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Environmental flow assessment of Saryu (Himalayan River) through various integrated hydrological approaches

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Abstract
A large number of people depend on Himalayan rivers for a wide range of functions, including biodiversity conservation, irrigation, and domestic water supply. For example, approximately 361,259 people (as per the Census of 2023) rely on the Saryu River in the region of Uttarakhand, India for their short- and long-term needs. To support these functions and ensure their sustainability, it is essential that rivers and streams remain healthy and undergo continuous monitoring and assessment. Therefore, the present study focuses on conducting an Environmental Flow Assessment (EFA) of the Saryu River, a significant Himalayan river located in the Bageshwar district of Uttarakhand. EFA is performed using four different hydrological approaches, and the corresponding results are tabulated to assess environmental benefits. The differences and complementarities of various methods used for environmental flow assessment are also investigated, compared, and discussed. The minimum flow required in the river, i.e., the environmental flow, is evaluated through four desktop methods using data collected at four different gated sites along the Saryu River. Based on the results, it is observed that hydrology-based methods of EFA represent a necessary first step in planning environmental allocations and can be particularly helpful in developing countries. Furthermore, the complementary features of existing environmental flow assessment techniques can prove very useful in arriving at justified estimates of environmental flows, even in conditions with limited basin-specific eco-hydrological knowledge. Finally, a suitable environmental flow schedule for various gauged stations of the river, i.e., the release schedule from the dams, is suggested to mitigate the negative impacts on the riverine ecosystem.

Keywords: *Environmental flow Assessment, Annual Average Flow, Hydrological Approaches, Flow regime.*

Introduction

Rivers are the lifeblood of biological and socioeconomic systems, although making up less than 1% of the world's surface water (Mehmood et al., 2024). They are disproportionately important in maintaining riparian habitats, wetlands, and flood-plains. Because of the inherent usefulness of fresh-water systems for drinking, agriculture, navigation, cultural traditions, and ecological stability, civilizations have historically thrived near riverbanks (Abdi and Yasi, 2015; Mehmood et., 2024). Globally, extensive water resource development projects, including dams, barrages, weirs, canals, and reservoirs, have been put into place to meet the increasing demand for water. Essential services including flood control, irrigation, hydropower production, and municipal water supply are supported by these infrastructures (Baubekova et al., 2024). Nonetheless, the normal flow patterns of rivers have been significantly changed by these interventions. Anthropogenic activities have resulted in the regulation or fragmentation of more than 50% of the world's major rivers, which has decreased aquatic biodiversity, changed sediment movement, decreased ecological connectedness, and degraded habitat (Postel and Richter, 2003; Baubekova et al., 2024). River flows have been significantly decreased in several areas, and in severe situations, they have completely stopped during dry seasons (Postel and

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Richter, 2003; Vörösmarty et al., 2010). In addition to having an effect on aquatic ecosystems, these disturbances have an effect on human livelihoods that depend on riverine services, including agriculture, fishing, water quality control, and cultural customs (Nilsson et al., 2005). According to Hydrological cycle, the water around us is absorbed to land/soil and as rivers flow and reach the sea, the self-purification capacity of rivers and streams degrade the organic content. But at present the rate of pollution of aquatic resources is far beyond the carrying capacity of lakes and streams (Tharme, 2003). In the past, water infrastructure projects were frequently carried out without giving ecological sustainability or downstream effects any thought. Reduced groundwater recharge, fish habitat loss, decreased availability of resources such as fuel wood and fodder, disturbance of religious and recreational activities, and biodiversity loss in floodplain and riparian zones were all consequences of this carelessness (Nilsson et al,., 2005; ABDI and Yasi, 2015). These unfavourable results highlight how important it is to include Environmental Flow (EF) factors in water resource management. The quantity, time, and quality of water flows necessary to support aquatic ecosystems and the human communities that depend on them are referred to as environmental flows, environmental water requirements, or environmental water demands (Acreman and Dumbar, 2004). By preserving vital flow patterns required for species survival, sediment movement, water quality, and connection among various river components, EF protects the biological integrity of rivers (Nilsson et al., 2005; Dyson et al., 2008). Incorporating EF into river basin planning and water policy promotes socioeconomic growth and poverty reduction in addition to ecological health (Nilsson et al., 2005; Sri Lakshmi et al., 2016). Environ-mental Flow Assessment (EFA) approaches have changed dramatically over the past six decades to address ecological sustainability while supporting human water usage needs. More than 200 EF techni-ques have been developed worldwide and can be broadly divided into four categories: Holistic Approaches, Habitat Simulation Models, Hydraulic Rating Techniques, and Hydrological Index Techniques (Postel and Richter, 2003). Because of their ease of use, affordability, and appropriateness for early stages of planning, hydrological techniques—which are based on historical streamflow data—are among the most often used (Tennant, 1976). These techniques prescribe flow regimes required to preserve river ecosystems using indices including average annual flow, minimum flow, and monthly data. Hydraulic and habitat simulation methods, on the other hand, measure the impact of discharge variations on the availability of physical habitat for indicator species. In order to forecast habitat appropriateness, these models frequently need comprehensive field data on depth, velocity, and substrate at particular cross-sections (Tennant, 1976; Postel and Richter, 2003). Integrating hydrology, biology, geomorphology, water quality, and socioeconomic factors, holistic approaches are multidisciplinary. These methods are more appropriate for environmental impact assessments and river restoration planning, and they offer a more thorough understanding of the ecological reactions to changed flow regimes (Hughes and Münster, 2000; Postel and Richter, 2003). Despite the benefits, hydrological approaches are frequently criticized for ignoring flow variability that is essential to ecosystem functioning and oversimplifying intricate ecological processes (Postel and Richter, 2003; Vörösmarty et al., 2010). This study examines the suitability of many desktop hydrological techniques in Environmental Flow Assessment for the Saryu River, a well-known Himalayan river that passes through the Bageshwar district of Uttarakhand, in order to overcome these constraints. The Tennant Method, Hughes and Münster Method, 7Q10 Method, Modified Tennant Method, and a Seasonal Flow Allocation Method are among the techniques used (Tharme, 2003: Acreman and Dumbar, 2004). Data gathered from four gated locations along the river are used to compare the ecological implications of each strategy and assess its outputs. This study intends to inform integrated river basin management techniques that strike a balance between ecological needs and developmental goals by examining the similarities and differences between these approaches.

Methodology

Study area

Saryu, a Himalayan River, is a tributary of river Mahakali which in turn is a tributary of river Ganga. The Saryu River flows through the Bageshwar and Pithoragarh districts of Uttarakhand state in India. This river originates from Kautela Dhar range of the Himalayas at an elevation of 4114 meters above mean sea level. The total length of this river from its origin up to its confluence with Eastern Ramganga at Rameshwar is approximately 126 km. The district of Bageshwar is located in the northern parts of the province of Uttarakhand State in India. It encompasses an area of 2310 sq. km and is

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situated between 29° 42' 40'' to 30° 15' 56'' Latitude and 79° 23' to 80° 90' E Longitude. The area of study that comprises the Saryu River Basin is shown in Figure 1 and the land use pattern of the entire catchment of Bageshwar district is presented in Table 1 respectively.

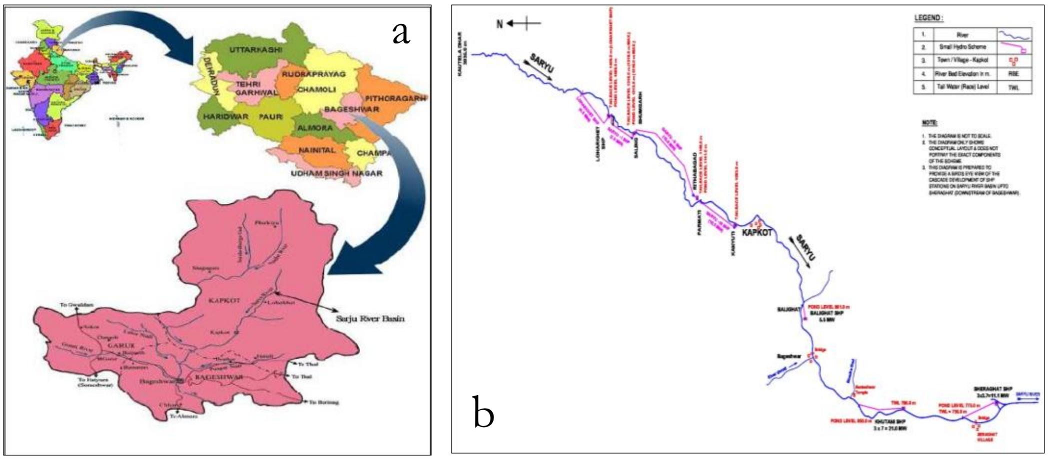

Figura 1
(a) *Saryu River basin in District Bageshwar in Uttarakhand*
(b) *Small hydro projects built on Saryu River*

Table 1
Land Use Pattern in the Catchment.

Class	Area Sq. Km	Percentage %
Builtup/Rural	0.24	0.01
Agricultural/ Crop Land	138.73	6.17
Forest/Evergreen/Semi Evergreen	1221.8	54.3
Forest, Scrub forest	71.77	3.19
Barren/Unculturable/Wasteland	15.61	0.69
wetlands/Water bodies	18.96	0.84
Builtpu/Mining	1.38	0.06
Agricuture/Fallow	205.16	9.12
Forests/Decidious	100.5	4.47
Grass Gazing	179.45	7.98
Barren/ Unculturable/Wasteland	67.03	2.98
Snow/Glacier	229.38	10.19
Total	2250	100

Hydrological flow data of 25 years is collected for Khutani site; a Site identified for locating a small hydropower station from the discharge data gauged at the Bageshwar site of Central Water Commission (CWC). This data is taken as the most representative flow. The flow data for other sites is obtained by proportioning the available flow data of the Khutani site using the catchment areas of the respective sites. Figure 2 shows the 10 daily average flow of river Saryu using 25 years discharge data.

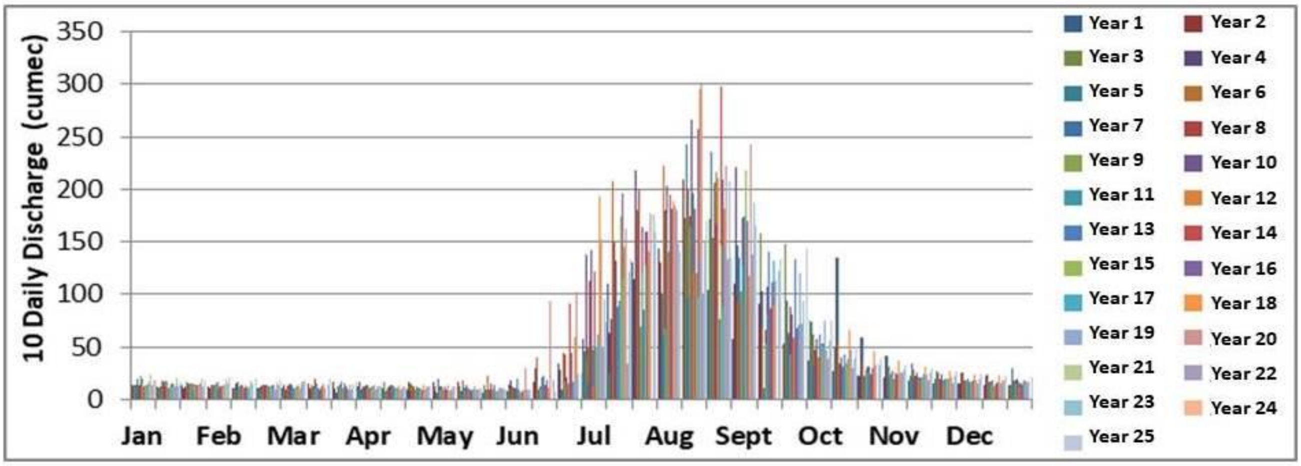

Figure 2. *10 daily average flow of the river Saryu using 25 years discharges data*

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EFA Methods

The environmental flow for the Saryu River has been assessed using six hydrologic methods. The workflow of this study has been shown in Figure 3. First of all, the entire river reach is divided into four gauged sites and the features of these sites are given in Table 2. The longitudinal section of the river basin from Loharkhet weir site to Seraghat and the details of different hydro-project are shown in Fig. 1(b). Four reaches considered for the estimation of environmental flows are:

- from Origin to Loharkhet Weir Site;
- from Loharkhet Balighat Weir Site;
- from Balighat Weir Site to Khutani Weir Site;
- from Khutani to Seraghat.

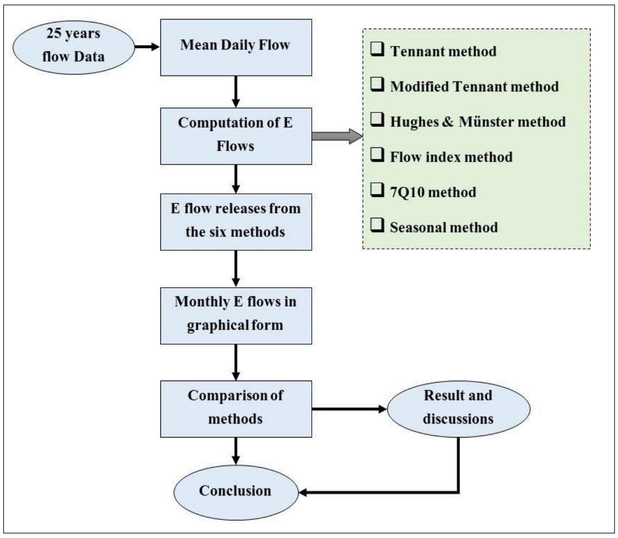

Figure 3. *Work flow chart showing the steps taken and e-flow methodology applied*

Table 2. *Salient features of different sites corresponding to Sarju River basin*

Salient Features	Name of the Site			
	Loharkhet	Balighat	Khutani	Seraghat
District	Bageshwar	Bageshwar	Pithoragarh	Pithoragarh
Village	Loharkhet	Balighat	Khutani	Seraghat
Geographical coordinates	79°57'30"E 30°02'00"N	79°51'07"E 29°52'78"N	79°49'25"E 29°47'03"N	79°53'42"E 29°42'49"N
River bed Elevation (MSL) m	1708	946	832	750
Total Catchment Area(sq.Km)	780	713.5	1402	1461

Results and Discussion

Tennant Method (also known as Montana method)

The Tennant method used in this study was originally called the "Montana method" by Tennant as it was created using data from the Montana region (Tennant 1975), and was developed through field observations and measurements. The Tennant Method simply focuses on streamflow requirements which are based on the observation of aquatic-habitat conditions in the river. These aquatic-habitat conditions are similar in rivers carrying the same proportion of the Average Annual flow (AAF) or the Mean Annual Flow (MAF). This method establishes a streamflow requirement based on a predetermined percentage of MAF. To account for seasonal variability, Tennant (1976) established different streamflow requirements for monsoon and non-monsoon seasons as given in Table 3. In the present analysis, 10-daily discharge data for the period of 25 years has been used and the estimated environmental flow allocation for different sites corresponding to Saryu River is given in Table 4 below.

Narrative description of general condition of flow	% MAF (April–Sept) for India: monsoon season (June–Sept)	% MAF (Oct–March) for India: non-monsoon season (Oct–May)
Flushing or maximum	200%	200%
Optimum range	60 – 100%	60 – 100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe Degradation	<10%	<10%

Table 3 *Relations between aquatic-habitat conditions and mean annual flow described by Tennant method*

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Table 4. *Recommended mean annual flow for different sites of river Saryu.*

Recommended flow regimes for Tennant method in different sites Saryu River (in cumec)								
Narrative description of flow for Aquatic-habitat	Recommended flow regime (% of MAF in cumec) October to March				Recommended flow regime (% of MAF in cumec) June to September			
	Loharkhet	Balighat	Khutani	Sheraghat	Loharkhet	Balighat	Khutani	Sheraghat
Flushing or maximum	1566	1678	2798	2910	1566	1678	2798	2910
Optimum range	470-783	503-839	839-1399	873-1455	470-783	503-839	839-1399	873-1455
Outstanding	470	503	839	873	386	420	700	727
Excellent	386	420	700	727	313	336	560	582
Good	313	336	560	582	157	168	280	291
Fair or Degrading	235	252	420	436	78	84	140	145
Poor or Minimum	78	84	140	145	78	84	140	145
Severe Degradation	<78	<84	<140	<145	<78	<84	<140	<145

Modified Tennant Method

Looking into the importance of the flow variability in the river system, the constant allowance for EF based on MAF will be not adequate for Indian River systems due their large flow variations during the monsoon and non-monsoon periods. In the Saryu River system also, there are rivers which have great variation in the flow during low flow and high flow seasons (refer Fig. 2). Hence, the above method is not properly fitted as we have calculated the allowance for EF taking the MAF at different sites. Therefore, a modification in the methodology is necessary, in which the allowable estimated EFs should be temporally distributed according to the temporal variation of stream flows. This modified method is called as the "Modified Tennant Method". Here, we consider the temporal variation of river flows and thus, the required EFs will also be temporarily distributed as required. In this analysis, 10-daily discharge data for the period of 25 years has been used. The first step of this methodology is to estimate the MAF of the respective reaches which is given in Table 5. This step also includes the allocation of EF volume with respect to different aquatic-habitat conditions. The second step in this modified Tennant method is important to derive the monthly flow distribution of MAF for the reach. This step is carried out by analyzing the monthly discharge data which is followed by the estimation of mean monthly flow. The estimated monthly distribution of MAF at different sites is presented in Table 6.

Table 5 *Estimated environmental flow allocation for the sites of Saryu River*

Estimated environmental flow allocation for the site of Saryu River using Tennant method					
Reach/ Site name	MAF (cumec)	Aquatic Habitat Condition			
		Poor 10% MAF	Fair 25% MAF	Fair 30% MAF	Good 40% MAF
Origin to Loharkhet Weir Site	805	80.5	201.25	241.5	322
Loharkhet Balighat Weir Site	867	86.7	216.75	260.1	346.8
Balighat to Khutani Weir Site	1448	144.8	362	434.4	579.2
Khutani to Seraghat	1503	150.3	375.75	450.9	601.2

Table 6 *Monthly % distribution of MAF for different sites/reaches by Modified Tannent Method considering the good acquatics habitat condition.*

Month	% Distribution	Loharkhet Good : 40% MAF		Balighat Good : 40%MAF		Khutani Good : 40%MAF		Seraghat Good : 40% MAF	
		MCM	Cumec	MCM	Cumec	MCM	Cumec	MCM	Cumec
JAN	2.64	8.5	3.28	9.16	3.53	15.29	5.9	15.87	6.12
FEB	2.15	7.45	2.88	7.45	2.88	12.45	4.8	12.93	4.99
MAR	2.27	7.88	3.04	7.88	3.04	13.16	5.08	13.66	5.27
APR	2.01	6.96	2.68	6.96	2.68	11.62	4.48	12.06	4.65
MAY	1.95	6.77	2.61	6.77	2.61	11.3	4.36	11.73	4.52
JUN	3.69	12.79	4.94	12.79	4.94	21.36	8.24	22.18	8.56
JUL	20.02	69.44	26.79	69.44	26.79	115.96	44.74	120.38	46.44
AUG	31	107.51	41.48	107.51	41.48	179.54	69.27	186.38	71.91
SEP	18.81	65.23	25.17	65.23	25.17	108.93	42.03	113.09	43.63
OCT	7.94	27.55	10.63	27.55	10.63	46	17.75	47.75	18.42
NOV	4.23	14.68	5.66	14.68	5.66	24.51	9.46	25.44	9.82
DEC	3.3	11.43	4.41	11.43	4.41	19.09	7.36	19.81	7.64
Total	100	346.19	133.56	346.85	133.81	579.2	223.46	601.28	231.98

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Hughes and Munster Method

This hydrology-based approximation of EF requirement is incorporated with portions of both base flow and quick flow that would contribute to maintaining freshwater ecosystem's productivity and dynamics. Further, to be consistent with the emerging terminology, these components are referred to as the environmental low-flow requirement (LFR) and the environmental high flow requirement (HFR). HFR is taken from Table 7 which is approximated by a set of. thresholds linked to the different LFR levels. LFR is believed to approximate the minimum requirement of water of the fish and other aquatic species throughout the year. HFR is important for river channel maintenance, as a stimulus for processes such as migration and spawning, for wetland flooding and recruitment of riparian vegetation. The sum of LFR and HFR forms the total EWR. Flow-duration curve is constructed and the value corresponding to Q_{90} is the LFR value. Flow-duration curve is plotted on a natural scale, with % time on X axis and discharge on Y axis, Figure 4. From this curve, the Q_{90} value is estimated and is used for further calculations.

Low Flow Req. (Q_{90})	HFR	Comment
If Q_{90} < 10% MAR	Then HFR = 20% MAR	Basins with very variable flow regimes. Most of the flow occurs as flood events during short wet season
If 10% MAR ≤ Q_{90} < 20% MAR	Then HFR = 15% MAR	-
If 20% MAR ≤ Q_{90} < 30% MAR	Then HFR = 7% MAR	-
If Q_{90} ≥ 30% MAR	Then HFR = 0	Very stable flow regimes. Flow is consistent throughout the year. Low-flow requirement is the primary component.

Table 7 *Estimation of environmental high-flow requirement (HFR)*

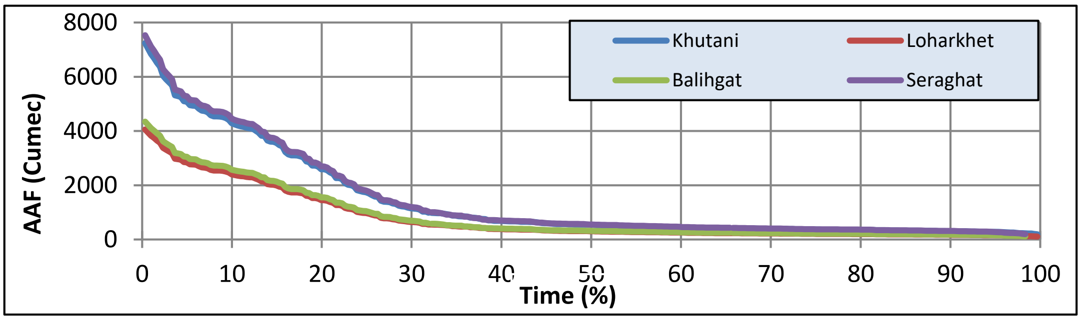

Figure 4 *Flow duration Curve for different sites of the Saryu River Basin.*

In this paper, the 90% dependable flow for the four sites is evaluated. Then the Mean Annual Runoff (MAR) is calculated, which is equal to the value that was previously found out (in Tennant Method) and it was MAR = AAF. . With the values of Q_{90} and MAR, The evaluated value of HFR for each site of the basin are shown in table 8. In this case, Q_{90} lies between 20% to 30% of MAR for each site and hence the value of HFR comes out to be 7% of MAR.

Site	Loharkhet	Balighat	Khutani	Seraghat
MAFor AAF (Cumec)	783	839	1399	1455
LFR = Q^{90} (Cumec)	171	184	306	381
HFR = 7% MAR (Cumec)	55	59	98	102
EVR (Cumec)	226	243	404	483

Table 8: *Calculated HFR for four sites of Saryu River*

Flow Index method

The flow Index Method enables to calculate the value of the minimum instream flow (MIF) that must be maintained downstream water diversion to maintain vital conditions of ecosystem functionality and quality. This method is based on Q_{355}, which is defined as the flow not exceeded more than 355 days per year and the mean values of the average, the natural flow is less than Q355 value only for 10 days in a year:

$$MIF = Q_{355}\, K_a\, K_b\, K_c \qquad [1]$$

where K_a = Corrective coefficient for different environmental sensitivities of the required river stretch

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(0.7 to 1.0), K_b = 1 (since 2005 when the rule was supposed full play) and Kc = Corrective coefficient to account for different level of protection due to the naturalistic value of the required area (1.0 to 1.5). When the slope of the FDC is flat and Q90 ≥ 30% of AAF, the flow in the river is very stable throughout the year, and the ecosystem is getting used to have a constant rate of flow in the river most of the time. This type of ecosystem is more sensitive to any change in river flow regime and therefore the value of K_a will be taken as 1. When the FDC slope is steep, say Q90 < 10% of AAF, the river flow is very unstable and present high extreme values (floods and droughts). Under this condition, the ecosystem is getting used to water scarcity during some periods of the year; therefore, this ecosystem is less sensitive to changes in flow regime, because the river naturally presents a wide variability in flow regime. In this case, the value of K_a can be taken as 0.7. If the recovery of natural conditions of the river flow must be done gradually, as other uses of water will be affected then the value of K_b could be 0.25. In the case of no significant abstractions, the value of K_b will be 1. The K_c factor increases the value of MIF, for protection of special conditions in the river ecosystem like naturalistic and tourism values, fisheries development and medicinal or religious issues. Q_{355} is correspond to the flow not having exceeded more than 355 days in a year. This value is determined from the flow-duration curve (Figure 4). Then the corrective coefficients K_a, K_b and K_c are determined. The concept of "environmental sensitivity" is linked with FDC. From FDC (Fig. 4) Q_{355} corresponds to 97.3%. It is determined from the FDC and is given in Table 9 for all the four sites of the river. The value of K_a is then estimated through the values of Average Annual Flow and Q_{90}. In this case the Q_{90} falls between 10% to 30% of Average Annual Flow. The Value of the corrective Coefficient K_a is 1 for Q90 ≥ 30% of AAF and is 0.7 for Q90 < 10% of AAF. K_a for different sites is calculated below, K_b is taken as 1, and K_c as 1.5 assuming that the naturalistic value of interest area is high and the desire level of protection is maximum.

Table 9. *Calculation of MIF by Index Flow Method*

Site	Mean AAF	Q_{90}	Condition	K_a	K_b	K_c	Q_{355}	MIF
Loharkhet	783	171	30% AAF > Q90 > 10%AAF	0.877	1	1.5	144	189.4
Balighat	839	184	30% AAF > Q90 > 10%AAF	0.879	1	1.5	154	203.1
Khutani	1399	306	30% AAF > Q90 > 10%AAF	0.878	1	1.5	257	338.5
Seraghat	1455	318	30% AAF > Q90 > 10%AAF	0.878	1	1.5	268	353

7Q10 Method

Simply, the 7Q10 means "seven-day, consecutive low flow with a ten-year return frequency; that would be expected to occur once in ten years," the lowest stream flow for seven consecutive days. This method is the second most widely used hydrological environmental flow method and has been used for various purposes in various countries like - Protection or regulation of water quality from wastewater discharges or waste load allocations, Habitat protection during drought conditions and Criteria for aquatic life. The 10 daily average discharge data is used for evaluating the E flows. The discharge data is converted into Mean Annual Flow for each year. This mean annual flow data ranked in descending order is used to determine the 10-year return period and the lowest flow is termed as environmental flow. The ten year return period is taken as the 'Year 1' flow (with closest return period to 10) The flow of the year 'Year 1' as the Environmental flow. But the formula intends to determine the lowest 10 daily average data. In this problem, if we assume that 70 % of this lowest monthly flow is minimum 10 daily flow, then it will be 0.7 * 304.43 = 213 cumec. Figure 5 shows the Environmental. Flow for differ-rent sites of Saryu River basin using 7Q10 Method for the 10 year return period (Year 1').

Seasonal Method

The proposed minimum flows are estimated for the two cases:

I. For cases in which 25 years flow data, monthly average flow data is considered.

II. For 90 % dependable year (year 1').

The identification and incorporation of these important flow characteristics will help to maintain the river's channel structure, diversity of the physical biotopes and processes. It is important when using this method to identify the four different and main seasons are along the year and can be outlined as follow

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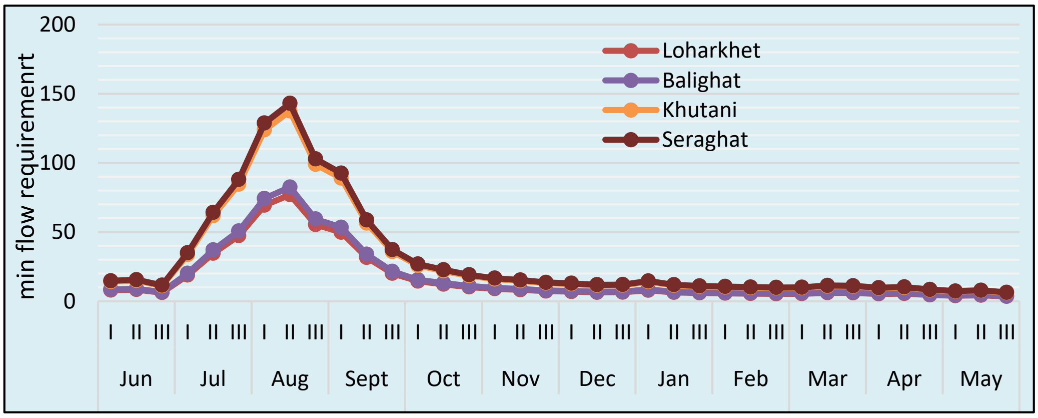

Figure 5 *Environmental Flow or different sites of Saryu River basin using 7Q10 Method for the 10 year return period*

Table 10: *Estimation of Min. flow for different sites of Saryu River basin Using Seasonal Method for Case 1 & case 2*

Season	Month	No. of days in a Block	Loharkhet Site		Balighat Site		Khutani Site		Sheraghat Site	
			Min flow (cumec)							
			CASE 1	CASE 2	CASE 1	CASE 2	CASE 1	CASE 2	CASE 1	CASE 2
I	Jun	10	1.93	1.42	2.07	1.53	3.45	2.54	3.59	2.65
		10	3.25	1.4	3.48	1.5	5.8	2.5	6.04	2.6
		10	5.18	5.81	5.55	6.23	9.25	10.38	9.62	10.8
	Jul	10	12.07	9.55	12.93	10.24	21.56	17.06	22.42	17.74
		10	18.36	18.49	19.67	19.81	32.78	33.02	34.09	34.34
		11	23.48	21.82	25.16	23.38	41.93	38.97	43.61	40.53
	Aug	10	25.82	24.15	27.66	25.88	46.11	43.13	47.95	44.86
		10	30.11	25.83	32.26	27.68	53.77	46.13	55.92	47.98
		11	28.34	17.49	30.37	18.74	50.61	31.23	52.64	32.48
	Sept	10	24.1	9.58	25.82	10.26	43.04	17.1	44.76	17.79
		10	15.8	6.8	16.92	7.29	28.21	12.14	29.34	12.63
		10	12.95	6.75	13.88	7.23	23.13	12.06	24.06	12.54
II	Oct	10	2.92	2.05	3.12	2.2	5.21	3.66	5.41	3.81
		10	2.56	1.47	2.75	1.58	4.58	2.63	4.76	2.74
		11	1.78	1.27	1.91	1.36	3.18	2.27	3.31	2.36
	Nov	10	1.48	1.22	1.59	1.3	2.65	2.17	2.76	2.26
		10	1.31	1.02	1.41	1.09	2.35	1.82	2.44	1.89
		10	1.17	0.87	1.25	0.93	2.08	1.55	2.17	1.61
	Dec	10	1.06	0.85	1.14	0.91	1.9	1.52	1.98	1.58
		10	0.98	0.75	1.05	0.8	1.75	1.33	1.82	1.38
		11	0.95	0.7	1.02	0.75	1.69	1.25	1.76	1.3
	Jan	10	0.85	0.75	0.91	0.8	1.52	1.33	1.58	1.39
		10	0.79	0.69	0.84	0.74	1.41	1.24	1.46	1.28
		11	0.76	0.76	0.82	0.81	1.36	1.35	1.41	1.41
	Feb	10	0.73	0.71	0.78	0.77	1.31	1.28	1.36	1.33
		10	0.72	0.61	0.77	0.66	1.29	1.1	1.34	1.14
		8	0.7	0.6	0.75	0.64	1.24	1.07	1.29	1.12
III	Mar	10	1.38	1.28	1.48	1.37	2.46	2.29	2.56	2.38
		10	1.37	1.22	1.47	1.3	2.44	2.17	2.54	2.26
		11	1.37	1.4	1.47	1.5	2.45	2.51	2.55	2.61
	Apr	10	1.29	1.36	1.38	1.46	2.31	2.44	2.4	2.53
		10	1.25	1.25	1.34	1.34	2.23	2.24	2.32	2.33
		10	1.21	1.1	1.3	1.18	2.17	1.96	2.26	2.04
	May	10	1.22	1.26	1.3	1.35	2.17	2.24	2.26	2.33
		10	1.15	0.57	1.23	0.61	2.05	1.02	2.13	1.06
		11	1.17	0.73	1.26	0.79	2.09	1.31	2.18	1.36

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. ***Season I***
- High flow season is influenced by the monsoon.
- Covers the months from May to September.
- Minimum flow during this period is assumed as 30% of average flow

Season II
- Average flow period for the month of October.
- Transitional period between the wet and dry period.
- Minimum flow is taken as 20% of average flow.

Season III
- Low or lean or dry flow season.
- Covers the months from November to March.
- Minimum flow is taken as 15% of average flow.

Season IV
- Average flow period covers the month of April.
- A transitional period between the wet and dry period.
- Minimum flow is taken as 20% of average flow.

For case I, The data was analyzed and Annual Average and average daily discharges were determined from the historic. Since the weather pattern is different in India, three seasons only will be considered with Season I from May to September, Season II from October to February and season III from March to May. For case 2, where first of all, Average Annual flow is determined for the four sites of the River basin. Then the 90% percent dependable year is determined. The probability nearest to 90% is of the 'year 1'. Hence the 90% dependable year is 'year 1'. The Minimum flow is considered for the 'year 1' and the different propor-tions of the minimum flow requirement are tabulated in Table 10. The minimum flow requirements for the different sites of the Saryu River basin Using seasonal Method for the two cases are shown in table 10.

Table 11. *Tabular comparison of EF between Tennant method, Huges & Munster Method and flow Index method*

Methods	Loharkhet		Balighat		Khutani		Seraghat	
	June-Sept	Oct - May	June-Sept	Oct - May	June-Sept	Oct - May	June-Sept	Oct - May
Tennant	313	157	336	168	560	280	582	291
Hughes and Munster	226		243		404		483	
Index Flow	189.43		203		338		353	

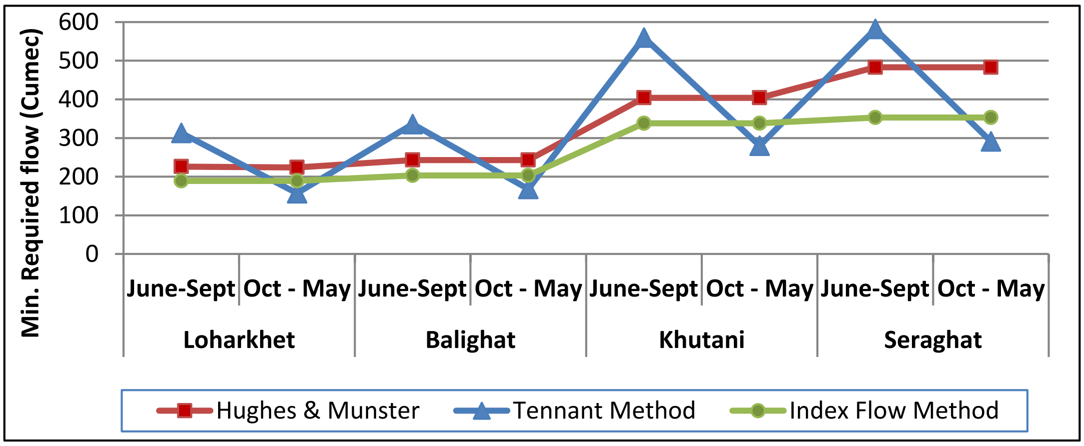

Figure 6
Variation of Min. required flow using three methods

Results and Discussion

In remote or data-poor areas, hydrological methods are commonly used to predict minimal environmental flows for river systems, especially those based on histo-rical stream flow data and 90% reliable flow values (Smakhtin et al., 2004). These techniques have the benefit of requiring little field data, which makes them affordable and quite simple to apply in baseline environmental flow studies (Arthington et al., 2006). The Tennant Method, sometimes known as the Monta-na Method, is one of the most widely used hydrological techniques. It suggests using set percentages of the mean annual flow (MAF) to represent various ecolo-gical circumstances. According to this standard-setting approach, a flow of 30% MAF normally maintains a "good" aquatic habitat, where depth and velocity are enough for fish passage and the general health of the ecosystem (Acreman and Dumbar, 2004). These flow allocations provide a useful starting point for flow regulation in rivers without comprehensive ecological

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data, despite the fact that they are based on generalized assumptions and are not adjusted for local ecological conditions (Richter et al., 2012). The current study validated the selection of "good" aquatic habitat characteristics by finding that the flow condition equal to 30% MAF maintained the proper depth and velocity for fish movement, particularly over riffle sections. The Modified Tennant Method was created especially for Indian river systems to overcome the drawbacks of consistent allocation throughout the seasons. By con-forming to the region's natural monthly flow variation patterns, this method more accurately distributes environmental flow (EF) (Shakhtin and Anputhas, 2006). An appropriate EF allocation is 40% during the monsoon season (June–September) and 20% during the non-monsoon season (October–May) for regulated rivers like the Saryu that are impacted by weirs and hydroelectric facilities. A conservative 40% allocation was used in this study to provide "good" habitat conditions all year long. The 90% dependable flow of the 90% dependable year, which represents the minimum flows that take place during extremely dry conditions, is used by the Hughes and Münster Method to estimate EF (Dyson et al., 2008). These flows act as ecological thre-sholds below which the system enters stress. In order to generate more balanced flow recommendations, the approach also permits adjust-tment by utilizing long-term flow statistics that cover both wet and dry years (Tennant, 1976). The Saryu River's reasonably consistent flow regime was demon-strated by Q90 values, which ranged between 20 and 30% of Mean Annual Runoff (MAR), and High Flow Requirement (HFR) values, which were roughly 7% of MAR. This is supported by the Flow Duration Curve's (FDC) flat slope, which is associated with a higher percentage of stable baseflows and less flow variability (Hughes, 2001). Because of its ease of use and low data requirements, the 7Q10 Method—which is typically used to establish low-flow criteria for pollution control and water quality standards—has also been modified for environmental flow evaluations (Vogel and Fennessey, 1995). However, compared to other hydrological approaches, this method usually yields higher EF values, which might be difficult to sustain in rivers with little flow or strict regulations. The 7Q10 approach produced the highest EF estimates for the Saryu River, especially during the monsoon months when the river's discharge peaks as a result of inputs induced by rainfall. With strong flows during the monsoon season (June to September) and low flows during the winter and pre-monsoon seasons (October to May), the Saryu River exhibits significant seasonal variability, similar to that of the majority of Himalayan rivers. This pattern was seen in EF estimates, which recommended minimal values from January to May and maximum flows from July to September. In a rain-fed system, where runoff is strongly correlated with precipitation events, this seasonal tendency is expected, requiring EF techniques that take temporal variability into account (Jain et al., 2007).

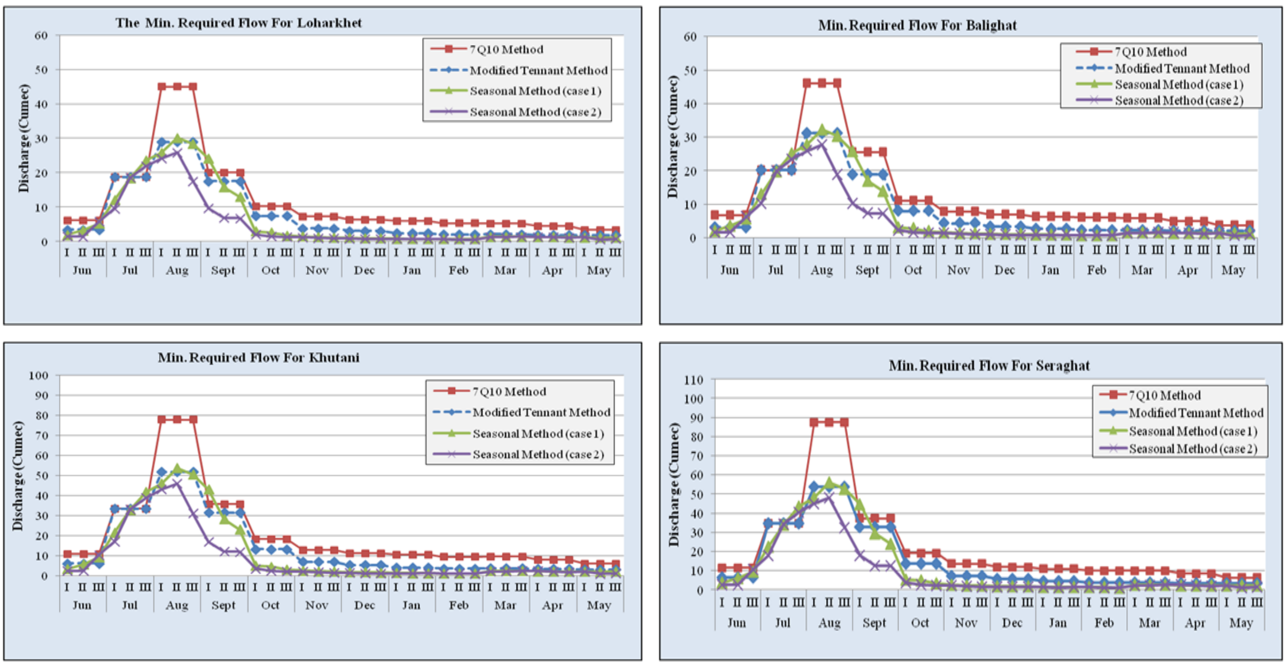

Figure 7. *Comparison of E Flows obtained from different Methods*

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