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# Assessment of Hydrologic Alteration Caused by Human Interventions in Flow Regimes of the Godavari River

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## ABSTRACT

The purpose of presented research was analysis and assessment of the variability and spatial pattern of hydrologic changes in the regimes of the main streams of the Godavari River due to the Sri Ram Sagar dam (18°58′03″N, 78°20′35″E) and Jayakwadi dam (19°29′8.7″N, 75°22′12″E). Sri Ram Sagar dam was built n 1977 and its storage capacity 3,172,000,000 $m^3$ whereas Jayakwadi dam was built n 1976 and its storage capacity 2,909,000,000 $m^3$. The hydrologic regime alterations of Godavari River was analyzed by using the daily stream flow data from the four selected hydrologic stations namely ; Perur, Yelli, Dhalegaon, Mancherial. The Range of Variability Approach (RVA) method was adopted. All the calculations were made by using IHA software version. The study revealed that some hydrologic parameters are highly altered, especially the number of reversals, indicating higher variability. The highest impact was found at Dhalegaon and Mancherial as these hydrological stations were located just below the downstream of the selected dam. The order of affected hydrological stations follows mostly the down stream course of Godavari River. The study indicated that the hydrological behavior of main course of the Godavari River altered alot in the present modern age of development.

**Keywords** IHA, Flow alteration, RVA, Godavari River.

## INTRODUCTION

The rivers are the driver of various critical natural processes which shaped the evolution of life on earth even helped various human patterns of civilization along its bank. The continuous increase of water demand for various fields such as irrigation abstractions, drinking water, hydroelectric power generation, leads to the construction of various large scaled water resources projects which modified the biotic and abiotic components of the river environment. The constructions of large numbers of dams, reservoirs, hydropower projects on rivers streams and even pollution impairs the quality of our rivers water, both in its quality and functionality of the life cycle processes associated with it. Approximately, two-thirds of the world's rivers are suffered from the construction of nearly 50,000 large dams over the past century (WCD 2000). The permanent interventions such as a dam or water diversions, tends to shift the ecosystem toward a new equilibrium which may only be reached over

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long-time scales, especially if interventions continue to modify the flow or sediment regime (Richter *et al.* 2006). The alterations of river flow regime in down stream of dams have negative effects on the health of the riparian ecosystems, the geomorphology of the riverbed and riparian zone as well as the quantity and quality of river waters.

## MATERIALS AND METHODS

The IHA software determines how affected hydrologic regimes are by the human-induced disturbances. The IHA software uses the Range of variability approach (RVA), proposed by the Richter *et al.* (1997), which uses the pre-impact natural variation of IHA parameter values as a reference for determining the degree of alteration of natural flow regimes. The IHA will calculate a total of 67 statistical parameters. These parameters are sub-divided into 2 groups, the IHA parameters and the Environmental Flow Component (EFC) parameters. There are 33 IHA Parameters and 34 EFC Parameters. The IHA can compute the result whether to compare two distinct time periods or analyze trends over a single time period. If the hydrologic system experienced an abrupt change such as construction of a dam, the IHA can be used to analyze the flow regime by computing the hydrologic parameters for two time periods, before and after the impact. The hydrologic systems that have experienced a long-term accumulation of human modifications, the IHA can compute and graph linear regressions to evaluate the trend Table 1.

When analyzing the change between two time periods or comparing two hydro data files, the IHA software enables the users to implement the Range of variability approach (RVA). The RVA uses the pre-development natural variation of IHA parameter values as a reference for defining the extent to which natural flow regimes have been altered. The pre-development variation can also be used as a basis for defining initial environmental flow goals. Richter *et al.* (1997) suggest that water managers should strive to keep the distribution of annual values of the IHA parameters as close to the pre-impact distributions as possible. RVA analysis generates a series of hydrologic alteration factors, which quantify the degree of alteration of the 33 IHA flow parameters. The RVA analysis is only available for IHA parameters and not for EFC parameters.

In an RVA analysis, the full range of pre-impact data for each parameter is divided into three different categories. The boundaries between categories are based on either percentile values (for non-parametric analysis) or a number of standard deviations away from the mean (for parametric analysis), which are specified by the user. This yields an automatic delineation of three categories of equal size : The lowest category contains all values less than or equal to the $33^{rd}$ percentile ; the middle category contains all values falling in the range of the $34^{th}$ to $67^{th}$ percentiles and the highest category contains all values greater than the $67^{th}$ percentile.

The program then computes the expected frequency with which the "post-impact" values of the IHA parameters should fall within each category (in the non-parametric default, this would be 33% for each of the three categories). The program then computes the frequency with which the "post-impact" annual values of IHA parameters actually fell within each of the three categories. This expected frequency is equal to the number of values in the category during the pre-impact period multiplied by the ratio of post-impact years to pre-impact years. Finally, a Hydrologic Alteration (HA) factor is calculated for each of the three categories as per equation 1.

$$HA = \frac{\text{Observed frequency} - \text{Expected frequency}}{\text{Expected frequency}} \quad .....(1)$$

A positive hydrologic alteration value means that the frequency of values in the category has increased from the pre-impact to the post-impact period (with a maximum value of infinity), while a negative value means that the frequency of values has decreased (with a minimum value of -1). Using the $33^{rd}$ and $67^{th}$ percentiles ensures that in most situations an equal number of pre-impact values will fall into each category, which makes the results easier to understand and interpret.

The degree to which the RVA target ranges are not attained is accepted as a measure of hydrologic

**Table 1.** The detailed information of HA parameters and their ecosystem influences.

| Sl. No. | IHA parameter group | Hydrologic parameters | Ecosystem influences |
|---|---|---|---|
| 1. | Magnitude of monthly water conditions | Mean or median value for each calender month | Habitat availability for aquatic organisms |
| | | 1. Mean or median value for January | Soil moisture availability for plants |
| | | 2. Mean or median value for February | Availability of water for terrestrial animals |
| | | 3. Mean or median value for March | |
| | | 4. Mean or median value for April | |
| | | 5. Mean or median value for May | |
| | | 6. Mean or median value for June | Availability of food/cover for fur bearing mammals |
| | | 7. Mean or median value for July | |
| | | 8. Mean or median value for August | |
| | | 9. Mean or median value for September | Reliability of water supplies for terrestrial animals |
| | | 10. Mean or median value for October | |
| | | 11. Mean or median value for November | Access by predators to nesting sites |
| | | 12. Mean or median value for December | |
| | | | Influences water temperature, oxygen levels, photosynthesis in water column |
| | | Subtotal 12 parameter | |
| 2. | Magnitude and duration of annual extreme water conditions | 1. Annual minima 1-day mean | Balance of competitive, ruderal, and stress- tolerant organisms |
| | | 2. Annual minima 3-day means | |
| | | 3. Annual minima 7-day means | |
| | | 4. Annual minima 30-day means | Creation of sites for plant colonization |
| | | 5. Annual minima 90-day means | |
| | | 6. Annual maxima 1-day mean | Structuring of aquatic ecosystems by abiotic vs biotic factors |
| | | 7. Annual maxima 3-day means | |
| | | 8. Annual maxima 7-day means | Structuring of river channel morphology and physical habitat conditions |
| | | 9. Annual maxima 30-day means | |
| | | 10. Annual maxima 90-day means | |
| | | 11. Number of zero-flow days | Soil moisture stress in plants |
| | | 12. Base flow index: 7-day minimum flow/mean flow for year | |
| | | | Dehydration in animals |
| | | | Anaerobic stress in plants |
| | | Subtoral 12 parameters | Volume of nutrient exchanges between rivers and floodplains |
| | | | Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments |
| | | | Distribution of plant communities in lakes, ponds, floodplains |
| | | | Duration of high flows for waste disposal, aeration of spawning beds in channel sediments |
| 3. | Timing of annual extreme water conditions | 1. Julian date of each annual 1-day maximum | Compatibility with life cycles of organisms |
| | | 2. Julian date of each annual 1-day minimum | Predictability/avoidability of stress for organisms |

**Table 1.** Continued.

| Sl. No. | IHA parameter group | Hydrologic parameters | Ecosystem influences |
|---|---|---|---|
| | | | Access to special habitats during reproduction or to avoid predation |
| | | Subtotal 2 parameters | Spawning cues for migratory fish |
| | | | Evolution of life history strategies, behavioral mechanisms |
| 4. | Frequency and duration of high and low pulses | 1. Number of low pulses within each water year | Frequency and magnitude of soil moisture stress for plants |
| | | 2. Mean or median duration of low pulses (days) | Frequency and duration of anaerobic stress for plants |
| | | 3. Number of high pulses within each water year | Availability of floodplain habitats for aquatic organisms |
| | | 4. Mean or median duration of high pulses (days) | Nutrient and organic matter exchanges between river and floodplain |
| | | | Soil mineral availability |
| | | Subtoral 4 parameters | Access for waterbirds to feeding, resting, reproduction sites |
| | | | Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses) |
| 5. | Rate and frequency of water condition changes parameters | 1. Rise rates : Mean or median of all positive differences between consecutive daily values | Drought stress on plants (falling levels) |
| | | 2. Fall rates : Mean or median of all negative differences between consecutive daily values | Entrapment of organisms on islands, floodplains (rising levels) |
| | | | Desiccation stress on low-mobility streamedge (varial zone) organisms |
| | | 3. Number of hydrologic reversals | |
| | | Subtotal 3 parameters | |
| | | Grand total 33 | |

alteration. A positive (negative) HA value indicates that the respective parameter values fell within the target range more (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 (TNC manual 2009). Richter *et al.* (1998) proposes the degrees of HA to be classified in minimal alteration (0–33%, L), moderate alteration (34–67%, M) and high alteration (68–100%, H). At least 20 years of data should be used for the pre-impact period in order to account for natural climate variability (Richter *et al.* 1997).

Here, we study the hydrologic regimes alterations of Godavari River, based on the widely adopted RVA method using IHA software, applied on daily stream flow data from the four selected hydrological stations along the main stream by comparing the hydrologic regime from post-impact to the pre-impact period. The present study aimed at quantifying and characterizing the alteration of natural water regimes after the construction of various dams on these rivers and assessing the spatial pattern of these alterations. As such, we discuss the possible causes leading to alterations of the flow regime and the potential ecological implications induced by these changes.

## Study area

River basins are the basic form of hydrological units utilized for the water resources planning. As the second largest basin of India, Godavari accounts nearly 9.5% of India's total geographical area and falls into the Deccan Plateau lying between 73°24′ to 83°4′ east longitudes and 16°19′ to 22°34′ north latitudes. It spreads over Maharashtra (48.7%),

**Table 2.** The detailed information of the four selected hydrological stations on the Godavari River used for the estimation of hydrologic alteration of the flow regimes using IHA software.

| Hydro station | Lat | Location Long | Subbasin | River | Data availability | Considered impact year |
|---|---|---|---|---|---|---|
| Perur | 18.55°N | 80.37°E | Godavari lower | Godavari | 1965-2015 | Pre impact: 1966 -1977<br>Post impact: 1982-2015 |
| Yelli | 19.13°N | 77.34°E | Godavari middle | Godavari | 1976-2015 | Pre impact : 1979 -1994<br>Post impact: 1995-2015 |
| Dhale-gaon | 19.22°N | 76.36°E | Godavari upper | Godavari | 1965-2015 | Pre impact: 1966 -1976<br>Post impact: 1981-2015 |
| Man-cherial | 18.85°N | 79.44°E | Pranhita and others | Godavari | 1965-2015 | Pre impact: 1967 -1977<br>Post impact: 1982-2015 |

Andhra Pradesh (23.7%), Chhattisgarh (12.4%) and Odisha (5.7%) in addition to these, the smaller parts of Madhya Pradesh (7.8%), Karnataka (1.4%) and Union territory of Puducherry (0.01%). Godavari is the largest peninsular river which raises at an elevation of 1067 m in the western ghats near the Triambak hills in the Nasik district of Maharashtra and finally drained into the Bay of Bengal along with its principal tributaries. According to CWC, the basin area is 312812.0 km$^2$.

The daily stream flow (discharge) and cross-section data were downloaded from WRIS- INDIA website for Godavari basin. The hydrological data for non-classified rivers are provided freely from this website. For the assessment of hydrologic flow regimes alterations along the main stream the Godavari River the four hydrological gauging stations viz. Dhalegon, Yelli, Mancherial and Perur were considered. All the gauging stations selected for the present study were situated on the downstream of the considered dam in sequences i.e. Dhalegon and Yelli gauging stations were situated on the downstream of the Jayakwadi dam, whereas for Mancherial and Perur gauging stations, Sri Ram Sagar dam was considered whose impacts on the river flow regimes was analyzed Table 2.

## RESULTS AND DISCUSSION

In the present study, the effects of hydrological change on the water flow regimes due to major two dams namely; Sri Ram Sagar dam and Jayakwadi dam along the main stream of the Godavari River. The four hydrological gauge stations viz. Dhalegon, Yelli, Mancherial and Perur gauge stations were selected to carry out this study. Therefore, the pre- and post- impact periods were separated by the year of opening of dam and chosen as the impact year. In the last decades, the hydro projects have affected the water regimes of the Godavari River. All the stream flow sequences used in this study starts with 1965, except for the sequence recorded at Yelli station, which starts in 1976. A non-parametric RVA analysis (Ritcher *et al.* 1996) was adopted to carried out this study due to its robustness which considered, the median (50$^{th}$ percentile) as the central tendency and the category boundaries 17 percentiles from the median. Thus, the low and high boundaries of the RVA target range are established by the 34$^{th}$ and 67$^{th}$ percentile values calculated from the pre-impact values. The HA of each parameter is calculated as per equation 4.1.

$$\text{HA (\%)} = \frac{(\text{Observed frequency} - \text{Expected frequency})}{\text{Expected frequency}} * 100 \qquad (4.1)$$

For the assessment of spatial extent of hydrologic alteration along the river, the overall degree of HA were need to determined. For this considered the influences of most IHA indicators contributing to the total degree of hydrologic alterations with the value greater than or equal to 67$^{th}$ percentile in the basin and were statistically significant IHA parameters. The mean of absolute values of each IHA factor for the selected hydrological stations were calculated. These means are ranked and the percentile values were calculated. The IHA factors for which the mean exceeds the 67$^{th}$ percentile are statistically significant

**Table 3.** The percentile calculation for the four selected gauge station for the main stream of the Godavari River.

| Sl. No. | 33 parameters | Dhalegaon (%) | Yelli (%) | Mancheria (%) | Perur (%) | Abs. mean (%) | 33 parameters along with Abs. mean (%) in ascending order | | Percentile calculation (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | June | -81.14 | -100 | 3.529 | -73.53 | 62.78 | Date of maximum | 4.07 | |
| 2 | July | -81.14 | -49.21 | -87.06 | 41.18 | 44.06 | 7-day maximum | 6.98 | |
| 3 | August | -100 | -61.9 | -74.12 | 41.18 | 48.71 | 30-day maximum | 9.04 | |
| 4 | September | -68.57 | -49.21 | -67.65 | -2.941 | 47.09 | 3-day maximum | 12.05 | |
| 5 | October | -68.57 | -74.6 | -74.12 | -11.76 | 57.26 | Low pulse count | 19.69 | |
| 6 | November | -87.43 | -61.9 | -74.12 | 5.882 | 54.39 | 90-day maximum | 21.05 | |
| 7 | December | -74.86 | -87.3 | -87.06 | -29.41 | 69.66 | High pulse count | 21.39 | |
| 8 | January | -93.71 | -100 | -41.76 | 32.35 | 50.78 | May | 31.55 | |
| 9 | February | -87.43 | -100 | -48.24 | 5.882 | 57.45 | Rise rate | 36.22 | |
| 10 | March | -93.71 | -87.3 | -74.12 | -64.71 | 79.96 | High pulse duration | 37.49 | 33rd percentile |
| 11 | April | -100 | -61.9 | -54.71 | -20.59 | 59.3 | Fall rate | 41.95 | = 42.5 |
| 12 | May | -93.71 | -61.9 | -2.941 | 32.35 | 31.55 | 1-day maximum | 43.09 | |
| 13 | 1-day minimum | -93.71 | -100 | -28.82 | -38.24 | 65.19 | July | 44.06 | |
| 14 | 3-day minimum | -93.71 | -100 | -2.941 | -29.41 | 56.52 | 30-day minimum | 45.93 | |
| 15 | 7-day minimum | -93.71 | -87.3 | -9.412 | -47.06 | 59.37 | Low pulse duration | 46.15 | |
| 16 | 30-day minimum | -93.71 | -100 | -22.35 | 32.35 | 45.93 | Date of minimum | 46.6 | |
| 17 | 90-day minimum | -93.71 | -87.3 | -15.88 | -38.24 | 58.78 | September | 47.09 | |
| 18 | 1-day maximum | -93.71 | 14.29 | -54.71 | -38.24 | 43.09 | Number of zero days | 48.62 | |
| 19 | 3-day maximum | -68.57 | 65.08 | -41.76 | -2.941 | 12.05 | August | 48.71 | |
| 20 | 7-day maximum | -62.29 | 39.68 | -28.82 | 23.53 | 6.98 | January | 50.78 | |
| 21 | 30-day maximum | -62.29 | 39.68 | -54.71 | 41.18 | 9.04 | November | 54.4 | |
| 22 | 90-day maximum | -100 | 26.98 | -61.18 | 50 | 21.05 | 3-day minimum | 56.52 | 67th percentile |
| 23 | Number of zero days | -65.08 | -100 | -26.47 | -2.941 | 48.62 | October | 57.26 | =56.8 |
| 24 | Base flow index | -100 | -87.3 | -67.65 | -47.06 | 75.50 | February | 57.45 | |
| 25 | Date of minimum | 0.5714 | -74.6 | -74.12 | -38.24 | 46.60 | 90-day minimum | 58.78 | |
| 26 | Date of maximum | -49.71 | 26.98 | -61.18 | 67.65 | 4.07 | April | 59.3 | |
| 27 | Low pulse count | -76.43 | -4.762 | 18.63 | -16.18 | 19.69 | 7-day minimum | 59.37 | |
| 28 | Low pulse duration | -43.43 | -56.46 | -28.82 | -55.88 | 46.15 | June | 62.79 | |
| 29 | High pulse count | -37.14 | -34.69 | -46.08 | 32.35 | 21.39 | 1-day minimum | 65.19 | |
| 30 | High pulse duration | -30.86 | -12.93 | -83.82 | -22.35 | 37.49 | Number of reversals | 68.23 | |
| 31 | Rise rate | -62.29 | -87.3 | -80.59 | 85.29 | 36.22 | December | 69.66 | |
| 32 | Fall rate | -81.14 | 1.587 | -67.65 | -20.59 | 41.95 | Base flow index | 75.5 | |
| 33 | Number of reversals | -68.57 | -87.3 | -61.18 | -55.88 | 68.23 | March | 79.96 | |

and considered in the calculation of the overall degrees of HA. Then, for each hydrological station the mean of the absolute values of the selected HA factors were calculated, thus determining the spatial assessment of HA (Richter *et al.* 1998).

A percentile is defined as the point below which a certain percent of the observation lie. 67th percentile is calculated by arranging the given data in ascending order and then proceeds with the formula, $\frac{p}{100}(n+1)$, where p = 67, n = 33 (no. of data pieces).

From $\frac{67}{100}(33 + 1) \rightarrow 22.8$, 67th percentile is calculated by averaging the 22nd and 23rd data piece of the ascending arranged data set whereas 33rd percentile is calculated by averaging 11th and 12th data piece of the ascending arranged data set as from,

$$\frac{33}{100}(33+1) \rightarrow 11.2.$$

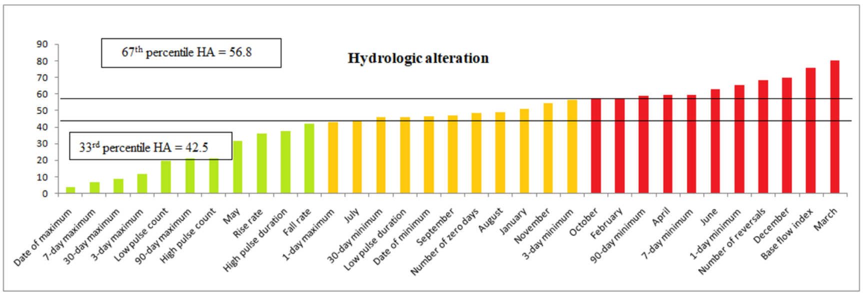


**Fig. 1.** Hydrologic alterations of 33 IHA parameters along the main streams of the Godavari River basin for the four selected gauging stations (Red_ High Alteration, Orange_Medium Alteration and Green_ Low Alteration).

## Hydrologic alteration at the selected gauging station

At Dhalegaon guage station, the mean annual flow decreases whereas flood free seasons increases in post impact period. High to Moderate Hydrologic alteration was seen for most of the parameters at this gauging station except only two parameters, date of minimum (0.5714) and High pulse duration (–30.86), showed the low alterations (Table 3). At Mancherial guage station, the mean annual flow decreases whereas flood free seasons increases in post impact period. High to Moderate alteration was seen for most of the parameters at this gauging station except the parameters, monthly flows for June (3.529), monthly flows for May (–2.941), 1-day minimum (–28.82), 3-day minimum (–2.941), 7-day minimum (–9.412), 30-day minimum (–22.35), 90-day minimum (–15.88), 7-day maximum (–28.82) and no. of zero days (–26.47), showed the low alterations (Table 3). At perur guage station, both the mean annual flow and flood free season are decreases in post impact period. Low to moderate alteration was seen for most of the parameters at this gauging station except the parameters, monthly flows for June (–73.53%), date of maximum (67.65%) and rise rate (85.29%) showed the high alterations (Table 3). At Yelli guage station, the mean annual flow decreases and flood free season are increases in post impact period. High to moderate alteration was seen for most of the parameters at this gauging station except the parameters, 1-day maximum (14.29%), 90-day maximum (26.98%), date of maximum (26.98%), low pulse count (–4.76%), high pulse duration (–12.93%), fall rate (1.587%), showed the high alterations (Table 3).

The spatial extent of hydrologic alteration along the main stream of the Godavari River, the overall degree of HA is determined by averaging the IHA factors for the entire four considered hydrologic gauging stations and taking the absolute mean values. These absolute mean values of the 33 parameters ranked and the percentile values at 33rd percentile and 67th percentile equal to 42.5 and 56.8 respectively were calculated (Table 3). The ranked median absolute degrees and percentile value of 33 indicators of hydrologic alteration were provided in Fig.1 to detect statistically significant contributions to IHA factors. Thereafter, the hydrologic alteration factors were singled out according to the absolute mean values of the IHA factors exceeding the 67th percentile i.e. 56.8%. From this we find 11 parameters showing high degree of hydrologic alteration for the main stream of the Godavari River, these parameters are October, February, 90-day minimum, April, 7-day minimum, June, 1-day minimum, Number of reversals, December, Base flow index and March.

The 11 most affected parameters for the main stream of the Godavari River along the four considered gauge stations, situated in sequential manner to the downstream of the considered dam i.e. Jayakwadi dam and Sri Ram Sagar dam shown in Table 4. Now, these 11 statistically significant parameters were considered for the calculation of the overall degrees of HA. From this we have seen that the median of flow in March was the most affected parameter with HA factor equal to 79.96%. The hydrologic alteration of parameters varied from the Dhalegaon and Mancherial with HA factor 87% followed by the Yelli with HA factor 47% and Perur with HA factor

**Table 4.** The most alterated parameters and their absolute means for the four selected gauge stations for the Godavari main stream.

| Most affected parameters | Dhalegaon (%) | Yelli (%) | Mancherial (%) | Perur (%) | Abs. mean (%) |
|---|---|---|---|---|---|
| October | -68.57 | -74.12 | -74.6 | -11.76 | 57.26 |
| February | -87.43 | -48.24 | -100 | 5.882 | 57.45 |
| 90-day minimum | -93.71 | -15.88 | -87.3 | -38.24 | 58.78 |
| April | -100 | -54.71 | -61.9 | -20.59 | 59.3 |
| 7-day minimum | -93.71 | -9.412 | -87.3 | -47.06 | 59.37 |
| June | -81.14 | 3.529 | -100 | -73.53 | 62.79 |
| 1-day minimum | -93.71 | -28.82 | -100 | -38.24 | 65.19 |
| Number of reversals | -68.57 | -61.18 | -87.3 | -55.88 | 68.23 |
| December | -74.86 | -87.06 | -87.3 | -29.41 | 69.66 |
| Base flow index | -100 | -67.65 | -87.3 | -47.06 | 75.50 |
| March | -93.71 | -74.12 | -87.3 | -64.71 | 79.96 |
| Abs. mean (%) | 87 | 47 | 87 | 38 | 65 |

38% and the overall hydrologic alteration factor for the main stream of the Godavari River was 65% (Table 4). From this table, we have seen that the hydrologic alterations were decreases, as we move far away from the dam in the downstream side.

## CONCLUSION

The overall conclusion of this study revealed that the gauging station which is situated near the downstream of the dam suffers more hydrologic alteration of the flow regimes than the gauging station which is situated far away from the dam. Perur was the least affected gauge station having low hydrologic alteration factor than all other gauge stations because it was situated much away from the considered dam whereas the gauging station Dhalegaon and Mancherial were the most affected by the hydrologic alteration. The gauge station Dhalegaon and Mancherial showed almost equal hydrologic alteration factors because these two gauge station were located just below the downstream of the Jayakwadi dam and Sri Ram Sagar dam respectively. To minimize the ecological impacts, it is essential to analyze the existing operation rules and develop new reservoir management schemes.

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