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APPLICATION OF HYDROLOGICAL METHODS TO ASSESS THE ENVIRONMENTAL FLOW OF GORAI RIVER IN BANGLADESH

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ABSTRACT

Environmental flow requirement certifies natural condition prominence of a river. Due to terrestrial position, the rivers in Bangladesh have to face very high flow in wet season and low flow in dry season. Since the present condition of a river flow characteristics has proven on historic flow data, the estimation of environmental flow requirements (EFR) for the rivers are censoriously important for Bangladesh. The purpose of the study is to assess the EFR of Gorai River and to evaluate the change in flow characteristics in recent time compared to past. Two stations are selected to assess the environmental flow circumstance for Gorai River system. The selected stations are Gorai Railway Bridge and Kamarkhali Transit. There are several methods for calculating the environmental flow requirements of a river system. Three popular methods namely Mean Annual Flow (MAF), Flow Duration Curve (FDC) and Constant Yield (CY) methods are used here for estimation of the environmental flow of the selected stations. These methods are appropriate for hydrological attitude and in use of chronological flow data.

Daily discharge data of selected stations were collected from Bangladesh Water Development Board (BWDB) and analyzed for two periods i.e. G1 period (for the year 1984 to 1999) and G2 period (for the year 2000 to 2016), and IHA software (version 7.1) has been applied. It is found that the estimated environmental flows of Gorai River at Gorai Railway Bridge station are 202.4 Cumec and 195.9 Cumec for MAF and CY methods, respectively. Here, the average EFR is estimated as 199.15 Cumec. In the Kamarkhali transit station of Gorai River, the environmental flows are estimated as 159 Cumec and 217 Cumec for MAF and CY methods, respectively. Thus, the average value of environmental flow was estimated as 188 Cumec. Deficient flow situation was observed from December to May in both of the stations according to the estimated environmental flow requirement. For both of the stations, the highest and lowest flowing months were found as August and March, respectively. It is observed that, the river condition is good at high flow season but the flows in low flow season became lower than the environmental flows required for good habitat quality.

Keywords: *Environmental Flow Requirement, Mean Annual Flow, Flow Duration curve, Constant Yield, Indicators of Hydrologic Alteration.*

1. INTRODUCTION

The Rivers afford several belongings and amenities for nature. The river comprises a source of water used for domestic, trade and agricultural purposes, a means of power generation and unwanted discarding, directions for navigation and locates for recreational and spiritual accomplishments. In the recent time, river flow system in freshwater discharge is reflected as a main variable by the river scientists due to its durable guidance on the environmental aspects. But hydrologic systems show a foremost task in shaping the biotic configuration, function of aquatic, wetland, and riparian ecologies (Richter et al., 1996). The Environmental flow requirement is an assessment for how much of the original flow establishment of a river should endure to flow down it and onto its floodplains in order to sustain indicated valued geographies of the ecosystem, hydrological commands for the rivers.

The future circumstances of the ecosystem are largely dependent on the environmental flow requirement. In this study, The EFR for Gorai river has been estimated; it is a river in south west region of Bangladesh that carries its flow from Ganges River. The upstream part of the Gorai river carries freshwater and then brackish water in the estuary. It is the main source of upland freshwater supply in this region (Moly et al., 2015). The Environmental flow requirement is different for different regions. Moreover, the impact of the identical flow requirement is not same for all the areas. However, for the awareness and protection against threat as well as for the mitigation of danger, it is necessary to assess the temporal and spatial changes in flow characteristics of Gorai River and to estimate the Environmental Flow Requirement (EFR) of the river that can be used for future orientation in management purposes. The River used to expulsion into the Bay of Bengal through the Madhumati and Baleswar Rivers and thus attends as a essential appliance for conserving both the environment and economy of the region (Islam and Gnauck, 2011). Due to excessive extraction from the Ganges River in its upstream inside India, its distributaries inside Bangladesh are gradually fallen to death for not receiving their dry season flow. Implementation of the Farakka Barrage results in reduction of flow through the Gorai River and deposition started ensuing in the off-take. As a result, two types of environmental impacts have been created in the Gorai catchment area. The sediment particles are settling down on the river bed rapidly, which is one of the major problems of Gorai River morphology. On the other hand, the saline sea water is pushed up in the upstream area due to capillary upward movement. The main objective of this study is to assess the flow characteristics of Gorai River and to estimate the Environmental Flow Requirement (EFR) of the river that can be used for future reference in management purposes.

2. METHODOLOGY

The research is outlined as to study the changes of flow characteristics for two stations in Gorai river system (Gorai Raiway Bridge station and Kamarkhali station) through the comparison between past and recent times and the environmental flow requirement was estimated to sustain natural ecosystem. The analysis of discharge on Gorai river system were carried out through Mean Annual Flow (MAF), Flow Duration Curve (FDC) and Constant Yield (CY) methods. All the methods belong to hydrological approach and use historical flow data. For determination of EFR, IHA (Indicators of Hydrologic Alteration) software is used (IHA, 2009), where the software quickly processed daily hydrologic records to enable characterization of natural water conditions and facilitate evaluations of human-induced changes to flow regimes.

The IHA software contains 67 parameters, which are sectioned into two groups, 33 IHA parameters and 34 EFC (Environmental Flow Component) parameters. Mean daily discharge (Cumec) data have been collected from the Bangladesh Water Development Board (BWDB) for the years 1984 to 2016. All hydrologic indices have been calculated from daily mean flow records using the Indicators of Hydrologic Alteration (IHA) software (version 7.1). A common approach to assess hydrologic alteration involves a comparison of flow regimes between past and more recent time. The flow for last thirty years was analyzed using IHA Software for two periods: G1 period (for the year 1984 to 1999) and G2 period (for the year 2000 to 2016).

Moreover, the classification of seasons based on discharge reported in Moly et al. (2015) is applied in the analysis of the present study. Depending on mean monthly flow, Gorai flows were categorized in three separate seasons named low flow season for the months of February to May (mean annual flow ≤100 Cumec), high flow season from July to October (mean annual flow ≥1000 Cumec) and intermediate flow season from November to January and June (mean annual flow from > 100 to < 1000 Cumec).

In this study of Gorai river system, the seasonal variation approach used in the Teesta River case by Mullick (2010) is adopted. The seasons are categorized as high flow season for the months of June to September, intermediate flow season for October, November, April and May and low flow season for the months of December to March.

3. RESULTS AND DISCUSSIONS

3.1 General Features of the Gorai River Flow

The river data had been analysed using IHA software in two different ways, first is single period analysis (1984-2016) and second as a two-period analysis: G1 period (1984-1999) and G2 period (2000-2016). The river characteristics of G1 period were compared with G2. For further investigation of the flow data, annual flow has been categorized in three dispersed seasons subjected on the amount of mean monthly discharge. The seasons are categorized as high flow season (HFS) for the months of June to September, intermediate flow season (IFS) for October, November, April and May and low flow season (LFS) for the months of December to March. For the investigation of flow data, Range of Variability Approach (RVA) method is also used which offers a flow target that resembles the expected flow regime with the primary objective of protecting natural ecosystem (Mullick et al., 2010). The flow characteristics and RVA are analyzed by the IHA software.

In the LFS, the discharge is the lowest in the Gorai River system. By considering mean monthly annual flows of Gorai railway Bridge station, it is found that August has the highest discharge of 5089 Cumec as a single period analysis as shown in Table 1. For two period analyses, it is found 5633 Cumec for G1 period (1984-1999) and 4577 Cumec for G2 period (2000-2016) as shown in Table 2. Here the March is found to be the lowest flowing month having a discharge of 23.22 Cumec as a single period analysis and 11.26 Cumec for G1 period and 34.47 Cumec for G2 period.

On the other hand, in the mean monthly annual flows at Kamarkhali Transit station, August has the highest discharge of 3467 Cumec as a single period analysis as shown in Table 1. For two period analyses, it is found 3942 Cumec for G1 period (1984-1999) and 3159 Cumec for G2 period (2000-2016) as shown in Table 3.2. Here the March is found to be the lowest flowing month having a discharge of 14.05 Cumec as a single period analysis and 19.08 Cumec for G1 period and 10.8 Cumec for G2 period.

Some other general characteristics are also shown in Table 1 and 2. The mean annual flow for Gorai Railway Bridge is found as 1012 Cumec and for Kamarkhali transit 795 Cumec. The extreme lowest flowing season is found in March and highest flowing season found in August. For Gorai Railway Bridge station the low flow threshold estimated by IHA is 5.783 Cumec and high flow threshold is 1390 Cumec. Whereas for Kamarkhali Transit station, the low flow threshold estimated by IHA is 12.54 Cumec and high flow threshold is 1128 Cumec. March is the lowest flowing month where flows are far lower than high flow threshold. The annual CV found for both the stations are nearly same; for Gorai Railway Bridge it is 1.5 and for Kamarkhali Transit station it is 1.45. The flow predictability is also nearly same as 0.46 and 0.48; the constancy/predictability is same for both as 0.29, percent of flood in 60-day period is found 0.88 for Gorai railway Bridge station and 0.91 for Kamarkhali Transit station. Flood free season is also nearly same 236 and 238; one day minimum flow is 23.22 for Gorai railway Bridge station and for Kamarkhali Transit station it is found 14.02. One day maximum flow for Gorai railway Bridge station is 5089 Cumec and Kamarkhali Transit station is 3467 Cumec, and rise rate is slightly higher for Gorai railway Bridge station (44.86) than the Kamarkhali Transit station is (30.03). The fall rate for Gorai railway Bridge station is 33.93 and for Kamarkhali Transit station is 26.08. The high flow threshold for the Gorai railway Bridge station is found as 1390 Cumec whereas for Kamarkhali Transit station it is found as 728 Cumec, this is lower than the Gorai railway Bridge station.

Table 1: General Characteristics of flows in Gorai Railway Bridge and Kamarkhali Transit stations as a single Period analysis

River Characteristics	**Gorai railway bridge**	**Kamarkhali Transit**
Period	**Total**	**Total**
Mean annual flow (Cumec)	1012	795.1
Annual C.V.	1.5	1.45
Flow predictability	0.46	0.48
Constancy/Predictability	0.29	0.29
% of flood in 60d period	0.88	0.91
Flood-free season	236	238
1-Day minimum flow	23.22	14.025
1-Day maximum flow	5089	3467
Base flow index	0.0348	0.0366
Rise rate	44.86	30.03
Fall rate	-33.93	-26.08
High flow threshold	1390	1128
Extreme low flow threshold	5.783	12.54

Table 2: General Characteristics of flows in Gorai Railway Bridge and Kamarkhali Transit stations as two-period analyses

River Characteristics	**Gorai railway bridge**		**Kamarkhali Transit**	
Period	**G1**	**G2**	**G1**	**G2**
Mean annual flow (Cumec)	1086	942.6	888.7	734.5
Annual C.V.	1.55	1.42	1.54	1.34
Flow predictability	0.53	0.49	0.5	0.53
Constancy/Predictability	0.31	0.27	0.29	0.28
% of flood in 60d period	0.91	0.91	0.83	0.88
Flood-free season	253	247	252	270
1-Day minimum flow	11.26	34.47	19.08	10.8
1-Day maximum flow	5633	4577	3942	3159
Base flow index	0.0281	0.0413	0.0587	0.0223
Rise rate	53.93	36.86	34.6	27.34
Fall rate	-41.11	-27.18	-34.67	-20.52
High flow threshold	1593	1593	957	957
Extreme low flow threshold	1.36	1.36	17.55	17.55

Table 3 shows the mean monthly flows for Gorai railway bridge station. It shows that the flows in January to May are lower than 100 Cumec for G1 period (1984-1999) and the flows in February to April are lower than 100 Cumec for G2 period (2000-2016). Whereas for total period (1984-2016) analysis the flows in February to May are lower than 100 Cumec. According to (Mullick et al. (2010) the flows in December to March are low flow seasons for Gorai railway bridge station. The flow values in June found slightly higher than 100 Cumec; and July to September flows are the high flow season. These mean monthly flows are higher for Gorai railway bridge station as HFS occurs in the month of June to September. The flow again starts decreasing in October and November. The Intermediate flow season occurs in the month of April, May, October and November.

Table 3: Mean monthly flows for different flow season at Gorai railway bridge station

Month	Season	G1 period (1984-1999) Cumec	G2 period (2000-2016) Cumec	Total period (1984-2016) Cumec
April	IFS	37.18	70.55	54.37
May		54.06	106.6	81.13
June	HFS	290.8	441.4	368.4
July		2239	1942	2086
August		3972	2925	3432
September		3925	2831	3362
October	IFS	1686	1784	1736
November		464.6	580.6	524.3
December	LFS	141.5	253.3	199.1
January		59.97	150.6	106.7
February		42.17	86.5	65.01
March		34.89	68.49	52.2

It is found for Gorai railway bridge station that, mean monthly flows satisfies LFS in November to June months. Whereas July to October flows are the high flow seasons. It is also observed in Table 3 that the March is the lowest flowing month and the flow is 34.89 Cumec in G1 period (1984-1999), 68.49 Cumec in G2 period (2000-2016), and for total period (1984-2016) the March flow is 52.2 Cumec in Gorai railway Bridge station. August is the highest flowing month and the flow is 3972 Cumec in G1 period (1984-1999), 2925 Cumec in G2 period (2000-2016), and for total period (1984-2016) the August flow is 3432 Cumec in Gorai railway Bridge station. The mean monthly flows of Gorai railway bridge station shows that HFS duration is 4 months and LFS duration is 8 months. In the 8 months of LFS duration, the June, November and December flows can be considered as intermediate flow season as per the mean monthly flows.

Table 4 shows the mean monthly flows of Kamarkhali Transit station. It shows that the flows in January to March are lower than 100 Cumec for G1 period (1984-1999) and the flows in January to April are lower than 100 Cumec for G2 period (2000-2016). Whereas for total period (1984-2016) analysis the flows in January to April are lower than 100 Cumec. According to Mullick (Mullick et al,. 2010) the flows in December to March are low flow seasons for Kamarkhali Transit station. The flow values in June found slightly higher than 100 Cumec; and July, August, September flows are the high flow season. These mean monthly flows are higher for Kamarkhali Transit station as HFS occurs in the month of June to September. The flow again starts decreasing in October and November. The Intermediate flow season occurs in the month of April, May, October and November.

Table 4: Mean monthly flows for different flow season at Kamarkhali Transit Station

Month	Season	G1 period (1984-1999)	G2 period (2000-2016)	Total period (1984-2016)
April	IFS	137.3	44.64	81.05
May		154.1	100.4	121.5
June	HFS	324.5	397.2	368.6
July		1741	1580	1643
August		3177	2460	2742
September		2923	2197	2483

October	IFS	1496	1201	1317
November		397.5	459.6	435.2
December	LFS	112.4	182	154.6
January		54.35	68.09	62.7
February		39	38.66	38.8
March		40.15	28.25	32.93

It is found for Kamarkhali Transit station that, mean monthly flows satisfies LFS in November to June months. Whereas July to October flows are the high flow seasons. It is also observed in Table 4 that the March is the lowest flowing month and the flow is 40.15 Cumec in G1 period (1984-1999), 28.25 Cumec in G2 period (2000-2016), and for total period (1984-2016) the March flow is 32.93 Cumec in Kamarkhali Transit station. August is the highest flowing month and the flow is 3177 Cumec in G1 period (1984-1999), 2460 Cumec in G2 period (2000-2016), and for total period (1984-2016) the August flow is 2742 Cumec in Kamarkhali Transit station. The mean monthly flows of Kamarkhali Transit station show that HFS duration is 4 months and LFS duration is 8 months. In the 8 months of LFS duration, the May, June, November and December flows can be considered as intermediate flow season as per the mean monthly flows.

3.2 Environmental Flow Requirement of Gorai River

The Environmental Flow Requirement of Gorai River is calculated in three different methods. The estimation of flows is describing as follows.

3.2.1 Mean annual flow (MAF) method

Table 3 and Table 4 shows summary of Mean monthly flows at low flow season (LFS), Intermediate flow season (IFS) and high flow season (HFS). It is observed that the lowest flow of Gorai Railway bridge station occurs in March as 34.89 Cumec in G1 period; and for Kamarkhali it is also observed in the March that is 28.25 Cumec in G2 period. The highest flow occurs for Gorai railway bridge Station in the month of August as 3972 Cumec in G1 period and for the kamarkhali station it is observed as 3177 Cumec in G1 period in the month of August as well.

According to MAF method, November to June is found as the low flow season (LFS) in both the stations. Whereas the high flow season (HFS) According to MAF method are July to October in both the stations. The June and November are the month of Intermediate flow seasons (IFS) or flow transition season in both the stations. In these months the flows are changing their patterns. The high flow comes to decrease at the month of November after which low flow season starts. Whereas low flow comes to increase at the month of April and May after which high flow season settles. It is observed that the flow in pre-monsoon starts increasing in June. The peak highest flow is found in monsoon period in the month of August, and then it again starts decreasing in the month of October. After the monsoon, the flow comes to a minimum level in the month of March.

Figure 1 describes the Comparison of Mean Monthly Flows with EFR in MAF method at Gorai Railway Bridge station. It shows that, mean annual flow of Gorai Railway Bridge station is 1012 Cumec during 1984 to 2016. The EFR value in MAF method for Gorai Railway Bridge is found as 202.4 Cumec. Mean monthly flows for April and May are lower than the environment flow required but the flows in June to November are more than the EFR by mean annual flow method. Again the flows in December to March are less than the required EFR value by mean annual flow method. Generally high flow seasons satisfies the EFR required flow but the flows in low flow seasons are normally less than the EFR by MAF method.

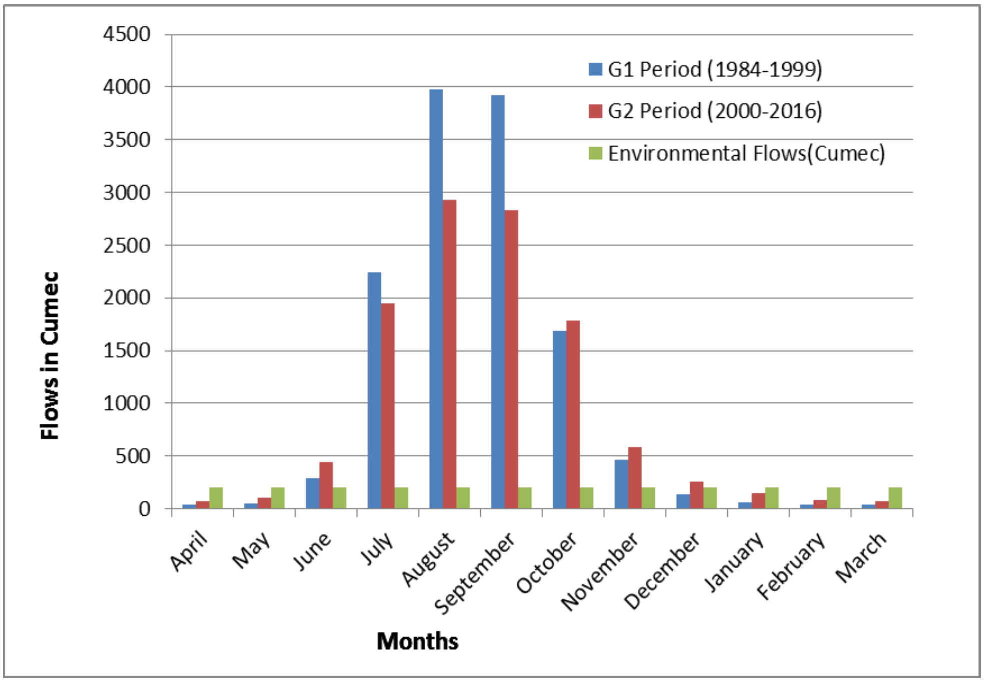

Figure 1: Comparison of Mean Monthly Flows with EFR in MAF method at Gorai Railway Bridge station

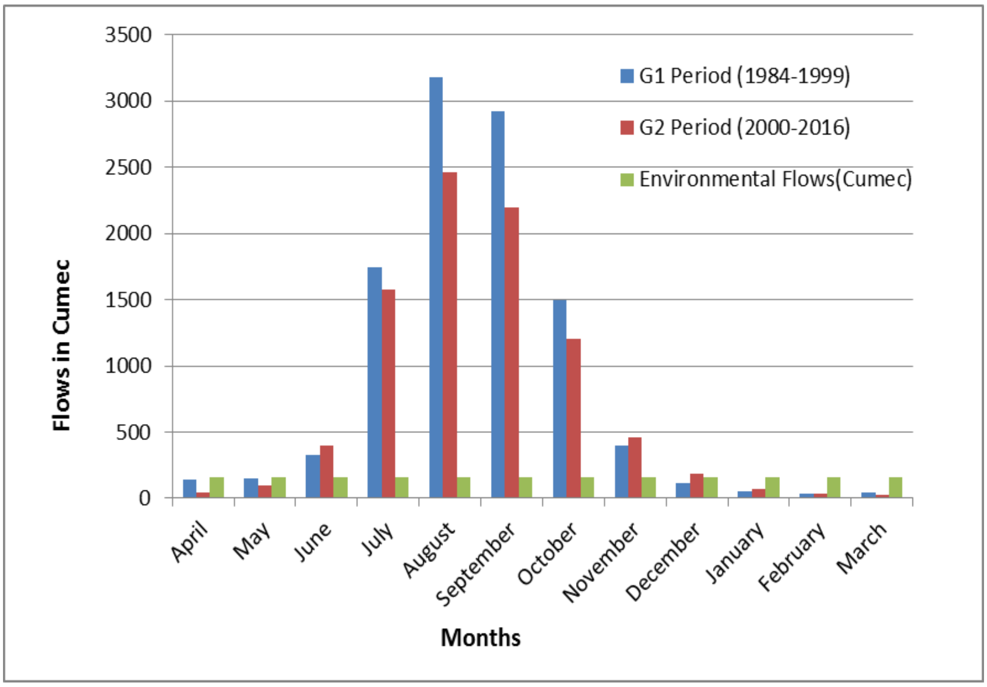

Figure 2: Comparison of Mean Monthly Flows with EFR in MAF method at Kamarkhali Transit station

Figure 2 describes the Comparison of Mean Monthly Flows with EFR in MAF method at Kamarkhali transit station. Mean annual flow of Kamarkhali transit station is 795.1 Cumec during 1984 to 2016. According to habitant quality, environmental flow requirement in MAF is found as 159.02 Cumec for kamarkhali transit station. Mean monthly flows for April and May are lower than the environment flow required but the flows in June to November are more than the EFR by mean annual flow method. Again the flows in December to March are less than the required EFR value by mean annual flow method. Generally high flow seasons satisfies the EFR required flow but the flows in low flow seasons are normally less than the EFR by MAF method.

3.2.2 Flow Duration Curve (FDC) method

Table 5 shows summary for FDC values at different flow seasons. For the EFR in low flow season, this FDC values are taken at 90% value, for Intermediate flow season this FDC values are taken at 50% value and for high flow season it is taken 50% values of FDC. The lowest flow of Gorai Railway bridge station in FDC method is found in March as 127.1 Cumec in G1 period; and for Kamarkhali Transit station it is also observed in March flow that is 83.8 Cumec in G1 period. The highest flow occurs for Gorai Station in the month of August is 4051 Cumec in G1 period and for the kamarkhali station it is observed 3743 Cumec in G1 period in the month of August as well. According to FDC method, November to June is found as the low flow season (LFS) in both the stations. Whereas the high flow season (HFS) According to FDC method are July to October in both the stations. The June, November and December are the month of Intermediate flow seasons (IFS) or flow transition season in both the stations. In these months the flows are changing its patterns. The high flow comes to decrease at the month of November after which low flow season starts. Whereas low flow comes to increase at the month of April and May after which high flow season settles. It is observed that the flow in pre-monsoon starts increasing in June. The peak highest flow is found in monsoon period in the month of August, and then it again starts decreasing in the month of October. After the monsoon, the flow comes to a minimum level in the month of March.

Table 5: Percentile flow of monthly FDC (90% for LFS and 50% for IFS and HFS)

Months	**Season**	**Gorai railway bridge**			**Kamarkhali Transit**		
		G1 (1984-1999)	**G2 (2000-2016)**	**Total (1984-2016)**	**G1 (1984-1999)**	**G2 (2000-2016)**	**Total (1984-2016)**
April	IFS	9.589	51.5	44.27	46.6	16.13	33.98
May		31.51	92.09	66.53	81.55	50.24	59.73
June	HFS	197.2	273	246.9	217	216.9	217
July		2517	2107	2247	1720	1597	1717
August		4051	3037	3516	3743	2366	2564
September		3785	3195	3529	2866	2444	2581
October	IFS	1481	1404	1438	1290	1124	1132
November		447.6	572.5	473.9	276.6	381.9	337
December	LFS	369.4	514.2	395.2	273.2	394.1	281.5
January		164.2	395.2	260.1	153.3	182.3	180.6
February		132.4	189.7	167	116.5	129.2	124.4
March		127.1	150.6	134.4	83.8	83.81	83.29

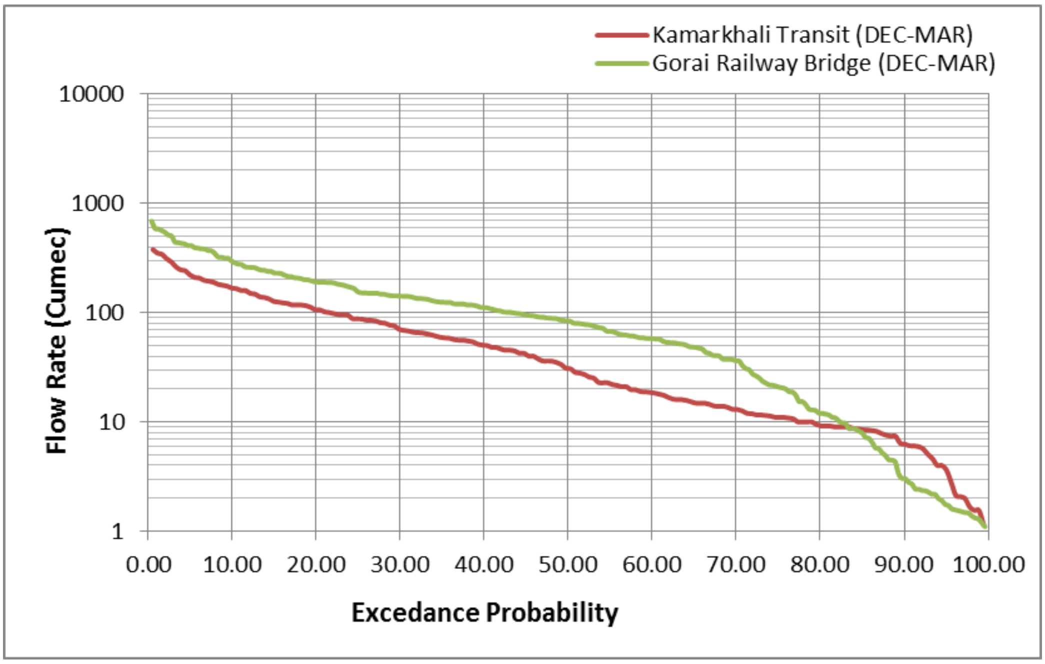

Figure 3: Flow Duration Curve at LFS for Gorai Railway Bridge and Kamarkhali Transit stations

Figure 3 shows the Flow Duration Curve for Gorai Railway Bridge and Kamarkhali Transit stations at LFS. From the Figure it is observed, for the Gorai railway bridge FDC values are higher than the Kamarkhali Transit stations FDC values through all the years. The FDC values crosses the Gorai Railway Bridge when the value of flow is nearer to 10 Cumec and it occurs at 83% of exceedence probability. According to FDC method the LFS requires 90^{th} percentile flow as EFR. The 90^{th} Percentile value on FDC for Gorai Railway Bridge station flow is found as 290 Cumec and the 90^{th} Percentile value on FDC for Kamarkhali transit station flow is found as 167 Cumec.

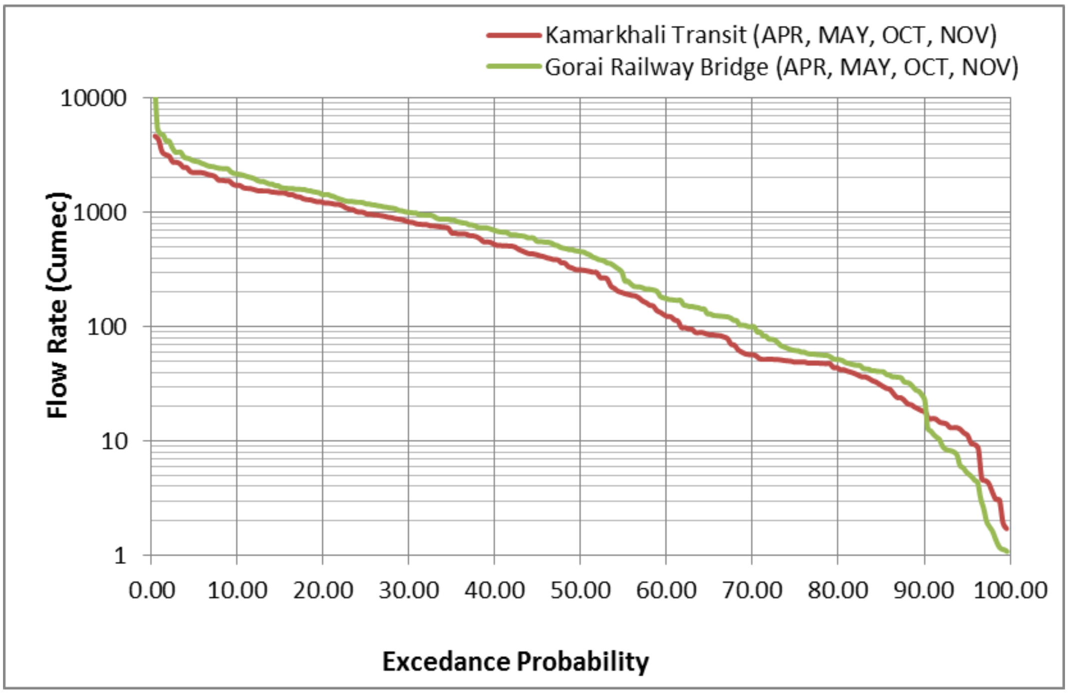

Figure 4: Flow Duration Curve at IFS for Gorai Railway Bridge and Kamarkhali Transit stations

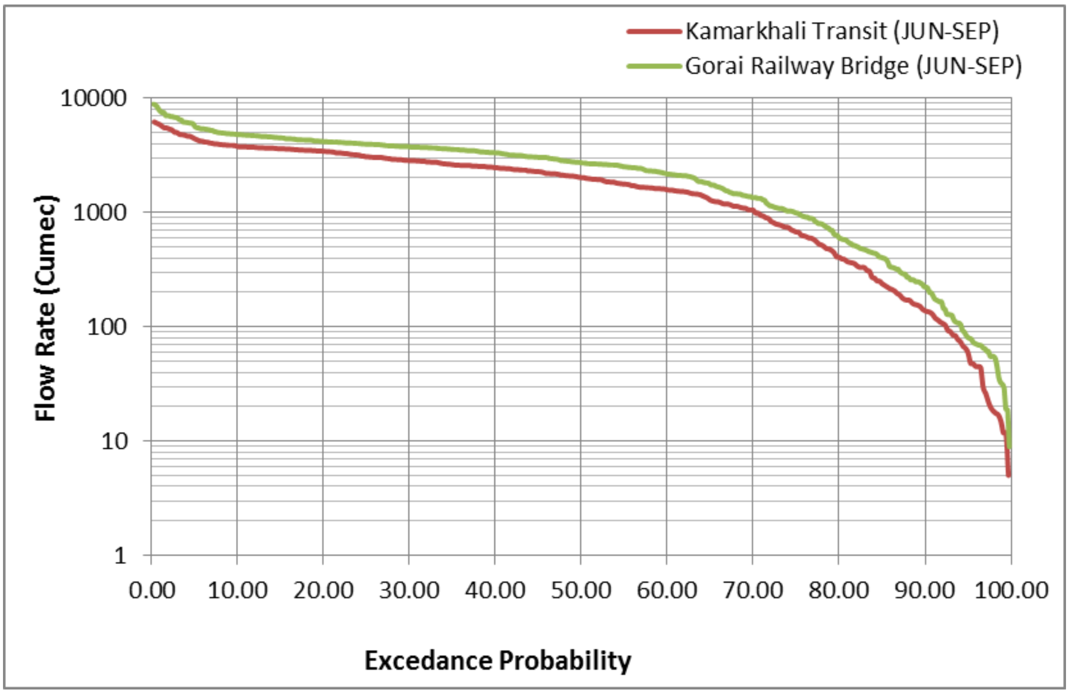

Figure 5: Flow Duration Curve at HFS for Gorai Railway Bridge and Kamarkhali Transit stations

Figure 4 shows the Flow Duration Curve for Gorai Railway Bridge and Kamarkhali Transit stations at IFS. From the Figure it is observed, for the gorai railway bridge FDC values are higher than the Kamarkhali Transit stations FDC values through all the years. The FDC values crosses the Gorai Railway Bridge when the value of flow is nearer to 18 Cumec and it occurs at 90% of exceedance probability. According to FDC method the IFS requires 50th percentile flow as EFR. The 50th Percentile value on FDC for Gorai Railway Bridge station flow is found as 455 Cumec and the 50th Percentile value on FDC for Kamarkhali transit station flow is found as 315 Cumec.

Figure 5 shows the Flow Duration Curve for Gorai Railway Bridge and Kamarkhali Transit stations at HFS. From the Figure it is observed, for the gorai railway bridge FDC values are higher than the Kamarkhali Transit stations FDC values through all the years. According to FDC method the HFS requires 50th percentile flow as EFR. The 50th Percentile value on FDC for Gorai Railway Bridge station flow is found as 2715 Cumec and the 50th Percentile value on FDC for Kamarkhali transit station flow is found as 2026 Cumec.

Table 6: Environmental flow Requirements based on FDC method

Flow season	**Percentile value on FDC**	**Gorai Railway Bridge station Flow (Cumec)**	**Kamarkhali transit station Flow (Cumec)**
High Flow	50th	2715	2026
Intermediate Flow	50th	455	315
Low Flow	90th	290	167

Table 6 shows the environmental flow requirement for the Gorai Railway Bridge station and Kamarkhali transit station based on FDC method. In case of Bangladesh Mullick et al. (2010), Hossain and Hosasin (2011) and Rahman et al. (2013) have used 90% (or 90th percentile) for low flow season and 50% (or 50th percentile) for Intermediate and high flow season to calculate environmental flow requirement of Teesta, Dudhkumar and Turag River respectively.

3.2.3 Constant Yield (CY) method

Table 7 shows summary for Constant Yield at low flow season (LFS) Intermediate flow season (IFS) and high flow season (HFS). It is observed that the lowest flow of Gorai Railway bridge station occurs in February as 3.073 Cumec in G1 period; and for Kamarkhali it is found in the month of March as 15.29 Cumec in G2 period. The highest flow occurs for Gorai railway bridge Station in the month of August as 4051 Cumec in G1 period and for the kamarkhali station it is observed as 3743 Cumec in G1 period in the month of August as well.

According to CY method, November to June is found as the low flow season (LFS) in both the stations. Whereas the high flow season (HFS) According to CY method is July to October in both the stations. The June and November are the month of Intermediate flow seasons (IFS) or flow transition season in both the stations. In these months the flows are changing its patterns. The high flow comes to decrease at the month of November after which low flow season starts. Whereas low flow comes to increase at the month of April and May after which high flow season settles. It is observed that the flow in pre-monsoon starts increasing in June. The peak highest flow is found in monsoon period in the month of August, and then it again starts decreasing in the month of October. After the monsoon, the flow comes to a minimum level in the month of March.

Table 7: Summary of Constant Yield at LFS, IFS and HFS

Months	Season	Gorai railway bridge			Kamarkhali Transit		
		G1 (1984-1999)	G2 (2000-2016)	Total (1984-2016)	G1 (1984-1999)	G2 (2000-2016)	Total (1984-2016)
April	IFS	9.589	51.5	44.27	46.6	16.13	33.98
May		31.51	92.09	66.53	81.55	50.24	59.73
June	HFS	197.2	273	246.9	217	216.9	217
July		2517	2107	2247	1720	1597	1717
August		4051	3037	3516	3743	2366	2564
September		3785	3195	3529	2866	2444	2581
October	IFS	1481	1404	1438	1290	1124	1132
November		447.6	572.5	473.9	276.6	381.9	337
December	LFS	89.58	226.9	195.9	61.87	113.6	108.7
January		27.83	120.7	88.99	21.69	25.82	23.76
February		3.073	79.8	49.29	20.69	16.95	17.26
March		12.06	59.5	41.18	38.79	15.29	20.23

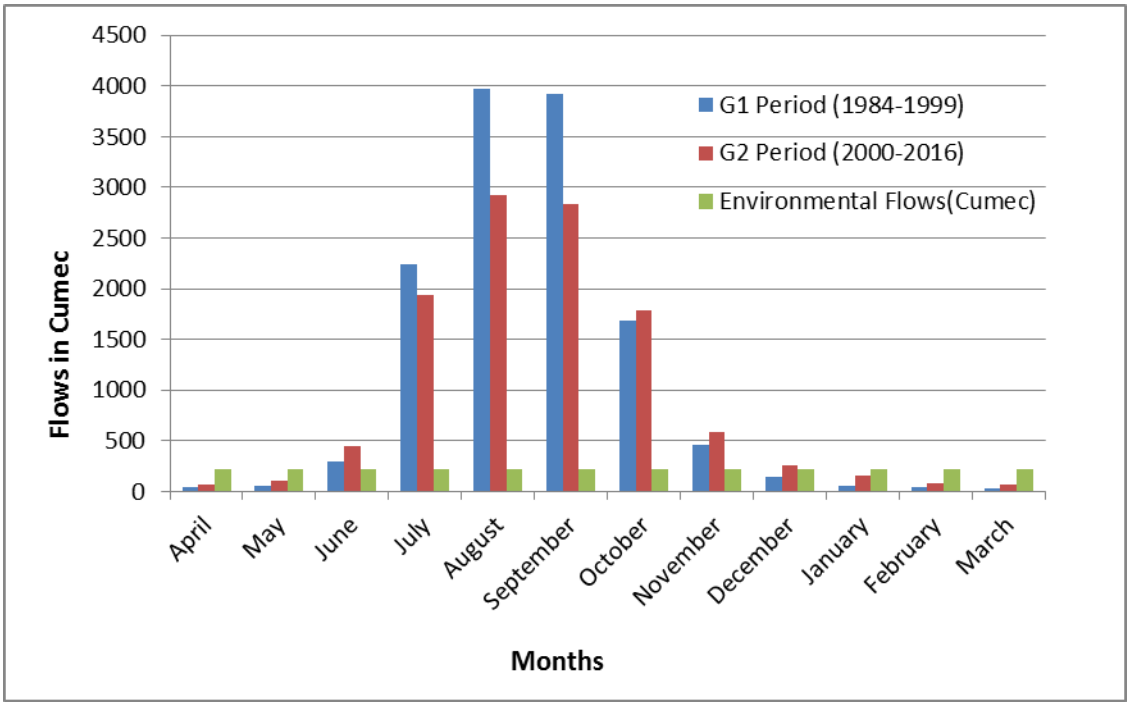

Figure 6: Comparison of Mean Monthly Flows with EFR in CY method at Gorai Railway Bridge station

Figure 6 describes the Comparison of Mean Monthly Flows with EFR in CY method at Gorai Railway Bridge station. The EFR value in CY method for Gorai Railway Bridge station is found as 221.4 Cumec. For this flow in the month of April and May the mean monthly flows are lower than the environment flow required but in June to November the flows are more than the EFR in CY method. Therefore, although the high flow season satisfies the flow required, the low flow season does not support this. Basically the flows in June and November are intermediate flow season where the flow season changes. Again the flows in December to March are less than the required EFR value in CY method. Generally high flow seasons satisfy the EFR required flow but the low flow seasons are normally less than the EFR flow by CY method at Gorai Railway Bridge station.

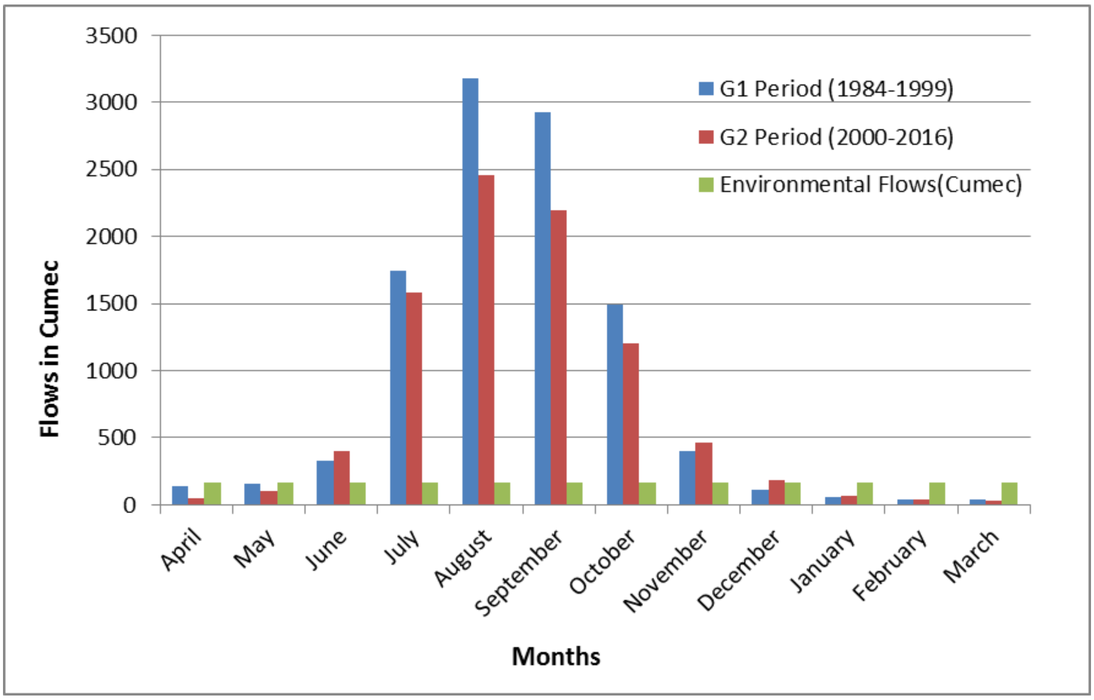

Figure 7: Comparison of Mean Monthly Flows with EFR in CY method at Kamarkhali Transit station

Figure 7 describes the Comparison of Mean Monthly Flows with EFR in CY method at Kamarkhali transit station. The EFR value in CY method for Kamarkhali transit station is found as 162.85 Cumec. For this flow in the month of April and May the mean monthly flows are lower than the environment flow required but in June to November the flows are more than the EFR in CY method. Therefore, although the high flow season satisfies the flow required, the low flow season does not support this. Basically the flows in June and November are intermediate flow season where the flow season changes. Again the flows in December to March are less than the required EFR value in CY method. Generally high flow seasons satisfy the EFR required flow but the low flow seasons are normally less than the EFR flow by CY method at Kamarkhali transit station.

Table 8 shows Summary of monthly Flow values computed by three methods for Gorai Railway bridge station, here in MAF method lowest flow occurs in March which is found as 52.2 Cumec, and the flow start increasing from April. The increasing rate is very slow from April to May, in June the flow has rapid increase and in July the flow has a high frequency. it continue the rapid high flow up to September, after September the flow again start decreasing and in October it has a downward slope of decrease. In November it has started drop the flow and decreases up to March. The low flow season (LFS) is December to March. Whereas the high flow season (HFS) found are June to September and the April, May, October and November are the month of Intermediate flow seasons (IFS) or flow transition season. In these months the flows are changing its patterns. The high flow comes to decrease at the month of October and November after which low flow season settles. Whereas low flow comes to increase at the month of April and May after which high flow season settles. In FDC method the lowest flow observed in April which is 44.27 and highest flow found in September which is found as 3529 Cumec and in CY method the lowest flow occurs in March is found as 41.18 Cumec and high flow found in September is found as 3529 Cumec. Among all methods the highest flow is 3529 found in September and the lowest flow is 41.18 found in March the overall flow condition are nearly same in above three described methods.

Table 8: Summary of monthly Flow values computed by three methods for Gorai Railway bridge station

Months	Season	MAF Method	FDC Method	CY Method
		Total	Total	Total
April	IFS	54.37	44.27	44.27
May		81.13	66.53	66.53
June	HFS	368.4	246.9	246.9
July		2086	2247	2247
August		3432	3516	3516
September		3362	3529	3529
October	IFS	1736	1438	1438
November		524.3	473.9	473.9
December	LFS	199.1	395.2	195.9
January		106.7	260.1	88.99
February		65.01	167	49.29
March		52.2	134.4	41.18

Table 9: Summary of monthly Flow values computed by three methods for Kamarkhali Transit station

Months	Season	MAF Method	FDC Method	CY Method
		Total	Total	Total
April	IFS	81.05	33.98	33.98
May		121.5	59.73	59.73
June	HFS	368.6	217	217
July		1643	1717	1717
August		2742	2564	2564
September		2483	2581	2581
October	IFS	1317	1132	1132
November		435.2	337	337
December	LFS	154.6	281.5	108.7
January		62.7	180.6	23.76
February		38.8	124.4	17.26
March		32.93	83.29	20.23

Table 9 shows summary of monthly Flow values computed by three methods for Kamarkhali Transit station, here in MAF method lowest flow occurs in March which is 32.93 the flow start increasing from April. The increasing rate is very slow from April to May, in June the flow has rapid increase and in July the flow has a high frequency. it continue the rapid high flow up to September, after September the flow again start decreasing and in October it has a downward slope of decrease. In November it has started drop the flow and decreases up to March. The low flow season (LFS) is December to March. Whereas the high flow season (HFS) found are June to September and the April, May, October and November are the month of Intermediate flow seasons (IFS) or flow transition season. In these months the flows are changing it patterns. The high flow comes to decrease at the month of October and November after which low flow season settles. Whereas low flow comes to increase at the month of April and May after which high flow season settles. In FDC method the low flow observed in April which is 33.98 and high flow found in September which is 2581 and in CY method the lowest flow occurs in February is 17.26 and high flow found in September is 2581 among all methods the highest flow is 2742 found in August and the lowest flow is 20.23 found in March the overall flow condition is nearly same in above three described methods.

3.5 Assessment of Environmental Flow

It is observed from the analysis that, the Mean annual flow of Gorai Railway bridge station is 1012 Cumec during 1984 to 2016, and Mean annual flow of Kamarkhali transit station is 795.1 Cumec during 1984 to 2016. As low flow season is the main concern, about 202.4 Cumec flow is required to maintain good condition for Gorai Railway bridge station and 159 Cumec flow is required for Kamarkhali transit station in MAF method. The relationship between the magnitude and duration of stream flows is presented by flow duration curve (FDC). FDCs are used mainly to set environmental flow purposes. Flow duration intervals are stated as percentage of exceedance, with zero corresponding to the highest stream discharge in the record (i.e. flood conditions) and 100 to the lowest (i.e. drought conditions). As low flow season is the main concern, the environmental flow requirement based on FDC in LFS is found as 290 Cumec for Gorai Railway bridge station and 167 Cumec flow is required for Kamarkhali transit station in FDC method. During the low flow season the minimum requirement based on FDC method is retained during both intermediate and high flow seasons but not for low flow season which is the main concern. Environmental flow considering CY method for Gorai Railway bridge station is found as 221.4 Cumec and for Kamarkhali transit station it is found as 162.85 Cumec. The flow found in CY method is close enough to environmental flow requirement obtained from MAF and FDC methods.

The calculated environmental flow requirement based on Tennant method (MAF), FDC method and CY method are 202.4 Cumec, 290 Cumec and 221.4 Cumec respectively for Gorai Railway bridge station, whereas for Kamarkhali transit station it is found as 159 Cumec, 167 Cumec and 162.85 Cumec, respectively. By taking the average of these three values, the needed environmental flow of the Gorai Railway bridge station is found as 237.93 Cumec for Gorai Railway bridge station and for Kamarkhali transit station it is found as 162.95 Cumec. The river flow meets the environmental flow requirement in high flow season and intermediate flow season.

Table 10 shows the Flow requirement according to habitat quality for Gorai Railway Bridge and Kamarkhali Transit station. Here the flow requirement according to habitat quality are shown in high flow season and low flow season for both the Gorai Railway Bridge and Kamarkhali Transit station, the percentage of mean annual flow for flushing flow is 200%. For Gorai Railway bridge station it is found as 2024 Cumec. For high flow season and low flow season both the requirement is same and for Kamarkhali Transit station it is found as 1590.2 Cumec. The optimum range is 60% to 100% for both low flow and high flow season and outstanding flow at HFS 60% and LFS will be 40% of the mean annual flow and for the excellent flow it is required 50% of high flow season and 30% at low flow season of the MAF and for a good quality of flow it is required 40% at HFS and 20% at LFS. For a fair quality of flow it is required 30% at HFS and 10% at LFS. The quality will be Poor if the flow is 10% in both HFS and LFS. Severe degradation is occurred if the flow less than 10% for both the seasons. Considering the habitat quality, it is found that, for Gorai Railway bridge station the severe degradation is occurred if the flow is less than 101.2 Cumec and for Kamarkhali transit station the severe degradation is occurred if the flow is less than 79.51 Cumec. The severe degradation is occurred if the flow is less than the lowest flow after which the river can be lost its environmental habitat quality below this flow level.

Table 10: Flow requirement according to habitat quality for Gorai Railway Bridge and Kamarkhali Transit station

Flow Requirement	**High Flow Season (HFS) (Cumec)**		**Low Flow Season (LFS) (Cumec)**	
(% of MAF)	**Gorai station**	**Kamarkhali station**	**Gorai station**	**Kamarkhali station**
Flushing flow (200%)	2024	1590.2	2024	1590.2
Optimum range (60-100%)	607.2 - 1012	477.06 - 795.1	607.2 - 1012	477.06 - 795.1
Outstanding (60% at HFS, 40% at LFS)	607.2	477.06	404.8	318.04
Excellent (50% at HFS, 30% at LFS)	506	397.55	303.6	238.53
Good (40% at HFS, 20% at LFS)	404.8	318.04	202.4	159.02
Fair (30% at HFS, 10% at LFS)	303.6	238.53	101.2	79.51
Poor (10%)	101.2	79.51	101.2	79.51
Severe degradation (<10%)	<101.2	<79.51	<101.2	<79.51

It is observed that, the river condition is good at the high flow season but when the flow comes in low flow season it becomes lower than the environmental flows required for good habitat quality. The flows in the month of January to May are less than the EFR required. The flows of these months are less than the severe degradation flow. It shows severe problems for both the stations. For the Gorai river, it is necessary to maintain the flow values more than the severe degradation throughout the year to sustain the habitat quality for the river. The three methods show different values for environmental flow requirement. The flow requirements in the low flow season for three methods are found lower than the required flow in both stations. It shows that the river is endangered for habitat quality in low flow seasons. In every method it proved that, the Gorai River has flow scarcity because of the low flows from upstream. The reason is the construction of farakka barrage in the upstream. It causes to decrease the flow in the low flow season. The other factors are the cultivation and water use of the local people from river. Construction of houses in the river bank and dumping of garbage in river side causes the narrowing of the flow channel which causes reduction of flow from upstream to downstream. This wide ranging difference of EFR is due to the variation of habitat quality and flow seasonality. A flushing habitat quality requires the largest amount of flow whereas a 'fair' habitat quality requires the minimum amount of flow.

Observing all three methods it is found that, the discharge of G1 period is generally lower than G2 period in the month November to June, whereas the discharge of G1 period is generally higher than G2 period in the month July to October at Gorai railway Bridge station. On the other hand for Kamarkhali transit station, the discharge of G1 period is generally lower than G2 period in the month November to January, whereas the discharge of G1 period is generally higher than G2 period in the month February to October.

4. CONCLUSIONS

The estimated environmental flow for the Gorai Railway bridge station is found as 237.93 Cumec, which is the average of calculated environmental flow determined by MAF method (202.4 Cumec), Flow duration curve method (290 Cumec) and constant yield method (221.4 Cumec). The flows in June to November month meet the environmental flow requirement. From December to May, the river does not have sufficient discharge to meet environmental flow requirement. In the Gorai Railway bridge station, low flow season suffers in severe water shortage due to significant flow reduction in recent time.

The estimated environmental flow for the Kamarkhali Transit station is found as 162.95 Cumec, which is the average of calculated environmental flow determined by MAF method (159 Cumec), Flow duration curve method (167 Cumec) and constant yield method (162.85 Cumec). The flows in

June to November month meet the environmental flow requirement. From December to May, the river does not have sufficient discharge to meet environmental flow requirement.

Observing MAF, FDC and CY methods it is found that, the discharge of G1 period is generally lower than G2 period in the month November to June, whereas the discharge of G1 period is higher than G2 period in the month July to October at Gorai railway Bridge station. On the other hand, for Kamarkhali Transit station, the discharge of G1 period is generally lower than G2 period in the month November to January, whereas the discharge of G1 period is higher than G2 period in the month February to October.

It is observed that, the river is endangered for habitat quality in low flow seasons. In every method it proved that, the Gorai River has flow scarcity because of the low flows from upstream. The estimated environmental flow requirement found in FDC method is highest among three methods for both the Gorai Railway Bridge station and Kamarkhali Transit station. So considering the flow conservancy, the FDC method is the best for estimation of environmental flow requirement of a river. Again the EFR of LFS, IFS and HFS can be estimated in FDC method which is absent in MAF and CY methods.

REFERENCES

BWDB (2017). Bangladesh water development board, yearly data, Ministry of Water Resources, Govt. of the Peoples Republic of Bangladesh.

IHA (2009) The Nature Conservancy, 2009. Indicators of Hydrologic Alteration Version 7.1User's Manual.

Islam SN, Gnauck A (2011). Water shortage in the gorai river basin and damage of mangrove wetland ecosystems in sundarbans, Bangladesh. 3rd International Conference on Water & Flood Management (ICWFM-2011), Dhaka, Bangladesh.

Mullick RA, Babel MS, Perret SR (2010). Flow characteristics and environmental flow requirements for the Teesta River, Bangladesh, Proceedings of international conference on environmental aspects of Bangladesh (ICEAB10), Japan.

Moly, SQ, Mirza ATM R, Saadat AHM (2015). Environmental Flow Characteristics of the Gorai River Bangladesh, International Journal of Scientic Research in Environmental Sciences, 3(6), 208-218.

Richter BD, Baumgartner JV, Wigington R, Braun DP (1997). How much water does a river need? Freshwater Biology, 37: 231-249.