Indian J. Dryland Agric. Res. & Dev. 2022 37(1): 42-47 10.5958/2231-6701.2022.00009.4

# Rainfall Variability Analysis Using Standardized Precipitation Index in Arid Climate of Andhra Pradesh in Sub-tropical India

**B. Sahadeva Reddy, K.V.S. Sudheer, K. Ashok Kumar, Y. Pavan Kumar Reddy, A. Malliswara Reddy and C. Radha Kumari**

*AICRP for Dryland Agriculture and Agrometeorology, Achaya N.G. Ranga Agricultural University, Agricultural Research Station, Ananthapuramu-515001, Andhra Pradesh*

Email: sahadevardd@gmail.com

**ABSTRACT:** Rainfall is the major limiting weather parameter for crop production in tropical and subtropical regions. Its intensity and distribution across the seasons decide the success of agricultural production system in dryland areas. The historical rainfall data of Ananthapuramu district was used to analyze variability in monthly and seasonal distribution. Based on IMD criteria, the long-term rainfall data for a period of 140 years (1877-2016) was categorized as excess, normal and deficit and used for assessing the variability of monthly and seasonal rainfall. The intensity of drought was also assessed using Standardized Precipitation Index. The results indicated that Ananthapuramu district received mean annual rainfall of 550 mm with 25.1% CV during the study period. The district received excess rainfall in 31 years, normal rainfall in 76 years and deficit rainfall in 33 years. It is observed that variability in rainfall was lower for SWM and NEM as compared to CWP and HWP seasons. Among 33 years of deficit rainfall, 22 and 18 years recorded normal rainfall during SWM and NEM respectively based on SPI values. It is also observed that SWM received near normal precipitation for 69 years during normal rainfall years. The SPI analysis showed that near normal rainfall was received in 12 and 14 years during SWM and NEM respectively in excess rainfall years. It can be concluded that Standardized Precipitation Index serves as a good indicator for assessing severity of drought to plan for various activities under agricultural sector in dryland areas.

**Key words:** Climate change, rainfall variability, standardized precipitation index



## Introduction

Among different weather parameters, rainfall is a stochastic variable with an erratic distribution. Standardized Precipitation Index (SPI) expresses the actual rainfall as a standardized departure with respect to rainfall probability distribution function and hence the index has gained importance in recent years as a potential drought indicator permitting comparisons across different rainfall zones (Naresh Kumar *et al*., 2009). For assessing severity and categorization of droughts, several drought indices based on rainfall and other parameters have been developed (Sivakumar *et al*., 2011). It is necessary to devise a drought index with due consideration to the prevailing conditions in a target region and also for an intended purpose. The drought interpretation at different time scales using SPI is proved to be superior to Palmer Drought Index (Guttman, 1998). Sukumar *et al*., (2010) studied rainfall characteristics of Coimbatore and analyzed long-term trends of monthly, seasonal and annual rainfall. In the absence of reliable and physically based seasonal forecasts, the crop management decisions and planning would rely on statistical analysis of historical rainfall records. There would be a large variation in the annual rainfall due to various factors. The erratic rainfall and its variability would affect the economic prosperity of any nation. Out of 40 lakh ha of rainfed area of Andhra Pradesh, 45% of area is concentrated in scarce rainfall zone consisting of Ananthapuramu (546 mm) and Kurnool (630 mm) districts. About 25% of rainfed area of Andhra Pradesh is in Ananthapuramu district, which is a rain shadow area and has 2nd lowest rainfall in the country, next to Jaisalmar in Rajasthan. The rainfall in the zone is just sufficient to take up a crop of 15-18 weeks duration, and even a little variation in monthly or seasonal rainfall would adversely affect the prospects of rainfed crops (Reddy, 2017). During the last 18 years, Ananthapuramu experienced three years of normal rainfall and 15 years of drought. In this parched scenario, 90% of cultivated land (11 lakh ha) depends on rain, and 70% of population depends on farming for livelihood (Reddy *et al*., 2020). Under this situation, long-term rainfall analysis helps the dryland farmers in selection of suitable crops, varieties, cropping patterns, farming systems, etc., and also helps policy makers in taking decisions on areas that are more prone to droughts. Hence, there is a need to assess the long-term variability in rainfall in dryland areas of Andhra Pradesh. The present study was taken up with an objective of long-term (140 years *i.e.* from 1877 to 2016) analysis of variability in rainfall under arid climate in Ananthapuramu district of Andhra Pradesh and to assess the intensity of drought using Standardized Precipitation Index (SPI).

## Materials and Methods

Monthly rainfall (mm) for the period 1877 to 1950 (Reddy, 2017); 1951 to 2005 was collected from Directorate of Economics and Statistics, Ananthapuramu (DES, 2006) and from 2006 to 2016 from Directorate of Economics and Statistics, Ananthapuramu (https://des.ap.gov.in) and used for assessing the trends and their variability over years.

**Statistical analysis of rainfall patterns**

The variability of rainfall in the study period was assessed based on mean, standard deviation, coefficient of variation (%), skewness and kurtosis. Assessment of monthly, seasonal (cold weather period (CWP) (January-February), hot weather period (HWP) (March-May), south-west monsoon (SWM) (June-September) and north-east monsoon (NEM) (October-December)) and annual rainfall was made by computing the standardized precipitation index values of rainfall. The study period was divided into three categories based on IMD (India Meteorological Department) viz., years which received (i) excess rainfall, (ii) normal rainfall and (iii) deficit rainfall. The trends were assessed based on regression coefficients derived using the regression model of rainfall as a function of years, and tested based on Mann and Kendall Test. The consistency of rainfall was assessed using mean and coefficient of variation of rainfall over years.

**Standardized Precipitation Index**

The Standardized Precipitation Index (SPI) is determined based on the probability of precipitation for any time scale (McKee, 1993; Naresh Kumar *et al*., 2009). The probability of observed rainfall is transformed into an index. Long-term values are fitted to a probability distribution, which is subsequently transformed to normal distribution, so that the mean SPI value for the location and desired period would be zero (Edwards and McKee, 1997). Positive SPI values would indicate greater than median rainfall, while negative SPI values would indicate less than median rainfall. Since SPI values are normalized, wetter and drier climates could be represented in the same manner. Based on SPI values, the drought condition could be considered as (i) Extremely wet, if SPI ≥ 2.0; (ii) Very wet, if SPI ranges from 1.5 to 1.99; (iii) Moderately wet, if SPI ranges from 1.0 to 1.49; (iv) Near normal, if SPI ranges from -0.99 to 0.99; (v) Moderately dry, if SPI ranges from -1.0 to -1.49; (vi) Severely dry, if SPI ranges from -1.5 to -1.99; and (vii) Extremely dry, if SPI ≤ -2.0.

Using mean and standard deviation of rainfall for any time scale, SPI is determined using the following formula as described by Patel *et al.,* 2017.

$$SPI_{ij} \approx X_{ij} - \mu_{ij} / \sigma_{ij}$$

where, $SPI_{ij}$ is the SPI of $i^{th}$ month at $j^{th}$ time-scale; $X_{ij}$ is precipitation total for $i^{th}$ month at $j^{th}$ time-scale; $\mu_{ij}$ is long-term mean and $\sigma_{ij}$ *is* standard deviation associated with $i^{th}$ month at $j^{t}$ time-scale.

The Standardized Precipitation Index (SPI) values were determined on monthly and seasonal scale for 140 years which were grouped into extremely wet, very wet, moderately wet, near normal, moderately dry, very dry and extremely dry.

## Results and Discussion

**Grouping of years based on excess, normal and deficit rainfall**

A grouping of 140 years from 1877 to 2016 was made into 3 categories viz., years which received (i) excess rainfall (> 654.5 mm), (ii) normal rainfall (445.5 to 654.5 mm) and (iii) deficit rainfall (< 445.5 mm). Out of 140 years, maximum of 76 years (54.3%) fell in normal rainfall group, followed by 33 years (23.6%) in deficit rainfall group and 31 years (22.1%) in excess rainfall group. The seasonal distribution of rainfall in Ananthapuramu district is depicted in Table 1.

**Table 1: Distribution of rainfall in different seasons in Ananthapuramu district during 1877 to 2016**

| Statistic | CWP | HWP | SWM | NEM | Pooled |
|---|---|---|---|---|---|
| Mean | 5.4 | 74.9 | 319.9 | 149.8 | 550.0 |
| Minimum | 0.0 | 12.5 | 100.5 | 16.0 | 276.3 |
| Maximum | 81.8 | 211.3 | 652.5 | 321.3 | 953.7 |
| CV (%) | 200.0 | 47.0 | 34.5 | 46.6 | 25.1 |
| Kurtosis | 19.3 | 0.9 | 0.4 | -0.4 | -0.3 |
| Skewness | 3.7 | 0.7 | 0.7 | 0.1 | 0.2 |

The season-wise grouping indicated that maximum number of 63 years (45.0%) in SWM, 54 years (38.6%) in HWP and 41 years (29.3%) in NEM received normal rainfall among 140 years. Similarly, 51 years (36.4%) received excess rainfall in NEM, compared to 38 years (27.1%) in HWP and 35 years (25.0%) in SWM seasons. During 55 years (39.3%) with excess rainfall, SWM had a majority of 23 years (41.8%) compared to 20 years (36.4%) in NEM and 12 years (21.8%) in HWP season (Table 2). Among 76 years (54.3%) of normal rainfall, a majority of 47 (61.8%), 35 (46.0%) and 28 years (36.8%) were under SWM, HWP and NEM seasons, respectively. Among 33 years (23.6%) with deficit rainfall, a majority of 23 (69.7%), 17 (51.5%) and 12 years (36.4%) were under SWM, NEM and HWP respectively. Maximum of 40 years of deficit rainfall was observed in SWM, followed by 35 years in HWP and 33 years in NEM season. Venkatachalapathi *et al*., (2012) observed that 20, 5, 25 and 50% of years were deficit, scanty, excess and normal years, respectively at Ananthapuramu.

**Table 2: Grouping of seasonal rainfall into excess, normal and deficit category during excess, normal and deficit rainfall years**

| Type of rainfall | Excess rainfall (>19%) | | | | Normal rainfall (±19%) | | | | Deficit rainfall (-20% to -59%) | | | | Pooled | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CWP | HWP | SWM | NEM | CWP | HWP | SWM | NEM | CWP | HWP | SWM | NEM | CWP | HWP | SWM | NEM |
| Excess | 7 | 12 | 23 | 20 | 18 | 20 | 12 | 30 | 7 | 6 | 0 | 1 | 32 | 38 | 35 | 51 |
| Normal | 3 | 10 | 7 | 8 | 7 | 35 | 47 | 28 | 0 | 9 | 9 | 5 | 10 | 54 | 63 | 41 |
| Deficit | 21 | 9 | 1 | 3 | 51 | 21 | 17 | 18 | 26 | 18 | 24 | 27 | 98 | 48 | 42 | 48 |
| Total | 31 | 31 | 31 | 31 | 76 | 76 | 76 | 76 | 33 | 33 | 33 | 33 | 140 | 140 | 140 | 140 |

### SPI values of monthly rainfall in deficit years

The SPI values ranged from -0.39 to 3.28 in January, -0.33 to 1.24 in February, -0.49 to 3.41 in March, -1.10 to 1.76 in April, -1.62 to 2.17 in May, -1.47 to 2.32 in June, -1.30 to 1.78 in July, -1.16 to 0.91 in August, -1.81 to 1.52 September, -1.69 to 1.20 in October, -1.07 to 0.82 in November and -0.51 to 1.92 in December with mean of 0.12, -0.21, 0.05, -0.19, -0.32, -0.22, -0.36, -0.54, -0.70, -0.69, -0.49 and -0.17 respectively. Among the SPI values of monthly rainfall observed during deficit years, May, June and July received near normal rainfall in 23, 23 and 24 years respectively (Table 3). September and October months received normal rainfall in 18 and 17 years respectively in deficit years, while they were moderately dry in 11 years. August received near normal rainfall in 26 years among deficit years.

**Table 3: Categorization of monthly SPI values during deficit rainfall years (No. of years = 33)**

| Month | Extremely wet | Very wet | Moderately wet | Near Normal | Moderately dry | Very Dry | Extremely dry |
|---|---|---|---|---|---|---|---|
| January | 2 | 1 | 2 | 28 | 0 | 0 | 0 |
| February | 0 | 0 | 1 | 32 | 0 | 0 | 0 |
| March | 2 | 0 | 3 | 28 | 0 | 0 | 0 |
| April | 0 | 2 | 0 | 30 | 1 | 0 | 0 |
| May | 1 | 0 | 1 | 23 | 7 | 1 | 0 |
| June | 1 | 0 | 2 | 23 | 7 | 0 | 0 |
| July | 0 | 1 | 3 | 24 | 5 | 0 | 0 |
| August | 0 | 0 | 0 | 28 | 5 | 0 | 0 |
| September | 0 | 1 | 0 | 18 | 11 | 3 | 0 |
| October | 0 | 0 | 2 | 17 | 11 | 3 | 0 |
| November | 0 | 0 | 0 | 26 | 7 | 0 | 0 |
| December | 0 | 2 | 0 | 31 | 0 | 0 | 0 |

### SPI values of different seasons in deficit years

The SPI values were computed for four seasons viz., cold weather period, hot weather period, south-west monsoon and north-east monsoon. The SPI values ranged from -0.50 to 2.26 in CWP, -1.77 to 1.78 in HWP, -1.99 to -0.11 in SWM and -1.89 to 0.65 in NEM. The SPI values ranged from -1.98 to -0.82 for annual rainfall. Among 33 years of deficit rainfall, maximum of 30, 22, 22 and 18 years recorded normal rainfall during CWP, HWP, SWM and NEM respectively based on SPI values (Table 4). The annual rainfall was near normal in 8 years. Among 76 normal rainfall years, maximum of 67, 54, 69 and 63 years received normal rainfall during CWP, HWP, SWM and NEM respectively.

**Table 4: Categorization of seasonal SPI values during deficit rainfall years (No. of years = 33)**

| Season | Extremely wet | Very wet | Moderately wet | Near Normal | Moderately dry | Very Dry | Extremely dry |
|---|---|---|---|---|---|---|---|
| CWP | 1 | 2 | 0 | 30 | 0 | 0 | 0 |
| HWP | 0 | 1 | 2 | 22 | 5 | 3 | 0 |
| SWM | 0 | 0 | 0 | 22 | 6 | 5 | 0 |
| NEM | 0 | 0 | 0 | 18 | 8 | 7 | 0 |
| Annual | 0 | 0 | 0 | 8 | 17 | 8 | 0 |

### SPI values of different months in normal rainfall years

The SPI values ranged from -0.39 to 6.36 in January, -0.33 to 3.94 in February, -0.49 to 3.16 in March, -1.12 to 4.21 in April, -1.49 to 4.95 in May, -1.29 to 2.12 in June, -1.27 to 4.68 in July, -1.23 to 3.09 in August, -1.75 to 2.54 September, -1.67 to 2.38 in October, -1.07 to 2.85 in November and -0.51 to 4.39 in December respectively. Monthly rainfall in normal rainfall years was near normal for maximum number of years (Table 5). Extreme dry rainfall situation was not observed in any month. Very dry rainfall situation was observed during September in 5 years.

**Table 5: Categorization of monthly SPI values during normal rainfall years (No. of years = 76)**

| Month | Extremely wet | Very wet | Moderately wet | Near normal | Moderately dry | Very dry | Extremely dry |
|---|---|---|---|---|---|---|---|
| January | 3 | 0 | 0 | 73 | 0 | 0 | 0 |
| February | 3 | 2 | 3 | 68 | 0 | 0 | 0 |
| March | 1 | 0 | 2 | 73 | 0 | 0 | 0 |
| April | 6 | 1 | 6 | 59 | 4 | 0 | 0 |
| May | 3 | 4 | 4 | 58 | 7 | 0 | 0 |
| June | 2 | 2 | 5 | 60 | 7 | 0 | 0 |
| July | 1 | 4 | 2 | 63 | 6 | 0 | 0 |
| August | 3 | 1 | 5 | 61 | 6 | 0 | 0 |
| September | 1 | 1 | 7 | 59 | 3 | 5 | 0 |
| October | 1 | 3 | 9 | 55 | 7 | 1 | 0 |
| November | 4 | 5 | 7 | 55 | 5 | 0 | 0 |
| December | 4 | 1 | 2 | 69 | 0 | 0 | 0 |

**SPI values of different seasons in normal rainfall years**

The seasonal SPI values ranged from -0.50 to 3.50 in CWP, -1.66 to 3.87 in HWP, -1.99 to 1 in SWM and -1.78 to 2.14 in NEM during normal rainfall years. The SPI values ranged from -0.75 to 0.72 for annual rainfall. Maximum number of years in different seasons fell under the category of near normal (Table 6). Based on SPI values, it was observed that SWM received near normal rainfall for a maximum number of 69 years followed by CWP and NEM.

**Table 6: Categorization of seasonal SPI values during normal rainfall years (No. of years = 76)**

| Season | Extremely wet | Very wet | Moderately wet | Near Normal | Moderately dry | Very Dry | Extremely dry |
|---|---|---|---|---|---|---|---|
| CWP | 5 | 0 | 4 | 67 | 0 | 0 | 0 |
| HWP | 3 | 4 | 5 | 54 | 6 | 4 | 0 |
| SWM | 0 | 2 | 1 | 69 | 3 | 1 | 0 |
| NEM | 1 | 1 | 6 | 63 | 3 | 2 | 0 |
| Annual | 0 | 0 | 0 | 76 | 0 | 0 | 0 |

**SPI values of different months in excess rainfall years**

Among 31 excess rainfall years, maximum of 26, 16, 12 and 14 years were normal under CWP, HWP, SWM and NEM seasons respectively. The annual rainfall was near normal in 11 years. SWM was extremely wet, very wet and moderately wet in 4, 7 and 8 years respectively during 31 excess rainfall years. Based on NEM rainfall, 3, 4 and 7 years occurred under extremely wet, very wet and moderately wet groups respectively. Based on monthly rainfall, August, September and October received less normal rainfall compared to other months. The wetness of these months in all the three categories was high compared to remaining months. October was extremely wet in 5 years, followed by August in 4 years. September was 3, 3 and 5 times extremely wet, very wet and moderately wet among 31 excess rainfall years. SPI values ranged from 0.39 to 3.24 in January, 0.33 to 8.54 in February, 0.49 to 7.60 in March, 1.12 to 2.46 in April, 1.32 to 2.61 in May, 1.34 to 3.96 in June, 0.92 to 3.62 in July, 1.11 to 4.25 in August, 1.08 to 2.83 September, -1.47 to 2.54 in October, -0.99 to 4.08 in November and -0.51 to 6.30 in December with mean of 0.07, 0.10, 0.26, -0.01, 0.23, 0.37, 0.64, 0.77, 0.70, 0.53, 0.33 and 0.19 respectively. Among 31 years, maximum number of years were found to have near normal rainfall based on SPI values during the study period (Table 7). The number of years under near normal category ranged from 17 in October to 29 in February over years. None of the 31 years were either very dry or extremely dry based on SPI values.

**Table 7: Categorization of monthly SPI values during excess rainfall years (No. of years = 31)**

| Month | Extremely wet | Very wet | Moderately wet | Near normal | Moderately dry | Very dry | Extremely dry |
|---|---|---|---|---|---|---|---|
| January | 3 | 1 | 0 | 27 | 0 | 0 | 0 |
| February | 1 | 1 | 0 | 29 | 0 | 0 | 0 |
| March | 3 | 0 | 0 | 28 | 0 | 0 | 0 |
| April | 2 | 1 | 3 | 22 | 3 | 0 | 0 |
| May | 2 | 2 | 2 | 22 | 3 | 0 | 0 |
| June | 4 | 1 | 1 | 21 | 4 | 0 | 0 |
| July | 4 | 3 | 4 | 20 | 0 | 0 | 0 |
| August | 4 | 3 | 4 | 19 | 1 | 0 | 0 |
| September | 3 | 3 | 5 | 19 | 1 | 0 | 0 |
| October | 5 | 2 | 3 | 17 | 4 | 0 | 0 |
| November | 2 | 1 | 3 | 25 | 0 | 0 | 0 |
| December | 2 | 1 | 0 | 28 | 0 | 0 | 0 |

**SPI values of different seasons in excess rainfall years**

The SPI values ranged from -0.50 to 7.10 with mean of 0.12 in CWP, -1.75 to 2.59 with mean of 0.28 in HWP, -0.92 to 3.02 with mean of 1.19 in SWM and -1.92 to 2.46 with mean of 0.67 in NEM season, compared to 0.81 to 2.93 with mean of 1.38 based on annual rainfall. The analysis indicated that a majority of 31 years of excess rainfall years have received near normal rainfall based on SPI values of different seasons (Table 8). The number of years under near normal group ranged from 12 years in SWM to 26 years in CWP season among excess rainfall years compared to 11 years when annual rainfall was considered for classification.

**Table 8: Categorization of seasonal SPI values during excess rainfall years (No. of years = 31)**

| Season | Extremely wet | Very wet | Moderately wet | Near normal | Moderately dry | Very dry | Extremely dry |
|---|---|---|---|---|---|---|---|
| CWP | 1 | 1 | 3 | 26 | 0 | 0 | 0 |
| HWP | 2 | 2 | 6 | 16 | 4 | 1 | 0 |
| SWM | 4 | 7 | 8 | 12 | 0 | 0 | 0 |
| NEM | 3 | 4 | 7 | 14 | 0 | 3 | 0 |
| Annual | 5 | 6 | 9 | 11 | 0 | 0 | 0 |

**Trends in seasonal and monthly SPI values**

The analysis of trends based on Mann and Kendall test using monthly SPI values indicated that there was a non-significant decreasing trend in the SPI values of January, July, September and November with negative test statistic values of -0.661, -0.263, -0.793 and -1.221 respectively compared to critical value of 1.96 at $p < 0.05$ level of significance. A comparison of the critical and computed statistics of Mann and Kendall test indicated non-significant decrease in the rainfall or degree of wetness. The trend was reverse for February, March, April, May, June, August, October and December with positive values of 0.659, 0.942, 0.337, 0.378, 0.186, 0.177, 0.204 and 0.038 respectively based on the Mann and Kendall test statistic. Compared to critical value of 1.96 at $p < 0.05$ level of significance, the test indicated that there was a non-significant increase in the SPI values suggesting non-significant increase in either rainfall or degree of wetness.

The analysis indicated that there was a non-significant decreasing trend in the SPI values of CWP, SWM and NEM seasons with negative values of -0.324, -0.721 and -0.845 based on the Mann and Kendall test statistic. Compared to critical value of test statistic at $p < 0.05$ level of significance, this indicated a non-significant decrease in either rainfall or degree of wetness. However, the trend was reverse in case of HWP season with positive value of 1.074 based on the test statistic. Thus, there was a non-significant increase in the SPI values of HWP season based on the Mann and Kendall test statistic at $p < 0.05$ level of significance suggesting a non-significant increase in the rainfall or degree of wetness.

## Conclusions

Based on the study conducted on assessment of historical rainfall of 140 years at Ananthapuramu, it is observed that there was a non-significant decreasing trend in the rainfall in different months, seasons and annual rainfall during the study period. The SWM and NEM rainfall, apart from annual rainfall had a lower variability over years compared to CWP and HWP seasons. Mean rainfall of CWP, HWP, SWM and NEM seasons was 5.4, 74.9, 319.9 and 149.8 mm respectively and mean annual rainfall was 550 mm (CV of 25.1%), with skewness of -0.4 and kurtosis of 0.9 during 140 years indicating platy-kurtic nature of rainfall over years. Using SPI values, a classification of years into deficit, normal and excess rainfall years was made separately with monthly and seasonal rainfall in order to assess the changing climatic scenario at Ananthapuramu. Among seasons, SWM had a minimum deviation of rainfall compared to historical mean rainfall. Maximum of 76 years had normal rainfall compared to 31 years with excess rainfall and 33 years with deficit rainfall observed under HWP, SWM and NEM seasons.

## References

DES (Directorate of Economics and Statistics). 2006. A profile of rainfall statistics in Andhra Pradesh (1951-52 to 2004-2005). Government of Andhra Pradesh, Hyderabad. India.

Draper NR and Smith H. 1998. Applied regression analysis, 3rd Edition, Wiley, New York, pp 736.

Edwards DC and McKee TB. 1997. Characteristics of 20th century drought in the United States at multiple scales, *Atmospheric Science*, paper no. 634, May 1-30.

Guttman B and Nathaniel. 1999. Accepting the standardised precipitation index: A calculation algorithm. *Journal of the American Water Resources Association*, 35(2): 311-322.

McKee TB, Doesken NJ and Kliest J. 1993. The relationship of drought frequency and duration to time scales. *In*: Proceedings of the 8th conference on applied climatology, 17-22 January, Anaheim. American Meteorological Society: Boston, pp 179-184.

Naresh Kumar M, Murthy CS, Seshasai M and Roy PS. 2009. On the use of standardized rainfall index (SPI) for drought intensity assessment. *Meteorological Applications*, 16(3), 381-389.

Patel NR, Chopra P and Dadhwal VK. 2017. Analyzing spatial patterns of meteorological drought using standard precipitation index. *Meteorological Applications,*14: 329-336.

Reddy RA. 2017. Environmental deterioration: Water conservation management in Anantapur district of Andhra Pradesh. *International Journal of Applied Research,* 3(6): 503-512.

Reddy VR, Reddy YVM and Reddy MS. 2020. Introduction. *In*: Climate-Drought Resilience in Extreme Environments, Springer, https://doi.org/10.1007/978-3-030-45889-8_1.

Reddy YVM. 2017. Ananthaprasthaanamu. Kadalika Prachuranalu, Anantapur, India. Vol. (2): 314-317.

Sivakumar MVK, Motha, RP, Wilhite DA and Wood DA. 2011. Agricultural drought indices. *In*: Proceedings of the WMO/ UNISDR expert group meeting on agricultural drought indices, 2-4 June 2010, Murcia, Spain: Geneva, Switzerland: World Meteorological Organization, AGM-11, WMO/TD No 1572; WAOB-2011, pp 182.

Sukumar S. Devadas C S C and Brema J. 2010. Rainfall distribution and variability in Coimbatore District, Tamil Nadu using GIS technique. *International Journal of Earth Sciences and Engineering*, 9: 596-603.

Venkatachalapathi V, Mrudula G, Narasimha Rao SBS, Anitha V, Sudheer KVS and Reddy MVS. 2012. Rainfall characteristics of Ananthapuramu district of Andhra Pradesh. *Progressive Research*, 7 (Special): 262-266.