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COMPARISON OF SEVEN METEOROLOGICAL INDICES TO MONITOR DROUGHT STATUS IN DROUGHT PRONE DISTRICTS OF RAJASTHAN

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ABSTRACT

There are various drought indices which are normally used in drought monitoring and risk management. Rainfall, temperature, evaporation and other hydro meteorological parameter are crucial part to assessment of drought. Thousands of drought indices have been developed in the world in recent past years for this purpose. This paper identifies the applicability and comparison of drought indices in drought prone area in Rajasthan state by assessing the performance of seven drought indices. The indices include Standardized Precipitation Index (SPI), Percentage of Normal (PNI), Deciles Index, (DI), China Z Index (CZI), Modified China Z Index (MCZI), Rainfall Anomaly Index (RAI), Z score index. These indices are compared by using 53 years of rainfall data (1950-2002) in seven drought prone district in. The performance, efficiency and significance are also tested by applying different statistical tests. The comparison of seven drought indices also based on relative drought frequency and drought classes. In result, Z score index is most suitable indices and CZI and MCZI also showing good result so Z score index can be used instead of SPI in drought prone district of Rajasthan. RAI is least efficient and its relative error is also high so RAI is least suitable indices for drought monitoring.

Keywords: - SPI, PNI, DI, CZI, MCZI, RAI, Z score index

1. INTRODUCTION

Drought is known to be worst meteorological hazard of nature (Mishra and Desai 2005). Drought is an event which lasts from month to years. Drought can be occur at any part of world and in any type of environment like arid, semi-arid or humid (Wilhite 2000). The inter-annual variability in precipitation makes the arid region always at drought risk due to greater probability of below average precipitation (Smakhtin and Schipper 2008). According to the Centre for Research on the Epidemiology of Disasters (CRED), the drought causes large scale economic losses in a region and makes it more vulnerable for other hydro-meteorological disasters (Guha-Sapir et al. 2014). Obasi (1994) reported extreme meteorological events contribute approximately 85% of the natural disasters. The drought frequency and intensity provide valuable information to policy makers for making timely contingency plans (Morid et al. 2006).

The main focus of present study is the comparison of various drought indices and to evaluate the applicability and performance of drought indices in India by evaluating the performance of 15 drought indices. The indices include Standardized Precipitation Index (SPI), Percentage of Normal (PNI), Deciles Index, (DI), China Z Index (CZI), Modified China Z Index (MCZI), Rainfall Anomaly Index (RAI), Z score index. This would also be helpful to hydro meteorological services for monitoring and early warning of drought, the water resource management and future climate change adaptation in the region..

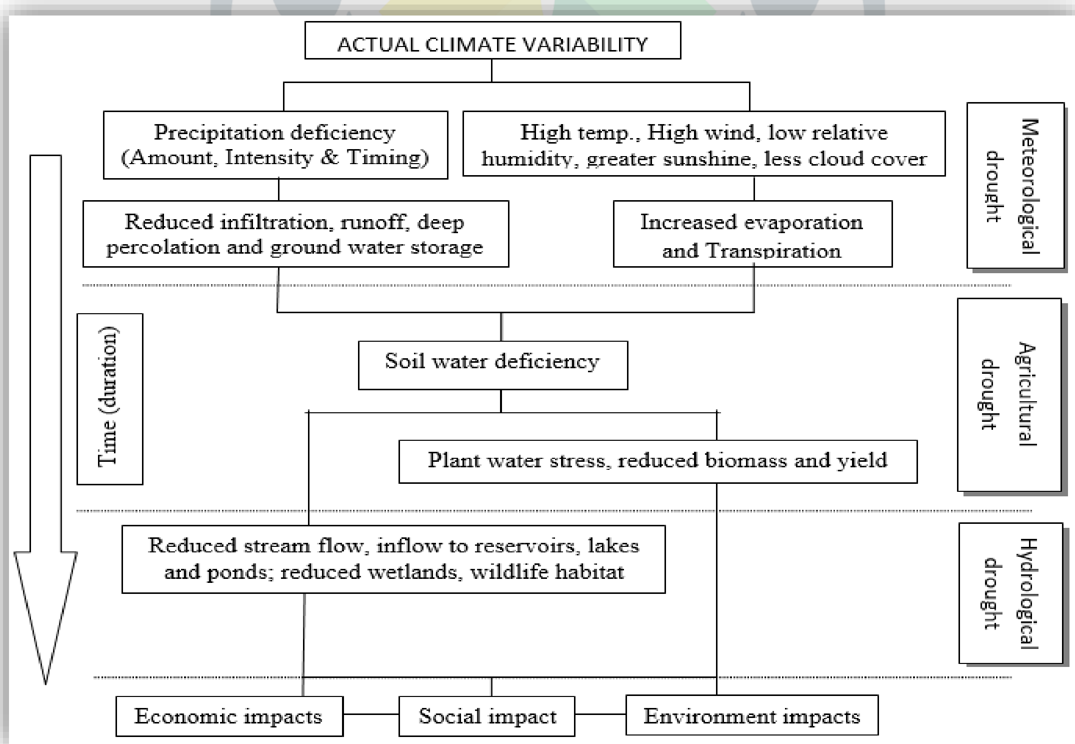

Figure 1: Relationship between various types of drought and duration of drought events. (Source: Wilhite D A. 2000)

Meteorological drought is defined as a lack of precipitation over reasons for a period of time. Precipitation has been commonly used for meteorological drought analysis (Chang. 1991). Considering drought as a precipitation deficit with respect to average values (Gibbs. 1975). Several studies have analyzed drought using monthly precipitation data. Hydrological drought is related to a period with inadequate surface and subsurface water resources for established water uses for a given water resources management system. Streamflow data have been widely applied for hydrologic drought analysis (Dracup et al. 1980; Frick et al. 1990; Mohan and Rangacharya. 1991; Clausen and Pearson. 1995). From regression analyses relating drought in streamflow catchment properties, it is found that geology is one of the main factors influencing hydrological droughts (Zecharias and Brutsaert. 1988; Vogel and Kroll. 1992).

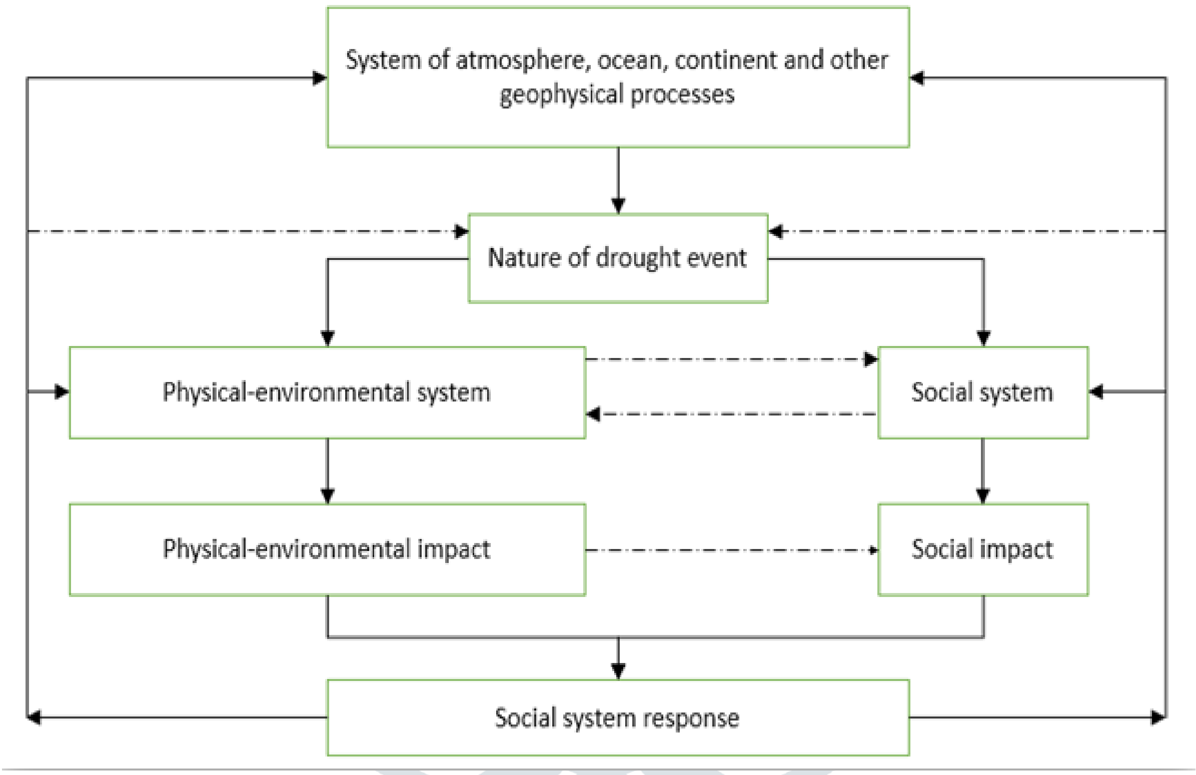

Figure 2: Drought viewed in a systems context (Source: Yevjevich et al. 1978)

With increasing standard of living of people in the world, our dependency on water is too much due to urbanization and industrialization the stress on the water body is increasing, due to it our ground water level is decreasing, the water in the river and lake become dry. Industrialization also affects the quality of water increasing demand of water and increasing population intensifies the threat on our water body.

2. METHODOLOGY

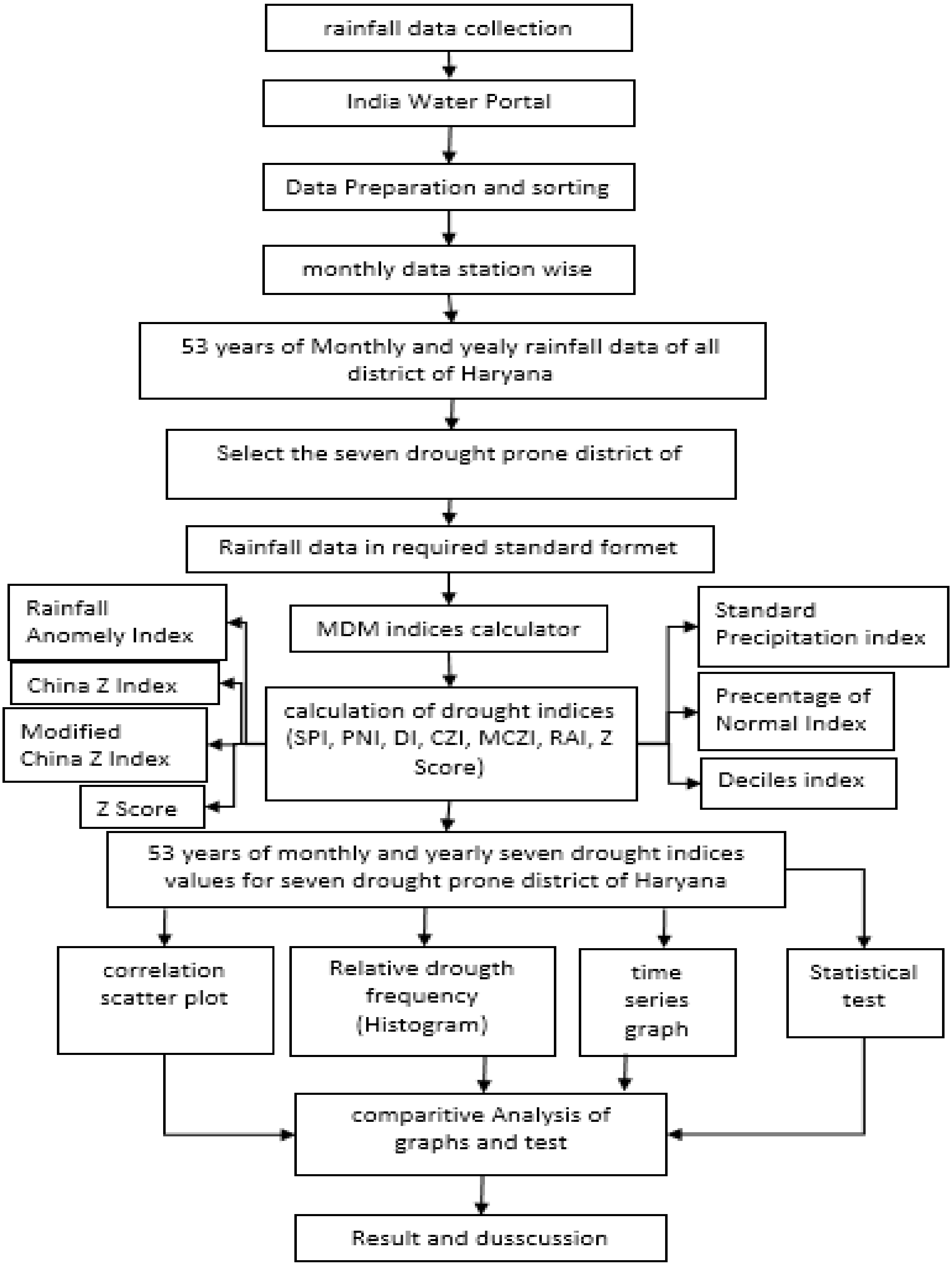

Figure 3: Flowchart of Methodology for comparing the performance of drought indices

2.1 Calculation of drought indices

2.1.1 Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) for any location is calculated, based on the long-term precipitation record for the desired period. The available long-term rainfall data is fitted to gamma probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and the desired period is zero (Mckee et al., 1993). This transformed probability is the SPI value, which varies between 2.0 and 2.0, with extreme Southside this range occurring at 5% of the time (Edwards and Mckee, 1997). The SPI is perhaps the most popularly used drought index. Developed SPI to identify and (Mckee et al., 1993) monitor drought events using monthly rainfall data. Continuous long-term data of at least 30 years is required to compute SPI; it does not allow missing data. The complete procedure for estimation of SPI is available in Edwards and Mckee (1997).

Table 1: Drought classification according to Standard Precipitation Index

S. no.	SPI Values	Category	Probability of Occurrence
1	2.00 and above	Extremely wet	2.3
2	1.50 to 1.99	Very wet	0.4
3	1.00 to 1.49	Moderately wet	9.2
4	-0.99 to 0.99	Near normal	68.2
5	-1.00 to -1.49	Moderately dry	9.2
6	-1.50 to -1.99	Severely dry	4.4
7	-2.00 and less	Extremely dry	2.3

2.1.2 China Z-Index (CZI)

China Z-Index (CZI) is extensively used by National Climate Centre (NCC) of China to monitor drought conditions throughout the country (Wu et al., 2001; Dogan et al., 2012). CZI assumes that precipitation data follow the Pearson Type III distribution and is related to Wilson–Hilferty cube-root transformation (Wilson and Hilferty, 1931) from chi-square variable to the Z-scale (Kendall and Stuart, 1977). The value of CZI is calculated as

$$\mathbf{CZI} = \frac{\mathbf{6}}{\mathbf{C_{st}}}\left(\frac{\mathbf{C_{st}}}{\mathbf{2}}\mathbf{Zscore} + \mathbf{1}\right)^{\frac{1}{3}} - \frac{\mathbf{6}}{\mathbf{C_{st}}} + \frac{\mathbf{C_{st}}}{\mathbf{6}}$$

where, C_{st} is coefficient of skewness for ‘t’ time step. Many studies comparing the CZI with that of SPI and Z-score reported similar results (Morid et al., 2006). Further, Wu et al., 2001 suggested that because of simplicity in calculating drought severity at monthly time step using CZI, it can be preferred over SPI, where rainfall data are often incomplete.

Table 2: Drought classification by China Z index

S. no.	CZI Values	Category
1	2.00 and above	Extremely wet
2	1.50 to 1.99	Very wet
3	1.00 to 1.49	Moderately wet
4	-0.99 to 0.99	Near normal
5	-1.00 to -1.49	Moderately dry
6	-1.50 to -1.99	Severely dry
7	-2.00 and less	Extremely dry

2.1.3 Modified CZI (MCZI)

To calculate MCZI, Wu et al., 2001 used a median of precipitation instead of mean precipitation. This attempt minimized the difference between MCZI and SPI. Classification of modified China Z index is similar to China Z index as shown in table 4.

2.1.4 Statistical Z-Score (Z-Score)

This index is also as simple as RD and calculated by subtracting the long-term mean from an individual rainfall value and then dividing the difference by the standard deviation. The Z-Score does not require adjusting the data by fitting the data to the Gamma or Pearson Type III distributions. Because of this, it is speculated that Z-Score might not represent the shorter time scales (Edwards and Mckee, 1997). Because of its simple calculation and effectiveness, Z-Score has been used in many drought studies (Komuscu, 1999; Morid et al., 2006; Tsakiris and Vangelis, 2004; Wu et al., 2001; Dogan et al., 2012). Various researchers also acclaimed that it is as good as SPI and can be calculated on multiple time steps. It can also accommodate missing values in the data series like CZI. The drought classification of Z score index is same as SPI, CZI, and MCZI as shown in table 4.

2.1.5 The decile index (DI)

The decile index is widely used in Australia to monitor drought. Long-term monthly precipitation data is ranked in descending order to make cumulative frequency distribution (Gibbs and Maher 1967). The distribution depicts decile index. The first decile precipitation amount should not exceed by the lowest 10% of the total. The second decile is the amount between 10 and 20% of the total and so on. The severity of the drought can be assessed by comparing the amount of precipitation in a month or over a period of several months with the cumulative distribution precipitation falls is termed to be much below normal (decile 1 and 2). Decile 3 and 4 (20–40%) shows below normal, decile 5 and 6 (40–60%) indicate near normal and so on.

Table 3: Drought classification by Deciles index

S. No.	Desiles	Classes	Weather condition
1	1-2	<20%	Extreme drought
2	3-4	20%-40%	Moderate drought
3	5-6	40%-60%	Normal
4	7-8	60%-80%	Moderate wet
5	9-10	80%-100%	Extreme wet

2.1.6 Percent of normal index (PNI)

The percent of normal precipitation is one of the simplest measurements of rainfall for a location. Analyses using the percent of normal are very effective when used for a single region or a single season. Percent of normal is also easily misunderstood and gives different indications of conditions, depending on the location and season. It is calculated by dividing actual precipitation by normal precipitation typically considered to be a 30-year mean—and multiplying by 100%. This can be calculated for a variety of timescales. Usually, these time scales range from a single month to a group of months representing a particular season, to an annual or water year. Normal precipitation for a specific location is considered to be 100%. Morid et al., 2006 and Masoudi and Hakimi, (2014) used the following equation to monitor drought in the region.

$$PNI = \frac{P_i}{P} \times 100$$

Where, P_i = Total precipitation of each year

P = Average climatology for a period from 1951 to2014.

2.1.7 Rainfall Anomaly Index (RAI)

From the precipitation data, the Annual Rainfall Anomaly Index (RAI) was calculated to analyze the frequency and intensity of the dry and rainy years in the studied area. In addition, the monthly RAI was calculated for specific years of the historical series aiming to analyze the distribution of rainfall in the years of a greatest anomaly. RAI, developed and firstly used by Rooy (1965) and adapted by Freitas (2005), constitutes the following equations:

$$\mathrm{RAI} = 3\left[\frac{\mathrm{N} - \overline{\mathrm{N}}}{\overline{\mathrm{M}} - \overline{\mathrm{N}}}\right], \text{for positive anomalies}$$

$$\mathrm{RAI} = -3\left[\frac{\mathrm{N} - \overline{\mathrm{N}}}{\overline{\mathrm{X}} - \overline{\mathrm{N}}}\right], \text{for negative anomalies}$$

Where:

N = current monthly/yearly rainfall, in order words, of the month/year when RAI will be generated (mm)

$\bar{N}$ = monthly/yearly average rainfall of the historical series (mm);

$\bar{M}$= average of the ten highest monthly/yearly precipitations of the historical series (mm);

$\bar{X}$= average of the ten lowest monthly/ yearly precipitations of the historical series (mm); and positive anomalies have their values above average and negative anomalies have their values below average.

2.2 Pearson correlation coefficients

The Pearson Product Moment Correlation Coefficient, commonly termed as correlation coefficient (r), is a measure of colinearity between two arrays and most widely used test statistics. Correlation Coefficient is computed for the entire period of record creating a cross-correlation matrix. It is calculated using Eq.

$$r = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{x_i - \bar{x}}{S_x}\right)\left(\frac{y_i - \bar{y}}{S_y}\right)$$

Where, $\boldsymbol{x_i}$ and $\boldsymbol{y_i}$ represent the values of arrays with 'n' number of elements being compared and *x* and *y* are the mean values of two arrays and $\boldsymbol{S_x}$ and $\boldsymbol{S_y}$ are the standard deviation of $\boldsymbol{x_i}$ and $\boldsymbol{y_i}$ respectively. The r measures the degree of similarity in variation about the means of two values.

2.3 Time series Graphs

Time series analysis is the collection of data at specific intervals over a period of time, with the purpose of identifying trends, cycles, and seasonal variances to aid in the forecasting of a future event. We can know the increasing and decreasing trends of drought indices.

2.4 Relative drought frequency

Indices are compared with their drought severity level. Some indices are showing the higher value of severity level and some showing its lower value but shows a higher value for the moderate and normal level of drought. In this analysis, we are trying to show relative drought frequency of different drought class with using the histogram.

2.5 Statistical tests

Seven indices performance is assessed with SPI by using statistical criterion, for example, STDEV, SEM, MBE, MAE, SEE, CRM, RMSE, CA, EF, RE%, R, r, D, and confidence level (C) (Willmott 1982; Willmott and Wicks 1980). The STDEV measures the variability within the data, whereas SEM estimates the variability among different data. The SEE measures the accuracy, whereas MBE provides the difference between the mean of predicted and observed variable. Furthermore, MAE is less sensitive to extreme values than RMSE; therefore, it is preferred for small or limited datasets. The lower values of MAE, RMSE, MBE, SEE, and SEM shows high efficiency and vice versa (Tanny et al. 2008). The positive and negative values describe over and underestimation respectively (Wackernagel 2003). CA represents the coefficient of adjustment. EF closer to 1 represents model is more efficient and suitable, whereas a negative value shows uncertainty and inconsistency in the result (Kouchakzadeh and Nikhbakht 2004).

The confidence index (C) may be calculated by the product of the model lineal correlation coefficient (R) by concordance (D). The values of concordance and confidence index vary from 0 to 1, where 1 indicates a complete agreement between the observed and predicted indices and 0 indicates complete disagreement.

These various test with name and there formula shown in table 3. These formula will be used for analysis because every test having some significance.

Table 3: Various statistical test and its formula which is used for analysis

S. No.	Test	Formula
1	Standard deviation (STDEV)	$St_{obn} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n-1}}$
2	Root mean square error (RMSE)	$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i)^2}{n}}$
3	Mean bias error (MBE)	$\mathrm{MBE} = \frac{\sum_{i=1}^{n}(y_i - x_i)}{n}$
4	Mean absolute error (MAE)	$\mathrm{MAE} = \frac{\sum_{i=1}^{n}\lvert y_i - x_i\rvert}{n}$
5	Standard error of estimate (SEE)	$\mathrm{SEE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n-2}}$
6	Standard error of mean (SEM)	$\mathrm{SEM} = \frac{St_{dev}}{\sqrt{n}}$
7	Relative error (%) (RE)	$\mathrm{RE}(\%) = \frac{\mathrm{MBE}}{\bar{x}} \times 100$
8	Coefficient of adjustment (CA)	$\mathrm{CA} = \frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{\sum_{i=1}^{n}(y_i - \bar{X})^2}$
9	Ratio ($\check{r}$)	$\check{r} = \frac{y_{avg}}{x_{avg}}$

10	Concordance index (D)	$D = 1 - \frac{\sum_{i=1}^{n}(y_i - x_i)^2}{\sum_{i=1}^{n}[\lvert y_i - \bar{X}\rvert + \lvert x_i - \bar{X}\rvert]^2}$
11	Correlation coefficient (r)	$r = \frac{\sum_{i=1}^{n}(x_i - \bar{X})(y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(y_i - \bar{Y})^2 \sum_{i=1}^{n}(x_i - \bar{X})^2}}$
12	Efficiency (EF)	$EF = \frac{\sum_{i=1}^{n}(x_i - \bar{X})^2 - \sum_{i=1}^{n}(y_i - \bar{Y})^2}{\sum_{i=1}^{n}(x_i - \bar{X})^2}$

3. RESULT AND DISCUSSION

3.1 Coefficients of determination (Pearson):

Correlation coefficient (r) and coefficient of determination (R^2) are the effective test to measure the potential of model to anticipate the events. It is highly admissible by geographers as the most reliable measure to test the model's ability to estimate events (McCuen and Snyder 1975). The values near to 1 indicate good relationship.

Table 4: Coefficients of determination (Pearson) between all drought indices for Ajmer district.

Variables	SPI	PNI	DI	MCZI	CZI	RAI	Z SCORE
SPI	1	0.737	0.916	0.936	0.972	0.917	0.893
PNI	0.737	1	0.700	0.685	0.794	0.860	0.874
DI	0.916	0.700	1	0.855	0.924	0.886	0.826
MCZI	0.936	0.685	0.855	1	0.944	0.848	0.875
CZI	0.972	0.794	0.924	0.944	1	0.963	0.950
RAI	0.917	0.860	0.886	0.848	0.963	1	0.972
Z SCORE	0.893	0.874	0.826	0.875	0.950	0.972	1

Table 5: Coefficients of determination (Pearson) between all drought indices for Barmer district.

Variables	spi	pni	Czi	mczi	rai	di	Z SCORE
SPI	1	0.704	0.934	0.850	0.864	0.887	0.835
PNI	0.704	1	0.804	0.638	0.879	0.687	0.898
CZI	0.934	0.804	1	0.902	0.950	0.901	0.947
MCZI	0.850	0.638	0.902	1	0.756	0.767	0.824
RAI	0.864	0.879	0.950	0.756	1	0.870	0.959
DI	0.887	0.687	0.901	0.767	0.870	1	0.788
Z Score	0.835	0.898	0.947	0.824	0.959	0.788	1

Table 6: Coefficients of determination (Pearson) between all drought indices for Bikaner district.

Variables	spi	pni	Di	czi	mczi	rai	zscore
SPI	**1**	0.152	0.334	0.325	0.282	0.292	0.267
PNI	0.152	**1**	0.649	0.770	0.560	0.849	0.869
DI	0.334	0.649	**1**	0.883	0.702	0.861	0.784
CZI	0.325	0.770	0.883	**1**	0.838	0.939	0.956
MCZI	0.282	0.560	0.702	0.838	**1**	0.678	0.768
RAI	0.292	0.849	0.861	0.939	0.678	**1**	0.950
Z SCORE	0.267	0.869	0.784	0.956	0.768	0.950	**1**

Table 7: Coefficients of determination (Pearson) between all drought indices for Jalore district.

Variables	spi	pni	Czi	mczi	rai	di	z score
spi	**1**	0.730	0.947	0.889	0.887	0.883	0.867
pni	0.730	**1**	0.798	0.647	0.882	0.695	0.896
czi	0.947	0.798	**1**	0.920	0.948	0.909	0.938
mczi	0.889	0.647	0.920	**1**	0.781	0.789	0.834
rai	0.887	0.882	0.948	0.781	**1**	0.875	0.962
di	0.883	0.695	0.909	0.789	0.875	**1**	0.795
z score	0.867	0.896	0.938	0.834	0.962	0.795	**1**

Table 8: Coefficients of determination (Pearson) between all drought indices for Jaisalamer district.

Variables	spi	pni	Czi	mczi	rai	di	z score
spi	**1**	0.604	0.898	0.857	0.814	0.876	0.777
pni	0.604	**1**	0.788	0.664	0.866	0.683	0.881
czi	0.898	0.788	**1**	0.935	0.948	0.908	0.950
mczi	0.857	0.664	0.935	**1**	0.813	0.822	0.868
rai	0.814	0.866	0.948	0.813	**1**	0.876	0.959
di	0.876	0.683	0.908	0.822	0.876	**1**	0.804
z score	0.777	0.881	0.950	0.868	0.959	0.804	**1**

Table 9: Coefficients of determination (Pearson) between all drought indices for Nagaur district.

Variables	spi	pni	Czi	mczi	rai	di	zscore
spi	**1**	0.729	0.957	0.890	0.886	0.862	0.880
pni	0.729	**1**	0.791	0.646	0.864	0.672	0.886
czi	0.957	0.791	**1**	0.922	0.945	0.884	0.952
mczi	0.890	0.646	0.922	**1**	0.774	0.769	0.847
rai	0.886	0.864	0.945	0.774	**1**	0.867	0.954
di	0.862	0.672	0.884	0.769	0.867	**1**	0.780
zscore	0.880	0.886	0.952	0.847	0.954	0.780	**1**

Table 10: Coefficients of determination (Pearson) between all drought indices for Churu district.

4. CONCLUSION

Despite different underlying statistical distributions, the SPI, CZI and Z-Score have performed in a similar manner. This similarity may point to the importance of utilizing long-term precipitation records for drought analyses (which can remove marginal differences between the indices). Given the similarity in the performance of several indices, the choice of an index may partially be based on such criteria as input information requirements, simplicity of calculations and current level of acceptance in operational practice in the world. the PNI should not be recommended for drought monitoring in the drought prone district of Rajasthan since they have been found to declare 'extreme drought' conditions unreasonably frequently (about three to four times more often than 'normal'). The DI appeared to be very sensitive, which leads to unrealistically high temporal and spatial variations in wet conditions and the variations being more pronounced during summer. It is possible that the DI sensitivity could be reduced if it is used with temporal scales larger than 1 month. It is important to note that Z score index is most efficient indices among seven. RAI is least efficient and its relative error is also high. CZI and MCZI show almost similar result as there correlation coefficient, efficiency relative drought frequency and statistical tests. Overall, Z score index is most suitable indices and CZI and MCZI also showing good result so Z score index can be used instead of SPI in drought prone district of Rajasthan.

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