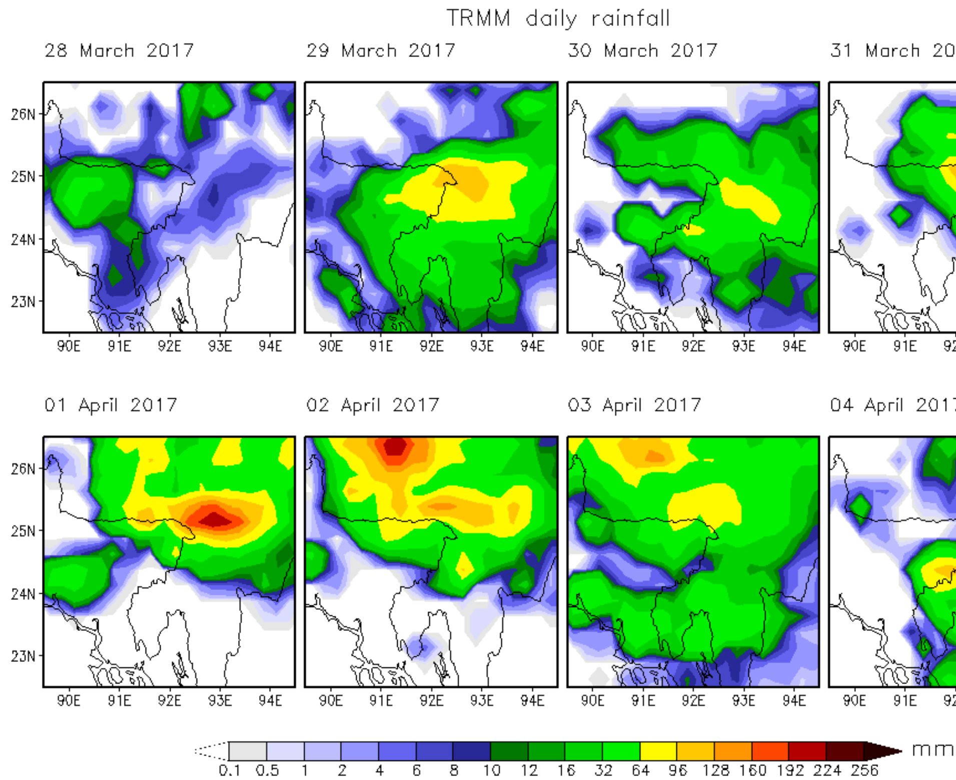
Research Project on Developing Flash Flood Early Warning System, Capacity Building and Knowledge Management for the Haor Region of Bangladesh

QUARTERLY REPORT (OCT -DEC 2019)



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STUDY TEAM

Dr. A.K.M. Saiful Islam	Principal Investigator (Weather and Climate Modelling)
Dr. G.M. Tarekul Islam	Co-Investigator (Hydrology, Remote Sensing and GIS)
Dr. Mashfiqus Salehin	Co-Investigator (Hydrologic Modelling)
Dr. Sujit Kumar Bala	Co-Investigator (Flood Forecasting and Early Warning System)
Dr. M. Shahjahan Mondal	Co-Investigator (Hydrodynamic Modelling)
Dr. Sara Nowreen	Co-Investigator (Hydrodynamic Modelling)
Ms. Binata Roy	Co-Investigator (Hydrodynamic Modelling)
Md. Enayet Chowdhury	Co-Investigator (Weather and Climate Modelling)
Ms. Tanjila Akhter	Co-Investigator (Hydrodynamic Modelling)
Dr. Mohan Kumar Das	Research Associate (Weather Data Analysis and Assimilation)
Ms. Nur Shadia	Research Assistant (Weather Modelling)
Ms. Nahruma Mehzabeen Pieu	Research Assistant (Hydrological Modelling)
Md. Akramul Haque	Research Assistant (Hydrodynamic Modelling)

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ABBREVIATIONS AND ACRONYMS

3DVAR	Three-Demiensional Variational Data Assimilation
ANN	Artificial Neural Network
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Meteorological Department
BoB	Bay of Bengal
BUET	Bangladesh University and Engineering and Technology
BWDB	Bangladesh Water Development Board
CALIP	Climate Adaptation and Livelihood Protection
DAE	Department of Agriculture Extension
DDM	Department of Disaster Management
DEM	Digital elevation model
DL	Danger Level
DoE	Department of Environment
FAO	Food and Agricultural Organization
FFFS	Flash Flood Forecasting System
FFWC	Flood Forecasting and Warning Center
FNL	Final Analysis data
GFS	Global Forecast System
GPM	Global Precipitation Measurement
HEC-HMS	Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HTML	Hypertext Markup Language
IFAD	International Fund for Agricultural Development
IMD	India Meteorological Department
IWFM	Institute of Water and Flood Management
LBC	Lateral Boundary Conditions
LGED	Local Government Engineering Department
MPS	Microphysics Scheme
NARX	Nonlinear Autoregressive Network with Exogenous inputs

NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NE	North East
NGO	Non-Government Organization
NMM	Non-hydrostatic Mesoscale Model
NSE	Nash-Sutcliffe efficiency
NWP	Numerical Weather Prediction
PBIAS	Percentage Bias
PBL	Planetary boundary layer
RHD	Roads and Highways Department
RHWL	Record High Water Level
SRTM	Shuttle Radar Topography Mission
TRMM	Tropical Rainfall Measuring Mission
USGS	United States Geological Survey
WRF	Weather Research and Forecasting Model
WRF-ARW	Advanced Research version of the Weather Research and Forecasting
XML	eXtensible Markup Language.

CHAPTER ONE

THERMODYNAMIC FEATURES OF FLASH FLOOD PRODUCING STORMS OVER THE NORTHEAST REGION OF BANGLADESH

1.1 Introduction

Prediction of flash flood producing rainstorm is important and a challenging job as the event is short in duration. This event occurs due to torrential rain and causes landslide over the hilly region, huge inundation over the wetland and enormous destruction of crops. It has a huge impact on livelihoods too. A timely prediction might preclude loss of properties and lives. The influx of moisture from the Bay of Bengal (BoB) energizes the Mesoscale convective system (MCS) (Tyagi et al., 2011 and 2013; Rasmussen and Houze, 2012; Medina et al., 2010; Virts and Houze 2016) as it passes over Meghalaya and northern parts of Bangladesh and thus produces heavy convective and/or stratiform rain over Meghalaya and the surroundings areas. Extreme precipitation and runoff are the root causes of flash flood. The stretches of valley and highland plateaus of Indo-Bangla region play an important role in the weather system due to its extraordinary geography and climate. In the central part of the location is the Khasi hills and its eastern section is the Jaintia hills. In the western part of the region, Garo hills is located which is almost plain. The highest elevation of the Khasi hills is Shillong peak which is 1961 m. The region has many rainfed and seasonal rivers namely Bhogai, Nitai, Kynshi (Jadukata) etc. The valley and plateaus of Indo-Bangla region is the wettest place on planet earth. During 1-1 April 2017, torrential rain occurred over the Meghalaya range of India, producing a devastating flash flood at the Haor area of Sunamganj district in Bangladesh. Especially in Sohra, which is also known as Cherrapunji (Lat. 25.3 N; Lon. 91.7 E), the annual average rainfall is 11,777 mm (India Meteorological Department rainfall data) whereas in the nearby village Mawsynram (Lat. 25.28^{o} N; Lon. 91.35 ^{o} E) the annual rainfall is 11,872 mm. In Cherrapunji, the 43-year average (1973 to 2015) rainfall for the month of April is 843.2 mm (http://www.cherrapunjee.com/cherrapunjee-rain/). On the other hand, in April 2010, monthly average rainfall was 2734 mm, which is significantly greater compared to that in April 2009 (636.2 mm) and April 2011 (226.3 mm). The nearest record is found in the year 2016 when the rainfall is 2297.3 mm in April.

The non-hydrostatic mesoscale weather models are proficient for simulation of high impact weather systems which lead to heavy rainfall episodes over South Asia (Routray et al., 2005, 2010; Deb et al., 2008; Kumar et al., 2008, 2014; Mohanty et al., 2012; Vaid, 2013). Conversely, there are also some limitation of forecast skills of precipitation of Numerical Weather Prediction (NWP) models (Rama Rao et al., 2007; Roy Bhowmik and Das et al., 2008; Sikka and Rao, 2008). Therefore, there is a requirement for efforts to develop NWP model ability in short-range prediction of convective storms which are responsible for heavy rainfall events causing flash floods and related hazards. Presence of the low-level jets in the south of the trough and the upper-level jets in the north of Bangladesh strengthen the south-north baroclinicity in the mid troposphere. On the other hand, comprehensive evaluation of convective system over Bangladesh with cloud-resolving resolution has not been performed. It is also noted that such kinds of experiments using NWP model have not been accomplished for high impact weather events over the northeast (NE) region of Bangladesh. In the past, many studies explained that there is an anomalous propagation in the Bay of Bengal (BoB) and its moist flow across the subcontinent to the Arabian Sea area together (Dimri et al., 2017, Houze et al., 2011 and Webster et al., 2010). This process stimulated high pressure over the Tibetan Plateau and favor moisture flow towards the mountainous topography.

In this study, attempt has been taken to identify and apprehend the various thermodynamic instabilities that resulted in the localized flash-flood-producing heavy rainfall over NE region of Bangladesh.

1.2 Observed characteristics of pre-monsoon extreme weather events and Synoptic main features

Rainfall events causing flash flood have been selected for investigation based on surface synoptic observations. The list of the events is presented in **Table 1.1**. Thunderstorms associated with squalls and gusty winds were reported at Sylhet and neighboring regions on the dates selected for the study. The flash flood was accompanied by heavy rain (24 hours accumulated) as recorded by Bangladesh Meteorological Department (BMD) and India Meteorological Department is given in **Table 1.1**.

Table 1.1: The flash flood events.

Date	Station	24 hours accumulated rainfall (mm)
1 April 2017	Sylhet	124.0
	Cherrapunji	280.0
2 April 2017	Sylhet	71.0
	Cherrapunji	237.4

Synoptic main features for the events are as follows-

- An upper air trough above mean sea level and associated western disturbances runs from central Uttar Pradesh to Gangetic West Bengal across Jharkhand with embedded cyclonic circulations over east Uttar Pradesh and neighboring region.
- Strong southerly moister flow from the Bay of Bengal was prominent.

1.3. Precipitation retrieved from TRMM

The spatial distribution of rain intensities retrieved from TRMM 3B42RT for the flash flood event over Bangladesh that occurred on 28 March 2017 to 04 April 2017 is shown in **Figure 1.1**. The rainfall area covers almost the north, northeast and east of Bangladesh. The **Figure 1.1** shows rainfall amount of the order of 160-224 mm day^{-1} on 1 and 2 April 2017. After 3 April 2017, rainfall areas are seen over northeastern part of Bangladesh and the Meghalaya region with an amount of > 64 mm.

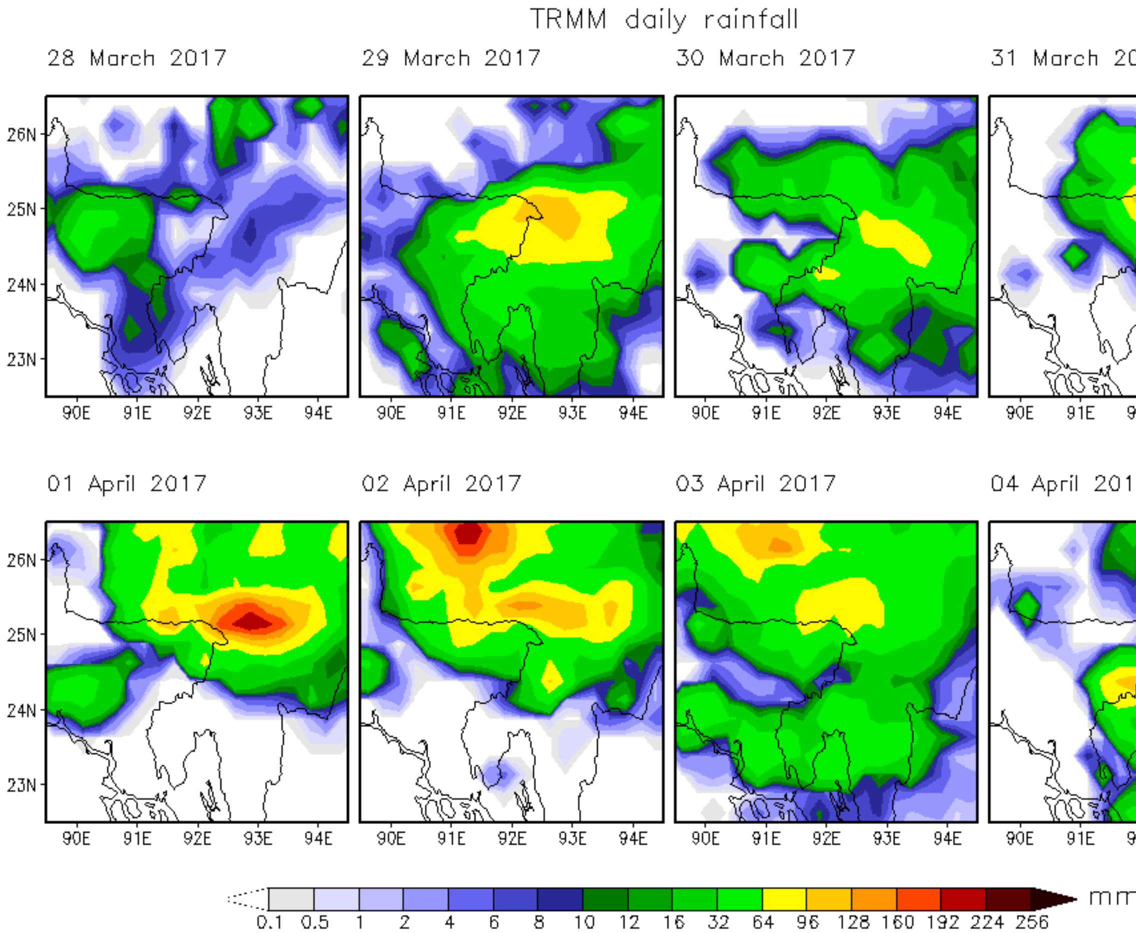

Figure 1.1: Accumulated daily rainfalls retrieved from TRMM on 28 March 2017 to 04 April 2017

1.4 Methodology and Data used

The Advanced Research Weather Research and Forecasting model (ARW), version 3.7.1 (Skamarock et al., 2008) is used in this study. It is a three-dimensional, fully compressible, non-hydrostatic model. In the present study, 0.50° × 0.50° gridded NCEP Global Forecast System (GFS) data are used as initial and Lateral Boundary Conditions (LBC) for the domain. The model main features (Das et al., 2015 d; Litta et al., 2012) employed for this study are summarized in **Table 1.2**.

Table 1.2: Features of numerical model configurations.

Model	**WRF Version 3.7.1**
Map projection	Mercator
Horizontal Resolution	Nest: 27, 9 and 3 km
Vertical Levels	40
Topography	USGS
Time integration	Semi Implicit
Vertical differencing	Arakawa's Energy Conserving Scheme
Convection	Kain-Fritsch (new Eta) scheme (Kain 2004)
Planetary boundary layer	Yonsei University Scheme (YSU)
Cloud microphysics	WRF Single-Moment 6-Class (WSM6) (Hong and Lim, 2006)
Surface layer	Monin-Obukhov
Radiation	RRTM (LW), SW (Dudhia 1989)
Land surface processes	Unified NOAH Land Surface Model
Horizontal grid scheme	Arakawa C-grid

1.5 Results and discussion

In this section, certain diagnostics of the flash flood simulated by the model are presented. In the present simulation, the model was run for a period of 75 h, starting at 0000 UTC on 31 March 2017, as initial values. The thermodynamic features of the flash flood producing storm is obtained by the model, and compared with observations available from Radio Sonder observations.

1.5.1 Observed and model simulated thermodynamic features analysis obtain from T–Φ gram

Model Simulated characteristics of the flash flood producing rainstorm event such as thermodynamic indices from T– Φ gram. Meteorological fields during the rainstorms events are compared with available observations (**Figure 1.2**). The T– Φ grams of rainstorm event showed instability in the atmosphere. Thermodynamic indices (LI, KI, and TTI) of all the events are examined at the station of where rainstorms reported.

RS Station Observation	Model Simulated

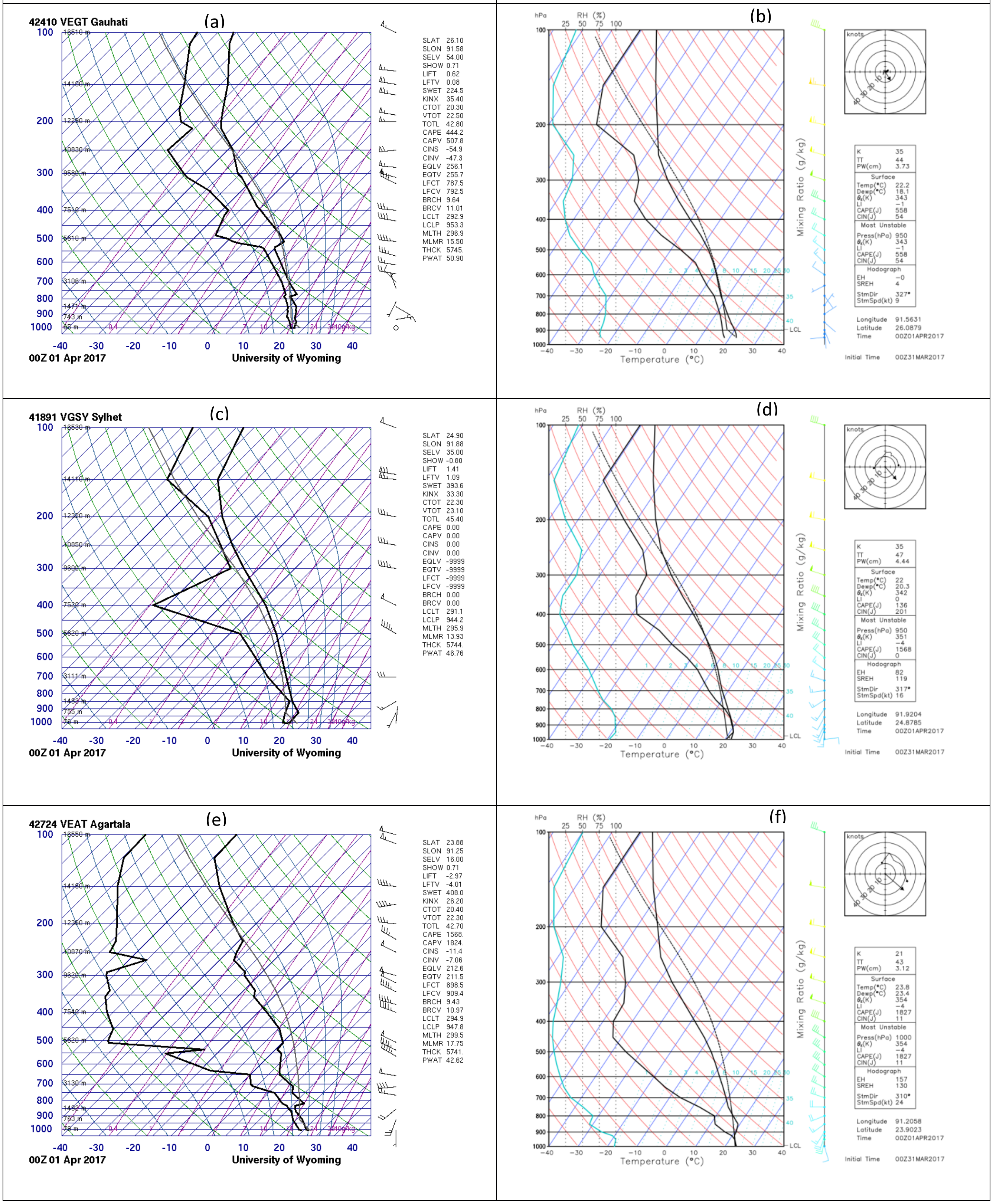

Figure 1.2: Observed and model simulated Skew-t analyses for the event.

All the three available RS observations (Sylhet, Guwahati, and Agartala) at 0000 UTC of April 1, 2017, show very low CAPE value. That means the atmosphere was stable in the morning. Instability developed after 0300 UTC. But there was no RS observation at that time. Satellite, radar, and ground observations showed the instability in the atmosphere. Observed skew-T at 0000 UTC over Guwahati, Agartala region indicate moderate to high convection over the region.

5.2 Model simulated thermodynamic features over Cherrapunjii obtain from T–Φ gram

Model could simulate all the time steps of the event. Model simulated output times were selected by analyzing the best result near the time of occurrence. In all the time steps, the values are near the critical values (Fig. 3) which are studied by Tyagi et al. (2011, 2013).

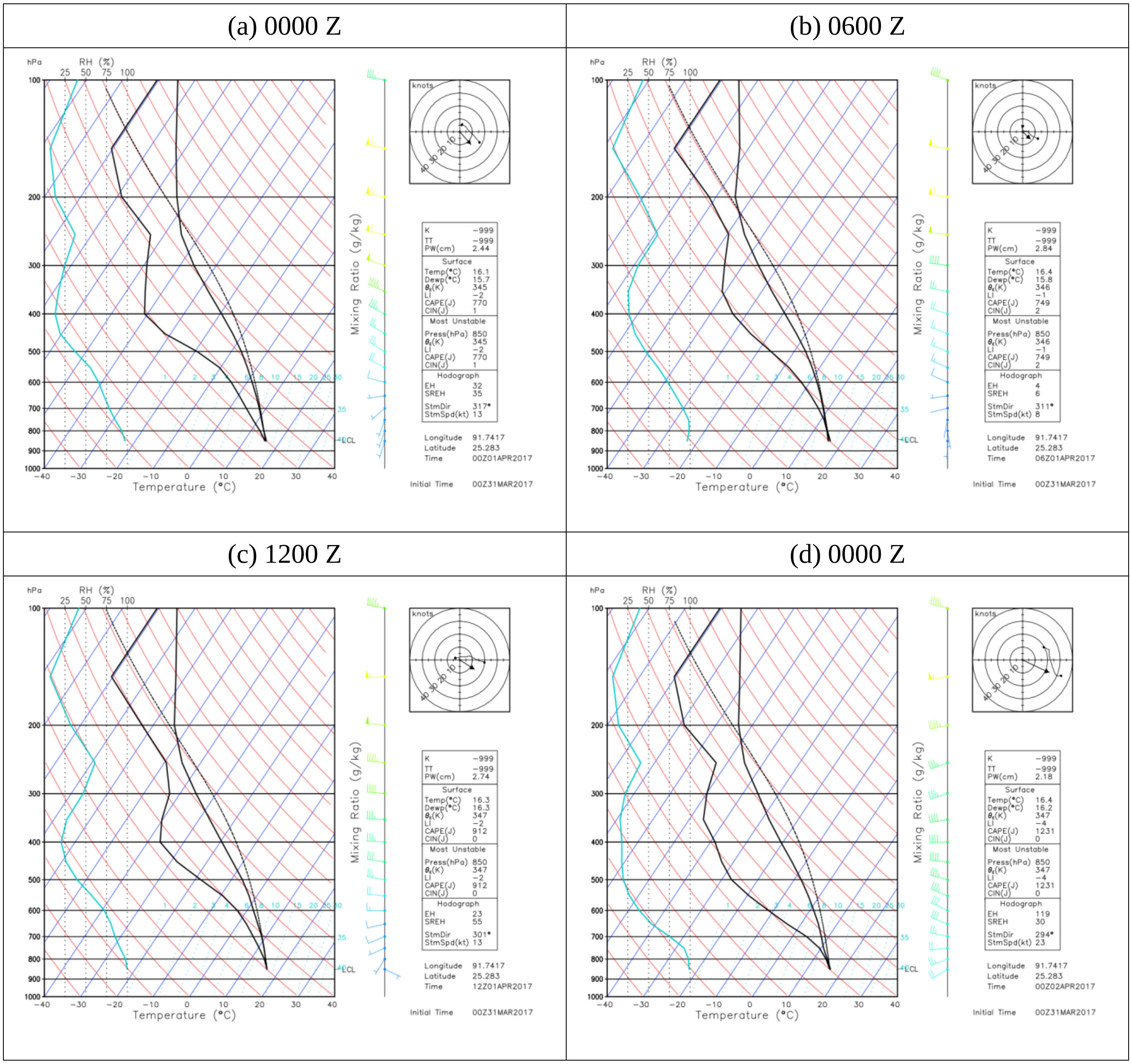

Figure 1.3: Observed and model simulated Skew-t analyses for the event.

The model showed development of storm producing squall lines at 0600 UTC of April 1, 2017, at Cherrapunjii region. Stability indices simulated by model show significant threshold value of various indices which initiate the storm event. The model simulated skew-T at 0600 UTC over the Cherrapunjii region showed strong convection persisted and Lifted index (LI) was -2 to -4 which indicate highly unstable environment.

1.6. Summary

On the basis of the current study, subsequent conclusions can be drawn-

- From the spatial pattern of rainfall retrieved from TRMM, it can be clearly seen that the rainfall amount and spread are well captured for the event. It is found that the TRMM underestimated daily precipitation over the specific station observation.
- The instability indices from T–Φ gram analysis are well captured by the model runs in comparison with that in the available observation. The larger CAPE values in the model runs for two locations out of three locations could be attributed to higher moisture convergence aided by stronger moisture-laden winds in the lower atmosphere. The model runs have well represented the different stages of storm evolution as compared to the observation.
- Model simulated instability parameter specially LI indicate strong negative value (-4) over the region of Cherrapunjii which is significant findings of the study.

CHAPTER TWO

HYDROLOGICAL MODELING USING HEC-HMS FOR FLASH FLOOD

2.1 Introduction

The Meghna Basin, a complex basin system with bowl shaped low lands (haor areas) and hilly catchment, lies both inside and outside Bangladesh. About 60% of the basin lie in the Indian subcontinent and even that part has three different basin (with three different topology), which are: the Meghalaya basin in the upper northern area, the Barak basin on the upper east and the Tripura hills in the lower southern part of the basin. Sudden Orographic rain in the pre-monsoon period transcends the hilly regions of Meghalaya, into the intermittent and ephemeral rivers slopes and floods the surrounding haor areas within hours as described in Das et al. (2017). These sudden inundations or flash flood occur within hours, inundating the crops and usually lasting for less than 4-days. These inundations are helpful to agriculture and pisciculture but the flash flood of 2010 and lasted for more than 1 week and caused massive devastation, causing a huge loss the economy. The flash flood in 2017 destroyed more than 20000 hectares of agricultural crops in the month of April alone according to the Monthly Hazard incidence report of May 2017. If the farmers could be warned about the level and duration of flash flood before its onslaught, they would know when to harvest their crops to avoid a repeat of the scenario on 2017. There is no hydrological model to forecast pre-monsoon yet, but a well calibrated and validated hydrological model could generate continuous discharge data at different trans-boundary rivers of North-East region which can be incorporated in HEC-RAS model to forecast water levels at different rivers of the Meghna basin during pre-monsoon period.

This chapter of the report focuses mainly on the hydrologic model HEC-HMS and its components. The annual report of 2018 showed the parameters used to calibrate the model. The model has already been successfully calibrated for 9 discharge stations and this chapter will show the updated calibration and validation of those stations. This chapter will also show the forecast results for pre-monsoon period of 2017 and how Artificial Neural Network (ANN) was incorporate into the forecasts.

2.2 Data Collection

A total of 18 discharge observations were obtained from BWDB surveys as of 2018 and 20 rating curves were generated with RMSE between 10 and 50 for the calibration and validation of the model. The rating curves were added in the DSS-Vue archive and added to the model. 18 discharge stations were selected to calibrate and validate the model depending on the water level and discharge available, as shown in Figure 2.1. At locations where discharge data was not available, it was ensured that the water level pattern and was followed by the modelled discharge. The BWDB discharge stations are listed in the Table 2.1.

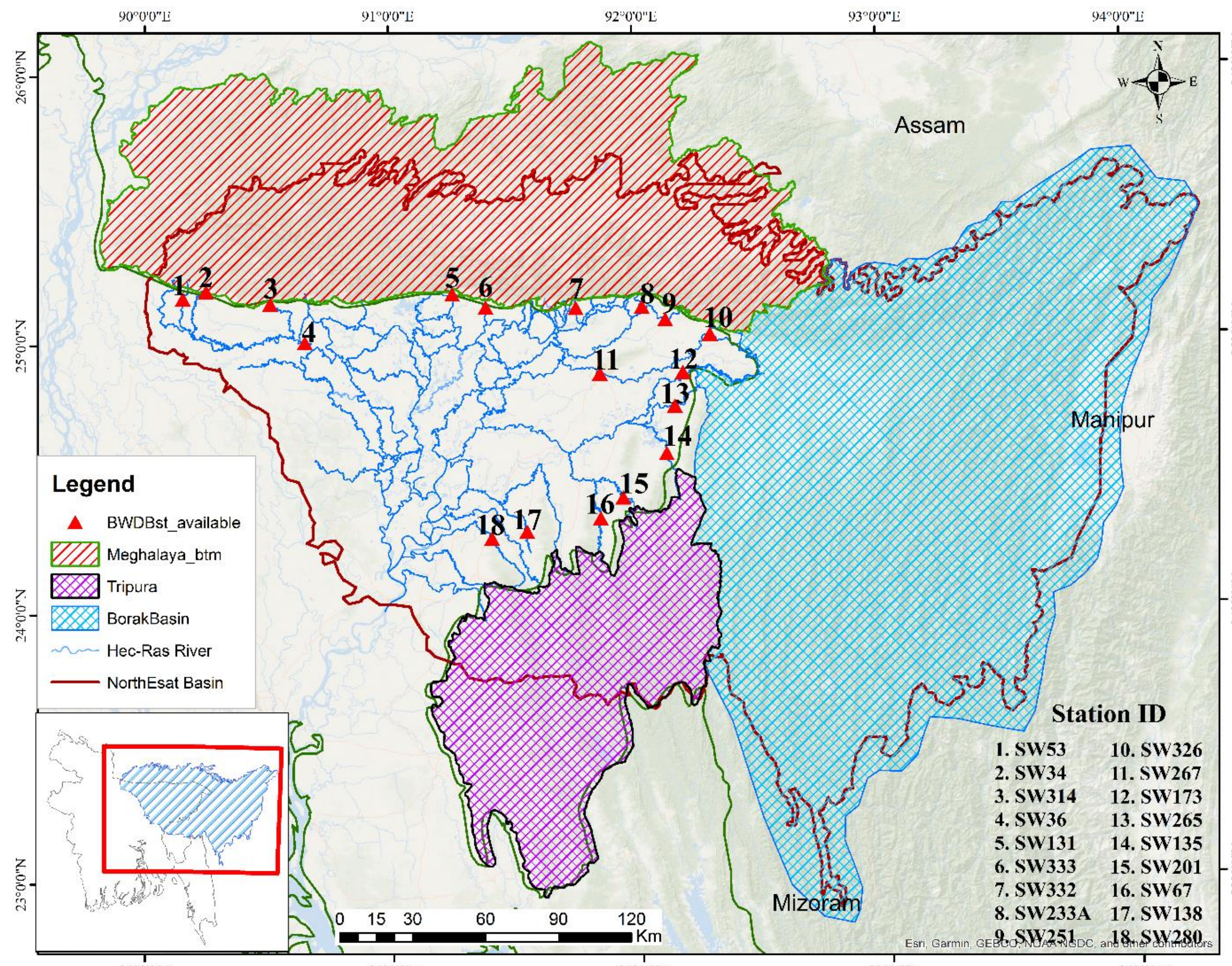

Figure 2.1: BWDB discharge stations used in this study.

Table 2.1: BWDB discharge stations used in this study.

No.	Name	Station ID	Type
1	Kamalganj	SW67	Inside Bangladesh
2	Laurergarh Saktiarkhola	SW131.5	Trans boundary
3	Sofiabad	SW138	Inside Bangladesh
4	Sheola	SW173	Trans boundary
5	Sylhet	SW267	Inside Bangladesh
6	Jaria Janjail	SW36	Inside Bangladesh
7	Monu Rly Bridge	SW201	Inside Bangladesh
8	Jafflong Spill	SW233A	Trans boundary
9	Sarighat	SW251	Trans boundary
10	Jaldhup	SW265	Trans boundary
11	Sutang Rly Bridge	SW280	Inside Bangladesh
12	Lubachara	SW326	Trans boundary
13	Islampur	SW332	Trans boundary
14	Muslimpur	SW333	Trans boundary
15	Nakuagaon	SW34	Inside Bangladesh
16	Juri	SW135	Inside Bangladesh

2.3 Overview of the Model

A continuous model of the basin was run using HEC-HMS as it best simulates event based rainfall-runoff models and peak flow according to Razmkhah (2016). The loss was modelled using Soil Moisture Accounting (SMA) method and the parameters were estimated from Singh et al. (2015) and Azmat.et. al. (2017). Clark Unit Hydrograph (Clark UH) was used to simulate transform method where the time of concentration was calculated using Kirpich’s formula. The base flow of the basin was simulated using the recession method while flood routing was done using Muskingum-Cunge method. Monthly evapotranspiration data, used to simulate loss, was obtained from MOD16A2 V006. Land-use data was obtained from GlobCover which was used to determine the parameters for simulate loss. The model is being calibrated and validated using rainfall from BWDB and BMD data inside Bangladesh and IMD data in the Meghalaya and Barak basin as shown in Figure 2.2.

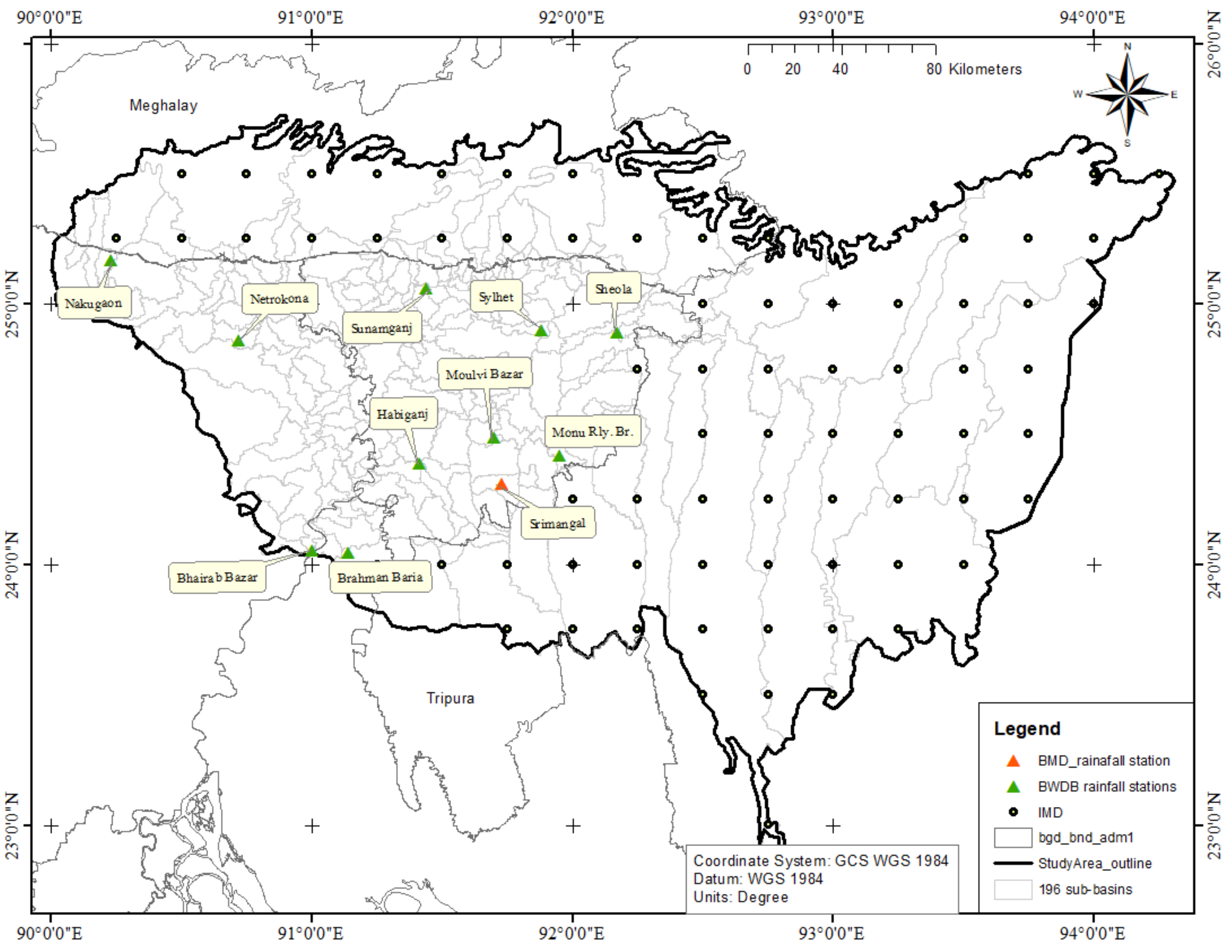

Figure 2.2: Rainfall stations used to calibrate HEC-HMS model.

2.4 Model Results

Model calibration is done where the model generated discharge at a specific location and a specific time range is compared with the measured discharge at that location and at the same time range. The calibration time range was taken for the model from 2010 to 2012. It must be confirmed that the parameters assigned during the calibration period could also replicate the real physical scenario at the same location but at a different time range. Thus validation is done which, again, compares the model generated discharge with the measured discharge. The calibration time range taken for the model from 2013 to 2017. Several parameters are considered to check the model performance. **PBIAS** or Percent Bias is done to check the average tendency of the simulated data to be higher or lower than the observed data, that is, the bias of the model against the observed discharge data. $\boldsymbol{R^2}$ or coefficient of determination, value was checked to determine how well the observed versus simulated data fits the 1:1 line. **NSE**, or Nash-Sutcliff Efficiency was calculated to check the efficiency of the model at projecting the observed discharge. **RSR**, or RMSE-observations Standard Deviation Ratio, was used as it standardizes RMSE using standard deviation of the observed term so that the resulting statistic and reported values can apply to various constituents. The ideal range of each of the statistical parameters are shown in Table 2.2 below which was collected from Moriasi et al. (2007).

Table 2.2: Performance rating of different evaluation parameters.

Performance Rating	$\boldsymbol{R^2}$	**RSR**	**NSE**	**PBIAS (%)**
very good	$0.8 \leq R^2 \leq 1$	0.00 < RSR < 0.50	0.75 < NSE < 1.00	PBIAS < ±10
Good	$0.7 \leq R^2 < 0.8$	0.50 < RSR < 0.60	0.65 < NSE < 0.75	±10 < PBIAS < ±15
Satisfactory	$0.5 \leq R^2 < 0.7$	0.60 < RSR < 0.70	0.50 < NSE < 0.65	±15 < PBIAS < ±25
Unsatisfactory	$0.5 \leq R^2$	RSR > 0.70	NSE < 0.50	PBIAS > ±25

Out of the 18-discharge station inside Bangladesh, 16 stations were successfully calibrated and validated while the other 2 stations are a bit difficult to work out due to the complex topology and rainfall. While there are room for improvement in 8 stations in terms of R^2, they all perform well as indicated by the other parameters. The evaluation parameters found for each station at the calibration period of 2010 to 2012 are shown in the Table 2.3. The parameters found for the validation period of 2013 to 2017 are shown in Table 2.4.

Table 2.3: Evaluation for the calibration period of 2010 to 2012.

Station Name	Station ID	River Name	R^2	comment	NSE	comment	PBIAS	comment	RSR	comment
Kanairghat	266	Surma	0.72	good	.66	good	2.32	very good	.59	good
Shaktiarkhola	131.5	Jadukata	0.64	Satisfactory	0.9	very good	27.6	unsatisfactory	0.32	very good
Muslimpur	333	Jadukhali	.788	good	0.988	very good	17.805	Satisfactory	0.110	very good
Islampur	332	Dhala	0.55	Satisfactory	0.973	very good	13.23	good	0.18	very good
Jafflong	233A	Piyan	0.721	good	0.965	Very good	15.399	Satisfactory	0.186	very good
Sarighat	251	Sarigowain	0.73	good	0.92	very good	7.44	very good	0.285	very good
Lubachara	326	Lubha	0.73	good	0.96	very good	9.41	very good	0.21	very good
Sylhet	267	Surma	0.72	very good	0.6	Satisfactory	5.27	very good	0.63	Satisfactory
Sheola	173	Kushiyara	0.77	good	0.98	very good	13.52	good	0.14	very good
Jaldhup	265	Sonai bordal	0.9	very good	0.92	very good	-8.13	very good	0.2	very good
Juri	135	Juri	0.699	Satisfactory	0.866	very good	13.554	good	0.366	very good
Monu	201	Monu	0.520	Satisfactory	.96	very good	20.93	Satisfactory	.2	very good
Kamalganj	67	Dhalai	0.475	unsatisfactory	0.946	very good	14.190	good	0.233	very good
Motiganj	192	Lungla binja	0.200	unsatisfactory	0.941	very good	50.546	unsatisfactory	0.244	very good
Sofiabad	138	Korangi	0.75	good	0.92	very good	22.25	very good	0.28	very good
Sutang	280	Sutang	.71	good	0.92	very good	6.12	very good	0.3	very good

Table 2.4: Evaluation for the validation period of 2013 to 2015.

Station Name	Station ID	River Name	R^2	comment	NSE	comment	PBIAS	comment	RSR	comment
Kanairghat	266	Surma	0.692	Satisfactory	.82	very good	-23.58	Satisfactory	.42	very good
Shaktiarkhola	131.5	Jadukata	0.82	very good	0.98	very good	31.16	Unsatisfactory	0.137	very good
Muslimpur	333	Jadukhali	0.842	very good	0.960	very good	66.122	Unsatisfactory	0.201	very good
Islampur	332	Dhala	0.8	very good	0.44	Unsatisfactory	12.78	good	0.74	Unsatisfactory
Jafflong	233A	Piyan	0.091	Unsatisfactory	0.970	very good	10.408	good	0.174	very good
Sarighat	251	Sarigowain	0.803	very good	0.855	very good	52.2	Unsatisfactory	0.38	very good
Lubachara	326	Lubha	0.96	very good	0.96	good	21.69	Satisfactory	0.18	very good
Sylhet	267	Surma	0.69	Satisfactory	0.94	very good	18.47	Satisfactory	0.23	very good
Sheola	173	Kushiyara	0.86	very good	0.98	very good	10.73	good	0.12	very good
Jaldhup	265	Sonai bordal	0.939	very good	0.98	very good	12.34	good	0.14	very good
Juri	135	Juri	0.668	Satisfactory	0.777	very good	0.803	very good	0.473	very good
Monu	201	Monu	0.466	Unsatisfactory	0.853	very good	13.403	good	0.384	very good
Kamalganj	67	Dhalai	0.614	Satisfactory	0.822	very good	8.854	very good	0.422	very good
Motiganj	192	Lungla binja	0.378	Unsatisfactory	0.564	Satisfactory	9.726	very good	0.660	Satisfactory
Sofiabad	138	Korangi	0.68	Satisfactory	0.64	Satisfactory	9.18	very good	0.5	good
Sutang	280	Sutang	0.52	Satisfactory	0.9	very good	19.07	Satisfactory	0.3	very good

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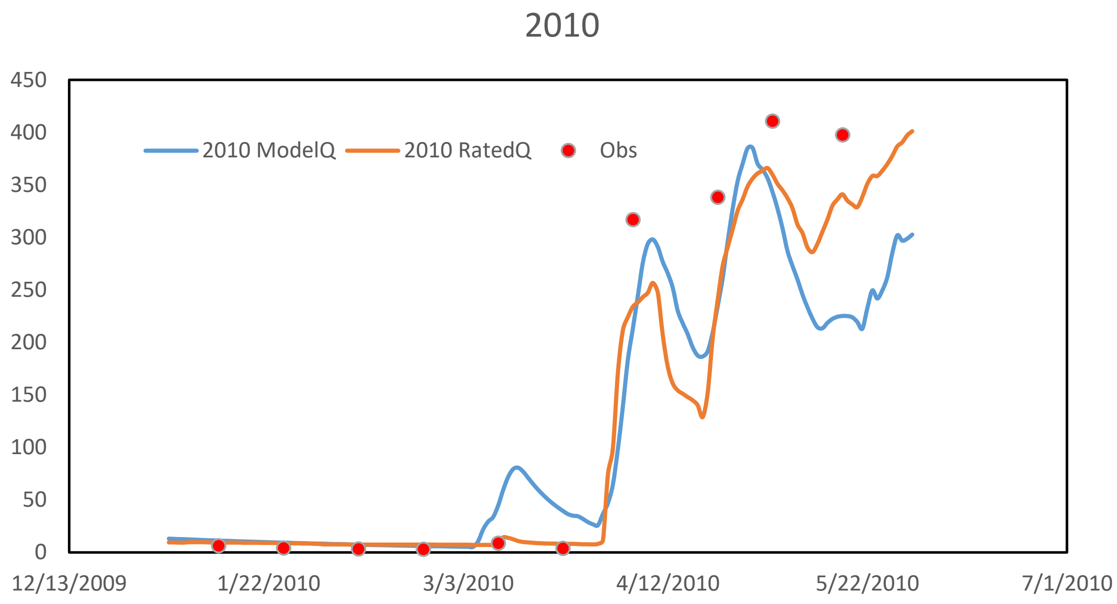

Figure 2.3 Calibrated result of Jaldhup (SW265) station in the Sonaibordal River for the year 2010.

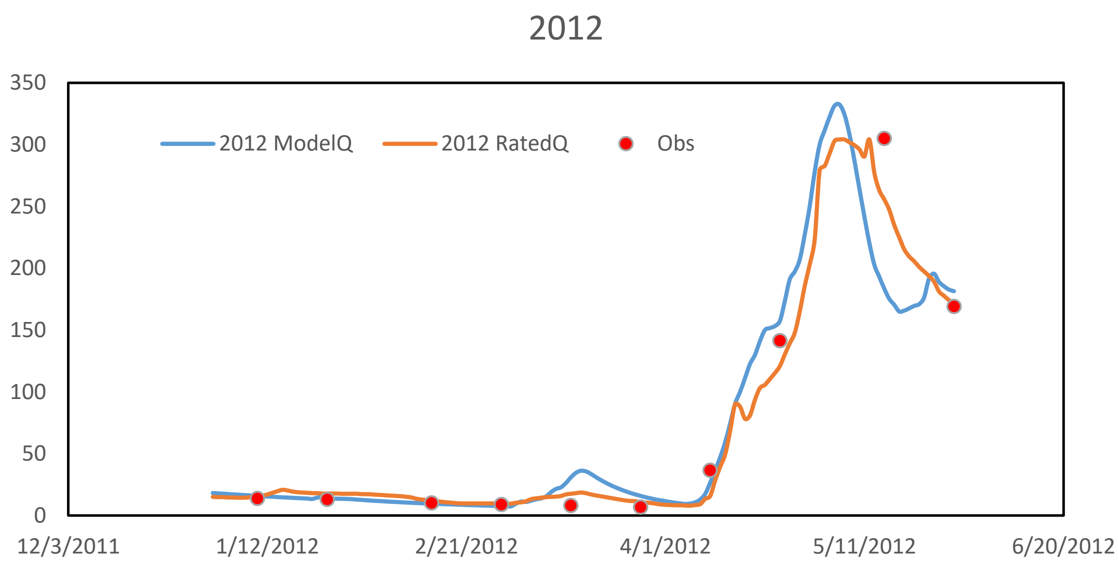

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Figure 2.4 Calibrated result of Jaldhup (SW265) station in the Sonaibordal River for the year 2012.

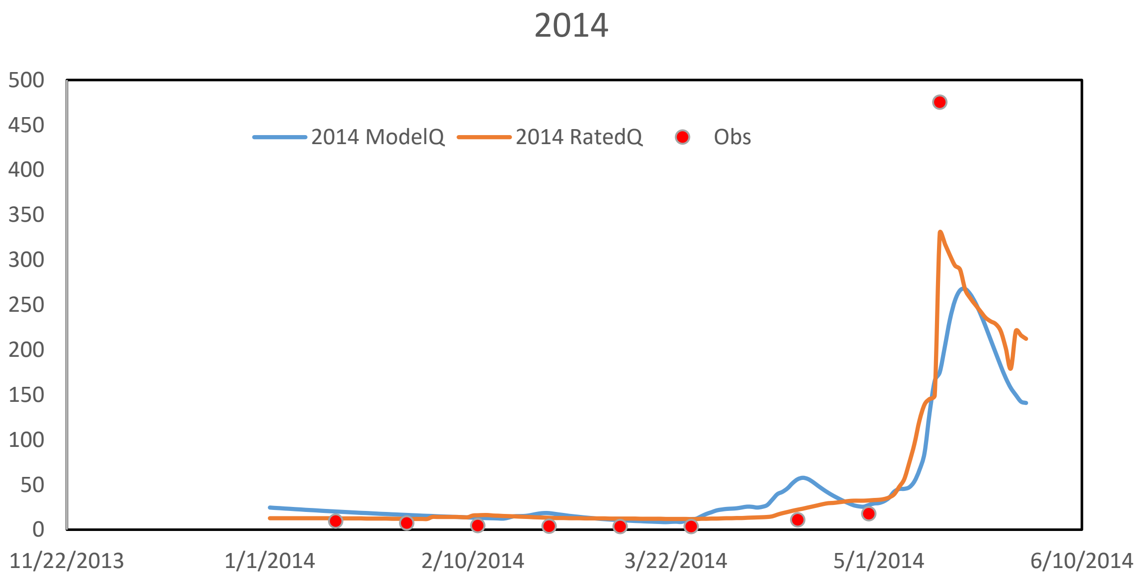

Figure 2.5: Validated result of Jaldhup (SW265) station in the Sonaibordal River for the year 2014.

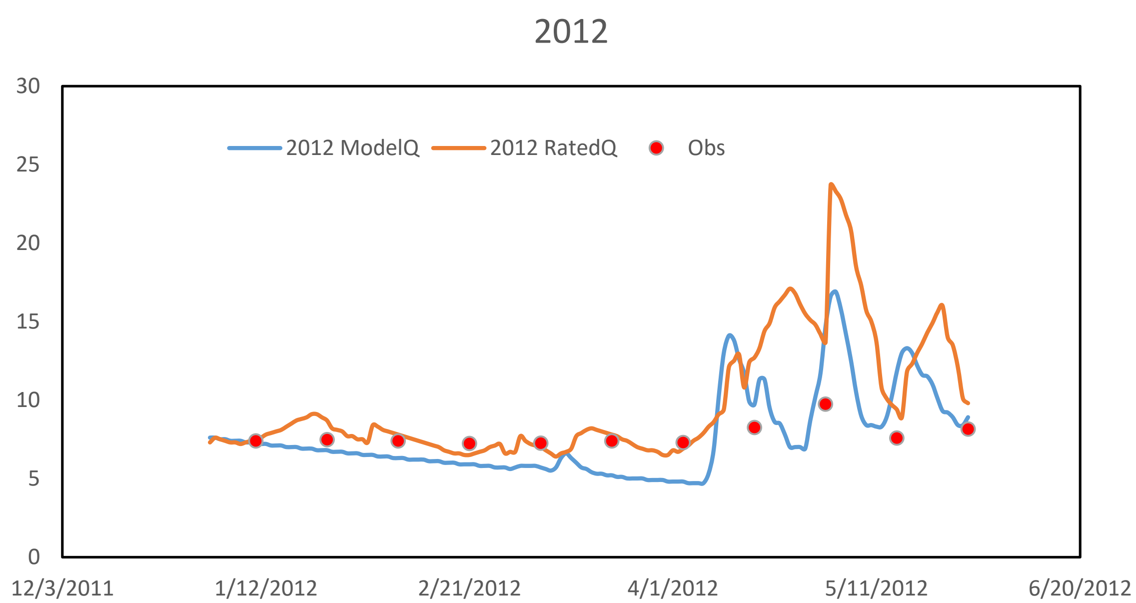

Figure 2.6: Calibrated result of Sofiabad (SW138) station in the Korangi River for the year 2012.

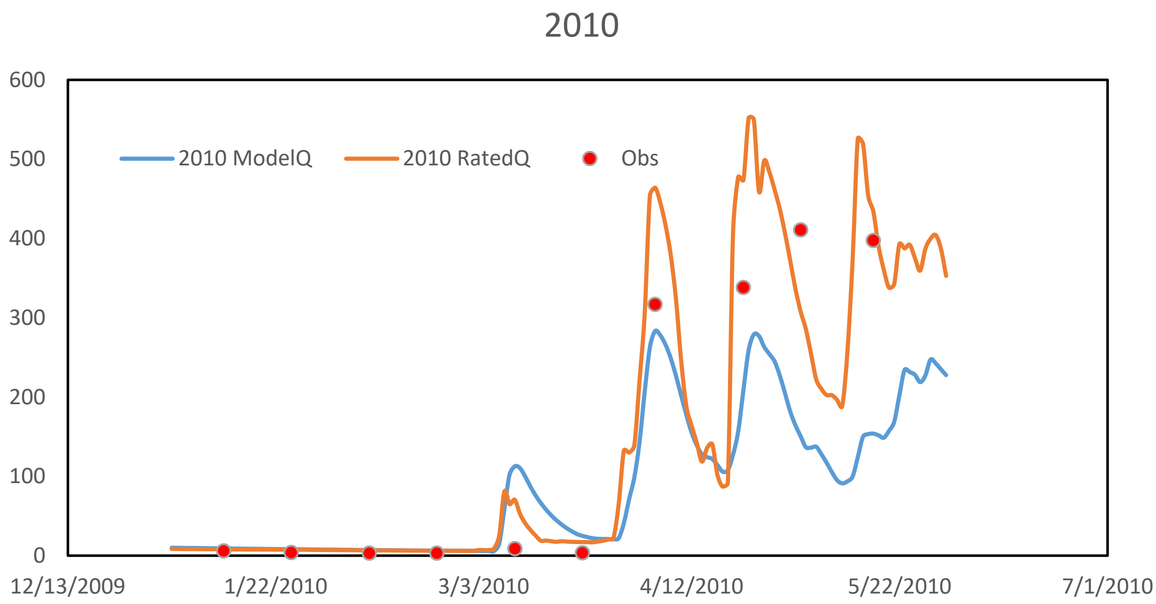

Figure 2.7: Calibrated result of Lubhachara (SW326) station in the Lubha River for the year 2010.

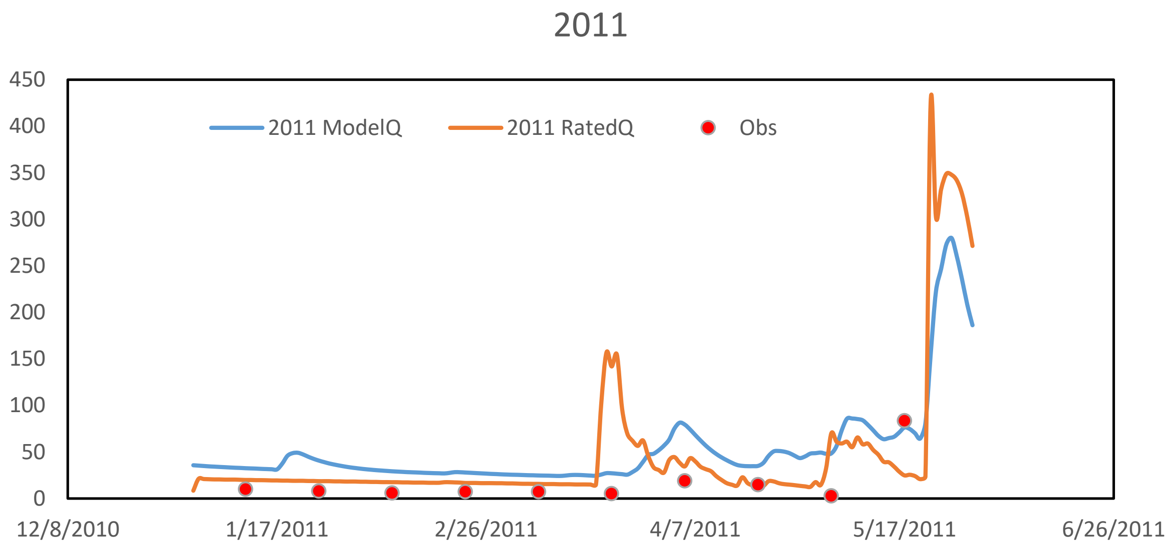

Figure 2.8: Calibrated result of Lubhachara (SW326) station in the Lubha River for the year 2011.

Further revision is required at some stations. Some limitations within the HEC-HMS modelling system, for example the inability to model flow in the floodplain or bifurcation, will make calibration at some stations very difficult but the aim will be to match the flood peak in order to model the flow during flash floods. The stations have been validated for the pre-monsoon season for the years 2013 to 2017.

CHAPTER THREE
HYDRODYNAMIC MODELING

3.1 Introduction

The Meghna Basin, located in the north-east region of Bangladesh at the foothills of Meghalaya and Assam of India is a bowl shaped basin with low lands (haor areas) and mostly hilly catchment areas. Sudden heavy rainfall in these hills during the pre-monsoon season rushes down in a very short time, about 6 hours, and floods the low-lands. In 2010 alone, the loss was more than 150 cores BDT (NIRAPAD, 2010) as flash flood occurred during the harvesting period. In this year, flash flood in the northeast region inundated more than 11 lakhs hectare area of Boro crop, among which 85% crops were damaged causing a loss of more than 150 crores. Also in 2017, the flash floods devastated many districts in the northeast region including Sunamganj, Sylhet, Moulvibazar and Habiganj, destroying more than 200,000 hectares of agricultural lands in the month of April (NIRAPAD, 2017). To save the crops by harvesting before the occurrence of flashflood, a proper early warning system is an important need. A hydrodynamic model can be used to route the water at the foot of the hill through the complex system of rivers in the north-east region, to estimate the river surface profile and get an early indication of water level and hence flash flood. This knowledge can be used to generate an early warning system for flashflood.

The Hydrodynamic model using HEC-RAS 1-D module to simulate water level and predict the flashflood will be discussed in this chapter. The aim is to predict water level based on input flow data and analyze flood level using measured cross-section and streamflow data of the river network. The model will generate water levels at various sections which can be used by the forecast stations for early warning of flashflood and be disseminate to the concerned so that appropriate actions can be taken to minimize the loss and damages due to flash flood.

Several cross sections and flow data have been updated and the Hydrologic and Hydrodynamic model have been coupled for modelling purpose. A unsteady flow analysis has been performed to achieve the objective of this project of improving the current flood forecasting and warning system The modeled basin and the rivers are shown in Figure 3.1

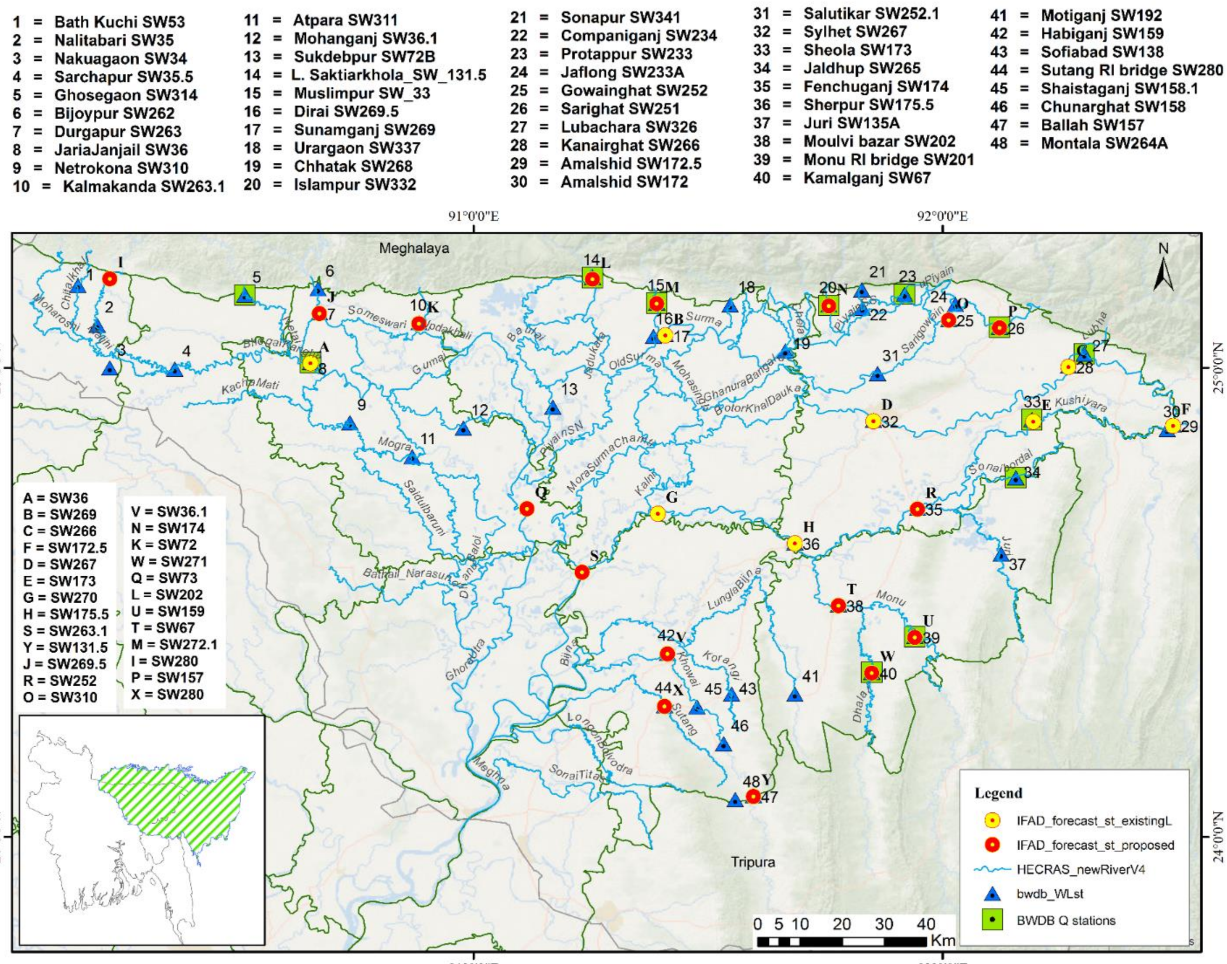

Figure 3.1: The Meghna basin and its rivers.

3.2 Model Update

For calibration, a change has been made to the model in the input data focusing on those station such as Juri, Sofiabad, Monu, Gowainghat, Nakuagaon which gave unsatisfactory result. To develop the hydrodynamic model, flow boundary conditions are necessary for upstream. Rating curves have been used for eighteen rivers. Measured discharge are not available for the rest stations. For these stations, flow data generated by the HEC-HMS Hydrologic model have been used as a boundary condition to proceed to further analysis. Table 3.1 shows the boundary condition used for the rivers in the model.

Channel roughness is a sensitive parameter in development of hydraulic model for flood forecasting and flood inundation mapping. The requirement of multiple channel roughness coefficient Manning's '*n*' values along the river has been adjusted depending on observed water level. Range of the Manning's n is 0.02 to 0.062

Table 3.1: Boundary conditions in modeled rivers.

SL	River Name	Boundary condition	SL	River Name	Boundary Condition
1	Moharoshi	HMS	16	Lubha	Rating Curve
2	Chitalkhali	Rating Curve	17	Barak	HMS
3	Bhogaikangsha	Rating Curve	18	Sonaibordal	Rating Curve
4	Netai	Rating Curve	19	Juri	Rating Curve
5	Someswari	HMS	20	Monu	Rating Curve
6	Karnobilja	HMS	21	Dhalai	Rating Curve
7	Jadukhali	Rating Curve	22	LunglaBinja	Rating Curve
8	Kashhimara	HMS	23	Korangi	Rating Curve
9	Nawagang	Rating Curve	24	Khowai	Rating Curve
10	Chela	HMS	25	Sutang	Rating Curve
11	Juliachara	HMS	26	LongolBhodra	Rating Curve
12	Dhala	Rating Curve	27	SonaiTitas	HMS
13	Omayan Chella	Rating Curve	28	Kachamati	HMS
14	Ipiyan	HMS	29	Bathail Nausad	HMS
15	Sarigowain	Rating Curve			

3.3 Calibration and Validation

The calibration of the hydrodynamic model includes the choice of an appropriate value of Manning's 'n' such that simulated result from the HEC RAS model should be close to the observed stages along the river. Here, an attempt has been made to calibrate the model for various experimental flows of the river. Calibration period is 2010 to 2012. The performance of the calibrated model has been verified for flood of year 2013 to 2015. Simulated results have been obtained close to the observed stages. The performance is reasonably good for the stations.

Four statistical criteria were used to assess the performance of the HEC-RAS model. Coefficient of determination (**R^2**) describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable. The Nash-Sutcliffe efficiency (**NSE**) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance. NSE indicates NSE ranges be-tween $-\infty$ and 1.0 (1 inclusive), with NSE as 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. **RSR** standard-sizes RMSE using the observations standard deviation, and it combines both an error index**.** RSR is calculated as the ratio of the RMSE and standard deviation of measured data.

Here, Table 3.2 shows the ranges of the statistical parameter. Table 3.2 shows the calibration parameters of some of the stations.

Table 3.2: Calibration parameters (R2, NSE, PBIAS) for forecast stations.

Station	Station ID	River Name	R^2	Comment	NSE	Comment	PBIAS	Comment
Amalshid	SW172.5	Barak	0.912	Very Good	0.698	Good	0.912	Very Good
Juri	SW135A	Juri	0.822	Good	0.985	Very Good	-9.421	Very Good
Sofiabad	SW138	Korangi	0.995	Very Good	0.999	Very Good	-.673	Very Good
Sheola	SW173	Kushiyara	0.935	Very Good	0.99	Very Good	-19.979	Satisfactory
Fenchuganj	SW174	Kushiyara	0.961	Very Good	0.692	Good	-21.044	Satisfactory
Sherpur	SW175.5	Kushiyara	0.869	Very Good	0.714	Good	-14.507	Good
Moulvi	SW202	Monu	0.869	Good	0.956	Very Good	-19.21	Satisfactory
Jaflong	SW233A	Jaflong	0.738	Good	0.95	Very Good	0.023	Very Good
Companiganj	SW234	Surma	0.91	Good	0.96	Unsatisfactory	-0.108	Very Good
Sarighat	SW251	Sarigowain	0.765	Good	0.753	Very Good	2.804	Very Good
Gowainghat	SW252	Sarigowain	0.818	Good	0.975	Very Good	-12.21	Good
Salutikar	SW252.1	Sarigowain	0.87	Good	0.99	Very Good	-1.379	Very Good
Jaldhup	SW265	Sonaibardal	0.953	Very Good	0.769	Very Good	6.540	Very Good

Kanairghat	SW266	Surma	0.901	Very Good	0.99	Very Good	-20.927	Satisfactory
Sylhet	SW267	Surma	0.900	Very Good	0.804	Very Good	-13.199	Good
Chhatak	SW268	Surma	0.871	Very Good	0.588	Satisfactory	-23.272	Satisfactory
Sutang	SW280	Sutang	0.887	Very Good	0.878	very good	-1.378	Very Good
Lubachara	SW326	Lubachara	0.94	Very Good	0.99	Very Good	-16.017	Satisfactory
Islampur	SW332	Dhala	0.72	Good	0.99	Very Good	-0.779	Very Good
Sonapur	SW341	Omayan Chella	0.87	Very Good	0.98	Very Good	-0.940	Very Good
Kamalganj	SW67	Dhala	0.87	Very Good	0.99	Very Good	-0.409	Very Good

Table 3.3: Model performance rating.

Parameter	Very good range	Good	Acceptable Range
R^2	0.9 –1.0	0.8 – 0.9	0.7 – 0.8
RSR	0 – 0.5	0.5 – 0.6	0.6 – 0.7
NSE	0.75 - 1	0.65 – 0.75	0.5 – 0.65
PBIAS	$<\pm10$	$\pm10 - \pm15$	$\pm15 - \pm25$

Table 3.4: Statistical Parameters for the calibration period.

Station	Station ID	River Name	R^2	Comment	NSE	Comment
Amalshid	SW172.5	Barak	0.912	Very Good	0.698	Good
Juri	SW135A	Juri	0.822	Good	0.985	Very Good
Sofiabad	SW138	Korangi	0.864	Very Good	0.999	Very Good
Sheola	SW173	Kushiyara	0.935	Very Good	0.99	Very Good
Fenchuganj	SW174	Kushiyara	0.961	Very Good	0.692	Good
Sherpur	SW175.5	Kushiyara	0.869	Very Good	0.714	Good
Moulvi	SW202	Monu	0.869	Good	0.956	Very Good
Jafflong	SW233A	Jaflong	0.738	Good	0.95	Very Good
Companiganj	SW234	Surma	0.91	Very Good	0.96	Very Good
Gowainghat	SW252	Sarigowain	0.818	Good	0.975	Very Good
Salutikar	SW252.1	Sarigowain	0.87	Very Good	0.99	Very Good
Jaldhup	SW265	Sonaibardal	0.953	Very Good	0.769	very Good
Kanairghat	SW266	Surma	0.901	Very Good	0.99	Very Good
Sylhet	SW267	Surma	0.900	Very Good	0.804	Very Good
Chhatak	SW268	Surma	0.871	Very Good	0.588	Satisfactory
Sutang	SW280	Sutang	0.887	Very Good	0.878	Very Good
Lubachara	SW326	Lubachara	0.94	Very Good	0.99	Very Good
Islampur	SW332	Dhala	0.72	Good	0.99	Very Good
Sonapur	SW341	Omayan Chella	0.87	Very Good	0.98	Very Good
Kamalganj	SW67	Dhala	0.87	Very Good	0.99	Very Good

The model has been successfully calibrated for almost all water level stations with R^2 ranging from 0.75 to 0.99. The calibration results at various stations are shown in Figure 3.2 to 3.6

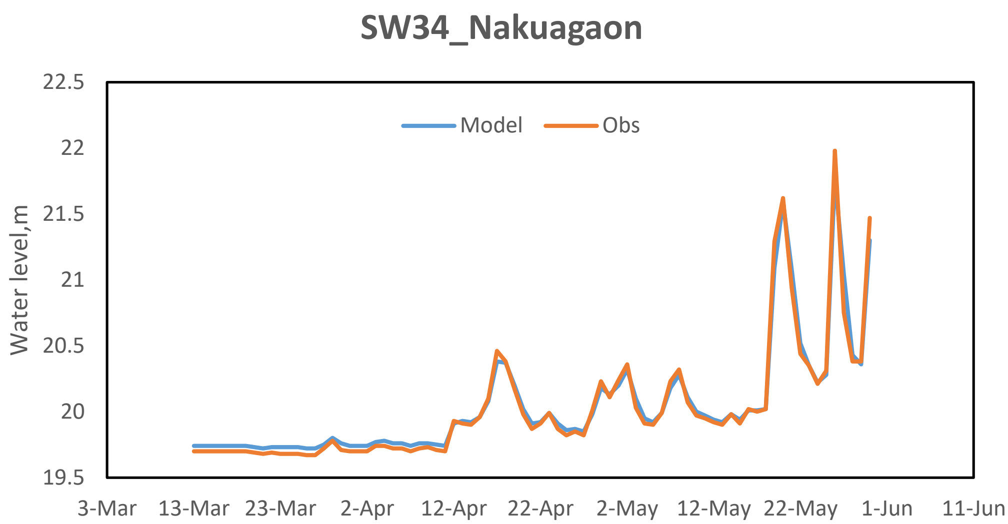

Figure 3.2: Calibration results of Nakuagaon (SW34) station on the Boghaikangha River.

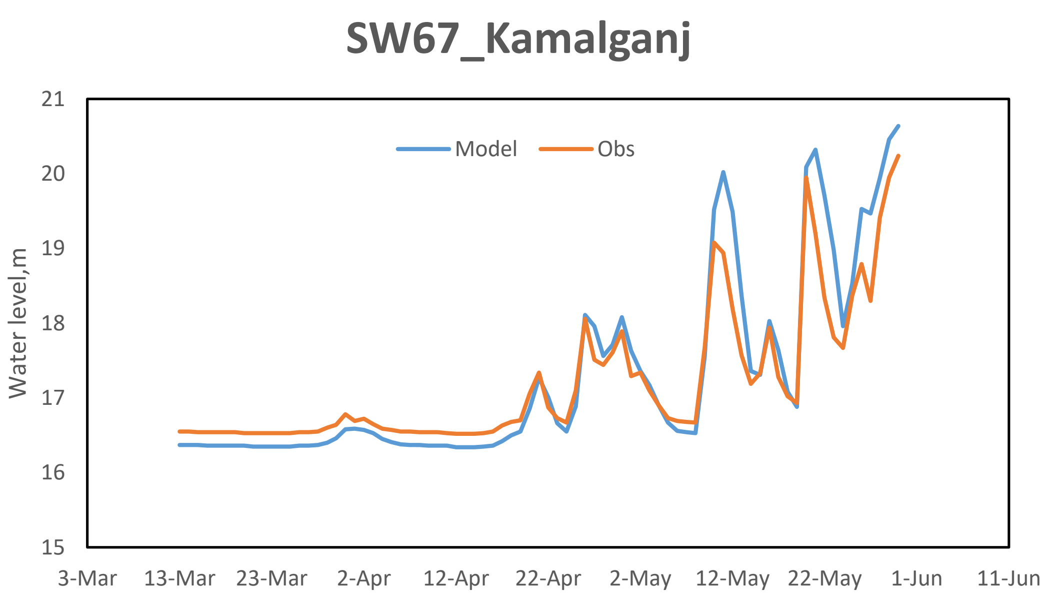

Figure 3.3: Calibration results of Kamalganj (SW67) station on the Dhalai River.

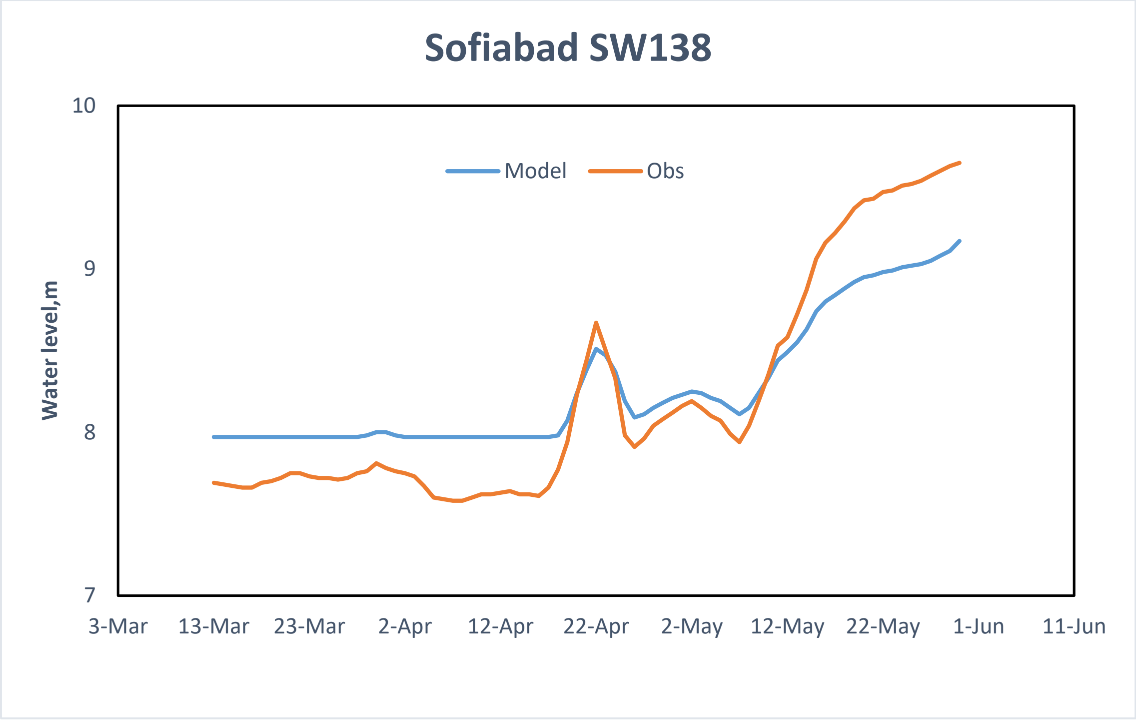

Figure 3.4: Calibration results of Sofiabad (SW138) station on the Korangi River.

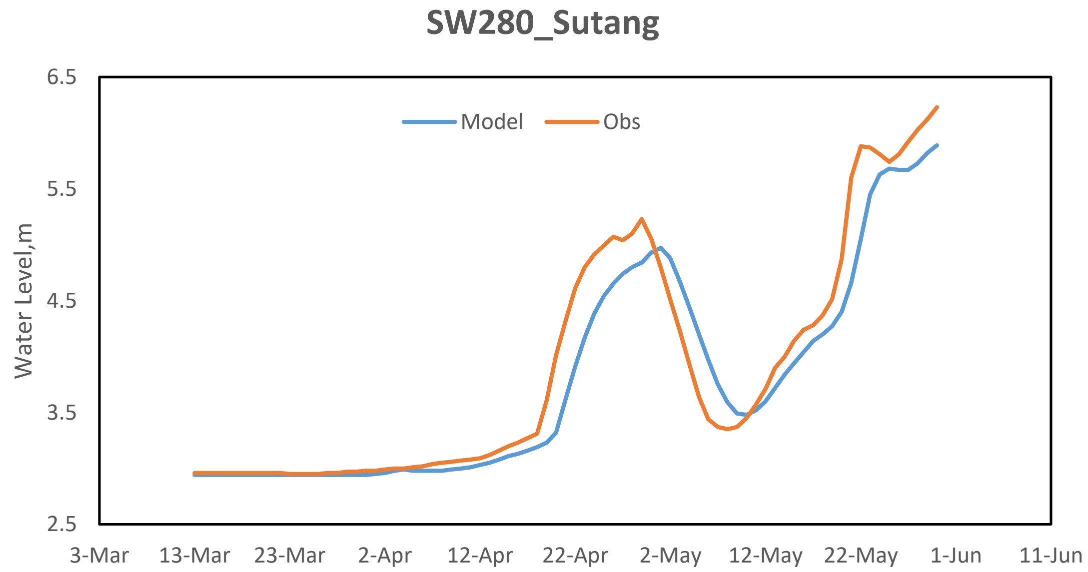

Figure 3.5: Calibration results of Sutang (SW280) station on the Korangi River.

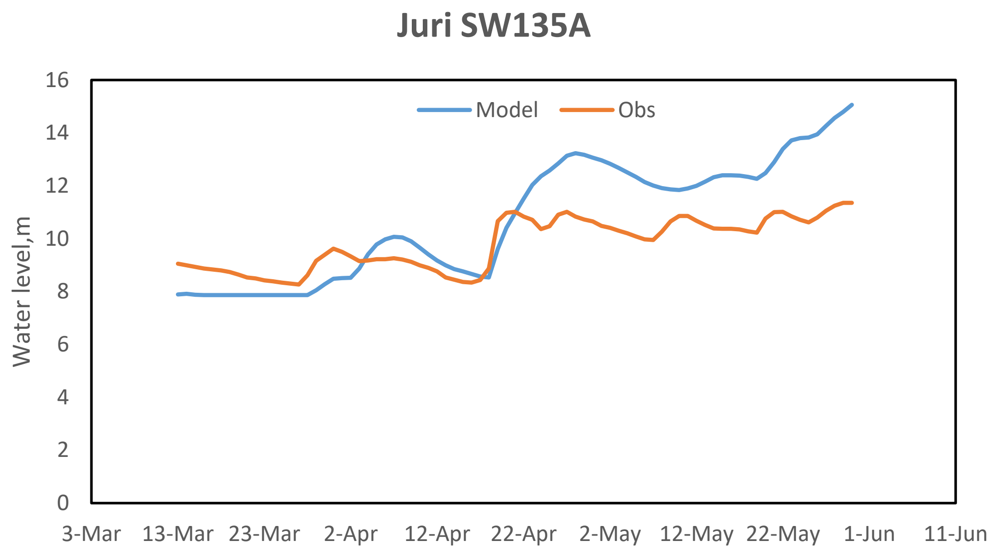

Figure 3.6: Calibration results of Juri (SW135A) station on the Juri River.

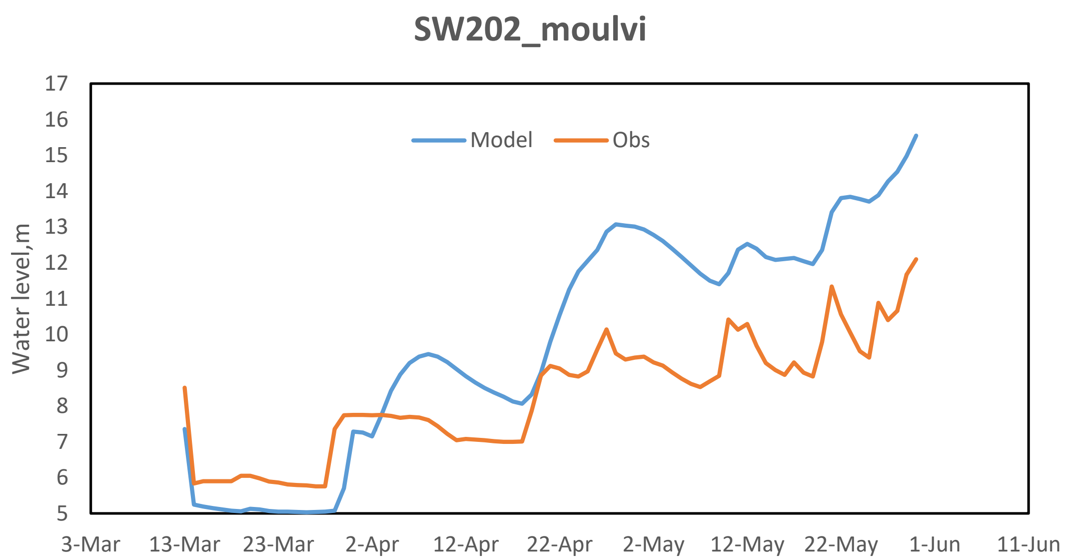

Figure 3.7: Calibration results of Moulvibazar (SW202) station on the Monu River.

3.4 Summary

Good statistical parameters are obtained for Juri, Sofiabad, Monu, Gowainghat, Nakuagaon stations during the calibration and validation period. In Juri river, R^2 and NSE were 0.711 and -0.284 respectively but after model update R^2 and NSE are now 0.822 and 0.985 respectively. The remaining stations also show good statistical parameter like Juri station. Now this model is suitable for flash flood forecasting especially in pre-monsoon season (March to May).

CHAPTER FOUR

DISSEMINATION AND MODELING INTERFACE USING DELFT-FEWS

4.1 Introduction

Delft-FEWS is a hydrological forecasting and warning system. Being an open data handling platform, it is a collection of configurable modules for constructing an operational water management system. Though it was originally designed for hydrological forecasting and warning, Delft FEWS is being used for real time control and forecasting and warning in other disciplines as well. In operational forecasting, real world processes are simulated using different hydrological and hydraulic models. These models change rapidly due to the increasing availability of real time data from terrestrial networks, from radar and satellite based systems, as well as due to advances in meteorological forecasting. This calls for a flexible approach in establishing sustainable real time decision support systems that can adapt to these changing needs. Through Delft-FEWS, operational forecasting systems can be constructed, and it allows flexibility in the integration of models and data. Delft-FEWS system contains no inherent hydrological modelling capabilities within its code base. Instead it relies entirely on the integration of (third party) modelling components.

The forecasting system needs to import and process the meteorological forecast data to serve as future precipitation inputs for the hydrological and hydraulic model chain. Figure 4.1 provides a schematic view of the connection between the forecasting system to real time data acquisition systems and dissemination systems. Figure 4.1 also shows the link to climatological and reference information, as well as archived data.

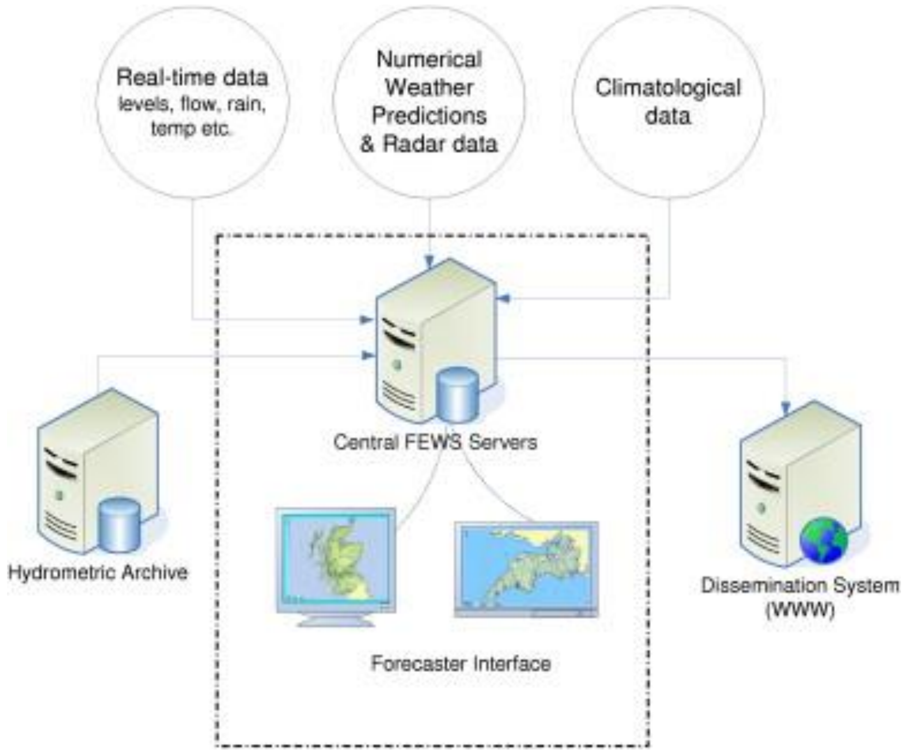

Figure 4.1: Schematic structure of a flood forecasting system, showing the position of Delft-FEWS and links to other primary systems within the operational environment.

4.2 Overview of Delft-FEWS

With the changing needs posed on operational forecasting systems, the design philosophy of Delft-FEWS follows the concept described by Argent et al. (2009) in that it provides a shell through which an operational forecasting application can be developed specific to the requirements of an operational forecasting center. Harvey et al. (2002) note that when accommodating a wide range of modelling concepts, the inclusion of model specific knowledge in the central data model would significantly increase complexity. Rather than evolve around a (set of) models and modelling concepts in a model-centric approach, the foundation of Delft-FEWS is data-centric, with a common data-model through which all components interact. All time series data (both scalar and gridded) are stored in this common data-model in a database. Modelling capabilities are then linked to the system through one of the interfaces provided to the data-model.

All operational forecasting systems require (real-time) data from hydrological and meteorological observation networks to be imported. In most operational systems, data from several sources is considered, with different data networks typically using different formats for storing and publishing data. Efficient import of data from these different sources poses a significant challenge, not only due to the variety of formats being used, but in many cases also due to differences in the meta-data provided. In the current generation of Delft-FEWS, an alternative approach is now being used, where a dedicated Java class is developed for each (new) data format. This data source specific Java class is only required to parse the particular format, and then submit the parsed data to a generic data handling framework that forms part of the import module.

Delft-FEWS will work to connect the meteorological, WRF, hydrological, HEC-HMS, and hydrodynamic, HEC-RAS, components of the project. It reads the NetCDF files from WRF forecast directly and connects to the HEC-HMS and HEC-RAS model through adapters specific for each program. The HEC-HMS adapter is configured to access the hydrological data from HEC-HMS directly from Delft-FEWS. The HEC-RAS adapter works by copying the HEC-RAS model data into the FEWS environment and modifying the global properties for HEC-RAS model and boundaries. The Figure 4.2 shows as the data exchange between HEC-RAS and Delft-FEWS.

Delft-FEWS has an extensive library of data processing functions. This includes specific hydrological functions, such as transforming stage data to discharge, applying temperature lapse rates, and applying bias correction using an ARMA model. All of the models that have been integrated with Delft-FEWS and are currently running in operational systems follow this approach. Delft-FEWS generates the input data as a set of XML files to a defined location; an adapter developed specifically for the model in question transforms this to the required native format in a pre-processing step; Delft-FEWS executes the model; and the adapter to that model then converts the native formatted results into XML formatted files in a post processing step. Delft-FEWS subsequently imports the results into the database from the XML files (Figure 4.3)

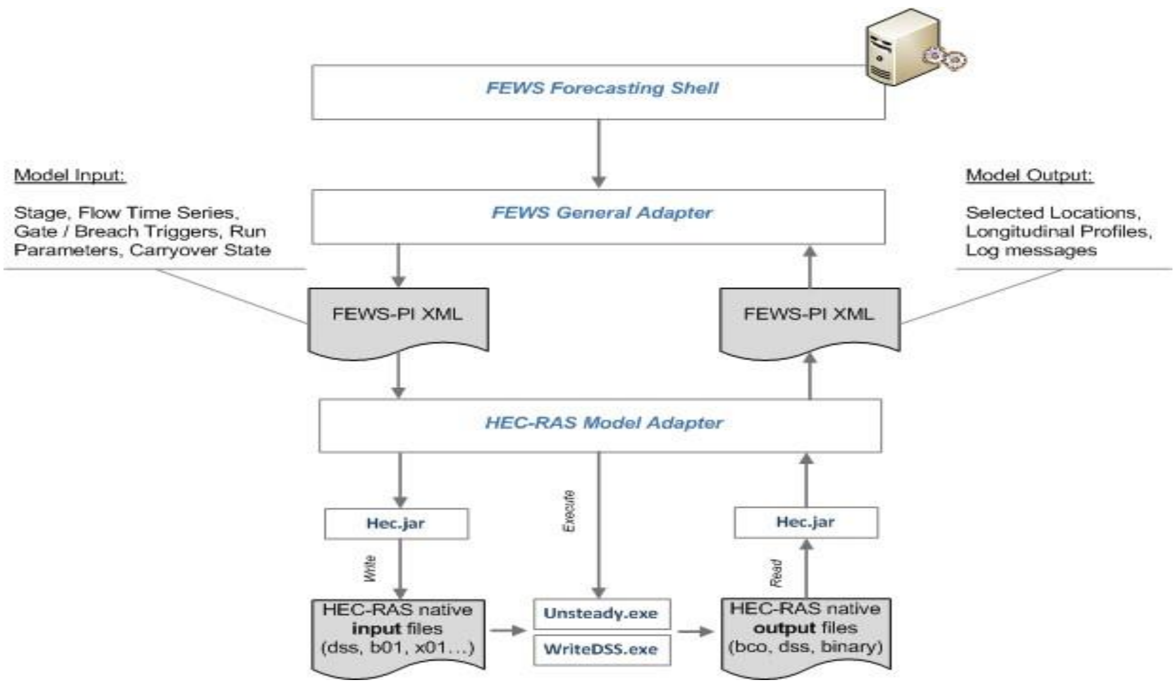

Figure 4.2: Data flows involved during run of HEC-RAS v.4.1 model FEWS (adapter from Deltares, 2011).

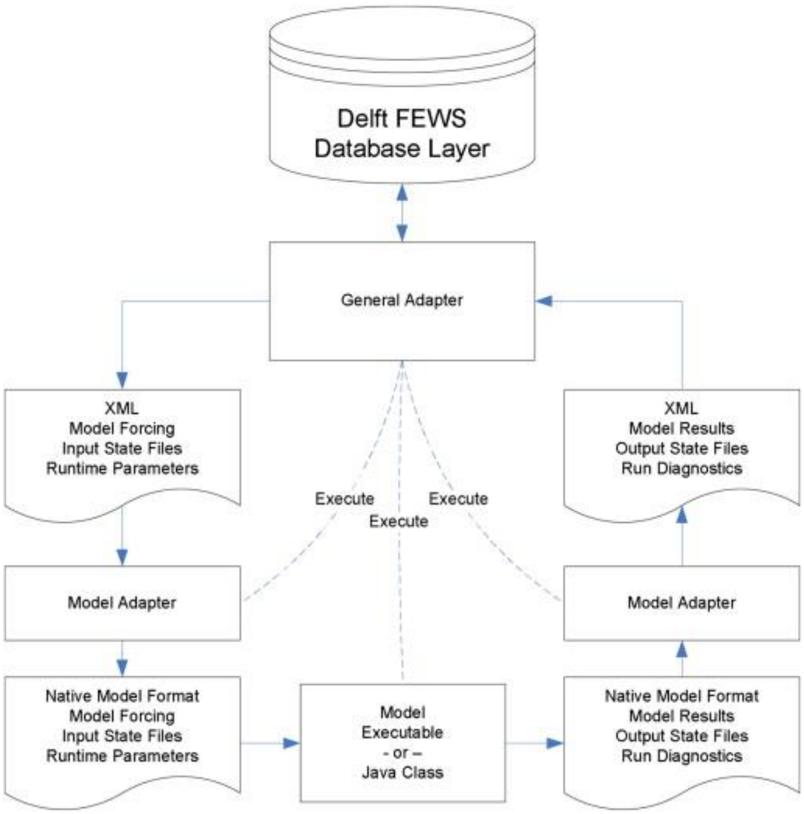

Figure 4.3: Linking Delft-FEWS with external models

Delft-FEWS can generate web reports with graphs, tables as well as summary reports. These are generated based on HTML templates.

4.3 Model Update

FEWS has been updated for the north-east region of Bangladesh. Stations where discharge data will be obtained and read from HEC-HMS run has been added to the system as shown in Figure 4.4.

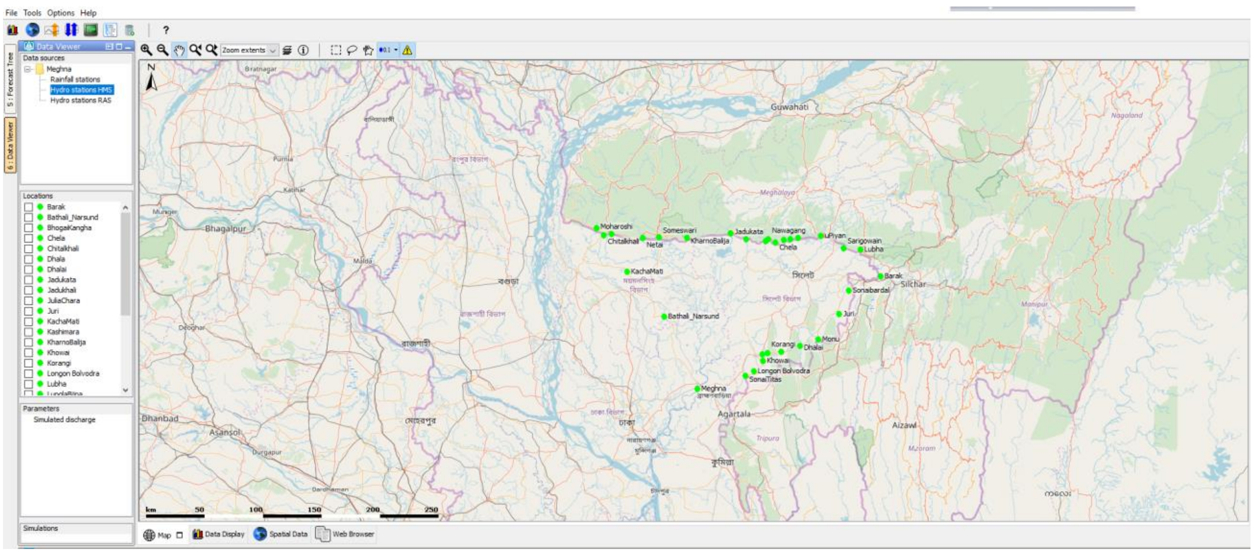

Figure 4.4: Hydro stations (for HEC-HMS) which would show the water flow data

Rainfall stations were added into the Delft FEWS system. Rainfall data will be added at these locations which will be directly read from NetCDF, the format of the data obtained from WRF. The rainfall stations incorporated into the FEWS system is shown in Figure 4.6.

The water level and flow data was successfully incorporated into the system. The system could also read NetCDF rainfall data. Incorporated rainfall data in the FEWS system are shown in Figure 4.7.

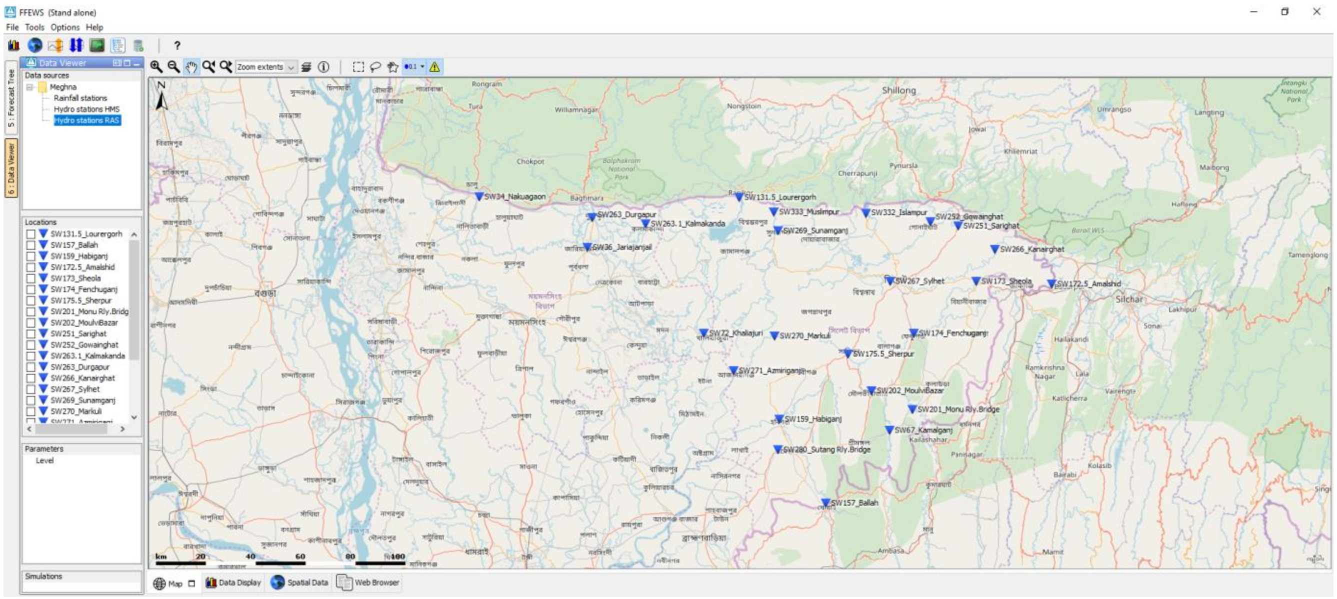

Figure 4.5: Hydro stations (for HEC-RAS) which would provide the water level forecast.

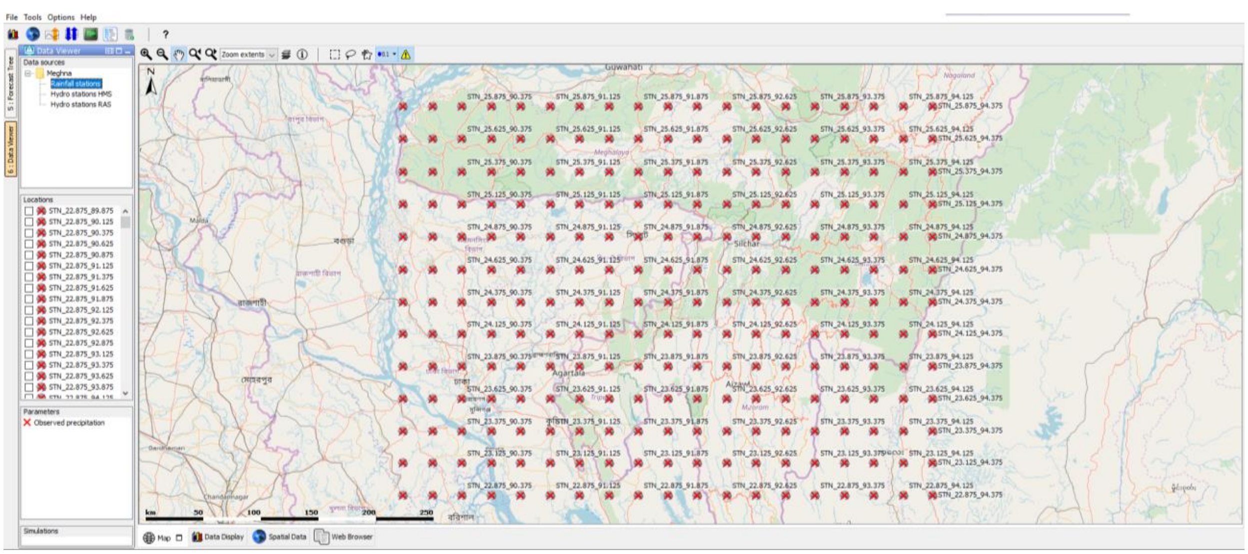

Figure 4.6: Rainfall data generated from WRF simulation over the Meghna basin.

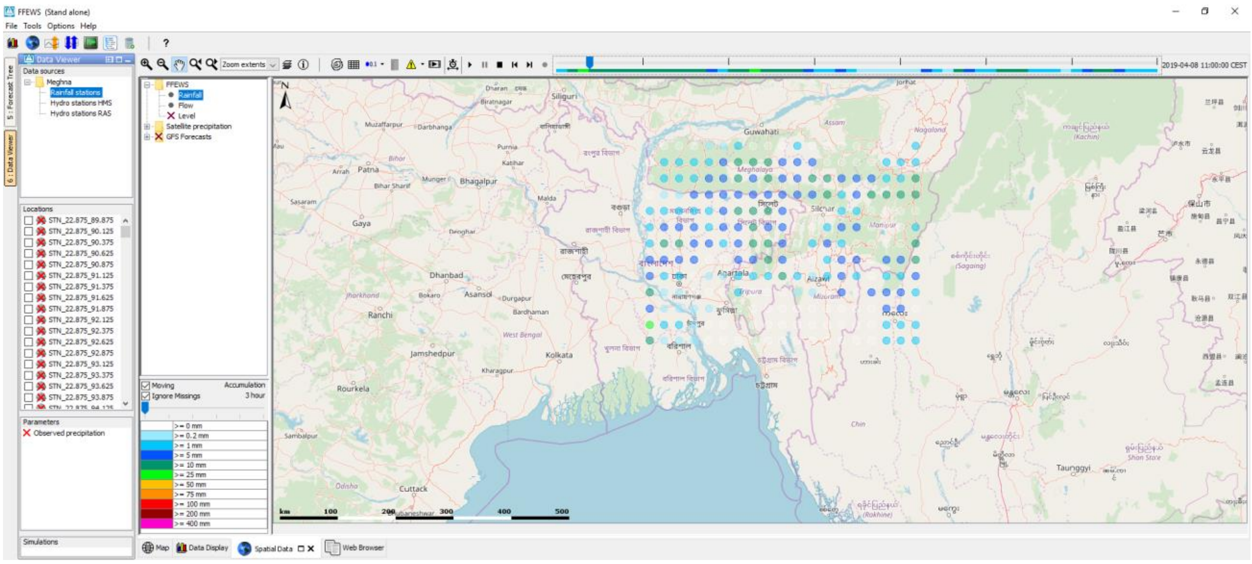

Figure 4.7: Rainfall data in NE region of Bangladesh.

Water flow display was successfully incorporated in the system shown in Figure 4.8. An adapter file was written to fit HEC-HMS data in the Delft-FEWS interface which is an XML document. By clicking on any one station of the Hydro Stations HMS, the forecast data for discharge can be displayed in the interface. One of the examples is shown in Figure 4.9. Precipitation forecast is shown in Figure 4.10.

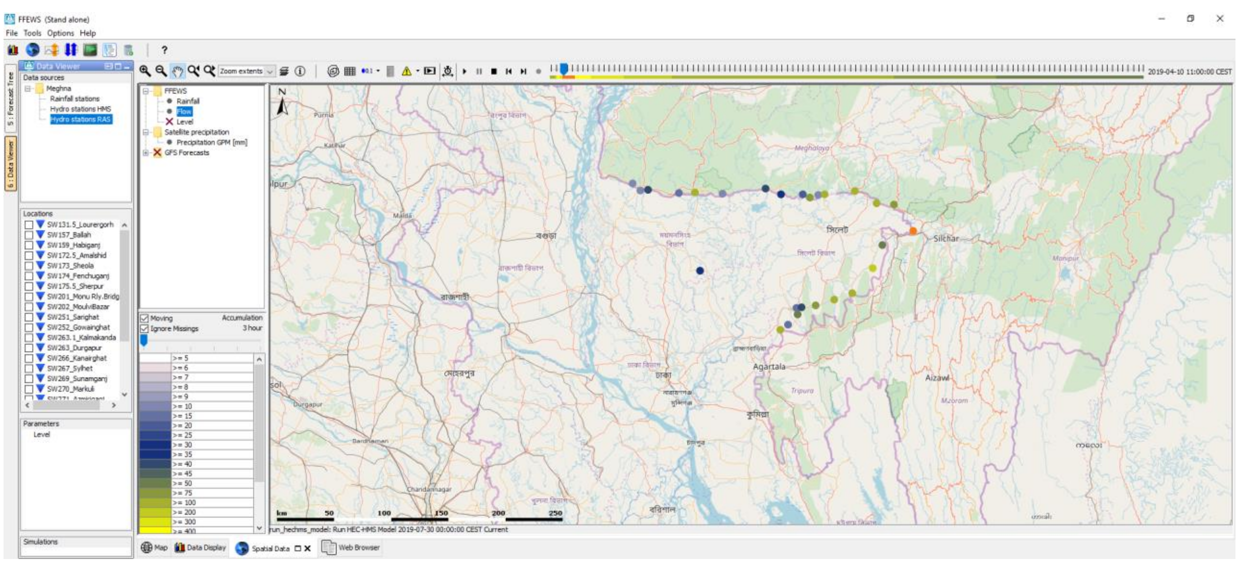

Figure 4.8: Spatial data display for flow

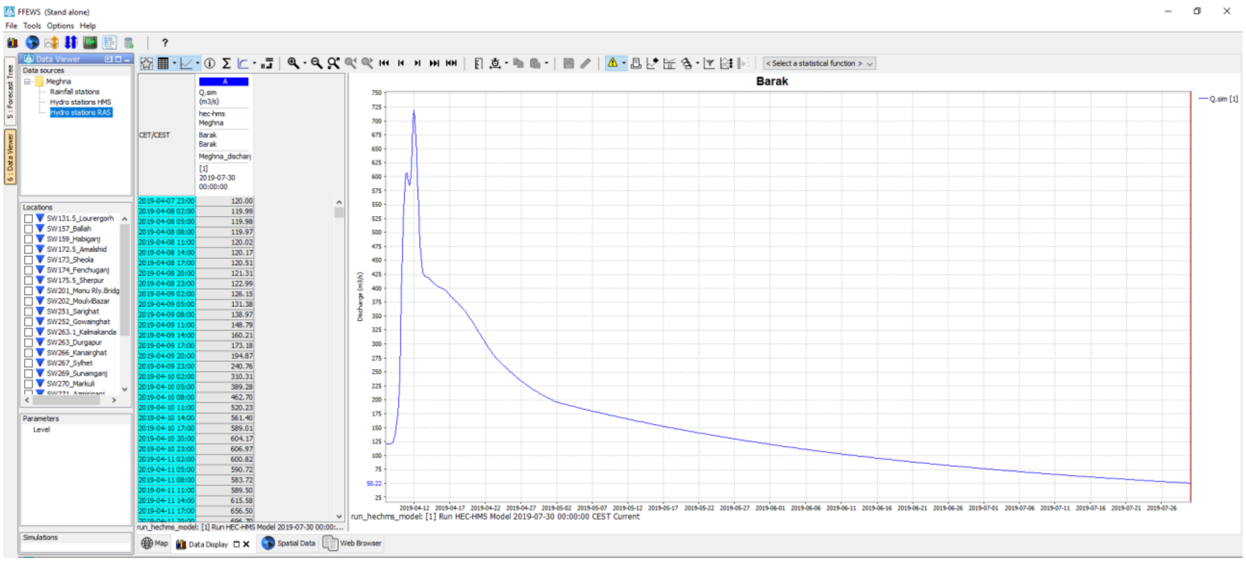

Figure 4.9: Discharge hydrograph for Barak station.

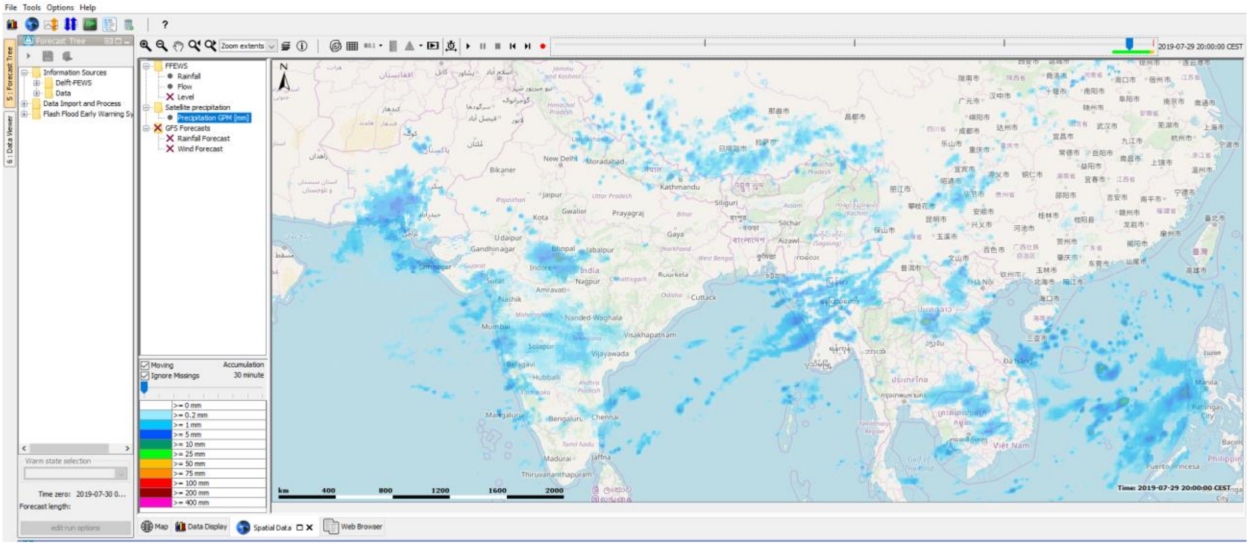

Figure 4.10: Precipitation distribution map using GPM.

Now all that remains is to automate the process using adapters. Both models can be run using directly from Delft-FEWS system and the results can also be directly accessed from the internet where it can be disseminated into the public. The challenges for developing a modern flood forecasting and warning system are found in the integration of large data sets, specialized modules to process the data, and open interfaces to allow easy integration of existing modelling capacities.

In response to these challenges, Delft-FEWS provides a state of the art flood forecast and warning system.

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