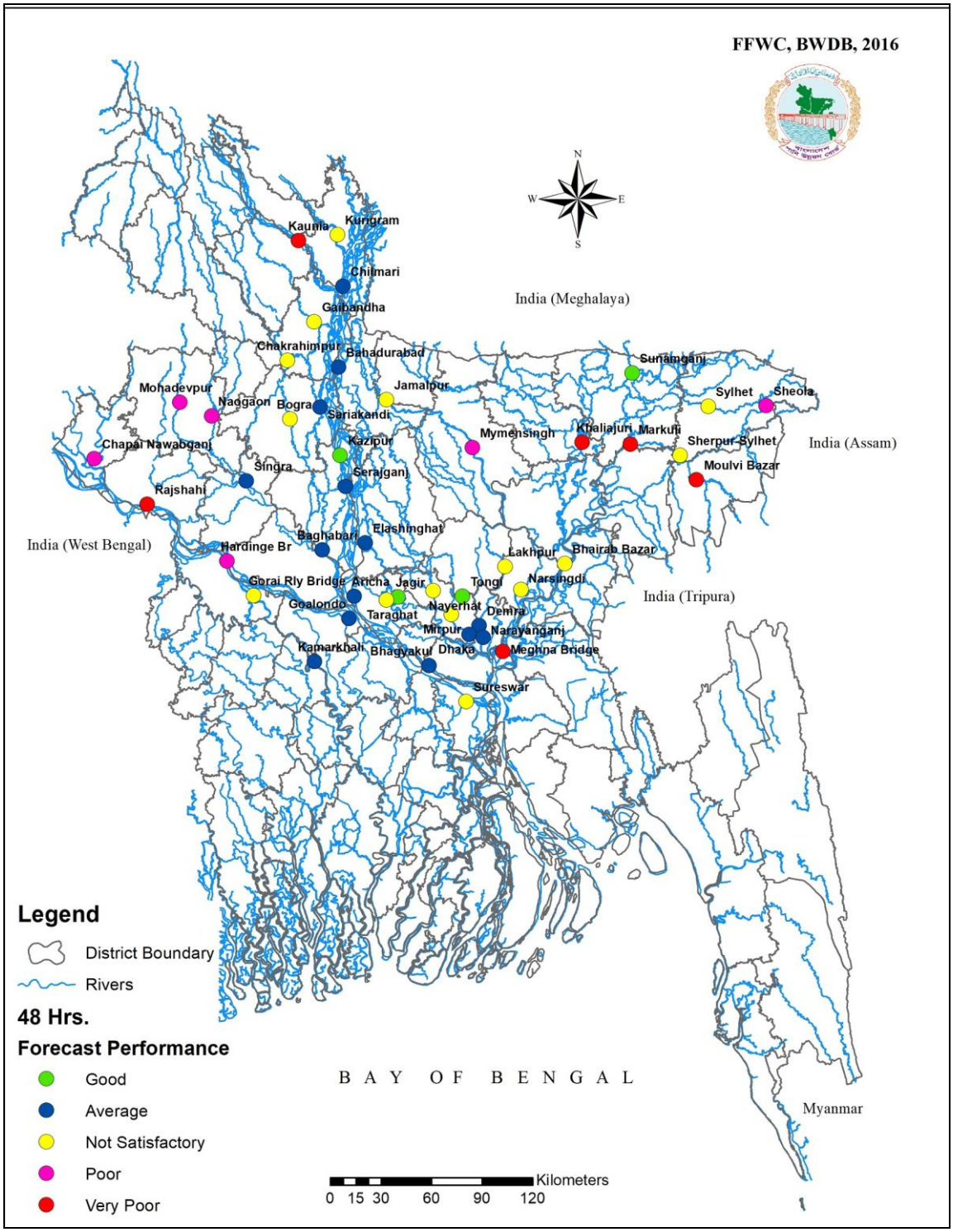


Figure 4.2 : 48 hr Forecast Evaluation (Year, 2016)

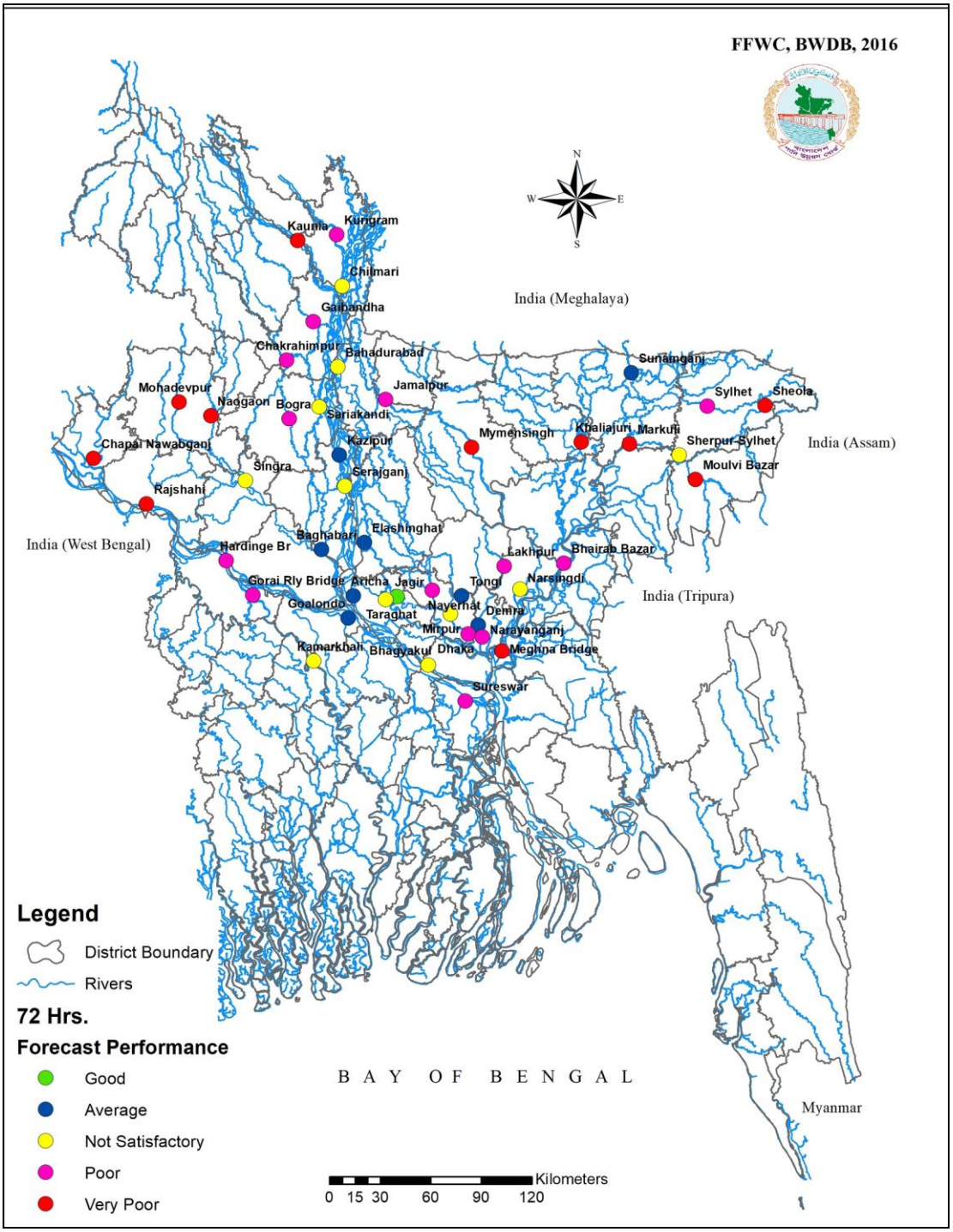


Figure 4.3 : 72 hr Forecast Evaluation (Year, 2016)

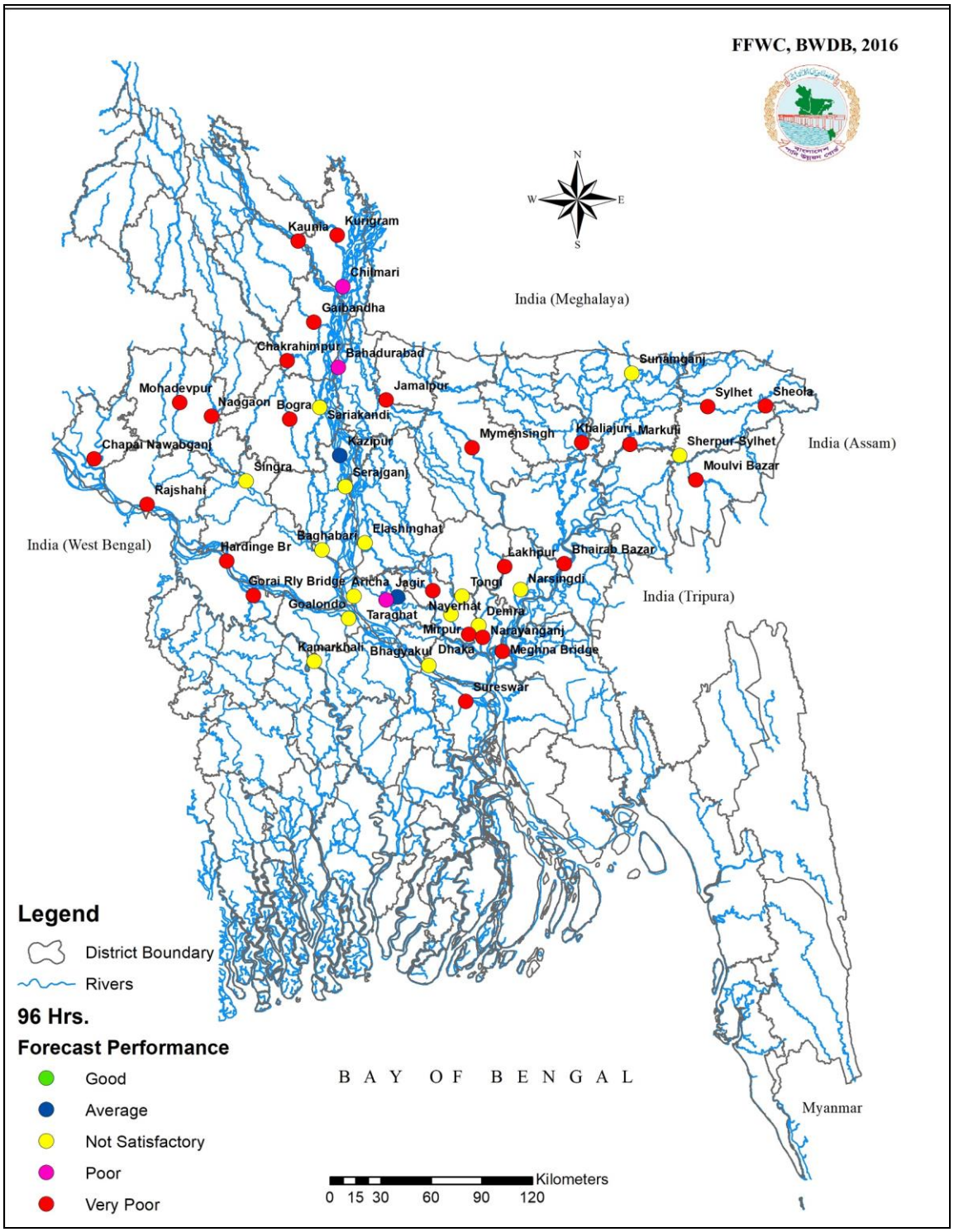


Figure 4.4 : 96 hr Forecast Evaluation (Year, 2016)

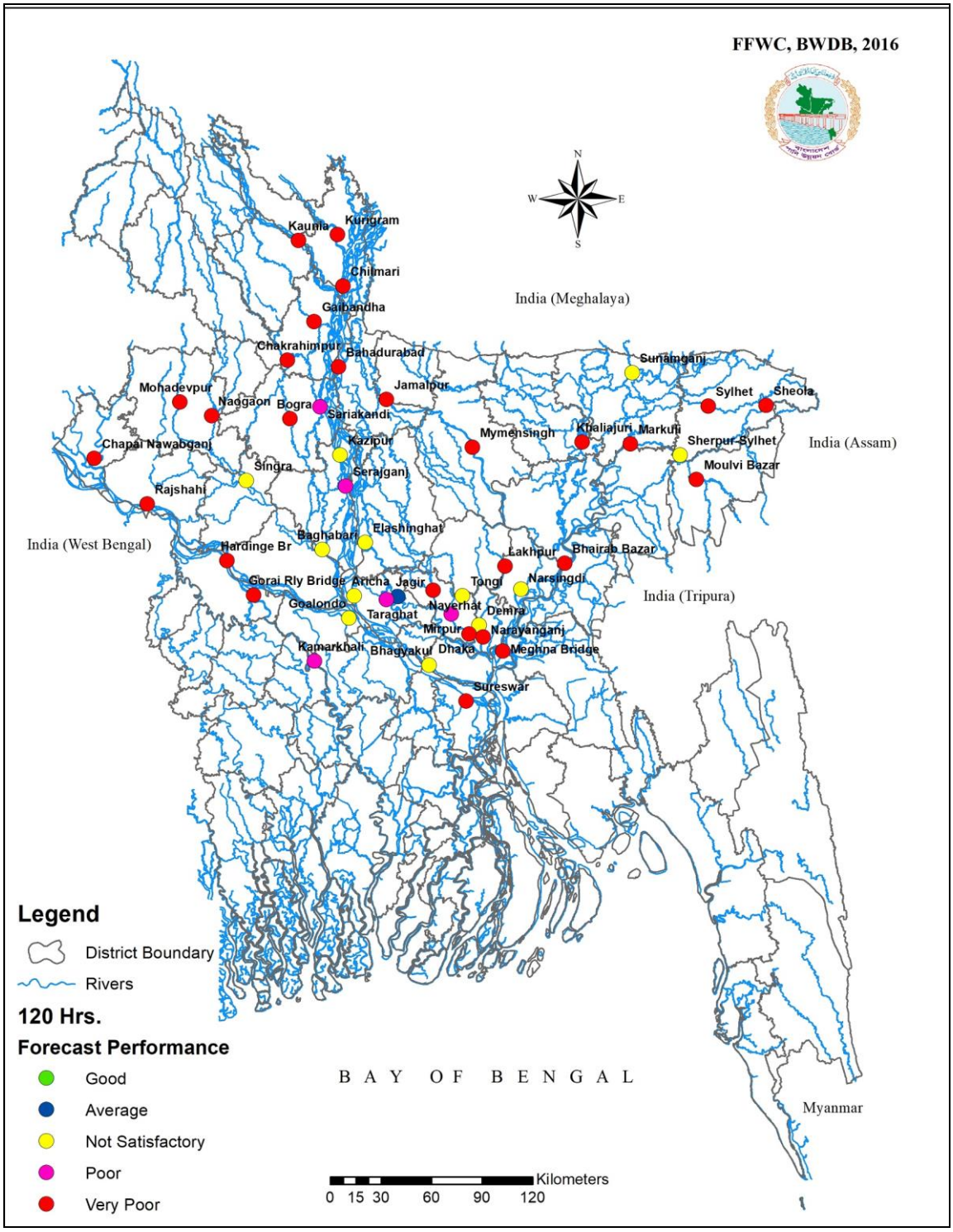


Figure 4.5 : 120 hr Forecast Evaluation (Year, 2016)

4.4.2 Medium Range (upto 10-days) Probabilistic Forecast Performance

CFAN (Climate Forecast Application Network) utilizes ECMWF (European Centre for Medium-Range Weather Forecasts) weather prediction data in their model to generate 51 sets of ensemble discharge forecasts data on the Brahmaputra at Bahadurabad and on the Ganges at Hardinge-Bridge in Bangladesh. The updated FFWC model was taken for

customization for real-time flood forecasting utilizing CFAN predictions. The customized FFWC model used for the flood forecasting of extended lead-time (medium range upto 10-days) using climate forecast application data has been named CFAB-FFS (CFAB Flood Forecasting Study) model.

In addition to existing 24, 48, 72, 96 & 120 hrs deterministic forecast, CFAN model generates medium range 10 days lead-time probabilistic forecasts for mean, upper bound and lower bound WL at 37 locations listed below on experimental basis. The Mean Water Level forecast made from the mean discharge and the mean rainfall forecast of all 51 ensemble series. The Upper bound and Lower bound water corresponds to +1 standard deviation from the mean and -1 standard deviation from the mean respectively.

The statistics of forecast performance based on the MAE, RMSE and r^2 at different time-scale up to 10 days for the 37 number of stations under FFWC system have been presented through Table 4.5 to Table 4.8.

Table 4.7 : Performance of 3-day Probabilistic Forecast

Stations	Standard Deviation (-1)			Mean			Standard Deviation (+1)		
	MAE (m)	RMSE (m)	r^2	MAE (m)	RMSE (m)	r^2	MAE (m)	RMSE (m)	r^2
Aricha	0.24	0.28	0.95	0.15	0.18	0.96	0.10	0.14	0.96
Baghbari	0.19	0.25	0.95	0.17	0.21	0.94	0.15	0.19	0.94
Bahadurabad	0.52	0.60	0.89	0.35	0.42	0.92	0.26	0.34	0.90
Bhagyakul	0.17	0.22	0.87	0.16	0.20	0.88	0.20	0.24	0.88
Bhairab Bz	0.26	0.43	0.67	0.26	0.43	0.67	0.26	0.42	0.67
Chandpur	0.25	0.32	0.62	0.25	0.32	0.62	0.25	0.32	0.62
Demra	0.15	0.17	0.93	0.15	0.17	0.93	0.15	0.17	0.93
Dhaka	0.19	0.24	0.78	0.20	0.24	0.78	0.21	0.26	0.77
Dirai	0.30	0.41	0.80	0.30	0.41	0.80	0.30	0.41	0.80
Elashinghat	0.34	0.40	0.91	0.27	0.31	0.90	0.20	0.25	0.89
Faridpur	0.11	0.13	0.98	0.11	0.13	0.98	0.11	0.13	0.98
Goalondo	0.22	0.27	0.94	0.15	0.18	0.95	0.13	0.18	0.95
Gorai Rly. Br	0.27	0.34	0.97	0.21	0.28	0.98	0.34	0.45	0.97
Hardinge Br	0.36	0.46	0.96	0.31	0.41	0.97	0.51	0.66	0.96
Jagir	0.13	0.21	0.95	0.14	0.21	0.95	0.14	0.21	0.95
Jamalpur	0.33	0.40	0.94	0.30	0.36	0.94	0.28	0.36	0.94
Kamarkhali	0.18	0.23	0.98	0.15	0.21	0.99	0.26	0.34	0.98
Kanaighat	1.06	1.64	0.44	1.06	1.64	0.44	1.06	1.64	0.44
Kazipur	0.42	0.50	0.93	0.31	0.37	0.93	0.22	0.29	0.93
Madaripur	0.13	0.16	0.85	0.13	0.16	0.86	0.14	0.18	0.87
Mawa	0.15	0.17	0.95	0.10	0.13	0.96	0.11	0.15	0.95
Mirpur	0.17	0.23	0.87	0.18	0.23	0.87	0.19	0.23	0.86
Mohadevpur	0.60	0.81	0.70	0.60	0.81	0.70	0.60	0.81	0.70
Moulvibazar	0.83	1.20	0.01	0.83	1.20	0.01	0.83	1.20	0.01
Mymensingh	0.33	0.45	0.88	0.33	0.45	0.88	0.34	0.45	0.88

Naogaon	0.44	0.59	0.78	0.44	0.59	0.78	0.44	0.59	0.78
Narayanganj	0.21	0.29	0.67	0.21	0.29	0.67	0.21	0.29	0.66
Narsingdi	0.12	0.14	0.94	0.12	0.14	0.94	0.12	0.14	0.94
RekabiBazar	0.11	0.15	0.90	0.14	0.19	0.89	0.14	0.19	0.89
Sariakandi	0.42	0.49	0.92	0.29	0.35	0.93	0.20	0.27	0.93
Serajganj	0.41	0.46	0.91	0.28	0.33	0.92	0.18	0.25	0.92
Sheola	1.06	1.65	0.21	1.06	1.65	0.21	1.06	1.65	0.21
Sherpur	0.19	0.28	0.65	0.19	0.28	0.65	0.19	0.28	0.65
Sunamganj	0.32	0.48	0.78	0.32	0.48	0.78	0.32	0.48	0.78
Sureshwar	0.27	0.34	0.46	0.24	0.32	0.48	0.23	0.34	0.48
Sylhet	0.63	1.05	0.58	0.63	1.05	0.58	0.63	1.05	0.58
Tongi	0.11	0.14	0.94	0.11	0.14	0.94	0.12	0.15	0.94

Table 4.8: Performance of 5-day Probabilistic Forecast

	Standard Deviation (-1)			Mean			Standard Deviation (+1)		
Stations	MAE (m)	RMSE (m)	r^2	MAE (m)	RMSE (m)	r^2	MAE (m)	RMSE (m)	r^2
Aricha	0.45	0.50	0.87	0.24	0.29	0.89	0.22	0.29	0.85
Baghbari	0.38	0.45	0.85	0.29	0.35	0.84	0.28	0.35	0.77
Bahadurabad	0.75	0.84	0.84	0.52	0.59	0.85	0.38	0.45	0.84
Bhagyakul	0.29	0.35	0.80	0.18	0.23	0.83	0.26	0.33	0.79
Bhairab Bz	0.30	0.44	0.68	0.30	0.43	0.67	0.30	0.43	0.66
Chandpur	0.36	0.44	0.36	0.36	0.44	0.36	0.36	0.44	0.36
Demra	0.19	0.23	0.87	0.19	0.24	0.86	0.21	0.26	0.85
Dhaka	0.19	0.26	0.79	0.22	0.28	0.78	0.28	0.33	0.74
Dirai	0.51	0.64	0.53	0.51	0.64	0.53	0.51	0.64	0.53
Elashinghat	0.57	0.66	0.81	0.40	0.47	0.78	0.35	0.43	0.63
Faridpur	0.18	0.21	0.95	0.18	0.21	0.95	0.18	0.21	0.95
Goalondo	0.42	0.48	0.84	0.24	0.28	0.86	0.26	0.34	0.81
Gorai Rly. Br	0.49	0.73	0.89	0.36	0.48	0.93	0.50	0.65	0.93
Hardinge Br	0.64	0.94	0.84	0.55	0.68	0.89	0.73	0.92	0.88
Jagir	0.21	0.30	0.93	0.20	0.28	0.93	0.21	0.27	0.93
Jamalpur	0.57	0.69	0.89	0.46	0.57	0.89	0.39	0.51	0.88
Kamarkhali	0.37	0.54	0.92	0.29	0.39	0.94	0.43	0.56	0.94
Kanaighat	1.41	1.91	0.29	1.41	1.91	0.29	1.41	1.91	0.29
Kazipur	0.66	0.76	0.83	0.46	0.55	0.84	0.35	0.43	0.84
Madaripur	0.20	0.26	0.71	0.18	0.23	0.71	0.23	0.28	0.68
Mawa	0.27	0.32	0.89	0.16	0.20	0.90	0.19	0.25	0.86
Mirpur	0.22	0.28	0.85	0.22	0.28	0.84	0.24	0.29	0.81
Mohadevpur	0.73	1.01	0.57	0.73	1.01	0.57	0.73	1.01	0.57
Moulvibazar	1.09	1.45	0.02	1.09	1.45	0.02	1.09	1.45	0.02
Mymensingh	0.54	0.70	0.75	0.52	0.69	0.75	0.50	0.68	0.76
Naogaon	0.64	0.82	0.59	0.64	0.82	0.59	0.64	0.82	0.59
Narayanganj	0.22	0.30	0.70	0.24	0.32	0.68	0.28	0.37	0.62
Narsingdi	0.17	0.20	0.89	0.17	0.20	0.89	0.17	0.20	0.89

RekabiBazar	0.16	0.21	0.85	0.24	0.29	0.77	0.24	0.29	0.77
Sariakandi	0.64	0.72	0.85	0.41	0.50	0.88	0.31	0.38	0.86
Serajganj	0.64	0.72	0.82	0.40	0.49	0.84	0.32	0.39	0.81
Sheola	1.36	1.88	0.12	1.36	1.88	0.12	1.36	1.88	0.12
Sherpur	0.31	0.41	0.42	0.31	0.41	0.42	0.31	0.41	0.42
Sunamganj	0.50	0.69	0.58	0.50	0.69	0.58	0.50	0.69	0.58
Sureshwar	0.38	0.45	0.27	0.33	0.42	0.27	0.34	0.48	0.21
Sylhet	0.90	1.35	0.37	0.90	1.35	0.37	0.90	1.35	0.37
Tongi	0.15	0.19	0.90	0.17	0.21	0.89	0.20	0.24	0.87

Table 4.9: Performance of 7-day Probabilistic Forecast

	Standard Deviation (-1)			Mean			Standard Deviation (+1)		
Stations	MAE (m)	RMSE (m)	r^2	MAE (m)	RMSE (m)	r^2	MAE (m)	RMSE (m)	r^2
Aricha	0.62	0.71	0.69	0.36	0.45	0.70	0.34	0.41	0.64
Baghbari	0.59	0.67	0.66	0.44	0.53	0.63	0.41	0.49	0.54
Bahadurabad	0.92	1.02	0.74	0.64	0.71	0.76	0.43	0.53	0.77
Bhagyakul	0.44	0.50	0.66	0.25	0.30	0.69	0.29	0.37	0.65
Bhairab Bz	0.32	0.43	0.72	0.31	0.42	0.71	0.32	0.42	0.69
Chandpur	0.45	0.53	0.12	0.45	0.53	0.12	0.45	0.53	0.12
Demra	0.24	0.29	0.81	0.26	0.32	0.79	0.30	0.36	0.74
Dhaka	0.20	0.27	0.79	0.23	0.30	0.78	0.33	0.39	0.70
Dirai	0.72	0.84	0.28	0.72	0.84	0.28	0.72	0.84	0.28
Elashinghat	0.81	0.91	0.62	0.54	0.65	0.57	0.46	0.55	0.39
Faridpur	0.24	0.26	0.93	0.24	0.26	0.93	0.24	0.26	0.93
Goalondo	0.58	0.67	0.68	0.36	0.43	0.67	0.36	0.46	0.58
Gorai Rly. Br	0.62	0.83	0.85	0.50	0.68	0.84	0.66	0.88	0.82
Hardinge Br	0.75	0.98	0.82	0.72	0.89	0.78	0.93	1.21	0.73
Jagir	0.32	0.40	0.92	0.25	0.33	0.92	0.23	0.29	0.93
Jamalpur	0.88	1.03	0.83	0.67	0.81	0.84	0.44	0.58	0.86
Kamarkhali	0.49	0.64	0.89	0.38	0.52	0.88	0.55	0.73	0.85
Kanaighat	1.69	2.11	0.13	1.69	2.11	0.13	1.69	2.11	0.13
Kazipur	0.83	0.96	0.76	0.60	0.68	0.75	0.46	0.55	0.73
Madaripur	0.29	0.36	0.59	0.22	0.27	0.58	0.26	0.33	0.52
Mawa	0.42	0.48	0.77	0.26	0.30	0.75	0.26	0.34	0.66
Mirpur	0.25	0.31	0.85	0.25	0.30	0.84	0.30	0.34	0.78
Mohadevpur	1.01	1.29	0.31	1.01	1.29	0.31	1.01	1.29	0.31
Moulvibazar	1.00	1.40	0.00	1.00	1.40	0.00	1.00	1.40	0.00
Mymensingh	0.71	0.89	0.68	0.65	0.84	0.69	0.62	0.82	0.68
Naogaon	0.82	1.02	0.37	0.82	1.02	0.37	0.82	1.02	0.37
Narayanganj	0.28	0.37	0.61	0.29	0.39	0.57	0.34	0.47	0.46
Narsingdi	0.21	0.26	0.83	0.21	0.26	0.83	0.21	0.26	0.83
RekabiBazar	0.21	0.28	0.78	0.32	0.39	0.63	0.32	0.39	0.63
Sariakandi	0.81	0.92	0.79	0.53	0.60	0.82	0.36	0.44	0.81
Serajganj	0.86	0.95	0.74	0.52	0.62	0.76	0.38	0.46	0.74
Sheola	1.58	2.08	0.04	1.58	2.08	0.04	1.58	2.08	0.04
Sherpur	0.40	0.50	0.27	0.40	0.50	0.27	0.40	0.50	0.27

Sunamganj	0.67	0.84	0.40	0.67	0.84	0.40	0.67	0.84	0.40
Sureshwar	0.48	0.57	0.12	0.40	0.48	0.14	0.43	0.56	0.08
Sylhet	1.12	1.51	0.22	1.12	1.51	0.22	1.12	1.51	0.22
Tongi	0.19	0.23	0.87	0.21	0.26	0.84	0.28	0.33	0.79

Table 4.10: Performance of 10-day Probabilistic Forecast

	Standard Deviation (-1)			Mean			Standard Deviation (+1)		
Stations	MAE (m)	RMSE (m)	r^2	MAE (m)	RMSE (m)	r^2	MAE (m)	RMSE (m)	r^2
Aricha	0.76	0.91	0.33	0.50	0.60	0.38	0.45	0.55	0.35
Baghbari	0.78	0.92	0.31	0.62	0.74	0.28	0.57	0.68	0.24
Bahadurabad	1.06	1.20	0.56	0.74	0.86	0.61	0.58	0.71	0.60
Bhagyakul	0.55	0.65	0.38	0.34	0.40	0.41	0.38	0.46	0.35
Bhairab Bz	0.33	0.43	0.79	0.31	0.41	0.77	0.33	0.43	0.74
Chandpur	0.48	0.58	0.04	0.48	0.58	0.04	0.48	0.58	0.04
Demra	0.29	0.37	0.73	0.30	0.40	0.70	0.36	0.48	0.64
Dhaka	0.27	0.33	0.76	0.27	0.35	0.70	0.37	0.46	0.61
Dirai	0.84	0.95	0.18	0.84	0.95	0.18	0.84	0.95	0.18
Elashinghat	0.97	1.16	0.23	0.67	0.83	0.25	0.58	0.68	0.17
Faridpur	0.32	0.34	0.89	0.32	0.34	0.89	0.32	0.34	0.89
Goalondo	0.73	0.85	0.37	0.49	0.58	0.37	0.49	0.61	0.29
Gorai Rly. Br	0.95	1.10	0.63	0.75	0.93	0.63	0.80	1.11	0.62
Hardinge Br	1.04	1.24	0.59	0.87	1.11	0.55	1.08	1.40	0.50
Jagir	0.52	0.64	0.84	0.36	0.48	0.86	0.27	0.37	0.89
Jamalpur	1.14	1.34	0.74	0.82	0.98	0.77	0.51	0.65	0.81
Kamarkhali	0.77	0.91	0.69	0.63	0.77	0.65	0.66	0.91	0.62
Kanaighat	1.83	2.15	0.05	1.83	2.15	0.05	1.83	2.15	0.05
Kazipur	0.95	1.13	0.61	0.69	0.82	0.64	0.57	0.69	0.62
Madaripur	0.45	0.50	0.40	0.27	0.34	0.34	0.32	0.42	0.20
Mawa	0.57	0.65	0.41	0.35	0.43	0.42	0.34	0.44	0.36
Mirpur	0.31	0.38	0.83	0.28	0.36	0.78	0.35	0.43	0.72
Mohadevpur	1.24	1.62	0.07	1.24	1.62	0.07	1.24	1.62	0.07
Moulvibazar	0.80	1.23	0.03	0.80	1.23	0.03	0.80	1.23	0.03
Mymensingh	0.93	1.09	0.65	0.80	0.96	0.65	0.73	0.90	0.63
Naogaon	1.06	1.29	0.06	1.06	1.29	0.06	1.06	1.29	0.06
Narayanganj	0.39	0.50	0.40	0.38	0.51	0.36	0.42	0.57	0.30
Narsingdi	0.29	0.37	0.70	0.29	0.37	0.70	0.29	0.37	0.70
RekabiBazar	0.33	0.40	0.63	0.40	0.51	0.47	0.40	0.51	0.47
Sariakandi	0.93	1.08	0.64	0.63	0.74	0.68	0.48	0.59	0.68
Serajganj	0.99	1.14	0.53	0.64	0.77	0.58	0.49	0.59	0.58
Sheola	1.77	2.19	0.00	1.77	2.19	0.00	1.77	2.19	0.00
Sherpur	0.50	0.59	0.07	0.50	0.59	0.07	0.50	0.59	0.07
Sunamganj	0.77	0.88	0.29	0.77	0.88	0.29	0.77	0.88	0.29
Sureshwar	0.54	0.62	0.14	0.41	0.51	0.15	0.42	0.56	0.15
Sylhet	1.30	1.57	0.09	1.30	1.57	0.09	1.30	1.57	0.09
Tongi	0.21	0.28	0.78	0.26	0.33	0.73	0.37	0.43	0.64

Following charts showing the MAE and r^2 plots for Serajganj, Hardinge Bridge and Bhairab Bazar stations for monsoon 2016 indicate that as the lead time gets longer, the r^2 value decreases and MAE increases, which is an indicator of less accurate forecast with higher lead time.

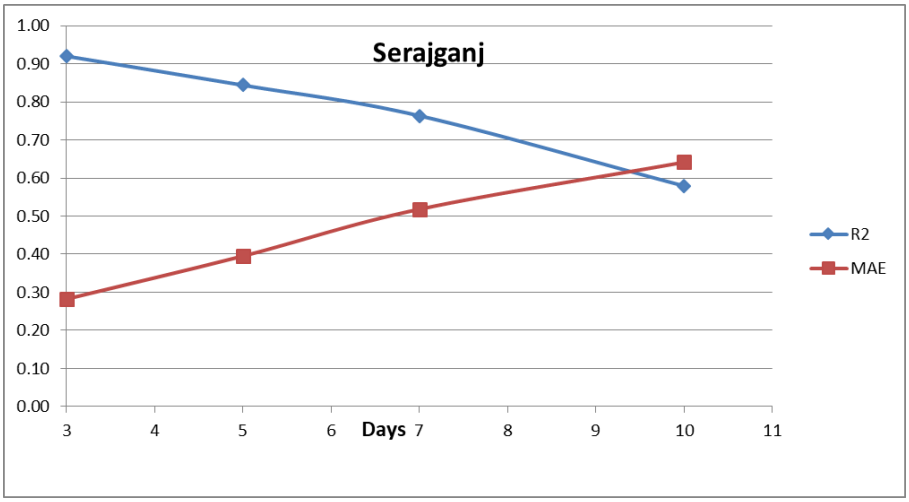


Figure 4.6 : MAE and r^2 Plot of Sirajganj for 10-days Probabilistic Forecast (Year, 2016)

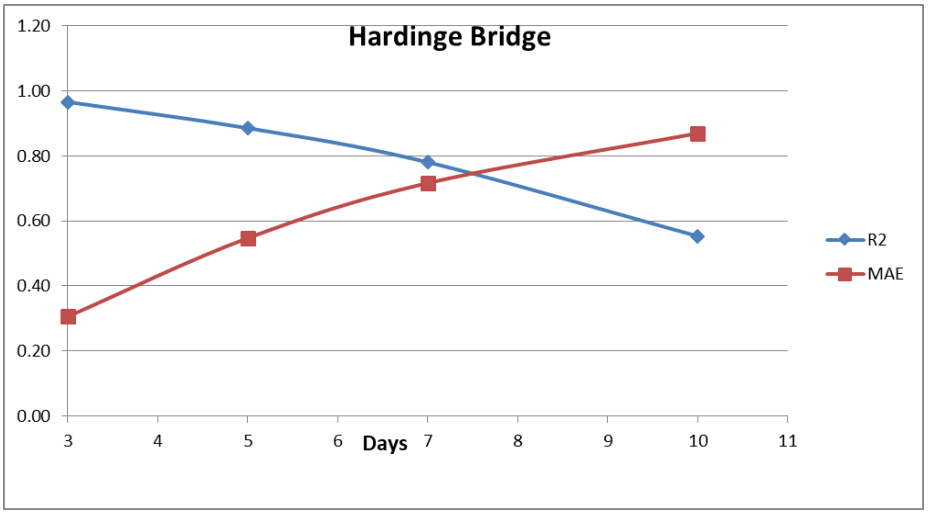


Figure 4.7 : MAE and r^2 Plot of Hardinge Bridge for 10-days Probabilistic Forecast (Year, 2016)

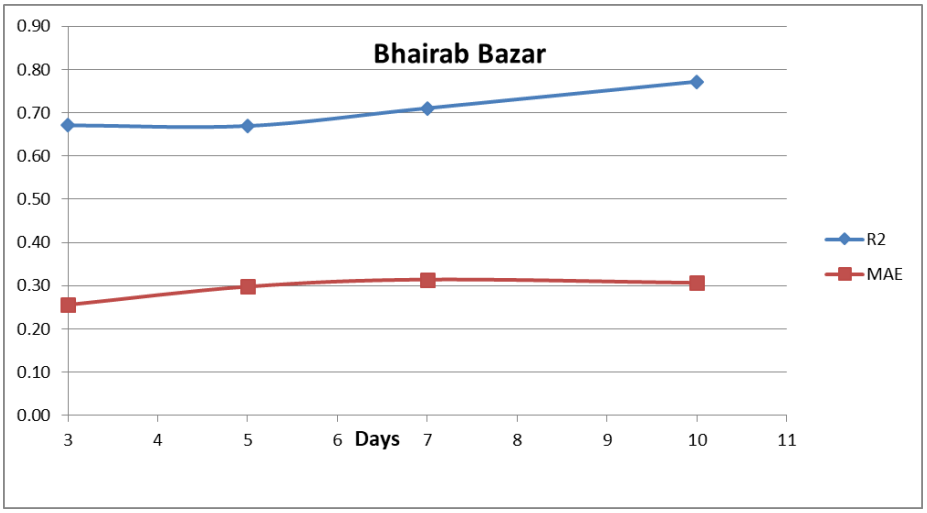


Figure 4.8: MAE and r^2 Plot of Bhairab Bazar for 10-days Probabilistic Forecast (Year, 2016)

Average of MAE and r^2 of all the 37 probability based flood forecast stations are also indicating the variability of the forecast & observe is increasing with the higher lead time.

CHAPTER 5 : INUNDATION STATUS

Flood inundation occurs due to overtopping or overflowing of flood water to the river banks. In our country, this situation at a particular place occurs when the river water level exceeds the danger level of that particular place. During normal flooding, it is expected and observed that flood plain along the major rivers becomes inundated and after that flood water progressively enters the adjacent residential and commercial areas depending upon the location and severity of flood situation. In the year 2016 monsoon, the country as a whole experienced slightly above normal flooding, but it did not prolong to severe condition.

The water level in 2016 flowed above danger level for short (1-day) duration to maximum 29-days. Various places of the four basins- the Brahmaputra, the Ganges, the Meghna and South Eastern Hill basin experienced flooding at different magnitude. The South Western part of the country experienced flooding in few places primarily due to drainage congestion and high tide. During the monsoon-2016 there was less flash flood condition in the of the country.

Out of 30 Water Level (WL) monitoring stations in the Brahmaputra basin, at 17 stations WL crossed and remained over the respective DLs that caused short to medium duration flood. This year's flood hit the basin in the end of 2nd week of July for medium duration which lasted upto the first week of August. The significant stations that were above and remained over DLs are Dharala at Kurigram for 16 days, Teesta at Dalia for 8 days, Brahmaputra at Chilmari for 23 days, Ghagot at Gaibandha for 8 days, Jamuna at Bahadurabad and Sariakandi both for 17 days, Serajgonj for 12 days, Atrai at Baghabari for 16 days, Gur at Singra for 10 days, Dhaleswari at Elasin ghat for 34 days, Shitalakya at Narayanganj for 12 days, Kaliganga at Taraghat for 13 days and Dhaleswari at Jagir for 11 days during months of July and August. As a result, low-lying areas of Kurigram, Lalminiorhat, Gaibandha, Bogra, Rangpur, Serajgonj, Tangail, Jamalpur, Manikganj, Natore and Narayangonj districts experienced short to medium duration flooding.

In the Ganges basin out of 25 WL monitoring stations, at 4 stations river exceeded their respective DLs during monsoon 2016, which were Goalondo, Sureswar and Bhagyakul on Padma, Jhikorgacha on Kobodak during the monsoon 2016. The WL of the Padma both at Goalondo and Bhagyakul flowed for 17 days and at Sureswar for 22 days above their DL. The low lying areas of Faridpur, Rajbari, Munshigonj and Shariatpur districts were affected by moderate intensity flooding during end of the month of July to first week of August. Some flooding situation was prevailing in low laying part of Satkhira, Khulna and Jessore districts due to lack of drainage congestion along with very high rainfall and high tide during monsoon period.

Out of 26 WL monitoring stations in the Meghna basin, at 18 stations water flowed above their respective DLs resulting floods of different durations which started from end of April and continued to mid of September. These are Kanaighat, Sylhet, and Sunamganj stations on Surma River; Amalshid, Sheola and Sherpur on Kushyara River; Habiganj and Ballah on Khowai river, Sarighat at Sarigowain river; Lorergarh on Jadukata river; Durgapur at Someswari, Jariajanjail at Kangsha, Brahmanbaria on Titas and Nakuakaon on Bhugai. Among them, in Kanaighat (31 days), Sunamgonj (9 days), Amalshid (25

days), Sheola (27 days), Sherpur (18 days), Jariajanjail (29 days), Khowai at Ballah stations flood water flowed above their respective danger levels for duration of 2 to 4 weeks or more during August-September period. As a result, moderate intensity floods were observed in the districts of Sylhet, Sunamgonj, Netrokona, Sherpur, and Habigonj during the monsoon 2016.

Rivers in the South Eastern Hill basin are mostly flashy in nature and river water flowed above danger level for short period of time and the maximum of the monitored water level stations crossed danger level during first half of July period due to influence of southwest monsoon. Due to excessive rainfall during first week of month July, a short duration flash flood hit in the basin. A short duration flash flood occurred in Parshuram (Muhuri), Narayanhat (Halda river), Bandarban (Sangu), Dohazari (Sangu) and Chiringa (Matamuhuri). As a result, some areas of Chittagong Hill Districts were affected by short duration flash flood.

FFWC prepared model based nationwide inundation maps based on coarse digital elevation model (DEM). Flood maps havd been generated from FFWC Flood Forecasting Model output results file found from MIKE 11 FF Rainfall-Runoff and Hydrodynamic modeling simulation using customized MIKE 11 GIS model as a routine activity during monsoon period. Here, Digital Elevation Model (DEM) having 300 m spatial resolution is used with MIKE 11 GIS tool. This is to mention here that flood peak arrived in Brahmaputra Basin in end of July, Ganges Basin in end of August and Upper Meghna river in first week of August. Among FFWC observed stations total number of 44 flood monitoring stations flowed above danger level during 2016 monsoon. Figure shows the observed typical inundation map for 23rd of July and then 24, 48, 72, 96 and 120 hours forecasted inundation maps. An approximate inundated area has been calculated based on inundation map generated in FFWC. The result shows about 48,675 sq-km which is 33% of the total country area, and this is considered maximum inundation area for the flood season. This inundation area excludes the permanent water body i.e. rivers, lakes, haors, ponds etc. To calculate the permanent water body is also a crucial issue. Some literature reviews and remote sensing based analysis depict that there are approximately 6-8% permanent water body existent in Bangladesh.

Flood inundation for whole country is a macro level product showing a general overview of flood situation of the whole country due to coarse resolution DEM. A detail, authentic and finer resolution DEM shall significantly improve generation of inundation maps and providing local level forecast.

FFWC presented flood model domain does not cover coastal part, so model result is not appropriate for inundation analysis or verification of that part.

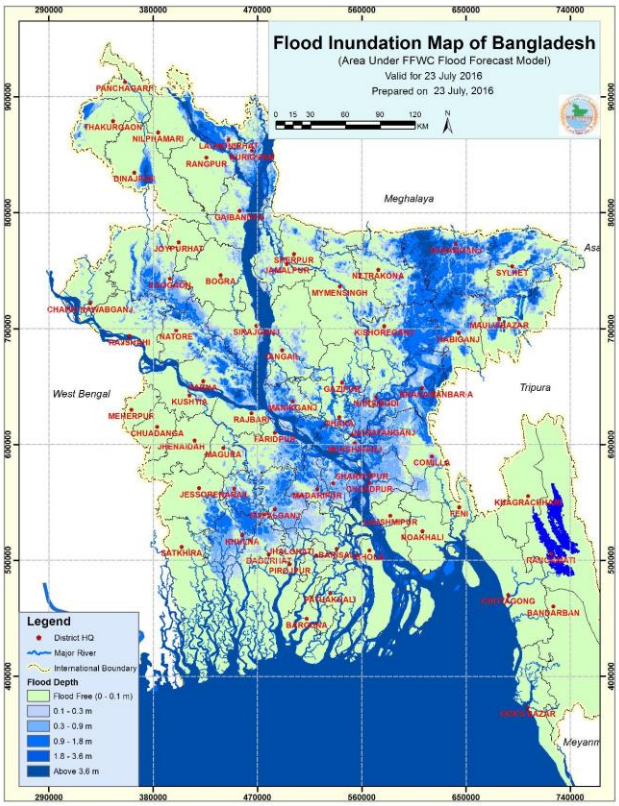


Figure 5.1: Flood Inundation Map of Bangladesh as on 23 July 2016

FFWC operates MIKE 11 FF Flood super model for flood forecasting purposes which excluded coastal region. Moreover periodic updating of river geometry is necessary for the best performance. Catchment characteristics, river morphology and climatology had been changed significantly which were not incorporated in the model in recent time. That's why current inundation map provides underestimation as well as overestimation in some places.

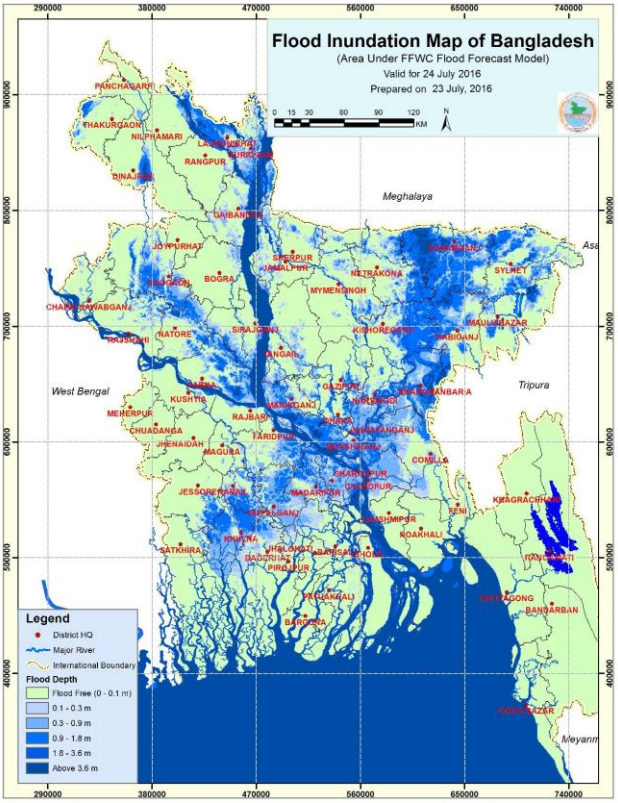


Figure 5.2: Flood Inundation Map of Bangladesh (24hr Forecast Based on 23 July 2016)

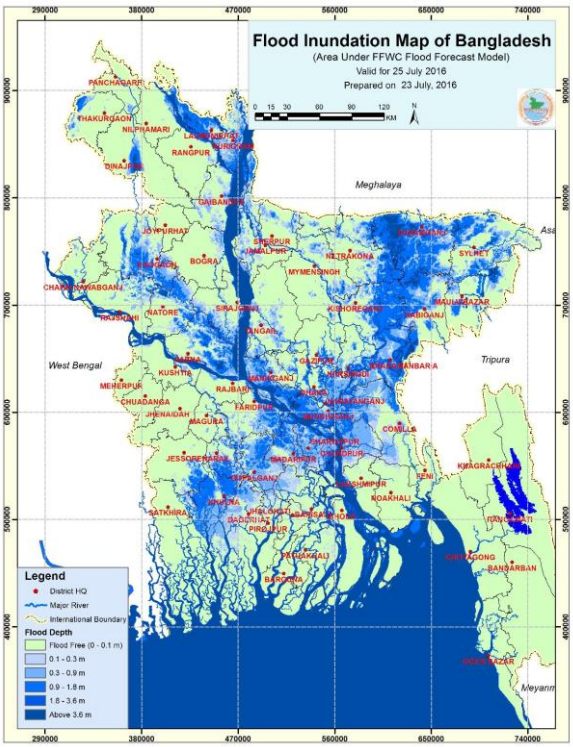


Figure 5.3: Flood Inundation Map of Bangladesh (48hr Forecast Based on 23 July 2016)

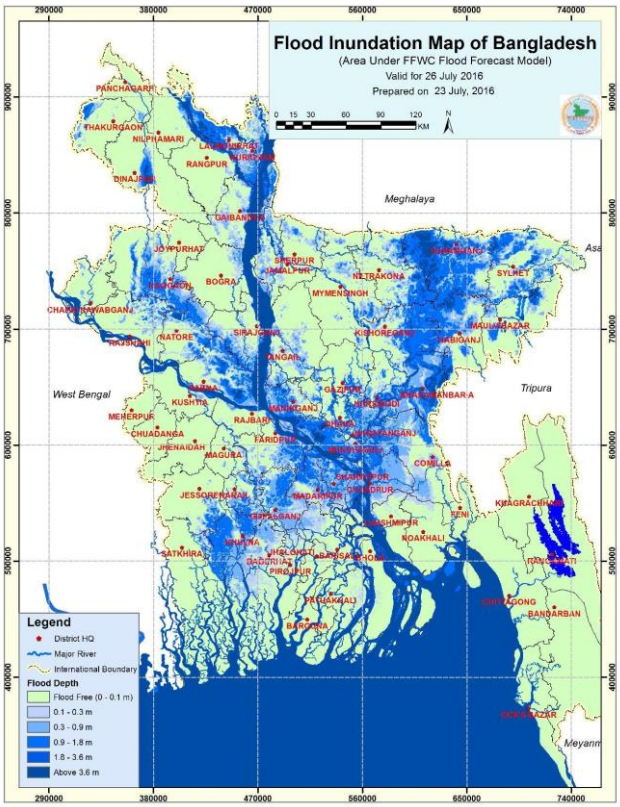


Figure 5.4: Flood Inundation Map of Bangladesh (72hr Forecast Based on 23 July 2016)

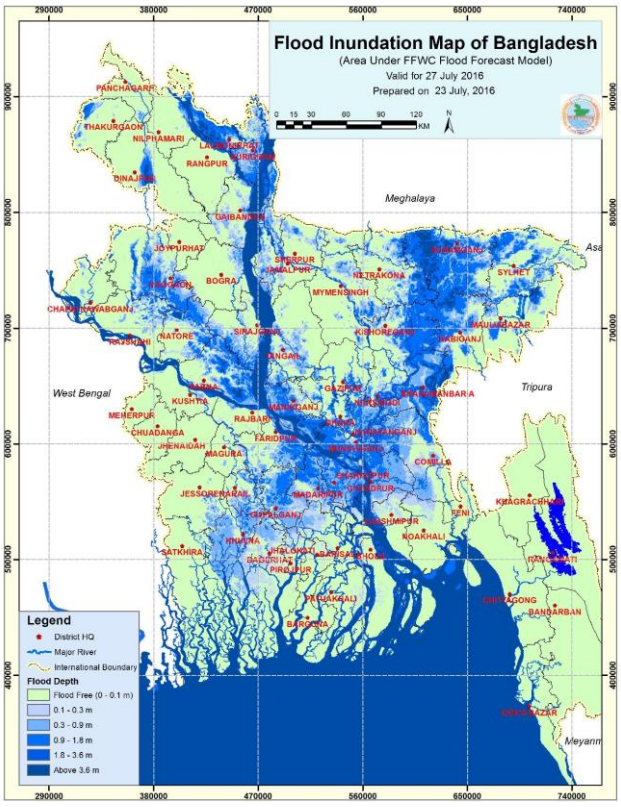


Figure 5.5: Flood Inundation Map of Bangladesh (96hr Forecast Based on 23 July 2016)

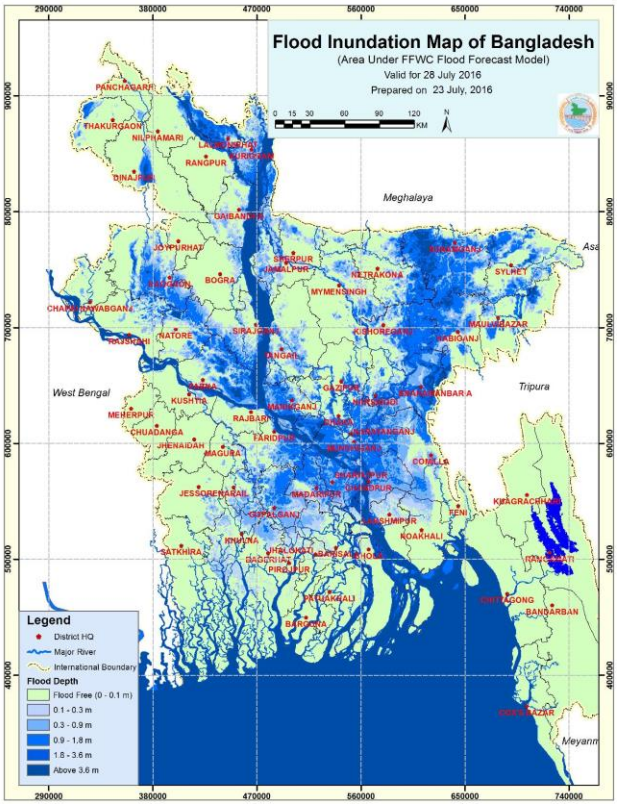


Figure 5.6: Flood Inundation Map of Bangladesh (120hr Forecast Based on 23 July 2016)

CHAPTER 6: CONCLUSIONS

The flood is a recurrent problem in Bangladesh. The country is an active delta; it has numerous networks of rivers, canals and coast creeks with extensive flood plains through which surface water of about 1.7 million sq-km drains annually. Floods are normal monsoon phenomena in the deltaic plains of Bangladesh. Although the livelihood of the people in Bangladesh is well adapted to normal monsoon flood, the damages due to inundation, riverbank erosion or breach of embankment, etc. still occur in various regions in almost every monsoon. They often have disastrous consequences: major damage to infrastructure, loss of property, crops, cattle, poultry etc., human suffering and impoverishment of the poor. With every major flood in Bangladesh, food security and poverty situation adversely affected.

The flood warning message was disseminated through different news media, news agencies, fax, e-mail, web-site (www.ffwc.gov.bd) and IVR (1090) through mobile phone. The flood forecast information has been used by various communities and organizations: national and international disaster management and relief operators, many Government agencies, NGOs and BWDB itself.

The characteristic of river varies from river to river and differs from region to region. Usually, in the Brahmaputra basin, flood begins in the late June while in the Ganges basin it starts from the second half of July. The part of Meghna, North and South-Eastern Hill basins is vulnerable to flash flood at the beginning or even pre-monsoon causing loss of standing crops and source of hardship for the population.

Presently, FFWC has issued daily flood bulletin from May to October with a forecast lead-time of 24hrs, 48hrs and 72hrs, 96 hrs and 120 hrs (upto 5 days) along with warning messages and flood inundation maps. FFWC provides flood forecast 54 locations along the major river systems of Bangladesh. Location specific and impact based forecast is essential to reduce flood damage significantly. FFWC has also started to provide location specific forecast for flood infrastructure like Brahmaputra Right Embankment, Meghna-Dhonagoda Irrigation Project. Further improvement is needed to increase reliability of location specific forecast. Longer lead-time is always desirable to minimize loss and damage. But, there is lots of uncertainty with forecasting. FFWC is trying to increase forecast lead-time so that people can be benefited from flood forecast message. As part of increasing lead-time, FFWC is collaboration with Regional Integrated Multi-Hazard Early Warning System (RIMES) utilizing ECMWF weather prediction data over the GBM basin to generate 51 sets of ensemble discharge forecasts on the Brahmaputra at Bahadurabad and on the Ganges rivers at Hardinge-Bridge. Based on the ensemble discharge, 10-day lead time probabilistic flood forecast of 38 points for the major rivers of Bangladesh is issued by FFWC.

The forecast of FFWC is very good up to 72 hours. With the increasing lead-time forecast performance affected due to some uncertainties in boundary estimation of flood model. The forecasting evaluation shows that was quite satisfactory for the major river system and needs further attention for small and flashy rivers.

The maximum flooded area was 33% of the whole country (48,675 sq-km approximately).

Annex-1

EXPERIMENTAL 5 Days Forecast (24, 48, 72, 96 & 120 Hrs), FFWC, BWDB

Supported by CDMP-II

SL NO	River	Station	D.L.	Today	24-hrs forecast	24-hrs +Rise -fall	24-hrs +above -below D.L.	48-hrs forecast	48-hrs +Rise -fall	48-hrs +above below D.L.	72-hrs forecast	72-hrs +Rise -fall	72-hrs +above -below D.L.	96-hrs forecast	96-hrs +Rise -fall	96-hrs +above -below D.L.	120-hrs forecast	120-hrs +Rise -fall	120-hrs +above -below D.L.
				25-07	26-07	26-07	26-07	27-07	27-07	27-07	28-07	28-07	28-07	29-07	29-07	29-07	30-07	30-07	30-07
				6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM	6:00 AM
			(meter)	(meter)	(meter)	(cm)	(cm)	(meter)	(cm)	(cm)	(meter)	(cm)	(cm)	(meter)	(cm)	(cm)	(meter)	(cm)	(cm)
1	Atrai	Mohadevpur	18.59	16.76	16.64	-12	-195	16.72	+8	-187	16.89	+17	-170	16.91	+2	-168	16.89	-2	-170
2	Atrai	Atrai	13.72	-	13.73	-	+1	13.75	+2	+3	13.77	+2	+5	13.80	+3	+8	13.82	+2	+10
3	Atrai	Singra	12.65	12.65	12.69	+4	+4	12.71	+3	+6	12.74	+3	+9	12.78	+4	+13	12.82	+4	+17
4	Karatoa-Atrai-GGH	Baghabari	10.40	10.62	10.79	+17	+39	10.98	+19	+58	11.14	+16	+74	11.27	+13	+87	11.36	+9	+96
5	Little Jamuna	Naogaon	15.24	14.60	14.50	-10	-74	14.42	-8	-82	14.38	-3	-86	14.39	+1	-85	14.40	+1	-84
6	Karatoya	Chakrahimpur	20.15	19.45	19.44	-1	-71	19.39	-4	-76	19.34	-5	-81	19.30	-5	-85	19.25	-4	-90
7	Karatoya	Bogra	16.32	13.06	12.95	-11	-337	12.91	-4	-341	12.94	+3	-338	13.01	+7	-331	13.08	+7	-324
8	Teesta	Kaunia	30.00	28.65	28.79	+14	-121	28.96	+17	-104	29.11	+15	-89	29.18	+7	-82	29.03	-15	-97
9	Ghagot	Gaibandha	21.70	21.85	22.05	+20	+35	22.19	+14	+49	22.29	+10	+59	22.39	+10	+69	22.39	0	+69
10	Dharla	Kurigram	26.50	27.45	27.62	+17	+112	27.78	+15	+128	27.88	+11	+138	27.97	+9	+147	28.02	+5	+152
11	Brahmaputra	Chilmari	24.00	24.69	24.88	+19	+88	25.04	+16	+104	25.16	+12	+116	25.24	+8	+124	25.27	+3	+127
12	Jamuna	Bahadurabad	19.50	20.11	20.30	+19	+80	20.46	+16	+96	20.58	+12	+108	20.67	+9	+117	20.70	+3	+120
13	Jamuna	Sariakandi	16.70	17.15	17.33	+18	+63	17.46	+13	+76	17.56	+11	+86	17.64	+8	+94	17.68	+4	+98
14	Jamuna	Kazipur	14.85	-	15.05	-	+20	15.23	+18	+38	15.38	+15	+53	15.49	+11	+64	15.55	+6	+70
15	Jamuna	Serajganj	13.35	13.55	13.78	+23	+43	13.99	+22	+64	14.17	+18	+82	14.31	+13	+96	14.39	+8	+104
16	Jamuna	Porabari	12.27	-	12.13	-	-14	12.33	+20	+6	12.50	+17	+23	12.63	+13	+36	12.71	+8	+44
17	Jamuna	Aricha	9.40	9.20	9.38	+18	-2	9.58	+19	+18	9.75	+17	+35	9.89	+14	+49	9.98	+10	+58
18	Old Brahmaputra	Jamalpur	17.00	15.41	15.61	+20	-139	15.80	+19	-120	15.97	+17	-103	16.07	+10	-93	16.14	+7	-86
19	Old Brahmaputra	Mymensingh	12.50	9.77	9.96	+19	-254	10.17	+21	-233	10.36	+19	-214	10.54	+18	-196	10.70	+15	-180
20	Bangshi	Nayerhat	7.32	5.43	5.51	+8	-181	5.61	+9	-171	5.73	+12	-159	5.84	+11	-148	5.96	+12	-136
21	Old Dhaleswari	Jagir	8.23	-	8.32	-	+8	8.46	+15	+23	8.65	+19	+42	8.90	+25	+67	9.14	+24	+91
22	Dhaleswari	Kalagachia	4.88	-	5.24	-	+36	5.36	+12	+48	5.49	+13	+61	5.64	+15	+76	5.76	+13	+88
23	Kaliganga	Taraghat	8.38	7.41	7.56	+15	-82	7.74	+18	-64	7.96	+21	-42	8.16	+20	-22	8.34	+19	-4
24	Tongi Khal	Tongi	6.08	5.24	5.33	+9	-75	5.43	+10	-65	5.55	+12	-53	5.67	+13	-41	5.80	+12	-28
25	Turag	Mirpur	5.94	5.24	5.34	+10	-60	5.44	+10	-50	5.57	+13	-37	5.70	+13	-24	5.83	+13	-11
26	Buriganga	Dhaka (Mill Barrack)	6.00	-	5.27	-	-73	5.38	+12	-62	5.52	+14	-48	5.68	+15	-32	5.82	+14	-18
27	Buriganga	Dhaka (Hariharpara)	5.79	-	5.27	-	-53	5.38	+12	-41	5.52	+14	-27	5.67	+15	-12	5.81	+14	+2
28	Balu	Demra	5.75	5.12	5.23	+11	-52	5.34	+11	-41	5.47	+13	-28	5.61	+14	-14	5.74	+13	-1
29	Lakhya	Narayanganj	5.50	5.22	5.33	+11	-17	5.44	+12	-6	5.58	+14	+8	5.73	+15	+23	5.86	+13	+36
30	Dhaleswari	Elashinghat	11.40	12.10	12.27	+17	+87	12.42	+15	+102	12.55	+13	+115	12.66	+11	+126	12.74	+8	+134
31	Lakhya	Lakhpur	5.80	4.83	4.93	+10	-87	5.04	+11	-76	5.17	+13	-63	5.31	+14	-49	5.44	+13	-36
32	Dhaleswari	Munshiganj	5.20	-	5.26	-	+6	5.38	+12	+18	5.52	+14	+32	5.67	+15	+47	5.81	+14	+61
33	Mohananda	Chapai Nawabganj	21.00	19.55	19.62	+7	-138	19.69	+7	-131	19.75	+5	-125	19.71	-4	-129	19.71	+1	-129
34	Ganges	Rajshahi	18.50	16.98	17.03	+5	-147	17.09	+6	-141	17.14	+5	-136	17.16	+2	-134	17.13	-3	-137
35	Ganges	Hardinge Br	14.25	13.28	13.34	+6	-91	13.40	+6	-85	13.46	+6	-79	13.50	+4	-75	13.50	0	-75
36	Ganges	Talbaria	12.80	-	12.67	-	-13	12.74	+7	-6	12.82	+7	+2	12.88	+6	+8	12.89	+1	+9
37	Padma	Goalondo	8.65	8.82	8.99	+17	+34	9.18	+18	+53	9.35	+17	+70	9.48	+14	+83	9.58	+9	+93

Note: 1) 24 hrs. rise/fall indicates changes in water levels from today 6 A.M. to 26-7-2016 6:00 A.M.

2) 48 hrs. rise/fall indicates changes in water levels from 26-7-2016 6:00 A.M. to 27-7-2016 6:00 A.M.

3) 72 hrs. rise/fall indicates changes in water levels from 27-7-2016 6:00 A.M. to 28-7-2016 6:00 A.M.

4) 96 hrs. rise/fall indicates changes in water levels from 28-7-2016 6:00 A.M. to 29-7-2016 6:00 A.M.

5) 120 hrs. rise/fall indicates changes in water levels from 29-7-2016 6:00 A.M. to 30-7-2016 6:00 A.M.

6) "+ above" means water level flowing above danger level, "-below" means water level flowing below danger level.

Page: 1 of 2

Figure 6.1: A sample of 5 days Forecast Bulletin

Annex-2

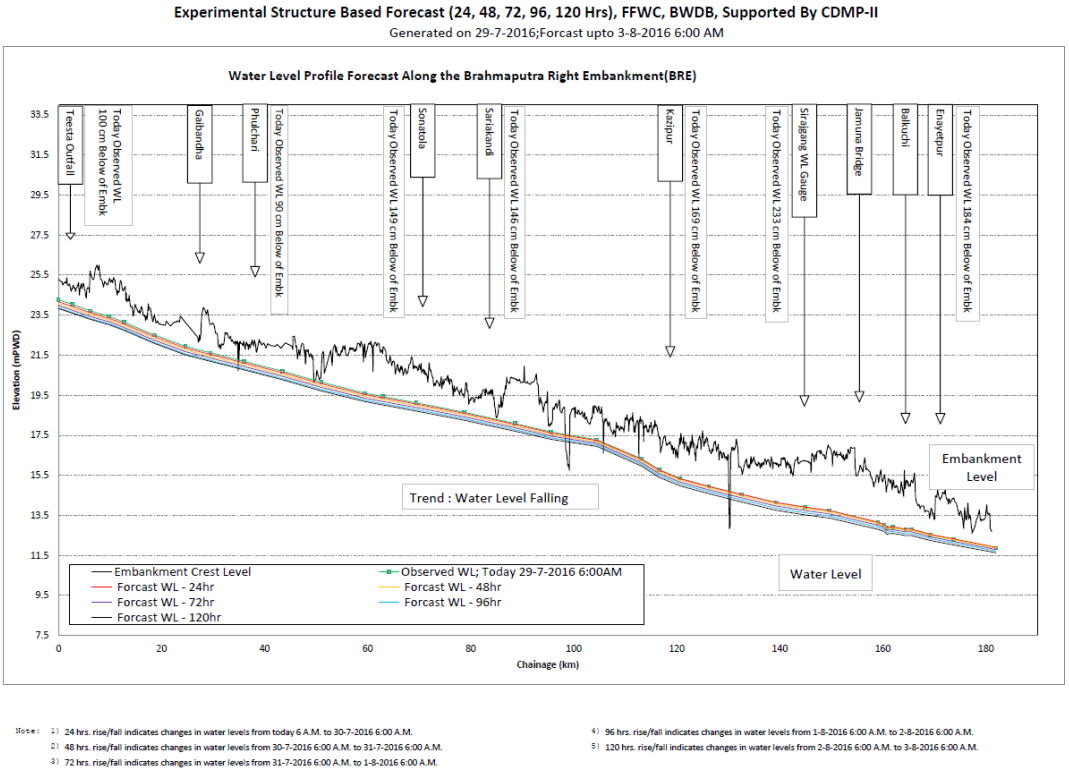


Figure 6.2: A sample of Structure Based Forecast Bulletin

Annex-3

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

ই-মেইল ঃ ffwcbwdb@gmail.com, ffwc05@yahoo.com; ওয়েবসাইট ঃ www.ffwc.gov.bd. দূরালাপনি ঃ ৯৫৫৬১১৮, ৯৫৫৩৭৫৫ ফ্যাক্স ঃ ৯৫৫৭৬৮৬

বৃষ্টিপাত ও নদ-নদীর অবস্থা
১৩ শ্রাবণ ১৪২৩ বং/২৮ জুলাই ২০১৬খৃঃ

এক নজরে নদ-নদীর পরিস্থিতি

- ব্রহ্মপুত্র-যমুনা,গঙ্গা-পদ্মা ও কুশিয়ারা নদ-নদীসমূহের পানি সমতল বৃদ্ধি পাচ্ছে, অপরদিকে সুরমা নদীর পানি সমতল হ্রাস পাচ্ছে।
- আগামী ৪৮ ঘন্টায় ব্রহ্মপুত্র-যমুনা ও গঙ্গা-পদ্মা নদ-নদীসমূহের পানি সমতল বৃদ্ধি অব্যাহত থাকতে পারে।
- আগামী ৪৮ ঘন্টায় সুরমা নদীর পানি সমতল হ্রাস অব্যাহত থাকতে পারে, অপরদিকে কুশিয়ারা নদীর পানি সমতল আগামী ২৪ ঘন্টা পর কমতে শুরু করতে পারে।
- আগামী ৪৮ ঘন্টায় ব্রহ্মপুত্র ও যমুনা নদ-নদী সংলগ্ন গাইবান্ধা, জামালপুর, বগুড়া, সিরাজগঞ্জ জেলাসমূহের নিম্নাঞ্চলে এবং গঙ্গা-পদ্মা নদী সংলগ্ন রাজবাড়ি, মানিকগঞ্জ, মুন্সিগঞ্জ ও শরিয়তপুর জেলাসমূহের নিম্নাঞ্চলে বন্যা পরিস্থিতির অবনতি অব্যাহত থাকতে পারে।
- আগামী ৪৮ ঘন্টায় ধরলা নদী কুড়িগ্রামের নিম্নাঞ্চলে ও সুরমা নদী সুনামগঞ্জ জেলার নিম্নাঞ্চলে বন্যা পরিস্থিতির উন্নতি হতে পারে।
- ঢাকার আশেপাশের বুড়িগঙ্গা, বালু, তুরাগ, শীতলক্ষ্যা প্রভৃতি নদ-নদীসমূহের পানি সমতল বৃদ্ধি পাচ্ছে যা আগামী ৪৮ ঘন্টা পর্যন্ত অব্যাহত থাকতে পারে।

বিপদসীমার উপর দিয়ে প্রবাহিত স্টেশন (১৩ শ্রাবণ ১৪২৩ বঙ্গাব্দ/২৮ জুলাই ২০১৬খৃঃ সকাল ৯.০০ টার তথ্য অনুযায়ী):

পানি সমতল স্টেশন	নদীর নাম	বিগত ২৪ ঘন্টায় বৃদ্ধি(+)/হ্রাস(-)(সে.মি.)	বিপদসীমার উপরে (সে.মি.)
কুড়িগ্রাম	ধরলা	-৬	+১০০
গাইবান্ধা	ঘাঘট	+১৭	+৮৬
ফুলবাওয়া	ব্রহ্মপুত্র	+১২	+৪
চিলমারী	ব্রহ্মপুত্র	+৮	+৯৬
বাহাদুরাবাদ	যমুনা	+১৫	+১১৩
সারিয়াকান্দি	যমুনা	+১১	+৮৬
কাজিপুর	যমুনা	+২৭	+৬৫
সিরাজগঞ্জ	যমুনা	+১৪	+৭২
আরিচা	যমুনা	+১৬	+৩০
সিংড়া	তুর	+৪	+১৩
বাঘাবাড়ি	আত্রাই	+১৫	+৭৫
এলাসিন	ধলেশ্বরী	+১০	+১১০
গোয়ালন্দ	পদ্মা	+৬	+৬০
তাশুরুল	পদ্মা	+১০	+২৮
সুনামগঞ্জ	সুরমা	-২৫	+৩২
জারিয়াজঙ্গাইল	কংস	-৯	+১০৫
ব্রাহ্মণবাড়িয়া	তিতাস	+৭	+২৭

বারিপাত তথ্য

গত ২৪ ঘন্টায় উল্লেখযোগ্য বৃষ্টিপাত (গত কাল সকাল ০৯:০০ টা থেকে আজ সকাল ০৯:০০ টা পর্যন্ত) :

স্টেশন	বারিপাত (মি.মি.)	স্টেশন	বারিপাত (মি.মি.)
কাশাইঘাট	৫১.০	কুড়িগ্রাম	৩৮.০
রংপুর	৪২.০	শেওলা	৩৮.০

নদ-নদীর অবস্থা (আজ সকাল ০৯:০০ টা পর্যন্ত)

বিষয়	সংখ্যা	বিষয়	সংখ্যা
পর্যবেক্ষণাধীন পানি সমতল স্টেশন	৯০	অপরিবর্তিত	০
বৃদ্ধি	৫৮	তথ্য পাওয়া যায় নাই	৫
হ্রাস	২৭	বিপদসীমার উপরে	১৭

For Further Query, Feel Free to Contact:
01712731191, 01714845246;

(রিপন কর্মকার)
সহকারী প্রকৌশলী
বন্যা পূর্বাভাস ও সতর্কীকরণ কেন্দ্র
বাপাউবো, ঢাকা।
মোবাইল নং: ০১৭১৪৮৪৫২৪৬

Figure 6.3: A sample of summary statement of flood situation