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ORIGINAL ARTICLE

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Environmental sustainability of major rivers of Jharkhand, India

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ABSTRACT

Environmental flows (EFs) are the minimum quantity and quality of flows required to sustain freshwater ecosystems and human livelihoods. Achieving environmental sustainability in rivers involves managing EFs while balancing ecological, economic, and social goals and ensuring fair access to resources. In this study, EFs for four major rivers in Jharkhand - the North Koel, Sone, Damodar, and Mayurakshi - were determined using the Global Environmental Flow Calculator. The study used monthly flow data and Flow Duration Curve to estimate EFs to improve the condition of the rivers' ecosystems, known as Environmental Management Class (EMC). Results showed that EFs for the Jharkhand rivers ranged from 6% to 16.6% of the Mean Annual Runoff (MAR). For example, the North Koel River (Daltonganj) and other rivers in that region had EFs ranging from 6% to 12.6% of MAR, while the Kanhar River had EFs of 11.6% of MAR. The Damodar and related rivers had EFs ranging from 9% to 16.6% of MAR, and the Mayurakshi, Bansloi, and Basane rivers had EFs around 10% of MAR. Additionally, the study found that the Sankh river had a sustainability index of 12.0, indicating a very sustainable flow regime. The study highlighted that changes in flow characteristics could pose a significant threat to fish diversity and community structure, raising concerns about the future of these ecosystems. It emphasized the importance of managing water storage structures to maintain environmental flow, species diversity, flow fluctuation, and river pollution.

HIGHLIGHTS

- Environmental flows for four major rivers in Jharkhand were determined using the Global Environmental Flow Calculator.
- The Damodar and related rivers had EFs ranging from 9% to 16.6% of mean annual runoff, and the Mayurakshi, Bansloi, and Basane rivers had environmental flows around 10% of mean annual runoff.
- The SI value of 12.01 for Shank river signifies an exceptional level of sustainability.
- Environmental flow estimation is required for all the rivers where structural interventions have altered the flow.

1 | INTRODUCTION

Freshwater resources have become severely threatened in recent years due to rapid industrialization, urbanization, and agricultural intensification. These activities have resulted in changes in the natural flow regimes of rivers and streams, leading to the degradation of aquatic habitats, loss of biodiversity, and decline in water quality. Furthermore, the altered flow regimes have also impacted the social, economic, and cultural well-being of the local communities that depend on these freshwater resources. There is a growing recognition of the importance of maintaining or restoring natural flow regimes through the management of environmental flows. Environmental flow management aims to balance the needs of ecosystems and the people who depend on them by ensuring that sufficient quantities and quality of water are available for aquatic ecosystems and other users. Maintaining sustainable growth requires regular evaluation and upkeep of a river's environmental flow. It emphasizes the freshwater and estuarine ecosystems and the livelihood and well-being of those who depend on these environments. It minimizes the consequences of streamflow change on downstream aquatic, floodplain, and coastal ecosystems while lowering wastewater discharge. Also, it maintains water quality for the ecology that depends on water and for sustaining public health (Chen *et al.*, 2020). Applying environmental flows

(EFs) requires a comprehensive understanding of freshwater ecosystems' ecological, hydrological, and social dimensions (Singh and Mitra, 2018).

Tharme (2003) examined the status of environmental flow laws worldwide and reviewed 207 distinct techniques documented in nations across six continents. These techniques were divided into four major categories: Holistic, Habitat Simulation, Hydrological, and Hydrological Assessment Methods. Two further groups include combinatorial and other approaches. Later concept of environment flows was discussed to include more water demand, integrated assessment of environmental flows, apply neural network models to estimate environmental flow, apply a range of variability analysis (RVA) and wavelet transform analysis (Zolezzi *et al*., 2009). Numerous research works were conducted to determine environmental flows for different regions across the globe (Dubey *et al*., 2013; Bhattacharjee and Jha, 2014; Ramos *et al*., 2018; Singh and Mitra, 2018; Singh *et al*., 2019; Longobardi and Villani, 2020; Crook *et al*., 2021; Ni *et al*., 2022; Purnanjali and Kasiviswanathan, 2022). Most works use the available methods, e.g., the Hydrological Index Approach, Tennant (or Montana) Technique, Flow Duration Curve (FDC) and Wet Ambient Method. Even comparison studies are also noted. The findings have revealed a strong association between the catchment area and mean annual daily discharge, as well as the regime on socio-economic activities, particularly the livelihoods of fishing communities. This can contribute to the concept of striking a balance between development and sustainability.

Jharkhand is a state located in eastern India that boasts abundant freshwater resources supporting millions of people's lives and livelihoods. The study of the environmental flow of a river is a critical component of ensuring the sustainability of the river ecosystem and meeting human needs. Structural interventions such as dams, barrages, weirs, etc., affect the natural flow of the rivers. The alteration in the flow characteristics and water quality has threatened aquatic organisms, especially fish diversity and community structure. The EFs of the Damodar river basin have been assessed using the FDC (Singh and Mitra, 2018). The environmental flow regime was evaluated using a Flow Health Score for the Son river in the Ganga basin (Joseph *et al*., 2021). Recently, the North Koel river basin has faced environmental challenges, including deforestation, soil erosion, and water pollution, primarily driven by the expansion of agriculture and mining activities. Not much study is available for rivers of Jharkhand, which is gearing up for a boost in industrial activity; therefore, such study is required because water shall be abstracted from rivers only, which is expected to grow. In the present study, basic environmental flow using a global environmental flow calculator was determined for the North Koel river, Kanhar river under the Sone basin, Damodar river and Mayurakshi river, and the correlation between basic environmental flow and river sustainability was explored for the Sankh river. The flow analysis shall emphasize the importance of maintaining the EFs to ensure the well-being of humans reliant on river systems. This shall also accentuate and contribute to the idea of balancing between development and sustainability.

2 | MATERIALS AND METHODS

2.1 | Study Area

The study area comprises four basins, namely, North Koel, Sone, Mayurakshi and Damodar basin, located in the state of Jharkhand in the eastern part of India (Fig. 1). The North Koel river basin covers approximately 20,000 km^2. It is a tributary to the Sone river, eventually joining the Ganges river. With a climate marked by hot and dry summers and a monsoon season from June to September, the North Koel river basin is vital for agriculture. The principal tributaries are the Auranga and the Amanat, both joining it from the east. The Sone river basin is in central India and covers parts of Jharkhand, Bihar, and Uttar Pradesh. The portion in Jharkhand covers an area of approximately 21,000 km^2. The basin has several large dams, including the Tenughat and Konar dam. These dams provide hydroelectric power and irrigation water for the surrounding areas. The Mayurakshi river basin covers parts of Jharkhand and West Bengal in eastern India. The portion of the basin in Jharkhand covers an area of approximately 4,200 km^2. The Mayurakshi river in Jharkhand originates in the hills of the state's western region and flows through the districts of Dumka and Godda before entering West Bengal. The Mayurakshi river basin is also known for its unique ecology and biodiversity. The region is home to several protected areas, including the Mayurakshi Wildlife Sanctuary and the Ajodhya Hills Wildlife Sanctuary, which support a variety of flora and fauna. The Damodar river basin holds a significant position within the larger Ganga river basin, as it joins the Ganga on its right bank to the east of the Sone river. Originating in the Palamau district of Bihar at an elevation of 1366 m within the Chottanagpur Plateau, the Damodar river flows through the states of Jharkhand and West Bengal, encompassing a catchment area of 41965 km^2. Development projects, including the renowned Damodar Valley Corporation (DVC), have altered the river's flow, aiding flood control. The basin's industrialisation, power generation potential, irrigation capabilities, and navigational possibilities contribute to its importance. Managing the Damodar river basin is critical to ensure sustainable development and safeguard the ecological and social values associated with the river.

2.2 | Flow Duration Curve Method

In this study, a dataset spanning 14 years (2006-2019) was utilized to assess the environmental flow of the river. The

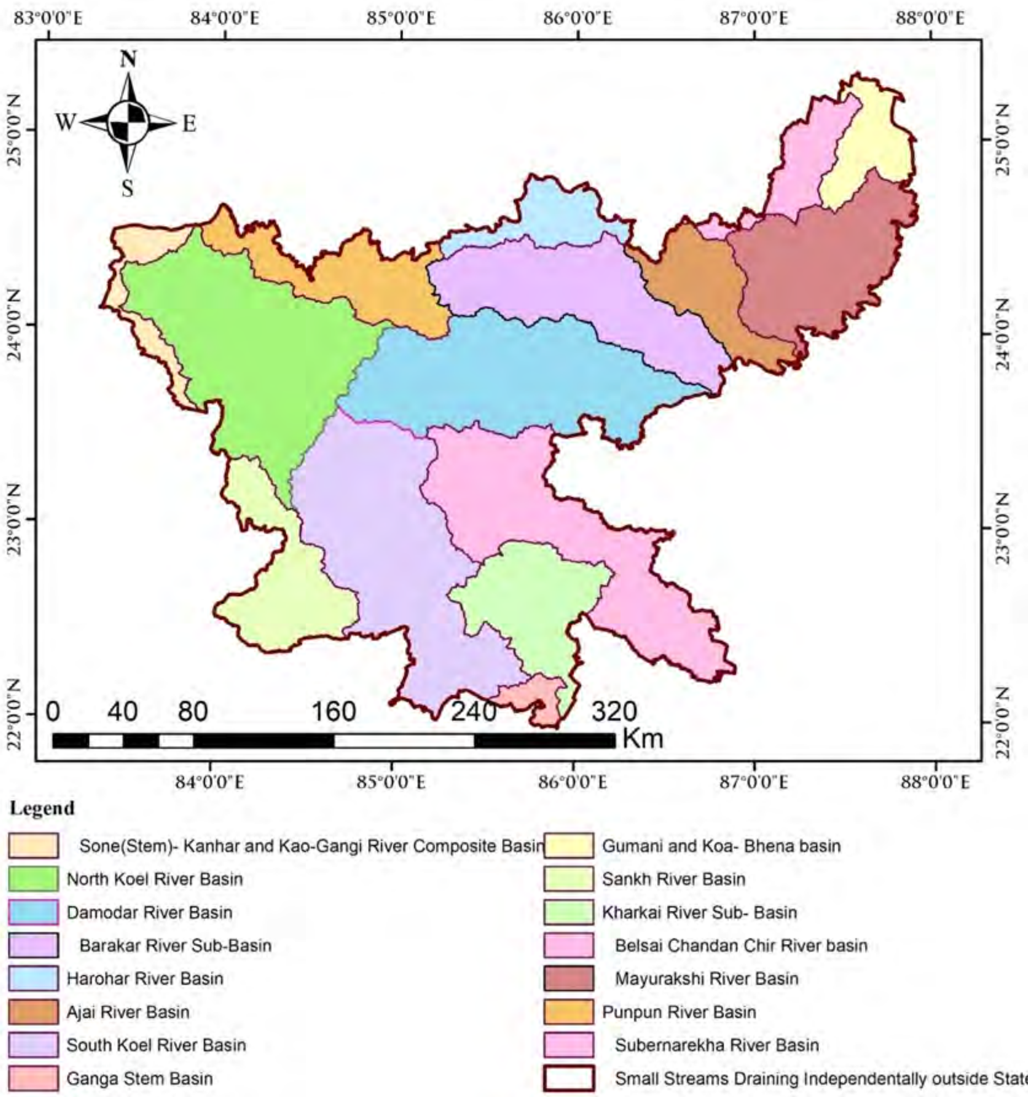

FIGURE 1 River basin map of Jharkhand

discharge data was obtained from the Water Resource Department of the Government of Jharkhand. The FDC is a cumulative frequency curve representing the percentage of time the average discharge at a particular location has equaled or exceeded a specific value. The FDC can represent daily, weekly or monthly discharge values. The discharge data were plotted on a logarithmic scale or as a percentage of the total discharge. Chronological sequences of events are not considered. The method is beneficial when created with long-term data ranging from 10 to 50 years. The method does not consider the biological perspective, as biotopes are primarily influenced by low variation and velocity (Tharme, 2003). A standard hydrological index is 7Q10. It defines the lowest Low measured for seven consecutive days within a 10-year return period. A variant of 7Q10 has been used in Canada, namely 7Q2. Since it uses a return period of 2 years, it provides a slightly higher threshold.

The other indices, Q95 and Q90 (daily lows exceeded 95% and 90% of the time), are prevalent and used in many countries. Hydrological variability at any given location mainly has five main characteristics such as depth, duration, amplitude, frequency, and timing. In the present study, the Q90 method was used. The data were arranged in descending order. The exceedance probability of the event P was determined by the given formula:

$$P = 100 \times \left(\frac{M}{n+1}\right) \qquad ...(1)$$

Where, M is rank and n is number of values. The Q90 method defines the flow that is exceeded 90% of the time. It defines the minimum low level for the aquatic environment and checks the discharge duration of small rivers. The water level should not fall below the low water level assigned by this method in order to maintain a healthy balance in the ecosystem. In the FDC method, the baseline environmental flow is often determined using the Q90 or Q95 discharge, representing the flow that exceeded 90% or 95% of the recorded period. However, the precise ecological significance and applicability of Q90 and Q95 are not clearly defined in existing studies, and their suitability can vary from river to river. To enhance the transferability of the baseline environmental flow index, the T-FDC method addresses this variability by selecting the mean values of Q90 and Q95 as the basic environmental flow (Singh and Mitra, 2018). This approach aims to provide a more standardized and consistent measure that can be applied across different rivers. For a specific month, the basic environmental flow can be determined by using the given method.

$$E_{min} = \frac{Q_{90} + Q_{95}}{2} \qquad ...(2)$$

Where, E_{min} is basic environmental flow, Q_{90} and Q_{95} represent the flow that exceeded 90% or 95% of the recorded period. The Global Environmental Flow Calculator (GEFC) is a tool designed to assess the water requirements of freshwater ecosystems. It utilizes monthly flow data and FDC to estimate EFs, which are aimed at maintaining or improving the condition of an ecosystem known as an Environmental Management Class (EMC). The GEFC offers six EMCs, each representing a different level of modification. By shifting the reference FDC along the probability axis, the FDC for each EMC is established, providing a range of EF scenarios. The choice of the most suitable EMC for a specific river relies on expert judgment. Once the FDC is determined, it can be converted into a time series of EFs. The main methods the GEFC uses are FDC, Ecosystem-flow models and Expert judgment. Ecosystem-flow models simulate the interactions between a river and its ecosystem. These models estimate the effects of different flow levels on river health. In some cases, the GEFC uses expert judgment to estimate environmental flows. This is required in case of limited data availability or a complex river ecosystem.

2.3 | River Sustainability Index

River sustainability integrates biological, social, and economic factors to ensure a river ecosystem's long-term vitality and balance. It entails controlling water availability and quality, maintaining ecosystem health, involving stakeholders, utilizing integrated management techniques, and implementing efficient regulations. River sustainability may be attained through preserving appropriate flows, preserving water quality, restoring ecosystems, incorporating communities, and using adaptive management. This promotes biodiversity, serves the requirements of many stakeholders, guarantees the river's resilience, and strikes a balance between economic growth and environmental preservation. In the end, maintaining the essential resources and ecosystem services of rivers increases the well-being of the present and future generations. Environmental flow data serves multiple purposes in assessing river sustainability. The FDCs derived from this data offer insight into the likelihood of different flow levels occurring and help establish minimum flow requirements for maintaining ecosystem health. Additionally, Sustainability Indices (SIs), calculated by comparing mean flow to minimum flow, provide a quantitative measure of a river's flow regime adequacy. They are employing environmental flow data to aid in formulating river management plans, encompassing various strategies to sustain the desired flow regime. These plans include regulating water withdrawals, preserving riparian areas, restoring natural flow patterns, managing pollution, facilitating fish passage, and promoting water conservation. By utilizing environmental flow data, river sustainability can be effectively evaluated and addressed through informed management practices (Arthington *et al*., 2006). The sustainability index was determined by using the following formula:

$$SI = \frac{Mean\ flow}{Minimum\ flow} \qquad ...(3)$$

Where, *SI* is the Sustainability Index. A higher *SI* denotes a more sustainable flow regime for the river. The *SI* range might change depending on the unique river and its ecology. However, it is generally accepted that a river's flow regime is sustainable if the *SI* is 1 or above. A river's flow regime is very sustainable if the *SI* is 2 or higher.

3 | RESULTS AND DISCUSSION

3.1 | North Koel River

The GEFC was applied to determine the EF requirement of the North Koel river downstream of the Daltonganj site. The estimation was based on FDC and involved categorizing river discharge into six EMCs utilizing the available discharge data. The EMC ranged from natural to critically modified (Fig. 2). From January 2006 to December 2019, the Mean Annual Runoff (MAR) of the river was determined to be 7399 Million Cubic Meters (MCM). According to the GEFC, in order to maintain the downstream stretch of the North Koel river in a moderate condition (Class C) and preserve essential ecosystem functions, it is necessary to release 12.5% of the MAR, equivalent to 924.875 MCM from the barrage (Table 1). Moreover, the GEFC estimated that for a slightly modified river (Class B), 28.6% of the MAR is required, while 56.2% is necessary to sustain the river in its natural state (Class A). It is important to note that these estimations assume the river's current classification as (Class C). If the river is categorized differently, the required environmental flow may vary accordingly. A similar analysis was made for the same river at different sites. The MAR of

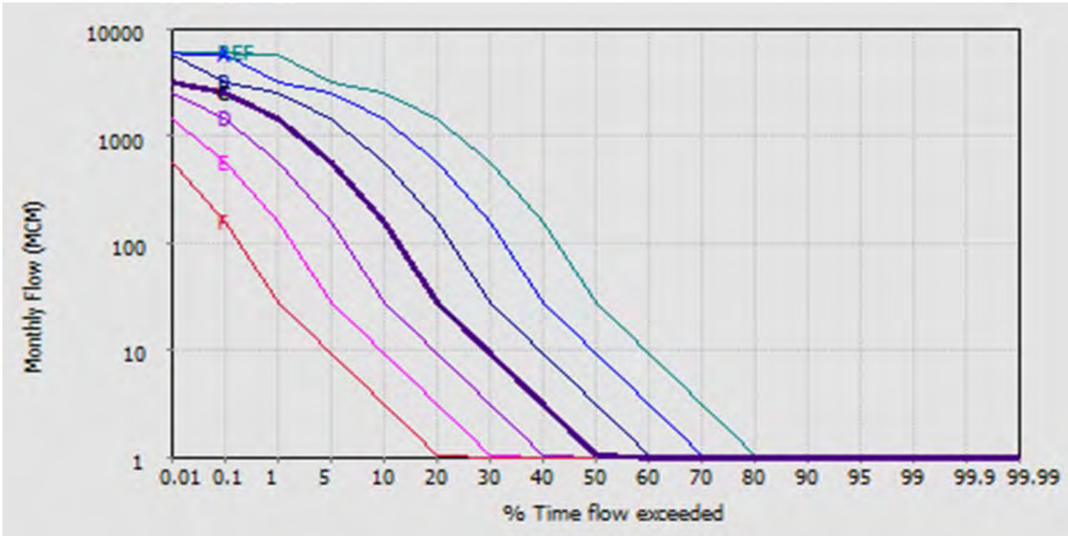

FIGURE 2 Flow Duration Curves (FDC) for six environmental management classes North Koel River at Daltonganj

TABLE 1 Estimated discharge (%) for different environmental classes for North Koel River-Daltonganj

	Default Environmental Management Classes	% MAR
A: Natural	Pristine condition or Minor Modification of in-stream and Riparian habitat	56.2
B: Slightly Modified	Largely Intact biodiversity and habitats despite water resource development and for basin modification	28.6
C: Moderately Modified	Although habitats and biota dynamics have been disturbed, basic ecosystem functions are still intact. Some sensitive species have been lost or reduced in extent.	12.5
D: Largely Modified	Large changes in natural habitat biota and basic ecosystem function have occurred. The species richness is lower than expected, and the presence of intolerant species is much lower.	4.5
E: Seriously Modified	Habitat diversity and availability have declined to a strictly lower-than-expected species richness. Only tolerant species remain, and indigenous species can no longer breed.	1.4
F: Critically Modified	Modification have reached a critical level and ecosystem has been completely modified with almost total loss of natural habitat and biota in the worst guess the basic ecosystem function have been destroyed and the changes is irreversible.	0.4

the river was determined to be 12952 MCM at the Garwah site. According to the GEFC, at this location, in order to maintain the downstream stretch of the North Koel river in a moderate condition (Class C) and preserve basic ecosystem functions, it is required to release 12.3% of the MAR, equivalent to 1548.81 MCM from the barrage. Moreover, the GEFC estimated that for a slightly modified river (Class B), 26.9% of the MAR is required, while 53% is necessary to sustain the river in its natural state (Class A). From January 2006 to December 2019, the MAR of the Amanat river was determined to be 1986 MCM (Fig. 3). According to the GEFC, in order to maintain the downstream stretch of the Amanat river in a moderate condition (Class C) and preserve basic ecosystem functions, it is necessary to release 6.1% of the MAR, equivalent to 121.46 MCM. Moreover, the GEFC estimated that for a slightly modified river (Class B), 15.4% of the MAR is required, while 38% is necessary to sustain the river in its natural state (Class A).

For the Auranga river to be in a moderate condition (Class C) and preserve basic ecosystem functions, the release of 12.6% of the MAR is required. Moreover, the GEFC estimated that for a slightly modified river (Class B), 26.7% of the MAR is required, while 51.5% is necessary to sustain the river in its natural state (Class A). The GEFC was utilized to assess the EF requirement of the Tahla river downstream of the Tahle site. From January 2006 to December 2019, the MAR of the river was determined to be 20106 MCM. For Tahla river to be Class C, it is required to release 6% of the MAR. For Class B, 16.7% of the MAR and for Class A, 42.5% is necessary to sustain the river in its natural state. Similarly, for the Domni Nala river downstream of the Kharaundhi site, the MAR of the river was determined to be 171.5 MCM. For Class C, the release of 6.7% of the MAR is required, whereas for Class B and Class A, 16.5% and 39.2% of the MAR are required, respectively. For the same river, different locations need a different release of water depending upon the requirement of rive to be a particular class. North Koel Reservoir Project comprises a dam on the North Koel river near the Kutku village in the Latehar district of Jharkhand, a barrage located 96 km downstream of the dam at Mohammadganj in Palamu

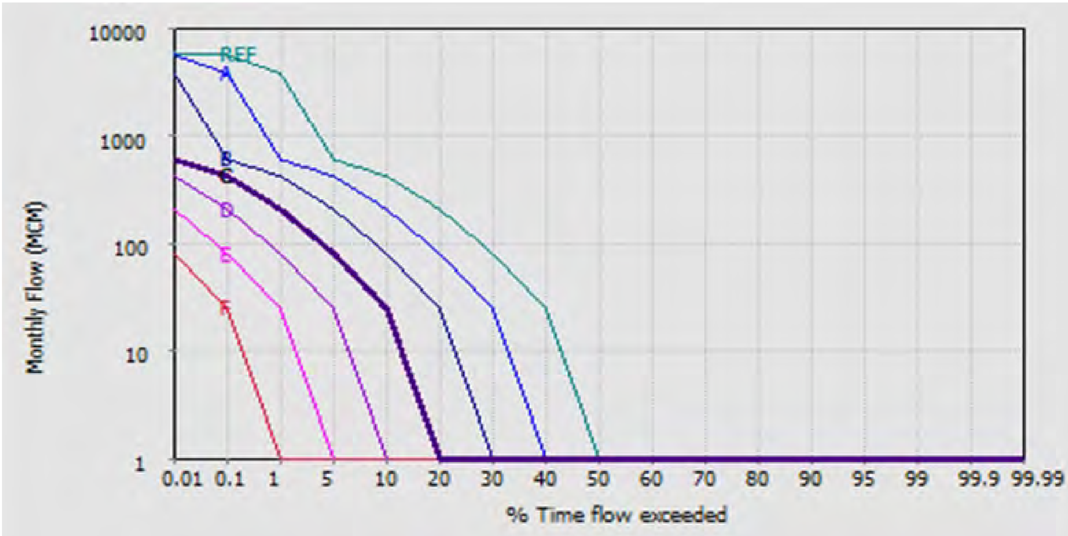

FIGURE 3 Flow Duration Curves (FDC) for six environmental management classes of Amanat River

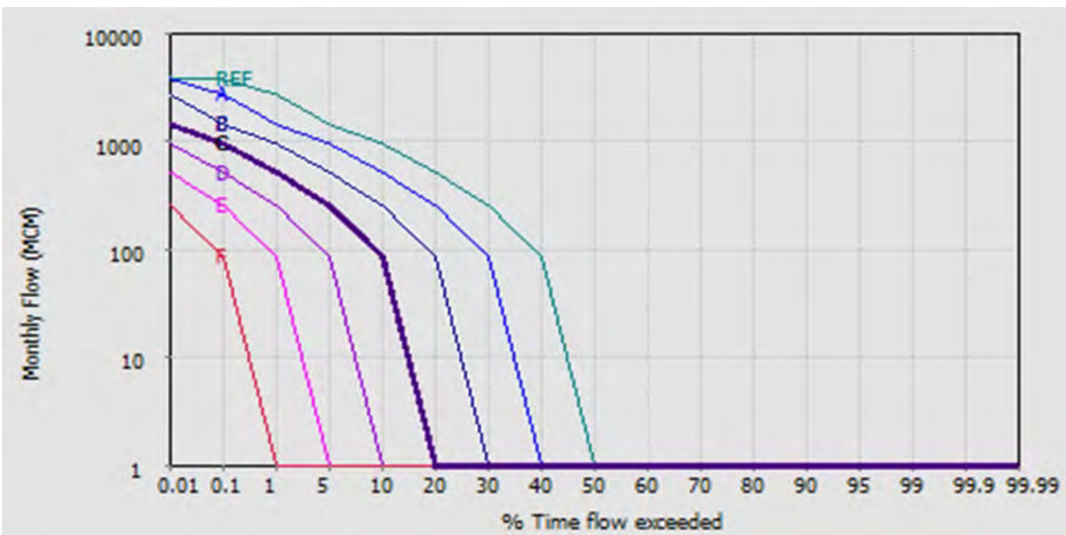

FIGURE 4 Flow Duration Curves (FDC)for six environmental management classes of Kanhar River

district, a right main canal (RMC) and a left main canal (LMC) from the barrage. reduce the reservoir level to save the core area of the Palamu Tiger Reserve from submergence.

3.2 | Sone Basin - Kanhar River

The GEFC was utilized to assess the EF requirement of the Kanhar river downstream of the Ramanujganj site. The MAR of the river was determined to be 3475 MCM (Fig. 4). To maintain the downstream stretch of the Kanhar river in a moderate condition (Class C) and preserve the functional ecosystem, the release of 11.6% of the MAR may be ensured. For a slightly modified river (Class B), 26.8% of the MAR is required, while 53.7% is necessary to sustain the river in its natural state (Class A). To maintain the river in moderate condition and to keep basic ecosystem functions intact, at least 18.9% of MAR was estimated, while the actual discharge of the river was merely 5.16% of MAR. The river presently holds 89 fish species, but 20 species reported in an earlier study were not observed, while 14 new fish species were encountered.

3.3 | Damodar River

The EF requirement of the Damodar river downstream of the Tenughat dam was assessed. From January 2006 to December 2019, the MAR of the river was determined to be 1559 MCM (Fig. 5). In order to maintain the downstream stretch of the Damodar river in a moderate condition (Class C) and maintain ecosystem, it is good to release 16.6% of the MAR, equivalent to 258.79 MCM. The GEFC estimated

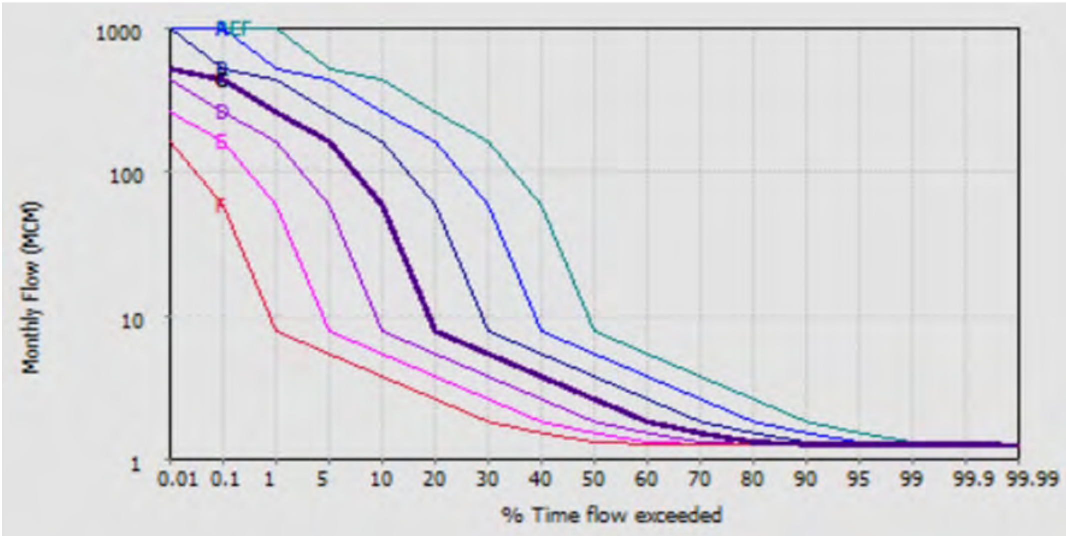

FIGURE 5 Flow Duration Curves (FDC) for six environmental management classes of Damodar River

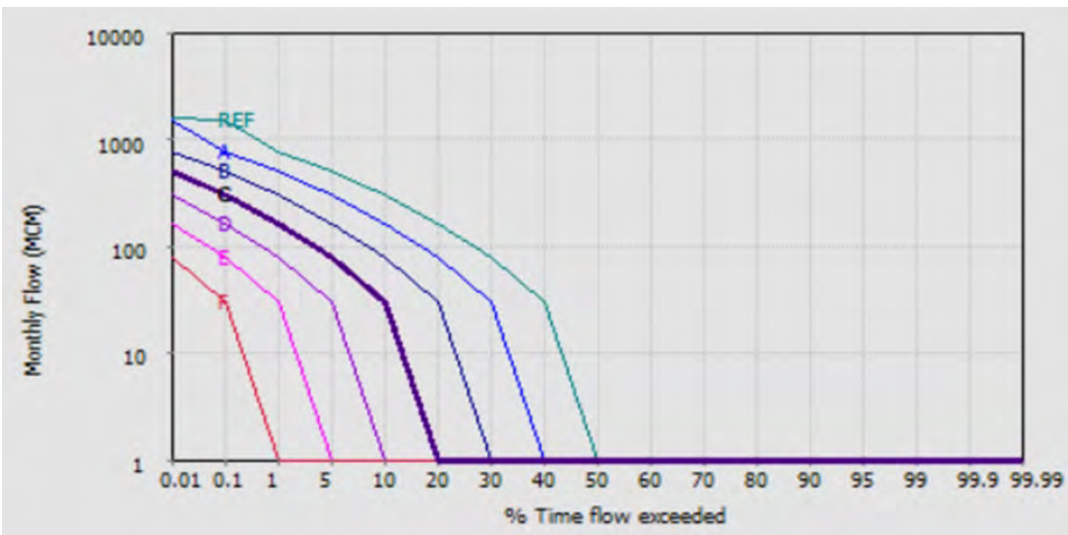

FIGURE 6 Flow Duration Curves (FDC) for six environmental management classes of Barakar River

that for a slightly modified river (Class B), 33% of the MAR is required, while 59% is required to sustain the river in its natural state (Class A). At another site at Ramgarh, the MAR of the Damodar river was determined to be 819.2 MCM. For Damodar river to be in Class C, it is necessary to release 12.2% of the MAR, equivalent to 99.94 MCM, from the barrage. Moreover, the GEFC estimated that for a slightly modified river (Class B), 28.6% of the MAR is required, while 56.6% is necessary to bring the river back to its natural state.

The GEFC was further utilized to assess the EF requirement of the Barakar river downstream of the Giridih site. The MAR of the river was determined to be 1073 MCM (Fig. 6). According to the GEFC, in order to maintain the downstream stretch of the Barakar river in a moderate condition (Class C) and preserve basic ecosystem functions, it is necessary to release 11.6% of the MAR, equivalent to 124.46 MCM. Moreover, the GEFC estimated that for a slightly modified river (Class B), 26.7% of the MAR is required, while 53.8% is necessary to sustain the river in its natural state (Class A). The MAR of the Bokaro river downstream of the Tenughat site was determined to be 384.5 MCM. To maintain the downstream stretch of the Bokaro river in a moderate condition (Class C) and preserve basic ecosystem functions, it is necessary to release 9% of the MAR, equivalent to 34.605 MCM, from the barrage. Moreover, the GEFC estimated that for a slightly modified river (Class B), 22.4% of the MAR is required, while 47.6% is necessary to sustain the river in its natural state (Class A). The MAR of the Saphi river was determined to be 452.6

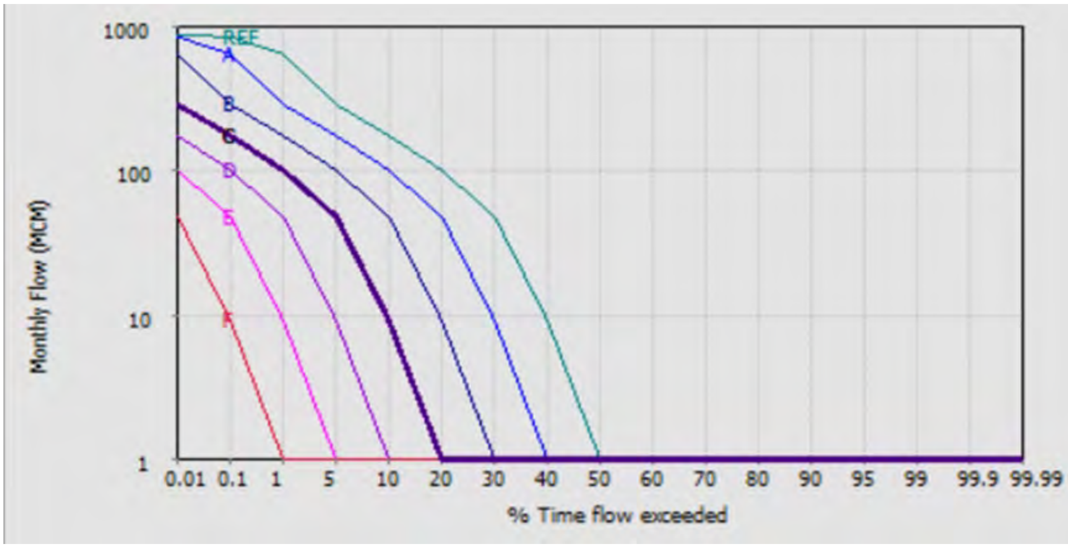

FIGURE 7 **Flow Duration Curves (FDC) for six environmental management classes of Mayurakshi River**

TABLE 2 **SI range for different levels of sustainability**

Sustainability Level	SI Range
Very Sustainable	2 or greater
Sustainable	1 or greater
Unsustainable	0.5 or less
Highly Unsustainable	0 or less

MCM. To maintain the downstream stretch of the Saphi river in a moderate condition and preserve basic ecosystem functions, it is necessary to release 11.9% of the MAR. Moreover, the GEFC estimated that for a slightly modified river (Class B), 26.9% of the MAR is required, while 53.6% is necessary to sustain the river in its natural state (Class A). It is important to note that these estimations assume the river's current classification as (Class C).

3.4 | Mayurakshi River

The GEFC was used to assess the EF requirement of the Mayurakshi river downstream of the Dumka site. The MAR of the river was determined to be 890.2 MCM (Fig. 7). According to the GEFC, for maintaining the downstream stretch of the Mayurakshi river in Class C, it is required to release 10.1% of the MAR, which is equivalent to 89.91 MCM. Moreover, the GEFC estimated that for a slightly modified river (Class B), 24.2% of the MAR is required, while 51% is necessary to sustain the river in its natural state (Class A). It is important to note that these estimations assume the river's current classification as (Class C). For the Bansloi river downstream of the Maheshpur site, the MAR was determined as 510.9 MCM. To maintain the downstream stretch of the Bansloi river, around 10.2, 24.9 and 51.9% of MAR is required to release to maintain the river in Class C, Class B and Class A, respectively. Further, a similar analysis was made for the Bassano river downstream of the Amrapara site. The MAR of the river was determined to be 620.9 MCM. According to the GEFC, to maintain the Basane river's downstream stretch in a moderate condition (Class C) and preserve basic ecosystem functions, it is necessary to release 10.5% of the MAR, equivalent to 65.19 MCM, from the barrage. Moreover, the GEFC estimated that for a slightly modified river (Class B), 25.3% of the MAR is required, while 52.2% is necessary to sustain the river in its natural state (Class A). The sustainability index for the Shankh river was found to be 12.01, indicating that it is very sustainable (Table 2).

The Global Environmental Flow Calculator (GEFC) has been used for rapid assessment of EFs in major rivers of the world. This has been developed by IWMI and uses the FDC for natural reference conditions and for each EMC subsequently. The user can select the most suitable EMC for the river in question. The higher the EMC, the more water will need to be allocated for ecosystem maintenance or conservation and more flow variability will need to be preserved. This has been nicely elaborated by Smakhtin and Anputhas (2006).

4 | CONCLUSIONS

The study was conducted to determine the environmental flow for 4 major rivers of Jharkhand along with the sustainability index for the Sankh river. The environmental flows were estimated using GEFC, which has specific advantages over the traditional method. For North Koel river, environmental flows were estimated at two locations ranging from 12.3 to 12.5 % of MAR. EFs requirement for tributaries of North Koel, such as Amanat river and Auranga river, was found to be 6.1 and 12.6% of MAR. Under Sone Basin, Kanhar river required a minimum flow of 11.6% of MAR under class C (moderately modified. For Damodar

Basin, EFs for all the rivers ranged from 9% to 12% of MAR. Bokaro river required 9% for MAR (34.605 MCM) under class C. For Mauyrakshi basin, environmental flows were found to be 10% of MAR under Class C (moderately modified). As many structural interventions are planned across the rivers in Jharkhand, information on minimum flows is essential to sustain the activities on the downstream side. The SI value of 12.01 for Shank river signifies an exceptional level of sustainability. This remarkable score indicates that the river's ecosystem is well-preserved, with minimal negative impacts from human activities. It reflects effective management practices and conservation efforts to maintain water quality, biodiversity, and ecological balance. Environmental flow estimation is required for all the rivers where structural interventions have altered the flow. This may be included as part of the development process.

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DATA AVAILABILITY STATEMENT

Data can be made available on request.

CONFLICT OF INTEREST

Authors have no relevant financial interests or personal relationships to disclose.

AUTHOR'S CONTRIBUTION

First author: Data collection, model set up and evaluation and analysis. Second author: Supervision, Drafting the manuscript.

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