HYDRO-METEOROLOGICAL INVESTIGATION OF 2015 FLASH FLOOD IN EASTERN HILL BASIN BANGLADESH

M.S. Hossain[1*], G. M. T. Islam[2], S. U. Raihan[1], S. M. Q. Hassan[3] & R. H. Khan[4]

[1]*Flood Forecasting and Warning Center, Bangladesh Water Development Board, Dhaka, Bangladesh*
[2]*Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh*
[3]*Bangladesh Meteorological Department*, Dhaka, Bangladesh
[4]*Regional Integrated Multi-Hazard Early Warning System, Thailand*
[*]*Corresponding Author: sazz176@yahoo.com*

ABSTRACT
The present study examines hydro-meteorological aspects of flash flood event during the last week of June 2015 in Eastern Hill Basin that caused severe damage to human lives as well as physical infrastructures. The consecutive extreme rainy days was responsible for the flash flood event. The one day maximum rainfall was recorded at Cox's Bazar 467 mm, Teknaf 218 mm, Chittagong 172 mm, Bandarban 153 mm and Lama 276 mm and a comparative analysis of monthly normal and actual rainfall showed that the basin received 92% more rainfall in the month of June, 2015. Frequency analysis of daily maximum rainfall has been carried out for Cox's Bazar gauge station, and the result shows that rainfall at Cox's Bazar exceeded 100 years return period. The water level all the rivers in the basin flowed above Danger Levels and caused inundation in vast area. The extreme rainfall caused flash flood, and it resulted debris/mud flow from the hilly areas, disrupting road communication and washed away several lives. The study showed that result of Numerical Weather Prediction (NWP) model and European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble forecast predicted very well in ahead of the flash flood event.

Keywords: Flash flood; rainfall; water level; flood damage; frequency analysis

INTRODUCTION
Flash floods are flood events where the water levels rise rapidly after a rainfall event, typically within a few hours. According to WMO, flash flood can be defined as a rapid onset flood of short duration with a relatively high peak discharge (WMO, 2007).The rainfall intensity and the hydrology of the catchment are both important factors in the flash flood dynamics, i.e. a given amount of rainfall in a given time may or may not result in a flash flood, owing to such factors as antecedent precipitation, soil permeability, terrain gradients, and so on (CSFFWS, 2006).
Eastern Hill Basin covers the greater Chittagong and Chittagong Hill Tract districts of Bangladesh. The Eastern Hill Basin of Bangladesh predominantly consists of hilly terrain and long strip of lowland coastal plains along the Bay of Bengal. This physical feature makes it vulnerable to flash flood as well as land slide. Heavy rainfall causes flash flood in different parts of the basin during monsoon period. The river systems and topography show that the rivers of this basin are composed of five hydraulically independent systems. These are- Muhuri-Feni, Karnafuli-Halda-Ichamati, Sangu, Matamuhuri and Bakkhali river system. The five river systems drain into the Bay of Bengal independently. Fig. 1 shows the study area.

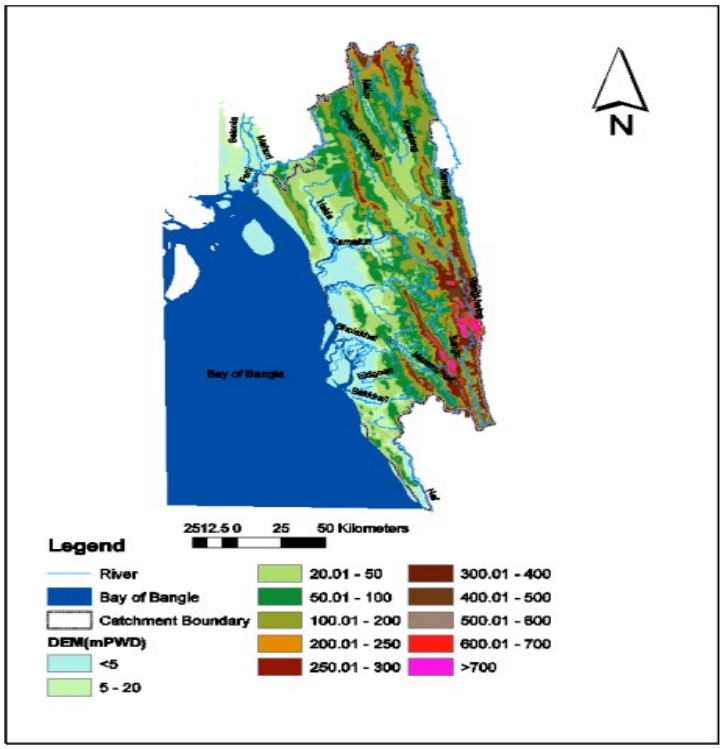


Fig.1: Eastern Hill Basin in Bangladesh

In June 2015, this basin received exceptionally higher rainfall than any other previous events (FFWC, 2015). The flash flood event of 2015 which occurred in last week of June is quite different from the historical events in terms of meteorological and hydrological phenomenon. This caused huge damage to physical infrastructures and washed away many lives. Some places for affected by flood which was never affected flood in recent history. The present study looks into the hydro-meteorological analysis of the 2015 flash flood event of this basin. It allows understanding of the characteristics of the meteorological behaviour of the event like intensity and amount of precipitation that caused severe damage. The hydrological conditions of the rivers like water level or flow played significant role in creating flooding situation. The present study finds out the number of days above Danger Level of flood water of the major rivers in the basin.

METHODOLOGY

The study is based on the analysis of related hydrological and meteorological data collected from the secondary sources like Bangladesh Water Development Board (BWDB) and Bangladesh Meteorological Department (BMD).Table 1 and Table 2 show the list of Meteorological and Hydrological gauge stations respectively and fig. 2 shows the locations of the gauges which have been used for the present study. Analysis includes calculation of normal rainfall for the month of June and compared with the actual rainfall. Two and five days total rainfall has also calculated that created flash flood event. The impact of the intensity of rainfall (3 hourly rainfall data) has been analysed to find the hydrological response. Frequency analysis of daily maximum rainfall data has been carried out to estimate rainfall for different return period.

Table1: List of rainfall gauge stations

Station Name	**Latitude**	**Longitude**
Cox's Bazar	21.450	91.967
Teknaf	20.867	92.300
Chittagong	22.350	91.817
Bandarban	22.194	92.219
Lama	21.793	92.212

Table2: List of water level gauge stations

Station	River	**Longitude**	**Latitude**
Lama	Mathamuhuri	92.2124	21.7926
Bandarban	Sangu	92.2192	22.1941
Dohazari	Sangu	92.0665	22.1571
Chiringa	Matamuhuri	92.0827	21.7727
Ramu	Bakkhali	92.1100	21.4260

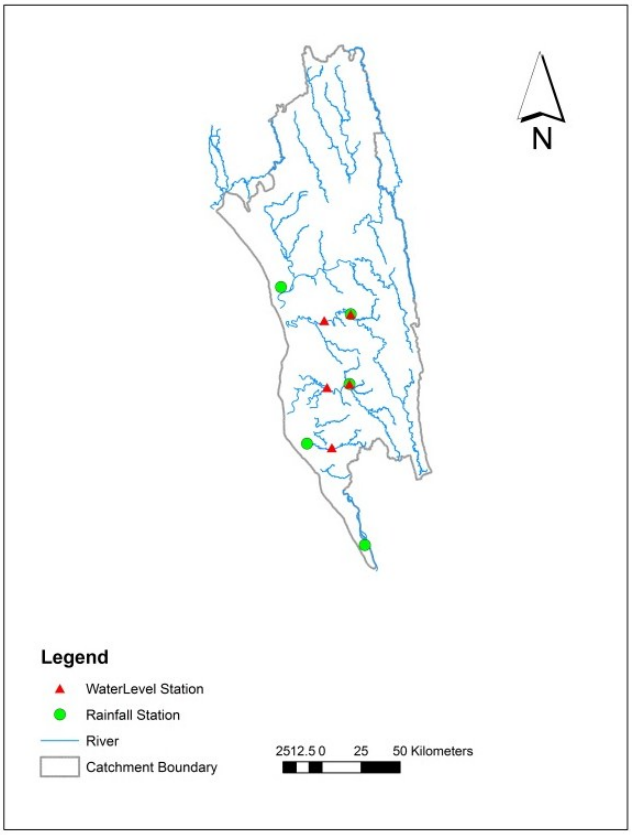


Fig. 2: Map of Gauge location in the study area

Results and Discussions

Rainfall Situation

Usually Eastern basin receives heavy rainfall during monsoon period. During June of 2015 all the rainfall measuring stations in this basin received above normal rainfall. Table 3 shows normal and actual rainfall. The Cox's Bazar and Teknaf had received more rainfall than monthly normal rainfall. Overall the basin received 92 % more rainfall than its monthly normal rainfall in June,2015.

Table 3: Normal and Actual Rainfall (mm) in South Eastern Hill Basin in June 2015

Station	Normal (mm)	Actual (mm)	Deviation (mm)
Bandarban	542.70	872.00	329.30
Lama	712.60	1330.00	617.40
Chittagong	628.40	763.00	134.60
Cox's Bazar	881.20	1551.00	669.80
Teknaf	262.00	1290.10	1028.10
Total	3027.00	5806.00	92 % more rainfall

The Synoptic situation shows that a low pressure had prevailed over Bangladesh along with active monsoon. The combination of these two weather phenomenon has created a favourable condition for heavy rainfall and the whole Eastern Hill Basin received very heavy to extreme rainfall. Table 4 presents the high amount of rainfall during the flash flood event in June, 2015.

Table 4: Recorded Rainfall during the flash flood Event

Date	Cox's Bazar	Teknaf	Chittagong	Bandarban	Lama
23/06/2015	75	0	111	157	274
24/06/2015	99	0	172	126	107
25/06/2015	467	213	154	140	276
26/06/2015	210	218	111	149	250
27/06/2015	263	215	81	46	71
28/06/2015	81	62	23	10	39

Table 5: 1-day maximum, 2-day and 5-day rainfall (in mm) at different gauge stations

Stations	**1-day Maximum**	**2-day total**	**5-day total**
Cox's Bazar	467	566	1120
Teknaf	218	432	710
Chittagong	172	326	541
Bandarban	157	283	618
Lama	276	381	987

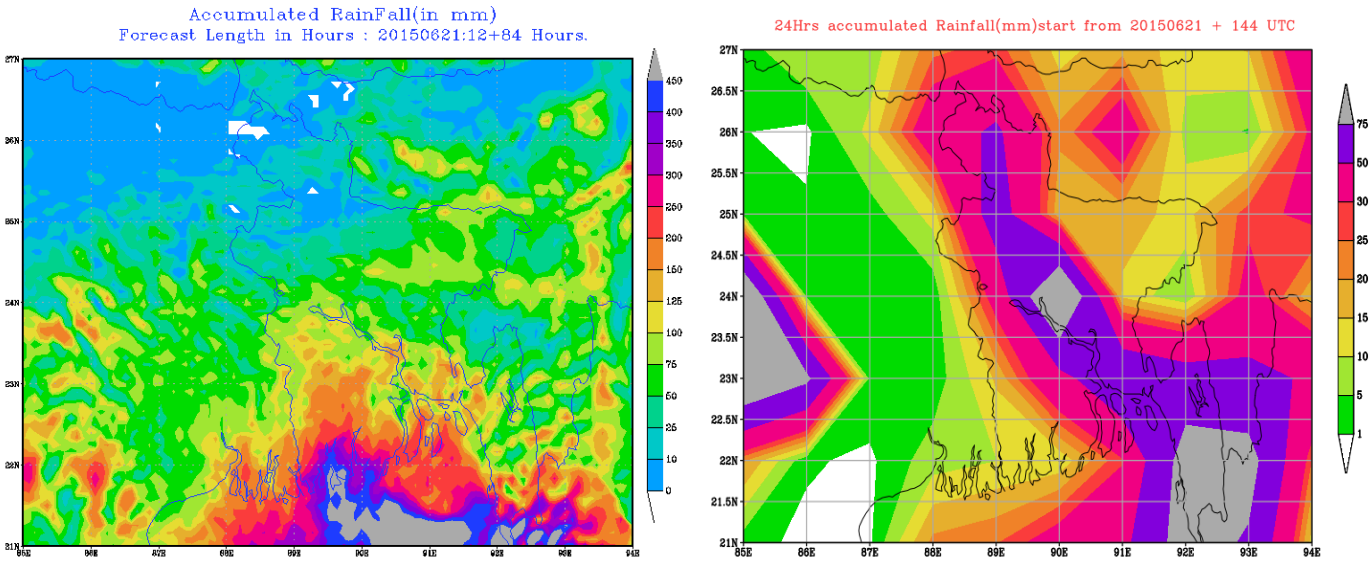
To investigate the cumulative effect of rainy days, 1-day maximum, 2-days and 5-days total rainfall amount was calculated (Table 5). The result shows consecutive very heavy to extreme rainfall had triggered the flash flood event. Frequency analysis of daily maximum rainfall was carried out for the same stations and result is presented in Table 6. According to frequency analysis Cox's Bazar received rainfall which has 100 year return period.

Table 6: Frequency analysis of rainfall data at Cox's Bazar

		Station: Cox's Bazar							
PDF	**Return Period**							**PPCC**	**Rank**
	2	**5**	**10**	**20**	**25**	**50**	**100**		
Normal	212.70	267.74	296.51	320.27	327.19	347.01	365.07	0.9009	5
Log Normal	204.84	256.13	287.87	314.02	326.06	353.38	380.27	0.9016	4
Pearson	193.97	252.73	296.98	341.81	356.37	401.86	447.56	0.9809	2
Log Pearson Type-III	196.36	250.29	292.29	351.67	351.67	400.89	454.63	0.9847	1
Extreme Value	201.96	259.75	298.01	334.71	346.35	382.22	417.82	0.9616	3

Rainfall forecast

ECMWF medium range weather forecast and WRF Predictions captured the event almost one week in advance. WRF Weather Forecast Model output which was simulated every day and ECMWF forecast for the whole week showed extremely heavy rainfall event in the Eastern Hill Basin. The heavy rainfall forecast for 72, 96 and 144 matched with the observed rainfall trend. For instance, 84 hour forecast of WRF Model and 144 hour forecast of ECMWF based on 20 June, 2015 showed extremely heavy rainfall event (Fig.3)



(a) (b)

Fig. 3: (a) WRF model forecast for June 21-24 and (b) ECMWF forecast for June 26 of extremely heavy rainfall, 2016 (Bangladesh Flash Flood Guidance System, FFWC)

Hydrological condition of major rivers

Muhuri, Karnaphuli, Halda, Sangu, Matamuhuri,Feni, Bakhkhali are the major rivers in this basin and all the rivers are flashy in nature. Water levels of the river Sangu, Matamuhuri and Bakhkhali crossed their respective danger levels during the flash flood event. However, the water level of these rivers did not cross the historical recorded highest (Table 7).

Table 7: Comparative WL of Few Stations in the South Eastern Hill Basin for June 2015

River	Station	Recorded Maximum (m)	Danger Level (m)	Peak Water Level 2015	Days above Danger Level
Sangu	Bandarban	20.70	15.25	16.1	1
Sangu	Dohazari	9.05	7.00	8.00	3
Matamuhuri	Lama	15.46	12.25	14.03	2
Matamuhuri	Chiringa	7.03	5.75	7.40	4
Bakhkhali	Ramu		5.79	7.13	3

The hydrological response is very quick for all these rivers due to high hydraulic gradients. The rivers got bank full flow immediately after the rainfall. The fig. 4 shows the hydrological response of Bakhakhali river during the flash flood event.

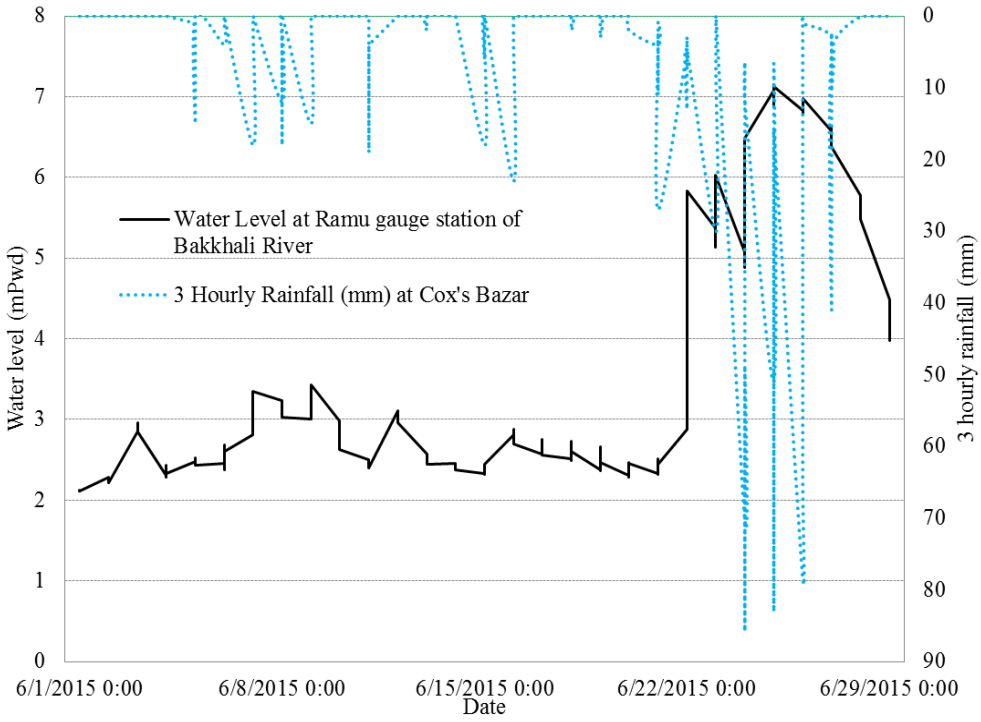


Fig. 4: Hydrological response of Bakhakhali River

CONCLUSIONS

The Flash flood event of 2015 was an exclusive one for Eastern Hill Basin as the whole basin received extreme rainfall for about a week; water level crossed danger levels, causing severe damages in some places. Hydrological analysis shows Rivers are extremely flashy in nature. At the same time initial soil moisture was favourable for flash floods due to rainfall at the beginning of June. However, this study did not investigate the soil moisture condition. The study shows single day heavy rainfall did not cause the flash flood, but continuous heavy rainfall during the week from 21 to 28, contributed to the event. NWP forecast is very useful for forecasting such flash flood events. Local Disaster managers may follow the NWP products from BMD's website and the flash flood guidance provided by FFWC. This will help them to take precautionary measures for reducing loss of invaluable human life and assets. As flash flood in this area comes with subsequent landslides, so, proper measure should be taken for the people who live at the foot hill.

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