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Original Article

Assessment of Meteorological Drought Indices for Monitoring Drought Condition in the Sone Command Area, Bihar, India- A case study

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Abstract: *Drought is a hazard that affects most settled areas occasionally or periodically. Drought is a common natural disaster in India. In India, more than 70 percent of people, primarily depend on agriculture. In the present study, average monthly rainfall data from 1901 to 2002 were analyzed to determine monthly and yearly metrological drought occurrence in the Sone command area of the state of Bihar, India. The average rainfall of the Sone command area is 1100 mm, seven different metrological drought indices, namely IMD method, Decile index, standard precipitation index, reconnaissance drought index, Percent of normal, Aridity index, and moisture adequacy index were selected mainly reflecting metrological droughts. Also, an effort has been made to find out the districts facing the most severe drought conditions. As per the results, the most common kind of SPI was normal to moderately dry and that of IMD Method was moderate drought condition. Index of Aridity and percent of the normal index did not show good results for the drought severity as they have predicted most of the months to have no drought condition. The moisture adequacy index shows disastrous drought every year. RDI and SPI index show the same results. The drought has been monitored by the use of several meteorological indices, and it is clear that the present study area is experiencing normal to moderate drought.*

Keywords: *Drought, IMD method, Standard Precipitation Index*

I. INTRODUCTION

Drought is a complex phenomenon characterized as below-average natural water availability in the form of precipitation, river runoff, or groundwater over a long period and throughout a large geographic area. Drought is a temporary phenomenon, whereas aridity is a permanent component of the climate [15]. Drought is a common occurrence in the climate. It may happen virtually anywhere, however, the way it manifests differs from area to region, making a universal description impossible [2, 21]. Drought in Libya, for example, might be defined as a time with less than 180 mm of annual rainfall, but drought in Bali could be described as only 6 days without rain. Drought is described as a lack of precipitation for an extended length of time, usually, a season or longer, resulting in water supply shortage for a particular activity, group, or environment. Drought may strike almost any climate in the world, including wet ones. It is the most complicated of all-natural disasters, affecting the most people. It can be as expensive as floods and storms, according to research. The most serious concern in drought-prone places is, of course, a lack of water. The fast growth of irrigation in some of these regions, particularly where groundwater is being taken, has already resulted in resource exhaustion and the need to halt agricultural exploitation in several cases.

Drought is a common natural disaster in India. This condition is caused by the monsoon's failure in both time and space. Drought-prone regions have been recognized in ninety-nine districts across thirteen states. The most impacted areas are in the north-western regions of the nation, where yearly rainfall is less than 700 mm. Many experts have studied meteorological drought in various parts of India [1, 3, 6, 8, 16, 18]. Drought indices are typically computed mathematical representations of drought severity that are assessed using climatic, hydrological, and meteorological inputs. Meteorological drought may be detected early on and is regarded as the most visible event in the occurrence and progression of various drought situations [7, 17]. The estimation of drought risk by integrating socioeconomic drought vulnerability with drought hazard based on the Standardized Precipitation Index [20]. In the earliest stage of drought monitoring, which utilizes rainfall data as the source, meteorological indices play a significant role. Standardized Precipitation Index (SPI), Decile Index, Reconnaissance drought index, Percent of normal, Aridity index, and Moisture adequacy index are some of the indexes that utilize just precipitation data to identify and monitor drought. These indices are assessed to monitor the present study's drought situation.

II. THE STUDY AREA

The study area is in the southern part of Bihar in India. The total length of the Sone River is 881 km. Sone River originates near Amarkantak in Madhya Pradesh. Sone River is an important tributary of the Ganga River. The study area also includes the Endrapuri barrage situated at Dehri on Sone. The total length of the Sone River is 784 km. The total catchment area of the river is 70,055 sq km. Sone command covers eight districts namely Patna Aurangabad, Jahanabad, Gaya, Bhojpur, Baxur, Rohtas, Bhabhua of Bihar. The mean annual rainfall in the study area is 1398 mm. The project is situated at latitude 24°18´N to24°59´ and longitude 84° 06´to 85°1´ E. the total Sone command area is 37,07,904 ha [9-14]. The soil type of the study area is usually clay loam. The major land use pattern of the study area is vegetation, water, barren land, urban, rock.

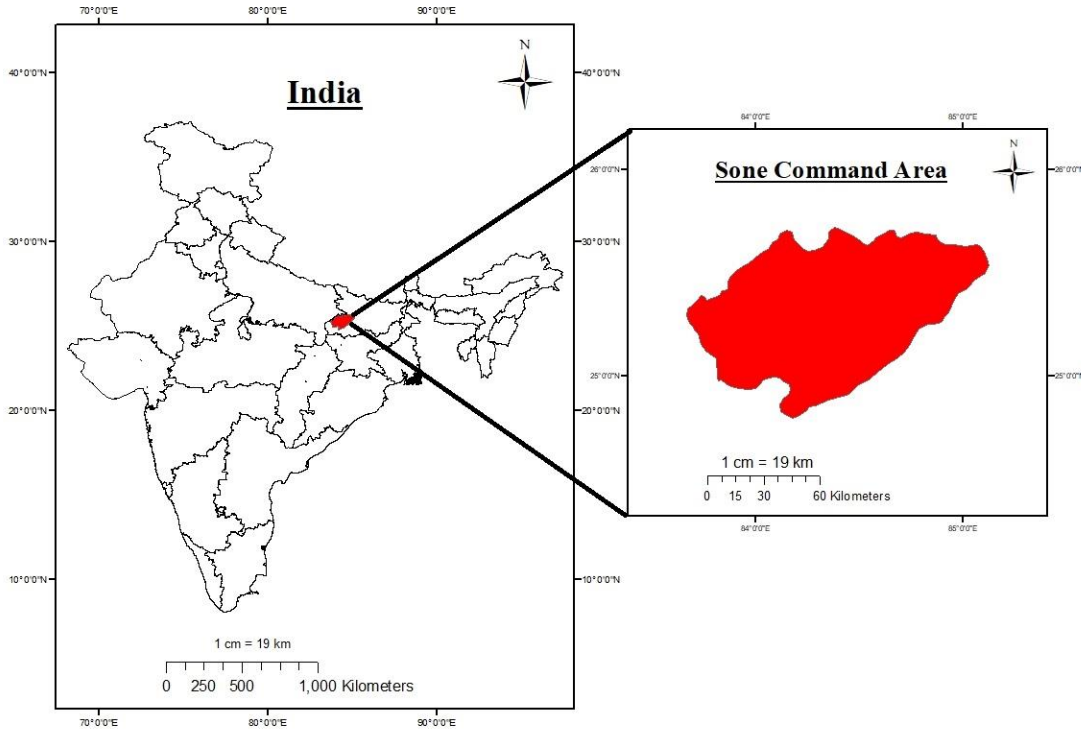

Figure 1: Sone Command Area

III. METHODOLOGY

For effective mitigation actions, drought estimation using various approaches is required. The IMD technique, the Reconnaissance drought index, the standard precipitation index, and the moisture adequacy index were all used. MS Excel is used to perform the calculations. For the year from 1901 to 2002 (102 years), the needed data was obtained from the Indian Metrological Department. Temperature, evaporation, and precipitation data were all required inputs.

A. Indian Meteorological Department (IMD) Method

Drought was measured using the percentage deviation Di of rainfall from long-term rainfall in IMD method. The method is set up in such a way that the surplus or shortfall of rainfall from previous time periods has an impact on the current time period's ability to satisfy the requirement for cumulative long-term mean rainfall.

$$D_i=(P_i-\mu)/\mu*100 \qquad (1)$$

Where, Pi is the mean rainfall of the respective year, μ = long term mean rainfall for the entire duration of the data.

B. Standard Precipitation Index (SPI)

McKee et al. (1993) established the Standardized Precipitation Index. Only precipitation is used to calculate the SPI [5]. The SPI gives precipitation a single numerical number that may be compared across areas and time spans with widely different climates. The index is calculated only on the basis of precipitation data. It is calculated by dividing the precipitation anomaly from the mean value for a particular time frame by the standard deviation. At least on time scales smaller than a year, the precipitation does not follow a normal distribution. As a result, the variable is changed to make the SPI a Gaussian distribution with a zero mean and unit variance. An index that has been modified in this way allows values from various locations to be compared. Furthermore, because the SPI is normalized, it may be used to monitor both wet and dry regions.

$$SPI=(X_i-X)/\sigma \quad (2)$$

Where, X is the mean annual rainfall, Xi is the annual rainfall at any year, and σ is the standard variation.
Standard deviation for precipitation is computed as:

$$\sigma=\sqrt{\frac{\sum (X-\bar{X})^2}{N}} \quad (3)$$

Where, N is the number of years.

C. Reconnaissance Drought Index (RDI)

Tsakiris, 2004 was the first to present new reconnaissance drought detection and evaluation index, with Tsakiris et al. 2006 providing a more detailed explanation [18]. The Reconnaissance Drought Index is a measure of drought that may be computed using the formulae below. The annual expressions are provided first for illustration reasons. The first expression, the starting value (α_o), is calculated for each month of the hydrological year or for the entire year and is given in aggregated form using a monthly time step.

$$\alpha_0^{(i)}=\frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \quad i=1 \text{ to } N, \text{ and } j=1 \text{ to } 12 \quad (4)$$

Where, Pij and PETij are the precipitation and potential evapotranspiration of the month j of the year i.

For each year, a second expression, the normalised RDI (RDIn), is derived using the following equation, where the parameter $\bar{\alpha_o}$ is the arithmetic mean of values calculated for the N years of data.

$$RDI_n^{(i)}=\frac{\alpha_0^{(i)}}{\bar{\alpha_0}}-1 \quad (5)$$

The third expression, the Standardized RDI (RDI st), is computed following similar procedure to the one that is used for the calculation of the SPI. The expression for the Standardized RDI is:

$$RDI_{st}^{(i)}=\frac{y^{(i)}-\bar{y}}{\hat{a}_y} \quad (6)$$

In which $y^{(i)}$ is the $\ln\alpha_o(i)$, $\bar{y}$ is its arithmetic mean and $\hat{a}_y$ is its standard deviation.

D. Index of Aridity

The index of aridity was developed by De Martoone in 1936 to calculate the aridity of a region based on rainfall and temperature. Later, the number of days (n) was included, and the monthly precipitation (P) was replaced with mean daily precipitation (p).
Index of Aridity is given by

$$I=\frac{P}{t+10} \quad (7)$$

Where, I = index of aridity, P = monthly precipitation, t = mean monthly temperature, °C
The modified index is given by the following equation

$$I=\frac{n\bar{p}}{t+10} \quad (8)$$

Where, n = number of days, $\bar{p}$ = mean daily precipitation.

E. Aridity Index

It is defined as the yearly water deficit as a percentage of the annual water requirement. Under unconstrained water supply conditions, potential evapotranspiration is the greatest loss of water owing to a combination of evaporation and transpiration. It's also known as compulsory PE. Actual evapotranspiration occurs when the magnitude of precipitation is less than PE, and the crop uses total precipitation plus a specific quantity of soil moisture to meet the evapotranspiration requirement (AE). When precipitation is less than the potential evapotranspiration (i.e. PPE), the actual evapotranspiration is the sum of precipitation and change in soil moisture. Aridity index is given as:

$$I_a=\frac{PE-AE}{PE}*100 \quad (9)$$

Where, Ia = aridity index, PE = potential evapotranspiration, AE = actual evapotranspiration
Method to determine the actual evapotranspiration
If precipitation < potential evapotranspiration

Then, actual evapotranspiration = precipitation
If precipitation > potential evapotranspiration
Then, actual evapotranspiration = potential evapotranspiration

F. Moisture Adequacy Index

The moisture adequacy index is the percent ratio of actual evapotranspiration to potential evapotranspiration. It was introduced by Subramanyam et.al (1963) to characterize the agricultural drought in India.
It is given as under:

$$MAI=AE/PE*100 \quad (10)$$

Where, MAI = moisture adequacy index, AE = actual evapotranspiration, PE = potential evapotranspiration

G. Decile

Gibbs and Maher (1967) introduced the term "Deciles" to avoid some of the flaws in the "Percent of Normal" method [4]. They established the method by splitting a long-term precipitation record's distribution of occurrences into tenths of the distribution. Each of the categories was dubbed a 'Decile.' As a result, the first decile is defined as the rainfall that is not surpassed by the lowest 10% of precipitation occurrences. The precipitation quantity not surpassed by the lowest 20% of occurrences is the second decile, and so on. The deciles are repeated until the tenth decile identifies the greatest quantity of precipitation in the long-term data. The fifth decile is really the median, and it refers to the amount of precipitation that has not been exceeded 50% of the time throughout the record period. The deciles are separated into five groups. The decile technique has one disadvantage: accurate decile calculation needs a long weather record.

Table 1: Drought Indices and their classification

Sl. No.	Indices	Range	Classification
1.	IMD Method	0 to -25	Mild
		-25 to -50	Moderate
		-50 to -75	Severe
		< -75	Extreme
2.	Decile Index	10 - 9	Very Humid
		8 - 7	Humid
		6 - 5	Humid to Normal
		4 - 3	Dry
		2 - 1	Very Dry
3.	Percent of Normal	> 100	No Drought
		< 100	Drought
4.	SPI and RDI	≥2	Extreme wet
		1.5 to 1.99	Severely wet
		1.0 to 1.49	Moderately wet
		0.0 to 0.99	Mildly wet
		-0.99 to 0.0	Mild drought
		-1.49 to -1.00	Moderate drought
		-1.99 to -1.50	Severe drought
		< -2.00	Extreme drought
5.	Aridity Index	50 - 60	Slight
		60 - 70	Moderate
		70 - 80	Severe
		> 80	Disastrous
6.	Moisture Adequacy index	> 10	Moderate
		10 - 20	Large
		20 – 30	Severe
		< 30	Disastrous

IV. RESULTS AND DISCUSSION

We used seven distinct meteorological drought indices to analyze the drought in the Sone command area, which includes 10 districts (Bhojpur, Aurangabad, Bhabhua, Jehanabad, Buxar, Palamu, Patna, Garhwa, Gaya, and Rohtas). We have displayed the specific findings of each district utilizing drought indices in this section initially in the sub-section sections. Then, in subsequent sub-sections, we compared the results using various approaches. We evaluated the SPI index to the remaining six methods as the standard drought index for the command area. The acquired results are detailed in the sub-sections.

A. IMD Method

Analyzing the drought by using IMD Method, there is no extreme drought occurs in last 102 years but severe drought occurred once in seven districts. Among ten districts, Buxar district occur a greater number of droughts and Garhawa district occur a smaller number of droughts. The results are given in Table-2.

Table 2: District wise number of drought years using IMD method

District	No. of no drought year	No. of mild drought year	No. of moderate drought year
Bhojpur	56	38	7
Jehanabad	53	41	7
Patna	54	40	8
Palamu	55	33	13
Rohtas	53	38	10
Aurangabad	53	36	12
Bhabhua	46	44	11
Buxar	38	51	12
Garhawa	73	24	5
Gaya	61	32	9

B. Decile Index

Analysing drought by Decile index, almost all districts in Sone command area come under no drought category (more than 90 percent) throughout last 102 years except Palamu district. The results are given in table3.

Table 3: District wise number of drought years using Decile Index

District	No. of no drought year	No. of weak drought year	No. of moderate drought year
Bhojpur	92	7	2
Jehanabad	89	8	4
Patna	89	10	3
Palamu	76	19	6
Rohtas	82	14	5
Aurangabad	89	10	2
Bhabhua	91	8	3
Buaxar	90	9	3
Garhawa	99	2	1
Gaya	94	6	2

C. Percent of Normal

Analysing the drought by percent of normal, Buxar facing a greater number of droughts and Palamu district facing a smaller number of droughts in compare to other districts. The results are given in Table-4.

Table 4: District wise number of drought years using Percent of Normal method

District	Number of No drought year	Number of Drought year
Bhojpur	56	46

Jehanabad	61	41
Patna	61	41
Palamu	76	26
Rohtas	58	44
Aurangabad	66	36
Bhabhua	54	48
Buaxar	52	50
Garhawa	77	25
Gaya	71	31

D. Standard Precipitation Index (SPI) and Reconnaissance Drought Index (RDI)

After analyzing drought by using SPI index and RDI index, almost the results are same in all districts in Sone command area. The results are given in Table-5.

Table 5: Number of drought years using SPI index and RDI index

District	Extremely wet		Very wet		Moderately wet		Near normal		Moderately dry		Severe dry		Extremely dry	
	SPI	RDI	SPI	RDI	SPI	RDI	SPI	RDI	SPI	RDI	SPI	RDI	SPI	RDI
Bhojpur	3	3	3	4	7	6	72	72	9	10	4	4	4	3
Jehanabad	4	2	2	3	9	8	70	74	9	9	5	4	3	2
Patna	3	3	4	3	8	7	71	75	8	3	5	6	3	5
Palamu	2	1	5	3	6	13	65	67	13	10	5	1	6	7
Rohtas	2	2	4	3	10	12	68	65	9	12	5	5	4	3
Aurangabad	2	0	5	4	8	12	69	67	11	10	4	3	3	6
Bhabhua	2	2	3	2	12	11	69	69	7	12	5	1	4	5
Buxar	3	2	2	4	9	12	74	68	6	9	4	4	4	3
Garhawa	1	1	7	1	7	11	67	74	11	8	5	3	4	4
Gaya	2	1	8	5	4	12	69	71	11	2	4	3	4	8

E. Aridity Index

The results obtained from the aridity index indicates that all districts in Sone command area having same results in every year from 1901 to 2002. The results are given in Table-6.

Table 6: District wise classification of drought throughout last 102 years using Aridity Index

District	Class			
	Moderate	Large	Severe	Disastrous
Bhojpur	145	47	34	998
Aurangabad	171	46	23	984
Bhabhua	173	41	30	980
Buxar	149	41	42	992
Garhawa	142	38	27	1017
Gaya	141	41	31	1011
Jehanabad	141	50	30	1003
Palamu	122	43	34	1025
Patna	131	42	28	1023
Rohtas	161	48	28	987

F. Moisture Adequacy index

The results obtained from moisture adequacy index indicate that almost every year in all ten districts in Sone command area facing the disastrous drought. The results are given in Table-7.

Table 7: District wise classification of drought throughout last 102 years using Moisture Adequacy Index

District	Class				
	Slight	**Moderate**	**Severe**	**Disastrous**	**No drought**
Bhojpur	34	24	34	192	940
Aurangabad	21	25	23	217	938
Bhabhua	23	28	30	214	929
Buxar	33	26	42	190	933
Garhawa	29	32	27	180	956
Gaya	22	25	32	182	963
Jehanabad	23	33	30	191	947
Palamu	26	28	34	165	971
Patna	20	29	29	173	973
Rohtas	24	19	28	209	944

V. CONCLUSION

The use of meteorological indicators such as the IMD method, Decile index, SPI, RDI, AI, percent of normal, and moisture adequacy index to monitor drought conditions based on rainfall data in an area has shown to be an effective and simple way of drought monitoring. These indices are calculated using the mean precipitation, mean potential evaporation and mean temperature data values. Based on results IMD method and SPI index was found to be the one of the best methods for metrological drought index computation. The Aridity Index and the Precipitation Effectiveness Index did not produce positive findings for drought severity, since these methods projected that most of the months would be no drought. According to the results obtained after evaluating these indices, the Sone command area is experiencing a meteorological drought in accordance with previous rainfall occurrences.

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