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Assessment of Flow Regime Change due to Inception of Majalgaon Dam

Ashish Kumar, Vinod Kumar Tripathi, Pradeep Kumar, Rajan Kumar, Abhishek Singh

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ABSTRACT

Rivers are one of the prime sources of fresh water and in these days these are being over exploited mainly by discharging industrial effluent, sewage water, in the river and constructing dams across the river banks. In this study, the flow regime change in the Godavari River after inception of Majalgaon dam were analyzed using range of variability approach (RVA) of Indicators of Hydrologic Alteration (IHA) framework. Streamflow gauged at Dhalegaon site was utilized for the analysis. Result showed that median stream flow values reduced during all the months after dam construction with 100% decrease in the month of February, March, April and May. And in the month of August, July, January, December, June, October, September and November, the median flow decreased by 98.28%, 96.81%, 95.23%, 92.99%, 89.77%, 89.24%, 85.11%, 80.42%, respectively. Peak flow magnitude reduced from 1260 m^3/sec during pre-dam inception to 654.70m^3/sec after-dam inception. The values of 1, 3, 7, 30 and 90-days minimum and maximum, number of zero days and base flow index were found as altered negatively. The median values of date of minimum and maximum were found shifted toward later days. HA values indicated negative alteration of 30.16, 13.57 and 57.69 % in the low pulse count, high pulse count and high pulse duration, respectively, but positive change (17.86%) in low pulse duration. The median values of fall rate and number of reversals dropped by 18.37 and 54.93 %, respectively, but this value for rise rate increased by 36.15%, which showed that streamflow takes lesser time to reach its previous state.

Keywords IHA, RVA, Flow alteration, Majalgaon dam, Godavari River.

INTRODUCTION

Flow regime is of prime importance for sustainable development of the aquatic and terrestrial ecosystem since even small change in magnitude, intensity, duration, timing and frequency of the river flow can led to water pollution, loss of water organism, loss

Ashish Kumar [1], Vinod Kumar Tripathi *[2], Rajan Kumar [4],Abhishek Singh [5]
[1] Research Scholar, [2, 4, 5] Assistant Professor, Department of Agricultural Engineering,
Institute of Agricultural Sciences,
Banaras Hindu University, Varanasi 221005, Uttar Pradesh India

Pradeep Kumar [3]
[3] Environmental Hydrology Division (EHD)
National Institute of Hydrology,
Roorkee, Uttarakhand, India

Email: vktripathi@bhu.ac.in
*Corresponding author

of economy and overall disturbance in the aquatic ecosystem. Hydrologic alterations in the flow regime due to manmade structures and flow regulation have attended the tremendous focus in the last decades. Different methodologies like Hydrologic Alteration Indexes, Mexican standard approach, Indicator of hydrologic alteration (IHA) have been developed and are being used on large scale for accurate estimation of the flow regime alteration.The range of variability approach (RVA) developed by Richter *et al.* (1997) was used to analyze the hydrological variations between the two time periods. Mean daily flow data from the Bayangaole water station were used to calculate 33 hydrological alteration components for various dam operation periods, including the Liujiaxia single operation period and the uniform scheduling period of the entire Yellow (Richter *et al*. 1996). Abbott *et al.* (2017) examined the short term and long-term response of extreme rainfall events on sediment yield for Oroua and Pohangina catchments, located in North Island of New Zealand (Lower North Island), by utilizing the Indicators of Hydrologic Alteration (IHA) program. He used Digital elevation model (DEM), geological, Land use/cover, daily storm, discharge and suspended sediment data for determining sediment load generation due to extreme storm events. Different series of the Landsat imageries and daily runoff data were explored for quantifying the wetland responses to river hydrology alterations due to inception of the dam constructed in the area in western portion of Inner Mongolia, China using combined remote sensing and IHA approach (Ablat *et al*. 2019).

Minimum threshold in the environmental flow for Guadalfeo River watershed situated in Spain was evaluated using environmental flow component (EFC) parameters of IHA (Aguilar and Polo 2016). Climate change and river regulation are the main region for the disturbance in the natural flow regime, Ashraf *et al*. (2016) carried out study for analyzing spatio-temporal variation in flow regime, by analyzing flow data of the Kemijoki (regulated) and the Tornionjoki (pristine) river, situated in Northern Europe, with similar physio-climatic condition, using Indicators of Hydrologic Alteration (IHA) approach. Results suggested that regulated river flow and changing climatic condition are the factor responsible for hydraulic alteration. Alteration in the magnitude and frequency of flow in the Uatuma River (northern affluent of the Amozon River) downstream of hydroelectric power plant was assessed by adopting IHA method and tree mortality due to change in flow regime was analyzed for flood adopted species (Assahira *et al*. 2017). A total 32 indicators of RVA and normalized difference vegetation index (NDVI) methodologies were used by Alrajoula *et al.* (2016) to detect the flow alteration and spatio-temporal variation in the land use/cover, respectively in the Blue Nile river reach upstream and downstream of Er Roseires Dam (Sudan). It was justified that owing to inception of the dam natural flow regime altered significantly while positive alteration was seen during dry season with flow higher than natural flow regime.

Arevalo-Mejia *et al.* (2020) utilized flow and socio-economic data with the help of Hydrologic Alteration Indexes on Rivers (IAHRIS) and the Mexican standard approach for determining the change in the flow pattern in all the catchments of Mexico (North America) and it was found that IAHRIS approach showed more descriptive information about hydrologic alteration than Mexican standard approach. Cui *et al.* (2020) assessed accumulated impact of climate change and dam construction by using new technique that combines a streamflow reconstruction technique, IHA, revised RVA and indicators of intra-annual flow variation approaches for Upper Yellow River Basin (UYRB). The outcomes indicated that used techniques can serve excellent tool for evaluation of effect of climate change and dam inception. Babel *et al.* (2012) simulated reservoir operation situated on La Nga river basin, Vietnam for analyzing impact on hydropower generation and natural flow regime based on RVA results. The findings showed that at hydropower plant at its full capacity and under selected RVA target range in downstream side, the power output can be improved 8 and 4% but reduction in overall hydrologic alteration by 24 to 27 %, respectively.

Ban *et al*. (2019) assessed the impact of the Three Gorges Dam on flow regime and carp communities through using various indicators of hydrology (IHs). The degree of alteration was estimated using the range of variability approach (RVA) and found the alarming change in the natural flow regime of the downstream side. Borgohain (2019) analyzed hydrological, morphological and socio-economic impacts in downstream impacts of the Ranganadi hydel project in Brahmaputra Basin, India using IHA and suggested mitigation plans that can be very beneficial for both present and future scenarios. Brouziyne *et al.* (2021) investigated flow regime change one of the largest watersheds in Morocco, the Bouregreg Watershed (BW) by using Soil and Water Assessment Tool (SWAT) and IHA techniques.

In line with these investigations, this study has been carried with the objectives: (i) bifurcation of the gauged streamflow data into pre-and post dam inception periods; (ii) development of IHA framework for determination of flow regime change post dam construction; (iii) RVA analysis of all the IHA parameters based on developed framework.

MATERIALS AND METHODS

Study area

The study has been carried out for the Godavari river basin by analyzing the streamflow data of Godavari River before and after the inception of Majalgaon Dam. Streamflow gauged at Dhalegaon site, which is situated in Parbhani district of Maharashtra state, with longitude and latitude as 76^{o}21’48” and 19^{o}13’13”, respectively, built on the bank of Godavari river. Majalgaon Dam built on Sindphana river in the year 1987 near Majalgaon in Beed district, Maharashtra, India. Majalgaon is situated at 76^{o}11’11” longitude and 19^{o}9’38.63” latitude. After flowing some distance north-eastwardly and northwardly it joins Godavari river at Manjarath village in Parbhani district, Maharashtra, in the upstream side of Dhalegaon gauging station.

Data acquisition

Streamflow data of total 50 years (from 1966 to 2015), gauged at Dhalegaon was collected from Krishna and Godavari Basin Organization, Divisional Office of Central Water Commission, Hyderabad (Andhra Pradesh). The runoff is computed with the help of stage graphs obtained using automatic water stage recorder expressed in the unit m^3/sec. Time series stream flow data were splitted into to two periods namely pre-dam inception period (from 1966 to 1987) and post-dam inception period (from 1988 to 2015).

Methodology

In Peninsular River, it is expected that anthropogenic pressures largely modify low-flow components of the flow regime with consequences for aquatic habitat and diversity in invertebrate species. Using the Indicators of Hydrologic Alteration (IHA) software developed by Richter *et al.* (1996) and Richter *et al.* (1997), segments of the Peninsular River whose hydrological regime is significantly influenced by anthropogenic activities will be identified.

The IHA software determines change in hydrologic regimes by human interventions using range of variability approach (RVA). There are 33 IHA parameters that can be analyzed using RVA which are divided in five groups based on magnitude, timing, frequency, duration, and change rate. Group 1: Comprises the twelve monthly median flows describing the normal flow condition which represents the availability or suitability of a habitat. Group 2: Present the magnitude and duration of annual extreme flows: 01, 03, 07, 30 and 90 days annual minima and maxima and the base flow index calculated as the seven-day minimum flow/annual mean flows which are relevant in modulating the structure and function of rivers and floodplains. Group 3: Contains the Julian dates for one-day annual maximum and minimum indicating the timing of the annual extreme flows. Changes in these parameters influence the life-cycle of organisms and the degree of stress associated with extreme water conditions. Group 4: Parameters indicate the frequency and duration of high and low pulses defined as the annual periods when the daily flows are above (below) the 75th (25th) percentile daily flow of the pre-impact period which influence the reproduction or mortality rates of different species and the population dynamics. Group 5: Parameters indicate the numbers and rates of positive and negative changes in flow between two consecutive days: Fall rate, rise rate, and number of reversals. Such changes can lead to drought stress on plants or entrapment of organisms along the edge of the water or nearby ponded depressions.

The HA of each parameter is calculated as follows:

$$\text{HA (\%)} = \frac{\text{Observed frequency} - \text{expected frequency}}{\text{expected frequency}} \times 100$$

Where the observed frequency is the number of years in which the observed parameter value fell within the target range, while expected frequency represents the number of years in which the value is expected to fall within the target range. The degree to which the RVA target ranges are not attained is accepted as a measure of hydrologic alteration. A positive or negative value of HA indicates that the respective parameter values fell within the target range more or less often than expected. A hydrologic alteration is zero when the observed frequency of post-impact annual values that fall within the RVA target range equals the expected frequency. Richter *et al.* (1996), proposes the degrees of HA to be classified in minimal alteration (L) 0-33%, moderate alteration (M) 34-67%, and high alteration (H) 68–100%.

RESULTS AND DISCUSSION

Hydrologic alteration in flow regime was analyzed on the basis of IHA parameters (magnitude, duration, timing, frequency and rate of changes) and RVA analysis. The impacts of Majalgaon dam built in the year 1987 across the river Godavari on riverflow measured at Dhalegaon were assessed using non-parametric approach of IHA tool. Since dam was constructed in 1987, the period from 1966 to 1987 were identified as pre-impact period and period from 1988 to 2015 were identified as post-impact period. RVA categories were defined on the basis of percentile values i.e. streamflow equal to or less than 33rd percentile were placed in low RVA category, streamflow values between 34th and 67th percentile were placed in middle RVA category and streamflow values greater than 67th percentile were placed in high RVA category. It was widely suggested that annual values of IHA parameters should be kept with close to pre-alteration values Richter *et al.* (1997). On the basis of IHA statistics, streamflow of both the periods were compared and

Table 1. IHA statistics for before and after Majalgaon dam construction. #, means number of zero days changed from 0 to 108.5.

IHA parameters	Pre-impact period: 1966-1987			Post-impact period: 1988-2015			Change in median (%)	RVA analysis		
	Min	Max	Median	Min	Max	Median		Expected	Observed	Hydrologic alteration (%)
Parameter Group-1										
June	0.55	159.6	11.96	0	81.15	1.22	-89.77	10.18	2	-80.36
July	3.2	534.7	61.2	0	414.6	1.95	-96.81	10.18	4	-60.71
August	3.92	851.7	126.5	0	510.3	2.17	-98.28	10.18	7	-31.25
September	10.15	1260	82.36	0	654.7	12.26	-85.11	10.18	8	-21.43
October	2.7	274.3	35.15	0	397	3.78	-89.24	10.18	4	-60.71
November	1.6	67.3	15.17	0	56.69	2.97	-80.42	10.18	1	-90.18
December	1	41.5	11.43	0	24.75	0.80	-92.99	10.18	2	-80.36
January	0.7	21	8.6	0	21.87	0.41	-95.23	12.73	0	-100
February	0.4	51.3	7.058	0	12.94	0	-100	10.18	3	-70.54
March	0.2	12.1	3.65	0	16.63	0	-100	10.18	3	-70.54
April	0.092	12.86	1.83	0	12.83	0	-100	10.18	2	-80.36
May	0	13.8	1	0	24.55	0	-100	10.18	2	-80.36
Parameter Group-2										
1-day minimum	0	4.5	0.268	0	3.923	0	-100	10.18	1	-90.18
3-day minimum	0	4.633	0.3212	0	4.226	0	-100	10.18	1	-90.18
7-day minimum	0	5.554	0.465	0	4.70	0	-100	10.18	2	-80.36
30-day minimum	0	9.067	0.830	0	11.72	0	-100	10.18	2	-80.36
90-day minimum	0.199	11.96	2.694	0	13.56	0.007	-100	10.18	2	-80.36
1-day maximum	348	6173	2778	0	7652	1045	-100	10.18	7	-31.25
3-day maximum	238.7	5557	1978	0	7049	652.10	-100	10.18	8	-21.43
7-day maximum	141.6	3703	1517	0	5416	461.20	-100	10.18	8	-21.43
30-day maximum	45.62	2079	661.3	0	1752	148.90	-99.72	10.18	9	-11.61

Table 1. Continued.

IHA parameters	Pre-impact period: 1966-1987			Post-impact period: 1988-2015			Change in median (%)	RVA analysis		
	Min	Max	Median	Min	Max	Median		Expected	Observed	Hydrologic alteration (%)
90-day maximum	22.22	1166	447.3	0	837.5	67.44	-62.38	10.18	8	-21.43
Number of zero days	0	37	0	0	365	108.50	#	24.18	4	-83.46
Base flow index	0	0.1732	0.003	0	0.052	0	-100	10.18	3	-70.54
Parameter Group-3										
Date of minimum	68	204	152	153	25	315	0.66	11.45	14	22.22
Date of maximum	167	290	236	232	144	290	-1.69	10.18	12	17.86
Parameter Group-4										
Low pulse count	0	13	4	0	17	5	25.00	11.45	8	-30.16
Low pulse duration	1	69	6	0	149	8	33.33	10.18	12	17.86
High pulse count	2	13	6	0	15	5	-16.67	12.73	11	-13.57
High pulse duration	1	74.5	4.5	0	41	2.5	-44.44	16.55	7	-57.69
Parameter Group-5										
Rise rate	0.27	6.257	1.46	0.398	250.10	1.985	36.15	10.18	4	-60.71
Fall rate	-2.73	-0.246	-1.225	-116.9	-0.169	-1	-18.37	10.18	7	-31.25
Number of reversals	80	178	142	0	143	64	-54.93	10.18	3	-70.54

based on RVA analysis, magnitude of hydrologic alteration (HA) was determined as mentioned in Table 1.

IHA Group 1: Magnitude of monthly water condition

Pre-dam inception, all the months showed some flow except May but after the dam construction there was no flow during atleast one day in each month. Peak flow occurred during September in the pre-and post-impact periods but magnitude reduced from 1260 m^3/sec to 654.70m^3/sec after dam inception. Median values of flow reduced during all the months after dam construction with 100% decrease in the month of February, March, April and May. In the month of August, July, January, December, June, October, September and November, the median flow decreased by 98.28%, 96.81%, 95.23%, 92.99%, 89.77%, 89.24%, 85.11%, 80.42%, respectively as depicted in Fig. 1. RVA analysis showed that there is negative HA in all the month with January as the highest altered month with 100% HA value. Rest of months also showed significant decrease in streamflow with the values of HA during the month of May, June, December and April as 80.36%, during the month of February and March as 70.54%, during the month of July and October as 60.71%. Erratic change in flow regime negatively affected oxygen levels, temperature and photosynthesis in the stream (Richter and Thomas 2007).

IHA Group 2: Magnitude and duration of annual extreme water conditions

During pre-impact period, the minimum values of 90-day minimum, 1, 3, 7, 30, 90-day maximum were found non-zero but post-impact period it reduced to zero. An increase in maximum values of 30, 90-day minimum, 1, 3, 7- maximum and no. of zero days were seen with the highest increase in no. of zero days (from 0 to 365 days). The median values of 1, 3, 7, 30, 90-day minimum, 1, 3, 7-day maximum and base flow index were decreased by 100% and the values of 30, 90-day maximum were decreased by 99.72 and 62.38 %, whereas the median value of no. of zero days was increased from 0 to108.5 days.

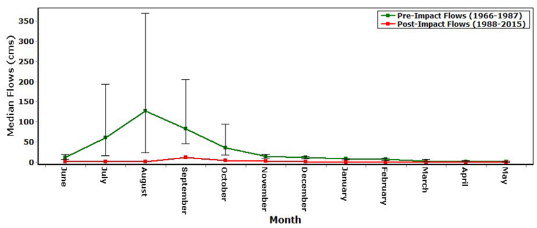

Fig. 1. Monthly Flow Alteration post- dam inception based on median values.

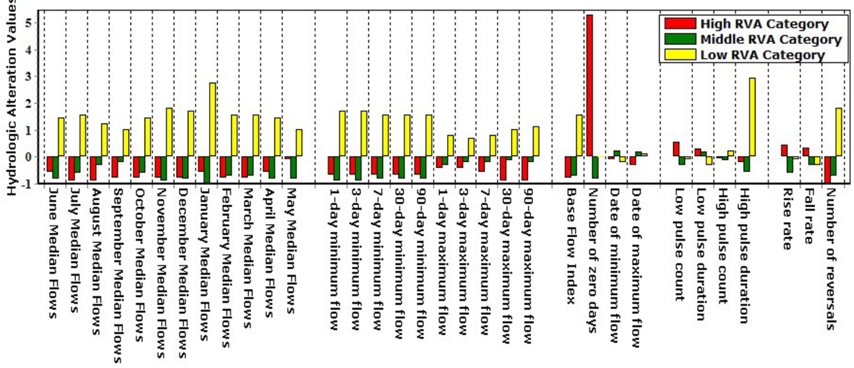

Fig. 2. Hydrologic alteration in all 33 IHA parameters.

All the parameters of Group-II were showed negative HA values, which indicated decrease in magnitude for all the parameters. The highest alterations were found in the values of 1 and 2-day minimum (90.18% alteration) followed by, no. of zero days (83.46% alteration), 7, 30 and 90-day minimum (80.36% alteration), base flow index (70.54% alteration), 1-day maximum (31.25% alteration), in 3, 7, 90-day maximum (21.43% alteration) and 30-day maximum (11.61% alteration) as shown in Fig. 2.

IHA Group 3: Timing of annual extreme water conditions

The median values of date of minimum and maximum were improved from 152 and 236 to 315 and 290, indicating shift of both dated towards later days. Positive HA (with 22.22 % alteration in the date of minimum flow and 17.86 % alteration in the date of maximum flow) were shown for the cases.

IHA Group 4: Frequency and duration of high and low pulses

The values of maximum low pulse count, low pulse duration, high pulse count were increased with the highest increase in low pulsed duration (69 Nos to 149 Nos), where as maximum values of high pulse duration were decreased from 74.5 days to 41 days. This indicated that low flows occurred most of the time in the river with sort time peaks. The median values of the low pulse count and duration were raised by 25 and 33.33%, respectively, while a fall of 16.67 and 44.44 % were shown in high pulse count and duration. HA values indicated negative alteration of 30.16, 13.57 and 57.69 % in the low pulse count, high pulse count and high pulse duration, respectively, but positive change (17.86%) in low pulse duration.

IHA Group 5: Rate and frequency of water condition changes

The median values of fall rate and number of reversals dropped by 18.37 and 54.93 %, respectively, but this value for rise rate increased by 36.15%. These values showed that streamflow takes lesser time to reach its previous state. Flow duration curve showed drastic change in the annual streamflow of the Godavari River after dam inception as showed in Fig. 3. Dam inception on the river bank poses ill effect on the sturgeon habitat of Chinese Yangtze River (Zhang *et al*. 2014). Since flow regulation instream biodiversity and fish population decreased significantly (Huang

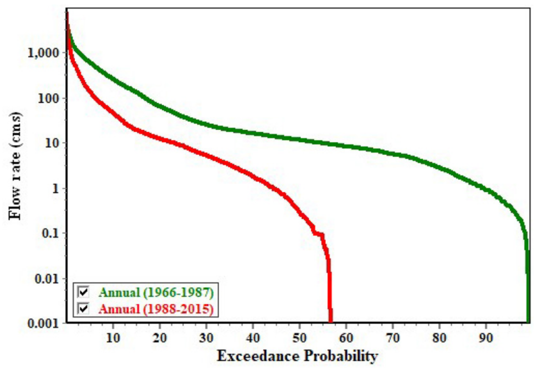

Fig. 3. Flow duration curve of annual time series data of pre-and post impact period.

2006). Study conducted by Zhang (2009) evolved that not only spawning rate of fish like Chinese sturgeon has diminished by 20% but a number of fish species are verge of extinction (Jiang 2011). Significant alteration in the values of rise rate (-60.71%), fall rate (-31.25%) and number of reversals (-70.54%) were seen, which indicated change in the pattern of streamflow.

CONCLUSION

IHA framework showed that the streamflow of Godavari River has altered drastically after the dam inception. Median stream flow values reduced during all the months after dam construction with 100% decrease in the month of February, March, April and May and in the month of August, July, January, December, June, October, September and November, the median flow decreased by 98.28%, 96.81%, 95.23%, 92.99%, 89.77%, 89.24%, 85.11%, 80.42%, respectively. Decreased flow during all the months poses danger for the survival of both aquatic and terrestrial animals by reducing the habitat availability. Peak flow magnitude reduced from 1260 m^3/sec during pre-dam inception to 654.70m^3/sec after-dam inception. Decrease in peak flow disturbed the self cleaning capability of the river. RVA analysis showed that there is negative HA in all the month with January as the highest altered month with 100% HA value, rest of months also showed significant decrease in streamflow with the values of HA during the month of May, June, December and April as 80.36%, during the month of February and March as 70.54%, during the month of July and October as 60.71%. All the parameters of Group-II were showed negative HA values, which indicated decrease in magnitude for all the parameters.

The median values of date of minimum and maximum were improved from 152 and 236 to 315 and 290, indicating shift of both dated towards later days. HA values indicated negative alteration of 30.16, 13.57 and 57.69 % in the low pulse count, high pulse count and high pulse duration, respectively, but positive change (17.86%) in low pulse duration. The median values of fall rate and number of reversals dropped by 18.37 and 54.93 %, respectively, but this value for rise rate increased by 36.15%, which showed that streamflow takes lesser time to reach its previous state. This study could be very helpful for detecting the change in hydrologic flow regime by using only streamflow data. Change in habitat availability for aquatic and terrestrial organisms and water quality in the river can effectively be determined by using IHA framework.

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