

# FLOOD CHARACTERISTICS ANALYSIS FOR SEVEN HYDROLOGICAL REGIONS OF BANGLADESH

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## ABSTRACT

Flood is the most common natural disaster of Bangladesh. The country is situated at the outlet of Ganges-Brahmaputra-Meghna (GBM) basin which is the third largest freshwater outlet of the world's oceans. The country has to bear the enormous pressure of this flow whereas only 7% of the total catchment of GBM basin lies within the territory of Bangladesh. This unique geographical feature makes Bangladesh more susceptible to regular flooding. Bangladesh is expected to be one of the most affected countries of global climate change. So, the flood characteristics are likely to be changed with this changing climate. Adaptation with the changing scenario of flood is very essential for effective flood management. Characteristics study of flood is the fundamental for planning the proper adaptation strategy. An attempt has been made in this research to analyze the characteristics of floods inside Bangladesh. Pettit test identified a change point in flooded area of Bangladesh in 1974 and the change in the mean is decreased significantly as per Mann-Whitney test. Increase of standard deviation indicates the occurrences of more extreme flood inundations during recent time. Change point also identified by Pettit test for the data series of water level (WL) duration above danger level (DL) for seven of the nine selected rivers. Mann-Whitney test identified that mean is decreased for five rivers and increased for two rivers. Occurrence of simultaneous peak in any two basins of the GBM basin is the main cause of severe flooding inside Bangladesh. Correlation analysis shows that among the Ganges-Brahmaputra-Meghna basins Jamuna and Surma river flow is highly correlated. Analysis shows that Annual Maximum series (AMS) and Peaks over Threshold (POT) both can be used for flood frequency analysis where GEV is suitable for AMS and GPA is suitable for POT. L-moment is a good tool for choosing appropriate frequency distribution. Converting the POT series to AMS and plotting on Gumbel paper, it is found that GEV of this converted series (POT to GEV) is better than GEV of AMS. Monthly discharges are significantly correlated with SOI and DMI for high flow months. Although the correlation is not significant for all months but it follows a periodic pattern and varies from month to month. SOI and DMI have opposite correlation with discharge. Relatively high correlation exists with zero to three months lag/lead for SOI whereas for DMI the lag/lead time varies from six to nine months.

**Key words:** *Correlation, Danger level, Peaks over threshold, Indian Ocean Dipole Mode Index, Southern Oscillation Index*

## INTRODUCTION

Flood is the most frequent natural disaster of Bangladesh. Bangladesh is visited by flood almost every year. Some of them are very catastrophic. Damage of flood is very crucial for the agriculture based economy of Bangladesh. Flood characteristics are changing with the changing scenario of global climate. To adopt with this changing scenario, characteristics study of flood is very important for planning future strategy. In this study, the historical hydrological data of nine selected rivers of seven hydrological regions of Bangladesh were studied to identify the characteristics of flood caused by these rivers and attempt has been made to find correlation of river discharges with global Indices like Southern Oscillation Index (SOI) and Indian Ocean Dipole Mode Index (DMI).

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## STUDY AREA

Bangladesh is situated at the confluence of three mighty rivers Ganges, Brahmaputra and Meghna. Apart from these three rivers, there are many rivers which create a net like network covering the whole country. For this study nine rivers have been selected from seven of the eight hydrological regions of Bangladesh. The list of the rivers with locations is presented in Table 1 and Figure 1 shows the map locating of the river gauging stations.

Table 1: Selected rivers and their locations

Sl.	Region	River Name	Station name and Location
1	NW	Teesta	Kaunia
2	NC	Jamuna	Bahadurabad
3	NC	Old Brahmaputra	Mymensing
4	NE	Surma	Sylhet
5	SW	Ganges	Hardinge Bridge
6	SW	Gorai	Gorai RB
7	SC	Arial Khan	Choudhury char
8	SE	Gumti	Comilla
9	EH	Halda	Panchpukuria

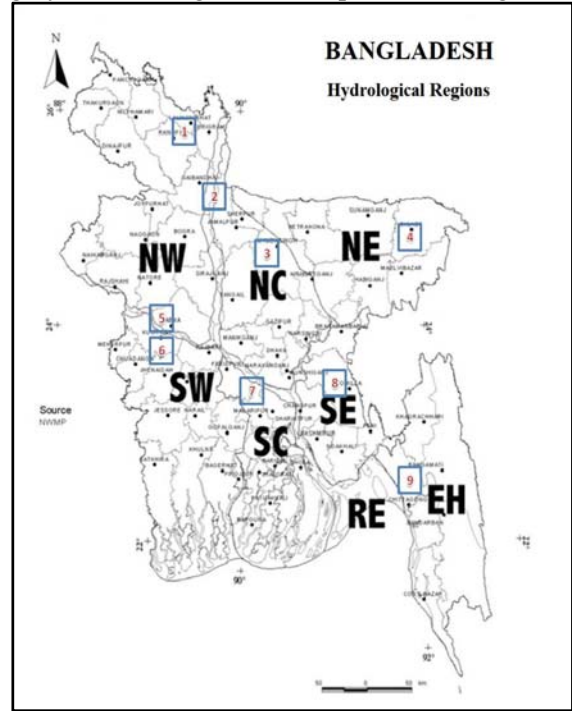


Figure 1: Hydrological regions of Bangladesh with selected station locations

## DATA USED

Water Level (WL), Danger Level (DL), Discharge and flooded area data are collected from Bangladesh Water Development Board. SOI data is collected from the website of Bureau of Meteorology, Australia and DMI data is collected from the website of JAMSTEC

## METHODOLOGY

**Analysis of flooded area and Water level above danger level:** Two non-parametric statistical tests are employed to analyze the flooded area and WL duration above DL. Pettett test is used to identify the change point the data series. The Pettitt test statistic  $U_k$  is calculated using the following equation (Pettitt, 1979):

$$U_k = 2 \sum_{i=1}^k M_i - k(n + 1) \quad (1)$$

Where,  $M_i$  is the rank of the  $i$ -th observation when the values  $X_1, X_2, \dots, X_n$  in the series are arranged in ascending order.  $n$  is the total number of data. Then the statistical change point test statistic (SCP) is defined as  $K = \max_{1 \leq k \leq n} |U_k|$ . So change point is that point where  $U_k$  attains maximum absolute value.

Based on that change point, the data series is divided into two groups and Mann-Whitney test is employed to check whether the change in the mean is significant or not before and after the change point. To perform the test, a time series data,  $y_t, t = 1, \dots, N$ , is broken into two sub-series,  $y_1, \dots, y_{N_1}$  and  $y_{N_1+1}, \dots, y_{N_2}$  of sizes  $N_1$  and  $N_2$  respectively. So  $N_1 + N_2 = N$ . The original time series is then rearranged in increasing order of magnitude to produce the new series,  $z_t, t = 1, \dots, N$ . The test of

the hypothesis that the mean of the first sub-series is equal to the mean of the second sub-series is then achieved through calculating the Mann-Whitney test statistic (Sales, 1993)

$$u_c = \frac{\sum_{t=1}^{N_1} R(y_t) - N_1(N_1 + N_2 + 1)/2}{[N_1 N_2 (N_1 + N_2 + 1)/12]^{1/2}} \quad (2)$$

Where  $R(y_t)$  is the rank of observation  $y_t$  in the ordered series  $z_t$ . The hypothesis of equal means of two subsets is rejected if  $|u_c| > u_{1-\alpha/2}$  where  $u_{1-\alpha/2}$  is the  $1-\alpha/2$  quantile of standard normal distribution and  $\alpha$  is the significance level of the test.

**Correlation between discharges of two rivers:** Severe flooding in Bangladesh is always caused by simulations arriving of peak flow in any two major rivers of the Ganages-Brahmaputra-Meghna (GBM) basin. Monthly average discharge data is used for correlation analysis. To check the correlation Pearson correlation coefficient is used. The Pearson correlation coefficient  $r$  measures the linear association of two variables (Hirsch et al., 1993). The value of  $r$  ranges from -1 to +1. For two sets of variables  $x$  and  $y$  the Pearson correlation coefficient  $r$  is defined as

$$r = \frac{\sum_{i=1}^n (x_i - \bar{X})(y_i - \bar{Y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{X})^2 \sum_{i=1}^n (y_i - \bar{Y})^2}} \quad (3)$$

By students'  $t$  statistics  $r$  can be tested on the null hypothesis “ $y_i$  is independent of  $x_i$ ”. The test statistics  $t$  is defined as  $t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$ . The null hypothesis will be rejected if  $|t| > t_{critical}$ , where  $t_{critical}$  is the point on the Student's  $t$  distribution with  $n-2$  degree of freedom with an exceedence probability of  $\alpha/2$  (Hirsch et al., 1993).

**Flood frequency analysis:** In this study both annual maximum series (AMS) and peaks over threshold (POT) data are used for frequency analysis to check whether POT has any advantage over AMS. As per recommendation of Cunnane, threshold of POT is selected such that the average number of peaks per year is greater than 1.65. L-moment has several advantages over conventional moments. L-moments suffers less from sampling variability, more robust for the presence of outliers in the data and more efficient for estimating underlying probability distribution from a small sample (Hosking J. R., 1990). So L-moment is used here for parameter estimation and L-moment ratio diagram is used to choose appropriate frequency distribution. AMS data is plotted of Gumbel paper and POT data is plotted on exponential paper to check the suitability of frequency distribution. To compare AMS and POT, POT data has been converted to AMS and plotted on Gumbel paper. The conversion equations are summarized here from Stedinger et. al. (1993). Let,  $\lambda$  be the arrival rate for a POT data series above a threshold  $x_0$ ,  $G(x)$  be the probability of that events when they occur are less than  $x$ , and thus falls in the range  $(x_0, x)$ . Then the arrival rate for any level  $x$ ;  $x \geq x_0$ , is  $\lambda^* = \lambda[1 - G(x)]$ . The CDF of corresponding annual maximum series is the probability that the annual maximum for an year will not exceed  $x$ . For independent events, the probability of no exceedences of  $x$  over a 1-year period is given by the Poisson distribution, so that

$$F_a(x) = \exp(-\lambda^*) = \exp\{-\lambda[1 - G(x)]\} \quad (4)$$

Substitution of Generalized Pateto distribution's CDF into Eq. 4 yields a GEV distribution for the AMS greater than  $x_0$  if  $k \neq 0$ .

$$F_a(x) = \exp\left[-\left(1 - k \frac{x - \xi}{\alpha^*}\right)^{1/k}\right] \quad (5)$$

When  $x \geq x_0$ , the  $\xi$  and  $\alpha^*$  can be defined as  $\xi = x_0 + \frac{\alpha(1-\lambda^{-k})}{k}$  and  $\alpha^* = \alpha\lambda^{-k}$

For Gumbel distribution, when  $k = 0$ , the Equations become

$$F_a(x) = \exp\left[-\exp\left\{-\left(\frac{x - \xi}{\alpha}\right)\right\}\right] \quad (6)$$

In this case transformed parameter  $\xi = x_0 + \alpha \ln(\lambda)$

**Correlation of discharge with SOI and DMI:** The Southern Oscillation Index (SOI) is considered as a Global climatic index as it has connection with many climatic phenomena around the world. SOI is the standardized anomaly of the Mean Sea Level Pressure difference between Tahiti and Darwin (Climate Glosary-Southern Oscillation Index(SOI), 2010). It is calculated as follows:

$$SOI = 10 \times \frac{P_{diff} - P_{diffav}}{SD(P_{diff})} \quad (7)$$

Where,  $P_{diff}$  = (average Tahiti MSLP for the month) - (average Darwin MSLP for the month),  $P_{diffav}$  = long term average of  $P_{diff}$  for the month in question and  $SD(P_{diff})$  = long term standard deviation of  $P_{diff}$  for the month in question.

Indian Ocean Dipole Mode Index (DMI) is defined as “Difference in SST anomaly between the tropical western Indian Ocean (50° E-70°E, 10°S-10°N) and the tropical south-eastern Indian Ocean (90° E-110°E, 10°S-0°S)” (Saji et al., 1999). It is another Climatic index and found to be independent even and not related with El Niño/Southern Oscillation. It accounts for about 12% of the sea surface temperatures variability in the Indian Ocean. To check the correlation of discharge with SOI and DMI, Pearson correlation coefficient is used. Monthly discharge values are correlated with monthly SOI and DMI.

## RESULTS AND DISCUSSION

**Flooded area of Bangladesh and WL duration above DL:** Pettitt test shows that there is a change point in the flooded area data series at 1974 which is significant at 95% confidence level. Mann-Whitney test shows that mean is decreased significantly after the change point. Standard deviation is increased after 1974 which indicates that more extreme events in recent time. The results are plotted in Figure 2. This analysis is performed for all rivers WL duration above DL data. Summary of the results are presented in Table 3.

Table 3: Summary of the test results of WL duration above DL

River name	Pettitt test result (SCP/CL)	MW test result (SCP/CL)
Teesta	1991/99%	Decreased/95%
Jamuna	1980/NS	Decreased/95%
Old Brahmaputra	No change point	
Surma	1986/NS	Decreased/95%
Ganges	1988/NS	Decreased/95%
Gorai	1988/99%	Decreased/95%
Arial Khan	1986/95%	Decreased/95%
Gumti	No change point	
Halda	1999/95%	Decreased/95%

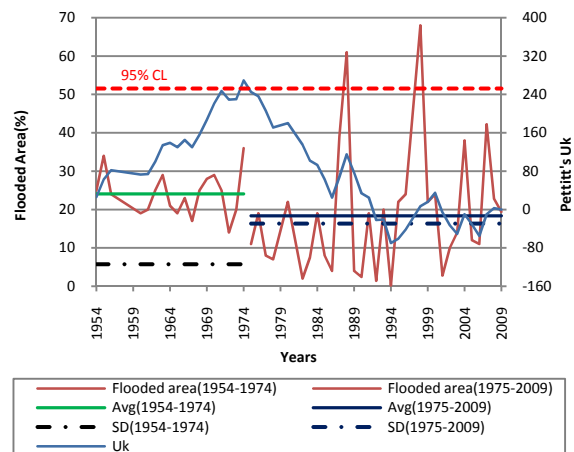


Figure 2: Flooded area with Pettitt test result  
SCP=Statistical change point, CL=Confidence level, NS=Not significant

**Correlation between discharges of two rivers:** Jamuna and Surma river flows have remarkable correlations for June, August and September. Ganges and Jamuna have little correlations but Ganges and Surma basin flows do not show any significant correlation. Figure 3 shows the correlations of all three groups of river from June to September. Highest correlation is found for the month of June for all rivers but no correlation exists between the discharges of

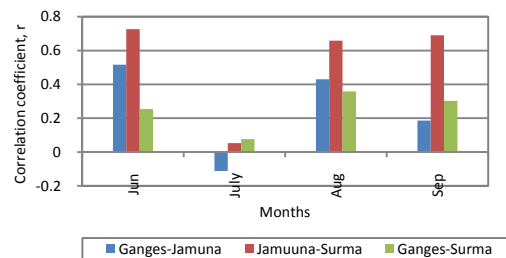


Figure 3 : Correlation coefficients for joint flow of three rivers

any two rivers for the month of July.

**Frequency analysis:** From the L-moment ratio diagram of both AMS and POT data, it is confirmed that GEV distribution is suitable for AMS series whereas GPA is suitable for POT. Six of the nine river's L-moment ratios are near to GEV line for AMS whereas seven are near to GPA line for POT. To check the suitability of distribution, CDF of AMS is plotted on Gumbel paper (Figure 4) along with the Normal, Gumbel and GEV distributions. Gumbel distribution is represented by a straight line in the Gumbel paper whereas GEV is a curved line based on the value of shape parameter. Normal distribution is also a curved line in Gumbel paper with a constant skewness. For POT CDF is plotted on Exponential paper (Figure 5) considering Exponential and Generalized Pareto (GPA) distribution. These two figures prove that appropriate frequency distribution can be selected from L-moment ratio diagram.

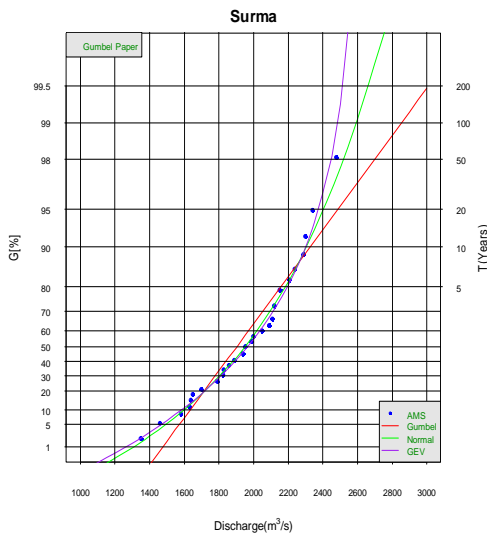


Figure 4: CDF plot of AMS for Surma river

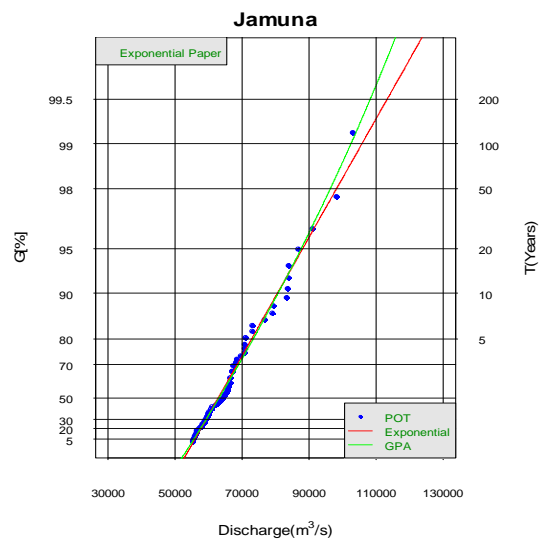


Figure 5: CDF plot of POT for Jamuna river

To compare POT with AMS POT data is converted to AMS using the methodology described earlier. AMS and POT data converted to AMS are plotted on Gumbel paper together with GEV and Gumbel distribution of AMS and POT converted to AMS (Figure 6). Shape of the GEV line depends on the data samples of lower range. For AMS data, data samples below the threshold level control the shape of the GEV line. If there are too many low values included in the AMS the curvature of the GEV line increases. It is easily found from the Figure 6 that GEV is suitable for AMS but in some cases GEV of POT data converted to AMS (POT to GEV) fits better than the AMS/GEV model. In this case Teesta is a good example where POT to GEV line is the most appropriate.

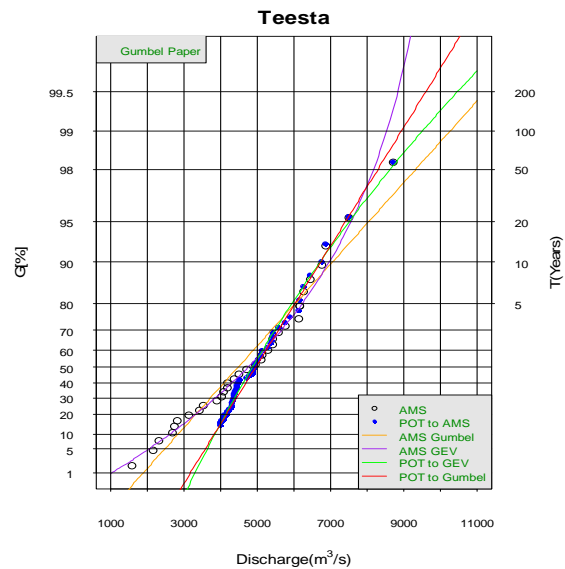


Figure 6: AMS and POT comparison plot

**Correlation of discharge with SOI and DMI:** The analysis of this study shows that SOI and DMI have link with the local discharge of Bangladesh. The correlation of SOI and DMI found to be significant for some high flow months for the main three rivers of GBM

basin. The pattern shows that, the July to September discharge has highest correlation with May to September SOI and lowest correlation with January to March SOI. The correlation value increases and decreases with a periodic way. In case of DMI, correlation value is highest for six to nine months previous DMI (end of previous year/start of the current year) and lowest for April and May DMI. The correlation of DMI with Jamuna is presented in Figure 6.

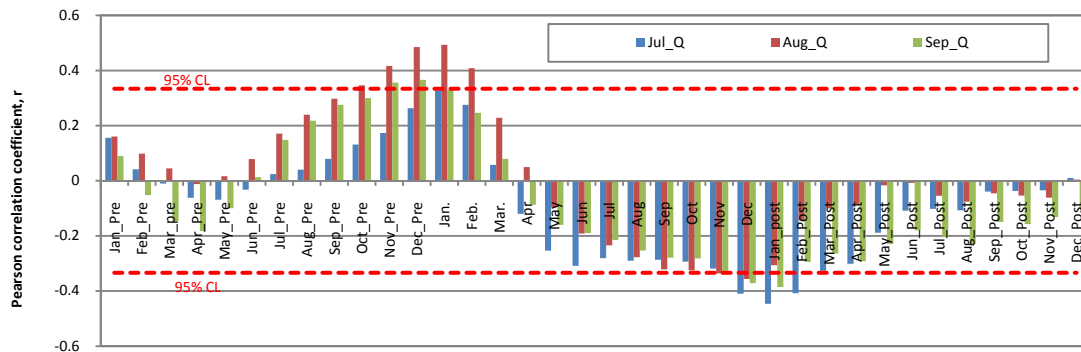


Figure 6: Correlation of DMI with Discharge of Jamuna

## CONCLUSION

Statistical tests identified change point in the data series of flooded area and WL duration above DL. Mean flooded area is decreased significantly whereas WL duration above DL increased for 2 rivers and decreased for 5 rivers and not changed for 2 rivers. Discharge of Jamuna is highly correlated with that of Surma. L-moment ratio diagram is an effective tool for selecting suitable frequency distribution. Better flood frequency results can be achieved by using the GEV distribution after converting POT data to AMS. SOI and DMI have significant correlation with discharge of major rivers for some flood flow months.

## RECOMMENDATION

Research could be done including more rivers and more than one station from same river. Validation check can be done whether Danger level of the important rivers need any modification at current situation. POT analysis can be done changing the threshold discharge to check whether it improves the result. Correlation of monthly discharges with SOI and DMI found in this study can be studied more to develop a model to predict the flood in advance of a season in Bangladesh.

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