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Environmental Flow Assessment (EFA) of Tawi River Discharge at the Jammu Location Using the Global Environmental Flow Calculator (GEFC)

Maharshi Yadav*†, Govind Pandey* and Pradeep Kumar**
*Department of Civil Engineering, Madan Mohan Malaviya University of Technology, Gorakhpur, Uttar Pradesh, India
**Environmental Hydrology Division, National Institute of Hydrology, Roorkee, India
†Corresponding author: Maharshi Yadav; maharshiyadav@outlook.com

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ABSTRACT

The water, food, and energy demands are the basic requirements of society. These demands are increasing daily due to an increase in population or lifestyle changes. To fulfill these ever-increasing demands, several water resource projects have come up which require the storage or diversion of river water. These interventions have caused widespread degradation of aquatic ecosystems. Due to the degradation of the aquatic ecosystem, several programs all around the globe began. In this series, Brisbane Declaration (2007) provided a more holistic definition of Environmental Flows (EFs) as the quantity, timing, duration, frequency, and quality of flows required to sustain freshwater, estuarine and near-shore ecosystems and the human livelihoods and well-being that depend on them. The present study was envisaged to assess for environmental flows of the Tawi river with a major objective of assessing the environmental flows of the Tawi river using the Global Environmental Flow Calculator developed by IWMI. The method provides E-Flows for different Environmental Management Classes. For the western Himalayan region, the river stretches in Environmental Management Class 'B' and 'C'. The assessment provides E-Flows in two ways: (i) the percentage of Mean Annual Runoff and (ii) average monthly environmental flows. E-Flows were estimated as 42.34% to 56.96% of Mean Annual Runoff and varied from 5.73 cumecs during November to 68.23 during August.

INTRODUCTION

The name of India itself can find the importance of rivers in India. India's name comes from a holy Himalayan River name Indus (Agoramoorthy 2015). This country is a land of rivers, and respect for great rivers such as Ganga, Godavari, Cauvery, Narmada Brahmaputra, etc., from east to west and north to south, can be found in daily life and cultural activities. Despite Rivers in India being respected as a mother, the conditions of major rivers are not very good. Pollution and alteration in Indian rivers cause damage to their habitat and imbalance in the ecological system of the riverine system. Gomati, Dikrong, Hindon, Subarnarekha, Ganga, Ghaggar, Kasardi, Kabini, Beas river, etc., are polluted with contaminants such as metals (Cr, Cu, Fe, Mn, Ni, Pb, etc.), pathogens, pesticides, carcinogens, etc. (Chakravarty & Patgiri 2009, Giri & Singh 2014, Jain et al. 2005, Kaushik et al. 2010, Kumar et al. 2018, Paul 2017, Taghinia et al. 2011, Yadav et al. 2022a, 2022b). Not only industrial and sewage discharge in surface water bodies polluting and threatening the ecology of rivers/lakes but the alteration in flow patterns of rivers caused by various water resource development such as dams, canals, etc. (Operacz et al. 2018, Yadav et al. 2021a, 2021b, 2022a, 2022b, 2022c). Also causing adverse impacts on river quality and habitat. Assessment of ecological imbalances and habitat degradation need to address to prevent the ecological structure of the riverine system. Due to the very high hydropower capacity of Himalayan rivers, alterations in natural flow patterns rivers are highly disturbed. India produces 12% of its total electric power via hydroelectricity. Globally India ranks 5th concerning hydroelectric power capacity. Tehri, Tapovan Vishnugadh, Vishnugadh Pipalkoti, Singoli Bhatwari, Phata Bhuyang, Madhyamaheshwar, etc., are various hydropower projects installed on Himalayan rivers that have a high socio-economical impact. Despite electricity generation by hydropower projects, many adverse impacts occur due to alterations in the flow pattern of rivers. Finding a river in natural condition along its entire stretch is nowadays a fairy-tales. Restoring rivers in their natural conditions or recovering them sustainably is very important.

ORCID details of the authors:

Maharshi Yadav : https://orcid.org/0000-0002-6503-2340
Govind Pandey: https://orcid.org/0000-0003-3520-4188

An ecosystem is a natural unit consisting of biotic factors (all animals, plants, bacteria, viruses, and other microorganisms) in an area functioning with all of the environment's non-living (abiotic) factors. A river reach may be considered an aquatic ecosystem, and its catchment is a terrestrial ecosystem. These two ecosystems support distinct ecologies.

Increasing recognition of protection worldwide is a prerequisite for ecosystems where human beings are supplied with water (Dugan et al. 2002, Dyson et al. 2003).

Maintaining the ecosystem of the riverine system is a very cost-effective and valuable path to deliver services despite delivering manmade high technologies and monstrous structures (Emerton & Bos 2004). Identifying the full value and significance of the benefits of ecological systems, their investigation thoroughly can work as a potential protective tool for humans and animals in future profits. Recognition and investigation of ecosystem benefits can save their values and provide help for their sustainable development. Big efforts and technological advancement fail seriously without considering the ecological balance.

For identifying the health of the river system, parameters like quality and quantity of water, sediments and their transport, food chain and its supply, and interaction between biotic and abiotic factors are very important parameters, but the most important parameter for the riverine ecosystem and its complex ecosystem structure is its flow regime (Dyson et al. 2003). Identification and significance of the flow become the key concept in the evolution of environmental flow for the riverine system (Hairan et al. 2021, Poff et al. 2009).

Study Area

The present study selected Tawi River, a left-bank tributary of Chenab River, for the low flow frequency analysis (Vinod

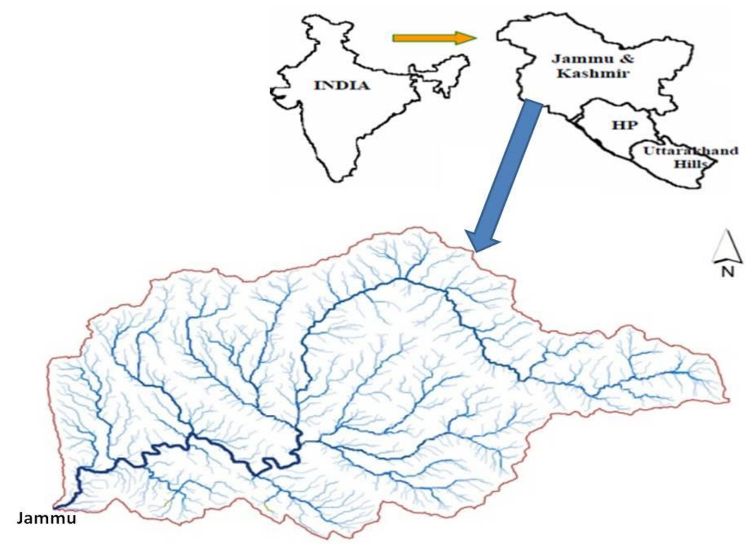


Fig. 1: Tawi river catchment area.

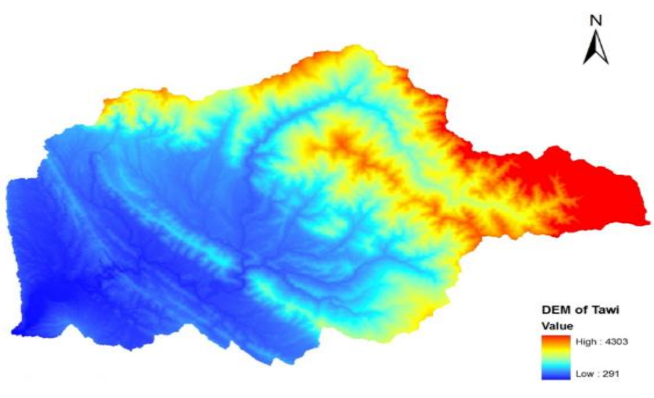


Fig. 2: Digital elevation mode (DEM) of Tawi catchment.

et al. 2016, Sharma & Chowdhary 2011, Sun et al. 2018, Goyal et al. 2005, Verma et al. 2012). From the Western Himalayan region, two riverine systems, the first Ganga riverine system, and the dual Indus river system are forming a great agricultural potential, hydroelectric generation potential, and other ecological systems for India. Tawi River, a major tributary of the Chenab River, originates from the Himalayan Glacame Kalikundi and its adjoining areas (Fig. 1). The shape of the basin is elongated in the upper part and broad in the lower part. The catchment area of the Tawi river up to Jammu is 2165 sq. km. After crossing the Jammu Ranbir canal, Tawi is divided into Nikki Tawi (flows towards the left) and Waddi Tawi (flows towards the right). The catchment area peaks at 6000msl in the glacier region and the lowest at 300 msl in the planer areas. Fig. 2 shows the digital elevation model of the Tawi River.

Mountainous Rivers have several sub-tributaries. Tawi River also has more than 2000 numbers of tributaries and sub-tributaries. Among the nine important tributaries of Tawi are Kali Kundi, Pitch, Margi, Chenani, Dhak Nalla, Naddal Khund, Calari, Pharos, and Gamhi. The length of Kali Kundi is about 4 km, and its elevation varies from 4000 m to 3200 m. The pitch length is 2.0km with an elevation variation of 3600 m to 3200 m. Margi has two breaks profile, the first at 3200 m and the second at 2600 m, and the length is about 9.5 km. Chenani has a 7.5km length with elevation variation from 1700 m to 1100 m. Dhak Nalla has 2.5 km, and Naddal Kund has a 15 km length. Gamhi is 19 km long with small breaks at different places with elevation variations of 700 m to 400 m.

The Climatic Condition and Hydrology of the Tawi Catchment Area

This region experiences a hot summer season and a very cold winter season. Temperatures fall below 5°C in winter. The temperature reaches to peak in the May-June months. Bhadarwah and adjoining areas are tropical mountain-type climatic areas. The middle part, mainly the area of the Udhampur district, is a mountainous climate with the effect of the southwestern monsoon. Southwestern part is influenced

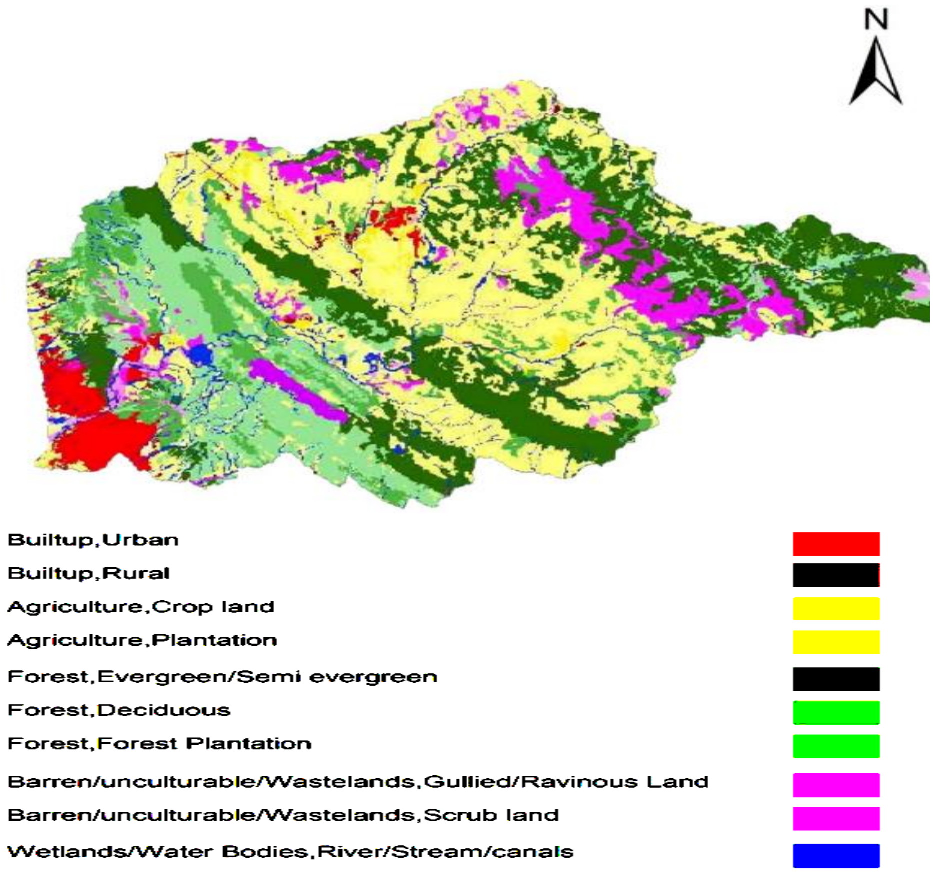


Fig. 3: Land use/Land cover in the Tawi river basin.

by monsoons and categorized as a subtropical wet and dry climate (Aqualogus 2018, Goyal et al. 2005, Jain et al. 2007, Sharma 2012).

55% of the total annual rainfall occurs from the end of June to the end of September. The average rainfall of Jammu district varies from 900 mm to 1000 mm. At higher altitudes, heavy snowfall occurs from December to February. According to the groundwater information booklet of CGWB (Aqualogus 2018), Jammu and Kashmir's rainfall is a major groundwater source in the Jammu district.

Groundwater quality is generally good for irrigation and domestic purposes, monitoring groundwater quality by CGWB. Considering the soil aspects of the Tawi river catchment area, the Doda district has alluvial soil. In midlands or foothills, the soil is generally sandy loam to silty clay loan due to the process of colluviation. At the Chenani location, due to the steep gradient in elevation potential of hydropower generation is utilized by various hydroelectric projects. Chenani I was commissioned in 1971 with three units (Unit I, Unit II, Unit III) and two more units in 1975 (Unit IV and Unit V) with a rated capacity of 17MW and a canal length of 18.64km. Chenani II was commissioned in 1996 with an installed capacity of 2MW in the Udhampur district, and Chenani III was commissioned in 2001 with an installed capacity of 3×2.5 = 7,5 MW. Tawi lift irrigation canal with coverage of 28.8km starts from Bahu fort, opposite Jammu city. Udhampur canal is 26.5 km long and used for 2400 acres of irrigation and power generation of 8000KW. Subsidiary Lift Scheme on Tawi Canal at Raya, A subsidiary lift scheme to irrigate 1100 hectares of the fertile tract of land: uphill of the Tawi canal in the village of Raya has been envisaged. Major land cover is given in Fig. 3.

MATERIALS AND METHODS

Smakhtin & Anputhas (2006) reviewed various hydrology-based environmental flow assessment methodologies and their applicability in the Indian context. Based on the study, they combined the FDC approach and connected it with the EMCs.

The IWMI approach of EFA includes various steps and is built on a period record basis. FDC calculation is considered the first step for the environmental water requirement (EWR) for the selected sites. The sites with observed flow data are called 'source' sites. The sites where reference FDC and time series are required for the EF estimation are called 'destination' sites. The destination site is more significant because alteration in upstream causes influences downstream. Calculating unregulated stream flow variability and monthly flow time series provides information on the flow variability in unaltered conditions.

Table 1: EMCs Classes.

EMC	Ecological description	Management perspective
A: Natural	Original state or least alteration in river stream and riparian territory.	Applied for safeguarded rivers and basins, Natural reserves, and parks. No new water projects such as dams, canals, and deviations are allowed.
B: Slightly modified	Mostly unbroken biodiversity & altered habitats despite water resources expansion and basin amendments.	Agricultural development and water supply structures are present or tolerable.
C: Moderately modified	The environments and dynamics of the changed biota have been a concern, but basic ecosystem functions are still integral. Some sensitive species are lost and reduced in extent. Alien species present	Several problems and complexities belong with the requirement of socio-economic development projects (Dams and decline in water quality)
D: Largely modified	Big alterations and modifications in basic natural ecosystems/habitats have occurred. Species and their population were found to be less than expected. Species that have low tolerance levels are found in much lower numbers. Alien species prevail	Potential and observable problems attached to various water supply and resource development programs (including dams, diversions, transfers, habitat modification, and water quality degradation)
E: Seriously modified	Diversity in habitat was found to be declined extensively, species richness at minimum, intolerant species vanished, and only tolerable species were found. Indigenous species of ecosystems are not able to breed. Alien species have almost overtaken the ecosystem	Very high human population density and extreme exploitation of water resources.
F: Critically modified	Modifications have reached a critically modified level, and the ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed, and the changes are irreversible	This status is not acceptable from the management's perspective. Management interventions are necessary to restore flow patterns, river habitats, etc. (if still possible/feasible) – to 'move' a river to a higher management category.

Source: Smakhtin & Anputhas (2006)

In all the FDCs approaches, table flow values with respect to the .01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9, 99.99 percentages are calculated based on available flow data. These points (i), by measuring 0.01 to 99.99 percent, ensure the variability of the whole range (ii) makes it simple for further steps. FDCs are designed straight from the observed record or form part of the record that could be considered 'unregulated.' Normally the earlier part of each record - preceding major dams' construction – is used to ensure that monthly flow variability, captured by the period-of-record FDC, is not seriously impacted. An FDC table is calculated for each destination site using a source FDC table from either the nearest or the only available observation flow station upstream.

EFs aim to maintain an ecosystem or upgrade it to, some prescribed or negotiated condition/status, also called environmental management class (EMC). The concept of EMCs is used in the IWMI approach. According to the EMC, class superiority signifies more water associated with maintaining the ecology and health of the riverine system. Natural flow amount needed naturally pristine condition of the river without alteration. EMCs A, B, C, D, E and F. are six EWR values described in Table 1.

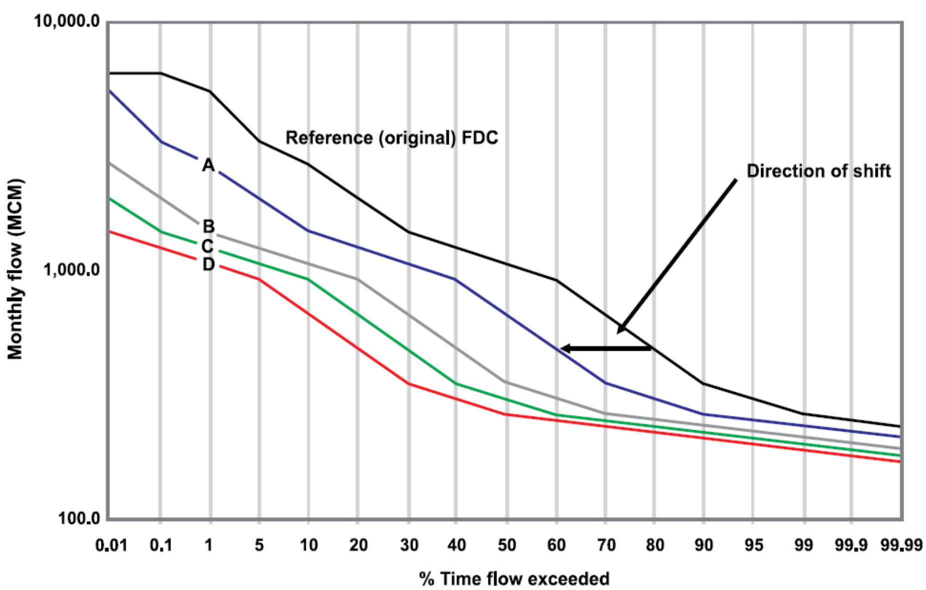
By lateral shifting the original reference FDC to the left with the probability axis, a new FDC is obtained, and for the last tail values of shifted curve, linear extrapolation techniques are used. To determine the EMC A class original reference, FDC is shifted a single step left to the probability axis. For EMC B, shifting is done for two steps left to the probability axis. For the EMC C, shifting is done in three steps left and so on for further EMCs (Fig. 4).

FDC made for an EMC summarizes the EF regime, which suits this EMC. The curve, however, does not reflect the actual flow sequence. At the same time, once such environmental FDC is determined, this can be converted into average monthly flow time series. Hughes & Smakhtin (1996) described a spatial interpolation process in detail for the FDC and EMC.

RESULTS AND DISCUSSION

Open to access software named The Global Environmental Flow Calculator (GEFC), which is designed and developed by the scientist and engineers of the International Water Management Institute (IWMI). Flow duration curves are the basis of this methodology. Flow duration curves are improved and established as Environmental Management Classes (EMCs) using FDCs as the basic approach. Open access freely offered GEFC software needs an average of monthly discharge data of rivers for a significant amount of time to assess environment flows (Shaeri Karimi et al. 2012, Sood et al. 2017, Uday Kumar & Jayakumar 2021).

The present study utilized the daily hydrological data of the Tawi River to evaluate the environmental flows. There are six EMCs (A, B, C, D, E, F) are presented in GEFC, mutable from Unmodified to Critically modified. Each EMC is ex-



(Source: Smakhtin & Anputhas 2006)

Fig. 4: Illustration of estimation procedure of environmental FDCs for different EMCs.

pressed by its exclusive FDC. In this methodology, seventeen fixed percentage points considered representative of the flow regime is taken for the computation of flow duration curves for different EMCs. The FDC for each EMC is estimated by the oblique shift of the original reference FDC to the left along the percentage exceedance probability (X-Axis) by one percentage point.

The FDCs for different EMCs of the Tawi River have been presented in Fig. 5. From this figure. It may be concluded that discharges generally decrease from EMC A to EMC F and tend to be approximately similar during the lean season.

The average monthly environmental flow series for different EMCs are shown in Fig. 6 and Table 2. The figure shows that the deviations in the discharges from the reference/natural flow are lower in the case of EMC 'A' and higher as we go from EMC 'A' to EMC 'F.' The lean season in the study area is from December to February, and the flows start increasing due to more snowmelt contribution. This reflects the flow values for different EMCs, as the

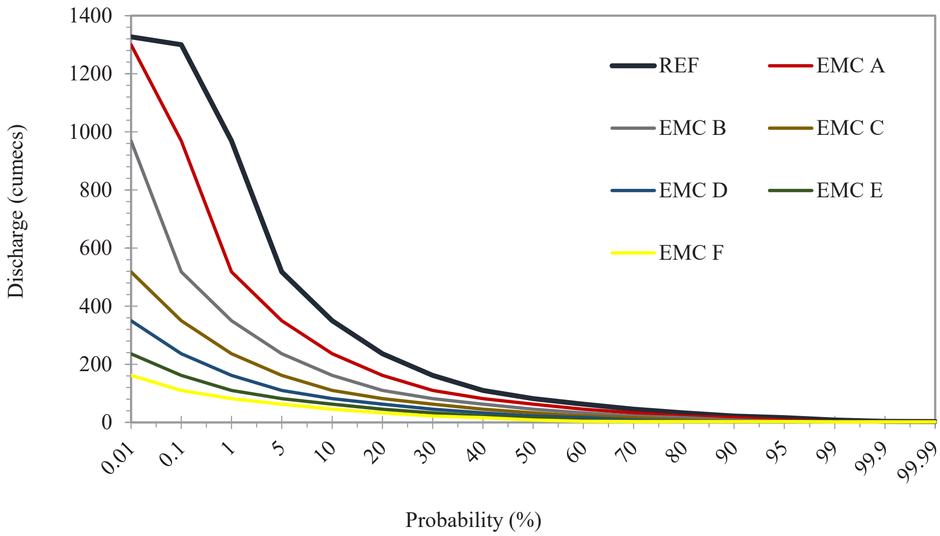


Fig. 5: Flow duration curves of Tawi River for different EMCs.

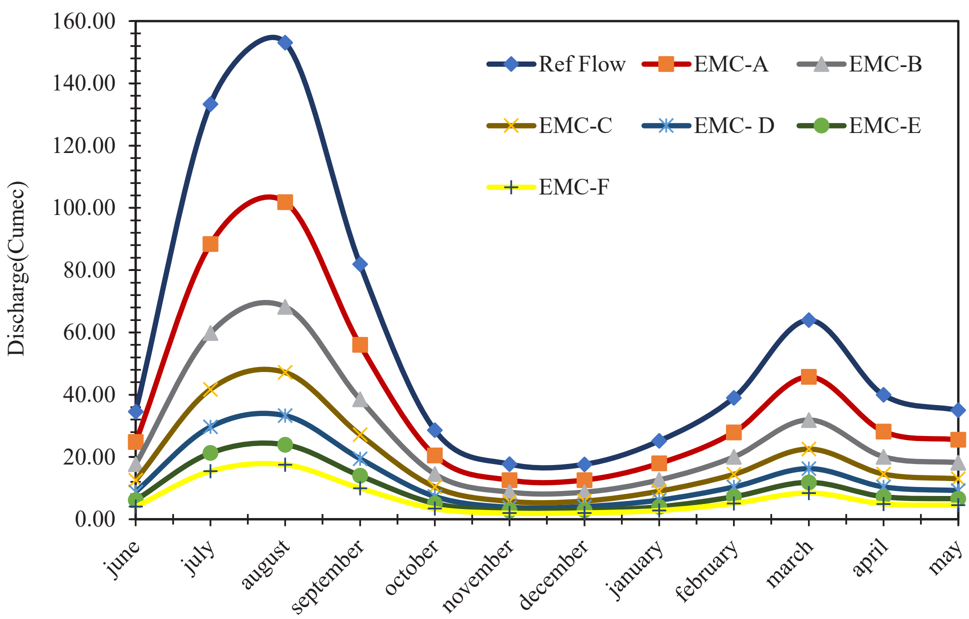


Fig. 6: Environmental flows of Tawi River for different EMCs.

Table 2: Environmental flows for different EMCs of Tawi River.

Month	Natural flows	Environmental flow (cumecs)					
		A	B	C	D	E	F
Jun	34.57	24.78	17.66	12.54	8.81	6.12	4.03
Jul	133.36	88.37	59.77	41.72	29.65	21.26	15.42
Aug	153.03	101.88	68.23	47.14	33.26	23.95	17.53
Sep	81.94	55.99	38.48	27.15	19.44	13.96	9.97
Oct	28.61	20.49	14.52	10.37	7.31	5.06	3.40
Nov	17.71	12.56	8.72	5.73	3.84	2.79	1.97
Dec	17.62	12.59	8.70	5.84	4.07	2.90	2.04
Jan	25.16	17.93	12.62	9.00	6.14	3.99	2.78
Feb	39.01	27.92	20.01	14.42	10.36	7.23	5.08
Mar	63.93	45.73	31.89	22.54	16.26	11.83	8.44
Apr	39.93	28.20	20.07	14.51	10.39	7.23	4.92
May	34.98	25.50	18.17	12.99	9.20	6.56	4.51
MAR (MCM)	1776	1362.01	1011.60	751.95	574.71	466.37	398.35
% of MAR	100.00	76.69	56.96	42.34	32.36	26.26	22.43

discharges for all the EMCs during the lean season are very close. Table 2 presents the environmental flows for different EMCs in two manners, i.e., the percentage of Mean Annual Runoff (MAR) and average monthly discharges. The table clearly shows that the percentage of Mean Annual Runoff (MAR) is higher to lower for EMCs from 'A' to 'F' (76.69% for EMC A and 22.43% for EMC F). The natural, as well as environmental flows are lowest in December.

Recommendations on the E-flows of the Tawi River

The status of the Ecological conditions of a river is subject to the Environmental management class. The definition of the EMC depends on the empirical relationship between flow variations and ecological conditions. The methodology given by IWMI requires various ecological parameters and their ratings to assess the class of EMC. Without hydro-ecological depth information and ecological condition, EMC-B and EMC-C can be considered for maintaining the river's health (Fig. 7).

December and November, with 17.62 cumecs and 17.71 cumecs values, are the lowest discharge value months in the Tawi River EFA analysis. Monsoon season months July and

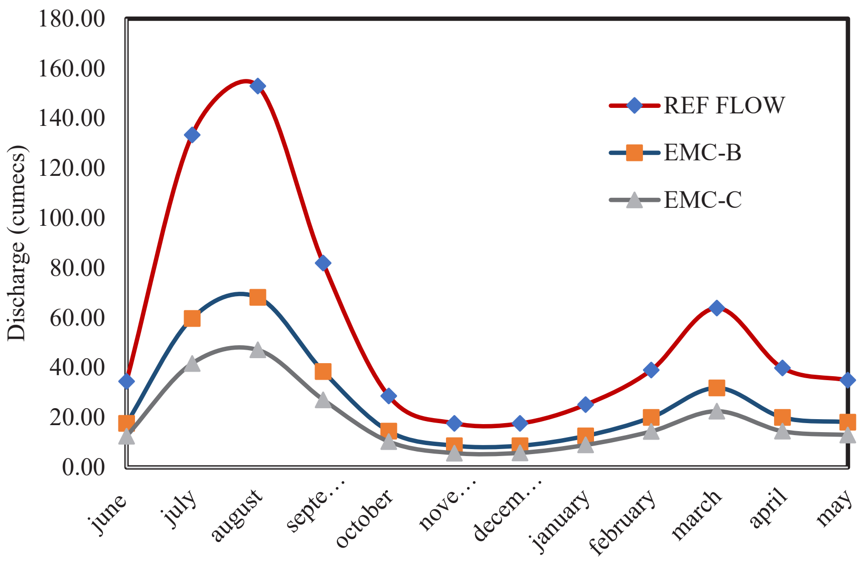


Fig. 7: Environmental flows of Tawi river for EMC 'B' and EMC 'C'.

Table 3: Environmental flow of Tawi river for EMC-B and EMC-C.

Month	Natural Flows (cumec)	Environmental Flows (cumec)	
		EMC-B	EMC-C
June	34.57	17.66	12.5421
July	133.36	59.77	41.7154
August	153.03	68.23	47.1427
September	81.94	38.48	27.1456
October	28.61	14.52	10.3683
November	17.71	8.72	5.72713
December	17.62	8.70	5.83923
January	25.16	12.62	9.0013
February	39.01	20.01	14.4194
March	63.93	31.89	22.5367
April	39.93	20.07	14.5075
May	34.98	18.17	12.9899

August have 133.36 and 153.03 cumecs discharge values. EFA analysis suggests a minimum of 5.72 cumecs discharge require to maintain the well-functioning ecological system of the river. Environmental flows for the various months for EMC-B and EMC-C are given in Table 3.

Hydro-Ecological assessment of Krishna River at five different locations De sugar, Yadgir, Agraharam, NSP and Vijayawada, 69.2%, 70.5%, 68.4%, 72%, and 71.31% of MAR value was measured for respective locations. Researchers estimated that 43% of the time river was not maintained to the required EF due to Socioeconomic projects (Uday Kumar & Jayakumar 2021). Environmental flow assessment of Shahr Chai River in Iran conducted by Karimi et al. reveals that 68.8%, 44.1%, 28.2%, 18.9%, 13.4%, and 10.0%, respectively, for EMC A to EMC F. Karimi et al. analyze GEFC, desktop reserve model (DRM) and low flow frequency analysis for Shahr Chai River and found that minimum 1.2 m3.s-1 which is 23% of natural MAR required for downstream for Urmia lake (Shaeri Karimi et al. 2012). EFA analysis of the Sone river was performed by Global Environmental Flow Calculator Software and estimated that a minimum of 18.9% of MAR is mandatory to uphold the reasonable condition of the sone river (Joshi et al. 2014). Environmental flows of the Tungabhadra River basin studied by the Priya et al. using GEFC reveals that Tungabhadra River basin by seeing the various discharge stations, which are Balehonuur, Haralahalli, Hosaritti, Shivamogga, Honalli, Rattihalli, and Tungabhadra Dam, with a mean annual flow (MAF) of 36%, 24.8%, 27.2%, 16.2%, 23.3%, 21.1%, and 12.2%, correspondingly, to preserve the ecological situations of the river (Chandi Priya et al. 2022). Several other researchers studied the Environmental assessment of Rivers (Omo-Gibe basin, Ethiopia , Selangor River, Zab River, Yangtze, Yellow and Lancang Rivers), using GEFC and analysed the EMCs and impact of various alterations in natural streams of rivers (Abdi & Yasi 2015, Hairan et al. 2021, Mahmood et al. 2020, Tesfaye et al. 2020).

CONCLUSIONS

FDCs were similar for a lean season (December to February) of river discharge, generally decreasing EMC A to EMC F, which was found to be the minimum for EMC F compared to reference flow. Environmental flow assessment of Tawi river discharge data was estimated using The Global Environmental Flow Calculator (GEFC), which reveals statistics for EMC A to EMC F. Mean annual runoff using original discharge data was calculated and compared with data obtained from GEFC for different classes of EMCs. EMC A was estimated at 1362 cumecs which are 76.69% of MAR. This indicates that 76.69% of MAR is required to maintain the natural condition of the river with the least alteration in flow or no alteration. It is suitable for protecting rivers from building projects such as dams and diversions. Tawi river is the Himalayan River which contains a high potential for hydropower projects for maintaining river ecological condition to the optimum level, and hydropower projects possibilities EMC B and EMC C are recommended. This study reveals 42 to 57 % of MARs fall under EMC B and EMC C. Minor irrigation expansion projects and Water supply structures are allowable in the EMC B category. For maintaining the ecological health of the Tawi river, it is recommended to maintain at least 42 to 57% of MAR during any socio-economic, irrigation, and water supply projects. Special attention requires in lean seasons in which discharge falls to very low values. Minimum discharge was found in November and December, 17.71 and 17.62 cumecs, respectively. Comparing EMC B and EMC C values for November and December, which vary between 8.7 to 12.59 cumecs to the original 17. 71 to 17.62 needs special attention during the development of any projects of stream diversions to maintain ecological conditions with minimum impact. Further investigation requires discharge data using GEFC for different EMCs before and after the impact of various hydropower and diversions projects at various locations to understand the impact of such projects on the eco-hydrology of the Tawi river.

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