Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 7 [12] November 2018 : 151-155

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.876
Universal Impact Factor 0.9804
NAAS Rating 4.95

ORIGINAL ARTICLE **OPEN ACCESS**

Comparison of Drought Indices at Different Stations of Chhattisgarh

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ABSTRACT
Comparison of three drought indices viz., SPI, PRFD and AI was carried out to find suitable drought index for meteorological drought assessment by taking four stations (Raipur, Bilaspur, Ambikapur and Jagdalpur) data for the period of 24 years (1991-2014). SPI and PRFD found more number of mild droughts at Bilaspur when compared to other three stations. Aridity index revealed that disastrous drought occurred at Jagdalpur (4 times), Bilaspur (3 times), Ambikapur (1 time) during 1991 – 2014 except Raipur. Drought severity values of SPI, PRFD and AI were correlated at different time scales and it revealed that good relation between SPI and PRFD at same time scale and it reduced at dissimilar time scales. Relationship between SPI vs PRFD as well as SPI vs AI was negative also very weak even at same time scales and different time scales. From this study, it may be concluded that Standardized Precipitation Index is better index than percent rainfall departure and aridity index for meteorological drought monitoring.
Keywords: *Drought assessment, Meteorological drought, Standardized Precipitation Index, Aridity Index, Chhattisgarh*

Received 12.08.2018 Revised 22.10.2018 Accepted 06.11.2018

INTRODUCTION

Drought is slow creeping; one of the major natural calamities and it varies from place to place depending upon normal climatic conditions, available water resources, agricultural practices and the various socio-economic activities. Drought in India is not uncommon and has resulted in tens of millions of deaths over the course of the 18th, 19th and 20th centuries. Indian agriculture is heavily dependent on the climate of India and the failure of the monsoons result in water shortages and reduced crop yield / crop failure. There were seven major droughts (1972, 1979, 1987, 2002, 2009, 2014 and 2015) occurred over India in the last 45 years and each drought resulted in significant reduction in food grains production of the country. In India, 33 and 35 percent of cultivable area is classified as chronically drought prone and drought prone area, respectively [7].The impact of drought varies with its duration, spatial spread and magnitude. These characteristics of the drought can be obtained by drought indices and give quantitative information to policy makers [2]. According to Zargar *et al.,*[14], the drought indices are nothing but quantitative measures by which drought intensity can be characterized by incorporating data from one or several variables (indicators) such as precipitation and evapotranspiration into a single numerical value. Many studies are there in literature on assessment and comparison of different drought indices [1, 4, 5, 9]. Keeping the above aspects in view, the present study was carried out to find appropriate drought index for meteorological drought monitoring.

MATERIAL AND METHODS

Daily data of rainfall and maximum and minimum temperature for the four stations *viz.,* Raipur, Bilaspur, Ambikapur and Jagdalpur collected from the database of the Department of Agrometeorology, Indira Gandhi KrishiViswavidyala, Raipur. The period of data is for 24 years from 1991 to 2014. In the present study three drought indices *viz.,* percentage rainfall departure, Standardized Precipitation Index and Aridity Index have been considered for comparison of its frequencies of different intensities and they have been explained briefly.

Percentage rainfall departure (PRFD)

The percentage rainfall departure is worked out by dividing the difference between actual and average annual rainfall with average annual rainfall and expressed as percentage. This index is easy to calculate (on daily, weekly, monthly, seasonal, annual and decadal basis) and understand. India Meteorological Department is using this index for week by week / monthly / seasonal progression of southwest monsoon rainfall over the country as well for drought declaration. In the present study, different categories of drought have been categorizedand furnished in Table 1.

Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is one of the numerous indices that are being used to detect and monitor the meteorological drought across the world. It is developed by Mckee *et al* [6] at Colorado State University, U.S.A. Hayes *et al.,* [4] reported that the World Meteorological Organization (WMO) declared (Lincoln Declaration on Drought Indices) in the year 2009 that Standardized Precipitation Index is the globally accepted index to characterize meteorological droughts and can be adopted by all National Meteorological and Hydrological Services around the world.It is defined as the number of standard deviations that the observed cumulative rainfall at a given time scales would deviate from the long-term mean. The following equation is used to compute the SPI and different categories of drought along with SPI values is furnished in table 1.

$$SPI = \frac{X_i - \overline{X_i}}{\sigma_i}$$

where, X_i = Rainfall received during i^{th}period,X_i= Normal rainfall for i^{th} period,σ_i=Standard deviation of rainfall during i^{th} period.

Aridity Index (AI)

Aridity is usually expressed as a generalized function of precipitation, temperature and or potential evapotranspiration (PET). In the present study, climatic water balance on monthly basis was carried out following the Thornthwaite and Mather [12] method. Aridity index is worked out by dividing water deficit values by PET and then multiplied by 100. A negative or a zero value of this anomaly would imply that as compared to the normal, the place experienced less arid/drought conditions; a positive value would indicate that the place had experienced more arid/drought conditions than the normal. The departed values of aridity index and their drought category is given in Table 1.

Potential evapotranspiration

The monthly potential evapotranspiration for the selected fourstations for the period 1991 - 2004 was computed using Thornthwaite equation [11]. This method of estimating PET is based solely on air temperature. PET estimates are based upon a 12-hour day (amount of daylight) and a 30-day month. Thornthwaite [11] gave the following formula for computing monthly evapotranspiration:

$$E = 1.6\ (10T/I)\ A$$

Where, E=Unadjusted PET (cm); T=Mean air temperature (^oC); I =Annual or seasonal heat index (summation of 12 values of monthly heat indices)i = (T/5) 1.514;

$$A = 0.675 \times 10^{-6} I^3 - 0.771 \times 10^{-4} I^2 + 1.79 \times 10^{-2} I + 0.4924$$

In the present study, three drought indices are compared to find performance of these indices for meteorological drought monitoring. For this purpose, analysis like frequency of drought at different intensities by each index, comparison of drought intensity values at different time scales (1, 3, 6, 9 and 12 months) using Pearson correlation coefficients, comparison of drought index during drought years declared by state government was carried out.

RESULTS AND DISCUSSION

Drought frequency of different intensities

Drought occurrence worked out for southwest monsoon season as this is the main rainy season of the state and almost 90 percent of the annual rainfall received in this period [10] and the results are furnished in Table 2. SPI and PRFD indicated that frequencies of near normal / mild drought weremore in Bilaspur when compared to other three stations. Based on aridity index, moderate drought occurred 4 times at Ambikapur, 5 times each at Bilaspur / Jagdalpur and at Raipur for 6 times. Large / moderately dry condition noticed at Raipur for 5 / 6times during the study period and in other stations it prevailed 2-4 times as per SPI and PRFD. However, aridity index indicated that large drought experienced only one year at Bilaspur and it varied from 2 to 4 years in other three stations.

Aridity index identified severe drought in 3 years during the study period at three stations (Raipur, Bilaspur and Ambikapur) whereas Jagdalpur experienced two severe droughts. At the same time, SPI

indicated that severely dry condition was observed one to two times at all stations except Jagdalpur. Disastrous or extremely dry condition is very rare event and SPI reveals that extremely dry situation prevailed only at Jagdalpur for two years. However, as per aridity index, disastrous drought occurred at three stations *viz.,*Jagdalpur (4 times), Bilaspur (3 times), Ambikapur (1 time) during 1991 – 2014 except Raipur. The value of aridity index was zero for 11 and 10 years out of 24 years at Jagdalpur and Bilaspur, respectively. Due to this, median value for AI became small and little increase in water deficit value resulted in to severe / disastrous drought condition. The results also revealed that PRFD showed no severe / disastrous drought events at all stations even during drought years (2000, 2002 and 2014) declared by state government [13].

Statistical relation among three drought indices

Correlation coefficient was worked out to compare three drought indices at different time scales for all four stations. For instance, Table 3 shows correlation coefficient and its average value of each timescale for Raipur station. From the table it can be noted that the strength of relation is positive and very good at same time scale and it reduced at different time scale for SPI and PRFD. For example, the correlation coefficient value between SPI-1 and SPI-3 is 0.56 and SPI-1 and SPI-6 is 0.46 likewise SPI-1 vs PRFD-1 is 0.69 and SPI-1 vs PRFD-3 is 0.48. It is understood that SPI and PRFD may be compared at similar time steps only and not at different time steps.

AI is computed based on water balance procedure taking potential evapotranspiration and maximum moisture holding capacity of soil into account. The intensity of aridity increases with increase in its value. At the same time, SPI and PRFD were worked out using rainfall only and their increased value in positive and negative side indicates excess and shortage of water availability, respectively. Hence, there is negative correlation between SPI vs PRFD as well as SPI vs AI and the relationship is also very weak even at same time scales and different time scales. Same type of results obtained for other three stations. The average correlation coefficient value between three drought indices for different time scales is shown in Table 3. It is noticed that SPI-6, SPI-9 and PRFD-9 had highest average correlation coefficient (0.39). This analysis revealed that SPI had good relation with PRFD and AI with other time scales (1, 3, 6, 9 and 12-month). It is also observed from the results of all four stations that SPI-6 has highest average correlation coefficient followed by SPI-9 with PRFD and AI. Jain *et al.,* [4] compared different drought indices through correlation analysis and found that 9 month time scale is more appropriate for comparison of drought indices. Okpara and Tarhule [8] evaluated three drought indices like SPI, SAI (Standardized Rainfall Anomaly Index) and BMDI (Bhalme and Mooley Drought Index) in the drought prone Niger Basin, West Africa and found that SPI is the robust and ranked first among other drought indices.

Comparison of drought indices during drought years

In order to find appropriate drought index for drought monitoring, drought severity values in southwest monsoon (southwest monsoon contributes almost 90% of annual rainfall) was compared during drought years. Drought years (2000, 2002 and 2004) declared by the Government of Chhattisgarh during the period 2000 – 2014 are noted from the farmers' portal (www.farmer.gov.in) for all four stations. Table 4indicates that no drought was declared by State Government in the year 2000 at Ambikapur and Jagdaplur. It is important to note that all the three drought indices showed no drought situation at Ambikapurin 2002 which was All India severe drought year. Among the three drought indices, AI could not identify drought at Raipur during 2000 and 2004 and at Bilaspur in 2004. It is also observed that SPI and PRFD could identify eight drought events out of 10 whereas AI spotted only five events. It suggests that SPI and PRFD is performing better when compared to AI. However, from the statistical relationship, it is found that SPI is better drought index for meteorological drought monitoring as it is having good correlation with PRFD and AI with all time scales. Pai *et al.,* [9] also reported that SPI is better drought index for drought monitoring at district level when compared to percent of normal precipitation.

Table 1. Threshold values for each drought index and their corresponding drought categories

S. No	Percentage rainfall departure		Standardized Precipitation Index		Aridity Index	
	% departure	Drought category	Values	Drought category	Departure from Std. deviation	Drought category
1	0 to -19.9	Mild	0 to - 0.99	Mild	0 - l / 2 **σ**	Moderate
2	-20 to -39.9	Large	-1.0 to -1.49	Moderately dry	1/2 **σ** - 1**σ**	Large
3	-40 to -59.9	Severe	-1.5 to -1.99	Severely dry	1**σ** - 2 **σ**	Severe
4	≤ -60.0	Disastrous	-2 and less	Extremely dry	>2 **σ**	Disastrous

Table 2. Frequencies of drought at different intensities as computed by different drought indices

Station	Drought index	No drought	Near normal / Mild / Moderate	Large / Moderately dry	Severe / Severely dry	Disastrous / Extremely dry
Raipur	SPI	11	7	5	1	-
	% RFD	10	8	6	-	-
	AI	12	6	3	3	-
Bilaspur	SPI	10	10	3	1	-
	% RFD	9	11	4	-	-
	AI	12	5	1	3	3
Ambikapur	SPI	12	8	2	2	-
	% RFD	11	9	4	-	-
	AI	12	4	4	3	1
Jagdalpur	SPI	12	8	2	-	2
	% RFD	11	9	4	-	-
	AI	11	5	2	2	4

Table 4. Drought category as identified by three drought indices during drought years

Station	SPI			PRFD			AI		
	2000	2002	2004	2000	2002	2004	2000	2002	2004
Raipur	MD	SD	Mild	Large	Large	Mild	No	Mod	No
Bilaspur	SD	Mild	MD	Large	Mild	Large	Mod	Dis	No
Ambikapur	DND	No	Mild	DND	No	Mild	DND	No	Large
Jagdalpur	DND	MD	No	DND	Large	No	DND	Mod	No
MD-Moderately dry; SD-Severely dry; DND-Drought Not declared; Mod-Moderate; Dis-Disastrous drought									

Table 3. Pearson correlation coefficient (s) between SPI, PRFD and AI at different time scales for Raipur station

Drought Index with time scale	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	PRFD-1	PRFD-3	PRFD-6	PRFD-9	PRFD-12	AI-1	AI-3	AI-6	AI-9	AI-12
SPI-1	1.00	0.56	0.43	0.39	0.33	0.69	0.48	0.42	0.41	0.33	-0.19	-0.12	-0.25	-0.19	-0.14
SPI-3	0.56	1.00	0.68	0.62	0.57	0.44	0.88	0.64	0.62	0.56	-0.22	-0.20	-0.16	-0.18	-0.28
SPI-6	0.43	0.68	1.00	0.82	0.77	0.26	0.51	0.93	0.79	0.75	-0.17	-0.16	-0.20	-0.23	-0.36
SPI-9	0.39	0.62	0.82	1.00	0.90	0.24	0.45	0.71	0.97	0.89	-0.16	-0.15	-0.17	-0.25	-0.40
SPI-12	0.33	0.57	0.77	0.90	1.00	0.20	0.42	0.65	0.85	0.99	-0.14	-0.15	-0.17	-0.26	-0.48
RD-1	0.69	0.44	0.26	0.24	0.20	1.00	0.49	0.28	0.25	0.20	-0.29	-0.12	-0.09	-0.10	-0.15
RD-3	0.48	0.88	0.51	0.45	0.42	0.49	1.00	0.55	0.48	0.42	-0.25	-0.23	-0.17	-0.18	-0.32
RD-6	0.42	0.64	0.93	0.71	0.65	0.28	0.55	1.00	0.74	0.65	-0.17	-0.16	-0.21	-0.25	-0.39
RD-9	0.41	0.62	0.79	0.97	0.85	0.25	0.48	0.74	1.00	0.86	-0.17	-0.14	-0.17	-0.25	-0.39
RD-12	0.33	0.56	0.75	0.89	0.99	0.20	0.42	0.65	0.86	1.00	-0.14	-0.14	-0.17	-0.26	-0.48
AI-1	-0.19	-0.22	-0.17	-0.16	-0.14	-0.29	-0.25	-0.17	-0.17	-0.14	1.00	0.74	0.13	-0.30	0.13
AI-3	-0.12	-0.20	-0.16	-0.15	-0.15	-0.12	-0.23	-0.16	-0.14	-0.14	0.74	1.00	0.59	0.04	0.16
AI-6	-0.25	-0.16	-0.20	-0.17	-0.17	-0.09	-0.17	-0.21	-0.17	-0.17	0.13	0.59	1.00	0.62	0.23
AI-9	-0.19	-0.18	-0.23	-0.25	-0.26	-0.10	-0.18	-0.25	-0.25	-0.26	-0.30	0.04	0.62	1.00	0.45
AI-12	-0.14	-0.28	-0.36	-0.40	-0.48	-0.15	-0.32	-0.39	-0.39	-0.48	0.13	0.16	0.23	0.45	1.00
Average	0.28	0.37	0.39	0.39	0.37	0.22	0.30	0.36	0.39	0.36	-0.01	0.07	0.06	-0.02	-0.09

CONCLUSIONS

Present study aimed to find appropriate drought index among three drought indices *viz.,* SPI, PRFD and AI for meteorological drought assessment. Four stations (Raipur, Bilaspur, Ambikapur and Jagdalpur) data for the period of 24 years (1991-2014) was used to compute drought severity values. Drought frequency analysis indicated that SPI and PRFD found more number of mild droughts at Bilaspur when compared to other three stations. Aridity index revealed that disastrous drought occurred at Jagdalpur (4 times), Bilaspur (3 times), Ambikapur (1 time) during 1991 – 2014 except Raipur. At the same time, no severe or disastrous drought was identified by PRFD. Correlation analysis between SPI, PRFD and AI at different time scales for four stations indicated that good relation between SPI and PRFD at same time scale and it reduced at dissimilar time scales. Negative correlation was observed between SPI vs PRFD as well as SPI vs AI and the relationship is also very weak even at same time scales and different time scales. Performance of drought indices was assessed during drought years and it is noticed that SPI and PRFD is performing better when compared to AI. Finally, it is interpreted from these results that Standardized Precipitation Index is better index than percent rainfall departure and aridity index for meteorological drought monitoring.

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CITATION OF THIS ARTICLE

Vinayak Pandey, Harsh Vardhan Puranik, D.R.Agashe A.S.R.A.S. Sastri and N. Manikandan· Comparison of Drought Indices at Different Stations of Chhattisgarh. Bull. Env. Pharmacol. Life Sci., Vol 7 [12] November 2018: 151-155