Hydrological Drought Monitoring of a Drought Prone Area

[1]Rachana Gupta, [2]Palli Abhijit

Students,
School of Civil Engineering,
Lovely Professional University, Punjab-144411

Abstract: **Monthly rainfall data of 30 years was used to compute Standardize Precipitation Index (SPI) values based on two parameter gamma distribution for Kadapa district of Andhra Pradesh state, India. By definition drought could also be an extended period of unusually low rainfall, especially one that badly influences growing environments. it's one among the foremost important water associated hazards. It shows a damaging effects towards hydrological, agricultural, ecological, economic, environmental and social frameworks. Understanding these effects is crucial for drought planning, relief (mitigation), and response. It also helps in drought mitigation well in advance. A drought index value may be a single number, which is more significant than raw numbers for result making. SPI has several characteristics which is an advantage over other indices, with its adaptability and simplicity. The standardized precipitation index (SPI) method is employed for observing and describing drought supported thirty (30) year precipitation data of Kadapa district. Finding drought index with twelve month duration basis and compare with the particular drought of the station. Positive SPI values indicate normal to excess precipitation conditions whereas negative values indicate normal to deficit precipitation conditions. As compared to the actual drought data with SPI index, it showed slight anomaly with respect to drought severity. Therefore, it is preferable that SPI indicator alone should be interpreted with caution when it comes to the assessment of drought intensity.**

Keywords: **Standardized Precipitation Index (SPI), DrinC, Rainfall Deviations, Meteorological Drought, Gamma Distribution, Normality Tests**

Introduction

In general, drought is defined as a natural phenomenon of less water availability in a specific period and over a specific area (Beran and Rodier 1985). Droughts are basically classified into four categories: Agricultural, climatological, socioeconomic and hydrological (Mishra A K, Singh V P, 2011).Among all meteorological drought is seen as an introducer to the other three kinds of drought, first a deficit in soil moisture is observed, decrease in stream flow, depletion of ground water table and finally indirect impact on society and human economy (Tsakiris 2017). Meteorological drought is a reoccurring drought which occurs due to insufficient precipitation over a region or area. The main issue with this kind of droughts is the severity cannot be predicted easily. There should be an understanding between the climatological and hydrological parameters which characterize the drought at its best for development of measures to mitigate the impacts of drought (Zhong et al, 2020). Rainfall plays a vital role in meteorological drought. Analysis of parameters such as hazard assessment, exposure assessment, sensitivity assessment, adaptive capacity assessment, drought vulnerability assessment of a drought prone area for an early drought warning system will not only help in policy making but also in adaptation of forthcoming circumstances by the residents (Sharafi et al., 2020). In India there are four categories to evaluate and monitor rainfall patterns; ; ±20% considered as normal deviation, -20% to -60% as deficit, < 60% as insufficient or scanty and < 20% as excess, these are given by the Indian Meteorological Department (IMD). A dryness in the upper layers or root zone results in agricultural drought, which results in the reduction of crop yield. In general, the onset of agricultural drought is followed by meteorological drought. The application of SPI method for agricultural practices emphasized that it provides almost same result as that of actual drought condition without applying any climatic limits (Shah et. al 2015) Some desirable traits of SPI are, its related to probability, it can be used for monitoring both dry and wet periods, it is normalized so that representation of wet and dry climates is easier (McKee T B, et al,. 1993). Since SPI is standardized it ensures that the frequency of extreme events can be compared at any location ((Hayes et al. 1999; Mishra and Desai 2005).Deficit in precipitation for a prolonged period over a region affects subsurface and surface water bodies, thus reducing reservoir, lake and streamflow levels which lead to hydrological ground water or hydrological drought which persists long after the culmination of meteorological drought. Drought indices are the most important and prominent elements in drought monitoring system. They guide us in characterizing the drought. Analysis of parameters such as hazard assessment, exposure assessment, sensitivity assessment, adaptive capacity assessment, drought vulnerability assessment of a drought prone area was proposed by Sharafi et al. (2020) for an early drought warning system as it will not only aid in policy making but also in adaptation of forthcoming circumstances by the residents

In 1965 Palmer introduced Palmer Drought Severity Index which became very popular and is based on temperature and precipitation. PSDI has several limitations like temporal scales and detection of onset drought events (Palmer, 1965). Palmer Drought Severity Index (PDSI) is an meteorological index and has many relations with hydrologic and agricultural drought. It addresses two of its main parameters i.e. intensity and beginning and end times (Palmer WC, 1968). McKee introduced Standardized Precipitation index in 1993 to study and monitor drought, which is also based on precipitation. As compared to other indicators SPI has many advantages like wide range of time scales, comparability across various locations and easy to calculate (McKee et. al, 1993). Similar to that there are other indicators like Standardized streamflow index (SSFI, Modarres, 2007), Standardized Runoff index (SRI) which depend on runoff and other entities. Reviews of drought indices are presented according to country/region in Smakhtin and Hughes (2004), Mishra and singh (2010), Heim jr (2002) and Niemeyer (2008).

These indices deal with any specific drought like meteorological, agricultural or hydrological. This is not adequate to completely study and get an idea of drought conditions since it's dependent on various parameters and one index may not be consistent with the findings obtained with other drought indices.

Table I. Drought categories from SPI (source: McKee et al., 1993)

SPI	Drought category
0 to −0.99	Mild drought
−1.00 to −1.49	Moderate drought
−1.5 to −1.99	Severe drought
−2.00 or less	Extreme drought

2. Study Area

Kadapa is one of the four districts in Rayalaseema region of Andhra Pradesh which are chronically effected by drought. This district is also endowed with rich history of flora & fauna. Kadapa district has an overall area of 15,379 sq.km and lies between the Northern latitudes of 13^0 43' and 15^0 14' and eastern longitudes of 77^0 55' and 79^0 29'. (Ministry of water resources, GOI)

Fig.1 Location of Kadapa district (Indianetzone.com)

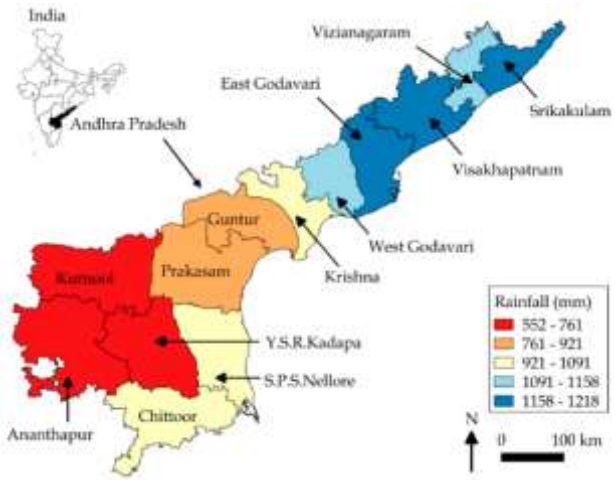

Fig.2 Rainfall distribution over Kadapa District (APSDPS)

Kadapa district has an annual normal rainfall of 699.6 mm. Pennar River and its main tributaries like Chitravati, Kunderu and Papaghni act as a water source. An area of about 22,000 ha is irrigated by means of canals and 1, 30,000 ha by bore wells and dug wells.

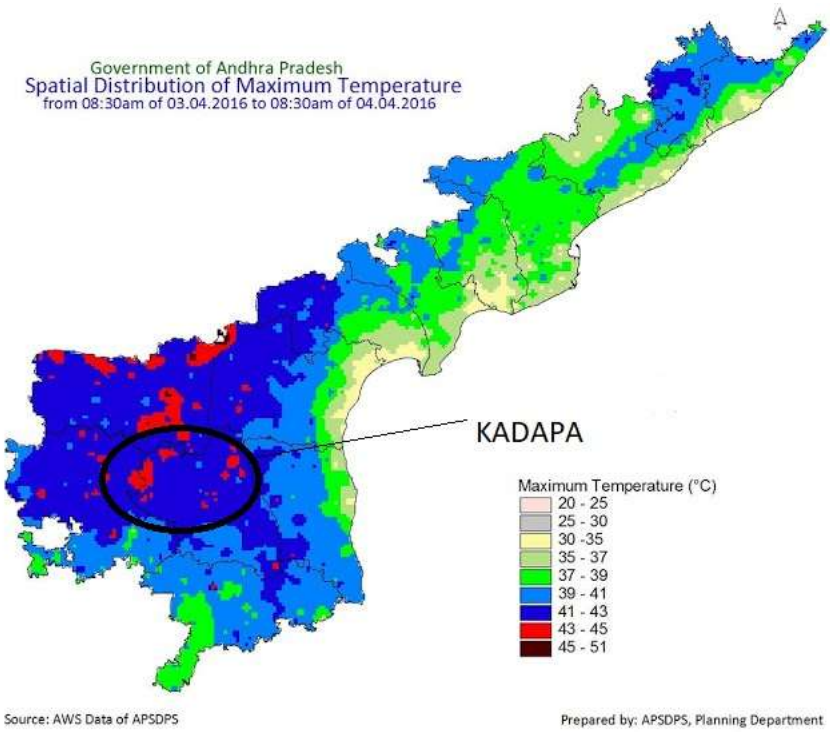

Fig.3 Temperature of Kadapa District(APSDPS)

2.1 Climate

Rayalaseema region lies in the semi arid and arid temporate region with a mean precipitation varying from 350 to 650 mm. South–West monsoon contribute about 90% of annual rainfall which occurs during June–September and the rest of the year remains dry. With May being the hottest month the temperature rises to 45^0C. Periodicities of winter rainfall over Rayalaseema are studied by using the IITM rainfall data.

The rainfall periodicities are calculated using maximum entropy method, which gave the results as 2.4 years, 3.3 years, 5 years and 13.4 years for the four stations Ananthapur, Chitoor, Kurnool and Tirupati. Due to these periodicities the effect of quasi-biennial is more on the northeast monsoon (Satyanarayana, et al, 2020).

2.2 Crop Pattern

Red and black soils are the primary soil deposits which provide a fertile area for farming. 53% of cultivated area is occupied by red soil and the rest by black. Major agricultural crops produced are paddy, red gram, ground nut and cotton. Fruits cultivated are banana, melons, mango, papaya etc.

3. Methodology

Drought indices are generally obtained by equations and procedures applying manually or stand-alone software/tools designed for this purpose, which may include one or more indices i.e. DrinC.

3.1 Arithmetic Procedure of SPI Calculation:

The calculation of SPI index needs only precipitation data as input. It is calculated by taking the effect of precipitation anomaly according to the average value for a given time period of scale, separated or distributed by its standard deviation (Mahesh Babu C et al, 2015). SPI is 0 mean Gaussian distribution function with unit variance. This allows us in the adjustment of index which helps in comparing values related to different areas. Computation of SPI was carried out based on two parameter gamma distribution function. The gamma distribution function is explained by probability density function or its frequency (Thom, 1966). SPI is designed to monitor or analyze both wet and dry conditions simultaneously on one or more time scales. Since SPI normalized we can monitor wet and dry climates on the same basis. SPI is just the difference of mean of precipitation for a specified time period divided by the standard deviation which is obtained by mean and SD of previous records. (McKee T B, et al,. 1993).

The index is founded based on the following aspects:

$$\text{SPI} = \frac{X_I - X}{\sigma} \dots\dots\dots\dots 1$$

Where

X = the mean annual rainfall at any year
X_I = the annual rainfall at any year
σ = the standard variation

3.2 SPI using DrinC

Drought is mainly characterized by its duration, severity and areal extent. Drought indices usually access the degree of drought severity in a simple and meaningful way. DrinC (Drought indices calculator) is a software which provides an adaptable and simple interface for the calculation of different indices.

With the help of DrinC we can calculate indices like Streamflow Drought Index (SDI), Reconnaissance Drought Index (RDI) and widely known SPI index (Dimitirs.T, 2015).

Drinc provides us the option to utilize both gamma and log-normal distributions, we can also compare the results between RDI and SPI (Tigkas.H, et al. 2014). The hydrological year in DrinC is from October – September which is the primary reference base, so the calculation period begins from October and the time intervals or steps are monthly, 3 months, 6 months and annual.

Table 2. Required input data for each index

Index	**Required input data**
Deciles	Precipitation
RDI	Precipitation, PET (or temperature)
SPI	Precipitation
SDI	Streamflow

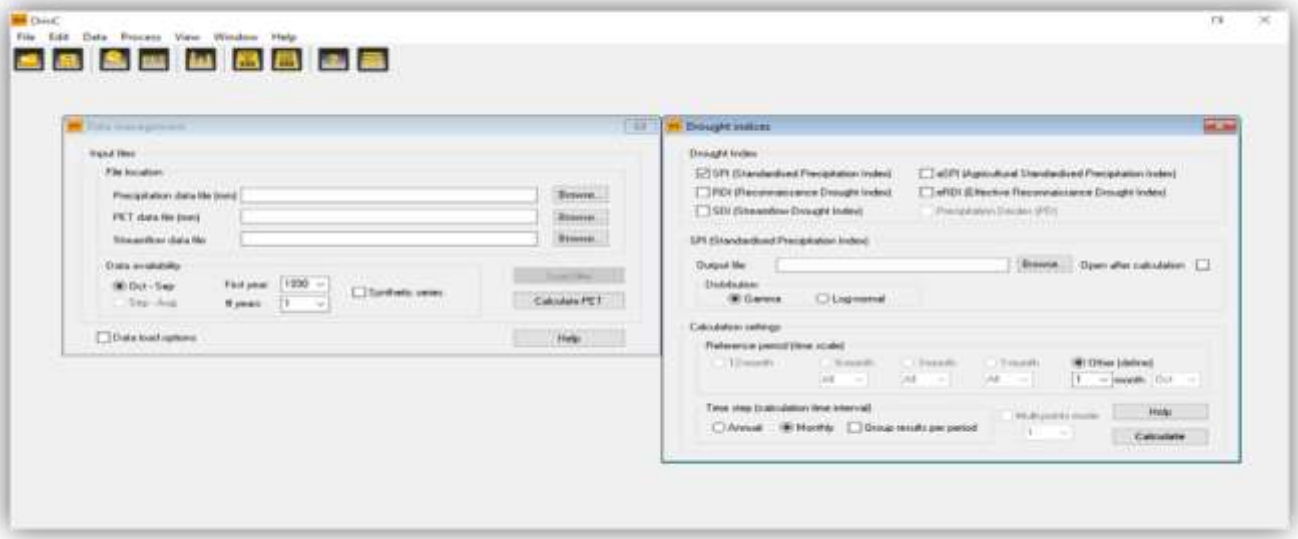

Fig.4 DrinC user interface from software

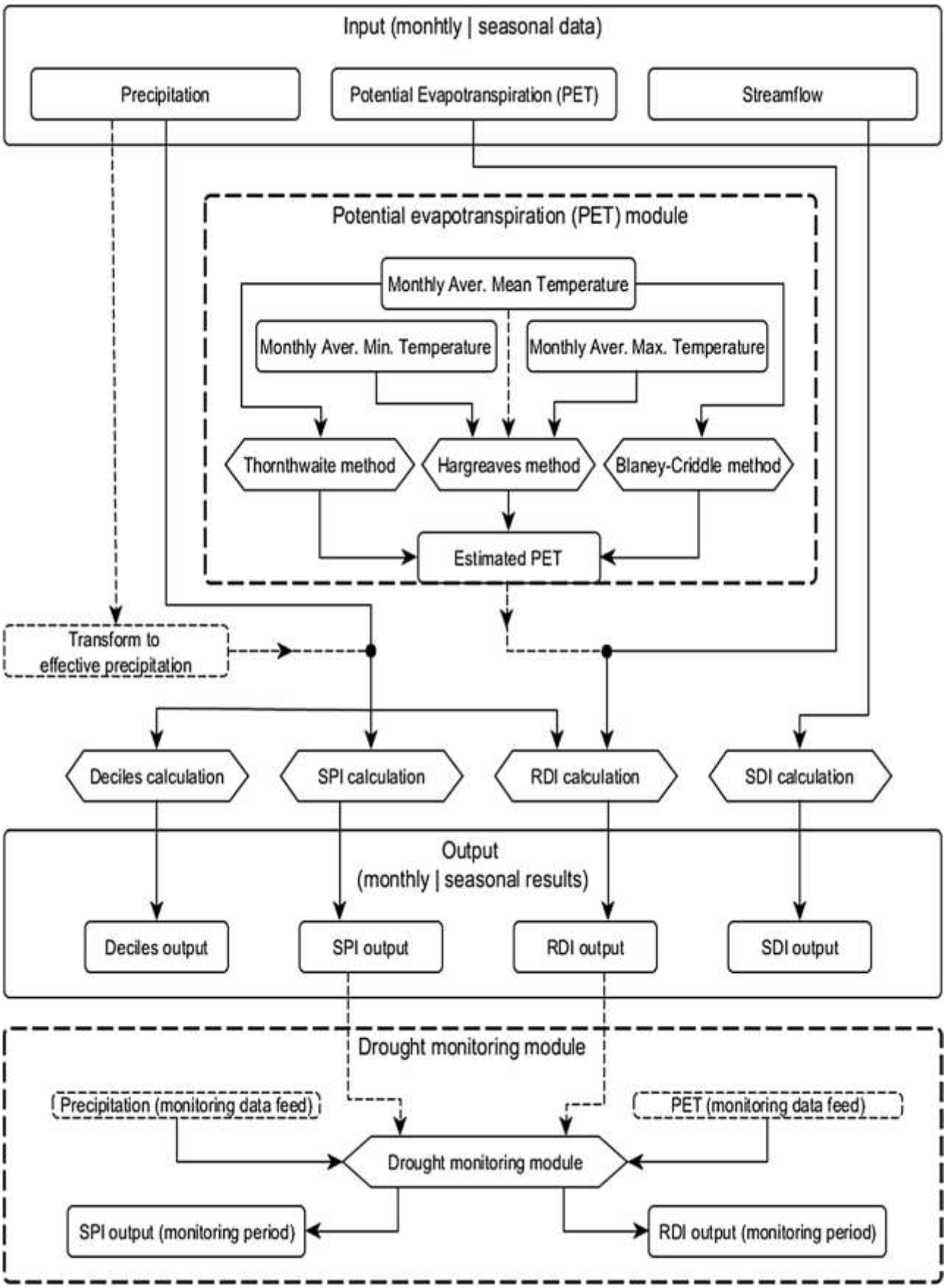

Fig. 5 The flow chart of DrinC software
Source: Dimitris.T, et al, 2015.

4. Results and Discussion

Precipitation data of 30 years from 1990–2019 was obtained from Varada V et al,. and was used in the computation of Standardized Precipitation index with DrinC. Monthly and annual SPI values were obtained. These SPI values are ranging from -2.5 – 2.5.

Negative values tend to show deficit in precipitation and drought. Mapping of the SPI output values has been done to obtain a spatial inference. As per directorate of agriculture, Andhra Pradesh 1992, 1994, 1999 and 2011 were classified under moderate or mild drought category where as 2002 and 2006 were classified as severe drought years. When consider the output of SPI values -1.21 and -0.87 for the same years respectively it showed an anomaly. For the years 2002 and 2006 SPI indicated mild and moderate drought as per Table 1. Many indicators are effected by the record length of data. This impact was studied by analysing different periods of time for 21, 22, 23 and so on till 29 years. This resulted in a total of 19 SPI values which indicated that SPI was stable and is not influenced by the length of record. This is also in harmony with the results of Wu et al (2005). This character of SPI makes it a sturdy indicator (Naresh Kumar, et al, 2009).

Statistical analysis of SPI has also been done with respect to precipitation data and showed a Standard Deviation 184.71 which is quite large which shows there is a larger variation in rainfall patterns.

To measure the asymmetry about the mean, skewness is also calculated which gave an average of 0.44, so it lies towards the right of mean and is right skewed (Varada V et al). To analyze the spread of data, coefficient of variation is measured about the mean which was found out to be 27.24%. High coefficient of variation tends to be characterized a region by more extremes (alternating years of dry and wet climates).

Table 3. Statistical parameters for annual rainfall pattern of YSR Kadapa district during 1990-2019

Description	**Normal series**
Mean Rainfall (mm)	678.0
Standard deviation	184.71
Co-efficient of variation	27.24
Skewness	0.44

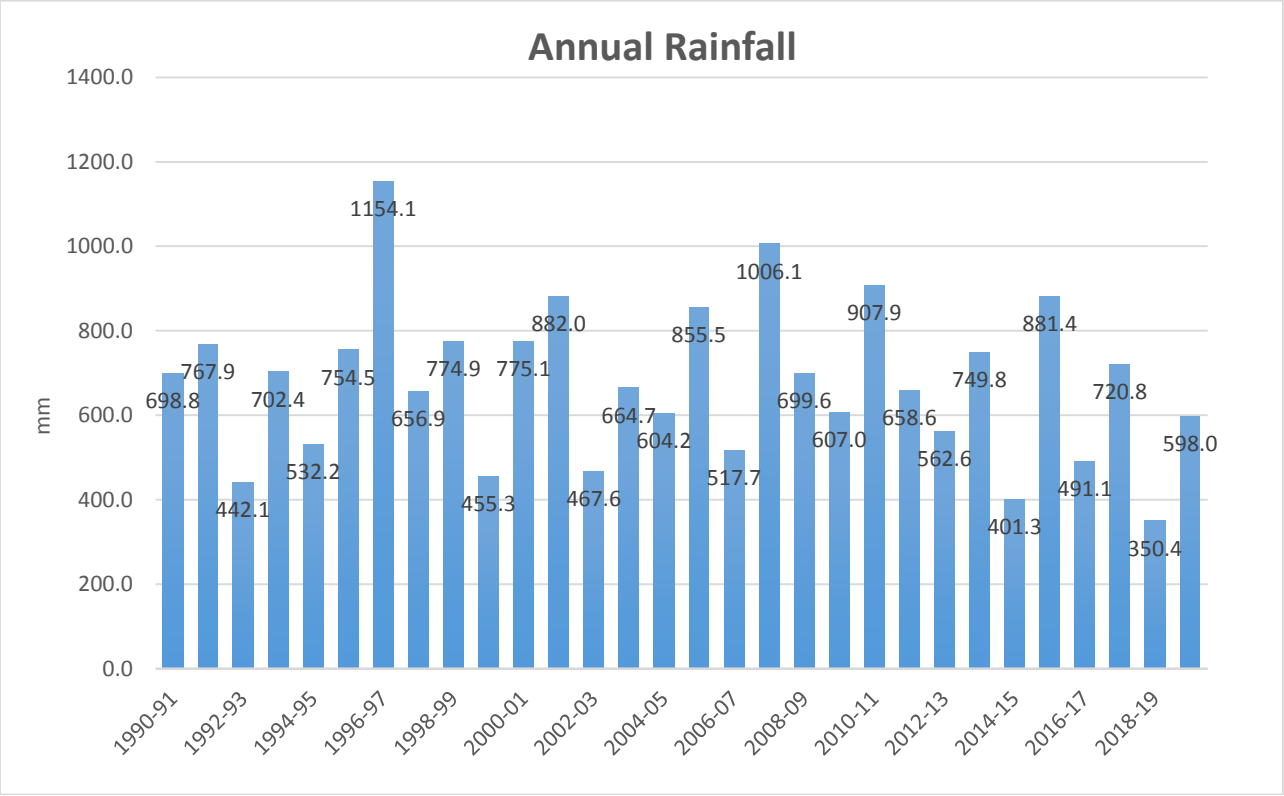

Fig.6 Annual rainfall distribution of YSR Kadapa district during 1990-2019

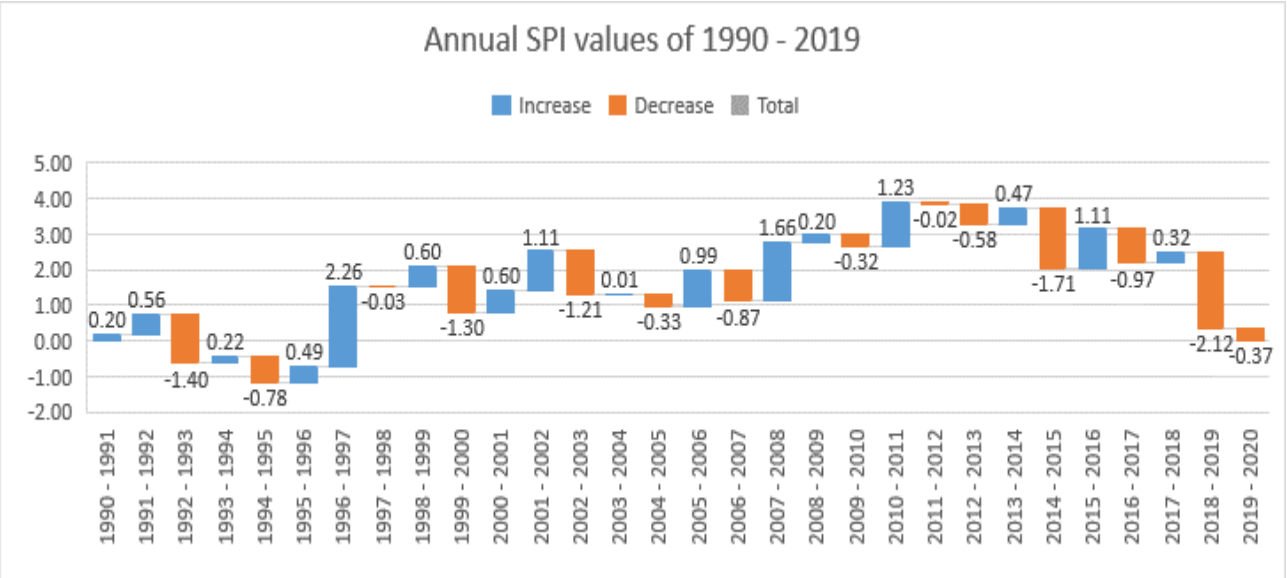

Fig.7 Annual SPI distribution of YSR Kadapa district during 1990-2019

5. Conclusion

An assessment of metrological drought has been done for Kadapa district in Rayalseema region of Andhra Pradesh based on precipitation data for the period 1990 to 2019(30 years). Index applied in the study was standardized precipitation index with the time scale of 12 months. The results of SPI showed that there is an anomaly so SPI as a stand-alone indicator is not preferred whereas there is a need of multivariate drought index (MDI) which takes multiple drought types into account. MDI takes precipitation, runoff and soil moisture as indicator variables, which makes it much more reliable as a region may be experiencing drought due to multiple regions (Deepthi, et al, 2015).

References

[1] Ashok K Mishra, Vijay P Singh, Drought Modelling - A review, Journal of Hydrology, Volume 403, pg. 157-175
[2] Beran M, Rodier J A (1985) Hydrological aspects of drought. Studiesand reports in hydrology 39, Unesco-WMO, Paris
[3] Central Ground Water Board, Ministry Of Water Resources, Government of India
[4] D Tigkas, H Vangelis, G Tsakiris, The Drought Indices Calculator (DrinC), 2014, Laboratory of Reclamation Works and Water Resources Management & Centre for the Assessment of Natural Hazards and Proactive Planning, School of Rural and Surveying Engineering, National Technical University of Athens, Greece, water@survey.ntua.gr
[5] Deepthi Rajsekhar, Vijay P Singh, Ashok K Mishra (2015). Multivariate drought index: An information theory based approach for integrated drought assessment, vol 526
[6] Dimitris T, Harris V, Geroge T, 2015. DrinC: A software for drought analysis based on drought indices, Earth Sci Inform, 8, 697-709
[7] Fanglei Zhong, Qingping Cheng, Ping Wang. Meteorological Drought, Hydrological Drought, and NDVI in the Heihe River Basin, Northwest China: Evolution and Propagation. Hindawi Advances in Meteorology. Volume 2020, Article ID 2409068, 26 pages
[8] Hayes M J, Svoboda M D, Wilhite D A, Vanyarkho O V (1999). Monitoring the 1996 drought using the standardized precipitation index. Bull Am Meterol Soc 80, 429-438. DOI: 10.1175/1520-0477(1999)080<0429:MTDUTS>2.0.CO;2
[9] Heim R R Jr (2002). A review of twentieth-century drought indices used in the United States. Bull Am Meteorol Soc 83 (8), 1149–1165
[10] Mahesh Babu C, Hemalatha T, Harish N. Meteorological Drought Assessment of Rayalaseema Region. Indian journal of applied Research, Vol 5, Issue 7, 2015
[11] McKee T B, Doesken N J, Kleist J (1993). The relationship of drought frequency and duration to time scales. 8th conference on applied climatology, Am Meteor Soc, Boston, pp. 179–184
[12] McQuigg J (1954). A simple index of drought conditions. Weatherwise 7 (3), 64–67
[13] Mishra A K, Singh V P, Desai V R (2009). Drought characterization: A probabilistic approach. Stoch Env Res Risk A 23 (1), 41–55
[14] Modarres R (2007). Streamflow drought time series forecasting. Stochastic Environmental Research and Risk Assessment, 21, 223–233. DOI: 10.1007/s00477-006-0058-1
[15] Munger T T (1916). Graphic method of representing and comparing drought intensities. Monthly Weather Rev. 44 (11), 642–643
[16] Naresh Kumar M, Murthy C S, Sesha Sai M V R, Roy P S (2009). On the use of Standardized Precipitation Index (SPI) for drought intensity assessment. Journal of the meteorological applications, 16, 381–389
[17] Niemeyer S (2008). New drought indices. Proceedings of the 1 International Conference on Drought Management: Scientific and Technological Innovations, Options Méditerranéennes, Series A, No. 80, Zaragoza, Spain, pp. 267–274

[18] Palmer W C (1968). Keeping track of crop moisture conditions, nationwide: The new crop moisture index. Weatherwise 21 (4), 156–161
[19] Palmer W C (1965). Meteorological drought, US Department of Commerce, Weather Bureau, Washington DC, 58
[20] Ravi Shah, Nitin Bharadiya, Vivek Manekar. Drought Index Computation Using Standardized Precipitation Index (SPI) Method For Surat District, Gujarat, Aquatic Procedia 4 (2015), 1243–1249
[21] Satyanarayana G C, Umakanth N, Ramesh K S, Basha S M, Naveena N, Dharma Raju A, Siva Sankar K. Periodicities of winter monsoon rainfall over Rayalaseema using Maximum Entropy Method. Vol. 63 No. 2s (2020)
[22] Shafer B A, Dezman L E (1982). Development of a surface water supply index (SWSI) to assess the severity of drought conditions in snowpack run of areas. Proceedings of the Western Snow Conference. Fort Collins. Colorado State University, pp. 164–175
[23] Sharafi L, Zarafshani K, Keshavarz M, Azadi H, Passel S V. Drought risk assessment: Towards drought early warning system and sustainable environment in western Iran, Ecological Indicators 114 (2020) 106276
[24] Smakhtin V U, Hughes D A (2004). Review of Automated Estimation and Analyses of Drought Indices in South Asia. Working Paper 83, International Water Management Institute (IWMI), Colombo, Sri Lanka
[25] Tsakiris G (2017). Drought risk assessment and management. Water Resour Manag 31 (10), 3083–3095
[26] Varada V, Venkatesh M, Rakesh P, Sagar V, Swaroop V. Statistical Analysis of 30 Years Rainfall Data of YSR Kadapa District, Andhra Pradesh, India. PAIDEUMA Journal, ISSN: 0090-5674
[27] Wu Hong, Svoboda Mark D, Hayes Michael J, Wilhite Donald A, Wen Fujiang, "Appropriate Application of the Standardized Precipitation Index in Arid Locations and Dry Seasons" (2007). Drought Mitigation Center Faculty Publications. 42