PREDICTION OF ENVIRONMENTAL FLOW CONDITION FROM RAINFALL USING RELATIONSHIP BETWEEN TENNANT METHOD AND STANDARDIZED PRECIPITATION INDEX

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ABSTRACT

In the present study, an effort has been made to describe the environmental flow condition of a watershed using Standardized Precipitation Index (SPI), a drought index based on the precipitation. Mohegaon, Manot, Hridaynagar and Sher are the four watersheds of upper Narmada Basin have been taken for the analysis. The purpose of this study is to derive relationship between environmental flow condition and the corresponding estimates of Standardized Precipitation Index which is used as measure of drought conditions. It is expected that these relationship will be useful in determining environmental flow conditions in ungauged sub-basins using rainfall data only. The study revealed an excellent relationship between SPI and percentage of average annual flow as the value of coefficient of determination are greater than 0.75. The analysis indicates that for each of the four watersheds the percentage of average annual flow increases with the increase in the value of SPI. It can be concluded that the relationships presented in this paper will be useful for estimating the EF condition for ungauged watersheds.

Keywords: Tennant method, Narmada basin, SPI, Environmental flow.

1. INTRODUCTION

With population growth and industrialization, the water demand has been increasing day by day, at times exceeding the water supply. For the conservation of natural ecosystem water has to be preserved in the rivers and it should be clean so that a healthy ecosystem can be maintained. The minimum amount of water required for the survival of rivers is known as Environmental flow (EF). The minimum supply of water to be maintained in the streams is called EF requirement which helps in the sustainability of aquatic lives and other natural ecosystem. The lack of requisite flow will influence the whole ecosystem. So the EF is necessary to carry out the needs of animal, vegetation and aquatic lives which depend on the river for their sustenance.

The socioeconomic development and climate change has affected the global hydrological cycles, threatening human water security, the health of aquatic environments and river biodiversity largely during past few decades (Vörösmarty et al., 2010; Jacobsen et al., 2012; van Vliet et al., 2013). These situations attract the attention towards the assessment of environmental flow requirement (EFR) and water scarcity (Vörösmarty et al., 2010; Kirby et al., 2014). Thus EFR is defined as the quality, quantity, and timing of the water flows required maintaining freshwater and estuarine ecosystems and the human livelihoods and well-being that depend upon these ecosystems (Brisbane Declaration, 2007). More than 200 methods are available and being used worldwide to calculate EFR to maintain healthy rivers (Tharme, 2003). These methods can be grouped into four categories: hydrological approach, hydraulic rating, habitat simulation, and holistic methods.

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Drought is a natural calamity, occurring due to less than average rainfall over a given period of time at given space which consequently leads to stream flow reduction and short-term water deficit. Further, the droughts cause lowering of water levels in lakes, reservoirs, and tanks etc. There are various drought indices were developed which are very useful for drought monitoring based on different parameters. Some of the common indices used to assess for meteorological droughts in India are Standardized Precipitation Index (SPI) (McKee et al., 1993), Effective Drought Index (EDI) (Byun and Wilhite, 1999) and percentage departure of annual and seasonal rainfall from corresponding mean are applied for identification of onset, termination and quantification of severity of drought events. Narmada is the largest west flowing river of the Indian peninsula. It is one of the important rivers of India. The Narmada basin extends over an area of 98,796 km$^2$ and lies between longitudes 72°32' E to 81°45' E and latitudes 21°20' N to 23°45' N. Here for the study four sub-basins were selected on the availability of data viz. Mohegaon, Manot, Hridaynagar and Sher. The map of Manot, Hridaynagar, Mohegaon and Sher catchments is presented in fig. 1.

The SPI is used to quantify the dry and wet conditions based on the precipitation, and Tennant method is used to describe the environmental flow condition of a river from severe degradation to flushing flow i.e. whether the river runs dry or have maximum flow based on the flow data. Since both SPI and Tennant Method are used to describe the dry and wet conditions based on the different parameters so, there might have some possibility to establish a relationship between these two methods.

The Standardized Precipitation Index (SPI) (McKee et al., 1993) has been used to assess meteorological dry and wet conditions. Among the various methods the hydrologic approach for the assessment of environmental flow is simplest and being widely used. For the assessment of environmental flow using the hydrological approach the observed discharge data of rivers are required. In this study the most popular Tennant method (Tennant, 1976) has been used to assess the environmental flow conditions in four sub-basins of Narmada River Basin system.
2. METHODOLOGY

2.1 Standardized Precipitation Index

Drought monitoring is based on identification and quantification of various drought characteristics viz. frequency, duration and severity. The magnitude of deficit can also be assessed for the past drought events. There are so many methods and indices were developed and being widely used for the assessment of drought events. Among the various drought indices the Standardized Precipitation Index (SPI) (McKee et al., 1993) is very popular and widely used for drought monitoring. Since SPI has some advantages over other indices first, SPI require only precipitation data so its evaluation is relatively easy and second, the SPI enables drought monitoring over different time scales viz. 1 month, 3 months, 6 months, 9 months, 12 months, 24 months etc. The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution preferably gamma distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero (McKee et al., 1993; Edwards and McKee, 1997). SPI is normalized index representing the occurrence of an observed rainfall when compared with the average rainfall of a particular location over a long reference period. SPI values represent the deficiency of rainfall from long-term mean. Negative SPI values represent the deficiency in rainfall while positive values of SPI show the surplus rainfall. The magnitude of SPI negative values are used to classify the severity of drought event. Higher the negative SPI value, more severe the drought event are likely to occur. The table 1 represents the different conditions classified on the basis of SPI values by McKee (1993).

Table 1. Drought conditions classified on the basis of SPI

<table>
<thead>
<tr>
<th>SPI Values</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 or more</td>
<td>Extremely wet</td>
</tr>
<tr>
<td>1.5 to 1.99</td>
<td>Very wet</td>
</tr>
<tr>
<td>1.0 to 1.49</td>
<td>Moderately wet</td>
</tr>
<tr>
<td>-0.99 to 0.99</td>
<td>Near Normal</td>
</tr>
<tr>
<td>-1.0 to -1.49</td>
<td>Moderately Dry</td>
</tr>
<tr>
<td>-1.5 to -1.99</td>
<td>Severely Dry</td>
</tr>
<tr>
<td>-2 or less</td>
<td>Extremely Dry</td>
</tr>
</tbody>
</table>

2.2 Tennant method

This method was developed by Donald Tennant in Montana region of USA (Tennant 1975, 1976a,b), also called as Montana approach and developed for the needs of fish. It used 58 cross-section and 38 different flows of 11 streams in Wyoming, Montana, and Nebraska (Mann, 2006). He established a relationship between aquatic habitat suitability and flow using subjective assessment of habitat quality and the empirical hydraulic data obtained from cross-channel transects. This method is based on the assumption that to uphold good stream environment some percentage of average flow is required. According to Tennant for short term survival the average depth and velocity of flow should be at least 0.3m and 0.25m/s respectively and the depth between 0.45 to 0.6m and velocity ranging from 0.45 to 0.6m/s found to be
optimal for the fish. These conditions were found at 10% and 30% of average annual flow (AAF) respectively in the different streams he studied. The different flow conditions based on percentage of average annual flow for low (October–March) and high (April–September) flow periods (Tennant, 1976) are given in the table below:

Table 2. Tenant method for EFR assessment

<table>
<thead>
<tr>
<th>Flow Condition</th>
<th>Oct-Mar</th>
<th>Apr-Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flushing flow</td>
<td>200% AAF</td>
<td>200% AAF</td>
</tr>
<tr>
<td>Optimum range of flow</td>
<td>60-100% AAF</td>
<td>60-100% AAF</td>
</tr>
<tr>
<td>Outstanding</td>
<td>40% AAF</td>
<td>60% AAF</td>
</tr>
<tr>
<td>Excellent</td>
<td>30% AAF</td>
<td>50% AAF</td>
</tr>
<tr>
<td>Good</td>
<td>20% AAF</td>
<td>40% AAF</td>
</tr>
<tr>
<td>Fair or Degrading</td>
<td>10% AAF</td>
<td>30% AAF</td>
</tr>
<tr>
<td>Poor or Minimum</td>
<td>10% AAF</td>
<td>10% AAF</td>
</tr>
<tr>
<td>Severe Degradation</td>
<td>10% AAF to zero flow</td>
<td>10% AAF to zero flow</td>
</tr>
</tbody>
</table>

In this study the SPI on 9 month time scale for the month of June was evaluated for every year. In the same manner the average flow of 9 months (October to June) was calculated for every year which is termed as annual flow. The average of annual flow of all the years is calculated and the percentage of annual flow of a particular year with respect to average annual flow is termed as percentage of average annual flow of that year. The analysis has been done check the relation between the percentage of average annual flow which describes the environment flow condition and SPI, the index based on precipitation.

3. RESULTS AND DISCUSSION

The analysis has been done for the different sub-basin to explore the relationship between environmental flow condition and SPI. The EF condition is described on the basis of percentage of average annual flow (AAF) (Tennant, 1976). The study is concern with non-monsoon season (October-June).

3.1 Mohegaon catchment

The rainfall and runoff data of 1982-1989 were used. The average flow of the 9 months (October-June) for each year was computed to estimate AAF, and %AAF to describe different flow conditions of the catchment. On the other hand, SPI for the same 9 months for each year was determined. A plot between %AAF and SPI is shown in Fig. 2. As seen from the figure, as SPI increases, %AAF also increases to describe a similar condition. The value of $R^2$ is 0.764, which shows a very good fit. Thus, from the available rainfall data, the EF condition of this catchment can be easily ascertained with the help of SPI.

3.2 Hridaynagar catchment

The rainfall and flow data of 9 years (1981-1989) were used. Following the similar procedure, as above, the derived %AAF is plotted against the corresponding SPI for Hridaynagar catchment in Fig. 2. $R^2 = 0.818$ exhibits an excellent relationship
between %AAF and the corresponding SPI. Thus, EF condition for this catchment can be ascertained using SPI.

### 3.3 Manot Catchment

The data of 8 years (1982 – 1989) were used, and the requisite plot with $R^2 = 0.864$ is shown in Fig. 2, again indicating an excellent fit.

### 3.4 Sher Catchment

Similar to the above, Figure 2 shows an excellent %AAF-SPI relation with $R^2 = 0.993$ with rainfall-runoff data of 6 years (1978-1983), leading to similar inference as above.

The flow condition corresponding to SPI values for each of the four catchments is presented in Figure 2.

![Figure 2. Percentage of average annual flow corresponding to different SPI values in four catchments](image)

### 4. CONCLUSION

The study has been done over the four sub-basins viz. Mohegaon, Manot, Hridaynagar and Sher of Narmada basin in Madhya Pradesh. The analysis has been done for different time period in different sub-basin based the data availability. The rainfall and flow data of these sub-basins were used in the analysis. The rainfall data were used to calculate the SPI on 9 month time scale for the month of June for these sub-basins. Average annual flows in the sub-basins were estimated using the flow data. The percentage of average annual flow which describes the environmental flow condition has been estimated for the lean period (October-June) for every year. The plot of % AAF and SPI for all the watersheds over which study has been done shows an increasing trend. The $R^2$ value for each of the watershed has been found to be greater than 0.75 which shows the best fit. The analysis revealed that in the lean period for a particular watershed the percentage of average annual flow increases with the corresponding increase in the SPI value i.e. higher the SPI value, environmental flow condition is good.

### REFERENCES


