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Assessment of environmental flows using hydrological methods for Krishna River, India

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Abstract. Krishna River is significantly affected due to Srisailam dam from past 30 years. The impact of this hydraulic structure drastically reduced the minimum flow regime on the downstream, which made the river nearing to decaying stage. In the present paper, Environmental Flow called minimum flow values released for the dam are estimated with the help of three hydrological methods viz., Range of variability Approach (RVA), Desktop Reserve Model (DRM), and Global Environmental Flow Calculator (GEFC). DRM method suggested considering the intermediate values obtained from among the three methods to preserve the ecosystem on the downstream of the river, which amounts to an average annual allocation of 9378 Million Cubic Meter (MCM) which is equal to 23.11% of mean annual flow (MAF). In this regard GEFC and RVA methods accounted for 22% and 31.04% of MAF respectively. The results indicate that current reservoir operation policy is causing a severe hydrological alteration in the high flow season especially in the month of July. The study concluded that in the case of non-availability of environmental information, hydrological indicators can be used to provide the basic assessment of environmental flow requirements. It is inferred from the results obtained from the study, that the new reservoir operations can fulfil human water needs without disturbing Environmental Flow Requirements.

Keywords: environmental flow; hydrological alteration; reservoir operations; ecosystem

1. Introduction

Water, as the carrier of life, maintains the basic natural needs of all the life activities and ecological processes in nature. Rivers are the major habitat for diverse flora and fauna, which offer a key source of food, income, and livelihood, particularly for those living in the riverfront. The rise of river water level is very much favourable for the growth of fish and helps in guiding the fish swim to spawning and allow them to feed on the downstream (Peres and Cancelliere 2016, Pfeiffer and Ionita 2017). Natural low water level provides a habitat condition that is necessary for the growth and reproduction of organisms in order to promote a healthy ecosystem and maintain necessary ecological processes (Poff *et al.* 2003, Liu *et al.* 2018). Similarly, many organisms which are present in wetlands and floodplains can only breed in high water level conditions. In the

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abundance of sand-rich rivers such as River Krishna, in India, sediment transport is also an important process for controlling flood risks. The seasonal flooding will be helpful for maintaining the groundwater recharge (King and Louw 1998).

The flow of water in the rivers is greatly altering due to the storage and diversion of water through dams and weirs for irrigation, hydropower, water supply etc. These structures significantly affect the ecosystem by decreasing the flow in rivers and fluctuating both the magnitude, seasonality of the flow and frequency of the floods (Peng and Lian 2016). Therefore, the alteration of river flows for human demand must be balanced with meeting the environmental needs without damaging the ecosystem (Abdi and Mehdi 2015, Ares 2018). This requires a sound understanding of freshwater systems and human uses of water, clear policies and strong legislation that recognize the environment as a user of fresh water, and capable institutions to guide the management process (Bunn and Arthington 2002, Wurbs and Hoffpauir 2017). Freshwater ecosystems helps to maintain the richness of global species in both plants and animals, whereas at the same time these services required minimum flows to ensure their quality and availability (Yang *et al.* 2017). Rivers provide numerous services for humans, including clean drinking water, food, building materials and religious and cultural values (Nilsson *et al.* 2005, Poff *et al.* 2003).

From 1970s onwards, scientists and researchers had a paradigm shift in their thinking that the construction of projects on rivers is seriously affecting the ecology and economy and thereby suggested that a minimum flow should be maintained along the river. By the 1990s, it was realised that the biological and social systems cannot be satisfied by a single minimum flow and this lead to the research in the area of Environmental flow (EF). The quality of water needed for maintaining the aquatic habitat and the ecological process is referred as "Environmental flow (EF)", or "Environmental Flow Requirements (EFR)" and the process to determine these requirements is called as Environmental Flow Assessment (EFA) (Smakhtin *et al.* 2006). According to the Brisbane Declaration (2007), "Environmental flows are the quality, timing and quality of water flow required to sustain freshwater and estuarine ecosystem and the human livelihoods and well-being that depend on this ecosystem. In a global water survey conducted with stakeholders who are being water specialists, 88% of the water specialists decided that the EF maintenance is necessary in order to protect the ecosystem. More than 50 countries pledged to work together to protect and reestablish the world rivers and lakes as a follow-up of Brisbane Declaration.

Many methods have been developed to determine the EFR during the past four decades, and these methods are named as Environmental Flow Assessment (EFA) methods (Tharme 2003). Studies on environmental flows are being conducted in many countries and the various approaches fall into four broad categories: hydrological, hydraulics, habitat modelling and holistic. The hydrological approach, suitable for setting primary goals and national strategic decisions, remains the most widely used method. For the streams in hilly areas, habitat and hydraulic methods have been used widely. In habitat method, the relation between flow velocity and aquatic species habitats are used to develop EF. The hydraulic method is based on the relationship between the area, wetted perimeter and its ecosystem. In comprehensive planning (holistic methods), the whole ecosystem is taken into consideration to determine EFR, whereas important flow events have to be identified for both ecological and social aspects (Magdaleno 2018). These approaches need a substantial amount of groundwork, and multidisciplinary expertise to have a long-term effect and to know detailed information about a river basin (Tharme and Smakhitn 2003).

In India, the understanding of EF is that some amount of water is to be released from upstream to downstream for environmental purposes but such type of flows can be minimal because of a substantial quantity of water by abstracted upstream (Boodoo *et al.* 2014, Joshi *et al.* 2014). Further, there are no well laid out policies that specify a certain amount of water to be released from the dams for aquatic ecosystem (Babel *et al.* 2012, Warner *et al.* 2014). Iyer (2005) has highlighted the importance of in- stream flows in India for different purposes.

The Central Water Commission (CWC) has conducted several studies on the EF in the Indian rivers and recommended the minimum flow from the dams. For the rivers in India, the minimum flow in any 10-day period must not be less than the observed 10- day flow, with 99% exceedance. Where 10-day flow data are not available, this may be taken as 0.5% of the 75% dependable annual flow (in m^3/s). One flushing flow is required during the high flow (HF) period with a peak flow of not less than 600% of the 75% dependable annual flow (in m^3/s). A single standard flow value for all rivers does not satisfy environmental requirements and hence, it is necessary to calculate EFR in a basin-to-basin approach (Jain and Kumar 2014, Uday kumar and Jayakumar 2018).

The present study estimates minimum environmental flow requirement values for Srisailam dam by using three different hydrological methods. The assessed ecological flows of Srisailam dam are recommended for release from the dam for protecting the ecosystem integrity on the downstream of the dam. A habitat analysis has been done to assess the suitable water velocity and wetted perimeter values for water life in the river by using the best among the methods used in the study. The other objective of this paper is to investigate the hydrological alteration and estimate the degree of ecological impact. This is done by comparing the calculated EFR values with post-dam period flow data.

2. Study area

The area taken up for the study is the Srisailam dam, built across the Krishna River in Kurnool District of Andhra Pradesh State in the southern part of India. The dam is located between $16^0 25'$ and $17^0 50'$ of the North latitudes and $78^0 40'$ and $80^0 05'$ of East longitudes as shown in Fig.1. This multipurpose dam was the one of the earliest in the series of large infrastructure projects initiated in India for improving food production and to meet the growing power demands.

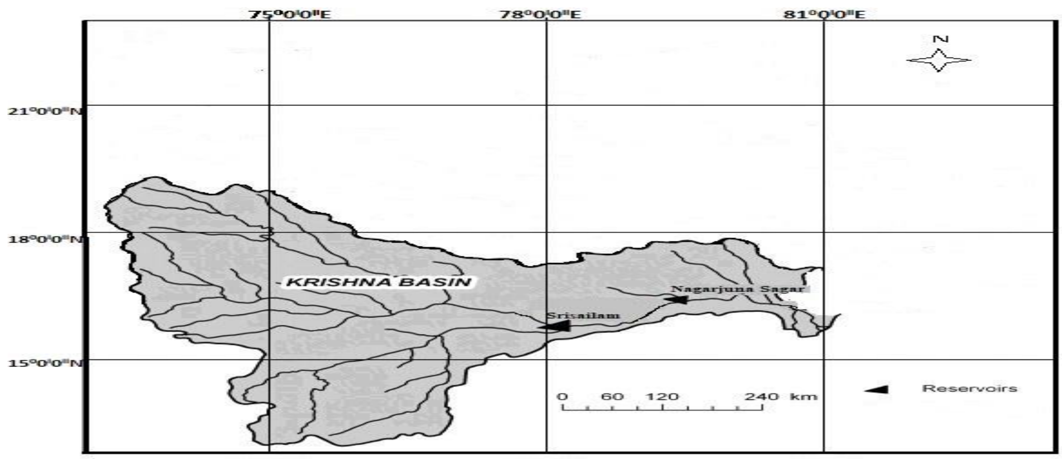

Fig. 1 Study area and location of gauging station

2.1 Data collected

Mean monthly discharge of regulated and unregulated data are collected at Nagarjuna Sagar Project (NSP) gauging station which is located in the downstream of Srisailam dam, constructed across River Krishna during 1984. The length of the data covers a period of 47 years, between 1968 and 2015.To identify the hydrological alteration and EFR, the discharge data length is divided into two periods as pre-construction (1968-1984) data which is consider as a natural flow data and post-construction (1985-2015) data which is consider as the altered flow data. Natural flow data is used to calculate EFR with the three methods. Altered flow data is used to study hydrological alteration caused by Srisailam dam.

3. Materials and methods

EFR methods range from relatively simple to high-confidence approaches. The hydrological methods, which are given in the literature (Richter *et al.* 1996, Hughes and Hannart 2003, Smakhtin and Anputhas 2006, Smakhtin *et al.* 2006) have been used by appropriate modification to suit the climate conditions of the present study area and are described below.

3.1 Flow duration curve shifting method

The Global Environmental Flow Calculator (GEFC) method was introduced by Smakhtin and Anputhas (2006). In the GEFC, 17 fixed percentiles (0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9 and 99.99%) are used to cover the whole range of flow variability from top to bottom. GEFC can assess water requirements for six ecological management classes (EMCs) A, B, C, D, E, and F, where all the EMCs explain the different eco-friendly condition of the river. These six classes range from unmodified to critically modified conditions, in which A and B are classified as an original and largely natural state, while classes E and F are classified as largely modified and environmentally unsustainable. Class D is set as the lowest allowable management condition, and Class C is classified as acceptable ecologically to maintain the ecosystem. For 17 fixed percentiles, Flow Duration Curve (FDC) is determined. First FDC is considered as original reference curve and is used as a reference curve. Next, the EMC requirements are calculated by shifting of the original reference FDC to one percent. Finally, EFR is calculated by dividing the total flow value of 17 fixed percentiles with each class by the mean annual flow and expressed as a percentage, which provides the percentage of MAF for each EMCs.

3.2 Desktop reserve model (DRM)

The DRM was developed by Hughes and Hannart (2003) in the South African region. Two different equations are developed to estimate the Maintained low flow requirements (MLFR) and Maintained high flow requirements (MHFR), as given in Eqs. (1) and (2). The total EFR is the combination of the MHFR and MLFR. MLFR is apportioned as maintenance low flow and drought flow. In calculating EFR, flow variability plays a significant role whereas within the model, two flow variability are used i.e., base flow index (BFI) and coefficient of variation of base flow (CVB). For calculating BFI, Q75 value is taken from natural flow duration curve and divided it by mean annual flow (i.e., BFI= Q75/MAF). Next, CV is calculated by averaging the coefficient of variation (CV) for three most important months during wet and dry seasons, which are in the model (July-Aug-Sep) and (Mar-Apr-May) respectively. This CV average is then divided by the BFI value to get a second variable CVB, which was used by Hughes and Hannart to calculate EFRs in the South Africa region. LP1, LP2, LP3, LP4, and HP1, HP2, HP3, HP4, are the desired environmental management class of (A, B, C, D) for low and high flow parameters.

Low flow requirements can be estimated by Eq. (1)

$$MLFR = \frac{LP4+(LP1*LP2)}{(CVB^{LP3})^{1-LP1}} \tag{1}$$

High flow requirements can be estimated by Eq. (2)

$$MHFR = \gamma \times HP2 + HP3 \tag{2}$$

If CVB > 15 then

$$MHFR = (\gamma \times HP2 + HP3) + (CVB - 15) \times HP4 \tag{3}$$

γ is a function of CVB and another desired environmental management class HP1 Mazvimavi *et al.* (2007) which is given by

$$\gamma = \frac{(\frac{Ln(CVB)}{Ln_{100}})^{HP1}}{HP1} \tag{4}$$

These model parameters were generated for South African rivers and the parameters have to be changed properly for different countries conditions. The seasons in the model are inbuilt to suit South Africa's climate conditions, primarily wet season months from January to March and dry-season months from June to August. This presumption cannot be modified inside the model. However, for the Krishna River, the key months of the wet season are July to October, and for the dry season, the key months are from March to May. To reflect these key months to suit Indian conditions, the input data information was shifted by 6 months (i.e., January got to be July and so forth) and the outcomes were readjusted.

3.3 Simplified range of variability approach

River flows naturally vary about a mean condition, and therefore, any explanation for the good conditions of environment needed to comprise of a range of normal variability. The Range of Variability Approach (RVA) (Richter *et al.* 1996, Gippel *et al.* 2009) classifies annual river management objectives based on a reasonable range of variation in hydrological characteristics. This range was distinguished by an average range, such as ±1 standard deviation from the mean, i.e., 25th to 75th percentile range. The RVA technique suggests that flow regime characteristics should lie within this targets for the same percentage of time as they were before the start of the regulation. For the 12 months, this range (25th to 75th percentile) is assumed based on the natural flow series. If the flow characteristics of post-construction series lie within this range, hydrological health score would be 1 whereas beyond this range, score will be less than 1. If the flow is greater than the 75th percentile value, on high flow seasons score is equal to1 and for low flow seasons, score is calculated by using Eq. (5). If the flows are less than 25th percentile, in any seasons score is calculated by using Eq.(6). Minimum monthly EFR is calculated by assuming score as 1 for 12 months by comparing with the pre-period flow. The calculated EFR flow regime condition follows natural flow pattern as in the pre-period flow but requires a high percentage of water. Derivation of EFR for each month will be with a score value of 1-0 range. The score values and the

Table 1 Flow health score range and its alteration condition

SL. No	Flow health score	Alteration condition
1	0.8-1	Very small
2	0.6-0.8	Small
3	0.4-0.6	Moderate
4	0.2-0.4	High
5	0.0-0.2	Very High

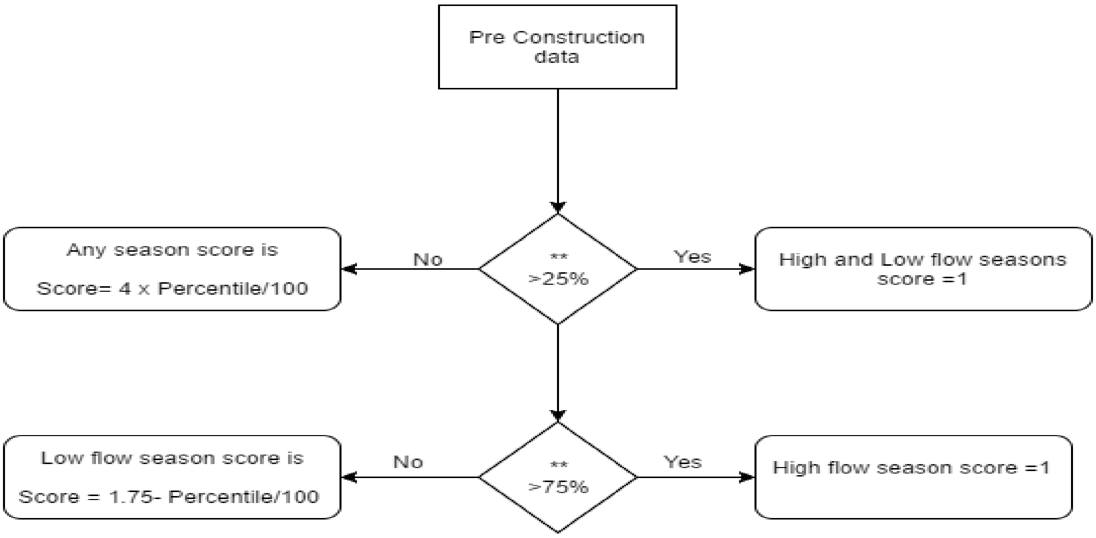

Fig. 2 Working flow chart of high and low flow seasons (**The percentile values are fixed based on the Post construction period data)

corresponding alteration conditons are given in Table 1. The working flow chart of Low flow (LF) and High flow (HF) seasons is presented in Fig. 2.

If flow is greater than 75th percentile in low flow season

$$\text{Low flow Season score} = 1.75 - \frac{\text{Percentile}}{100} \quad (5)$$

If flow is less than 25th percentile in any season

$$Score = 4 \times \frac{\text{Percentile}}{100} \quad (6)$$

3.4 Hydrological alteration calculation

Environmental flow regimes allow hydrologic alterations up to some. It is also well acknowledged that if environmental instream flows are altered too much, the function and structure of river regimes will change. The long-term alteration will have an influence on the physical, chemical, and biological properties of the river systems. For example, the residence time of water would impact the chemical properties, as well as the biological characteristics (Talukdar and Pal 2017, Pal and Talukdar 2018). As a result, altered riverine components are very likely to

Table 2 Alteration category proposed by Richter *et al.* (1996)

Sl. No	Flow non-attainment value	Alteration category
1	0-0.33%	Lowest alteration
2	0.34-0.66 %	Moderate alteration
3	>0.67%	Highest alteration

break a healthy aquatic system.

For analysing the alterations, the recorded flow regime data is divided into two time periods as 'Pre-Impact' and 'Post-Impact' periods. When analyzing the differences between the two time periods, the calculated EFR values with three methods are used as a Pre-Impact natural variation data for defining the extent to which natural flow regimes have been altered and quantify this alteration in a series of Hydrologic Alteration factors (HA). Richter *et al.* (1996) proposed three classes as the degrees of HA into three equal sizes as shown in Table 2. HA is equal to zero when both frequencies are equal. In the process of calculating HA, two variables, viz., the expected frequency and observed frequency are used. The expected frequency is equal to the number of non-attainment flow values during the Pre-Impact period multiplied by the ratio of Post-Impact years to Pre-Impact years. Observed frequency is the number of non-attainment flow values that fall in Post-Impact years. Finally, a Hydrologic Alteration factor is calculated by using Eq. (8).

$$\text{Expected frequency} = \frac{\text{Number of Post years}}{\text{Number of Pre years}} \text{X Number of values fall in Pre year} \tag{7}$$

$$\text{HA} = \frac{\text{Observed Frequency} - \text{Expected Frequency}}{\text{Expected Frequency}} \tag{8}$$

3.5 Habitat analysis

After calculating EFR it is necessary to calculate whether these requirements are sufficient for maintaining the surrounding environment along the river. To calculate habitat analysis around the river, hydraulics parameters, like river cross section, river length etc., are required. To extract this data, a 30 meters Digital Elevation Model (DEM) of the study area was downloaded from (https://earthexplorer.usgs.gov/). This DEM was exported into ArcGIS specifically to process the geospatial data. An extension tool of ArcGIS, namely, HECGeo-RAS is used to create geometric data from DEM which consists of the connectivity of the river system, cross section, data reach, river length, and stream junction information. The Generated geometric data is imported in to an HEC-RAS hydraulic model. HEC-RAS tool was run in 1-D model in unsteady case. In HEC-RAS simulation, water surface profiles are computed from one cross-section to the next cross-section by solving the standard step procedure of the energy equation.

4. Results and discussion

Incoming water at NSP is the outflow of Srisailam reservoir which was constructed during the year 1984.To calculate environmental flow requirements, the hydrological data collected is divided into two parts–the pre-impact period (1968-1984) and the post-impact period (1985-2015). Pre-impact data was used to find EFR by using the three hydrological methods. Post-impact data was

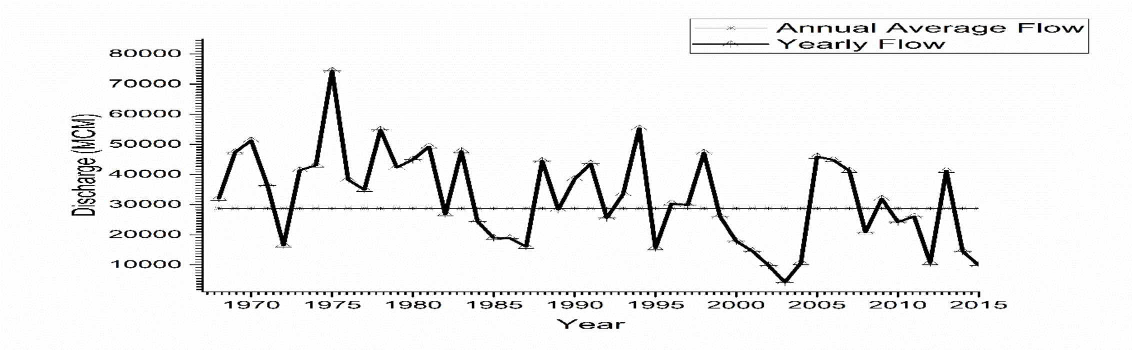

Fig. 3 Average annual flow series from 1968-2015

used to find hydrological alterations that could happen due to the presence of Srisailam dam. The incoming water registered depletion during the water-years between 1986 and 2004 after Srisailam reservoir started its operation. A declining trend is also observed in the incoming flow after 1999 up to 2004, as seen from Fig. 3.

In summary, DRM can estimate water necessities in four EMCs (A, B, C, and D). The explanation of the results for all the categories is similar. Hence, the results of one class (C), have been presented in Table 3. The results show that to preserve the stream in Class C, an average annual environmental flow allocation of 9378 MCM (i.e., 23.11% of MAF) is needed. This is the sum of the low maintenance flows 14.81% MAF (i.e., 6011 MCM) and high maintenance flows 8.3% of MAF (i.e., 3367 MCM). The drought-low-flows corresponds to 7.74% of MAF (i.e., 3141 MCM). Minimum and maximum EF requirements occur during the month of May and August with an estimated flow of 11 m^3/sec and 1362 m^3/sec respectively. These months are defined as dry and wet months.

The EFR, as a percent of natural average annual flow for different EMCs of the Krishna River at NSP by using the FDC shifting method is presented in Table 4. The method classifies the river discharges into six EMCs decreasing from the natural to the critically modified condition. As water allocation decreases, the protection of the ecosystem decreases. MAF of the river during the pre-impact period was estimated as 40,589 MCM. GEFD assessed 60% of MAF (i.e., 24353 MCM) for natural condition (Class A) and 36% of MAF (i.e., 14612 MCM) for slightly modified condition (Class B). To maintain the downstream stretch of the river Krishna in reasonable condition (Class C) and to keep the essential ecosystem function completely, 22% of MAF (i.e., 8929 MCM) discharge is estimated by GEFC. When compare GEFD with Tennant method, classes E and F fall below severe degradation condition. Fig.4 shows six EMCs flow duration curve.

The mean annual flow volume (MAF) 51.23% is essential to obtain a score of 1 for all months in the pre-impact period. Environmental flow for Srisailam dam are estimated by using Eqs. (5) and (6). The Proposed minimum flow for the downstream reach of Srisailam dam has taken two options, one for low risk, and another one is medium risk to the environment. Low-risk regime achieved a score of 0.6 with required 31.04% of MAF (i.e., 12591 MCM) in the pre-impact period with an average flow rate of 393 m^3/s. Medium risk regime achieved with a score of 0.4 and required 20.88% of MAF (i.e., 8490 MCM) with an average flow rate of 265 m^3/s which shown in Table 5. Monthly requirements and its score for two options are also given in Table 5.

The EFR values required to maintain the river in DRM (class C), GEFC (class C) and RVA

Table 3 The summary output from the DRM applied to the Krishna River at the Nagarjuna Sagar dam, based on 1968-1984 monthly flow series for Ecological Category = C

MAF = 40589 (MCM)				Total flow = 9378 (MCM) (23.11 %MAF)			
BFI Index = 0.49				Maintenance low flow= 6011 (MCM) (14.81 %MAF)			
CV(JA*S+MAM) Index = 1.70				Drought low flow = 3141 (MCM) (7.74 %MAF)			
				Maintenance high flow = 3367.29 (MCM) (8.3 %MAF)			
Observed flow (m^3/sec)				Environmental flow requirement (m^3/sec)			
				Low flows			
Month	Mean (μ) (m^3/sec)	SD (σ)	CV	Maintenance (m^3/sec)	Drought (m^3/sec)	High flow (m^3/sec)	Total maintenance EFR (m^3/sec)
January	176	106	0.60	44	23	2	46
February	140	90	0.64	34	18	1	35
March	112	99	0.88	26	14	1	27
April	94	93	0.99	19	10	0	19
May	87	86	0.99	11	2	0	11
June	462	374	0.81	51	27	0	51
July	2700	1105	0.41	293	153	113	406
August	4803	1886	0.39	566	296	795	1362
September	3243	1737	0.53	496	259	113	609
October	2426	2002	0.82	448	234	226	674
November	688	681	0.99	190	100	9	199
December	268	138	0.51	73	39	1	74

*Note: **J=** July, **A*=** August, **S=** September, **M=** March, **A=** April, **M=** May

Table 4 Estimated environmental flow requirements by using the FDC shifting method

Site	Record period	MAF (MCM)	Environmental flow requirements for different EMCs MCM					
			Class A	Class B	Class C	Class D	Class E	Class F
Gauging Station at NSP Dam	1967-1984	40589	24353 (60.5 %)	14612 (36.3 %)	8929 (22.0%)	5641 (13.9 %)	3653 (9.0 %)	2354 (5.8%)

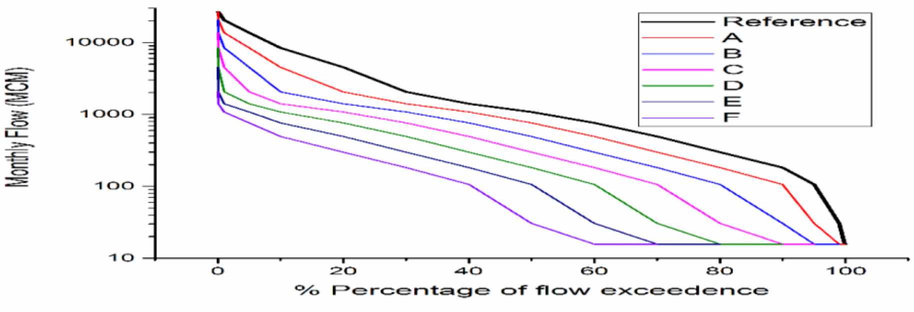

Fig. 4 Flow duration curve for six EMCs

Table 5 Recommended flow regimens of RVA method

Month	Score 1.0 (m^3/sec)	Score 0.8 (m^3/sec)	Score 0.6 (m^3/sec)	Score 0.4 (m^3/sec)
January	92	79	66	44
February	76	40	34	28
March	49	31	20	11
April	23	22	19	17
May	15	4	2	1
June	98	69	60	51
July	1826	1148	921	532
August	2986	2549	2115	1453
September	1452	1098	864	567
October	806	460	354	284
November	262	211	188	124
December	103	82	76	63
Average flow rate m^3/sec	649	483	393	265
Percentage of MAF	51.23%	38.10%	31.04%	20.88%

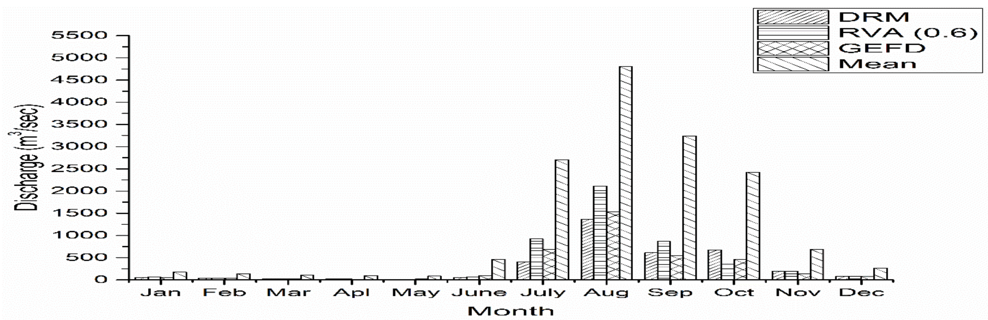

Fig. 5 Comparison of MAF with three different Hydrological methods for Srisailam

(low risk to environmental) are estimated as 23.11%, 22% and 31.04% of MAF respectively. On the other hand, it is observed that RVA approach, gives the highest flow recommendation when compared to the other two both approaches and the values computed with GEFC is in the lowest stage. When average monthly EFR is considered, a significant flow variation is observed in RVA method which signifies the lowest value in the dry season and highest value in the wet season, when compared with DRM and GEFC approaches. Fig. 5 illustrates average monthly EFRs for three different approaches. It is also observed that the flow will have high seasonality, with about 30% and 20% of annual flow taking place in August and September respectively, while in May, only 0.7% of the annual flow is taking place.

From the results using the three methods, it is observed that the RVA is giving high flow values in high flow season and very low values in low flow season. GEFC suggesting very low values in the two seasons, whereas DRM results are in intermediate which are favourable while considering human water needs. So in this study, results from the DRM are presented in the form of graphs and tables and the habitat analysis is carried out.

4.1 Alterations

To investigate the effects of Srisailam dam on the downstream of the dam, the work by Richer *et al.* (1996) was followed, which suggested that if the flow non-attainment ranges between 0%-0.33% represents low alteration, 0.34%-0.67% indicates medium alteration and 0.68%-1% illustrates high alteration. Recorded daily inflows at NSP from the year 1985-2015, were used to evaluate the hydrological variation. The calculated EFR under each method is considered as a benchmark of natural flow and used to find the flow non-attainment of each month over a period of 31 years (1985-2015). Fig. 6 shows that non-attainment of daily outflows of Srisailam reservoir with calculated EFR of DRM method. In summary, the number of years classified as low, moderate, and high alteration are 5, 15 and 11 years, respectively. Considering the month-wise analysis, it is seen that during the three months (February, March, and May), the flow has an alteration range from 0.33%-0.38%, and for the remaining three months (January, April, and June) has a low alteration range from 0.23%-0.28%. During the high flow season, flows in all the months shows an alteration range varying from 0.48%-0.64%, but in the month of July, the alteration in the flow is high (i.e., 0.81%).This is because of water available at dam in the month of July. In the downstream of the Srisailam reservoir, ecological system is preserved up to 2001 with an average alteration rate of < 0.33%. But after the year 2001, it is observed that most of the months have alternation rate high (>0.68%), due to the decrease of water flow from the reservoir. The hydrological alteration for different methods during high and low flow period presented in Table 6. According to RVA method, the alteration rates of the low flow season ranged from 0.27% to 0.39%, and overall average alteration rate was 0.31%. For high flow season, it ranged from 0.53% to 0.84%, and the total average alteration rate was 0.64%. In GEFC, the alteration rate of low flow season and high flow season ranged from 0.13% to 0.36% and 0.37% to 0.82% respectively. Overall alteration rate of low and high flow season were 0.28% and 0.57% respectively. The downstream of Srisailam dam has a highly regulated flow due to the reservoir operation by capturing high flows, and leading to persistently low flows in the high flow season, and then releases water during the low flow season, leading to persistently high flows in the low flow season. It may be noted that the low alteration during low flow season due to the hydroelectric activity. In high flow season, significant changes were observed due to the flow obstructed by the reservoir. Decreasing river flow will affect the flushing property and increases

Table 6 Fraction of the EF not met in the Post-Impact years

Methods/ Months	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
RVA	0.39	0.36	0.26	0.28	0.34	0.27	0.84	0.68	0.58	0.53	0.62	0.58
	M	M	L	L	M	L	H	H	M	M	M	M
	Low Flow Season =0.31 (L)						High Flow Season =0.64 (H)					
DRM	0.23	0.35	0.33	0.28	0.38	0.24	0.81	0.48	0.49	0.73	0.64	0.57
	L	M	M	L	M	L	H	M	M	H	M	M
	Low Flow Season=0.30 (L)						High Flow Season =0.62 (M)					
GEFC	0.27	0.36	0.13	0.26	0.4	0.29	0.82	0.59	0.37	0.66	0.53	0.5
	L	M	L	L	M	L	H	M	M	H	M	M
	Low Flow Season =0.28 (L)						High Flow Season =0.57 (M)					

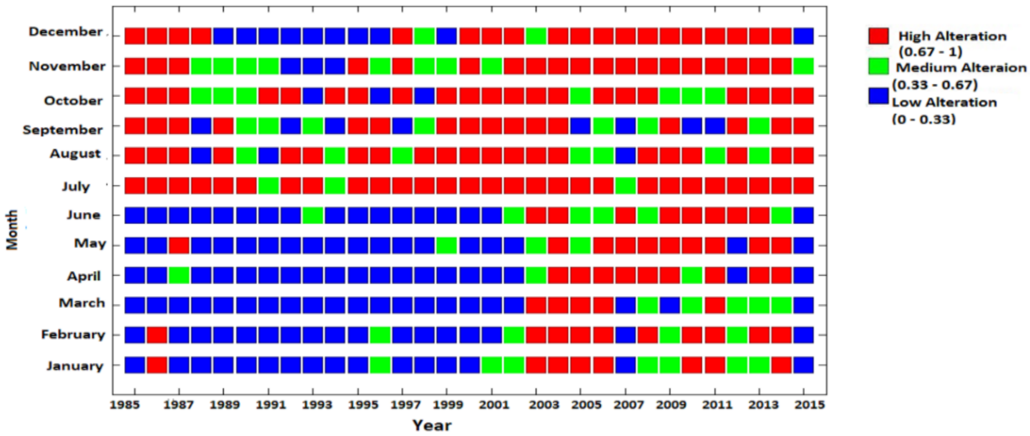

Fig. 6 Monthly and yearly alterations for DRM method

Table 7 Environmental flow requirements and corresponding water depth velocity

		DRM Method					
Month	Recommended EF values	Depth and velocity at 30Km d/s of the dam		Depth (m) and velocity(m/s) at 60 Km d/s of the dam		Depth (m) and velocity(m/s) at 90 Km d/s of the dam	
	Flow m^3/s	Wetted Perimeter (P_w) (m)	Velocity (m/s)	Wetted Perimeter (P_w) (m)	Velocity (m/s)	Wetted Perimeter (P_w) (m)	Velocity (m/s)
January	46	1.18	0.33	1.21	0.56	1.39	0.12
February	35	1.01	0.23	0.98	0.47	1.30	0.07
March	27	0.98	0.21	0.87	0.43	1.25	0.06
April	19	0.85	0.20	0.83	0.41	1.24	0.05
May	11	0.76	0.16	0.77	0.36	1.17	0.05
June	51	0.83	0.20	0.81	0.40	1.23	0.05
July	406	2.64	0.72	2.75	1.25	2.60	0.49
August	1362	3.02	0.77	3.32	1.54	2.91	0.57
September	609	2.46	0.54	2.46	1.20	2.34	0.43
October	674	2.53	0.68	2.64	1.20	2.53	0.45
November	199	1.66	0.49	1.75	0.76	1.67	0.23
December	74	1.47	0.43	1.55	0.68	1.56	0.19

sedimentation. As a result, fish population decreases, due to the loss of breeding and nursery grounds, which affect the breeding process. No ecological surveys have been conducted, but the low flow can affect the ecology of the river, benefits those species that rely on more regular flow, while adversely affecting those species that are seasonally drained.

4.2 Habitat analysis

In the absence of detailed information about all the various species and communities in a river ecosystem, fishes are taken as indicator species. The species of fishes found in Krishna river basin include the catfish, the carps, the Anguilla, the Notopterus, the Silonia, the Mystus, and the Seenghala. The minimum depth required for the sustenance of fish species observed in the study area is 0.5 to 0.7 m and 0.5 m/s flow velocity. The downstream of Srisailam dam is divided into three sections for calculating wetted perimeter and velocity of flow by using DRM method to find the condition for aquatic habitation along the river. The proposed minimum flow of DRM method, the corresponding depth of the flow and its velocity are given in Table 7. The depth available for recommended flows is above or equal to this range. The water surface profile and hydraulic information are calculated at 30, 60, and 90 Km, for the stretch of river Krishna having a length of 93 Km from the downstream of Srisailam dam (Chainage 0.0 Km) to NSP (Chainage 93 Km). Discharge is ranged from 11 m^3/sec to 1362 m^3/sec. With respect to this discharge, wetted perimeter was found to be 0.76 m to 3.32 m and water velocity was found to be 0.05 m/s to 1.54 m/s; respectively. Manning's 'n' value is taken as 0.035.

5. Conclusions

EFR and hydrological alteration are calculated based on the available flow data at NSP in between 1968 to 2015 years for Srisailam reservoir. The analysis of annual and monthly flow data shows that the river flow decreases significantly due to the reservoir operation on the upstream mainly during the period between 1999 and 2004. EFR is calculated by using three different hydrological methods to estimate the minimum flow requirements for protecting the ecology of downstream side of the Srisailam. Among the methods studied, flow values using RVA has high values during high flow season and low values during low flow season, when compared with other two methods. Flow values obtained by DRM and GEFC are almost the same except in the months of July and August, and severe hydrological alteration is observed in the month of July. EFR is essential for proper functioning of the riverine ecosystem and instream uses namely capturing fisheries, navigation, etc. As of now, Srisailam has no water policies to protect ecosystem on downstream of the dam. The outcomes of this study provide good information for water management officers to meet the environmental water needs without disturbing human needs.

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