Assessment of impacts of altered environmental flow on fishing in lower Damodar river basin, India

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Received: 13 September 2021 / Accepted: 19 February 2022 / Published online: 24 March 2022
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Abstract
Rivers are one of the prime sources of freshwater and act as the arteries of the Earth. While the growing pressure of meeting freshwater demands through extensive large and small-scale water infrastructures is indispensable, maintaining the river's natural flow is vital in sustaining the aquatic ecosystem harbored within it. Hence, it is essential to regulate the environmental flow for the sustainability of the rivers and their ecosystem management. This paper focused on analyzing the importance of maintaining the environmental flow by computing the degree of deviation in the river flow regime from the natural flow conditions. It used the Range of Variability Approach (RVA) to calculate the degree of deviation while also lending a special focus on the implications of altered river flow regime on the socio-economic activities especially fishing as a livelihood for the communities residing along the flanks of river Damodar in the downstream region. The daily discharge data measured during pre- and post-dam construction at the Durgapur barrage site of the lower Damodar river basin were used to compute the degree of alteration. It applied the convergent parallel mixed methodology to simultaneously analyse the qualitative responses and the quantitative data to effectively interpret the impact of altered environmental flow on the fishing livelihood of the communities. Thus, the analysis emphasized the importance of maintaining the environmental flow for ensuring the well-being of humans reliant on river systems. This shall also accentuate and contribute to the idea of balancing between development and sustainability.

Keywords Convergent parallel mixed method · Durgapur barrage · Range of variability approach (RVA) · Downstream flow regime

Introduction
Among several forms of water resources, rivers hold a great significance in the sustenance of the ecosystem. They serve as one of the most significant freshwater sources and the living arteries of the Earth. If harnessed efficiently and sustainably, rivers have the tenacity to serve as an impetus to the growth and development of water sectors. They are also habitat to one of the world's richest biodiversity, serving as a vital and vibrant ecosystem to several significant aquatic species across the world. Thus, the main purpose of effective water resources management has been to optimize the social and economic needs derived mainly from the river (Bergstrom and Loomis 2017) while simultaneously maintaining its environmental vitality. The sustenance of the river and its ecosystem lies in the pattern of consumerism that we impose through different water allocations. Constructing the dams across the river to tap the complete water usage for various purposes has historically been practiced worldwide. In India, the Grand Anicut Dam was constructed across river Cauvery by King Karikalan of the Chola Dynasty in the first century (Udhaya Nandhini et al. 2016). While development of cascade of dams in India depicts the different purposes for which the water is diverted, the eventual environmental cost incurred over the decades has also been indispensable (Tortajada et al. 2012). For instance, the event of hydropeaking is more evident in case of an increased demand for hydropower generation. This leads to rapid, short-term fluctuations in the river flow and water levels (Bakken et al. 2012; Boavida et al. 2020a; Widén et al. 2021). It results in highly negative
impacts, such as intermittent periods of drying that affect the downstream riverine ecosystem (Courret et al. 2021; Widén et al. 2021). Furthermore, due to these gigantic structures and the water retained or diverted by them, the river systems often experience a zero-flow state in the downstream. In some cases, the turbines cease operation completely, and hydroelectricity is not generated (Widén et al. 2021). Such drastic and abrupt functionalities of the hydropower plants and events such as hydropeaking trigger significant degresion of the river from the natural flow regime and imposes danger over the river ecosystem (Tuftan and Noack 2012). The extent of water resource management significantly depends on maintaining the river’s health within acceptable limits, including quality and quantity. Rivers hold a great significance in people’s lives, directly or indirectly, depending on the nature of their use. Every purpose for which the river flows are allocated holds immense meaning in achieving the larger development goals. The dynamicity of free-flowing rivers has always enticed humans. It is, however, the taming of rivers that evolved as an apparently better choice for development, diversification, and modernization of several needs. Furthermore, in India-like countries, rivers bear a plethora of values with a strong socio-cultural emotion ingrained in the river's free-flowing nature. Some of the most remarkable Indian river systems are the river Ganges, Godavari, Damodar, etc. People significantly associate their cultural beliefs and practices to these river systems compelling water releases to be according to their cultural and religious requirements of the river water levels (Lokgariwar et al. 2014).

Though rivers are personified and bestowed with such worth, the quality and health of the river system are constantly declining due to the growing demands coupled with poor management practices (Karimi et al. 2021; Poff et al. 1997). The health of a river is often related in terms of its flow velocity as well the conditions being favorable to support the aquatic ecosystem. Hence, post-construction of water infrastructures, it is vital to maintain the river flow regime proximal to the natural conditions to prevent the river health from deteriorating. The change in river flow regime is defined as the temporal variability of the streamflow at the gauging site (Botter et al. 2013). The specific components of a river flow regime vital to shaping the existing ecological processes are magnitude, frequency, duration and timing of discharge, and the rate of change of the hydrologic conditions. When the hydrologic conditions of the river change due to human interventions, it paves the path of alteration of these vital components in the river flow regime. It further leads to damage of the existing ecosystem functions especially the loss of sensitive and economically valuable aquatic species. Therefore, the natural conditions of the river flow regime when altered by the virtue of manmade structures, calls for an introspection into the existing reservoir management norms and scopes for improvement in terms of river flow releases. In recent decades, the necessity of healthy and timely river flows to sustain the ecosystem services are extensively acknowledged and realized as valuable to human society (Jain 2015). These thoughts and notions have constantly contributed towards improving the understanding of the concept of environmental flow. The principal idea of the environmental flow is to re-instate the altered regime to the proximal natural conditions for the benefits of the downstream ecosystems and the communities dependent on the river system. The Theun-Hinboun Expansion Project in Central Laos also focused on successfully operating a social action management plan to benefit the downstream communities. The project focused on creating livelihood opportunities for the displaced communities and to reduce the regressive socio-economic implications of the hydropower project over the downstream areas in the long run (Sparkes 2014). More often, a lack of planned development forces displacement of downstream communities resulting in poor opportunities. The famous Narmada Bachao Andolan symbolizes an endeavor against such unplanned displacement. Began during the construction of the Sardar Sarovar Dam in India, the Andolan focused to protect the downstream communities against the impacts of the dam (Tortajada et al. 2012). Furthermore, a case study on the Geheyan Dam, conducted by the Lund and Fudan Universities, also reiterated the underdevelopment of downstream communities because of different dam-induced implications such as restrained shipping facilities (Erdal 2012). There are several other unfortunate examples of river systems across the world to illustrate the harm caused to downstream regions and communities by altered river flow regimes. For instance, river Amu Darya, which was once the longest in Central Asia, has reduced its flows today to the extent that it does not even reach the Aral Sea (Cooper et al. 2006). The Yellow River, in China, which was infamous for its flood issues in the lower Sea, now suffers from stressful water conditions due to the declined releases from dams into the river downstream for three consecutive years (Giordano et al. 2004). Even in India, several water infrastructures have resulted in controlled river systems and deteriorated river health. The upper Ganga basin, comprising a cascade of dams, is one of the most controlled river systems across the nation. This led to significant degradation of the river health. Thus, it promoted the basin to be the first under the radar of the maiden environmental flow assessment conducted by the Ministry of Environment, Forest, and Climate Change (MoEF&CC) in collaboration with WWF. They undertook the Building Block Methodology at the basin scale to not just assess the environmental flow and cultural flow requirements but also to invest in local capacity building and improve the level of water allocation amongst its stakeholders. A similar perspective was later used to conduct an environmental flow
The underlying purpose of environmental flows is to sustain the river and the lives of people dependent on it. Several economic activities are dependent on rivers and the associated livelihood practices. Fisheries is one such livelihood that is directly reliant on the river health, the flow velocity, depth of the river, and to name a few. Environmental flow assessment and maintenance are crucial to sustaining such livelihood practices (Adeva Bustos et al. 2017; Karakoyun et al. 2018). The fate of the coastal fisheries in the Yellow River Delta due to the restrained and unregulated release of water from the upstream dams is a testament to the importance of environmental flow management for securing such livelihood practices (Giordano et al. 2004). Boavida et al. (2020b) argued that many unanswered questions still remain to establish the linkage between physical processes that impacts fish biota in response to unregulated environmental flow that leads to a highly unstable riverine environment.

The attempt to define environmental flow assessment through different hydrological, hydraulic, holistic, and habitat simulation techniques has always given significant attention to restoring flows to revive and protect the riverine ecosystem. The methods have evolved for the environmental flow assessment over decades, considering the different river characteristics (Bakken et al. 2012; Karimi et al. 2021). However, enhancement of these methods cannot deny the fact that environmental flow assessment is largely dominated by mathematical computation of flows even when the cultural and social components have considerable stakes in the flow requirements by people such as in the Ganges. These stakeholders have a significant contribution in establishing sustainable implementation of hydropower projects as well as in facilitating river management through the implementation of environmental flow regulations (Keeffe 2018; Wang 2012). Hence, excluding subjective stakeholder responses and perceptions generates a gap in the holistic interpretation of the concept of environmental flow. (Anantha and Dandekar 2012; Dams 2001; Keeffe 2018). Furthermore, the reduced flow velocity and volume at downstream sections due to the lesser release of upstream reservoir operations have derogative impacts on the riverine ecosystem and its fish population (Susmita Ghosh 2011). This study, therefore, aims to highlight the importance of stakeholder feedback in analyzing the importance of environmental flow requirements. It focuses on computing the degree of alteration from the natural flow regime of river Damodar flowing past Durgapur and Bankura in the Lower Damodar river basin, which is the study area for this research. While calculating the digression from the natural flow regime, the study also targets to analyze its impacts on fishing as a livelihood for several fishing communities downstream of the Damodar river basin. Drawing a parallel between the two components—on-field responses and historically recorded daily discharge data, the study imparts a more significant meaning and understanding of the importance of environmental flow for maintaining river health, aquatic ecosystem, and human well-being.

**Background of the problem**

The Lower Damodar river basin is a narrow and elongated geographical region drained by the river Damodar and its distributaries. The river originates from the Kharparpet hills in the Chottanagpur plateau of Jharkhand and then heads off eastward into the rolling plains of West Bengal. It, thereafter, passes through Bankura, Paschim Burdwan, Hugli, and Haora districts. The river finally merges into the Bhagirathi-Hugli river and drains into the Bay of Bengal (Bengal, 2018; Susmita Ghosh 2014).

On 7th July 1948, India beheld the first multipurpose river valley project, the Damodar Valley Corporation (DVC). It comprises of Tilaiya, Konar, Maithon, and Panchet dams in the upper stretches of the river and the Durgapur Barrage located in downstream. The Durgapur Barrage served as the passage through which the Damodar river entered from Jharkhand into West Bengal. The accomplishments of DVC over the past decades, when compared to the initial objectives of the project, reflect skewed outcomes. This affected the regional economy of lower basin region as well as the downstream stretch of the river (Bhattacharyya 2011b). The natural gradation of the river faced several obstructions and diversions that reduced it to a meager construct of human activity and a highly controlled system (Bhattacharyya 2011a; Karim and De 2020). Further, the frequent incidents of sediment deposition added to the project's failure (Bhattacharyya 2011a; Susmita Ghosh 2011) (i.e., thirty-three percent of the storage capacity was lost due to siltation). The Lower Damodar river basin has always been under the radar for extensive research related to flood hydrology and flood frequency (Bhattacharyya 2011a; Sandipan Ghosh and Guchhait 2016; Karim and De 2020). This is the first study on the Lower Damodar river basin to the authors' best knowledge to analyze the nature of the river flow regime with the objective to understand the minimum flow required to prevent the river from gradually choking. It reiterates the importance of environmental flow assessment for better management of the river system to secure the livelihoods reliant on the river Damodar.

Fisheries are one of the oldest means of economic gains in the region and form a major component of the food basket in the region. During the early fifties, nearly 89 fish species belonging to 20 families were identified in Lower Damodar. Amongst these, 25 fish species were found to have...
a commercial value. However, over the years, with increased occurrences of delinking and declining river depth, the number of fish species available for commercial fishing has reduced to 16 that belong to 6 families (CIFRI 2010; Susmita Ghosh 2011; Das 2013).

Hence, an entire argument revolves around the DVC transforming into a "defunct drainage" and affecting livelihoods, especially fisheries, downstream. Such damming practices not just trigger alterations to the flow depth and velocity downstream but also impact water levels upstream (Widén et al. 2021). Therefore, the paper focuses on evaluating the implications of environmental flow on the fishing communities in regions of Durgapur and Bankura (Fig. 1) with the Durgapur Barrage as the primary reference point (23° 28′ 48.15″ N; 87° 18′ 21.95″ E) of the study area. This study highlights the impacts of environmental flow alteration on the fishing communities and their livelihood in the regions proximal to the Barrage.

Data description

The paper used both qualitative and quantitative data related to the proposed study. The qualitative data was obtained through an interview conducted in different parts of Durgapur and Bankura (Fig. 2). The survey aimed to capture the insights of the people of the fishing communities reliant on the river Damodar for their livelihood practices, namely fishing. Thus, in Durgapur, four pallies and two villages in Bankura along with prominent markets in each of these regions were selected. A sample size of forty-one fishing households and ten individual fishermen at the fishing ghats were interacted for the study. These interactions served as the empirical evidence to substantiate the changes in the river flow regime and the need to improvise the concept of environmental flow for sustainable river and reservoir management.
The quantitative data comprises the daily river flow data (in m³/sec) obtained from the Teesta-Bhagirath Division of Central Water Commission (CWC). This data has been utilized to compute the degree of alteration using one of the methods of environmental flow assessments, namely the Range of Variability Approach (RVA). The given data set is divided into two timelines—the pre-impact period (1934–1948) and the post-impact period (1981–2013) to calculate the degree of deviation of the present river flow regime from the natural conditions. The pre-dam period is defined as the period that marks the commencement of recording the data till the beginning of construction of the water infrastructure, which, in this context, is the Durgapur Barrage across river Damodar. The post-dam period is marked soon after the completion of construction of the Barrage till the most recent year of data availability (Richter et al. 1998).

Furthermore, Fig. 3 illustrates annual hydrographs of pre- and post-dam construction. It is evident from Fig. 3 that the mean of post-dam hydrograph has shifted from the pre-dam. The reduced mean flows in the post-dam period clearly show the overall reduction in the environmental flow release. Further, the overall range across different months plotted using the maximum and minimum flow values have also widened significantly in the case of post-dam. This clearly indicates significant alteration in the natural flow.
the construction of the dam has brought the advantage of handling extreme flood events.

**Methodology**

The study is based on convergent parallel mixed methodology where after acquiring both the types of data (i.e., qualitative and quantitative), they are compared and analyzed simultaneously (Fig. 4). The qualitative study used the purposeful sampling technique as a certain population was required to answer the intended research objectives of this study (Creswell 2015). Furthermore, adding to the interview schedules, a market survey and oral history interview sessions were also conducted on field to add to the information repository. Lokgariwar et al. (2014) also used similar participatory tools for data collection in his study to conduct a detailed understanding of cultural flow requirement as a concept rooting from the larger discourse of environmental flow requirement. The oral history interviews played a pivotal role in shaping the interpretations on the river flow regime while the Barrage was being constructed. The interview intended to investigate further the seasonal variation in the fish availability, the change in fish demands, the alteration in the profit earned by the fishermen, and the probable reasons for the same. The overall objective of the survey was to unbiasedly assess the impacts reported by the fishermen in their fishing practices because of the altered flow regime components of river Damodar. A summary of the interview guide for data collection from the field is presented in Table 1.

The RVA is best suited to generate outcomes even in data-scarce conditions. It uses the daily river flow data and comprises 33 indicators grouped under five broad categories (Babel et al. 2012; Smakhtin et al. 2006). These categories have unique attributes that highlight the major impacts of the river flow characteristics on the river health, its ecosystem (Babel et al. 2012), and hence, the livelihood practices

**Fig. 4** Schematic representation of the methodology adopted in the study

| S. No | Questions                                                                 |
|-------|---------------------------------------------------------------------------|
| 1     | Where is the place of residence? (to map the native and migrated population in the fishing community) |
| 2     | How many members of the family are associated with fishing?               |
| 3     | How many years of being associated with fishing and the change in the river flow observed? |
| 4     | What are the types of fish available in the river? (to capture the impact of seasonal influence on the river flow and thus on the fish catches) |
| 5     | How are the fish catch and the rate determined? (to capture the implications of altered river flow on the price rate of the fish yields and thus the livelihood security) |
| 6     | What are the alternative sources of income during unsuccessful fish yields at the market? |
| 7     | What are the challenges faced from external factors besides the altered river flow regime? |
derived from the river system, such as fisheries. Each indicator has a range that strictly defines the natural range of river flow variability during the natural or pre-impact period. This method facilitates in reflecting on the alterations caused to the river flow regime post-human perturbations in the form of water infrastructures (Smakhtin et al. 2006) such as the Durgapur Barrage. Alterations in the river entail the capacity to harm the existing aquatic habitat and impair the livelihood practices that might depend on its flow. The RVA uses point-based data for computation and analysis. The point-based data for RVA analysis facilitates the measurement of hydrologic alteration in a temporal dimension (Hao et al. 2016; Karimi et al. 2021). These attributes reflect the advantages of using the RVA to analyze the impact of altered river flow regime post the construction of water infrastructures across the river. The technique involves forming an RVA target range using the 25th and 75th percentile method of non-parametric statistics. This technique sets the lower and upper range that provides the context to the IHA software to compare the present digression in the flow regime of Damodar. The software uses statistical (parametric and non-parametric) techniques to compute the RVA target range. The range obtained is derived from the flow data of the pre-dam period. It guides the river managers to maintain the river flow regime in the post-impact period within the boundaries for 50% of the period for which the data has been acquired. The RVA method, therefore, computes the degree of deviation using the following equation (Babel et al. 2012; Richter 1998):

$$D_i = \left| \frac{(N_0 - N_e)}{N_e} \right| \times 100,$$

where, $D_i$ is the degree of alteration for the $i$th indicator; $N_0$ is the number of observed flows of post-dam years for which the value of the hydrologic parameter falls; $N_e$ is the expected number of post-dam years for which the parameter falls within the RVA target range.

The RVA, for the benefit of the analysis, further associates qualitative classes to the numerical value of the degree of deviation. These classes impart greater meaning to the river alteration. They have been developed setting a 33% mark for each of the categories such as the low alteration (L) category caters to any degree of deviation (D%) that falls within 0–33% while the medium alteration (M) category comprises of any result within the range of 33–67% and the high alteration (H) category is represented by the range of 67–100%. The definitions of these qualitative classes provide an in-depth understanding of the ecological impacts associated with hydrologic alteration (Babel et al. 2012). Thus, these qualitative classes are combined with the river flow data and fishermen responses recorded from the field. This accentuates the analysis of the impacts of environmental flow alteration on fishing livelihood in the Lower Damodar river basin (Table 2).

### Results

The results of several flow-related parameters estimated through the RVA method are presented in Table 3, 4, 5, 6, and 7. These results consolidate the representation of the nature of river flow regime of Damodar. The results primarily depict the changing patterns of river flow regimes and associated river health under the taming effects. The degree of deviation (D) reflects the alteration caused in the river post the barrage construction. The alterations mapped in the river flow regime during the post-dam era might have certain impacts on the aquatic ecosystem (Courret et al. 2021; Karakoyun et al. 2018) as well as on the livelihood of the people who are directly intertwined with the river system. The characteristics of the parameter groups govern these impacts. Each of the parameters in the table conveys a certain connotation that further adds value to the interpretations reported in this paper.

| Table 2 | Summarization of the regime characteristics of the parameter groups |
|---------|-------------------------------------------------------------------|
| Parameters | River flow characteristics | Ecosystem influencing factors |
| Parameter Group 1—Magnitude of monthly flow | The magnitude of flow for each month | Habitat Availability for fishes |
| Parameter Group 2—Magnitude and duration of annual extreme flows and base flow condition | Magnitude and duration of annual extreme flows | Impacts the structure of the physical habitat and the aquatic ecosystem |
| Parameter Group 3—(Julian day): Timing of annual extreme flow | Duration of the annual extreme flows | Impacts the duration of the life cycle of fish species |
| Parameter Group 4—Frequency and duration of High and Low pulse | Frequency and duration of high and low pulses | Impacts the availability of floodplain habitat for aquatic organisms |
| Parameter Group 5—Rate and frequency of flow changes | Rate and frequency of water changes | Impacts the flow velocity of the river and hence the ecosystem |
### Table 3 The estimated degree of hydrologic alteration for parameter group 1

| Parameter Group 1—magnitude of monthly flow (m³/s) | RVA target | Expected count | Observed count | D% | IHA class |
|-----------------------------------------------|------------|----------------|----------------|----|-----------|
|                                               | Low  | High          |                |     |           |
| January                                       | 4.28 | 7.72          | 10.33          | 5.00 | 52 M      |
| February                                      | 3.28 | 8.72          | 10.33          | 6.00 | 42 M      |
| March                                         | 1.98 | 4.72          | 10.33          | 1.00 | 90 H      |
| April                                         | 1.13 | 3.00          | 12.40          | 2.00 | 84 H      |
| May                                           | 1.24 | 5.18          | 10.33          | 1.00 | 90 H      |
| June                                          | 11.14| 46.51         | 10.33          | 8.00 | 22 L      |
| July                                          | 113.00| 210.10        | 10.33          | 4.00 | 61 M      |
| August                                        | 215.90| 418.20        | 10.33          | 4.00 | 61 M      |
| September                                     | 200.70| 279.00        | 10.33          | 2.00 | 81 H      |
| October                                       | 44.52| 110.20        | 10.33          | 8.00 | 23 L      |
| November                                      | 6.00 | 30.62         | 12.40          | 13.00| 5 L       |
| December                                      | 3.28 | 14.76         | 10.33          | 11.00| 6 L       |

### Table 4 The estimated degree of hydrologic alteration for parameter group 2

| Parameter Group 2—Magnitude and duration of annual extreme flows and base flow condition (m³/s) | RVA target | Expected count | Observed count | D% | IHA class |
|------------------------------------------------------------------------------------------------|------------|----------------|----------------|----|-----------|
|                                                                                                  | Low  | High          |                |     |           |
| 1-day minimum                                                                                  | 1.00 | 1.00          | 28.93          | 17.00 | 41 M      |
| 3-day minimum                                                                                  | 1.00 | 1.00          | 24.80          | 16.00 | 35 M      |
| 7-day minimum                                                                                  | 1.00 | 1.00          | 22.73          | 16.00 | 30 L      |
| 30-day minimum                                                                                 | 1.03 | 1.50          | 10.33          | 0.00 | 100 H     |
| 90-day minimum                                                                                 | 2.26 | 4.70          | 10.33          | 0.00 | 100 H     |
| 1-day maximum                                                                                  | 1823.00| 2645.00       | 10.33          | 1.00 | 90 H      |
| 3-day maximum                                                                                  | 1349.00| 1950.00       | 10.33          | 0.00 | 100 H     |
| 7-day maximum                                                                                  | 927.10| 1221.00       | 10.33          | 0.00 | 100 H     |
| 30-day maximum                                                                                 | 467.40| 630.00        | 10.33          | 0.00 | 100 H     |
| 90-day maximum                                                                                 | 325.20| 416.10        | 10.33          | 0.00 | 100 H     |
| Number of zero days                                                                            | 0.00 | 0.00          | 31.00          | 31.00 | 0 L       |
| Base flow index                                                                                | 0.01 | 0.01          | 10.33          | 0.00 | 100 H     |

### Table 5 The estimated degree of hydrologic alteration for parameter group 3

| Parameter Group 3—(Julian day): Timing of annual extreme flow (m³/s) | RVA target | Expected count | Observed count | D% | IHA class |
|---------------------------------------------------------------------|------------|----------------|----------------|----|-----------|
|                                                                     | Low  | High          |                |     |           |
| 1-day minimum                                                      | 1.00 | 1.00          | 28.93          | 17.00 | 41 M      |
| 3-day minimum                                                      | 1.00 | 1.00          | 24.80          | 16.00 | 35 M      |

### Table 6 The estimated degree of hydrologic alteration for parameter group 4

| Parameter Group 4—Frequency and duration of High pulse and Low pulse (m³/s) | RVA target | Expected count | Observed count | D% | IHA class |
|---------------------------------------------------------------------------|------------|----------------|----------------|----|-----------|
|                                                                           | Low  | High          |                |     |           |
| Low pulse count                                                           | 4.28 | 6.00          | 16.53          | 1.00 | 94 H      |
| Low pulse duration                                                         | 5.62 | 13.52         | 10.33          | 1.00 | 90 H      |
| High pulse count                                                           | 7.28 | 9.00          | 14.47          | 2.00 | 86 H      |
| High pulse duration                                                        | 3.00 | 7.72          | 18.60          | 4.00 | 78 H      |
Table 7 The estimated degree of hydrologic alteration for parameter group 5

| Parameter Group 5—Rate and frequency of flow changes (m³/s) | RVA target | Expected count | Observed count | D% | IHA class |
|------------------------------------------------------------|------------|----------------|----------------|----|-----------|
| Rise rate                                                  | 8.88       | 20.72          | 10.33          | 0.00 | 100       |
| Fall rate                                                  | -15.60     | -5.56          | 10.33          | 6.00 | 42        |
| Number of reversals                                        | 79.84      | 88.88          | 10.33          | 0.00 | 100       |

The parameter group 1 (Table 3) highlights the monthly discharge statistics, emphasizing timing and magnitude as regime characteristics. It reflects the mean discharge of each calendar month. This also enables a better understanding of the monthly degree of alteration during the pre-dam era compared to the post-dam period. The twelve indicators under parameter group 1 also outline the extent of seasonal variation and alteration in the pre-dam period. The results in Table 2 are indicative of these variations. It may be noted that the month of April reports a high degree of alteration, 84%, in the post-dam period, which is indicative of the alteration that the river underwent post the barrage construction. However, when the dry month of April is compared to the monsoon months of June, July, and August, an alteration ranging from low to the middle has been recorded. This may be attributed to the lesser changed nature of rainfall received across the Lower Damodar river basin (Sandipan Ghosh and Guchhait 2016). Also, when viewed for the months of November or December, the degree of alteration is 5% and 6%, respectively. This representation of lower alteration shall be attributed to the water release policies of the upstream dams that chose to release lesser water during these months of the year (Sandipan Ghosh & Guchhait 2016). These have relative implications on shaping the interpretation of the impact of changing environmental flows on the river flow regime, the fish availability, and the security of livelihood practices of the associated communities.

Parameter group 2 (Table 4) indicates certain characteristics that emphasize analyzing the annual trends of alteration in the river flow regime. It focuses more on the extremes in the annual pattern of river flow regime including both minimum and maximum. This parameter and the underlying indicators are crucial to analyze the health of the river on a long-term basis. As interpreted from Table 4, the 90-day and 30-day indicators represent a high degree of alteration (100%) in the river body system during the post-dam period. The severity of these indicators' impacts has increased over time due to the construction of the Barrage and the water release policies by the upstream dams. These indicators being computed by the moving averages technique enhances the credibility of the parameter group on influencing the interpretations derived from the results and qualitative data.

Parameter group 3 (Table 5) focuses on the timing of the annual extreme flows. An alteration in the flow frequencies in terms of the frequency of flooding does impact the fish variety and population in the river (Zeiringer et al. 2018). The indicators are computed after a constant observation of the lowest and highest extreme flows across the years of data from pre-post-dam periods. It is the first day of either the lowest or highest flow for consecutive days taken into account. It is evident from Table 5 the degree of deviation has changed significantly and, subsequently, the river flow pattern according to these indicators.

Parameter groups 4 and 5 (Table 6 and 7) focus more on the frequency and duration of the river flow regime. The high and low pulse counts account for the nature of flows (high and low), and the "number of reversals" represents the frequency of times the hydrograph changes from the rising period to the falling period and vice-versa. A high alteration in the indicator of the number of reversals, as shown in Table 6, indicates a significant transition in the flow regime caused by altered water release post barrage construction. However, the RVA also makes specific recommendations on the application of certain parameter groups depending on nature, trend, and information provided by the river flow regime. The outcome of this paper highlights the impact of environmental flow on fishing practices as a means of livelihood for which parameter groups 1, 2, and 3 are the most applicable and have been discussed further. The greater relevance of the parameter groups can be identified concerning the ecosystem influencing factors stated in Table 2.

“Further to substantiate the quantitative outcomes from the RVA method, the qualitative insights derived from the field have been used (Table 1). The qualitative data was collected from the fishing communities and prominent market regions to analyse their interpretations on the impact of altered river flow patterns on their fishing livelihood. Figure 5 is a quantified representation of the extent of risk indicated by the fishing communities through their qualitative responses. Akin to the works of Kucukali (2011), these responses were grouped into risk factors (concerns) and the relative risk in percentage had been computed. Risk scores ranging from low risk factor to very high-risk factor was assigned which aggregated to a total of 100%. This led to mapping of the riskiest concern group and the least risky one. The concern regarded by most fishermen to be the riskiest and most detrimentally impactful on their fishing livelihood is the “declining water levels” (21% relative risk) followed by “lack of fish catch” (19% relative risk). They highlighted the negative impacts of such events on their daily incomes. Thus, as a consequence of unreliable
earning, women in the families of many fishermen have been either forced to resort to animal husbandry practices or other odd jobs. A similar pattern of qualitative data representation has also been followed by (Lokgariwar et al. 2014) in their study on the upper Ganga basin.

The primary insights delivered through this paper from quantitative and qualitative data have been further discussed below. The graphical representation of the tabulated data highlights the correlation of the degree of alteration of the river flow regime and the detrimental impacts on fishing post the barrage construction.

**Discussion**

The stringent demarcations of the RVA range on the graphs enable a better evaluation of the degree of alteration and understanding of the parameter groups. The range is the pictorial representation of the 25th and 75th percentiles used to develop the boundaries (Figs. 6, 7, 8, and 9). Based on that, the expected and observed flow counts are assessed. The range, in general, helps in comparing the occurrences of flow between the pre-and the post-dam era and supplements the qualitative insights obtained from the fishing communities in the Lower Damodar region.

Figure 6 substantiates the 52% medium class of hydrological alteration that the river flow regime has undergone post the barrage construction across Damodar. Compared to the pre-dam era, there are reduced flow occurrences within the RVA boundaries in the post-dam period. This, therefore, symbolizes the reason behind the medium-class alteration of the flow regime of river Damodar. Even in the month of May, the significantly low occurrences of flow within the RVA boundaries in the post-dam period as compared to the pre-dam era is indicative of the high degree of alteration in the downstream stretches of the river (Fig. 7). The low flows always have a tendency to serve as a limiting factor for habitat availability (Zeiringer et al. 2018). The habitable
grounds for fish breeding are affected with reduced flow and declining depth because of altered river flow patterns (Santosh Nepal 2014; Zeiringer et al. 2018).

Furthermore, the graphs (Figs. 7 and 8) represent the seasonal variation in the flow regime highlighted by parameter groups 1 and 2. Parameter group 2 emphasizes annual trends.
and its indicators, primarily 90 and 30 days maximum and minimum, which are one of the most significant. They reveal the impact of persistently altered river flow regime over a longer time. It can be inferred that these indicators emphasize the need for maintaining environmental flow requirements in the river system amidst seasonal fluctuations. Factually, the monsoon period across the Lower Damodar river basin has always been pronounced both prior and post the barrage construction. Consequently a lesser deviation from the natural flow regime is recorded in the month of June (Fig. 8). Hence, with an increase in the volume and velocity of river flow in Damodar, fishes like prawns are largely available. Prawns are among the most demanded fishes in the Durgapur and Bankura region.

But the summers and winters reflect significant deviation during the post-dam period (Figs. 6 and 7). Even during the post-monsoon period, the fishes require significant flow to support their movement across up and downstream trails. They need an amicable aquatic condition, especially during their spawning periods. But Fig. 9 depicts the state of the lower Damodar river, especially post the barrage construction, where there is reportedly high digression from the natural river flow regime in the month of September. The parameter group 3 (Table 5) also reiterates the alteration in the river flow regime through its annual indicators. As the quantitative computation is compared to the qualitative insights (Fig. 5), repercussions and extent of risk due to the altered flow regime could be inferred. In the CIFRI Report in 2010, it was highlighted that IUCN has tagged the Boal fish (Wallago attu) as threatened and other economically prominent fishes such as Catla (Cyprinus catla), to be no longer spotted in Damodar. The qualitative responses on seasonal variation also report similar detrimental impacts on their fishing livelihood (Fig. 5), which have severed with years of highly altered river flow patterns. These have significantly affected their income levels owing to the reduced availability of economically important fishes such as walking catfish (Silurus batrachus), Rohu (Cyprinus rohita), and to name a few (Fig. 5). These fishes have to be now exported from external markets into the town to meet the requirements as learnt from the regional market survey.

As a consequence of reduced fish availability and changed river flow regime, 90% of the fishermen in Durgapur and further downstream in Bankura have suffered reconcilable losses. Due to lesser fish catches, these fishermen have to spend long hours in the River, adding to their occupational risks and hazards (Fig. 5). Their ability to sell fishes outside Durgapur and Bankura has also been impaired because of lesser fish catches. Such situations of lack of earning opportunities have compelled many fishermen to even migrate out of Durgapur and Bankura, leaving behind their families in the pallies and villages.

Conclusions

The inter-relationship between the flow regime components of a river system and its aquatic life is controlled by diverse, complex mechanisms. The human interventions at various spatial and temporal scales have impacted the river flow patterns, mainly affecting the aquatic species and habitat structures. Amidst the diverse aquatic biota, reduction in fish population serves as the most prominent negative indicator of alterations in the river flow regime (Zeiringer et al. 2018). Therefore, it is essential to emphasize promoting sustainable river management practices by regulating the environmental flow that would aid in maintaining the health of the river and satisfy the livelihood needs of humans depending on the river system.

This paper focuses on combining the quantitative and qualitative analyses for linking the impacts of altered environmental flow with livelihood security of the fishing community in the Lower Damodar river basin. The degree of alterations (quantitative analyses) has been computed by the RVA method using the daily discharge data. The field survey (qualitative insights) was conducted to collect information on variation in fish availability over the years and understand the impacts on the economic stability of the fishing community.

A parallel analysis of the river discharge data and the qualitative response resulted in certain important and significant insights. A maximum of 84% and 90% alteration in the months of April and May, respectively, were found in the seasonal flow regime of the river (Table 3). This was also supported by the qualitative data collected from the field. 21% of the interviewed fishermen indicated the decline in water levels as highly risk factors leading to reduction in fish availability (Fig. 5). Further, indicators such as the 90-day maximum and minimum as well as the frequency and duration of high and low pulse counts reflect a high alteration post the barrage construction. All these quantitative results were well supported by the response of the fishermen community. The impacts caused due to these alterations would permanently damage the self-resilience of the river flow regime. If proper environmental flow regulations are not followed, the river would completely become unsuitable for fish breeding. Hence, a well-defined yet accommodative regulating policy on environmental flows for diverse Indian river basins should form one of the cores of future water discussions. Given the diversity brought by each river basin in India, a policy environment will better guide the implementation of environmental flow maintenance frameworks.

Acknowledgements The authors would like to thank the Co-Chief Editor and the reviewers for their valuable comments and remarks.
which have helped in improving the quality of the paper. This research received the classified Damodar river daily discharge data from the Teesta- Bhagirathi Division, Central Water Commission, Govt. of India. The author would like to thank Mr. Kaushlendra Singh and Dr. Ravindra Varma for supporting to obtaining the data. The first author would like to acknowledge the contribution of Dr. Suhas R Bhasme, Assistant Professor, Tata Institute of Social Sciences (TISS), Mumbai as the supervisor for the academic thesis related to this study. The field work and part of the analysis were conducted by the first author at TISS, Mumbai. The authors would also like to acknowledge everyone who aided in conducting the field research amidst Covid 19 limitations in India and the consensual participation of respondents in different palls of Durgapur namely Vidyasagar Pally, Subhash Nagar Pally, Ashish Nagar Pally, Bihari Para, Nadiha and in the two villages of Bankura, Methylai and Barjora.

Author contributions The first and second author have equally contributed to the conceptualization, data curation, methodology development, and writing—review & editing of the manuscript.

Funding No funds, grants, or other support was received.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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