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Environmental Flows Assessment by Drought Analysis

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Abstract- Environmental Flows (EFs) have been accepted as one of the most important factors deciding the survival of a river. This concept is fairly well understood in few developed countries however, in developing countries like India, EFs consideration in river water resource development and management poses great challenges. In this paper, EFs variability was estimated using Tennant's method, Hughes and Munster method and further comparing it with drought severity of study area using SPEI (Standardized Precipitation Evapotranspiration Index). The computed values further helps to establish a link between EF and drought severity and as a results helps to assess the health EF condition of the river basin. The estimated results could be used in future water resource and river health assessment in the basin.

Keywords: Environmental flows, SPEI, Drought, Tennant method, Hughes and Munster method

I. INTRODUCTION

Environmental flow (EF) is referred as the amount of water required for maintaining the ecosystem of the river. A critical part of this approach is the assessment and maintenance of Environmental Flows – 'sufficient water to sustain the integrity and functioning of aquatic ecosystems and the associated socio-economic and cultural functions' (UN, 2005).

Most of the rivers are excessively exploited to fulfill ever increasing demand from power, agricultural, industrial and municipal sectors.

Damming of rivers or tributaries is the root cause of river obstructions causing severe modifications and perturbations to the river flow, velocity, depth, substratum, pools, and ecology and fish habitats.

Each river system has an individual flow regime with particular characteristics such as seasonal pattern of flows, timing, frequency, predictability and duration of extreme events (e.g. floods and droughts), rates of change and other aspects of flow variability.

Accounting for natural differences in flow variability among rivers, and understanding its importance for the protection of freshwater biodiversity and maintenance of goods and services that rivers provide, is a daunting challenge for water managers and scientists.

The assessment of water requirements of freshwater-dependent ecosystems represents a major challenge due to the complexity of physical processes and interactions between the components of the ecosystems.

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With rise in concern about the impact of dams and flow regulation on river biota, more than 200 methods were developed for assessment of "minimum flow" or the "environmental flows" .

It is important to note that maintaining environmental flows helps a river system to maintain the ecological balance of river regime.

The Mahanadi River is one of the important river of India .As large number of dams has been constructed on the river for generation of electricity and meeting irrigation requirements. Thus it becomes very much important that certain adequate flow to be maintained for survival of river.

Tel River is an important tributary of Mahanadi River and its significance increases manifold as it lies in KRB basin which is considered the worst drought prone area of India.

In this study we have assessed EFR values for the selected area of study using Tennant method, Hughes and Muster method and further link the computed values with the computed drought severity of the area ,hence further drawing conclusions for developing a link between these two factors of importance.

II. REVIEW OF LITERATURE

A number of methodologies are in practice worldwide to estimate EFR of rivers. Tharme (2003) discussed the existence of more than 243 methodologies .In India limited numbers of studies have been reported.

Jha et al., 2008 carried out a appraisal for estimation of EF's and their utilization in two river system of India. In this method hydrological methods using daily discharge data and flow duration curve were used. The study calculated the value of environmental flow at different reaches of river. The result of the study concluded environmental flow values for maintaining the desired ecological flow of the river.

Kumara et al., 2010 carried out a study on EF in Bhadra River. The study carried Desktop analysis method and field investigation for the estimation of EF. The study had been carried two modules i.e Biophysical assessment and Socio Economic assessment. The study had been done to show how the people have affected by specified flow river alternations. Kaushal, 2008, carried out the study for environmental flow assessment of the upper stretch of river Ganga. The objective was to develop and apply EFA methodology in the Upper Ganga Basin and also EF analysis was done for a large river basin. Certain notional locations were chosen in Ganga Basin (representing certain stretches). Recommended flows were calculated by different working group i.e spiritual, geomorphology biodiversity, live lihood group. Each group found out and recommended flow for maintenance and drought year.

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Even for drought there are more than 150 drought indices exists and many more new indices come into account in the last decades.

As per the Ministry of Agriculture, 2009, the drought index value is typically a single unit less number for decision making. The Government of India, State Governments and the scientific community uses a number of indices to measure the intensity, duration, and spatial extent of drought. It is useful to also refer to these scientific indices for monitoring drought situation at the National and State levels.

Shukla and Wood et al., 2008 derived standardized runoff index (SRI) which incorporates hydrologic processes that determine the seasonal loss in stream flow due to the influence of climate. As a result, on month to seasonal time scales SRI is a useful complement to SPI for depicting hydrological aspects of droughts.

Thus it is clearly reflected that although the computation of EFR and drought is done on individual basis but none of the study directly links them together to develop a inter relation between these two aspects.

In this paper we are computing the EFR and drought individually for the selected area of study and hence on the basis of the attained values trying to link these two parameter, to develop a link between EF and drought.

The study is validated on the basis of two basins after checking that whether the achieved results for EF and drought severity indicate some pattern of resemblance.

III. THE STUDY AREA

3.1 Basin 1

The Mahanadi River Basin

The Mahanadi is a major river in East Central India. It drains an area of around 141,600 km^2 and has a total course of 858 km. It lies between east longitudes 80° 30' to 86° 50' and north latitudes 19° 21' to 23° 35'. The river flows through the states of Chattisgarh and Orissa.

Its farthest head waters lie 6 km from Pharsiya village 442 m above sea level south of Nagiri town in Dhamtari district of Chattisgarh.The Mahanadi River Basin (MRB) has a total of 6 dams Dudhawa, Gangrel, Murrum Silli, Hasdeo Bango, Tandula, Sondur Reservoir, Sikasar dams- located in Chattisgarh, Hirakud dam (largest dam on mahanadi river basin)- located in Orissa.

Prior to the Hirakud dam, the river carried more silt than any other river in the Indian subcontinent (Source: CWC) .The basin has a cultivable area of about 79,900 km^2 which is about 57% of the basin area & four percent of the total cultivable area of the country. Four Gauging stations (EF1, EF2, EF3, EF4, and EF5 & EF6) are taken whose details are shown and given in Fig 1 & Table 1.

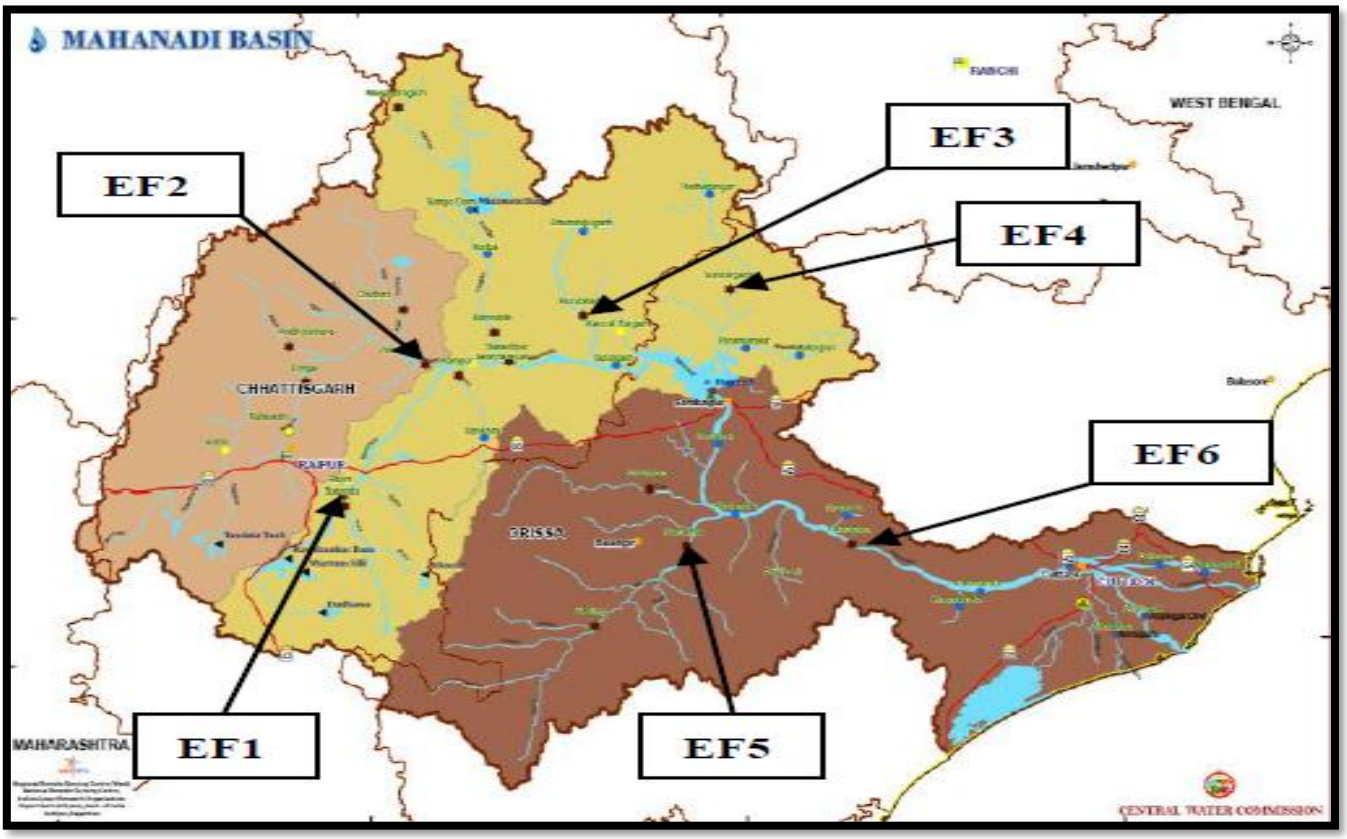

Fig. 1: Location of gauging sites in MRB

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Station ID	EFs Site	River	Location	Average Annual Precipitation(cm)
EF1	Rajim	(Sondur+ Pari+Mahanadi)	20º57'N 81º52'E	96.44
EF2	Jondhra	Mahanadi	21º43'N 82º20'E	95.06
EF3	Kuurubhata	Mahanadi	22º00'N 84º02'E	100.33
EF4	Sundargarh	IB	22º07'N 84º02'E	111.01
EF5	Kantamal	Tel	20º65'N 83º74'E	162.3
EF6	Tikarapara	Mahanadi	20º58'N 84º08'E	114.03

Table 1: Location of gauging sites in MRB

3.2 Basin 2

The Tel River

The study area is one of the watersheds of Tel river (Major tributary of Mahanadi river) located in the Kalahandi district of Odisha which is one of the worst drought affected districts of India.

The watershed covers an area of 2756 km^2 and lies between 19° 17′ and 20° 00′ N latitude and 82° 30′ and 82° 59′E longitude .

The study area experiences tropical wet and dry climate where the wet season (June–September) is much shorter and receives low precipitation from the south-west monsoon than the normal and the rest months of the year are generally dry.

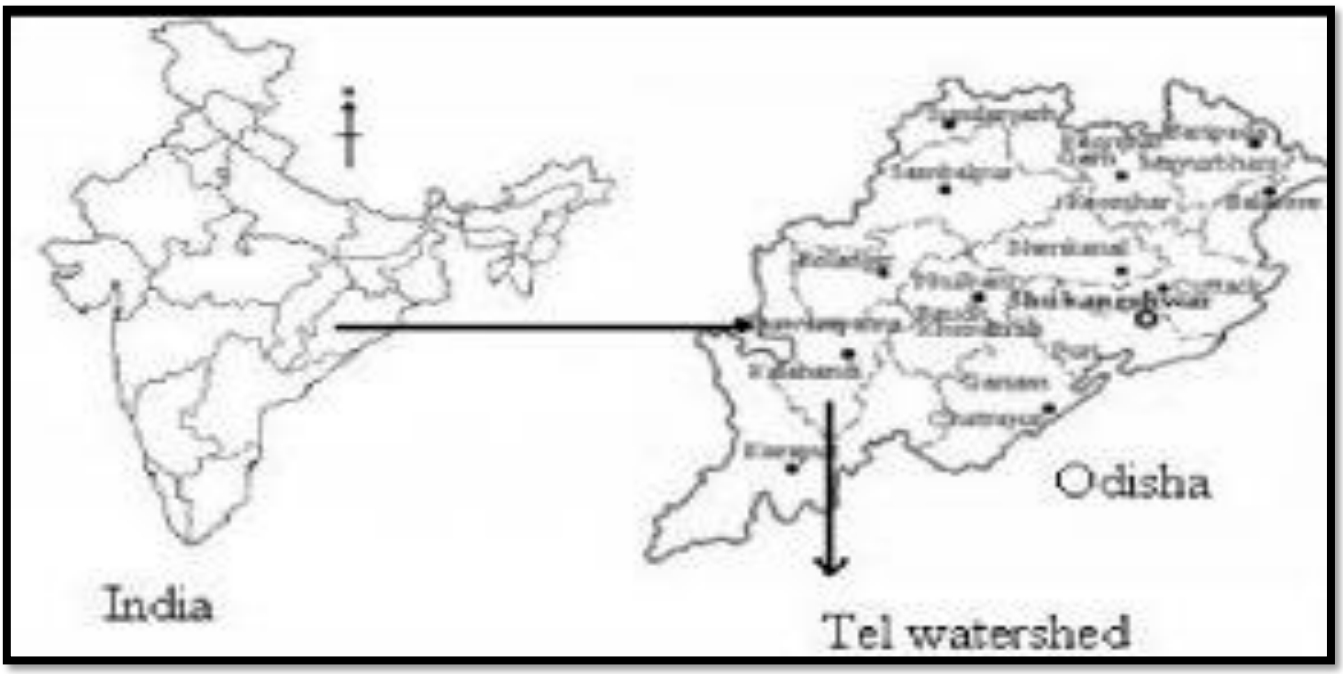

Fig. 2: Location of Tel River

Five Gauging stations (EF1, EF2, EF3, EF4, EF5) are taken whose details are shown and given in Figure 2 & Table 2.

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Station ID	EFs Site	River	Location	Average Annual Precipitation(cm)
EF1	Bhawanipatna	Tel	19º85'N 83º26' E	13.30
EF2	Dharangarh	Tel	19º84'N 82º79' E	14.00
EF3	Junagarh	Tel	19º86'N 82º94' E	13.78
EF4	Koksara	Tel	19º44'N 82º58' E	13.78
EF5	Jayapatna	Tel	19º47'N 82º99' E	13.78

Table 2: Location of gauging sites Tel River

IV. METHODOLOGY

In this conceptual approach, linking of Tennant Method, Hughes and Muster method along with drought severity indices in catchment area of river is done.

The Tennant's method was developed in 1976 (Tharme 2006).The recommended EF should follow the "excellent" condition (i.e. 30% and 50% of mean flow for the months October to March and Apr-Sept).

Objective	Recommended percentage of AAF	
	Autumn(Oct-Mar)	Spring-Summer(Apr-Sept)
Flushing or max flow	200%of AAF	200%of AAF
Optimum range of AAF	60-100%of AAF	60-100%of AAF
Percentage AAF required to maintain a river condition		
Outstanding	40%of AAF	60%of AAF
Excellent	30%of AAF	50%of AAF
Good	20%of AAF	40%of AAF
Fair or degrading	10%of AAF	30%of AAF
Poor or minimum	10%of AAF	10%of AAF
Severe or degradation	10%- of AAF to zero flow	10%-of AAF to zero flow

Table 3: Illustration of Tennant method

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In Hughes & Munster Method, the low flow requirement (LFR) and high flow requirement (HFR) is computed using this method .Q90 is the 90 % dependable discharge which is the low flow requirement. After comparing the mean annual flow (MAF) values from optimum range (i.e.100%) of Tennant method and 90% dependable discharge, the environmental water requirement(EWR/EFR) for different sites is computed using this methodology.

As the catchment area of the basin increases the value of EWR also increases.

Low Flow Requirement	High Flow Requirement
Q90<10%MAF	HFR=20%MAF
10%MAF≤Q90≤20%MAF	HFR=15%MAF
20%MAF≤Q90≤30%MAF	HFR=7%MAF
Q90≥30%MAF	HFR=0

Table 4: A Theoretical Rule for Environmental High Flow Assessment

For Drought severity computation SPEI (GLOBAL DROUGHT MONITOR) software is being used. The Standardized Precipitation Evapotranspiration Index (SPEI) is an extension of the widely used Standardized Precipitation Index (SPI).

The SPEI is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought. The SPEI values for different boundary conditions are tabulated below.

SPEI Values	Classification/Condition
>2.33	Extreme flood condition(Danger of Flood)
1.65	Wet condition
1.28	Slight surplus
0.84	Near normal
-0.84	Mild drought
-1.28	Moderate drought
-1.65	Severe drought
<-2.33	Extreme drought

Table 5: Classification of SPEI Values

V. RESULTS AND DISCUSSIONS

Using the drought severity, Tennant (or Montana) method and Hughes and Munster method, assessment is done. EF should be maintained in the river as per the computed values.The computed values of drought severity is compared with SPEI boundary condition, as per the amalgamated table 6, given below and hence the conclusions are drawn.

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Description of General Flow Condition (Tennant's Method)	SPEI Values (Standard Values)	Classification/Condition
Flushing or Max	>2.33	Extreme flood
Optimum Range	1.65-2.33	Wet condition
Outstanding	1.28-1.64	Slight surplus
Excellent	0.84-1.27	Near normal
Good	-0.84-0.83	Mild drought
Fair or Degrading	-1.28- -0.84	Moderate drought
Poor or Minimum	-1.65- -1.28	Severe drought
Severe Degradation	<-2.33	Extreme drought

Table 6: Reference Table for Linkage of EF and Drought Severity

The results indicate that from the values of drought severity computed, we can draw the conclusion to ascertain the health condition river and the of EF boundary conditions.

5.1 Computation for Mahanadi River

The values for EF in Mahanadi Basin is computed with help of Tennant's method ,Hughes and Munster method and the conclusions are drawn which are reflected in the tables 7 & 8.

General condition of flow(%)	% MAF in cumec from Oct-Mar					
	EF1	EF2	EF3	EF4	EF5	EF6
Flushing or max flow	32.88	154.12	43.28	52.98	211.4	1079.4
Optimum range of AAF	9.87-16.44	46.24-77.06	12.98-21.64	15.89-26.49	63.42-105.7	323.82-539.7
Outstanding	6.38	30.82	8.66	10.6	42.28	215.88
Excellent	4.93	23.12	6.5	7.94	31.74	161.91
Good	3.29	15.42	4.33	5.3	21.14	107.94
Fair or degrading	1.64	7.71	2.16	2.65	10.57	53.97
Poor or minimum	1.64	7.71	2.16	2.65	10.57	53.97
Severe or degradation	<1.64	<7.71	<2.16	<2.65	<10.57	<53.97

Table 7: EF Values during Oct-March

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General condition of flow(%)	% MAF in cumec from Apr-Septr					
	EF1	EF2	EF3	EF4	EF5	EF6
Flushing or max flow	311.8	865.4	248	343.6	1144.6	4746
Optimum range of AAF	93.87-155.9	259.62-432.7	74.4-124	103.08-171.8	343.38-572.3	1423.8-2373
Outstanding	93.54	259.62	74.4	103.08	343.38	1423.8
Excellent	77.95	216.4	62	85.9	286.25	1186.5
Good	62.36	173.08	49.6	68.72	228.92	949.24
Fair or degrading	46.79	129.81	37.2	51.54	171.69	711.9
Poor or minimum	15.6	43.27	12.4	17.18	57.23	237.3
Severe or degradation	<15.6	<43.27	<12.4	<17.18	<57.23	<237.3

Table 8: EF Values during Apr-Sept

The graphs shown underneath have been computed from SPEI and on the basis of the coordinates of the EF gauging sites for both MRB and Tel River.

The average value of the drought /low flow severity is computed (1955-2014) and hence the value obtained is compared with the SPEI drought table, therefore the conditions of flow i.e the EF, in the river is being determined.

Thus a fair idea can be made out with the help of computed drought analysis for kind of EF condition in river or with help of computed EF condition's of river, the kind of flow/drought condition (block values) can be ascertained.

Thus, the relation is indicative towards the fact that by help of computation of one value other value can be ascertained.

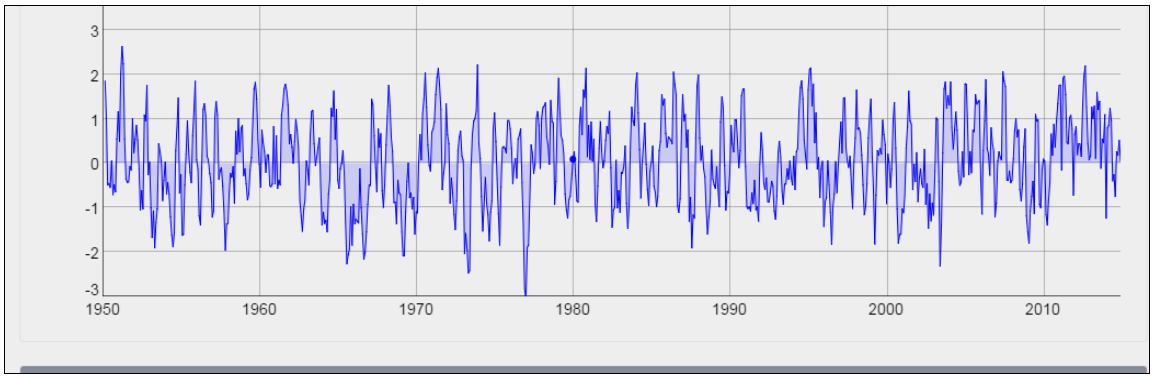

Fig. 3: SPEI drought analysis at EF1 (Rajim) avg value: 2.188

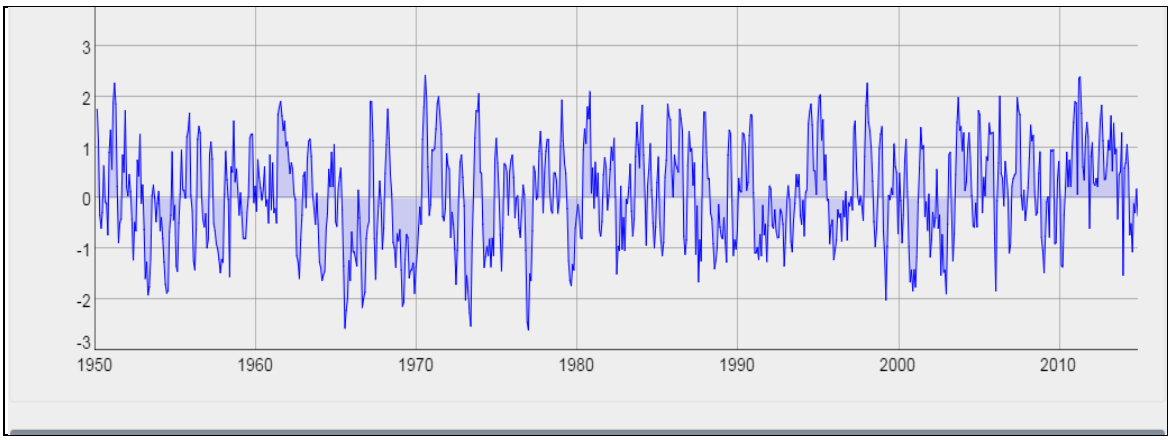

Fig. 4: SPEI drought analysis at EF2 (Jondra) avg value: 2.36

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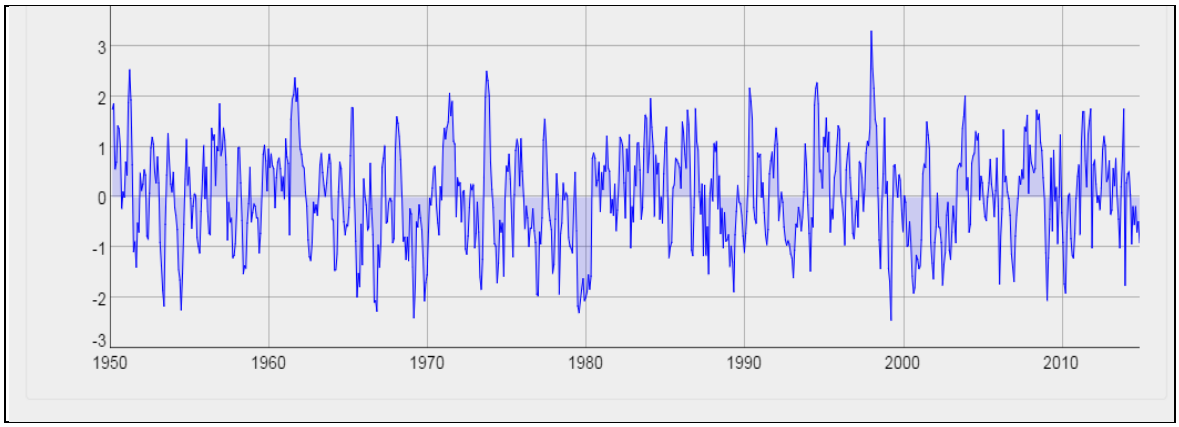

Fig. 5: SPEI drought analysis at EF3 (Kurubhata) avg value: 1.743

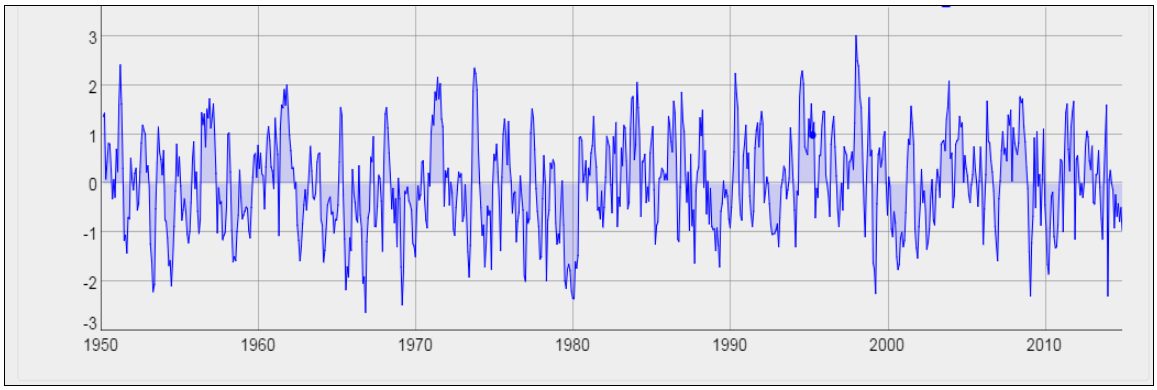

Fig. 6: SPEI drought analysis at EF4 (Sundergarh) avg value: 2.071

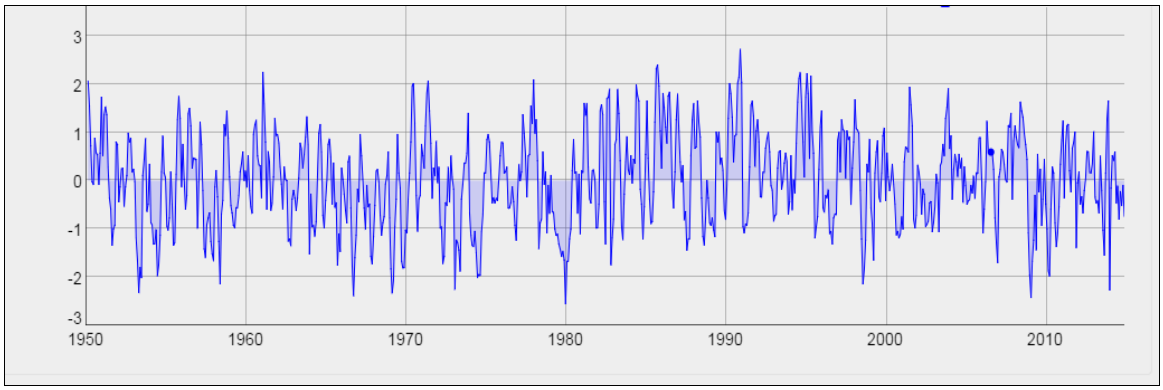

Fig. 7: SPEI drought analysis at EF5 (Kantamal) avg value: 1.894

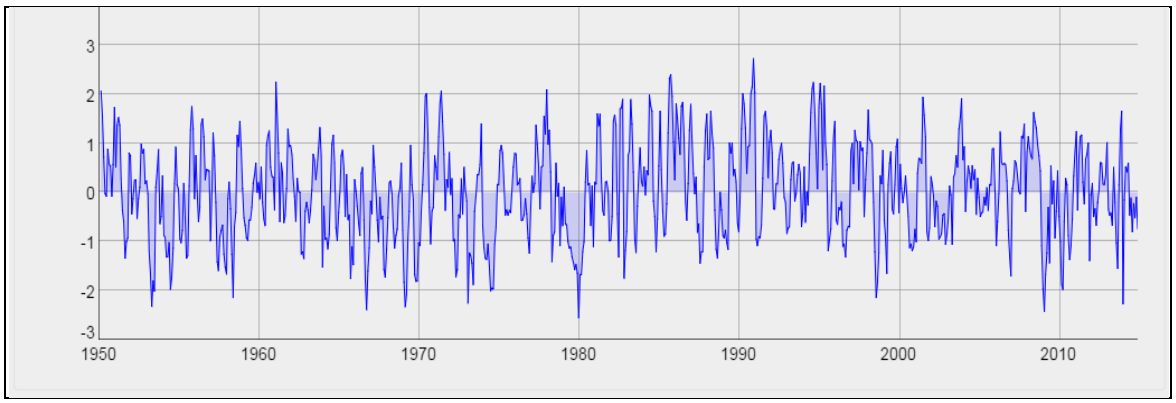

Fig. 8: SPEI drought analysis at EF6 (Tikarapara) avg value: 1.657

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The values computed area also checked with the help of Hughes and Munster method. The results obtained are given in table below.

Site	90% Dependable Flow(Q90) in cumec
Rajim	1.076
Jondhra	1.076
Kuurubhata	1.076
Sundargarh	1.076
Kantamal	1.076
Tikarapara	178.64

Table 9: 90% Dependable Flow Discharge of Different Sites

Thus depending on Q90, computed values of EWR for the given gauging sites of Mahanadi River are given in the table below.

Site	EWR in cumec Oct-Mar	EWR in cumec Apr-Sept
Rajim	4.36	65.512
Jondhra	16.48	175.22
Kuurubhata	5.40	51.76
Sundargarh	6.37	70.88
Kantamal	22.32	231.06
Tikarapara	178.64	1306.48

Table 10: Values of EWR

The comparative table between Tennant method, Hughes and Munster method is drawn underneath.

Site	Tennant Method Oct-Mar(30%)	Apr-Sept(50%)	Hughes and Munster Method(cumec) Oct-Mar	Apr-Sept	Drought Condition as per SPEI
Rajim	4.93	77.95	4.36	65.51	Wet
Jondhra	23.12	216.4	16.48	175.22	Extreme Wet
Kuurubhata	6.5	62	5.40	51.76	Wet
Sundargarh	7.94	85.9	6.37	70.88	Wet
Kantamal	31.74	286.25	22.32	231.02	Wet
Tikarapara	161.91	1186.5	178.64	1306.48	Wet

Table 11: Comparative Values of EF and Drought

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The values achieved ascertains that the values computed for EF with help of Tennant's method, Hughes and Munster method and values drawn from SPEI are indicating same reference values. Hence the study is affirmed in for this basin.

5.2 Computation for Tel River

In case of Tel River, the MAF is not available hence the computation is directly done based on SPEI and thus the health conditions of the river is ascertained.

Hence, further it can be said that the study is holding valid in even drought affected area where the EF conditions are either "Fair", "Poor", or just "Good".

From the study it is coming out clearly that the Tel River basin is adversely affected, the ecosystem and the health of river is also becoming endangered due to poor maintained EF in the river system.

In case the health of the river need to be improved minimum required flow that is 30% and 50% of mean annual flow for months of October to March and April to September, is needed to be maintained in the river system. The results of SPEI and comparative table are shown as under.

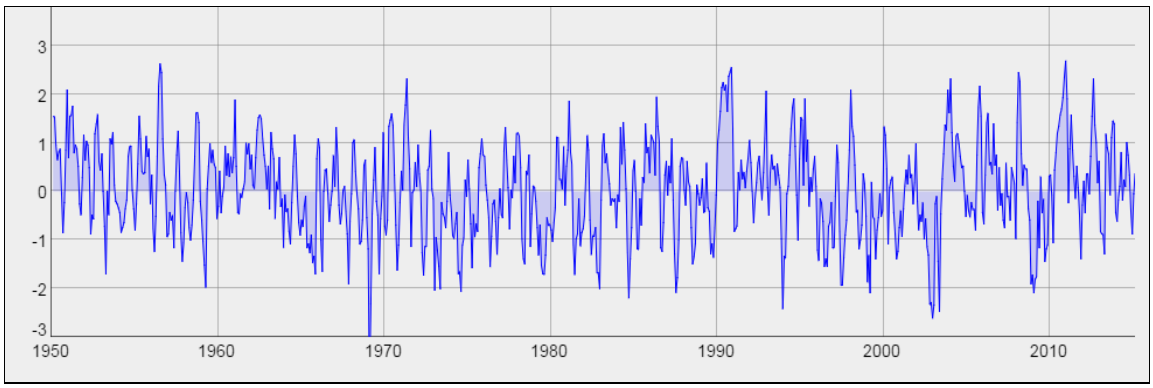

Fig. 9: SPEI drought analysis at EF1, Tel River (Bhawanipatna) avg value:-1.32

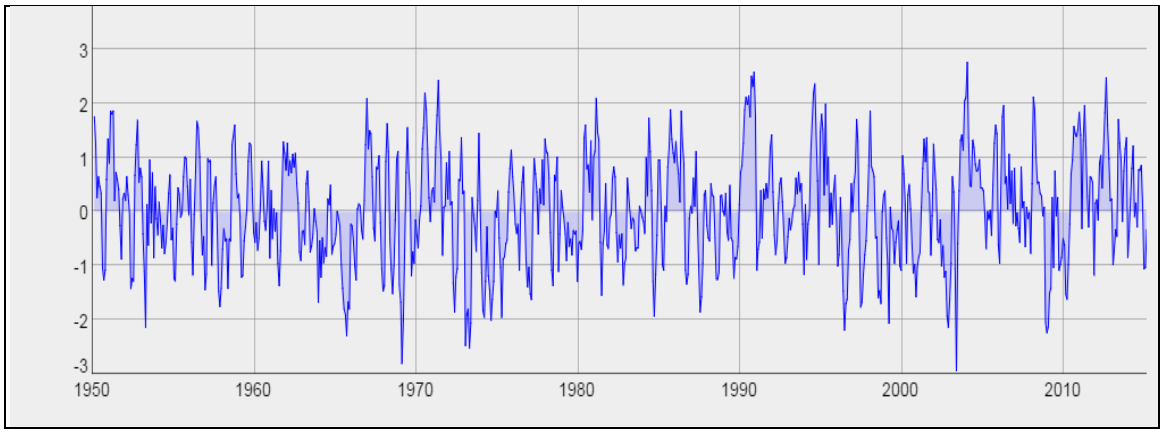

Fig. 10: SPEI drought analysis at EF2,Tel River (Dharangarh) avg value:-1.16

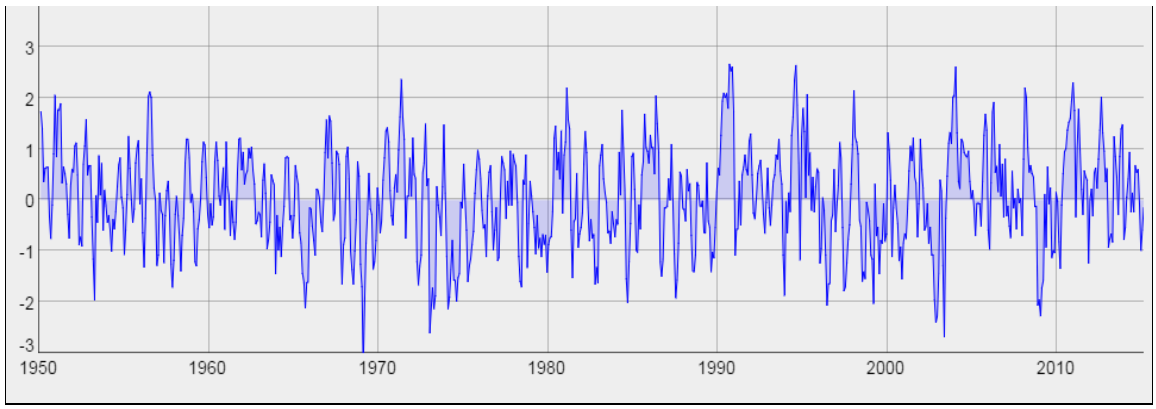

Fig. 11: SPEI drought analysis at EF3, Tel River (Junagarh) avg value:-1.28

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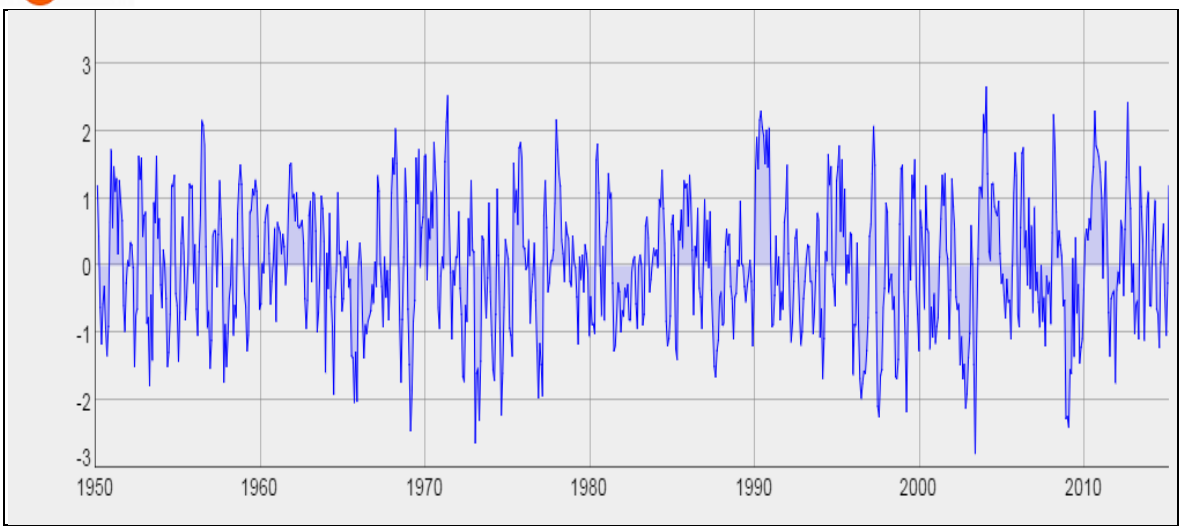

Fig. 12: SPEI drought analysis at EF4, Tel River (Kokasara) avg value:-1.36

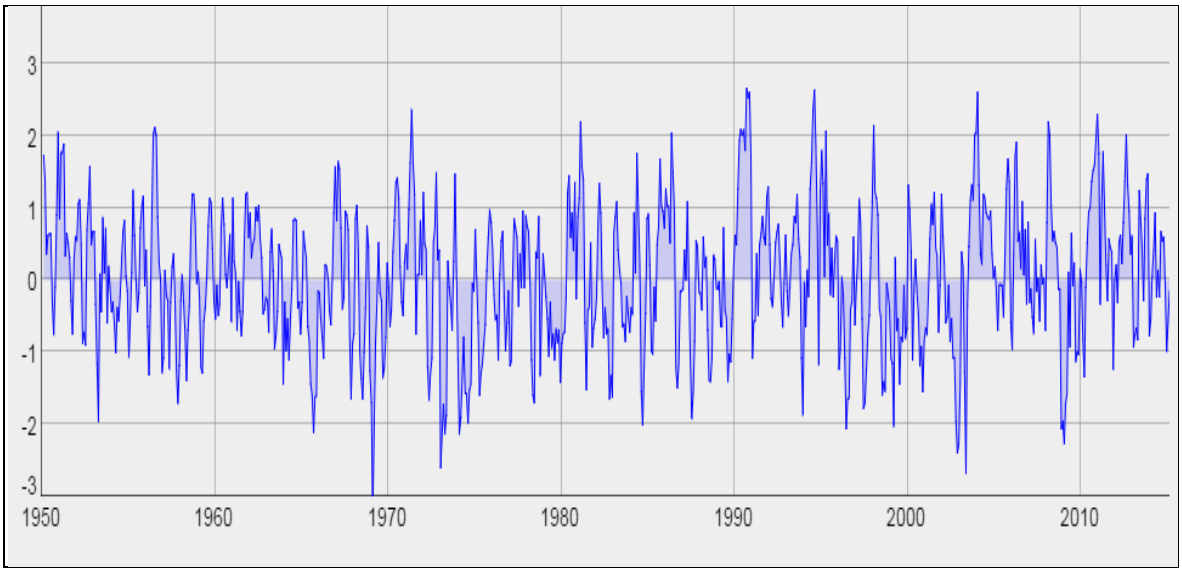

Fig. 13: SPEI drought analysis at EF4, Tel River (Jayapatna) avg value:-1.28

Station ID	EFs Site	Avg EF condition	Average Annual Ppt(cm)	Avg Drought Value	Drought Condition
EF1	Bhawanipatna	Degrading	13.30	-1.32	Moderate drought
EF2	Dharangarh	Good	14.00	-1.16	Mild drought
EF3	Junagarh	Degrading	13.78	-1.28	Moderate drought
EF4	Koksara	Degrading	13.78	-1.36	Moderate drought
EF5	Jayapatna	Degrading	13.78	-1.28	Moderate drought

Table 12: Comparative Values of EF and Drought in Tel River

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The degraded or poor EF conditions of these areas have been ascertained in various studies as the Tel River forms part of KRB basin which is a drought prone area.

5.3. ADVANTAGE OF THE CONCEPT

1. The EF values recommended and the drought severity computed will help water resource planner and decision makers for development of a new water resources projects such as the design of storage facilities, assessment of water available for municipal, agricultural or industrial purposes and operating rules that satisfy EFs.
2. Will help to compute the value of EF in absence of requisite data, with the help of drought severity analysis.
3. Will help to access the drought severity in the area and further take timely remedial actions for eradication's of implications.

5.4 DISADVANTAGE /LIMITATION OF THE CONCEPT

1. It is likely to generate results with low confidence as it is a new concept and requires more refinement in drawing results for various basins.
2. There is no provision to integrate other associated aspects, for instance-the ecology, biodiversity, riverine communities etc.
3. Thus, there is a need for betterment of the methodology, where all the aspects can be integrated to draw the result.

VI. CONCLUSIONS AND RECOMMENDATION

The paper presents the initial estimate of EFs recommendation using the conceptual method of drought, Tennant method and Hughes and Munster method. This method is a preliminary approach where insufficient ecological and hydraulic data is available.

The results indicate that in case the values of drought severity is computed (for the given region/basin) we can draw the conclusion to ascertain the values of river health condition or condition of EF as per the recommended percentages as specified by Tennant's method or Hughes and Munster method.

The computation for MRB is done to draw the link between drought and EF conditions when complete data is available for computation's and in the case of Tel River, it is done in order to ascertain the link between the drought and EF when the data is not adequately available and to also establish the result of study that when it is known that the area is drought prone (Tel River is within KRB basin, which is a drought prone area) then on assessment with SPEI how the EF conditions comes up.

Thus, it can be concluded that in case the values for drought severity is known for the river basin, then the EF conditions can be assessed and hence a fair idea can be made out that whether the minimum flow released in the river is adequate to maintain the regime of the river ecosystem or corrective actions are required to be undertaken.

The EF values recommended and the drought severity computed will help water resource planner and decision makers for development of a new water resources projects.

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