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Climate change and anthropogenic impacts of the freshwater flow in the gorai river system of Bangladesh

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Abstract
The Ganges River supplies fresh water to the South-West region of Bangladesh mainly through one of its distributaries—the Gorai River. The length of the river is 199 km and the area of the Gorai River catchment is 15,160 km². India commissioned a barrage on the Ganges River at Farakka in April 1975 to divert water and make the Bhagirathi-Hooghly River navigable. The Gorai used to discharge into the Bay of Bengal through the Mathumati and Baleswar Rivers. The Madhumati is connected to the Nabaganga at Bordia point. This is the drainage path of the Gorai water, which now reaches the Bay mainly via the Passur and Sibsa Rivers. The distribution of the Gorai River flow at Bordia between the Nabaganga and Madhumati Rivers and tidal conditions which influence the sediment concentration are not known. The objective of this study is to monitor the freshwater flow in the Gorai River System of Bangladesh. The study is carried out based on primary and secondary data sources. The variation of river flow within a natural range plays an important role in promoting the social-ecological sustainability of a river basin. In order to determine the extent of the natural range of variation, this study assesses hydrologic flow thresholds for the Lower Ganges River Basin. The flow threshold was calculated using twenty-two "Range of Variability (RVA)" parameters. The impact of Farakka Dam on the Lower Ganges River flow was calculated by comparing threshold parameters for the pre-Farakka period (from 1934 to 1974) and the post-Farakka period (1975–2013). The diversion has reduced the dry season discharge of the Ganges and Gorai rivers in Bangladesh. Statistical analyses indicate that the changes in the dry season discharge of these rivers are significant. The ecological consequences of such hydrologic alterations include the reduction of fish and agricultural diversity. Reduced discharge in the Gorai River has induced accelerated sedimentation and increased salinity in the southwest region of Bangladesh. The methodological approach presented in this study is applicable to other river basins.

Keywords: Gorai river, water shortage, threshold; river flow; range of variability (RVA)

1. Introduction

The Gorai is the major distributary of the Ganges River in the right bank and important provider of freshwater inflows to South-Western region of Bangladesh (Adams 1919) [1]. The length and catchment area of the river Gorai is 199 km and 15,160 km² respectively. This river normally receives 15% of Ganges River's annual flow volume. It is discharged into the Bay of Bengal through the Madhumati and Baleswar Rivers. The Madhumati was connected to the Nabaganga at Bordia point. This is the drainage path of the Gorai water, which now reaches the Bay mainly via the Passur and Sibsa Rivers. It also brings freshwater in the region through Bhairab and Mathabhanga Rivers. The Gorai is a crucial river for maintaining both the environment and economy of the region (EGIS 2000) [3].

Although human manipulation of river flow provides many societal benefits, it also degrades and eliminates valuable ecosystem services and threatens freshwater biodiversity (Bunn and Arthington 2002, Magilligan and Nislow 2005) [2, 11]. The flow volume declines during the dry-season and it impacts the region. Many of the Branch Rivers of the Ganges are blocked off due to the withdrawal of water at the upstream Farakka Barrage that was built in 1975. The Ganges River is important for agriculture, fisheries, forestry, industry, and drinking water supplies. The diversion of water has introduced significant changes in the hydrology of the Ganges River system in Bangladesh. For the shortage of water in the Gorai basin, saline water is penetrating in the upstream. As a result, the river system of the South-West region of Bangladesh starts to be affected by coastal saline water inflow in November, and reaches to a maximum in April and May (Mirza and Sarker 2004) [13]. This shortage of freshwater in the

Gorai basin is also the root cause of saltwater intrusion and damage of mangrove ecosystems and its services of the Sundarbans region. Assessment of river flow characteristics is essential for understanding and predicting the biological impacts of both natural and altered flow regimes on riverine biota. So, the specific objective of this experiment was to monitor the freshwater flow in the Gorai River System of Bangladesh

2. Materials and methods

2.1 Experimental sites and design

Five study points were selected considering the factor that the area should have no saline, slight saline, moderate saline and high saline zones. Considering the fact, Harding bridge point in the Padma River under Kushtia-Pabna districts (non saline zone), Kamarkhali bridge point in the Gorai River under Magura district (non saline zone), Bordia point in the Nabaganga River under Narail district (slight saline zone), Khan Jahan Ali bridge point in the Rupsha River under Khulna district (moderately saline zone) and Mongla port point (saline zone) in the Passur River under Bagerhat districts were selected. The location map of the study areas are shown in Figure 1.

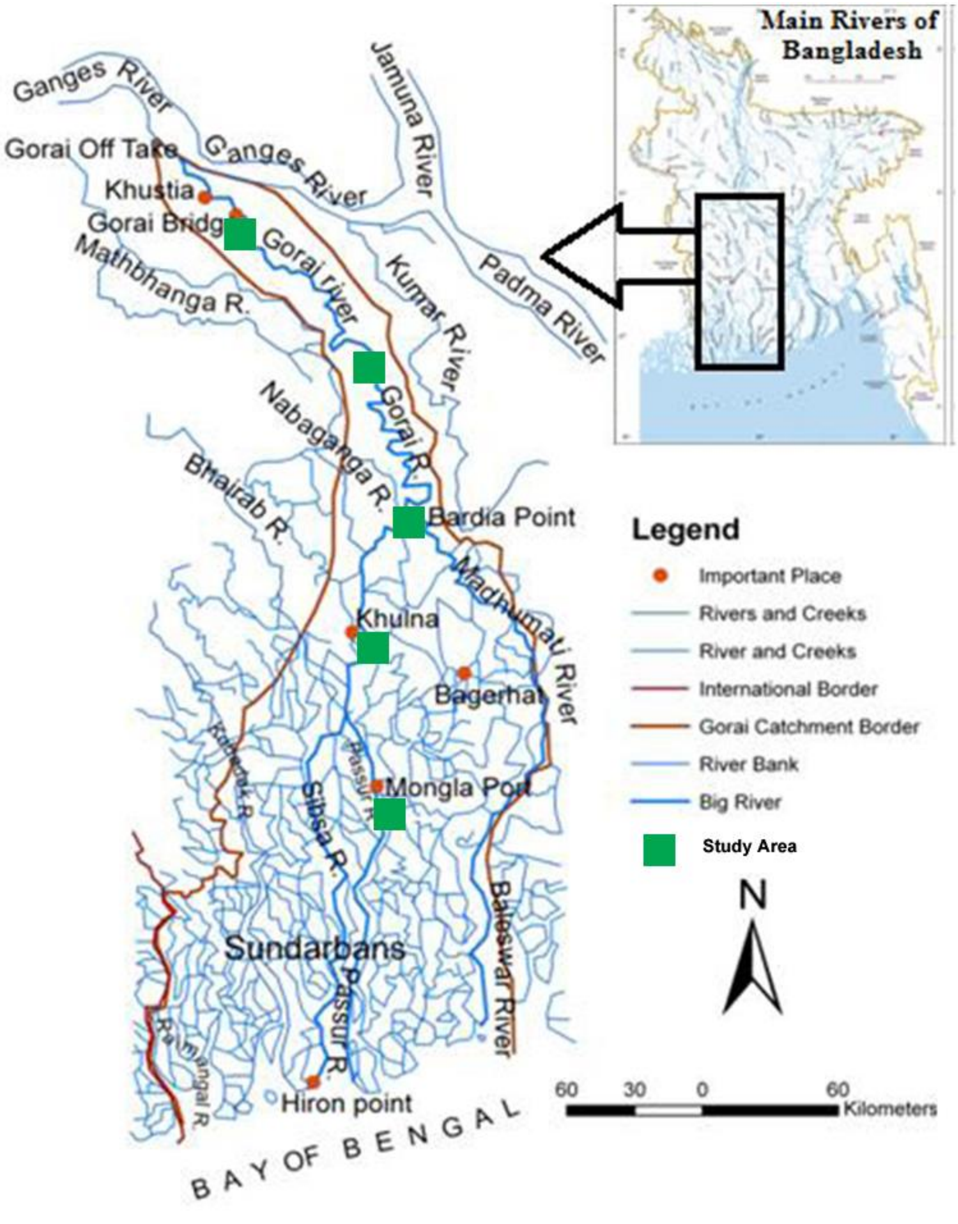

Fig 1: Gorai River in the South-Western region of Bangladesh (Islam and Gnauck 2011) [8]

The Gorai River catchment area is 15,160 km² and is located between 21° 30' N to 24° 0' N latitude and 89° 0' E to 90° 0' E longitude (Islam and Gnauck 2011) [8]. The Gorai gets fresh water from the Padma and it transmits this water to the Madhumati River to connect the Nabaganga River. Nabaganga is used to discharge freshwater into the Bay of Bengal through the Passur River.

2.2 Data collection

The present study was carried out based on primary and secondary data sources. The primary data collected from field investigation in 2012 and 2013. The information of Gorai River system in Bangladesh was collected from different government and nongovernmental organizations. Secondary data was collected from the EGIS reports on Gorai River restoration project, 2000. The specific special reports of EGIS, FAP 24, FAP 4 reports, Bangladesh Water Development Board (BWDB) and Bangladesh Center for Advanced Studies (BCAS) reports and publications were also used for this study. Besides these, some interviews were arranged with water engineers, environmentalists, geographers, geologists and sociologists and expert peoples on river systems and its ecology. The collected data were reconstructed, analyzed and visualized by using MS EXCEL, SPSS, Expert Fit, MATLAB and ArcGIS tools.

2.3 Assessment of the flow thresholds
To assess the flow thresholds, hydrological discharge data were collected. The major discharge measuring station of the lower Ganges basin in Bangladesh is at Harding Bridge Point, and long-term observation records of this station were available and accessible from the Bangladesh Water Development Board (BWDB). The qualities of data were high and used in major hydrological studies in flood forecasting and other planning purposes (Mirza 1997) [15]. The daily discharge data were collected from BWDB for the period of 1934 to 2014.

India began the operation of Farakka dam on 21 April 1975. Hence, the data series up to 1975 represents pre-Farakka flow, and data from 1975 onwards represent post-Farakka flow. To assess the hydrological data series, the hydrological year, 1 April to 31 March, instead of the calendar year was considered (Gain *et al*. 2011, Mirza 1997) [15, 7]. In addition to discharge data, available daily rain fall data were also collected from the Rajshahi station of the Bangladesh Meteorological Department (BMD) for the period 1964–2014.

2.4 Testing the natural condition of discharge
The first step for determining the flow thresholds considered the observation of data series that represented natural flow where no shifts and trends were found. For testing the natural condition, a linear trend analysis was conducted considering the fact that the natural flow series was trend-free and constitutes a stochastic process whose random component follows the appropriate probability distribution. Gain *et al.* (2011) [7] presented a detailed description on the method used for testing linear trends, which could be summarized as follows:

Assume that y_t, $t = 1, \ldots, N$ is an annual time series and N is the sample size. A simple linear trend can be written as:

$y_t = D + Mt$ (1)

Where, D and M are the parameters of the regression model. The rejection of hypothesis $M = 0$ can be considered as a detection of a linear trend. The hypothesis that $M = 0$ is rejected if:

$$T_c = \left| \frac{R\sqrt{(N-2)}}{\sqrt{(1-R^2)}} \right| \rangle T_{1-\alpha/2,v} \quad (2)$$

in which R is the cross-correlation coefficient between the sequences $y_1, \ldots, y_N$ and $1, \ldots, N$ and $T_{1-\alpha/2,v}$ is the $1 - \alpha/2$ quintile of the student t distribution with $v = N - 2$ degrees of freedom; α is the significance level, which is 5% (or 95% confidence level).

2.5 Assessment of thresholds using RVA approach
An analysis of the ecological flow threshold of natural variability is required to test the natural condition of flow. Reflecting different aspects of flow variability (magnitude, frequency, duration and timing of flows), Richter *et al.* (1997) [16] proposed the “Range of Variability Approach” (RVA). The hydrological variability and its associated characteristics play a critical role in sustaining aquatic ecosystem. The RVA method addressed this paradigm by incorporating into river management targets, a suite of ecologically-relevant hydrological parameters comprehensively characterize the natural stream flow regime.

The choice of the most appropriate measure of dispersion should be based on whether each parameter follows a normal or skewed distribution, and in the case of a normal distribution, one could use the standard deviation (SD) from the mean value as an initial threshold flow. In order to select an appropriate measure of dispersion, distribution of each of the 22 RVA parameters had been tested and found that all of the parameters followed a normal distribution. Therefore, values at ±1 SD from the mean were selected as thresholds for each of the twenty-two RVA parameters. Any considered parameter should thus stay in the limits (Gain *et al*. 2013, Richter *et al*. 1997) [6, 16]:

$$(\text{mean} - \text{SD}) \leq \text{Parameter} \leq (\text{mean} + \text{SD}) \quad (3)$$

Exceedance of these limits by a particular parameter may lead to considerable ecosystem stress over long time periods. This approach for setting initial flow thresholds had been used in this study.

3. Results
3.1 Natural condition of discharge in the Ganges basin
For the quantitative assessment of the natural flow condition, a trend test was carried out for the available discharge data series (1934–2014) and for the pre-Farakka period (1934–1974) in the Ganges basin. For assessing the trend, yearly maximum and minimum data series were considered. The pre-Farakka period (1934–1974) represented no intervention, and all of the series in that period were trend-free, as the calculated Tc for each series was lower than the critical value (2.02) at the 5% significance level (Table 1). However, for the available period (1934–2014), all of the series represented a significant trend.

Table 1: Result of the trend analysis for the yearly discharge

Yearly Series	Length of the Series	Trend: test statistic Tc	Critical value at 5% Significance Level, $T_{1-\alpha/2,v}$ (t distribution)	Results
Minimum discharge	1934-2014	*6.00*	*2.00*	*Significant trend*
	1934-1974	0.561	2.02	Trend does not exist
Maximum discharge	1934-2014	*2.33*	*2.00*	*Significant trend*
	1934-1974	1.51	2.02	Trend does not exist

3.2 Ecological flow threshold of the pre-Farakka period
After characterizing and testing the natural conditions of the observed data series, the ecological flow thresholds of twenty-two RVA parameters had been determined and it was reflecting different aspects of flow variability. A summary of these results are shown in Table 2. For assessing the mean and standard deviation values of each parameter (columns 2 and 3 of Table 2 respectively), the daily mean discharge series of a 41 years period (1934–1974) have been analyzed. Values at ±1 SD from the mean were selected as the ecological flow threshold for each of the twenty two RVA parameters. Minimum threshold (Mean − 1 SD) and maximum threshold (mean + 1 SD) values for each parameter are shown in columns 4 and 5 of Table 2 respectively. Different parameters with a lower and higher limit of threshold represent the seasonal variability of the flow within which an ecosystem can sustain itself.

3.3 Ecological flow threshold of the post-Farakka period
Once the threshold for ecological flow had been determined, the extent of alteration due to water diversion post-Farakka was subsequently analyzed. To investigate the impact of the Farakka dam, hydrological discharge for 39 years (from 1975 to 2014) were analyzed (Table 3).

In both dry and wet months, the flow was altered remarkably. Particularly in dry periods (especially in February and March), 100% of the post-Farakka periods (1975–2014) would have failed to meet the thresholds. Similarly, all of the years of the post-Farakka period failed to meet the lower threshold of the minimum flow parameters.

Table 2: Results of the selected Range of Variability Approach (RVA) parameter analysis (Columns 2–5) based on the data of the pre-Farakka period (1934–1974)

RVA parameters	Mean and standard deviation		Threshold flow (m^3/s)	
	Means (m^3/s)	SD (m^3/s)	Low	High
January	3,083	677	2,406	3,760
February	2,670	613	2,057	3,283
March	2,299	454	1,845	2,752
April	2,042	365	1,677	2,406
May	2,161	435	1,726	2,596
June	4,024	958	3,066	4,982
July	17,672	4,781	12,890	22,453
August	37,809	8,116	29,693	45,924
September	35,812	7,920	27,892	43,731
October	17,661	7,056	10,605	24,717
November	7,058	2,449	4,609	9,507
December	4,191	1,017	3,173	5,208
1-Day Minimum	1,677	446	1,231	2,123
3-Day Minimum	1,780	331	1,449	2,110
7-Day Minimum	1,824	300	1,524	2,124
30-Day Minimum	1,853	307	1,546	2,161
90-Day Minimum	2,122	330	1,793	2,452
1-Day Maximum	48,727	7,957	40,770	56,683
3-Day Maximum	48,367	8,040	40,327	56,406
7-Day Maximum	47,330	8,319	39,011	55,649
30-Day Maximum	41,846	8,070	33,776	49,916
90-Day Maximum	32,747	6,799	25,948	39,546

Table 3: Investigation of the failure (column 4) of the Range of Variability Approach (RVA) target of the post-Farakka period (1975–2014)

RVA Parameters	Threshold Flow (m^3/s) Based on the Data of Pre-Farakka Period		Failure Rate of RVA Target at Post-Dam Period (1975-2014)
	Low	High	
January	2,406	3,760	90%
February	2,057	3,283	100%
March	1,845	2,752	100%
April	1,677	2,406	94%
May	1,726	2,596	81%
June	3,066	4,982	68%
July	12,890	22,453	61%
August	29,693	45,924	36%
September	27,892	43,731	58%
October	10,605	24,717	32%
November	4,609	9,507	48%
December	3,173	5,208	71%
1-Day Minimum	1,231	2,123	100%
3-Day Minimum	1,449	2,110	100%
7-Day Minimum	1,524	2,124	100%
30-Day Minimum	1,546	2,161	100%
90-Day Minimum	1,793	2,452	100%
1-Day Maximum	40,770	56,683	42%
3-Day Maximum	40,327	56,406	42%
7-Day Maximum	39,011	55,649	45%
30-Day Maximum	33,776	49,916	39%
90-Day Maximum	25,948	39,546	32%

3.4 Monthly discharge in pre- and post-Farakka period in the Ganges River
The result for dry season months (from December to May) is shown in Figure 2, which illustrated that in January, February, March and April, the flow was reduced significantly.

The result of wet season months (from June to November) is also plotted in the Figure 3. Among the wet months, the flow of the post-Farakka regime failed to meet the criteria in the early wet season (June and July) compared to the pre-Farakka period.

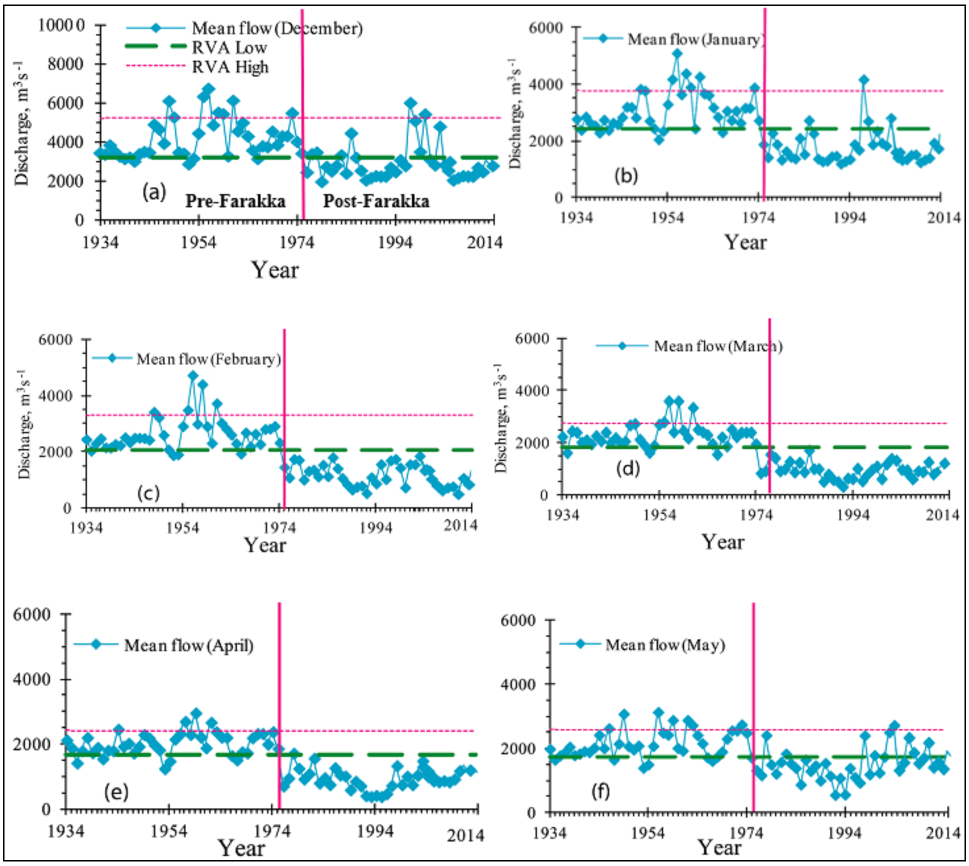

Fig 2: Monthly mean flow for the dry months of December (a), January (b), February (c), March (d), April (e) and May (f) in the pre- and post-Farakka period and a comparison with the threshold value

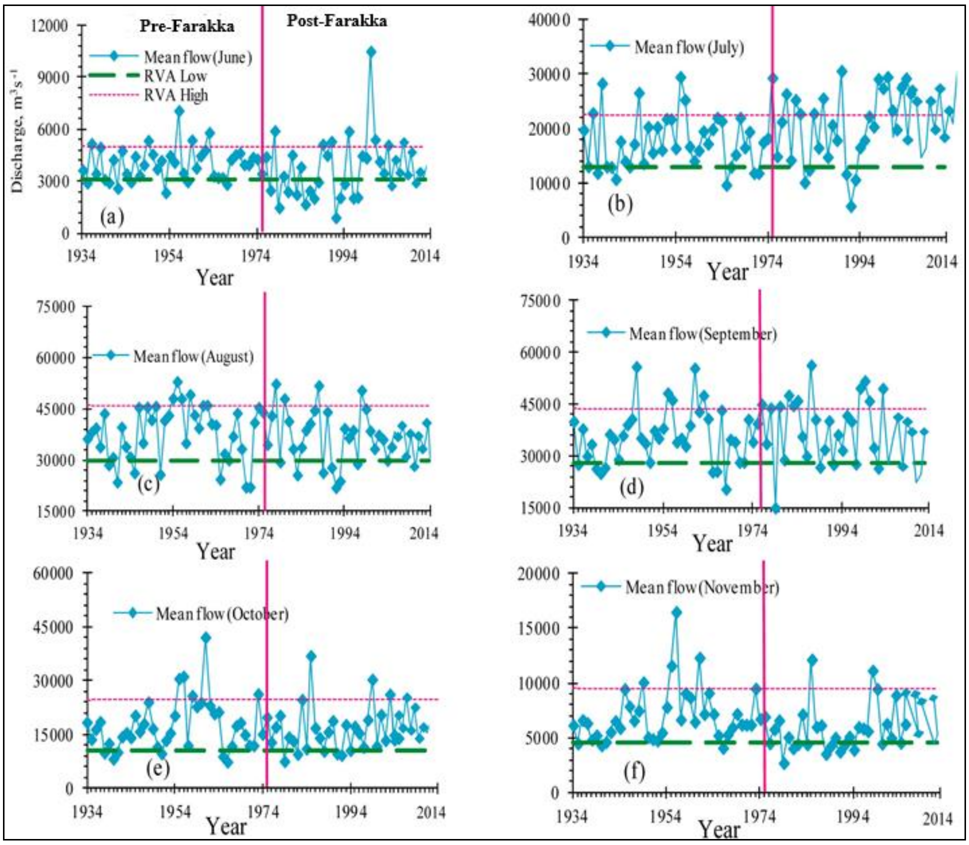

Fig 3: Monthly mean flow for the wet months of June (**a**), July (**b**), August (**c**), September (**d**), October (**e**) and November (**f**) in the pre- and post-Farakka period and a comparison with the threshold value

3.5 Ganges water levels and discharge at Harding bridge point
After constructing the Farakka barrage in 1975, it began diverting more than half of water (57%) to the Hooghly River in India (Figure 4). Harding Bridge in 1962 was 3,700 m^3/s and in 1968 when the average monthly flow of the Gorai River in the dry season exceeded 3,600 m^3/s and after this period the flow of Gorai River dropped to 1850 m^3/s in 1976.

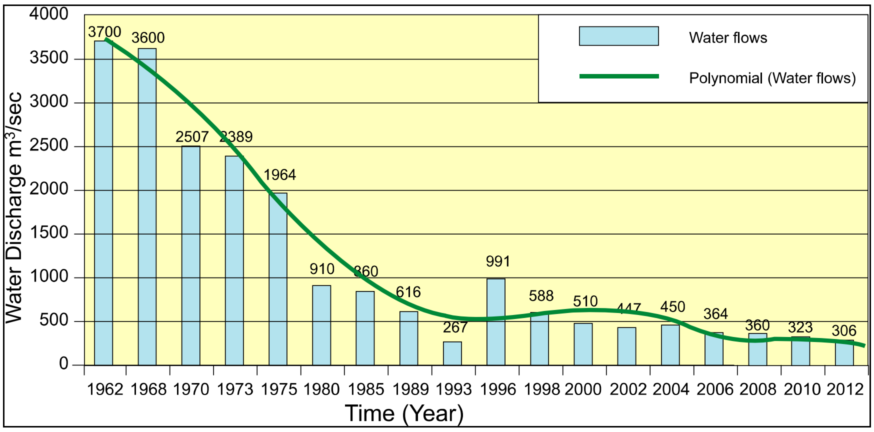

Fig 4: Ganges water levels at Harding bridge in the dry season

3.6 Water shortage and sedimentation in the Gorai River systems
Average yearly discharge of water the Gorai River system decreased day by day in post-Farakka period. While the average discharge were 780 m^3/s - 1050 m^3/s in the Harding Bridge point, Kamarkhali Bridge point, Bordia point, Khan Jahan Ali Bridge point and Mongla Port in 1988, these discharges reduced to 530 m^3/s - 790 m^3/s in 2013 (Figure 5).

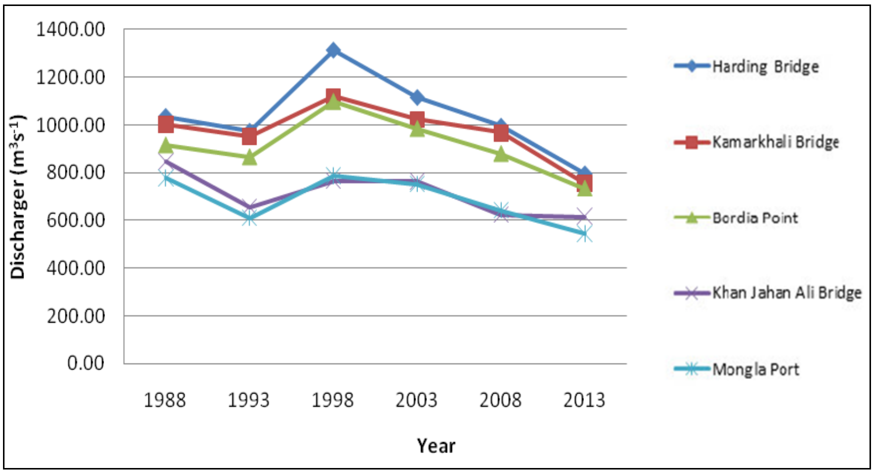

Fig 5: Average yearly discharge of water in some points of the Gorai River system in post-Farakka period

4. Discussions
It had been observed in post-Farakka period that, in August, September and October, the Ganges River flow was particularly dominated by monsoon rainfall, and about 70 per cent of Bangladesh's rain falls during this period, while the dry months (November–May) had a substantial decrease. During the monsoon all months also showed higher standard deviation. Therefore, the failure rate of the threshold criteria in the post-Farakka regime was not so high during these months, compared to other periods of the year. According to Mirza (1998) [14], India claimed that shifting in the discharge of water in the Ganges due to low winter and summer rainfall in northern India. FAP 4 (1993) [4] and FAP 24 (1993) [5] reported that, it was the physical intervention in the Ganges flow that had accelerated sedimentation in the Gorai mouth, which had almost isolated it from the Ganges River. As a consequence, the construction of Farakka dam had relatively less impact on the monsoon-dominated period. According to Live Science (2009) [10]., in the United States, Columbia River's flow declined by about 14 per cent over the 50-year period, largely because of reduced precipitation in the West. The Mississippi River, on the other hand, had an increase in flow of 22 per cent over the same period because of greater precipitation across the Mid-West. So, it can be said that climatic variability may affects the shifting of the discharge in Ganges River.

It was observed that in the post-Farakka period, a notable decline recorded in the discharge of the Gorai River. The river received a very low discharge in the dry months mainly due to reduced flow in the Ganges River. In 1993, freshwater discharge sharply declined than 1988 and then the freshwater flow was decreasing day by day. In 1993, freshwater flow in Bordia Point of the Nabaganga River of Narail was 1036 m^3/s and in 2013, it fallen down to 734 m^3/s. Similar declining flows was recorded in Harding bridge point, Khan Jahan Ali Bridge point and Mongla Port point. The analysis indicated that April was the worst month as the discharge decreased by 73% followed by 68% for March. On an average, the December–February discharge was reduced by 63%. A 58% decrease occurred for the May discharge. The results demonstrated that every year after the construction of Farakka dam, annual minimum flow failed to meet the threshold limit.

Similarly, annual maximum flows also failed to meet the threshold limit in the post-Farakka period. Islam and Gnauck (2009) [9], and EGIS (2000) [3] also recorded lowest flow of 9,437 m³/s on April, 1993 against a flow of 65,000 m³/s as the pre-diversion period of the Ganges. In 1995 and recent years, the flows had been recorded less than 500 m³/s (Islam and Gnauck 2009) [9]. It was visible that in post-Farakka period, freshwater discharge was decreasing and no freshwater discharge observed in the dry season since 1998 which is similar of the findings of Miah (2003) [12].

Natural causes might also play a part, but this is difficult to ascertain when physical interventions are made on a natural system. From this, it could be stated that, commissioning of the Farakka barrage is mainly responsible for the reduction of the downstream flow in the Ganges basin though some climatic factors might have the role.

5. Conclusions

The study showed that the RVA threshold criteria have been exceeded in most years since mid- 1970s. The diversion of the Ganges water at Farakka has caused hydrological changes in the mean monthly discharge of the Ganges and Gorai Rivers, accelerated in the Gorai River due to sedimentation, and increased salinity in the South-West region of Bangladesh. Natural causes might also play a part, but this is difficult to ascertain when physical interventions are made on a natural system. The calculated threshold flow of twenty-two RVA parameters can be used as initial targets for water resources and ecosystem management in the Lower Ganges Basin, particularly in Bangladesh. The governments of Bangladesh and India could consider allowing human perturbation and development activities within the calculated threshold ranges. The calculated thresholds can also be used for water allocation to meet household, fisheries, agriculture and industrial water demands. In trans-boundary river basin management within an integrated water resources management approach thresholds of flow variability can be used as a basis for negotiation with other riparian countries.

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