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ENVIRONMENTAL FLOW ASSESSMENT FOR THE GANGES-PADMA RIVER AT HARDINGE BRIDGE POINT

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ABSTRACT

This study computes the environmental flow (E-flow) of the Ganges-Padma River at the Hardinge Bridge station in Bangladesh. The rivers in Bangladesh experiences very high seasonal variability with high flow in rainy season and very low flow in winter. Therefore, it is very important to estimate the E-flow requirement to preserve riverine ecosystem health. In this study, the flow characteristics of the river has been evaluated comparing the pre-impact (1990–2004) and post-impact (2005–2019) conditions using four hydrological methods: Mean Annual Flow (MAF), Flow Duration Curve (FDC), Constant Yield (CY), and Range of Variability Approach (RVA). Flow data were collected from the Bangladesh Water Development Board (BWDB). For the pre-impact period, the calculated cumulative minimum E-flows from MAF, FDC, and CY methods were found as 1068 m^3/s, 426.5 m^3/s, and 785 m^3/s, respectively, with RVA prescribing a range of 551 to 887 m^3/s. For the post-impact period, they were 914 m^3/s, 690 m^3/s, and 871 m^3/s, respectively, with the RVA range remaining 551 to 887 m^3/s. The findings exhibit notable variation in flow regimes and the requirement of hydrological assessment for sustainable river management in Bangladesh.

Keywords: *Environmental Flow (E-flow) Assessment, Hydrological Methods, Ganges-Padma River.*

1. INTRODUCTION

Environmental flow (E-flow) has emerged as a critical aspect of river management and development since the mid-20th century (Akter & Ali, 2012; Mondal et al., 2020)). To maintain healthy river ecosystems while supporting water extraction, agriculture, hydropower, and industrial growth, assessing E-flow requirements has become important for both developed and developing nations (Acreman et al., 2014). Bangladesh, a riverine country with over 700 rivers in our country and 57 of which are transboundary (three with Myanmar and 54 with India), relies heavily on its river systems for livelihood and socio-economic development. The Ganges, one of the country's three major rivers, plays a vital role in maintaining regional hydrology and ecology (Ali & Hasan, 2022).

The study results in new environmental flow guidelines for the economically and environmentally important Ganges-Padma Rivers distributary canal in Bangladesh. The findings provide suggestions for the year-round flow levels needed to protect delta fishing profits, reduce saline intrusion, maintain ecosystem productivity and hilsa migration, and secure irrigation withdrawals during the dry season. As development and climate change continue to alter the hydrology of South Asian rivers, the study also demonstrates economically viable, scientifically sound environmental flow techniques that can be used in places with limited data (Dyson et al., 2003). Lastly, analyses demonstrate how proposed upstream irrigation expansion threatens transboundary flows that are essential to ecosystem health and human water security in downstream Bangladesh (Rahman et al., 2022). This study aims to determine the environmental flow requirements of the Ganges-Padma River at the Hardinge Bridge point, focusing on hydrologic, morphologic, and ecological functions. Besides, the study compares pre-impact and post-impact flow conditions associated with the construction of the Lalon Shah Bridge in 2004.

2. METHODOLOGY

2.1 Study Area

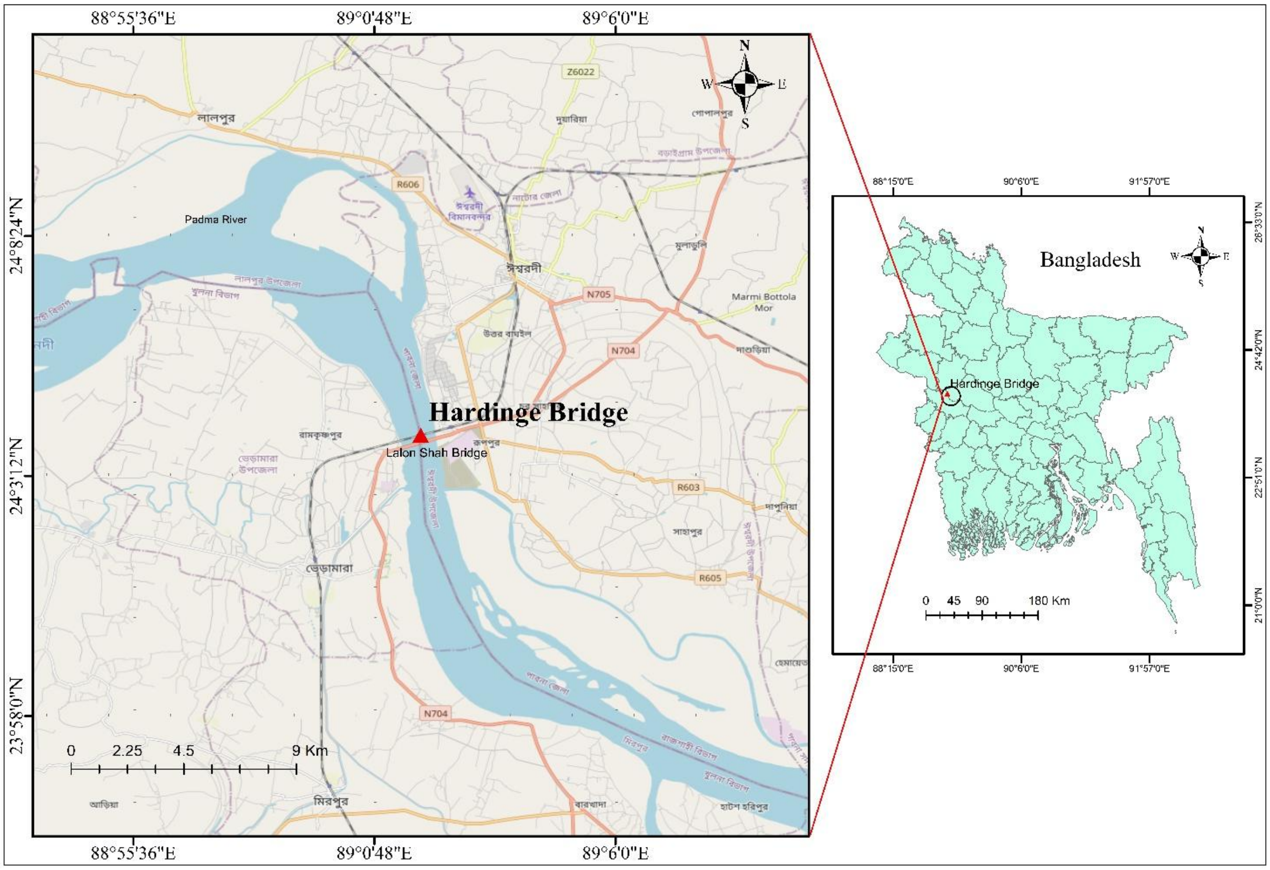

Figure 1: Location of the study area and the Ganges-Padma River in Bangladesh

The Hardinge Bridge section of the Ganges-Padma River was selected as the study site due to its hydrological significance and the availability of relevant data. Apart from the Paksey Transit station, it is the only location with continuous discharge records in this region. The catchment area at Hardinge Bridge lies within the central river system of Bangladesh, located between 24°00′–24°30′ N latitude and 88°45′–89°15′ E longitude, and flows through the Kushtia and Pabna districts. The Ganges-Padma River, originating from the Himalayan catchments, enters Bangladesh at the Rajshahi border and exhibits a wide, braided, and dynamic morphology influenced by seasonal variations in flow and sediment transport (Bari et al., 2013).

2.2 Methods For Environmental Flow Analysis

Environmental Flow Requirement (EFR) for the Ganges-Padma River has been assessed using four methods they are (i) Mean Annual Flow (MAF) method, (ii) Flow Duration Curve (FDC) method, (iii) Constant Yield (CY) method, and (iv) Ranges of Variability Approach (RVA). All the methods belong to the hydrological approach and use historical flow data. The Tennant approach is one of the most documented and employed methods of estimating environmental flow requirements (EFR). It determines EFR as a percentage value (10-200%) of Mean Annual Flow (MAF), depending on desired habitat quality (Saha, 2007). In the current study, discharge data of the Hardinge Bridge station, which are obtained from BWDB, were analyzed through IHA software for two phases: Pre-impact (1990–2004) and Post-impact (2005–

2019). The different percentages that have been used for calculating EFR for various habitat potentials are shown in Table 1.

Table 1: Percentage of MAF based on Tennant Method (Tennant, 1976)

Habitat quality	**% of MAF**	
	Low flow season	**High flow season**
Flushing or Maximum	200	200
Optimum	60-100	60-100
Outstanding	40	60
Excellent	30	50
Good	20	40
Fair	10	30
Poor	10	10
Severe degradation	<10	<10

The Flow Duration Curve (FDC) method establishes environmental flow requirements (EFR) based on the 50th percentile flow for the high-flow season and the 90th percentile flow for the low-flow season. Monthly FDCs were developed using thirty years (1990-2019) of discharge data from the Ganges-Padma River at Hardinge Bridge, obtained from BWDB. Flow analysis was conducted using IHA software for two periods: pre-impact (1990-2004) and post-impact (2005-2019).

The Constant Yield (CY) approach takes EFR as 100% of the median monthly flow for each month. For this study, median monthly flows have been estimated using two approaches: (i) median flow for each month of the record and (ii) median of annual medians of monthly medians (Chowdhury et al., 2024). Three decades of discharge data (1990-2019) of the Hardinge Bridge station, obtained from BWDB, were analyzed by IHA software for pre-impact (1990-2004) and post-impact (2005-2019) time intervals. The median monthly flows were directly used for the calculation of EFR for the uncontrolled Ganges-Padma River, as was done for the Surma, Kushiyara, and Teesta Rivers (Bari et al., 2013).

In IHA software, Range of Variability Approach (RVA) targets are established at ±1 standard deviation, based on the assumption that variations within this range have a limited ecological effect (Mullick et al., 2010). Pre-impact data are classified into low (≤33rd percentile), medium (34th-67th percentile), and high (>67th percentile) categories (Conservancy, 2009). Positive hydrologic alteration (HA) values represent increases in frequency, whereas negative values represent decreases. The Range of Variability Approach (RVA) was applied to interpret the IHA indicator results. In this method, pre-impact data for each of the 33 hydrologic parameters are divided into three categories based on percentile values (non-parametric) or standard deviations from the mean (parametric) (Richter et al., 1998). Finally, a Hydrologic Alteration (HA) factor is calculated for each of the three categories as:

HA (%) = (Observed frequency – Expected frequency) / Expected frequency

3. RESULTS AND DISCUSSIONS

Data analysis for both periods exhibits extensive hydrological variability as described by Tennant. Mean monthly values are shown in Table 2. Table 3 shows the percentage of Mean annual flows in different conditions according to Tennant. The mean annual flow (MAF) decreased from 10,680 m^3/s (pre-impact) to 9,138 m^3/s (post-impact) following the construction of the Lalon Shah Bridge.

April is identified as the driest month, and November to May as the dry season, and June to October as the wet season. According to Tennant classification, March and April flows are at a poor condition level (10% of

MAF), and February and May are just at that level. Flow in June is about 30% of MAF, showing moderate conditions. From January to May, the river ecosystem is highly stressed, while December flows are below the good condition level (40% of MAF). Conversely, July through October flows, especially August and September, are above average levels, which indicates flood conditions.

Table 2: Mean Monthly Flows at Hardinge Bridge point of Ganges-Padma River (m^3/s)

Months	**Pre-Impact (1990-2004)**	**Post-Impact (2005-2019)**
Jan	2362	1682
Feb	1199	1328
Mar	746	1098
Apr	740	1039
May	1297	1345
Jun	3726	3618
Jul	20365	18272
Aug	34488	28970
Sep	35475	26602
Oct	17394	16278
Nov	6309	6290
Dec	4069	3138

Table 3: Percentage of MAF

Habitat quality	**Percentage of MAF (%)**	**Flow Requirement (m^3/s)**	
		Pre-Impact (1990-2004)	Post-Impact (2005-2019)
Flushing flow	200	21361	18277
Optimum range	60-100	6408-10680	5483-9138
Outstanding	60 at HFS, 40 at LFS	6408 at HFS, 4272 at LFS	5483 at HFS, 3655 at LFS
Excellent	50 at HFS, 30 at LFS	5340 at HFS, 3204 at LFS	4569 at HFS, 2742 at LFS
Good	40 at HFS, 20 at LFS	4272 at HFS, 2136 at LFS	3655 at HFS, 1828 at LFS
Fair	30 at HFS, 10 at LFS	3204 at HFS, 1068 at LFS	2742 at HFS, 914 at LFS
Poor	10	1068	914
Severe degradation	<10	<1068	<914

Figure 2 puts together the mean monthly pre-impact flows (1990–2004) and the Estimated Environmental Flow Requirement (EFR) from the Mean Annual Flow (MAF) approach at Hardinge Bridge. Natural monsoon flows (July to October) are over 35,000 Cumec, while the prescribed e-flow is 21,000 Cumec, exhibiting a huge reduction. It's exactly the reverse during the dry period (January to May, November to December), with the e-flow matching or being slightly higher than natural flows to maintain minimum ecological needs. Figure 3 compares the post-impact flow record (2005–2019) with the MAF-based EFR. During the dry months, the record flows are only marginally above the EFR, while monsoon flows (from July to October) significantly exceed it, peaking in August and September. This suggests adequate ecological flows in the wet season but potential stress during the dry season.

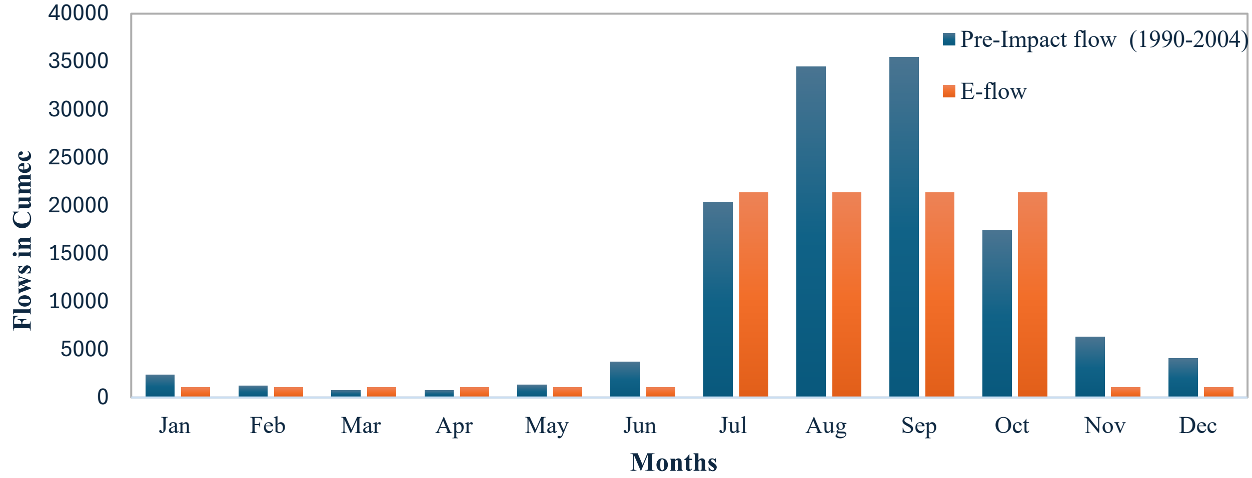

Figure 2: Comparison of Mean Monthly Flows with EFR in the MAF method at Hardinge Bridge station (1990-2004)

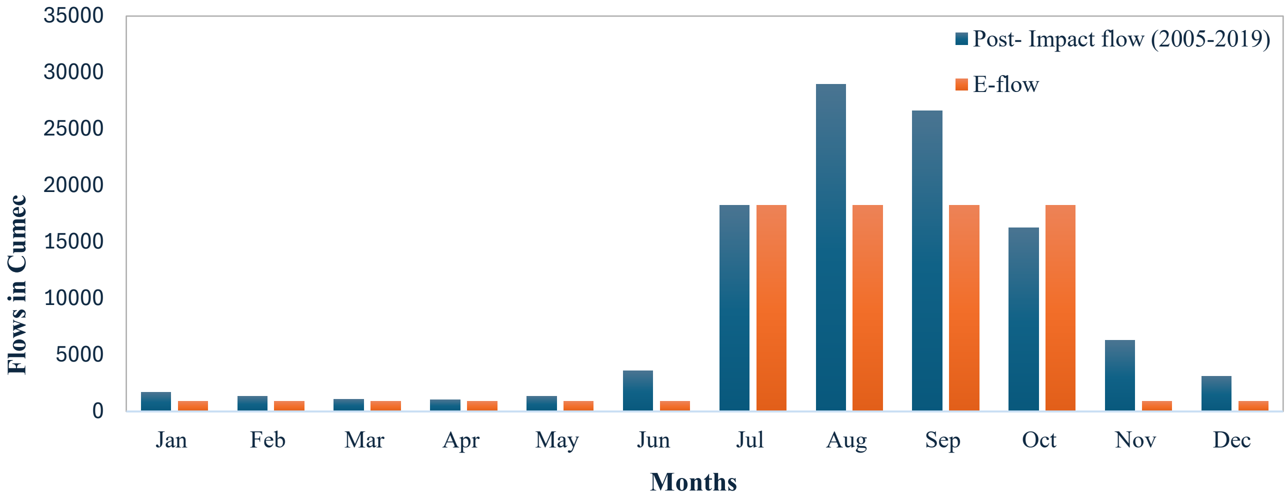

Figure 3: Comparison of Mean Monthly Flows with EFR in the MAF method at Hardinge Bridge station (2005-2019)

Table 4 shows FDC values for different seasons of flow. EFRs were derived from 90% exceedance in the low flow season (LFS) and 50% exceedance in the intermediate (IFS) and high flow seasons (HFS). The lowest flow at Hardinge Bridge was in March during both the periods 426.5 Cumec (Pre-impact) and 690 Cumec (Post-impact), and the highest flows were in September (33,600 Cumec) and August (26,734 Cumec), respectively. December to March are LFS, June to September HFS, and April to May, with October to November as IFS, according to FDC analysis. Flow increases from June, peaks during monsoon (August–September), and falls drastically after October to a low for the second time in March.

Table 4: Percentile flow of monthly FDC (90% for LFS and 50% for IFS and HFS) at Hardinge Bridge Point of Ganges-Padma River.

Months	**Seasons**	**E-flow (m^3/s)**	
		Pre-Impact (1990-2004)	**Post-Impact (2005-2019)**
April	IFS	787.5	935
May		1227.7	1209.5
June	HFS	3255	2776
July		16802.3	13115
August		32700	26734
September		33600	25704
October	IFS	14600	14056
November		5713	5749.5
December	LFS	1985	2131
January		1180	1156
February		659	950
March		426.5	690

Figure 4 shows the Flow Duration Curves (FDCs) of the Ganges-Padma River at Hardinge Bridge for 1990-2004 and 2005-2019. The former half depicts consistently higher flows, especially in the mid- to low-flow range (20–80% exceedance), indicating reduced discharge in recent years due to upstream regulation and climatic variability. Peak flows (<10% exceedance) are similar for both periods, but very low flows (>80%) have become much lower in the post-impact period as an indication of reduced baseflow. Overall, FDC comparison reveals a clear downward shift in median and low flows, indicating altered hydrological conditions and the need for sustainable environmental flow management.

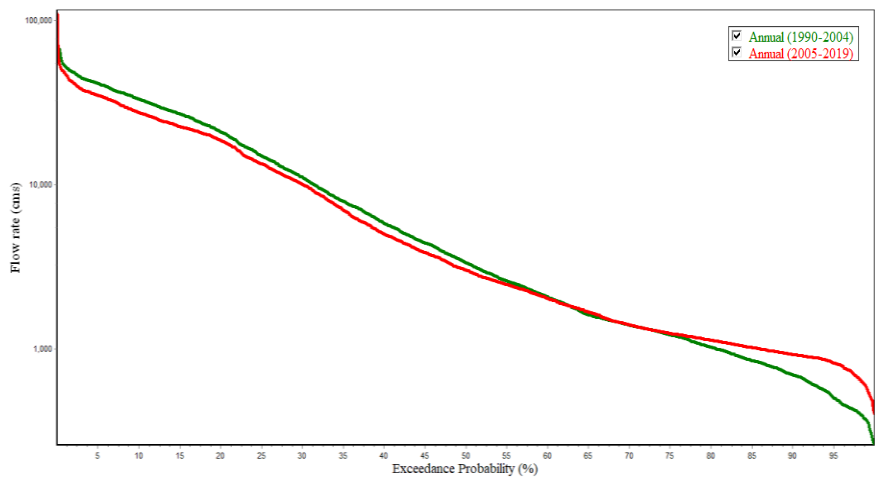

Figure 4: Annual Flow Duration Curve at Hardinge Bridge station for two different periods

Figure 5 compares mean monthly flows with Environmental Flow Requirements (EFR) estimated using the FDC method for (1990–2004) at Hardinge Bridge. Flows peak during July to September (>35,000 Cumec), where pre-impact and 50th percentile flows align, indicating adequate ecological conditions. In the pre- and post-monsoon months (April to June and October to December), flows remain slightly above EFR thresholds, while during the dry season (January to March), flows drop below 1,000 Cumec, nearing the 90th percentile and indicating ecological stress. Overall, monsoon flows meet ecological needs, but the dry season poses significant challenges for ecosystem sustainability.

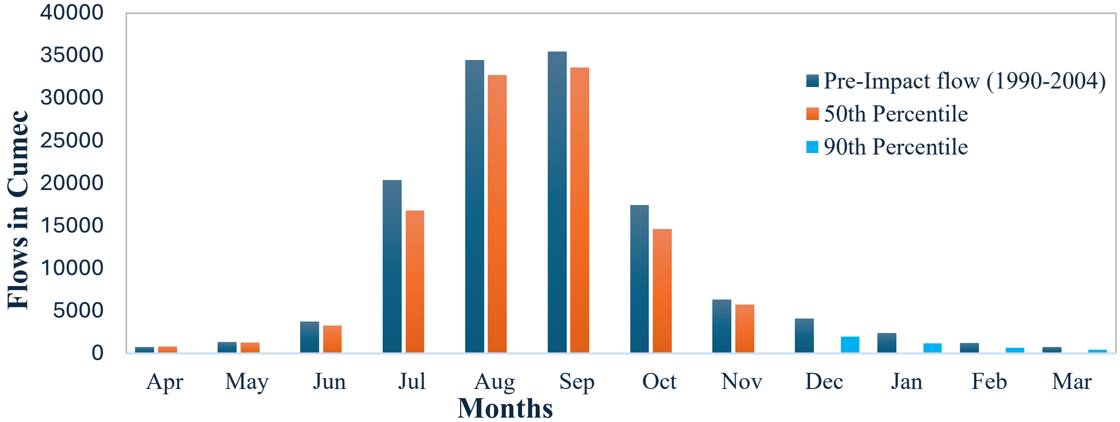

Figure 5: Comparison of Mean Monthly Flows with EFR in FDC method at Hardinge Bridge station (1990-2004)

Figure 6 compares mean monthly flows with Environmental Flow Requirements (EFR) using the FDC method for the post-impact period (2005–2019) at Hardinge Bridge. Peak flows during August–September (~29,000 Cumec) are notably lower than pre-impact levels (>35,000 Cumec). During the monsoon (July to October), flows align with the 50th percentile, indicating adequate ecological conditions despite reduced magnitudes. However, in the dry season (January to March), flows drop below 1,000 Cumec, nearing the 90th percentile threshold and reflecting severe ecological stress. Overall, while monsoon flows meet EFRs, reduced dry-season flows increase ecosystem vulnerability.

Figure 7 compares mean monthly flows at Hardinge Bridge (1990–2004) under pre-impact conditions with estimated Environmental Flows (E-flows) using the CY method. Peak flows occur during July to September, exceeding 30,000 Cumec, where E-flows closely match natural flows, reflecting the natural flood regime. In the dry season (November to March), E-flows are lower than pre-impact flows, indicating reduced water availability, while in transitional months (April to June), slightly higher E-flows suggest adjustments to sustain minimum ecological requirements

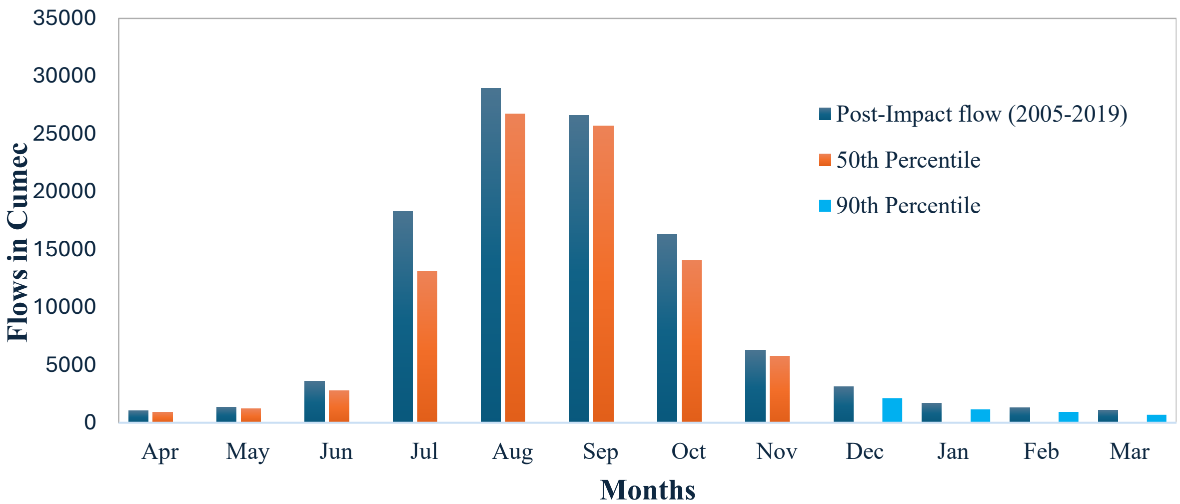

Figure 6: Comparison of Mean Monthly Flows with EFR in the FDC method at Hardinge Bridge station (2005-2019)

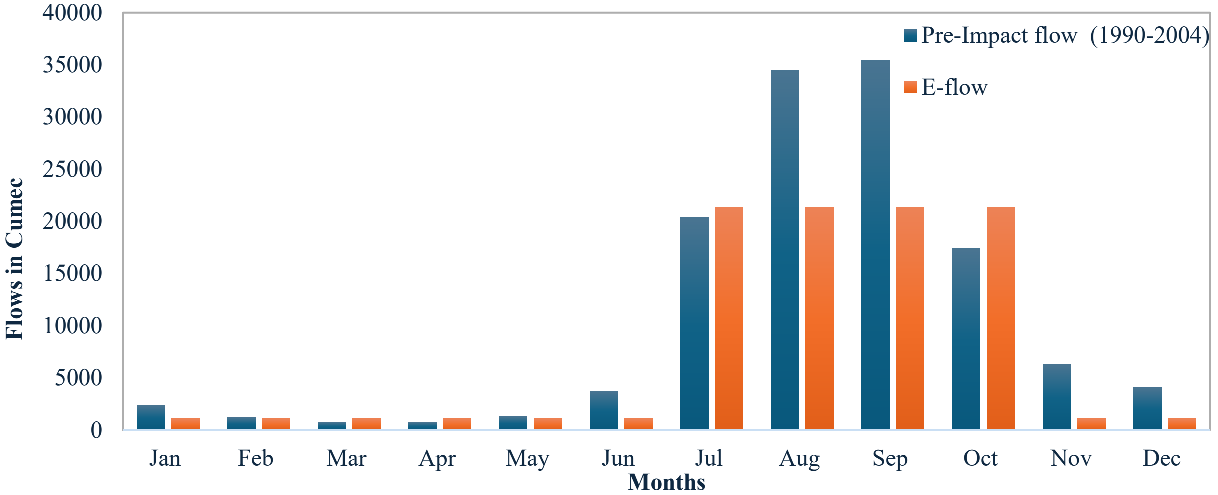

Figure 7: Comparison of Mean Monthly Flows with EFR in the CY method at Hardinge Bridge Station (1990-2004)

Figure 8 compares mean monthly flows at Hardinge Bridge (2005–2019) with Environmental Flows (E-flows) estimated using the CY method. Peak flows occur from July to September (25,000–30,000 Cumec), with close alignment between post-impact and E-flows in August–September, though July shows higher post-impact flows. During the dry season (December to March), both flows remain very low, with E-flows slightly higher to maintain ecological balance. Transitional months (April to June, October, and November) show moderate differences, with post-impact flows exceeding E-flows in wetter months and converging during low-flow periods.

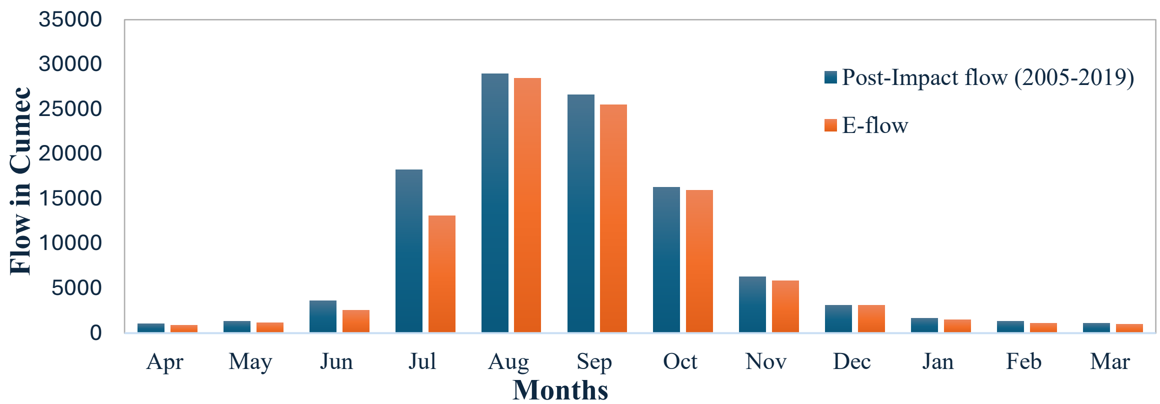

Figure 8: Comparison of Mean Monthly Flows with EFR in CY method at Hardinge Bridge station (2005-2019)

Figure 9 illustrates the hydrologic alteration categories of the Ganges-Padma River at Hardinge Bridge based on RVA targets. High positive RVA values occur from March to May and in November, while high negative values dominate from June to October and December to February. Low positive alterations appear in July–September and January, and low negative alterations in February to April, October, and December. Minimum flow indicators (1-, 3-, 7-, 30-, 90-day) increase with high RVA categories, whereas maximum flows increase with low RVA categories. The base flow index rises under high RVA and declines under low RVA conditions. Hydrologic Alteration Factor (HAF) values between ±0.2 to ±0.5 indicate moderate alteration, while values beyond ±0.5 represent high alteration levels.

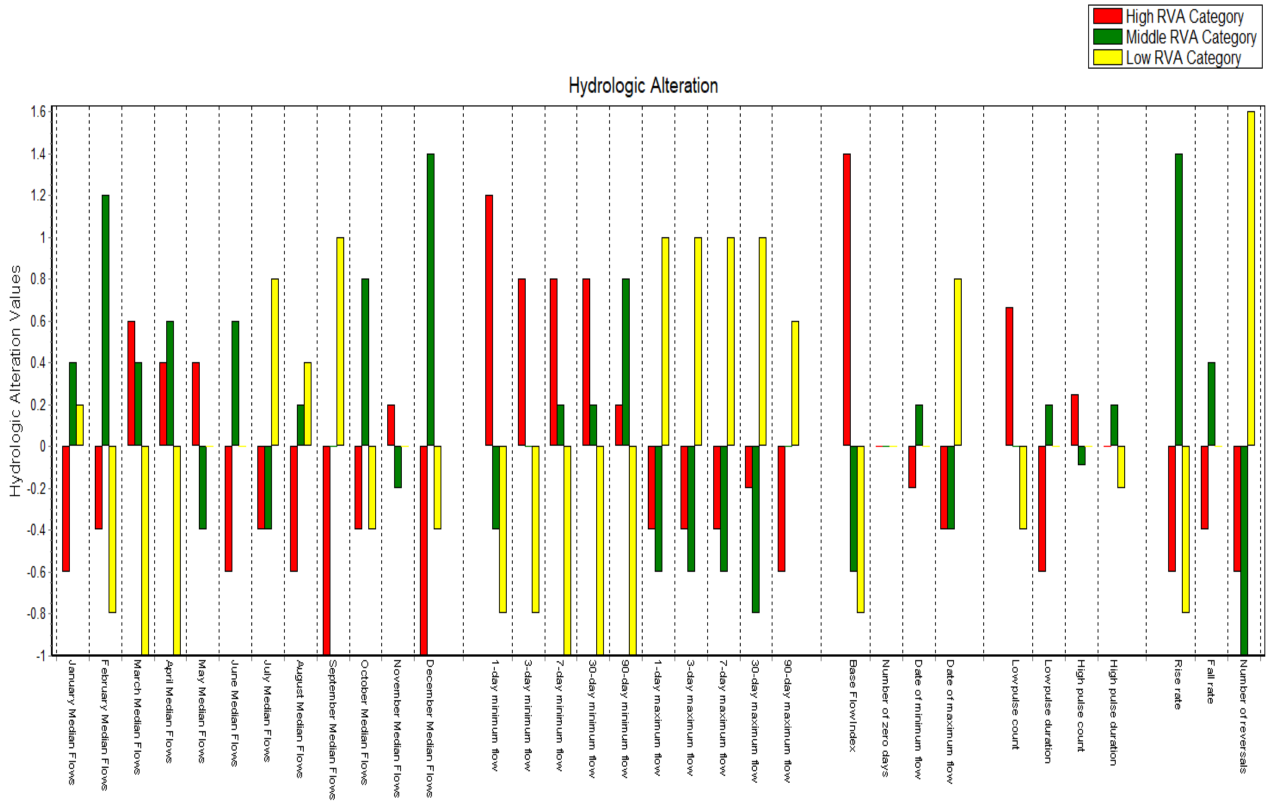

Figure 9: Category of Hydrologic alteration with RVA target for Hardinge Bridge station

The Monthly RVA Boundaries for Hardinge Bridge, comparing pre-impact (1990–2004) and post-impact (2005–2019) periods, shows a notable reduction in monthly flows during the high-flow season (June–October), with post-impact flows consistently lower than pre-impact levels. Peak flow decreased from 35,020 Cumec in September (pre-impact) to 28,440 Cumec in August (post-impact). In contrast, flow variations during the low-flow (December–March) and intermediate-flow (April–May, October–November) seasons remain relatively minor. Figure 10 illustrates the pre-impact flow characteristics of the Ganges-Padma River at Hardinge Bridge relative to RVA boundaries. A clear monsoonal pattern is evident, with low flows in April to May, rising in June, and peaking in July to September. The highest median flow (~35,000 Cumec) occurs in September, generally within the RVA high boundary but occasionally exceeding it, indicating hydrological variability. Post-monsoon flows decline from October and remain low through December to March, reflecting a natural flood pulse essential for sediment transport, floodplain inundation, and ecosystem balance. Figure 11 shows the post-impact flow regime at Hardinge Bridge, revealing significant hydrological alterations. While the seasonal pattern persists, peak flows in July to September decline below the RVA low boundary, reducing high-flow variability essential for floodplain connectivity and ecosystem health. Dry-season flows (November to March) remain near the RVA low boundary, indicating a flattened hydrograph. Overall, reduced amplitude between wet- and dry-season flows reflects diminished seasonal variability, likely due to upstream interventions and flow regulation.

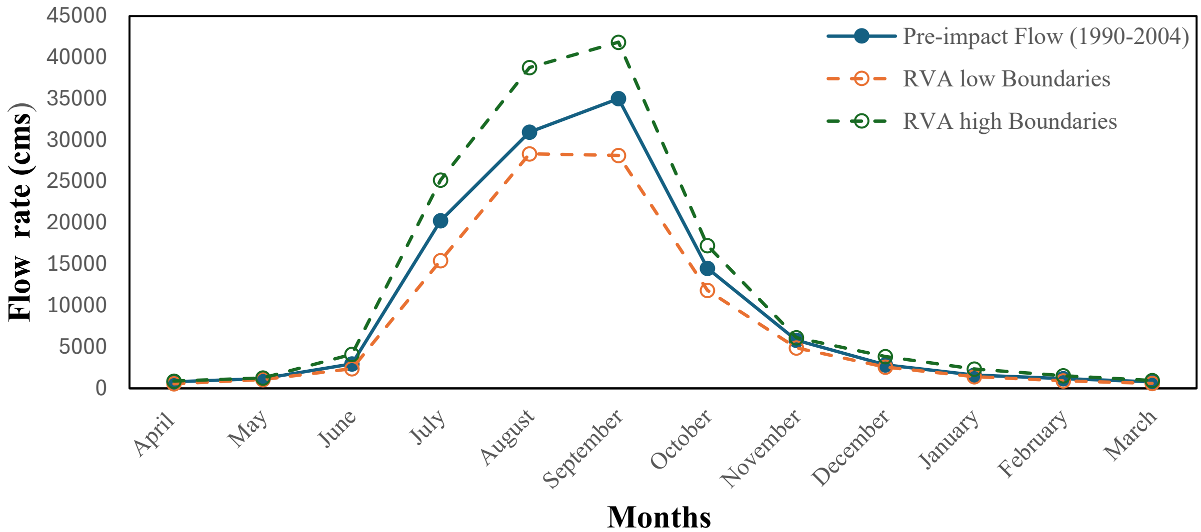

Figure 10: Flow Pattern with RVA Boundaries at Hardinge Bridge Station in Pre-Impact Periods (1990-2004)

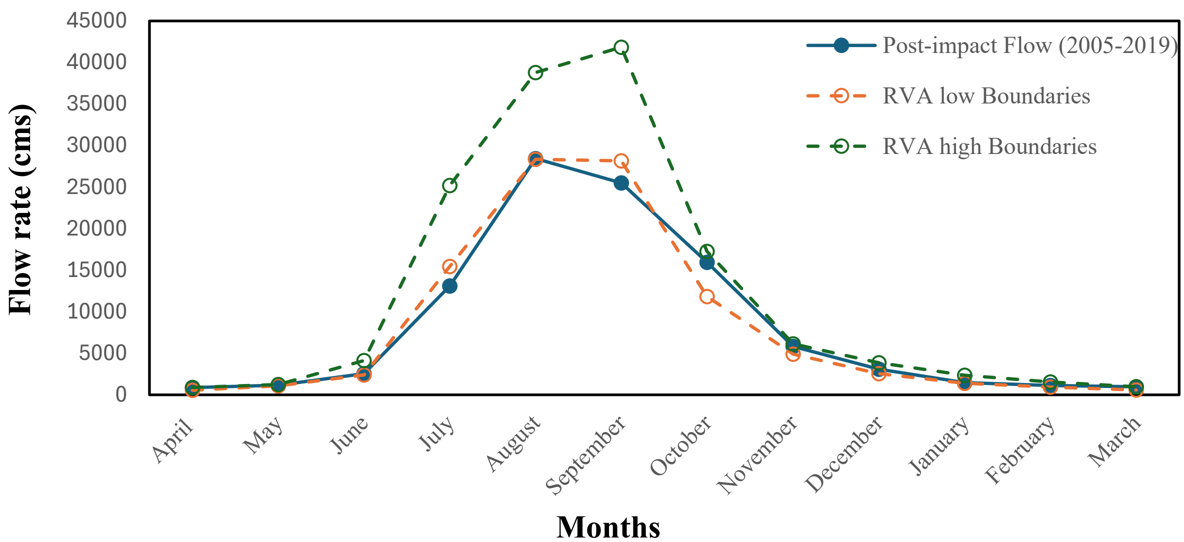

Figure 11: Flow Pattern with RVA Boundaries at Hardinge Bridge Station in Post-Impact Periods (2005-2019)

Table 5 compares pre-impact (1990–2004) Environmental Flow (E-flow) requirements with available flows using MAF, FDC, Constant Yield, and RVA methods. Dry-season flows (February to April, November to December, ≈740 to 1,200 m^3/s) often fall below or barely meet E-flow requirements, indicating ecological stress. Monsoon flows (July to September, ≈20,000 to 35,000 m^3/s) exceed all E-flow thresholds, supporting habitat variability. Transitional months (May, June, October) show moderate flows near requirements. RVA consistently suggests higher thresholds to preserve natural flow variability and ecosystem sustainability. Table 6 compares post-impact (2005–2019) Environmental Flow (E-flow) requirements downstream of Lalon Shah Bridge using MAF, FDC, Constant Yield, and RVA methods. Dry-season flows (February to May, ≈1,000 to 1,300 m^3/s) often fall short of RVA and Constant Yield thresholds, indicating ecological stress.

Monsoon flows (July to September, ≈18,000 to 29,000 m³/s) exceed all E-flow requirements, supporting ecosystem health. The transitional months exhibit moderate flows with variable compliance across methods. FDC and Constant Yield provide similar values, MAF provides limited monthly estimates, and RVA suggests higher thresholds to maintain flow variability. Overall, high monsoon flows are sufficient, but dry-season deficits highlight the need for management interventions.

Table 5: Comparison of Computed E-flow Requirements Pre-Impact Periods (1990-2004)

Month	**Available Flows**	**Hydrologic Approach**			
		MAF Method	Flow Duration Curve	Constant Yield	RVA
Jan	2362	-	1180	1623	1412-2340
Feb	1199	1068	659	1165	918.6-1538
Mar	746	1068	426.5	785	591.6-959
Apr	740	1068	787.5	788	551.1-887
May	1297	-	1227.7	1200	1072-1256
Jun	3726	-	3255	2968	2379-4120
Jul	20365	-	16802.3	20270	15450-25200
Aug	34488	21361	32700	30990	28350-38780
Sep	35475	21361	33600	35020	28170-41850
Oct	17394	-	14600	14500	11840-17270
Nov	6309	-	5713	5815	4891-6113
Dec	4069	-	1985	2830	2564-3867

Table 6: Comparison of Computed E-flow Requirements Post-Impact Periods (2005-2019)

Month	**Available Flows**	**Hydrologic Approach**			
		MAF Method	Flow Duration Curve	Constant Yield	RVA
Jan	1682	-	1156	1473	1412-2340
Feb	1328	914	950	1119	918.6-1538
Mar	1098	914	690	967.5	591.6-959
Apr	1039	914	935	871	551.1-887
May	1345	-	1209.5	1156	1072-1256
Jun	3618	-	2776	2535	2379-4120
Jul	18272	-	13115	13120	15450-25200
Aug	28970	18277	26734	28440	28350-38780
Sep	26602	18277	25704	25500	28170-41850
Oct	16278	-	14056	15950	11840-17270
Nov	6290	-	5749.5	5837	4891-6113
Dec	3138	-	2131	3103	2564-3867

4. CONCLUSION

The environmental flow requirement (EFR) of the Ganges-Padma River reflects its hydrological, morphological, and ecological characteristics, along with cultural dependencies. This study evaluates EFR using discharge data at Hardinge Bridge for two periods: Pre-impact (1990–2004) and Post-impact (2005–2019) to assess variations in flow regimes through multiple hydraulic methods: Mean Annual Flow (MAF), Flow Duration Curve (FDC), Constant Yield (CY), and Range of Variability Approach (RVA). For the Pre-impact period, the minimum E-flow values were 1068 m³/s (MAF), 426.5 m³/s (FDC), and 785 m³/s (CY), while for the Post-impact period, they were 914 m³/s (MAF), 690 m³/s (FDC), and 871 m³/s (CY). The RVA-based minimum range remained between 551.1 to 887 m³/s for both periods. Seasonal analysis shows that

April consistently represents the lowest flow month, whereas the highest flow shifts from September (Pre-impact) to August (Post-impact). Results indicate substantial seasonal variability, with significant flow increases in July and reductions in October across all methods. Overall, the study demonstrates that no single method adequately captures the full spectrum of environmental flow needs. Therefore, integrated and adaptive assessment approaches are necessary to address ecological sustainability and management objectives. The findings provide valuable insights for water managers in developing informed decisions on flow regulation and environmental risk management in the Ganges-Padma River system.

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