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Rainfall analysis over 31 years of Chintapalle, Visakhapatnam, high altitude and Tribal zone, Andhra Pradesh, India

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सार — जलवायु परिवर्तन और परिवर्तिता मॉनसून पर निर्भर कृषि को प्रभावित कर रही है, विशेष रूप से वार्षिक वर्षा की, पूरे भारत में वर्षा पैटर्न और वितरण को प्रभावित कर रही है। वर्षा की परिवर्तिताकी मात्रा स्थानों के अनुसार भिन्न होती है। फलस्वरूप, बदलती जलवायु के परिप्रेक्ष्य में वर्षा परिवर्ती की गतिकी की जांच करना जलवायु परिवर्तन के प्रभाव का मूल्यांकन करने और संभावित प्रशमन रणनीतियों को अपनाने के लिए महत्वपूर्ण है। अधिक जानकारी प्राप्त करने के लिए, भारत के आंध्र प्रदेश के विशाखापत्तनम जिले के चिंतापल्ले में वर्षा वितरणकी जाँच और मात्रा निर्धारित करने के लिए प्रवृत्ति विश्लेषण को नियोजित किया गया है। विश्लेषण के लिए अध्ययन क्षेत्र के विभिन्न कालिक पैमानों (मासिक, मौसमी और वार्षिक) के लिए इकतीस वर्षों 1990-2020 तक की लंबी ऐतिहासिक वर्षा डेटा श्रृंखला काउपयोग किया गया। प्रवृत्ति का पता लगाने के लिए सांख्यिकीय प्रवृत्ति विश्लेषण तकनीक, अर्थात् मान-केंडल (MK) परीक्षण का उपयोग किया गया। प्रवृत्ति परिमाण की गणना करने के लिए, सेन के ढलान की गणना के लिए थेल-सेन दृष्टिकोण (TSA) का उपयोग किया गया। 31 वर्षों के लिए डेटा का विस्तृत विश्लेषण इंगित करता है कि अध्ययन क्षेत्र में विभिन्न समय पैमानों पर वृद्धि और गिरावट की प्रवृत्ति और रैखिक प्रतिगमन से प्राप्त 2.13 मिमी प्रति वर्ष वार्षिक वर्षा के लिए सकारात्मक बढ़ती हुई प्रवृत्ति थी। वर्षा के विचलन विश्लेषण से क्षेत्र में अधिक बार सामान्य वर्षा की संभावना को दर्शाया गया। वर्षा विसंगति सूचकांक (RAI) विश्लेषण से पता चला है कि यह अधिकांश वर्षों के लिए सामान्य है। जबकि पिछले दस वर्षों में सूखे की आवृत्ति तीन गुना हो गई है, लेकिन परिमाण कम है। वार्षिक मानक वर्षण सूचकांक (SPI) के परिणाम बताते हैं कि 2002 प्रचण्ड रूप से शुष्क वर्ष है।अध्ययन के परिणाम जल संसाधनों के प्रभावी उपयोग के साथ वर्षा के जोखिमों को समझाने में मदद करेंगे जो आंध्र प्रदेश के चिंतपल्ले क्षेत्र में स्थिरता प्राप्त करने के लिए अग्रिम चेतावनी हेतु पूर्वानुमान प्रणालियों की सहायता से फसल उत्पादकता और प्राकृतिक संसाधनों के प्रबंधन की संभावना को बढ़ा सकते हैं।

ABSTRACT. Climate change and variability impacting the monsoon dependent agriculture, particularly of the annual rainfall, effecting the rainfall pattern and distribution across India. The extent of the variability of rainfall varies according to locations. Consequently, investigating the dynamics of rainfall variables from the perspective of changing climate is important to evaluate the impact of climate change and adapt potential mitigation strategies. To gain insight, trend analysis has been employed to inspect and quantify the rainfall distribution in the Chintapalle, Visakhapatnam district of Andhra Pradesh, India. Thirty-one years for the period from 1990-2020 long historical rainfall data series for different temporal scales (Monthly, Seasonal and Annual) of the study region were used for the analysis. Statistical trend analysis techniques, namely Mann-Kendall (MK) test' was used to detect the trend. To compute trend magnitude, Theil-Sen approach (TSA) was used for calculation of Sen's slope. The detailed analysis of the data for 31 years indicates that there were rising and falling trends on various time scales in the study area and positive increasing trend for annual rainfall with 2.13 mm per year derived from linear regression. Departure analysis of rainfall indicated that a possible chance of normal rainfall, more frequently in the area. Rainfall Anomaly Index (RAI) analysis revealed that normal for most years. While the last ten years, the frequency of drought occurrence has thrice, but the magnitude is low. The annual Standard Precipitation Index (SPI) results showed that 2002 is a severely dry year. The study results will help in persuading the rainfall risks with effective use of water resources which can increase crop productivity and likely to manage natural resources by assisting the forecast systems for advance warnings to achieve sustainability at Chintapalle region of Andhra Pradesh.

Key words – Linear regression, Man-Kendall test, RAI, SPI, Rainfall trend analysis and Sen's slope estimates.

1. Introduction

Global food security and climate change are the major challenges facing the world today and remain so in the future. Climate change and its influence on the uneven pattern of monsoon, extreme temperatures, droughts, floods, humidity, heat waves, cyclones and climate variability are apparent causing a serious threat to the food production systems and sustainability of ecosystems (Wang *et al.*, 2016), which the availability of fresh water resources will be reduced in future (IPCC, 2018). The changes in rainfall trends are directly associated with climatic changes and according to the IPCC 2018 report, limiting global warming to 1.5°C compared with 2°C would provide stability of natural resources and agro-ecosystems. Climate variability would exacerbate extreme weather and changing rainfall patterns leads to indirectly rising crop water demands in warmer climate (IPCC, 2014) ultimately decreasing crop productivity.

Rainfall is the major source of fresh water on earth and an important element of all types of life. The Agriculture mainly depends upon time of occurrence and amount of rainfall over any area globally to meets the rising demands of industrial and domestic water supply. Furthermore, agricultural sector is the key production system in India and contributes 16.5% of the gross domestic product while providing employment to around 66 per cent of the country's population (World Bank, 2019). Indian farmers mainly depend on the seasonal monsoon rains for agricultural production. At present, about 60% of the total net sown area is rainfed, contributing to a significant amount of the total food production as well as to the livestock population (Das *et al*., 2018). In a report of the Central Water Commission, India (CWC, 2005), the annual average precipitation in India is about 4000 billion cubic meters (BCM) of which only 3882.07 BCM were received annually. Therefore, it is apparent from the report that there is a reduction in the annual average rainfall over the country signifies a decreasing trend in precipitation (Mondal *et al.*, 2012). The yield of crops, particularly in rainfed areas, depends on the rainfall pattern, which makes it important to predict the probability of occurrence of rainfall from the past records of data using statistical analysis (Arvind *et al*., 2017).

The information regarding variability, trends, extreme events, climatology, etc. of the rainfall over the region are very valuable for scientists working in agriculture. The accurate prediction of rainfall variability is very valuable for crop yields. The variation in the temporal scale, distribution and amount of rainfall, can consequently bring changes in the social status of farmers. Consequently, understanding the rainfall variability and its prediction has become most important climate research all over the world. Its importance has further increased due to the projected changes in the rainfall patterns and frequency of extreme rainfall events over various parts of the globe in association with global warming (IPCC, 2007).

To cope with rainfall patterns, a comprehensive analysis of time 'series rainfall events at regional level is required for rainfall forecasting for current and future scenario. The interpreted results from such studies would profitably benefit natural resources management, enable drought mitigation, socio-economic development, and for the sustainability of a region. Tabari and Talaee (2011) have observed that trend analysis of climatic variables has recently received a great deal of interest from scientists and researchers. Characterization of spatio-temporal trends of meteorological variables is vital to assess climate-induced changes and recommend feasible adaptation strategies.

Rainfall variability and trends in extreme events were analyzed by several researchers in their studies using parametric and non-parametric techniques to study spatial and temporal trends of rainfall and other meteorological elements variability across the globe (Mahmood and Jia 2017; Mohorji *et al.*, 2017; Al Saleem 2018; Karam A. Elzopy *et al.*, 2020; Srivastava *et al.*, 2020) and in India (Pingale *et al.*, 2016; Panda and Sahu, 2019; Elbeltagi *et al*., 2020). For instance, Donat *et al.* (2014) suggested non-significant changes in spatio-temporal variability of precipitation in Saudi Arabia. In a study by Kiros *et al.* (2016) the spatio-temporal trend analysis of annual rainfall came up with different results reporting non-significant positive and negative trends in different parts of Northern Ethiopia. Conversely, Sharma *et al*. (2000) reported positive trend for the Kosi basin in Nepal and Kumar *et al*. (2005) reported the positive trend in Himachal Pradesh in India. The negative rainfall trends are reported by others, a decreasing trend in annual rainfall in the west of Ethiopia was also reported by Admassu and Seid (2006). However, Singh and Sen Roy (2002) for Beas basin and Kumar and Jain (2010) for Qazigund and Kukarnag of Kashmir reported a negative trend in rainfall. In other study, a decreasing trend in summer and annual rainfall in northern, northwestern and western parts with an increasing trend in annual rainfall in a few grid points in the eastern parts of Ethiopia has been observed (Wagesho *et al*., 2013).

The uniqueness of this investigation lies particularly in the high altitude zone, the rainfall can be extremely variable in space and time. Prior to this study, there were no studies conducted in this region due to lack of long-term rainfall data. Besides, this study was taken to assess

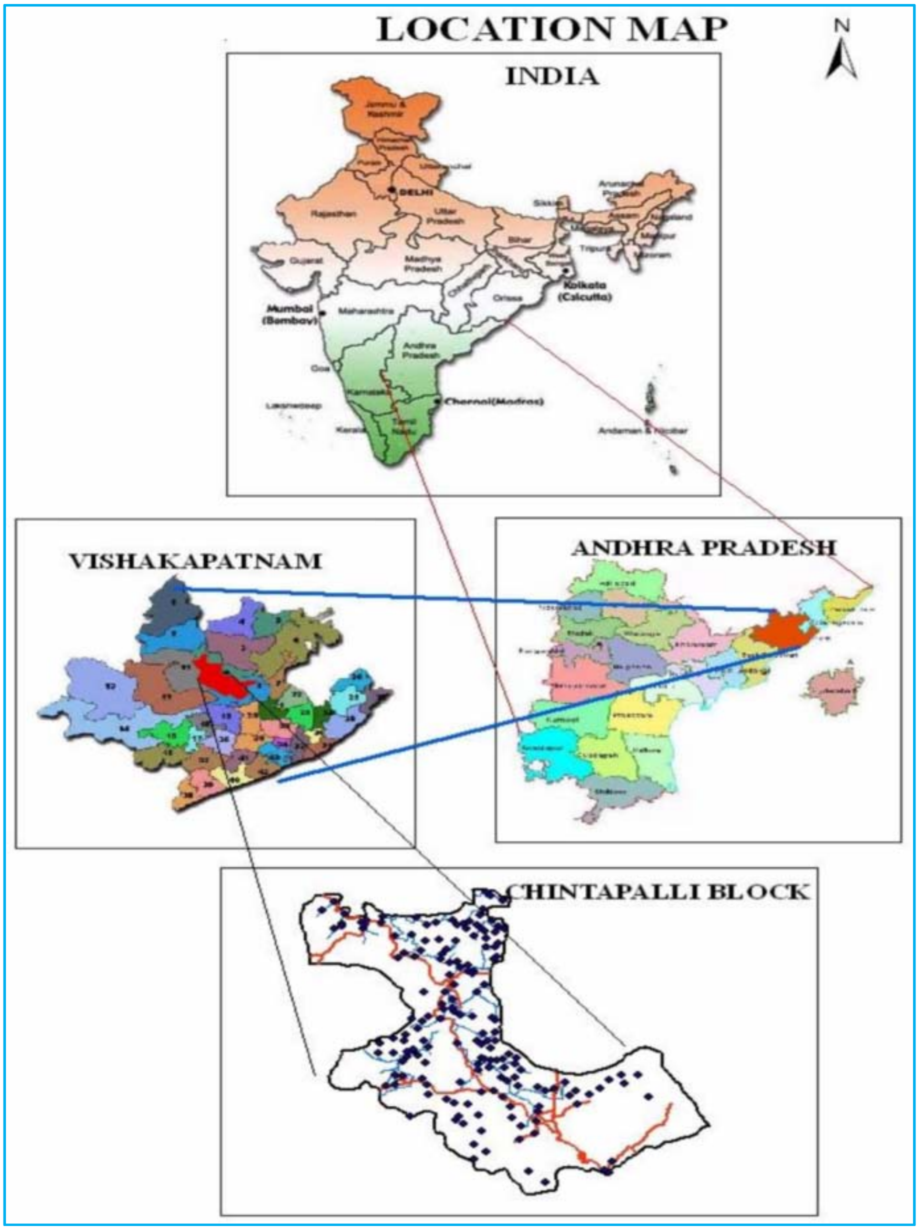


Fig. 1. Location of study area in India (Prakasam *et al*., 2010)

the changing water availability over the study area. Studies of different time series data have proved that rainfall trend is either decreasing or increasing. Therefore, in the present study, temporal characteristics of rainfall for Chintapalle region of Andhra Pradesh state, India were analysed using long-term (1990-2020) monthly rainfall data with the following objectives (*i*) the study aims to evaluate temporal trends and magnitude of annual, seasonal and monthly rainfall during long-term (1990-2020) and (*ii*) computation of long-term Rainfall Anomaly Index and Standard Precipitation Index for identifying rainfall deficit year using long-term annual rainfall data.

2. Study area

The Chintapalle area is located in a high altitude and tribal zone in Visakhapatnam district of Andhra Pradesh. It is situated at Latitude: 17.6765°N, Longitude: 82.3419°E at 768 meters elevated from mean sea level (Fig. 1). The study area falls under high rainfall region with an average annual rainfall of 1400-1500 mm. But due to the absence of efficient irrigation system, farmers lack assured irrigation facility. The region's climate differs greatly with landscape, slopes and season. The high altitude region is characterized by heavy rainfall

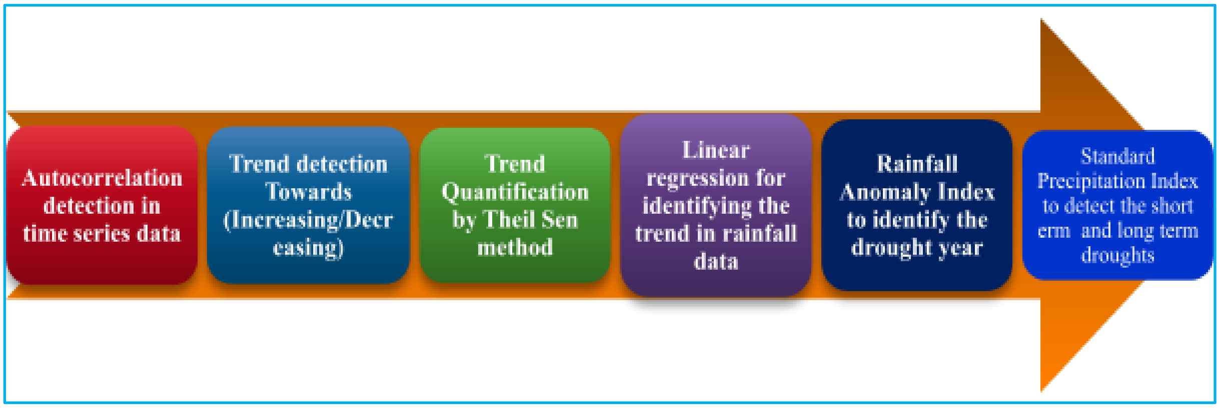


Fig. 2. Methodological framework of the study

influenced by the southwest monsoon, which arrives in the May- June and continues till the end September during the *kharif* season, followed by October and November in early *rabi* constitutes the retreating monsoon coupled with dry winter weather in January and high day temperatures are rising in the summer season. The minimum and maximum temperatures recorded are 3-12°C (Shekhar *et al.*, 2020) during winter season and 23-38°C during summer season. The region is more suitable for growing field and horticultural crops. Based on the above climatic situations where farmers plan their cropping systems, crop selection and other farm operations. The important field crops harvested in the study area are paddy, maize, ragi, sama, korra, groundnut, redgram, turmeric, ginger, rajmash, niger and sweet potato etc., In some situations, most of the farmers are facing problems like crop failure due to unfavourable weather conditions like continues heavy and unexpected rainfall and sometimes prolonged dry spells which are major constraints on the tribal farming community. Under such conditions by knowing the trend of rainfall of all the months by using non-parametric tests may gain knowledge for researchers and guide tribal farming community on cropping systems and choice of crops to be cultivated under adverse situations.

3. Material and methods

3.1. *Source of rainfall data*

The primary source of daily rainfall events is collected from rain gauges of meteorological observatory, GKMS unit, AMFU, Regional Agricultural Research Station (RARS), Chintapalle. Daily precipitation data for 31 years (1990-2020) were obtained from RARS, Chintapalle. The data includes daily precipitation events, maximum and minimum precipitation during a month and high intensity rainfall events. The temporal scale chosen for the study was monthly, seasonal and annual.

3.2. *Methodology for trend detection and quantification*

Statistically a trend is a significant change over time which is detectable by parametric and non-parametric procedures while trend analysis of a time series consists of the magnitude of trend and its statistical significance. Year wise data was arranged for all the months of 31 years and statistical distribution was applied to assess the behavior of data and trend analysis was done using real statistics software. In this study, the trend was investigated using non-parametric Man-Kendall (MK) test. A non-parametric test is taken into consideration over the parametric one since it can evade the problem roused by data a skew (Smith, 2000). The MK test has been formulated by Mann (1945) as a non-parametric test for trends detection and the test statistic distribution had been given by Kendall (1975) for testing non-linear trend and turning point. Since the MK test needs serially independent time series data, the autocorrelation is tested before the test is carried out. For serially correlated the rainfall data series, modified Mann-Kendall (MMK) was applied for trend detection. For quantification of trend magnitude, Theil-Sen approach (TSA) was used for calculation of Sen's slope. Further, the abrupt change year detection in the trend was performed using Rainfall Anomaly Index. The Methodological framework followed for the study was shown in Fig. 2.

3.3. *Detect autocorrelation*

Prior to trend detection by the MK test, the rainfall time series data was tested for autocorrelation using the following equation (Serrano *et al.*, 1999; Yue *et al.*, 2002). Autocorrelation is a time series technique to measure the linear relationship between lagged values of the time series. With a positive autocorrelation in the series, possibility for a series of being detected as having a

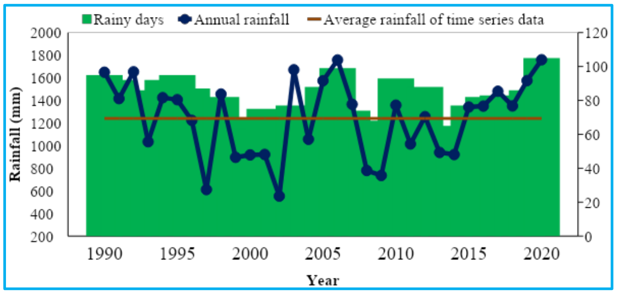


Fig. 3. Annual Rainfall (mm) and rainy days in Chintapalle region from 1990 to 2020

trend is more, which may not always be true. On the other hand, this is the reverse for negative autocorrelation in a series, where a trend is not detected. The Higher deviation of these coefficients from zero, indicates more dependency of the series at a specific time with its lag values (Al Subih *et al.*, 2021).

The lag-1 autocorrelation (ρ*k*) of a discrete time series for lag *k* is projected as:

$$\rho_k = \frac{\sum_{t=1}^{n-k} (x_t - \bar{x}_t)(x_{t+k} - \bar{x}_{t+k})}{\left[\sum_{t=1}^{n-k} (x_t - \bar{x}_t)^2 \times \sum_{t=1}^{n-k} (x_{t+k} - \bar{x}_{t+k})^2\right]^{1/2}}$$

where, $\bar{x}_t$ and Var (x_t) are considered as the sample mean and sample variance of the first ($n - k$) terms respectively, and $\bar{x}_t + k$ and Var $(x_t + k)$ are the sample mean and sample variance of the last ($n - k$) terms respectively.

The autocorrelation of time series data is tested using the following equation:

$$\frac{-1-1.645\sqrt{n-2}}{n-1} \le \rho k \le \frac{-1+1.645\sqrt{n-2}}{n-1}$$

Upper confidence limit $\le \rho k \le$ Lower confidence limit.

The time series data is serially correlated if ρk value is outside the upper and lower confidence limits, otherwise, it is independent observations. Plot of Autocorrelation functions (ACF) graphically indicates the magnitude of serial correlation (Naveena, 2015).

3.4. *Trend detection*

For independent time series data, MK test is used for trend detection. Modified Mann-Kendall tests are used for

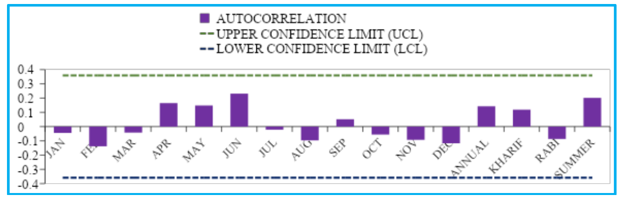


Fig. 4. Autocorrelations for Lag-1 at different temporal scales

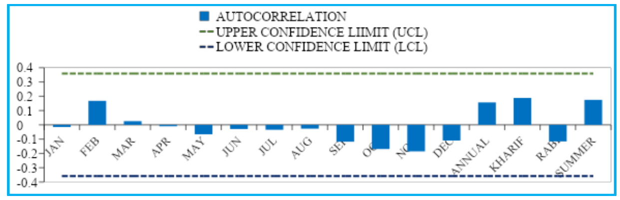


Fig. 5. Autocorrelations for Lag-2 at different temporal scales

trend detection when time series data is not random and affected by autocorrelation. The autocorrelation coefficient of time series data is calculated and tested at various confidence limits and results showed that no autocorrelation was detected in the rainfall data. Therefore, Mann-Kendall (MK) test can be performed instead of the MMK test to identify the trend in a given set of rainfall data.

Mann-Kendall Test : The Mann-Kendall (MK) test is a rank based non-parametric test performed to identify important trends in time series data (Pingale *et al.* 2016; Suryavanshi *et al.*, 2014). The Mann-Kendall test statistic (S) is computed by the following equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i)$$

The application of the trend test is done to a time series x_i that is ranked from i = 1,2,………*n*-1 and x_j, which is ranked from $j = i$ + 1,2,……….*n*. Each of the data points x_i are taken as to a reference point which is compared with the rest of the data points x_j so that,

$$\mathrm{sgn}(x_j - x_i) = \left[+1, > (x_j - x_i) 0, (x_j - x_i) - 1 < (x_j - x_i)\right]$$

It has been documented that when $n \ge 10$, the statistic S is approximately normally distributed with the mean E(S) = 0

The variance statistic is given as :

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18}$$

where, t_i is considered as the number of ties up to sample *i*. The test statistics Zc is computed as :

$$z_c = \left\{ \frac{S-1}{\sqrt{\mathrm{Var}(S)}} 0; \frac{S+1}{\sqrt{\mathrm{Var}(S)}} \right\} \quad \begin{matrix} \text{If } S > 0 \\ \text{If } S = 0 \\ \text{If } S < 0 \end{matrix}$$

Z_c here follows a standard normal distribution. At 5% significance level, the null hypothesis (no trend) and alternative hypothesis (trend) are tested. A negative value of Z_c refers a decreasing trend, and the positive value of Z_c refers to an increasing trend. The null hypothesis H0: there has been no trend in the given series was tested against alternate hypothesis H1: there has been a trend in given series. The null hypothesis where no trend was rejected when the computed Z_c - test the Statistic value was greater in absolute value than the critical value $Z_{1\text{-}0.5\alpha}$, at 95% level of significance.

3.5. *Quantification of magnitude of trend*

Trend quantification is done using the Theil-Sen approach (TSA). TSA is a non-parametric test used for estimating the magnitude of the trend (Theil 1950; Sen 1968). Here, the test estimates the median of all the slope (T_i) among all data pairs with the below equation (Sen, 1968):

$$T_i = \text{median}\left(\frac{xj - xk}{j - k}\right)$$

where x_j and x_k are considered as data values at time, *j* and *k* (*j*>*k*) correspondingly. The median of these *N* values of T_i is represented as Sen's slope and computed from:

$$Q_i = \left[T_{N+1/2} 1/2 \left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}} \right) \right] \quad \begin{matrix} \text{N is Odd} \\ \text{N is Even} \end{matrix}$$

Sen's slope is computed as $Q\text{med} = T_{(N+1)/2}$ if *N* appears odd, and it is considered as $Q\text{med} = [T_{N/2} + T_{(N+2)/2}]/2$ if *N* appears even. At the end, *Q*med is computed by a two-sided test at 95% confidence interval and then a true slope can be obtained by the non-parametric test. A Positive value of Q_i indicates a rising trend and a negative value of Q_i gives a falling trend in a time series.

3.6. *Linear regression*

For identifying the trend in the rainfall data, the statistical analysis of linear regression was used. Linear regression is one of the simplest methods to calculate the trend of data in the time series. The slope is also determined using the linear regression method. Similar to Sen's slope estimate, a positive value indicates an increase in the trend and *vice-versa*. The linear regression line is derived using the following equation:

$$y = a + bx$$

Here, 'a' is intercept and 'b' is the slope of the linear regression line. '*x* and *y*' are the dependent and independent variables respectively (Panda and Sahu, 2019).

3.7. *Departure analysis of rainfall (DAR)*

An area is considered to be drought affected if it receives seasonal rainfall less than 75 % of its normal value as per the classification of India Meteorological Department (Appa Rao 1986). DAR measures the deviation from the mean annual rainfall of a particular year. It can be calculated from the following formula:

$$\mathrm{DAR}(\%) = \frac{xi - xm}{xm} \times 100$$

where, *xi* is the annual rainfall of the year I, *xm* is the mean annual rainfall from the annual rainfall series

3.8. *Rainfall Anomaly Index (RAI)*

It is the simplest and effective index to measure rainfall deficit for long term data. Average monthly rainfall of Chintapalle for a period of 31 years (1990-2020) and the rainfall anomaly of each year were collected using long-term monthly rainfall of the study area. The years with low rainfall value indicates negative (Kumar *et al*., 2021).

The following formula was used to calculate the Rainfall Anomaly Index:

$$\mathrm{RAI} = \frac{[R - \mu]}{\sigma}$$

where, R = Rainfall; μ = Long term average annual rainfall; σ = Standard Deviation

3.9. *Standard Precipitation Index (SPI)*

McKee *et al.* (1993) was a key developer of SPI for monitoring the drought events. He categorized the SPI series into dry and wet conditions. At least a minimum of 30 years of long-term rainfall data is required to determine SPI because the shorter one is likely not to arrest the signals of climatic variability (Wu *et al.*, 2005). Further,

TABLE 1

Dry and wet condition categories based on SPI value

Categories	Extremely wet	Very wet	Moderately wet	Near normal	Moderately dry	Severely dry	Extremely dry
SPI value	2.0+	1.5 to 1.99	1.0 to 1.49	-0.99 to 0.99	-1.0 to -1.49	-1.5 to -1.99	-2 and less

TABLE 2

Statistical analysis of rainfall in Chintapalle from 1990 to 2020 along with Mann-Kendall Trend (Zc)

Temporal scale	Mean (mm)	Minimum (mm)	Maximum (mm)	Median (mm)	Standard deviation (σ)	Coefficient of Variation (%)	% of annual rainfall	Zc-test statistic
January	6.2	0.0	41.2	1	10.9	175.6	0.5	-0.56
February	8.3	0.0	72.0	1	14.8	179.0	0.7	-0.42
March	28.8	0.0	102.4	21	28.6	99.3	2.3	1.06
April	76.8	7.5	242.4	68	46.8	61.0	6.2	0.75
May	98.4	15.0	287.1	92	63.9	65.0	7.9	-0.54
June	164.4	36.8	342.6	146	88.9	54.1	13.3	0.00
July	213.3	36.6	548.8	199	102.8	48.2	17.2	-0.34
August	213.2	35.1	449.5	201	99.7	46.8	17.2	0.58
September	204.9	40.9	542.2	184	112.4	54.9	16.5	0.95
October	170.6	25.0	333.4	164	93.5	54.8	13.8	-0.73
November	44.5	0.0	316.8	28	58.5	131.5	3.6	0.48
December	11.2	0.0	125.2	0	30.9	275.0	0.9	0.51
Kharif	795.8	299.2	1214.4	849	235.4	29.6	64.1	0.20
Rabi	232.6	44.2	478.0	238	114.6	49.3	18.7	-0.03
Summer	212.2	91.6	447.0	196	95.3	44.9	17.1	0.12
Annual	1240.6	553.8	1759.7	1350	342.6	27.6	100.0	0.24

rainfall is statistically not equally categorized, therefore, the records of long-term rainfall is then matched into a standard normal distribution function using gamma probability distribution, with a mean of zero and variance of one (Sönmez *et al.*, 2005). In this study, SPI was calculated on a 1-, 3-, 6- and 12-month timescale for evaluation of meteorological drought in the Chintapalle district of Andhra Pradesh. The present study used the R software with SPEI package and categorized SPI series into seven categories of dry and wet conditions (Table 1).

Positive SPI values point to normal condition to wet condition and negative values indicate normal condition to dry condition. The SPI derived at the end of each year are compared using the given drought range for which bar plots are plotted to identify the drought year and its drought category are explained in the results sections.

4. Results and discussion

4.1. *Descriptive statistics of rainfall*

The descriptive statistics of different temporal scales for 31 years of rainfall using central tendency parameters mean and median and the dispersion of data from mean was done using standard deviation and coefficient of variation, and per cent annual rainfall are discussed in Table 2. And from the calculated table, it was observed that among the months, the highest amount of monthly mean rainfall was recorded in July (213.3mm) which contributed 17.2% to annual rainfall followed by August (213.2mm and 17.2%) and September (204.9mm and 16.5%) respectively. The lowest rainfall was recorded in the month of January (6.2mm) followed by February (8.3mm) and December (11.2mm) and contribution ranged between 0.5-0.7% to annual rainfall. September had the highest standard deviation of 112.4mm and a median of 184mm (Gajbhiye *et al.*, 2016; Kumar *et al.*, 2021). The average monthly rainfall coefficient of variation (CV) ranging from 46.8 to 275.0%. Rainfall variability can be understood by the CV, if CV is less than 20, then rainfall variability is less, if it is 20 to 30, then the variability is moderate and if CV, is more than 30, the rainfall variability is high (Hare, 2003). Based on this, from the calculated data, all the months had above 30% of CV highlighting the high variability of rainfall over the study area. The results indicated that the amount of rainfall in the region is extremely variable. The CV value for August month is less followed by July, June and September compared to December with high variability. This is mainly due to the monsoon period receiving adequate rain from the South-West monsoon compared to non-monsoon period. Moreover, within each month, the rainfall showed a distinct pattern for the study area (Table 2). It can be observed that in June month 342.6mm rainfall event occurred in the year 2007, whereas, the same month received 36.8mm during the year 2014. Similarly, in the November month no rainfall was received during the year 2002, whereas in the year 2012 the same month received 316.8 mm showing distinct rainfall variability within the months. The findings are in accordance with Singh and Mal, (2014) and Panda and Sahu, (2019).

Seasonally, the mean maximum rainfall (64.1% of annual rainfall) was received during the *kharif* season (795.8 ± 235.4mm) having a median of 849mm, whereas the mean minimum rainfall (17.1% of annual rainfall) was received during the summer season (212.2 ± 95.3mm) and the median with 196mm. The highest CV was found for *rabi* season rainfall (49.3%). The mean annual rainfall of the area during the study period was 1240.6 ± 342.6mm with a median value of 1350 mm and 27.6% coefficient of variation. Data showed that the minimum and maximum ever recorded annual rainfalls were 553.8 mm in 2002 (drought year) and 1759.7 mm in 2020 (wettest year), respectively indicating a highly variable rainfall events. The time series graph of annual rainfall of Chintapalle is presented in Fig. 3. The straight line in Fig. 3 represents the average annual rainfall for the time series (1990-2020) is 1240.6 mm which shows that out of 31 years, 12 years in the time series data recorded rainfall less than the average of the given time series. Based on the coefficient of variation values of three seasons (*kharif, rabi* & summer), rainfall variability was observed due to the even pattern of rainfall received during *kharif* season where the highest mean rainfall received during July month followed by August, September, October and June which is mainly due to the south west monsoon occurrence during the months with maximum number of rainy days and uneven pattern of rainfall received in *rabi* and summer seasons. Based on the mean monthly rainfall data, seasonal coefficient of variation and number of rainy days the study region can be assured with good amount of rainfall during the monsoon period and availability of sufficient soil moisture for various agricultural operations and crop growth. The study results are reconfirmed with Arvind *et al.* (2017) found rainfall pattern is found to be erratic based on standard deviation and coefficient of variation.

4.2. *Non-parametric trend analysis for rainfall in Chintapalle*

Time series rainfall data was tested for autocorrelation. It revealed that no autocorrelation was detected in the given data set, hence it may be concluded that the time series data under consideration is an independent on its past values. The data sets of different temporal periods at lag phase1 and lag phase 2 has not reached the upper confidence and lower confidence limits (Figs. 4&5). Hence, Mann-Kendall test was used for trend analysis (Kumar *et al.* 2021).

The results of Mann-Kendall trend analysis for monthly, seasonal and annual rainfall showed a positive and negative trend patterns over 31 years (Table 2). During the period 1990-2020, the monthly trend analysis shows positive rising trend for the months March, April, August, September, November and December. Of which September month resulted with highest positive trend with a magnitude of 2.15mm/year (Sen's slope) followed by August with a magnitude of 1.28mm/year, April and March being Sen's slope of 0.60mm/year and 0.43mm/year respectively. Followed by September (0.95). Negative falling trend was noticed for January, February, May, July and October. Highest negative trend was observed in October with a magnitude of -1.73 mm/year followed by May having Sen's slope of -0.82mm/year and July with a magnitude of -0.63mm/year. June recorded no trend (*Zc* value is 0). The positive increase trend of individual months is observed due to increase in the rainfall across the study period ensuring the farmers to cultivate crops. Furthermore, the months having positive trend falls under the South-West monsoon the *kharif* crops can be cultivated with assured irrigation. Since the Chintapalle region is a hill ecosystem the surface runoff water can be harvested and can be used for supplemental irrigation and irrigation to *rabi* crops. Whereas, negative trend for individual months is due to decreasing rainfall being low rainfall receiving months, which falls under the non-monsoon period except July and can be managed by adopting the contingency measures and irrigation can be applied from the harvested water. Whereas, the July month showed a negative trend and attributed due to change in rainfall pattern due to changing climate and

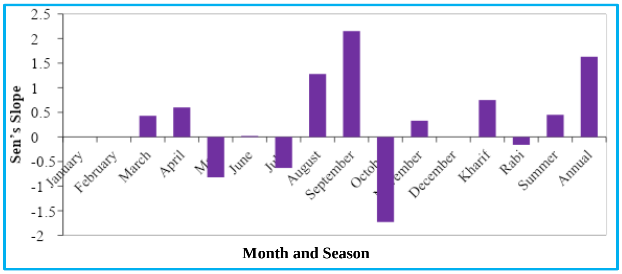
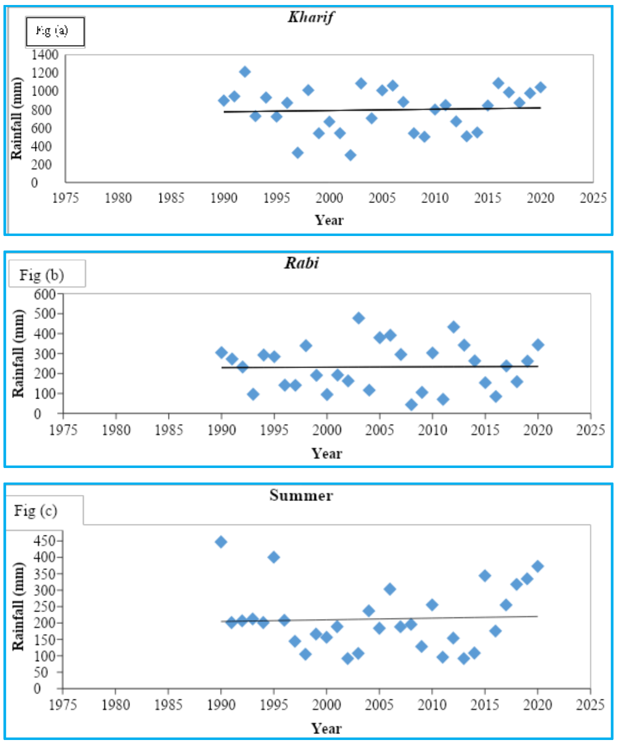


Fig. 6. Sen's Slope of 1990 to 2020 years rainfall events at different time scales



Figs. 7(a-c). Linear regression trends of seasonal rainfall for 31 years (1990-2020) (a) Jun- Sep (*Kharif*), (b) Oct to Jan (*Rabi*) and (c) Feb to May (Summer)

correlates with the findings of Mondal *et al.* (2012) who assessed the 40 years data of river basin of Odisha and opined that there are rising rates of precipitation in some months and decreasing trend in some other months obtained by these statistical tests suggesting overall insignificant changes in the area. June month has no trend since there is uniform rainfall distribution across the study period and variables involved are non-correlated.

Among seasonal rainfall, *kharif* and summer resulted in a positive rising trend with a magnitude of 0.75 and 0.45 mm/year and *rabi* season observed with a negative falling trend being Sen's slope of -0.16 mm/year for the study area. The assured rainfall during the South-West

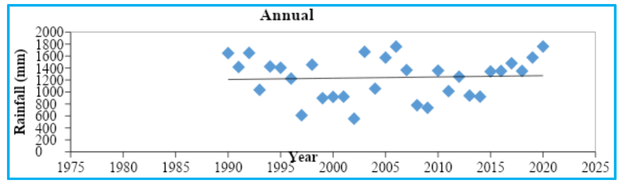


Fig. 8. Linear regression trends of annual rainfall for 31 years (1990-2020)

TABLE 3

Linear regression equations and R^2 values for different time scales

Seasons	Linear regression equation
Kharif	y = 1.41x – 2031
Rabi	y = 0.19x - 154.9
Summer	y = 0.51x - 807.4
Annual	y = 2.13x – 3035

monsoon has resulted in positive trend with an increase in rainfall of 0.75 mm per year. The hilly region receives convectional rainfall during summer which contributed towards positive rising trend with increase of 0.45mm rainfall per year (Prokop and Walanus, 2015). Whereas, uneven distribution of rainfall during *rabi* season has resulted in falling trend with -0.16mm rainfall per year. The annual rainfall from the MK test resulted in rising trend with a positive Sen's slope being 1.63 mm per year. This attributed due to increase in rainfall receiving months with higher magnitude has dominated the low rainfall receiving months with less magnitude contributing to positive increase in trend of annual rainfall during the study period in hill ecosystem. Results obtained using linear regression also showed a similar trend. Fig. 6 shows the magnitude of Sen's slope (Q) for 1990 to 2020 year rainfall data for different time scales. The results are in agreement with and Pingale *et al.* (2016) where the Sen's slope and percentage change in rainfall were estimated over the period of 100 years and revealed that overall upward precipitation trend even though no statistically significant trends were observed for the seasonal and annual scales.

The crop calendars of India are closely attached to the onset, amount, distribution and duration of rainfall which would greatly help the farmers. The main significance of the study is to carefully define the rainfall pattern impacted by climate change; mainly to perceive the change that has already occurred and ultimately plan and manage the water resources to overcome such increasing/decreasing trends (Hussain *et al.*, 2015).

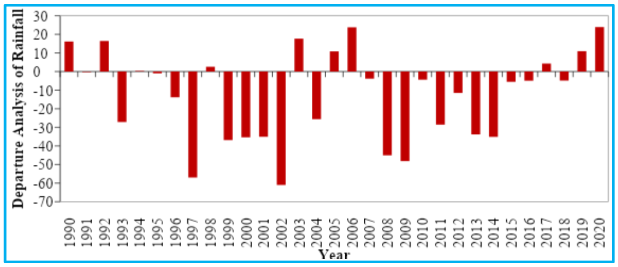


Fig. 9. Departure analysis of rainfall for the time series 1990-2020

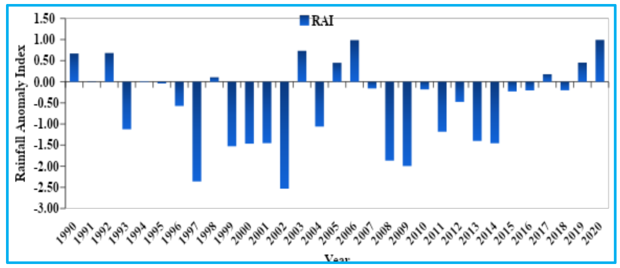


Fig. 10. Rainfall Anomaly Index of annual rainfall 1990-2020

TABLE 4

Departure analysis of rainfall (DAR) of Chintapalle from 1990 to 2020

DAR categories (%)	Rainfall regime	Years (1990-2020)	Maximum recorded annual deficit (%)
≥20	Excess	2	23.92
19 to -19	Normal	17	-13.84
-20 to -59	Deficit	11	-56.91
-60 to -99	Scanty	1	-61.00
≤ -100	No rain	0	-

TABLE 5

Rainfall Anomaly Index (RAI) of Chintapalle from 1990 to 2020

RAI categories	Rainfall regime	Years (1990-2020)
≥ 3	Extremely wet	0
2 to 2.99	Very wet	0
1 to 1.99	Moderately wet	0
0.5 to 0.99	Slightly wet	5
- 0.49 to 0.49	Near normal	13
-0.99 to -0.5	Slightly dry	1
-1.99 to -1	Moderately dry	9
-2.99 to -2	Very dry	3
≤ -3	Extremely dry	0

4.3. *Seasonal and annual trend using linear regression*

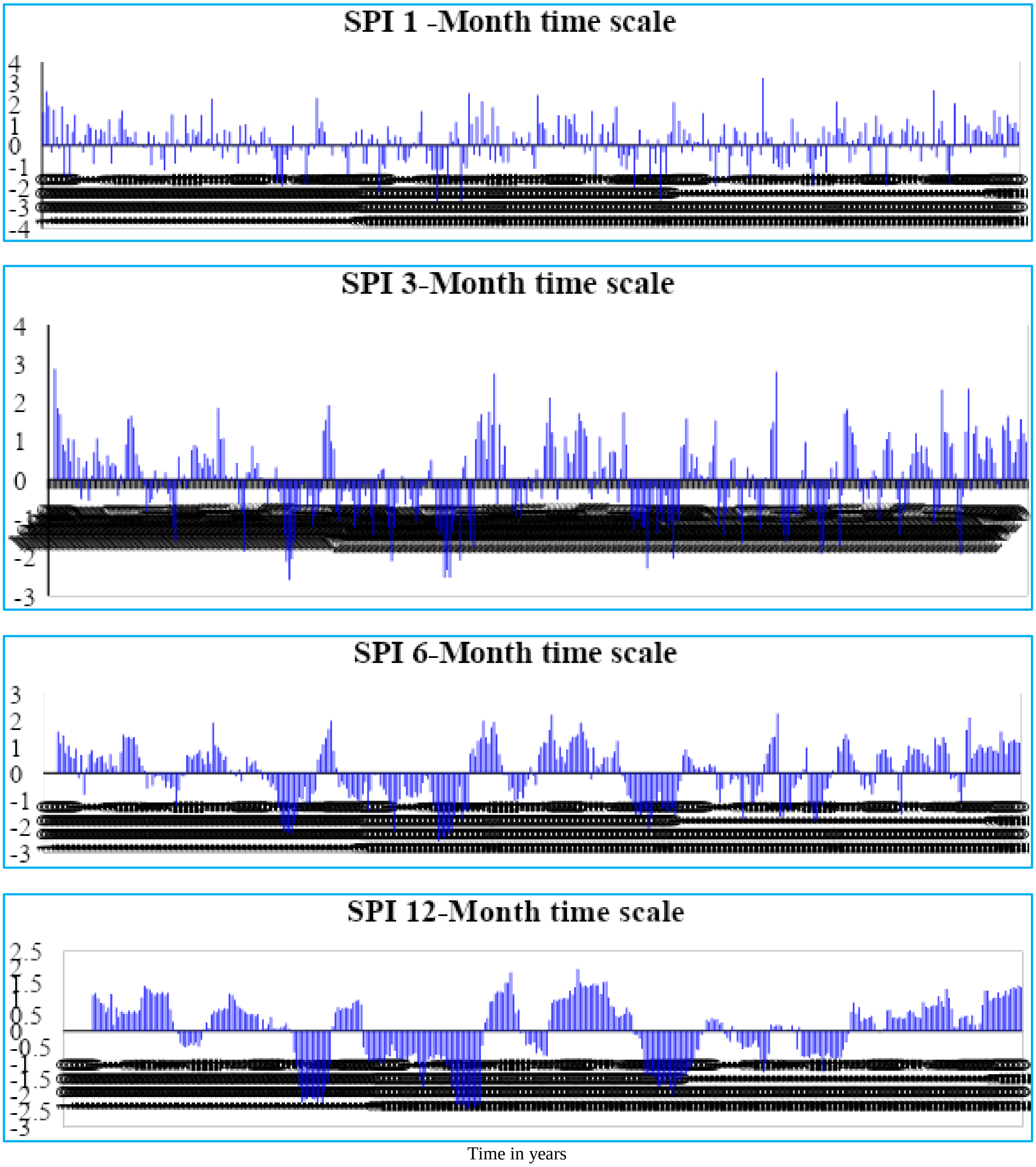
Using a linear regression model (Table 3), the rate of change by the slope of the regression line which in this region was about 2.13, 1.41, 0.19 and 0.51 mm/year for annual, *kharif*, *rabi* and summer, respectively (Fig. 7). The increasing trend for annual rainfall was found to be statistically non-significant. The annual rate of increase is higher, which might be due to increase in the monsoon rainfall season in the Chintapalle region. Annual rainfall observed an increasing trend in the studied region, where the linear regression is showing a positive slope of 2.13 mm/year (Fig. 8). This represents that at Chintapalle, annual rainfall has increased by 66 mm during 1990-2020 period are found in complete agreement with the magnitude and trend of rainfall in all the different significant periods in this study (Kumar *et al.*, 2021; Saini *et al.*, 2020; Panda and Sahu, 2019).

4.4. *Departure analysis of rainfall (DAR)*

The departure analysis of the rainfall indicated that the maximum annual rainfall deficiency during drought year was -61% during 2002. Computed values of departure analysis of rainfall from the 1990 to 2020 (Table 4 and Fig. 9) showed that, normal rainfalls were received for 17 years. However, the annual rainfall was in excess for 2006 and 2020 years, and deficit rainfall regime was experienced during 1993, 1997, 1999-2001, 2004, 2008-09, 2011, 2013-14 years and 2002 year was observed with scanty rainfall regime. Since, number of years falling under normal rainfall regime in this period, indicating a possible chance of the normal rainfall, more frequently. Therefore, based on the results, the departure of annual rainfall from normal rainfall was low and indicates normal rainfall. DAR results are in agreement with the coefficient of variation value of annual rainfall 27.6 indicating moderate variable rainfall (Hare, 2003). The normal onset of southwest monsoon is primarily responsible for the normal rainfall for the study region and deficit south west monsoon during the drought years prevailed drought conditions and subsequent water stress in the study area, thereby adversely affecting the major agricultural operations and correlate with the findings of Karam A. Elzopy *et al.* (2020) who analysed DAR for the 115 years and indicated the extreme dry periods and drought frequency (Thomas *et al.*, 2016).

4.5. *Rainfall Anomaly Index*

The Rainfall Anomaly Index was analyzed for a period of 31 years (1990-2020) to identify the years with meteorological drought. It can be observed from Fig. 10 and Table 5 that RAI was near normal for 13 years, slightly wet for 5 years, slightly dry for 1 year, moderately dry for 9 years and very dry for 3 years. Compared to



Figs. 11(a-d). Temporal distribution of SPI at (a) one month time scale of hill ecosystem of Chintapalle (1990-2020), (b) 3 month time scale of hill ecosystem of Chintapalle (1990-2020), (c) 6 month time scale of hill ecosystem of Chintapalle (1990-2020) and (d) 12 month time scale of hill ecosystem of Chintapalle (1990-2020)

DAR, RAI gives a better picture of representing the magnitude of drought in 4 classes as slightly dry to extremely dry. A large number of years are having negative RAI with a high magnitude being -2.5. The year 2002 occupied the first highest position of rainfall deficit followed by 1997 and 2009, which are remarkable years of very dry with drought occurrence. It can be noticed that very few years have positive RAI with low magnitude. The year 2020 has the highest rainfall magnitude, followed by the year 2006. The RAI results are found in complete agreement with the trend of DAR in this study as said by the researchers Karam A. Elzopy *et al.*, 2020 and Kumar *et al.*, 2021 where the trend analysis from 1901-2015 showed a significant negative trend in RAI and DAR values from 1901 to 1960 which revealing increase in drought frequency during this period. However, no significant trend in RAI and DAR was recorded after 1960.

4.6. *Standard Precipitation Index*

Between 1990 and 2020, SPI time series has been computed at different time scales for hill ecosystem and has been summarized and graphically presented in Figs. 11(a-d). The results of the SPI showed that few years exceeded the extreme wet event (SPI > 2) and extreme drought event (SPI ⇐ 2). Base d on the short term SPI (1-, 3-and 6-month time scales), several drought periods have occurred during the study period. Specifically, from an agricultural point of view, one of the most extremely drought events occurred during the monsoons in July 2002 according to 1-, 3-and 6-month time scales. Extreme drought events were observed in 2000, 2002, 2008 and 2011 during a 1-month timescale. In addition, the analysis of SPI-3 revealed that the years 1993, 1996, 1997, 2000, 2002, 2008, 2009, 2011, 2013, 2014, 2015 and 2018 were affected by extreme and severe drought conditions during SPI 3-month timescale. According to SPI 6-month timescale 1997, 1998, 2001, 2002, 2008-10, 2012-14 and 2017 experienced extreme and severe drought conditions. Similarly, in SPI 12-month timescale years 1997, 1998, 2001, 2002 and 2009. A part from this, *kharif* season was observed with extreme and severe drought events 1997, 2000, 2001-02, 2009, 2012-2014 years based on four timescales.

An overall analysis of the metrological event shows that based on 31 years rainfall data of hill ecosystem a mixture of both dry and wet events were identified. The estimation of drought severity over a specified region gives useful information for water management. Similar findings were reported by Saini *et al.*, (2020) that threshold values of SPI, seasonal and annual SPI values between 1961 and 2017 have been computed for 33 stations and revealed that annually, all stations have experienced either dry or wet conditions for a period of 20 years or longer over the study period of 57 years. Independently, each station has experienced 25-34 dry years and 23-32 wet years, some of which have been severe and consistent with Das *et al.,* (2020). The temporal study also shows that most of the drought events were experienced during the years 1997, 2002 and 2009 particularly during *Kharif* season. SPI-3 results revealed that the monsoon months are more vulnerable than the other seasons. Moreover, June is more prone to severe droughts, whereas July and August are more prone to extreme droughts. Akhtar *et al.*, (2021) who concluded that several drought events with numerous severities were detected in all the four districts of hilly regions during the period 1980-2013 of which 1985 received the most consistent drought event in hill ecosystem. The results of DAR and RAI showed the drought years as in SPI values observed for various time scales of the study area. A recent study on computation of SPI over India assessed by Nandargi and Aman, (2017) revealed that the hilly regions did not record severe droughts compared to plains in the Peninsular India, recorded six severe drought years.

5. Conclusion

In the present study, we have analyzed the rainfall trend of the Chintapalle region to understand the rainfall pattern and variability and provides comprehensive results of changing rainfall trends covering all major seasons of the Chintapalle, the High Altitude and Tribal (HAT) zone of Andhra Pradesh, India. Therefore, it can be concluded that there is evidence of some change in the trend of precipitation which may either positive or negative in different months of 31 years in Chintapalle region of hill ecosystem. The MK test resulted in positive and negative trends on different time scales. The magnitude of the increasing rainfall trend is found to be increasing in this region and correlated with linear regression which shows that the rainfall trend is found to be positively increasing. The assessment of drought years by DAR, RAI and SPI gave a clear understood of rainfall pattern of the study region with more of a normal rainfall and less frequent of drought periods. With increasing *kharif* rainfall, with less decreasing *rabi* rainfall favors the cropping period for timely sowing. Finally, this study assessed the trends of rainfall and drought and its occurrence, and it is expected that this study in hill ecosystem will be a valuable guide toward understanding the high rainfall events and dry periods which help in performing efficient crop planning and management strategies to reduce the problem of drought.

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