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Assessment of Drought in Andhra Pradesh using Different Meteorological Drought Indices

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ABSTRACT

Background: Climate change contributes to increased frequency of extreme weather events, such as drought. Drought is the common natural disaster in every region of the world. Drought is an aberrant climatic situation that has various impacts on communities. Governments of various states are spending millions of rupees in response to droughts. Proactive measures aimed at preventing or mitigating the effects of drought are more cost-effective. Assessment and monitoring are important in managing the drought risk in arid and semi-arid regions. Drought indices helps to quantify the severity of droughts.

Methods: Standardized precipitation index (SPI), per cent normal (PN), deciles index (DI), China Z-index (CZI), Z-score index (ZSI) were used in the present study to assess the drought severity.

Result: Results showed that the lowest value of SPI (-2.85) was found in the year 2018 which falls under extreme drought in Chittoor district, followed by Nellore - (2.85) and Anantapur (-2.46) in the year 2002. Extreme wet condition was found in Vishakapatnam district (3) followed by Prakasam (2.65) and Srikakulam (2.44) in the years 1990, 2007 and 1995. For deciles index, almost all the districts fall under drought conditions in the year 2002, 2009 and 2018. Deciles index showed more frequency in extreme drought condition for all the districts compare to SPI and PN. The correlation coefficient between SPI and CZI was lowest in West Godavari district with 0.82.

Key words: Climate change, Drought assessment, Drought indices, Meteorological drought.

INTRODUCTION

Climate change is a natural phenomenon, but the increase in greenhouse gases due to human activities, which alters the climatic system, have become triggers for more rapid changes and influences the occurrence of extreme climatic events (Babatunde *et al*., 2017). Climate change contributes to increased frequency of extreme weather events, such as drought. Drought is the common natural disaster in every region of the world. Drought is an aberrant climatic situation that has various impacts on communities by limiting water availability and has significant economic, social and environmental implications. To a meteorologist, drought is the absence of rain, while to the agriculturist it is the deficiency of soil moisture in the crop root zone to support crop growth and productivity (Gautam and Bana, 2014). Weather parameters like Rainfall, temperature, evaporation, transpiration, humidity and the subsurface water have influence on drought (Khosravi *et al*., 2017). It results from the atmospheric circulation patterns that fails produce enough precipitation and most prevalent in semi-arid areas (Mckay *et al*., 1989).

The state Governments of various states are spending millions of rupees in response to droughts. Proactive measures aimed at preventing or mitigating the effects of drought, on the other hand, are far more cost-effective than reactive measures aimed at recovery and rehabilitation. Key aspect in planning for drought is vulnerability assessment based on severity estimation and spatial distribution of meteorological droughts. Assessment and monitoring are important in managing the drought risk in arid and semi-arid regions to assure sustainable natural resource and agricultural management. Various drought indices have been established in the recent past to quantify the severity of droughts (Sridhara *et al*., 2021). The choice of a suitable drought characteristic for particular drought research depends on the hydro-climatology in the selected region, the type of drought regarded, the vulnerability of nature in that region, the purpose of the research study and the accessible information for the drought evaluation (Fleig *et al*., 2006). Standardized precipitation index (SPI), Per cent normal (PN), deciles index (DI), China Z-index (CZI), Z-score index (ZSI) were selected for the present study to characterize the drought.

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MATERIALS AND METHODS

The monitoring of drought was done for all districts of Andhra Pradesh, which is situated at 15.91°N latitude, 79.7°E Longitude. In Andhra Pradesh, the districts fall under drought category are Anantapur, Chittoor, Kadapa, Kurnool, Nellore and Prakasam. Summers in Andhra Pradesh are hot. On the hottest days, temperatures can reach 45°C, with daytime temperatures averaging 40°C. The temperature drops in the evening, but it remains around 28°C around with 960 mm of average rainfall over Andhra Pradesh. Daily rainfall data for Andhra Pradesh from 1980 to 2020 were collected from IMD. In the present study, for estimating the drought five meteorological indices *i.e.,* SPI, PN, DI, CZI, Z-ZSI were calculated on annual and monthly basis using MDM software. The methodology of drought indices is explained follows.

SPI was calculated using the following formula and classified scale as proposed by Mckee *et al*. (1993). The SPI is calculated mathematically based on the cumulative probability of a given rainfall event occurring at a station. The station's historic rainfall data is fitted to a gamma distribution, which has been found to fit the precipitation distribution quite well. SPI requires 30 years or more of continuous monthly precipitation data to calculate. The gamma distribution is normally defined as:

$$g(x) = \frac{x^{\alpha-1} - e^{\frac{-x}{\beta}}}{\beta^{\alpha} - \Gamma(\alpha)} \quad \text{for } x > 0$$

Where,
α>0 = Shape parameter,
β>0 = Scale parameter,
X = Precipitation amount.
$\Gamma(\alpha)$ = Gamma function.

According to SPI values, the drought was classifying, If SPI is (>+2.0) it is Extremely wet, if values are between (1.5 to 1.99) it is considered as very wet, the values between (1.0 to 1.49) considered as Moderately wet, (-1.0 to -1.49) Near Normal vii) (-2.0) Extremely Dry vi) (-1.5 to -1.99) Moderately Dry vi) (-1.5 to -1.99) Severely Dry.

One of the most basic drought monitoring tools is per cent of normal, which expresses actual rainfall as a percentage of normal rainfall. This index was calculated for both annual and monthly basis (Willeke *et al*., 1994).

$$PN = \frac{P_i}{p} \times 100$$

Where,
P_i =Monthly precipitation (mm) in time increment 'i'.
$\bar{P}$ = Normal precipitation (mm).

The PN values have been classified as wet (PN>100%), if PN is between 80-100% as normal condition, if PN ranged between 70-80%, considered as weak drought, where moderate drought varied with 55-70%, if values varied between 40-55% it is considered as severe drought and Extreme drought would considered with <40%.

The decile index (DI) is defined as a ranking of precipitation in a specific time interval over the entire historic period (Gibbs and Maher, 1967). If long-term climatic data is available, the deciles index provides an accurate statistical measurement of precipitation. Monthly historical precipitation data is specifically sorted from lowest to highest and divided into ten equal categories or deciles. In order to calculate Deciles, the long-term monthly rainfall records were first ranked from highest to lowest in order to create a cumulative frequency distribution. The Decile threshold ranges used to define drought conditions are as follows: If decile values ranged at 1-2 it is considered as Significantly below normal, if decile was 3-4 it is below normal, 5-6 decile wasconsidered as near normal, if decile ranged 7-8 it was above normal,where decile as 8-9 it was considered as extremely high.

The China-Z Index (CZI) is a drought index developed by the National Meteorological Centre of China (Ju *et al*. 1997). For calculating CZI following formula were used,

$$CZI_{ij} = \frac{6}{C_{si}} \times \left(\frac{C}{2} \times \varphi_{tj} + 1\right)^{1/3} - \frac{6}{C_{si}} + \frac{C_{si}}{6}$$

Where,
'i' = Time scale of interest.
'j' = Current month.
Czi = CZI amount in the jth month for the ith period.
C_{si} - Coefficient of skewness.
φ_{tj} = Standardized variation.

Wu *et al*. (2001) proposed the Modified China Z-Index (MCZI) to reduce variation in the data set, in which mean precipitation was replaced by median precipitation in the CZI equation. The classification of CZI were similar to SPI index.

The Z-Score index (CZI) calculation formula is shown below;

$$ZSI = \frac{P_i - \bar{P}}{SD} \times 100$$

Where,
p_i = Mean monthly precipitation (mm);
$\bar{p}$ = Precipitation in a specific month (mm)
SD-standard deviation of any time scale.

ZSI was used following classifications for drought: if the ZSI values were >0.25 it is considered as no drought, the values between 0.25 to-0.25 it is weak drought, values ranged between -0.25 to-0.52 considered as slight drought, while moderate drought falls under -0.52 to -0.84, ZSI values ranged between -0.84 to -1.25 denoted with severe drought and extreme drought fall under <-1.25.

RESULTS AND DISCUSSION

Drought monitoring through meteorological indices

The current study analysis is focused on understanding the drought with meteorological indices to actual rainfall, as well as the behavior of SPI, PN and DI in drought and normal years. The indices were used in this study to identify the occurrence of meteorological drought, its frequency and its spatiotemporal extent and the SPI indices was made to compare the results with PN, ZI, CZI and ZSI indices. The drought analyzed over 40 years by using SPI, PN and DI indices and drought years over the past data were presented in the Table 1. The SPI and DI indices showed more drought

Table 1: Drought years based on various meteorological indices.

District	All three indices (SPI, DI and PN)	Two indices (SPI and PN)	Two Indices (SPI and DI)	One index (SPI)
Anantapur	1980, 2002, 1986, 1999, 2000, 2014, 2009, 2018	1980, 2002	1980, 2002, 1986, 1999, 2000, 2014, 2009, 2018	1980, 2002
Chittoor	1992, 2002, 2018, 1982, 1986, 1994, 1999, 2016, 2006, 2014, 2018	1992, 2002, 2018	1992, 2002, 2018, 1982, 1986, 1994, 1999, 2016, 2006, 2014, 2018	1992, 2002, 2018
E. Godavari	1986, 1987, 2002, 1985, 1993, 2001, 2009, 2014, 2015, 1984	1986, 1987, 2002, 1984	1986, 1987, 2002, 1985, 1993, 2001, 2009, 2014, 2015, 1984	1986, 1987, 2002
Guntur	1984, 1986, 1992, 1999, 2009, 2002, 2011, 2018	1984, 1986	1984, 1986, 1992, 1999, 2009, 2002, 2011, 2018	1984, 1986
Kadapa	1984, 2016, 1988, 2018, 1982, 1985, 1986, 1989, 1999, 2014, 2016	1984, 2016, 1988, 2018, 1982	1984, 2016, 1988, 2018, 1982, 1985, 1986, 1989, 1999, 2014, 2016	1984, 2016, 1988, 2018, 1982
Krishna	2009, 2002, 1985, 1995, 2016, 1980, 1982, 1992, 1993, 2014	2009, 2002	2009, 2002, 1985, 1995, 2016, 1980, 1982, 1992, 1993, 2014	2009, 2002
Kurnool	1980, 1983, 1984, 1985, 1995, 2016, 1994, 2002,	1980, 1983, 1984,	2003, 2018, 1980, 1983, 1984, 1985, 1995, 2016, 1994, 2002, 2003, 2018	1980, 1983, 1984
Nellore	2016, 2014, 2018, 1982, 1984, 1988, 1989, 2003, 2012, 1999	2016, 2014, 2018	2016, 2014, 2018, 1982, 1984, 1988, 1989, 2003, 2012, 1999	2016, 2014, 2018
Prakasam	1988, 2018, 1986, 1987, 2011, 1980, 1982, 1984, 1988	1988, 2018	1988, 2018, 1986, 1987, 2011, 1980, 1982, 1984, 1988	1988, 2018
Srikakulam	1984, 2002, 2009, 1983, 1994, 1997, 2000, 2020, 1996	1984, 2002, 2009	1984, 2002, 2009, 1983, 1994, 1997, 2000, 2020, 1996	1984, 2002, 2009
Vishakapatnam	1985, 2002, 2009, 1984, 1999, 2018 1980, 1993	2009	1985, 2002, 2009, 1984, 1999, 2018 1980, 1993	2009
Vizianagaram	2002, 1984, 1980, 1981, 1985, 1999, 2001, 2004, 2009, 1994, 2000	2002, 1984	2002, 1984, 1980, 1981, 1985, 1999, 2001, 2004, 2009, 1994, 2000	2002, 1984
W. Godavari	2002, 1999, 2014, 1984, 2011, 2018, 2019, 1993, 2009, 2014, 2001	2002, 1999, 2014, 2001	2002, 1999, 2014, 1984, 2011, 2018, 2019, 1993, 2009, 2014	2002, 1999, 2014

Table 2: Frequency of different meteorological indices during 1980-2020.

Districts	Moderate drought			Severe drought			Extreme drought		
	SPI	DI	PN	SPI	DI	PN	SPI	DI	PN
Anantapur	10	15	15	2	10	2	2	10	2
Chittoor	5	5	10	5	12	0	2	12	2
E. Godavari	5	10	10	7	15	5	2	10	0
Guntur	12	20	12	5	7	0	2	12	0
Kadapa	5	7	10	12	10	7	0	12	0
Krishna	12	0	5	2	15	2	2	17	0
Kurnool	17	7	17	7	7	7	0	17	0
Nellore	7	12	2	2	15	5	5	10	0
Prakasam	15	12	10	5	7	2	0	12	0
Srikakulam	2	12	7	7	12	0	0	10	0
Vishakapatnam	10	15	2	2	10	0	0	10	0
Vizianagaram	5	0	5	2	20	0	2	10	0
W. Godavari	10	12	10	2	10	7	5	12	0

years in almost all the districts. The SPI and PN indices showed similarity over the drought years. Results showed that the lowest value of SPI (-2.85) was found in the year 2018 which falls under extreme drought in Chittoor district, followed by Nellore (-2.85) and Anantapur (-2.46) in the year 2002. Extreme wet condition was found in Vishakapatnam district (3) followed by Prakasam (2.65) and Srikakulam (2.44) in the years 1990, 2007 and 1995. According to per cent normal index, it was closely related to SPI index, the extreme drought was found in the year 2002, 2018 over Anantapur and Chittoor districts. For deciles index, almost all the districts fall under drought conditions in the year 2002, 2009 and 2018. These three indices *i.e.*, SPI, PN and DI were more or less identical and results showed with these three indices that wet and drought years are nearly close in monitoring the drought. Similar findings at Salehnia *et al*. 2017 concluded that the three indices *i.e.*, SPI, PN and DI are agreed mostly with same drought years.

To quantify the drought with long term observations of rainfall data, the meteorological indices were used to compare the results with drought year (2018) and normal year (2020) by illustrating with spatial maps.

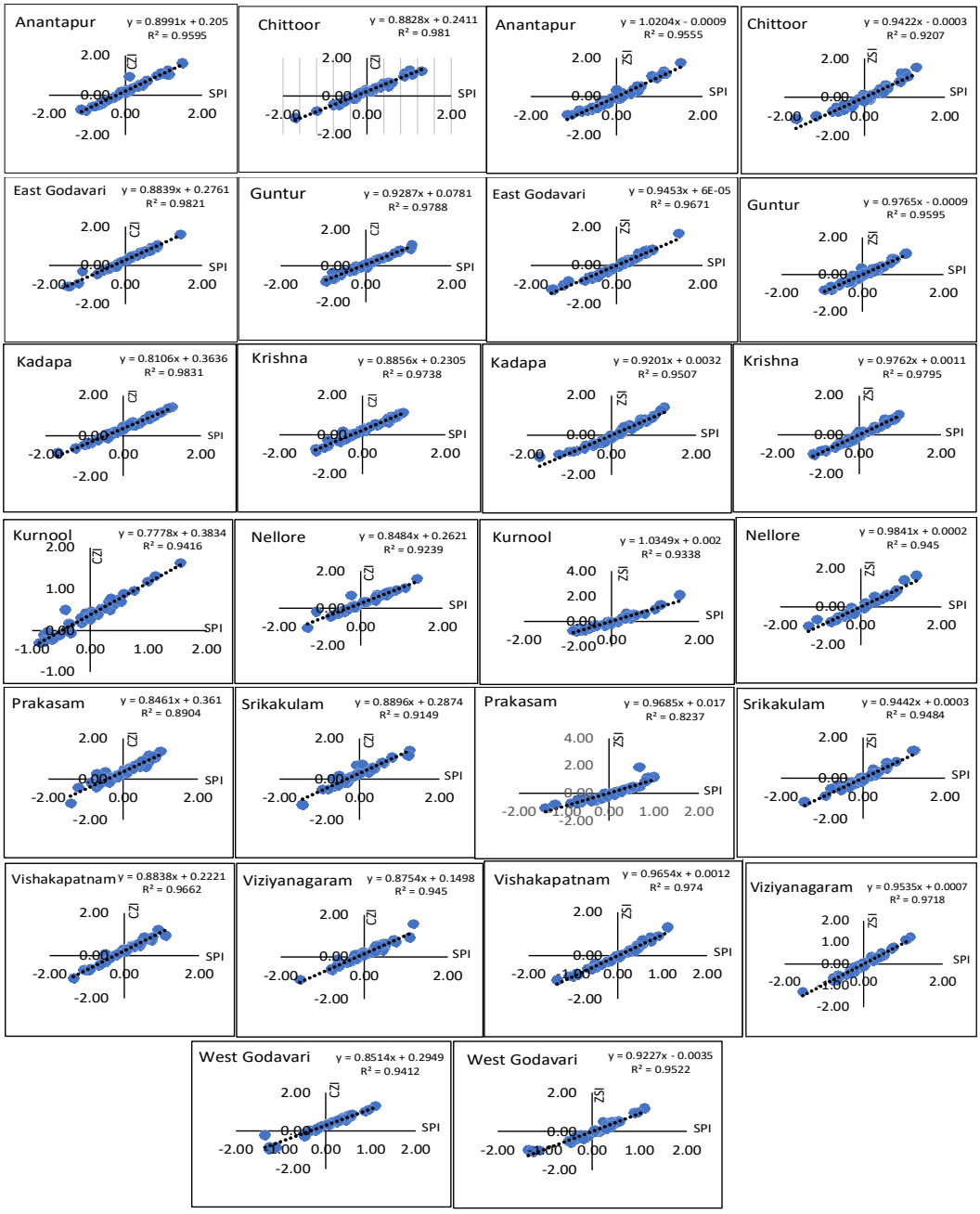

Fig 1: Scatter graph of SPI with CZI and ZSI for different districts of Andhra Pradesh from 1980-2020.

Table 3: Pearson's correlation coefficients of SPI with CZI and ZSI for 13 districts of Andhra Pradesh.

District	South West Monsoon		North East Monsoon	
	SPI with CZI	SPI with ZSI	SPI with CZI	SPI with ZSI
Anantapur	0.98	0.97	0.99	0.95
Chittoor	0.99	0.95	0.98	0.92
E. Godavari	0.99	0.98	0.97	0.93
Guntur	0.98	0.97	0.93	0.89
Kadapa	0.99	0.97	0.98	0.94
Krishna	0.98	0.98	0.97	0.92
Kurnool	0.97	0.96	0.97	0.94
Nellore	0.96	0.97	0.98	0.94
Prakasam	0.94	0.90	0.99	0.93
Srikakulam	0.95	0.97	0.89	0.93
Vishakapatnam	0.98	0.98	0.96	0.93
Vizianagaram	0.97	0.98	0.98	0.93
W. Godavari	0.97	0.97	0.82	0.90

Frequency of SPI, PN and DI indices

The frequency of drought for all the districts of study region were presented in the Table 2. From the table it was observed that the frequency of moderate drought found to be in more events than severe and extreme drought for all three indices. According to SPI and PN indices the findings were similar and frequency were also nearly close, while DI indices showed with more drought frequency for past 41 years. Mostly the Anantapur, Chittoor and Nellore districts were faced with extreme drought conditions analyzed with SPI and PN. Drought analyzed through deciles index were showed with more frequency in extreme drought condition for all the districts compare to SPI and PN. Similar results were found with Sridhara *et al*. (2021).

Comparison of SPI with CZI and ZSI indices

The SPI were calculated for the 13 districts of Andhra Pradesh from 1980-2020. The SPI were compared with CZI and ZSI indices by using the values of R^2 obtained for study area. From the Fig 1 it showed that the two indices showed good relationship with SPI in all the districts with R^2 ranged between 0.89 to 0.98 in CZI whereas, ZSI ranged between 0.82 to 0.97. The CZI had very close relationship with SPI that can be observed from the Fig 1. Pearson correlation coefficients among the indices with SPI index for south west and north east monsoons are presented in Table 3. The correlation coefficient between SPI and CZI was lowest in West Godavari district with 0.82, even though it was strong correlation between the indices. It has given the strong correlation among the indices for South west monsoon compared to north east monsoon. These findings were similar to Sridhara *et al*. (2021) and Salehnia *et al*. (2017).

CONCLUSION

From the present study, it can be concluded as among five meteorological indices the performance of SPI, CZI, ZSI and PN are similar compared to DI. Among the five indices DI showed more extreme dry events which may mislead intererpretation in drought monitoring. According to drought frequency in AP, moderate droughts are more frequent. The strong correlation of SPI with CZI and ZSI showed with better relationship for both south west and north east monsoon. According to this study SPI, PN, CZI and ZSI were found to be better indices for analyzing the meteorological drought in Andhra Pradesh using long term rainfall data.

Conflict of interest

This is to certify that authors have no conflict of interests with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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