

Evaluation of Meteorological Drought Impact Using Drought Indices



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Abstract Drought is said to occur when there is a lack of water or when there is less precipitation than usual. Drought is typically triggered by changes in environment and human activities; its severity can vary from place to place and this intensity will be measured using drought indices. This study used rainfall data from the last 100 years of five districts in Andhra Pradesh, namely, Kadapa, Prakasam, Krishna, East Godawari and Visakhapatnam, and drought severity is measured using indices such as the Standardized Precipitation Index (SPI), China Z Index (CZI) and Statistical Z-score (SZ Score). The SPI is known to be the world's standard drought measurement index, but the calculation of the SPI is very complex compared to other indices. Thus, by using all these three indices, drought is measured, and comparative analysis is done to find the best alternative for the five districts to find drought severity. The implementation of each index is compared in this analysis, and the findings indicate that CZI and SZ score can provide similar results in East Godawari and Visakhapatnam districts, whereas SZ score can provide similar results in Krishna, Prakasam and Kadapa districts, and shows slight deviation to the SPI for all time scales.

Keywords Precipitation · Drought · Standard Precipitation Index · China Z Index · Statistical Z-score

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1 Introduction

In a developing country like India, the majority of the population lives in rural areas, with agriculture as their primary source of income. Seasonal variations affect agricultural yield. But, now-a-days, seasonal changes do not occur properly, leading to shortages of water. This water shortage phenomenon is known as drought. Drought is a period of time in which an area experiences rainfall below its usual value. Drought is one of the most critical problems to be tackled. Droughts are known as meteorological droughts, hydrological droughts, agricultural droughts and socioeconomic droughts. Based on the rainfall data of an area, meteorological drought is assessed. Many drought indices are available for evaluating drought characteristics, including the Standard Precipitation Index (SPI), China Z Index (CZI), Statistical Z-score, Standard Precipitation Evaporation Index (SPEI) and Palmer Drought Severity Index (PDSI) [1].

The authors assessed dry and wet periods for Thanjavur city using Standard precipitation index (SPI), statistical Z-score and China Z index (CZI) and compared these indicators in different time scales; from this study, it is concluded that the results of CZI and Z-score are close to each other for annual and seasonal rainfall data and they are different from SPI in Thanjavur city [2]. The study explains each and every basic detail of drought like types of droughts, how to study drought, different types of drought indices, deciles [3, 4]. This study compared SPI, EDI, SZI, CZI, Reclamation Drought Index (RDI) and RDDI for their suitability in drought-prone districts of ken river basin. Multiple steps are applied to compute the severity for the five-time steps of 1,3,6,9 and 12 months and compared with each other. The process of calculation of drought index with all different indices is also explained [5–7]. The author has taken the monthly rainfall data (from June to October for 39 years) of two districts in Andhra Pradesh, namely, Ananthapur and Khammam as they were found to be low and high rainfall areas, respectively. They also found that SPI showed moderate dryness instead of extreme dryness and moderate wet instead of extreme wet, when the SPI values are compared with the actual rainfall of the two districts. They also concluded that SPI as a stand-alone indicator needs to be interpreted with caution to assess intensity of drought [8, 9]. The author states that calculation of SPI is not much easier when compared to other indices. In this paper, CZI and Z-score were used to assess drought impact along with SPI and final results were compared. The main aim of this paper is to find better alternative for SPI in their area for assessing drought.

2 Study Area

Andhra Pradesh is a state in India's south-east coastal region. Andhra Pradesh is made up of two principal regions: the southern region of Rayalaseema in the south-west, and the coastal region that is bordered on the east and north by the Bay of Bengal.

There are nine districts in Coastal Andhra and four in Rayalaseema that make up the entire state. The current study utilizes four districts from Coastal Andhra (Prakasam, Krishna, East Godavari and Visakhapatnam) plus one district from Rayalaseema (Kadapa) for its research.

The climate of Kadapa is semi-arid. It has a tradition of getting up to a temperature of over 46 degrees. Living in a hot and humid environment can be extremely unpleasant in the summer. Temperatures range from a minimum of 24 °C to a maximum of 43 °C during this period. It is not unusual for temperatures to exceed 43 degrees Celsius during heat waves. Daytime temperatures vary, with highs in the low to mid-thirties. 75% of the time, humidity is between 75 and 80% during the season. During the monsoon season, the region gets a great deal of rain. The city of Prakasam, with an average temperature of 24.5 degrees Celsius and an average rainfall of 975 mm by the monsoons arriving from the north-east and south-west, has an average temperature of 24.5 degrees Celsius. It is 44 °C hot. The dry winter months are normal (Fig. 1).

Because of its exceptionally hot summers and moderately hot winters, Krishna is known as tropical. The months of April to June have the hottest temperatures.

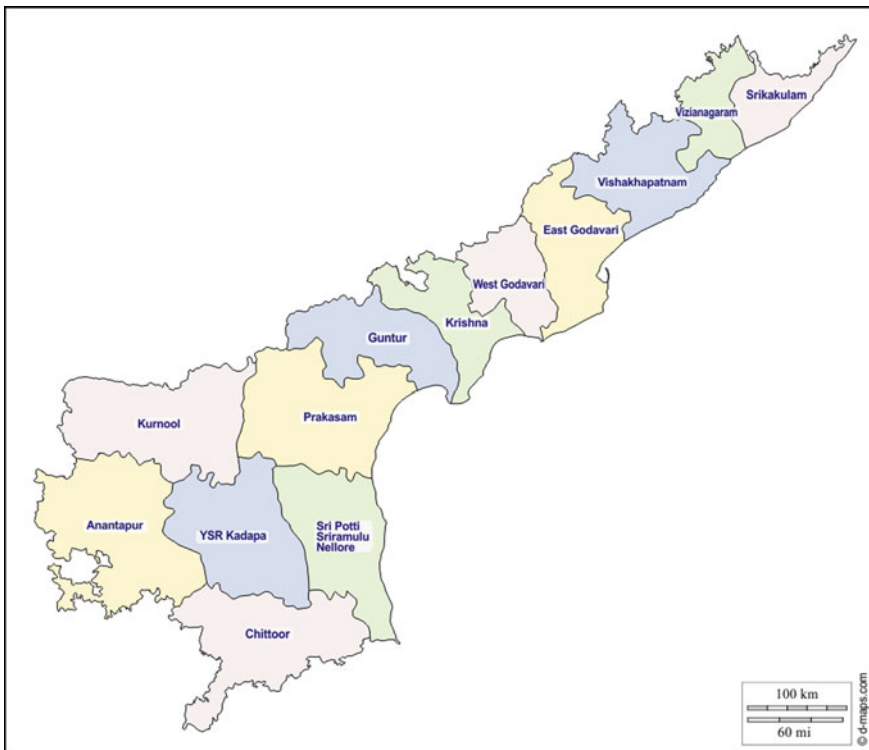


Fig. 1 Location of Study Area. Source <https://i.pinimg.com/originals/cf/6c/e7/cf6ce7c4f5221d22a4dbe956366b10f3.gif>

The south-west monsoon contributes to rainfall, with an annual rainfall of about 1030 mm in the country. East Godawari has a 144-km coastline. As it is situated in the coastal belt, the temperature remains humid for the majority of the year. Andhra Pradesh's green belt is situated in this district. It is covered with deciduous forests. Visakhapatnam has a tropical climate with both wet and dry seasons. The average mean temperature is between 24 and 30 degrees Celsius. The months of May and January have the highest and lowest temperatures, respectively. The highest and lowest temperatures ever recorded were 42 °C in 1978 and 20 °C in 1904. Rainfall comes from the south-west and north-east monsoons, with an annual rainfall of 1118.8 mm.

3 Methodology

Monthly Rainfall data of past 100 years, i.e. from year 1901 to year 2000 is collected from India water portal for all the five districts, i.e. Kadapa, Prakasam, Krishna, East Godawari and Visakapatnam. Drought intensity is measured by using indices like SPI, CZI and Z-score. The detailed procedure for calculation of each index is shown in Fig. 2.

3.1 Standard Precipitation Index (Spi)

The SPI is used as a standard measure for assessing dry and wet times. As a result, SPI is the most commonly used measure for estimating and characterizing meteorological drought around the world. It compares measured total precipitation amounts for an accumulation period of interest with the long-term historic rainfall record for that period to assess precipitation anomalies at a given location.

$$A = \ln \ln \left(\frac{x}{\alpha} \right) - \frac{\sum \ln \ln (x)}{n} \quad (1)$$

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right) \quad (2)$$

$$\beta = \frac{x}{\alpha} \quad (3)$$

$$g_x = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \quad (4)$$

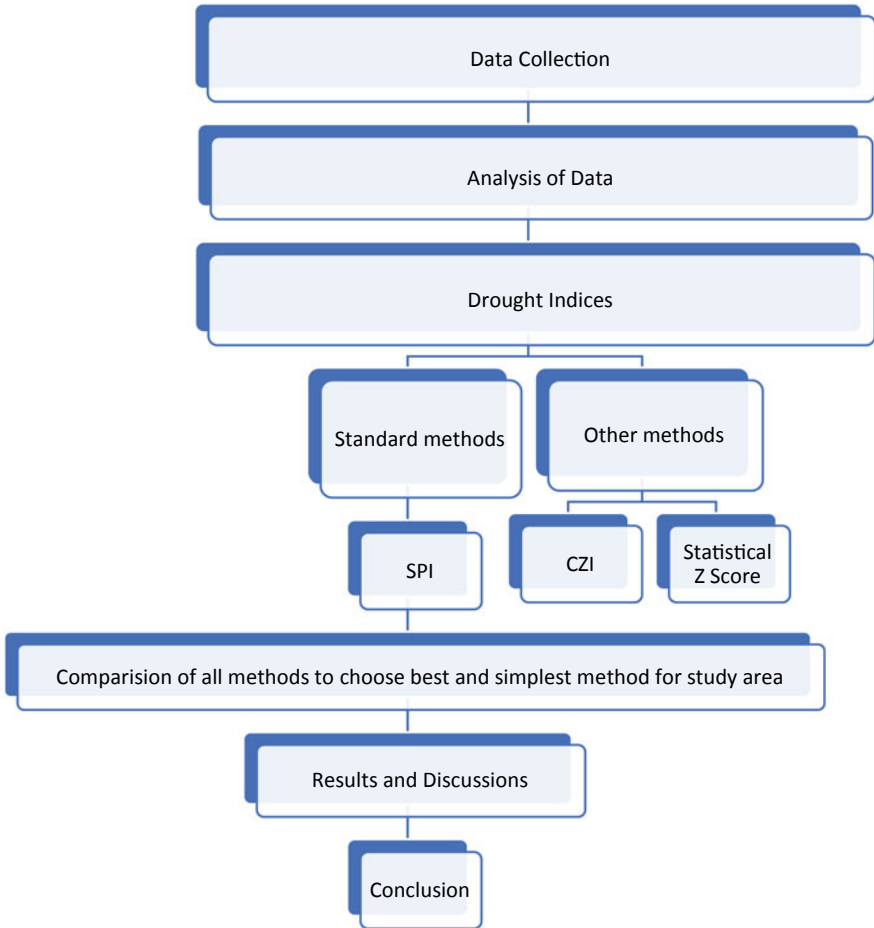


Fig. 2 Flow chart of methodology

$$G_x = \int_0^x g_x dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx \tag{5}$$

where \underline{x} = Mean precipitation.

n = Number of precipitation observations.

α (shape factor) parameter of the gamma probability density function.

β (scale factor) parameter of the gamma probability density function.

g_x = gamma probability distribution function.

G_x = cumulative probability distribution function.

3.2 Z-score

This index is determined by subtracting the long-term mean from a single rainfall value and then dividing the result by the standard deviation. The data does not need to be modified by fitting it to the Gamma or Pearson Form III distributions while using the Z-score. Z-score has been used in many drought studies due to its ease of measurement and effectiveness.

$$\varphi_{ij} = \frac{x_{ij} - \bar{x}_i}{\sigma_i} \tag{6}$$

$$\sigma_i = \sqrt{\frac{1}{n} \sum_{j=1}^n (x_{ij} - \bar{x}_i)^2} \tag{7}$$

$$\bar{x}_i = \frac{1}{n} \sum_{j=1}^n x_{ij} \tag{8}$$

where φ_{ij} = Z-score.
 x_{ij} = Precipitation of j^{th} month for period i .
 σ_i = Standard deviation.

3.3 China Z Index

The CZI is related to the Wilson-Hilferty cube-root transformation. Assuming that precipitation data obey the Pearson type-III distribution. After calculating values of each indices, moisture categories have to be assessed using Table 1.

$$Z_{ij} = \frac{6}{C_{si}} \left(\frac{C_{si}}{2} \varphi_{ij} + 1 \right)^{\frac{1}{3}} - \frac{6}{C_{si}} + \frac{C_{si}}{6} \tag{9}$$

Table 1 Ranges of SPI, China Z index and statistical Z-score for drought categorization

| Index | Moisture category |
|----------------|---------------------|
| > 2.0 | Extremely wet (EW) |
| 1.50 to 1.99 | Very wet (VW) |
| 1.00 to 1.49 | Moderately wet (MW) |
| -0.99 to 0.99 | Normal (N) |
| -1.49 to -1.00 | Moderately dry (MD) |
| -1.99 to -1.50 | Severely dry (SD) |
| <-2.0 | Extremely dry (ED) |

$$C_{si} = \frac{\sum_{j=1}^n (x_{ij} - \bar{x})^3}{n * \sigma_i^3} \tag{10}$$

where Z_{ij} – CZI.

φ_{ij} = z score.

X_{ij} = precipitation of j month for period i.

C_{si} =Coefficient of skewness.

σ_i =Standard deviation.

4 Results and Discussions

Using SPI, all five districts’ measured moisture categories were determined. In the Kadapa district, normal moisture levels have only occurred in 68 of the past 100 years. In 10 and 6 years, respectively, there are mild dry and wet periods. In the last 6 and 5 years, there have been exceptionally dry and rainy phases. In 1 and 4 years, respectively, extreme dry and wet cycles are observed. In the Prakasam district, normal moisture levels have only occurred in 68 of the past 100 years. In 9 and 9 years, respectively, mild dry and wet cycles are observed. In the last 5 years, there have been particularly dry and rainy periods. Extremely dry and rainy cycles occur every 2 years and every 2 years, respectively. In the Krishna district, normal moisture levels have only occurred in 63 of the past 100 years. In 5 and 10 years, respectively, mild dry and wet cycles are observed. In 9 and 5 years, respectively, there have been exceptionally dry and rainy phases. In 0 and 3 years, there are extreme dry and wet periods, respectively.

In the East Godawari district, normal moisture levels have only occurred in 59 of the past 100 years. In 18 and 12 years, mild dry and wet cycles are observed, respectively. In the last 5 and 4 years, there have been exceptionally dry and rainy phases. In 2 and 0 years, respectively, extreme dry and wet cycles are observed. In the Visakapatnam district, normal moisture levels have only occurred in 66 of the past 100 years. In 11 and 12 years, respectively, mild dry and wet periods are observed. In 1 and 5 years, respectively, exceptionally dry and rainy cycles have occurred. In 4 and 1 years, respectively, extreme dry and wet cycles are observed. Drought indices are compared using graphs with historic years on the x-axis and drought indices values on the y-axis. Different coloured lines are drawn here, such as red for SPI, yellow for Z-score and green for CZI. Annual trends of SPI, CZI and Z-score values for Kadapa and East Godawari are depicted in Figs. 3 and 4, respectively.

In Fig. 3, SPI and Z-score are barely differentiated but CZI shows more deviations from SPI. SPI and Z-score exposed very few number of extreme dry condition when compared to CZI. Prakasam and Krishna districts followed the same pattern as of Kadapa district.

In Fig. 0.4, all three indices, i.e. SPI, CZI and Z-score curves are in same pattern. Visakapatnam district followed the same pattern as of East Godawari district. Z-score

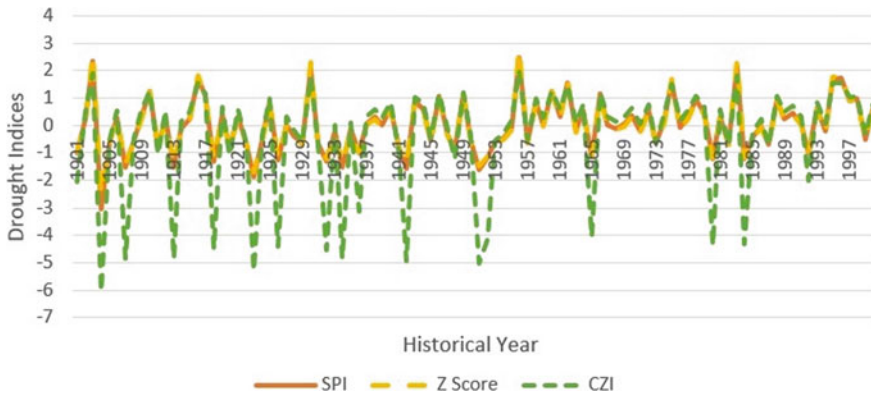


Fig. 3 Annual Pattern of three drought indices of Kadapa District

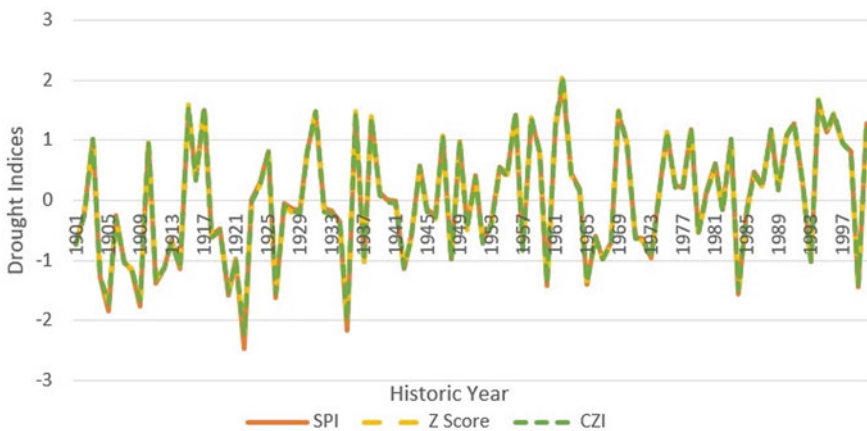


Fig. 4 Annual Pattern of three drought indices of East Godavari District

is showing more normal values when compared to CZI and SPI as its calculation is based on standard deviation. In some months, the rainfall may be heavy and in some low. Finally, it is giving average values coming to SPI, it shows more EW, VW, ED and VD. Even if the rainfall of the place is moderately wet, it shows EW and VW. China Z index shows more Normal, MW and MD categories.

4.1 Regression Analysis

Figures 5 and 6 depict the regression analysis of SPI vs Z-score and SPI vs CZI of Kadapa district, respectively. Regression coefficient of SPI vs Z-score is 0.9912

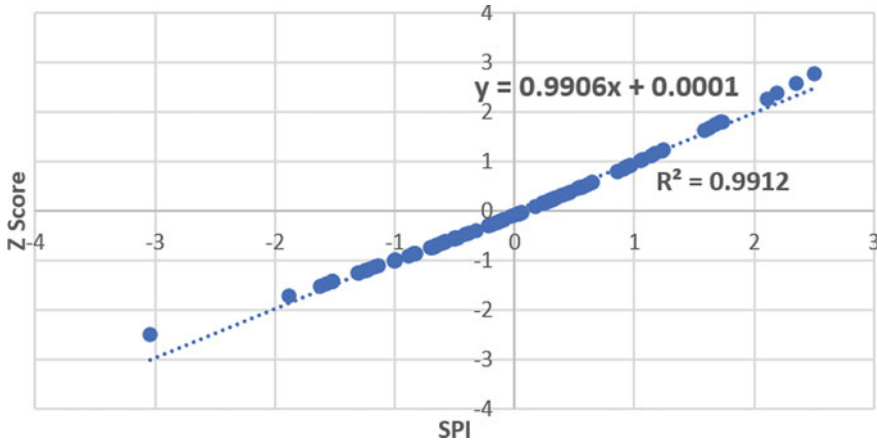


Fig. 5 Linear regression analysis of SPI versus Z-Score of Kadapa

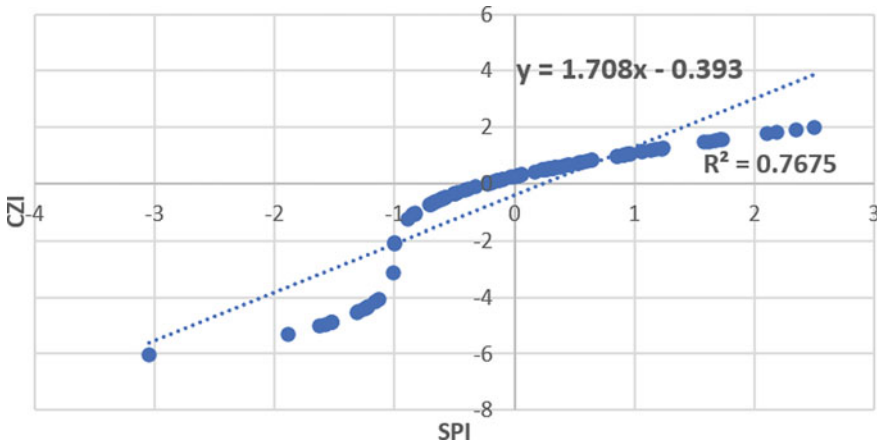


Fig. 6 Linear regression analysis of SPI versus CZI of Kadapa

whereas that of SPI vs CZI is 0.7675. This shows that Z-score depicts the same values of SPI with precision of 0.0088.

From the regression analysis of SPI vs Z-score and SPI vs CZI of Prakasam district, regression coefficient of SPI vs Z-score is 0.9898 whereas that of SPI vs CZI is 0.8056. This shows that Z-score depicts the same values of SPI with precision of 0.0101.

From the regression analysis of SPI vs Z-score and SPI vs CZI of Krishna district, regression coefficient of SPI vs Z-score is 0.9937 whereas that of SPI vs CZI is 0.7475. This shows that Z-score depicts the same values of SPI with precision of 0.0063.

Figures 7 and 8 depict the regression analysis of SPI vs Z-score and SPI versus CZI of East Godavari district, respectively. Regression coefficient of SPI vs Z-score is 0.996 whereas that of SPI vs CZI is 0.9977. This shows that Z-score and CZI depict the same values of SPI with precision of 0.004 and 0.0023, respectively.

From the regression analysis of SPI vs Z-score and SPI vs CZI of Visakhapatnam district, regression coefficient of SPI vs Z-score is 0.9941 whereas that of SPI vs CZI is 0.9993. This shows that Z-score and CZI depict the same values of SPI with precision of 0.0059 and 0.0007, respectively.

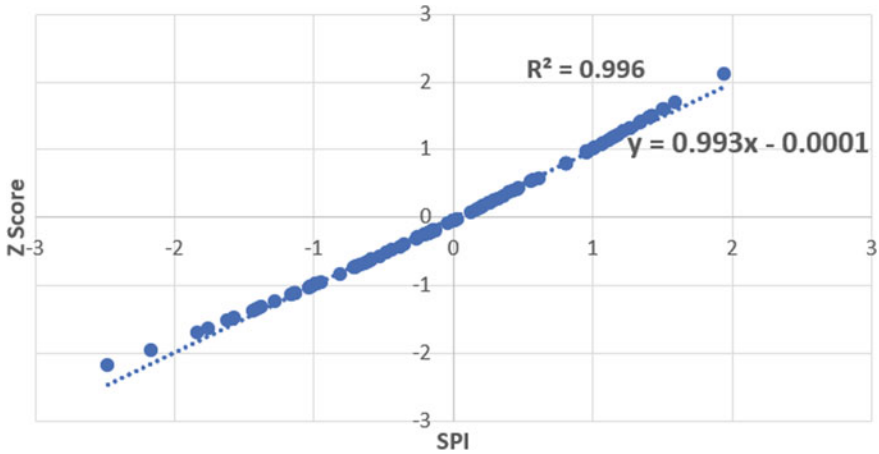


Fig. 7 Linear regression analysis of SPI versus Z-score of East Godavari

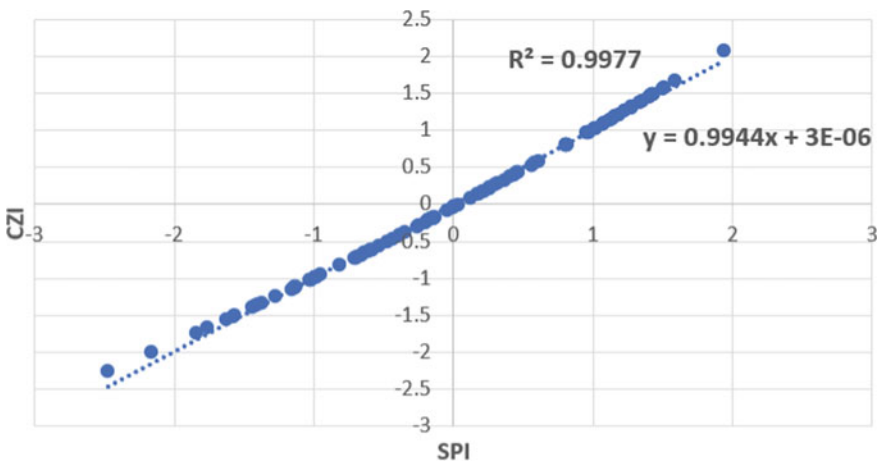


Fig. 8 Linear regression analysis of SPI versus CZI of East Godavari

5 Conclusions

The drought intensities of the five districts have been assessed with the help of three drought indices, i.e. SPI, CZI and Z-score. Different moisture categories are assessed for each of the five districts under study area by considering the time period of 1, 3, 4 and 12 months. Based upon drought indices values, moisture categories are classified as Extreme Dry (ED), Very Dry (VD), Moderate Dry (MD), Normal (N), Moderate Wet (MW), Very Wet (VW) and Extreme wet (EW).

SPI is a standard method but it is very complex and laborious to calculate. So, for assessing an easier and simpler method which shows similar values as SPI, Annual values of CZI and Z-score are compared with that of SPI for each district in our study area. There are so many methods available to compare these indices. In our present study, simple graphical comparison of indices and linear regression analysis are taken. From graphical analysis, it is evident that the graphs of Kadapa, Prakasam and Krishna have similar pattern and graphs of East Godawari and Visakapatnam are similar. In the graphs of Kadapa, Prakasam and Krishna, SPI and Z-score curves coincided, whereas CZI showed more deviations at extremes. In the graphs of East Godawari and Visakapatnam, all the three indices curves coincided, i.e. all indices show similar behaviour.

From regression analysis graphs, it is evident that for Visakhapatnam and East Godawari Districts, regression coefficients are around 1 for both CZI vs SPI graph and Z-score vs SPI graph. So, we can rely on both CZI and Z-score for evaluating drought characteristics instead of SPI for Visakapatnam and East Godawari. For Krishna, Prakasam and Kadapa Districts, regression coefficient of SPI vs Z-score graph is around 1, whereas regression coefficient of SPI vs CZI graphs are 0.74, 0.80 and 0.76, respectively. This implies Z-score values are very nearer to SPI, whereas CZI values show more deviation from SPI. So, we can rely on Z-score rather than CZI for Krishna, Prakasam and Kadapa. So, Z-score can be used for evaluation of drought instead of laborious and complex SPI for the five districts.

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