ASSESSMENT OF ECOLOGICAL STATUS OF A RIVER USING THE ECO-FLOW METRICS

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ABSTRACT

The hydro-ecological studies are important for any water resources development project. In the present study, river ecology studies including the flow duration curve and environmental flow requirement have been carried out for a sub-basin of the Mahanadi River (Hamp River). Flow duration curves (FDCs) are important hydrological tools, which are essential for water resource planning and management. These can condense a plethora of hydrological information into a single graphic image. FDCs are often used to summarize the impacts of potential anthropogenic and climate change scenarios on water resource systems. Results derived from the FDCs are used by hydrologist and engineers involved in planning and designing of various water resource projects. Other uses of FDCs includes evaluating the characteristics of hydropower potential of the river; design of drainage systems; flood- control studies; computing the sediment load and dissolved solids load of a stream; comparing the adjacent catchments with a view to extend the streamflow data, etc. Apart from these classical uses, the FDCs can also be used to assess the health of the river in terms of its ecological status.

The present study was taken up with an objective to identify the status of ecological health of the Hamp River, which is a tributary of Mahanadi River, based on the eco-flow metrics. The daily streamflow data of CWC G&D site at Andhiyarkhor, Chhattisgarh from the India-WRIS website, has been used. The flow duration curves (FDCs) for different periods like daily, monthly, annual etc. were developed. The 10-daily time series FDCs have been used to identify the ecosurplus and ecodeficit years along with their respective magnitudes. Further, an eco-flow metric for the Hamp River was prepared for the 34 years daily discharge data from the period 1974 to 2013. The results of the study conclude that Hamp River was an ecosurplus river for earlier years for the study period and gradually it is heading towards ecodeficit status. A rapid assessment of environmental flows for various environmental management classes (EMCs) was also performed for the same data with Global Environmental Flow Calculator (GEFC), developed by International Water Management Institute (IWMI). The results of the study confirm that the ecology of Hamp River is degrading over the years, which could be due to excess withdrawal of water of irrigation due to expanding agricultural activities in the catchment. .Although, the river ecology was under a sustaining condition in past, the metric has falling due course of time, which can be a signal of ecological deterioration in the future.

Keywords: Ecosurplus, Ecodeficit, Eco-Flow Metric, River Ecology, Flow Duration Curve (FDC).

1. INTRODUCTION

Changes in flow regime and river discharge are commonly observed in a large number of rivers worldwide as a response to environmental changes. However, the characteristics and the attribution of such changes are not fully understood. River discharge is given the most attention among all the components of the hydrological cycles for its critical importance ind designing and planning of water resource projects. Moreover, river flow regimes are critical components of the ecological integrity of the river systems. River discharge and flow regime changes are well recognized by ecologists as the primary drivers of a number of fundamental ecological processes in river ecosystems (Poff and Zimmerman, 2010). Understanding the characteristics of changes in river discharge and flow regime and analyzing the reasons for these changes are important for river management and river ecosystem protection.

The flow duration curves (FDCs) are very tools used to describe hydrological regimes. The FDC represents the relations between magnitude and frequency of flow by defining the proportion of time for which any discharge is equaled or exceeded. FDC represent use full graphical and analytical tools for evaluating flow variability at particular site. Since, FDCs contains lots of hydrological information into a single graphic image; these are often used to summarize the impacts of potential anthropogenic and climate change scenarios on water resource systems (Vogel & Fennessey, 1995). Gao et al. (2009) developed a few statistics to capture the key components of ecologically relevant flow variations using an eco-flow metrics (ecosurplus and ecodeficit) calculated from FDCs.

Researchers in many regions are observing changes in river discharges and flow regimes worldwide. The quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems is termed as environmental flows, which are essential for sustenance of the river ecology. Various methods have been evolved to assess these values for Indian contexts also (Jain & Kumar, 2014). In view of this, researchers have developed and applied a number of statistical tools and methods to characterize the various aspects of flow regimes to assess and quantify the ecological effects from hydrologic alterations. Indicators are needed for evaluating the ecological health of the river and degree of hydrologic alteration. To date, numerous hydrologic metrics have been published to analyze various aspects of the flow regime. These multiple hydrologic metrics enable researchers and policy makers to investigate the multiple effects of hydrological changes on the river ecosystems.

This paper explores the FDC based eco-flow conditions of river to assess the ecological health of river. Environmental flow requirements under different EMCs have also been estimated for sustaining the river ecology.

2. STUDY AREA

The present study is focused on the catchment area of Hamp River, which is a western tributary of the Mahanadi River in central India. The majority of study area is alluvial plains, which drains an area of 2141 km^2. The Hamp River emerges from Chilpi Range in Kabeerdham District of

Chhattisgarh state and confluences with Seonath River at 3 km upstream of Nandghat. The Hamp River rises at an elevation of 457 m and runs 204 km before it meets Seonath river covers parts of Kabeerdham and Bemetara districts of Chhattisgarh (Fig. 1).

The study area experiences hot moist /dry sub-humid climate. The 88% of rainfall occur in the monsoon season and month of May is the warmest month. And January and December are the coldest month. The average maximum temperature ranges from 22.12 - 47.23°C and average minimum temperature ranges from 9.77 - 23.79°C.

The average annual rainfall in the study catchment is around 1088 mm. The outlet of the watershed is at Andhiyarkhor. The rainfall reaches its maximum in the monsoon season that spans between June to September. March to May and October to November consider as pre-monsoon and post-monsoon, respectively.

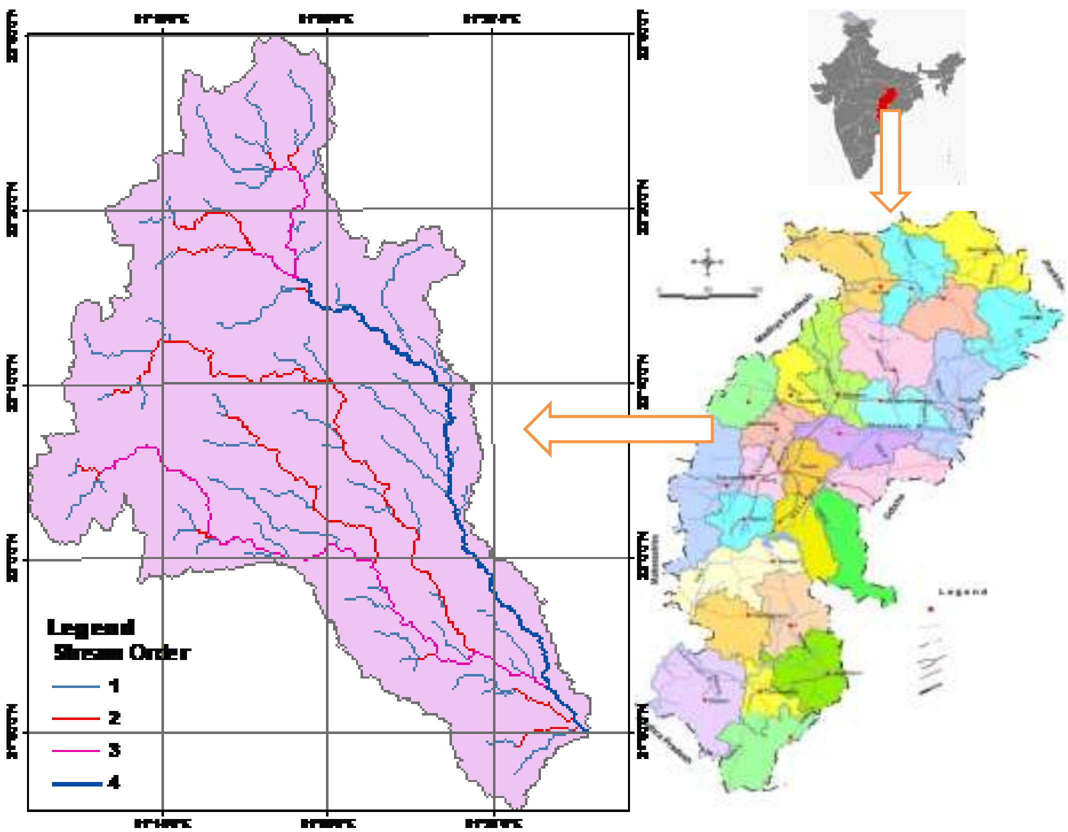

Fig. 1: Location Map of Hamp River Basin in India

3. DATA USED

The eco-flow metrics study of River Hamp was carried out with observed discharge data of Andhiyarkhore G&D site. This site is being maintained by CWC and daily data from the year 1979 to 2013 were used to determine the ecological status of the river. The data was collected from the India-WRIS (Water Resource Information System) website.

4. METHODOLOGY

4.1 Flow Duration Curve

The FDC is a cumulative frequency curve that shows the percent of time during which specified discharges were equaled or exceeded in a given period. A river with natural or regulated flow can easy have identified with the vigilance. The FDC is the integral of the frequency diagram. Perhaps a simpler concept of the FDC is that it is another means of representing stream flow data combining in one curve of the flow characteristics of a stream throughout the range of discharge. Although, the FDC does not show the chronological sequence of flows, it is useful for many studies. To prepare a FDC, the daily, weekly, or monthly flows during a given period are arranged according to magnitude, and the percent of time during which the flow equaled or exceeded the specified values is computed. The curve, drawn to average the plotted points of specified discharges versus the percent of time during which they are equaled or exceeded, thus represents an average for the period considered rather than the distribution of flow within a single year. FDCs find considerable use in water-resources planning and development activities and provides a convenient means for studying the flow characteristics of streams and for comparing one basin with another. An FDC simply plots Q as a function of its corresponding exceedance probability

$$P_p = \frac{m}{(N+1)} \times 100\ \% \qquad \text{` } \qquad \ldots (1)$$

Where, P_p = Percentage probability

m = Order number of the discharge

n = Number of data points used in the listing

The ordinate Q_p at any percentage probability P_p represents the flow magnitude in an average year that can be expected to be equalled or exceeded P_p percent of time and is termed as $P_p\ \%$ dependable flow. In a perennial river Q_{100} = 100% dependable flow is a finite value. On the other hand, in an intermittent or ephemeral river the stream flow is zero for a finite part of a year and as such Q_{100} is equal to zero.

The presence of a reservoir in a stream considerably modifies the virgin-flow duration curve depending on the nature of flow regulation.

4.2 Eco Flow Metrics

In the present study, ecosurplus and ecodeficit flow conditions were analyzed to evaluate the ecological instream flow regimes of a river basin. Vogel et al. (2007) proposed these conditions and eco-flow matrix has been analyzed for detecting the change of the river ecology. The ecosurplus and ecodeficit metrics are based on 25^{th} and 75^{th} percentile flow duration curves (FDCs). FDCs are constructed from streamflow data over a time interval of interest and provide a measure of the percentage of time duration that stream flow equals to or exceeds a given value. In the current study, annual ecosurplus and ecodeficit values were calculated using daily stream flow data.

In the current study, the annual, monthly, and daily FDCs were constructed for the available flow data (1979-2013). These FDCs were used to check the status of river ecology. Based on the 34 years of annual, monthly, daily and 10-daily FDCs, the 25th percentile FDC and the 75th percentile FDC were obtained. In order to get the desired 25th and 75th percentile years we opted for the 10 daily median FDC for the current 34 years daily data.

The 25th and the 75th percentile FDCs pertaining to the 10-daily flow data were then used as the upper and the lower limits of the river ecology to justify its status. The range from the 25th to 75th percentiles could be considered the normal range for the river ecology. If the 10 daily average FDC of a given year is located below the 25th percentile FDC, the area between the 25th percentile FDC and the 10 daily average FDC is defined as *ecodeficit* **(Fig. 2)**. This value represents how bad is the condition of river ecology. Conversely, if the 10 daily average FDC of a given year is located above the 75th percentile FDC, the area between the 75th percentile FDC and the 10 daily average FDC is called *ecosurplus*, which represents how good is the condition of river ecology **.**

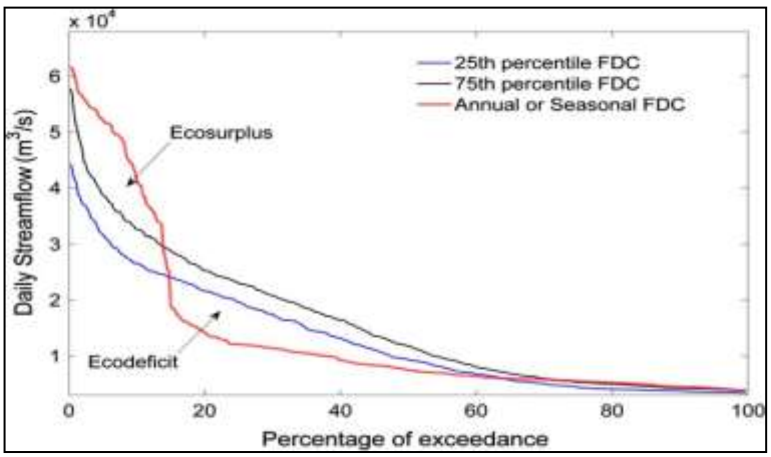

Fig. 2: Definition of Ecosurplus and Ecodeficit in the Flow Duration Curve (Gao et. al. 2012)

Later, the eco-values of all the years and the 10 daily average discharge data for the 25th and the 75th percentile years were averaged individually. All the positive averaged eco-values were divided by the sum of the averaged 25th percentile year and the maximum positive averaged eco-value. Similarly, all the negative averaged eco-values were divided by the sum of the averaged 75th percentile year and the minimum negative averaged eco-value. In the present study, the fractions of eco-values were termed as eco-flow metrics.

4.3 Environmental Flow Requirements

The global environmental flow calculator (GEFC) a software developed by International Water Management Institute (IWMI), Srilanka for desktop rapid assessment of environmental flows (EFs), was used to estimate the environmental flows requirements (EFR) (Sood et. al. 2017). The calculator uses monthly time series flow conditions and its corresponding Flow Duration Curve (FDC) – a cumulative distribution function of flows for EF estimation. The FDC is represented by

17 percentage points on the probability (X) axis. EFs aim to maintain an ecosystem or upgrade it to some prescribed or negotiated condition called 'Environmental Management Class (EMC)'. The higher the EMC, the more water is needed for ecosystem maintenance. Six EMCs are used in the calculators ranging from 'Unmodified' to 'Critically Modified'. Each EMC is represented by its unique FDC. The FDC for each class is determined by the lateral shift of the original reference FDC to the left along the probability (X) axis by one percentage point. Each EMC is effectively an EF scenario. The EMC best suited for the river in question may be selected-based on expert judgment. A FDC established for each EMC can be converted into an EF time series. By using this software, month-wise discharge from the barrage had been estimated and recommended for moderately modified class (Class C) of EMC of the river (Sood et. al. 2017)

All FDCs are represented by a table of flows corresponding to the 17 fixed percentage points: 0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9 and 99.99 percent. These points (i) ensure that the entire range of flows is adequately covered, and (ii) easy to use in the context of the following steps. FDC tables were calculated directly from the observed record or from part of the record which could be considered 'unregulated'. Normally the earlier part of each record - preceding major dams' construction was used to ensure that monthly flow variability, captured by the period-of-record FDC, is not seriously impacted.

Six EMCs are used in this study and six corresponding default levels of EFR may be defined. The set of EMCs is similar to the one described in DWAF (1997). An environmental FDC for any EMC only gives a summary of the EF regime acceptable for this EMC. The curve however does not reflect the actual flow sequence. The spatial interpolation procedure described in detail by Hughes & Smakhtin (1996) is used for this purpose.

Table.1 Environmental Management Classes

EMC	Ecological description	Management perspective
A: Natural	Pristine condition or minor modification of in-stream and riparian habitat	Protected rivers and basins. Reserves and national parks. No new water projects (dams, diversions, etc.) allowed
B: Slightly modified	Largely intact biodiversity and modified habitats despite water resources development and/or basin modifications	Water supply schemes or irrigation development present and/or allowed
C: Moderately modified	The habitats and dynamics of the modified biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species present	Multiple disturbances associated with the need for socio-economic development, e.g., dams, diversions, habitat modification and reduced water quality
D: Largely modified	Large changes in natural habitat, modified biota and basic ecosystem functions have occurred. A clearly lower than expected species richness. Much lowered presence of intolerant species. Alien species prevail	Significant and clearly visible disturbances associated with basin and water resources development, including dams, diversions, transfers, habitat modification and water quality degradation

E: Seriously modified	Habitat diversity and availability modified have declined. A strikingly lower than expected species richness. Only tolerant species remain. Indigenous species can no longer breed. Alien species have invaded the ecosystem	High human population density and extensive water resources exploitation
F: Critically modified	Modifications have reached a critical modified level and ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible	This status is not acceptable from the management perspective. Management interventions are necessary to restore flow pattern, river habitats, etc. (if still possible/feasible) – to 'move' a river to a higher management category

5. RESULTS AND DISCUSSIONS

5.1 FDCs for different periods (Annual, Monthly, Daily &10Daily):

The daily, monthly annual and 10-daily FDCs) for the given period of data are shown in Fig. 3. The 25th and the 75th percentile years from the 10-daily average FDC were then obtained.

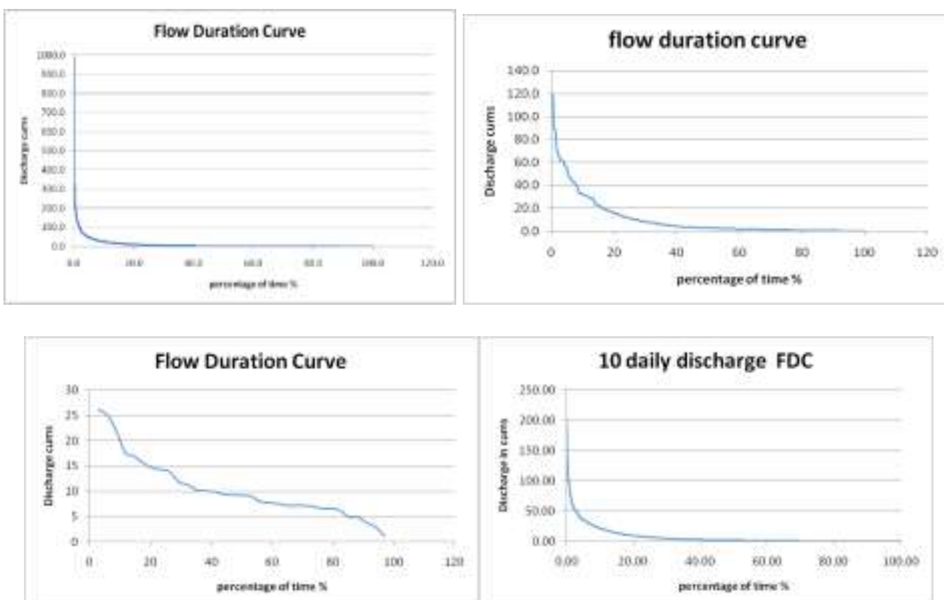

Fig.3: Daily, Monthly, Annual and 10-daily FDC, (1979-2013), at gauge station of Andhiyarkhor

5.1.1 25th and 75th Percentile FDCs for 10-daily average data:

The 10-daily average FDC was drawn and the 25th percentile year (Year 2010) and the 75th percentile year (Year 2003) identified, which were further used to drive the ecosurplus and ecodeficit flow conditions of each of the year of study period..

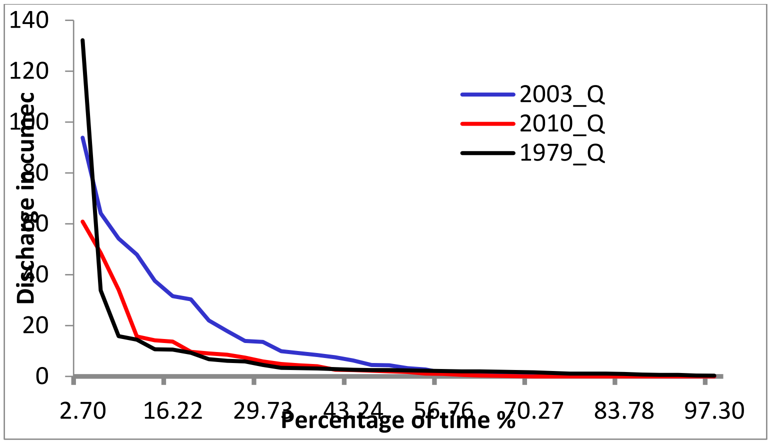

Fig.4: Testing of Year 1979 with 25th and 75th percentile FDCs

5.1.2 Ecosurplus and Ecodeficit Flows:

The ecosurplus and ecodeficit metrics are based on Flow Duration Curves (FDCs). The FDCs for the Year 2010 and 2003 (i.e. 25th and the 75th percentile years) were used as enveloping FDCs for determining the ecosurplus and the ecodeficit flow for each year's FDC. Fig. 4 shows the testing of year 1979 FDC for its eco-flow values. High flows values of 1979 (upper part of FDC) are more than the high flows values of 75 percentile year (year 2003), which indicated the ecosurplus conditions. On the other hand the low flow values of 1979 (lower part of FDC) are less than the low flows values of 25 percentile year (year 2010), which indicated the ecodeficit conditions. Overall year 1979 found to be the ecodeficit year with an absolute eco-value of -1.92 and standardized eco-value of -0.25.

5.1.3 Eco-Flow Metric:

Then, the ecosurplus and the ecodeficit flow data so obtained for all 34 years were further used to create an eco-flow metric. The eco-flow metric gives a clear indication of the flow type, which in result tells us about the river ecology. The eco-flow metric for the study period i.e. 1979-2013 for Hamp river basin is depicted in the figure 5.

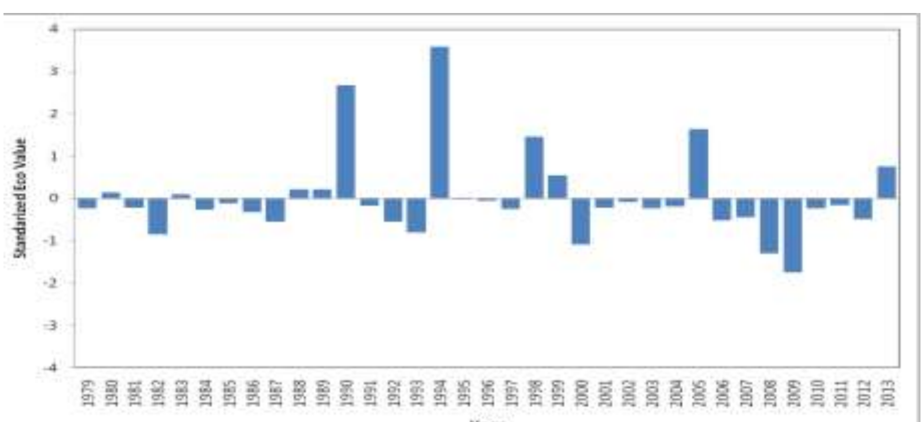

Fig.5: Standardized Eco-values at of Andhiyarkhor Station for period 1979-2013

Positive values of the Eco-Flow Metric indicates the better river ecology and negative values indicates the degrading ecological conditions. From the figure 5, it can be concluded that the river ecological conditions of the Hamp river is degrading over the years.

5.2 EFR:

The Global Environmental Flow calculator has been used to estimate environment flow requirement (EFR) of the Hamp River. The results for different environmental management classes along with the natural flow of river are demonstrates in the Fig. 6. The monthly distribution of the discharge, under natural and different environmental management classes at the Andhiyarkhor gauge station of the Hamp river can be seen. The graphical representation of natural flow and environmental flow for all the six classes are also shown in Fig 7.

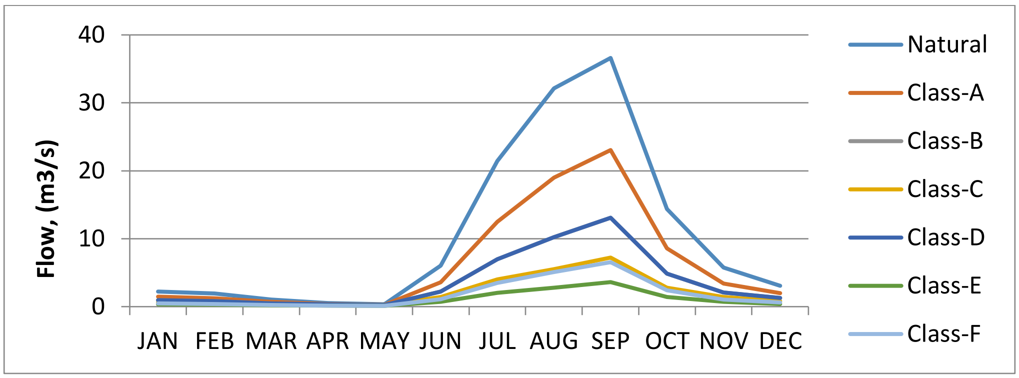

Fig.6: Monthly distribution of EFR under natural and different environmental management classes

6. CONCLUSION

Flow Duration Curves (FDCs), which abridge a plethora of hydrological information into a single graphic image, had been used to summarize the status of ecology of Hamp River for the last few decades. Results derived from the flow duration curves are used by hydrologist and engineers involved in planning and designing of various water resources projects. Many other significant uses of this curve prevail such as evaluating the characteristics of the hydropower potential of a river, design of drainage systems, flood-control studies, computing the sediment load and dissolved solids load of a stream, and comparing the adjacent catchments with a view to extend the streamflow data. Apart from these classical uses, the FDCs can also be used to assess the health of the river in terms of it ecological status.

In the present study, the flow duration curves for different time spans were abstracted from the daily discharge data for the Hamp River Basin for the period of 34 years (1979 to 2013) The FDCs created on daily, monthly annual and 10 daily average basis. For further research analysis, 10-daily average FDCs were used. Then, the 25th and the 75th percentile years were obtained with the help of this FDC, which in further were used to find the recently introduced metrics viz. eco-surplus and eco-deficit were analyzed for detecting the change in the river ecology. The eco-flow

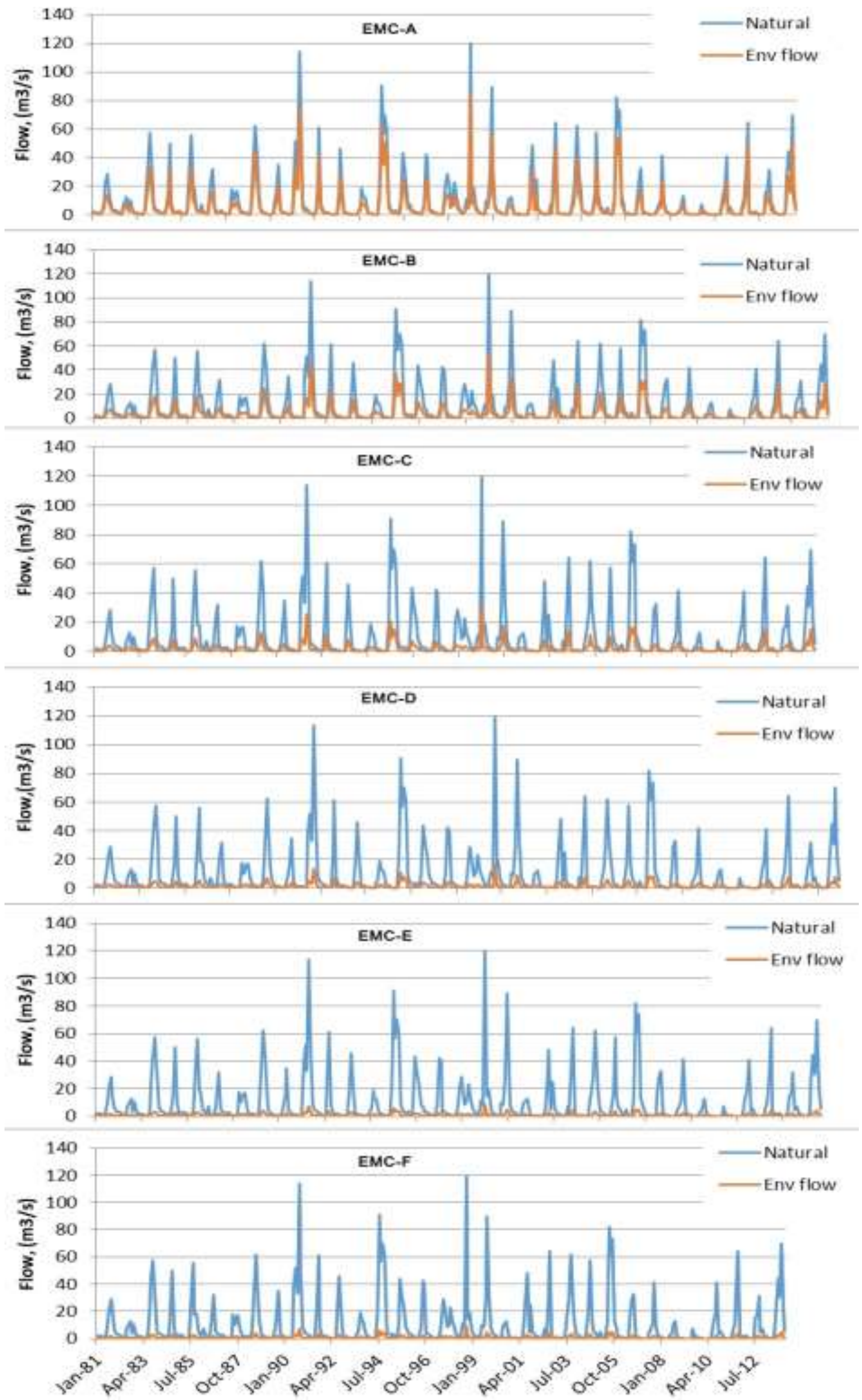

Fig.7: Natural flow & environmental flow for different EMC classes

metric was developed for all the years from the flow data so derived to know the status of the Hamp River and the effect on its ecology. The results of the study confirm that the ecology of Hamp River is deteriorating as 24 out of 34 years were found with eco-deficit flow and only 10 years were with eco-surplus flows. The degradation of river ecology might be triggered due to enhanced anthropogenic activities in terms of non-monsoonal farming in the catchment. For sustenance of the health of river, judicial and conjunctive uses of water resources is needs to be done at both micro and macro level planning. The global environmental flow calculator was used to calculate the monthly EFR flows for different environmental management classes, as show in the result.

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