



Spatio-temporal analysis of precipitation pattern and trend using standardized precipitation index and Mann–Kendall test in coastal Andhra Pradesh

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Abstract

The most expedient means of analysing global climate change is to analyse the precipitation along with major components of the global atmospheric circulation. Like other Coastal areas, Coastal Andhra is also vulnerable to extreme weather events. So, in this study, the trend and pattern of the precipitation of the Coastal Andhra have been analyzed using daily and monthly rainfall data of 36 years (1983–2018). The standardized precipitation index, rainfall anomaly index and Mann–Kendall tests have been used to analyse the trend and pattern of precipitation. The result showed that the average annual rainfall was 161 cm in 1983 which first declined to 147 cm in 1991 but increased to 181 cm in 2001 and again declined rapidly to 91 cm in 2018. Apart from this normalized difference vegetation index (NDVI) has been used for the years 1983, 1991, 2001, 2011 and 2018 for the validation of dryness and wetness. The statistical analysis shows that rainfall in the study area shows a declining trend at the rate of -1.27 cm per year as per the result obtained by the Sen, slope. Further, the association between mean annual rainfall and NDVI is found to be very strong with a higher positive value of the coefficient of determination.

Keywords Rainfall pattern · Dryness and wetness · Precipitation index · Non-parametric test · Normalized difference vegetation index · Coastal Andhra region

Introduction

Rainfall is an important phenomenon especially for agricultural and allied activities in the coastal Andhra Pradesh region in India (Mishra et al. 2021). Agricultural boost in terms of high yield is based on sufficient amount and distribution of rainfall all through the seasons in any region (Zachariah et al. 2020). Coastal Andhra plain supports a huge population and the region gets ample rainfall through the monsoon and post-monsoon rainfall seasons to sustain (Murthy et al. 2020). Precipitation is a key parameter of climate and climate change identification and also for documentation for future predictions and analysis (Trenberth 2011; Hackenbruch et al. 2017; Kirsta and Loucka 2020; Dong et al. 2021). Global warming has a direct impact on change in precipitation and increased temperature in terms of heat, which leads to accelerant evaporation and consequently drying of surface; result in growing intensity and duration of drought (Trenberth 2011; Hackenbruch et al. 2017; Upal 2020). Precipitation in the form of rainfall serves as the major supporter of living organisms and any alteration

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in frequency, amount and intensity might lead to major consequences for the human and natural systems which work dynamically (Pham et al. 2021). There is a direct effect of rainfall alteration on water resources, agriculture, hydrology, natural ecosystems and also on human health (Islam et al. 2020a; Kaihotsu and Tamagawa 2021). So, it is vital to study the variation of rainfall in terms of temporal and spatial patterns for the sustainable management of water resources (Cosgrove and Loucks 2015; Malik and Kumar 2020). Recent researches have shown variations in the trend of yearly and seasonal precipitation on a global, regional and local scale too (Šraj and Bezak 2020; Praveen et al. 2020; McHale et al. 2021).

In the last few decades, there is a global rise in temperature which has impacted the world climate in terms of increase in precipitation particularly in certain areas (Siddig et al. 2020). Disasters like floods and drought have been occurring in trend based on regions and patterns of precipitations (Hoepe 2016; Mujumdar et al. 2020). For instance, in North America, there is a larger increase and decrease of precipitations in some areas which results in extremities like flooding and drought (Selin and VanDeveer 2011; Brimelow et al. 2017). An increase in temperature results in the melting of glaciers which reduces ice volumes and there is an extension of surface water on lands, rivers, lakes, streams and seas, etc. (Hunt and Byers 2019). In addition to this, some studies predict the increasing number of droughts since there have been variable trends in precipitation patterns across the world (Teegavarapu 2019; Mondal et al. 2021). Extreme high or low amounts of precipitations over certain territory within a time interval causes severe damages to the natural environment, economy and society (Rahman and Islam 2019; Hunt and Menon 2020; Zhang and Zhou 2020; Nillama 2021). Rainfall pattern and trend in India has been irregular throughout the year which also fluctuates with seasons and regions. For instance, a decreasing trend was recorded in subdivisions of Chhattisgarh, Kerala and Jharkhand whereas an increasing trend was seen in Gangetic West Bengal, West Uttar Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Pradesh, Maharashtra, coastal Andhra Pradesh and North interior Karnataka over the recent year (Guhathakurta and Rajeevan 2008; Kumar et al. 2014, 2020). Similarly, the climatic conditions of Andhra Pradesh have been witnessing variations in their trends in recent times. Kumar et al. (2010) reported that mean annual rainfall had an increasing trend in coastal Andhra Pradesh by about 7–9%. Further, Subash et al. (2011) while studying the frequency of floods and droughts in the Eastern coastal region of India including Andhra Pradesh found that monsoon rainfall has an increasing trend. Coastal Andhra Pradesh exhibits seasonal variability in rainfall also and maximum rainfall is received in the monsoon season followed by post-monsoon, pre-monsoon and winter seasons

(Murthy et al. 2020). Besides, coastal Andhra is expected to witness an increased incidence of extreme climatic events in future (Jayasankar et al. 2021).

Studies were also one for assessing trends and patterns in precipitation in the different regions of the world (Šraj and Bezak 2020). For instance, negative trends of annual precipitation are observed in Africa and the Sahel region. Additionally, there were downward trends in precipitation in many other parts of Africa and South Asia (Onyutha 2018). Change in global precipitation patterns is due to change in radioactivity resulting from combined anthropogenic, volcanic and solar sources and these have also played a crucial role in observed trends in mean precipitation. For example, in North Africa i.e. South of Sahara continued aridity is reported throughout the area (Nicholson and Selato 2000; Onyutha 2018). This kind of pattern is persistently present in the western region of the continent and the driest period was observed in the year 1980s. Some recovery occurred during the 1990s, particularly in the easternmost region where precipitation in some years was just above the long-term average (Nicholson and Selato 2000). Even though the Southern part of Africa was relatively moist during the 1950s and 1970s and there was a significant downward trend in precipitation which was being observed since the late 1970s (Hulme and Carter 1998; Nicholson and Selato 2000; Onyutha 2018). Several studies were conducted in India on seasonal rainfall patterns and trends and future predictions such as Murthy et al. (2018) who studied the rainfall patterns and variations due to North-East monsoon in various regions of India using Analysis of Mean (ANOM). Similarly, Hazarika et al. (2016) used monthly rainfall data of Assam, India with a special focus on Dibrugarh employing the seasonal autoregressive integrated moving averages (SARIMA) approach to forecast the future rainfall patterns.

The methodologies have been proposed by scientists from various domains for assessing the magnitude of the precipitation and also to find excess and deficit precipitation (Sperber and Annamali 2014). The standardized precipitation index (SPI), rainfall anomaly index (RAI), Mann–Kendall test, regression, space-time Neyman–Scott (ST-NS), etc. have been used for the assessment of precipitation (Ozonur et al. 2021; Praveen et al. 2020). Along with the precipitation and its impact on land in terms of dryness or drought few methodologies have been developed which have resulted in the formulation of draught-prone assessment indices (Cheval 2015; Tefera et al. 2019; Sultana et al. 2021). The SPI is one of them which been used to evaluate the dryness and wetness of the region was first developed by McKee in 1993 (McKee et al. 1993; Radzka 2015; Saini et al. 2020). In SPI, the dryness and wetness estimation are based on precipitation variables. The wet and dry conditions of an area can be observed and monitored by SPI which is based on a variety of time scales from sub-seasonal to interannual scales (Pathak and

Dodamani 2019; Saini et al. 2020). Standard deviations mean that the observed precipitation would deviate from the long-term mean for normal distribution and fitted probability distribution for actual precipitation record has been expressed by the SPI. Since precipitation is not normally distributed, so a transformation is applied followed by fitting to a normal distribution (Cheval 2015; Sobral et al. 2019).

Climate change has a great impact on annual air temperature and precipitation rate which may be brought to the attention of scientists and scholars worldwide (Alexander 2016; Ballard et al. 2019; Islam et al. 2020a). Changes in annual temperature and precipitation are becoming evident on a global scale (Alexander 2016; Pumo and Noto 2021). Mann–Kendall test has been used for analysing climatic data such as precipitation. The test indicates how the trend is strong in terms of precipitation and also whether the trend is decreasing or increasing (Suryanto and Krisbiyantoro 2018; Nyikadzino et al. 2020).

The present study is conducted to understand the trends and pattern of precipitation in coastal Andhra Pradesh and also to assess the dryness and wetness conditions of the region. This study would be supportive in understanding precipitation patterns and may help in planning and formulation of policies especially in the field of agriculture and allied activities since the region is more favourable for agricultural activities. It can also assist disaster managers and other stakeholders of the area in terms of planning and developmental activities of the coastal area.

Data sources and methods

Study area

Andhra Pradesh is one of the 28 states of India located in south-eastern coast and lies between 12° 41' and 19° 07' North latitude and 76° 50' and 84° 40' East longitudes. The state is diversified into two natural regions based on physical and socio-economic conditions namely coastal Andhra and Rayalaseema. The coastal Andhra is comprised of nine districts and four Districts are included in the Rayalaseema region. The coastal Andhra has an area of 92,906 km² which account for about 57.99% area of the state and 69.20% population. Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Guntur, Krishna, Prakasam and S.P.S Nellore are the nine districts which are on the Coromandel Coast between the Eastern Ghats and the Bay of Bengal, from the northern border with Odisha to Pulicat Lake of South (Fig. 1). The region is drained by rivers like the Krishna, the Kaveri, the Penner and other rivers and this makes the area more favourable for agriculture and allied activities. Andhra Pradesh has the second largest coastline of 974 km. The

coastal Andhra experience a tropical climate and the average annual temperature and rainfall are 28 °C and 100 cm, respectively. There is the variability of precipitation pattern in the state during the south-west monsoon, pre-monsoon and post-monsoon. There is heavy rain occurring in the area due to strong monsoon currents and westerly moving tropical disturbances. During the pre-monsoon, there are short periods of heavy intense convective activities (Guhathakurta et al. 2005).

The Coastal Andhra has about 670 manual gauges and 2387 Automated Weather Stations (AWS). The data have been taken from 412 stations including both manual gauges and (AWS) for about 36 years from 1983 to 2018. Each station has a datum of 36 years and a further average of each station has been computed with monthly average data. After calculating the yearly average of each station, we combined the average of 412 stations and prepared a yearly database for the analysis (Table 1). The overall methodology of the study has been discussed in Fig. 2.

Standardized precipitation index (SPI)

To analyse the daily, monthly and annual mean precipitation of the study area, the SPI technique has been used. A decadal analysis of rainfall trends has also been done using the SPI developed by McKee et al. (1993). The positive value of SPI indicates more than mean precipitation, whereas negative values show less than mean precipitation (Table 2). The index is also used for the probability of occurrence of rainfall with longer period data set (McKee et al. 1993). There is huge relevance and significance of results obtained from the SPI. In meteorological and agricultural drought, short time scale data has proved its utility; whereas in the hydrological field, a longer set of data and time scale is required (Yisehak and Zenebe 2021; Uddin et al. 2020). Standardized precipitation index has been widely used in various fields of hydrology, agriculture, vulnerability assessment of vegetation and water resources, precipitation deficit, etc. (Cheval 2015; Brouzinyne et al. 2020). Many studies conducted with SPI and its relationship with other vegetation indices like NDVI (Ji and Peters 2003; Mohammed et al. 2020) have also discussed the relationship between NDVI and SPI based on moisture availability in the Great Plains of the United States and stated that correlation is significant in both grasslands and croplands.

$$\text{SPI} = \frac{x - \bar{x}}{\text{SD}} \quad (1)$$

where x = actual rainfall; \bar{x} = mean rainfall and; SD = standard deviation from normal rainfall.

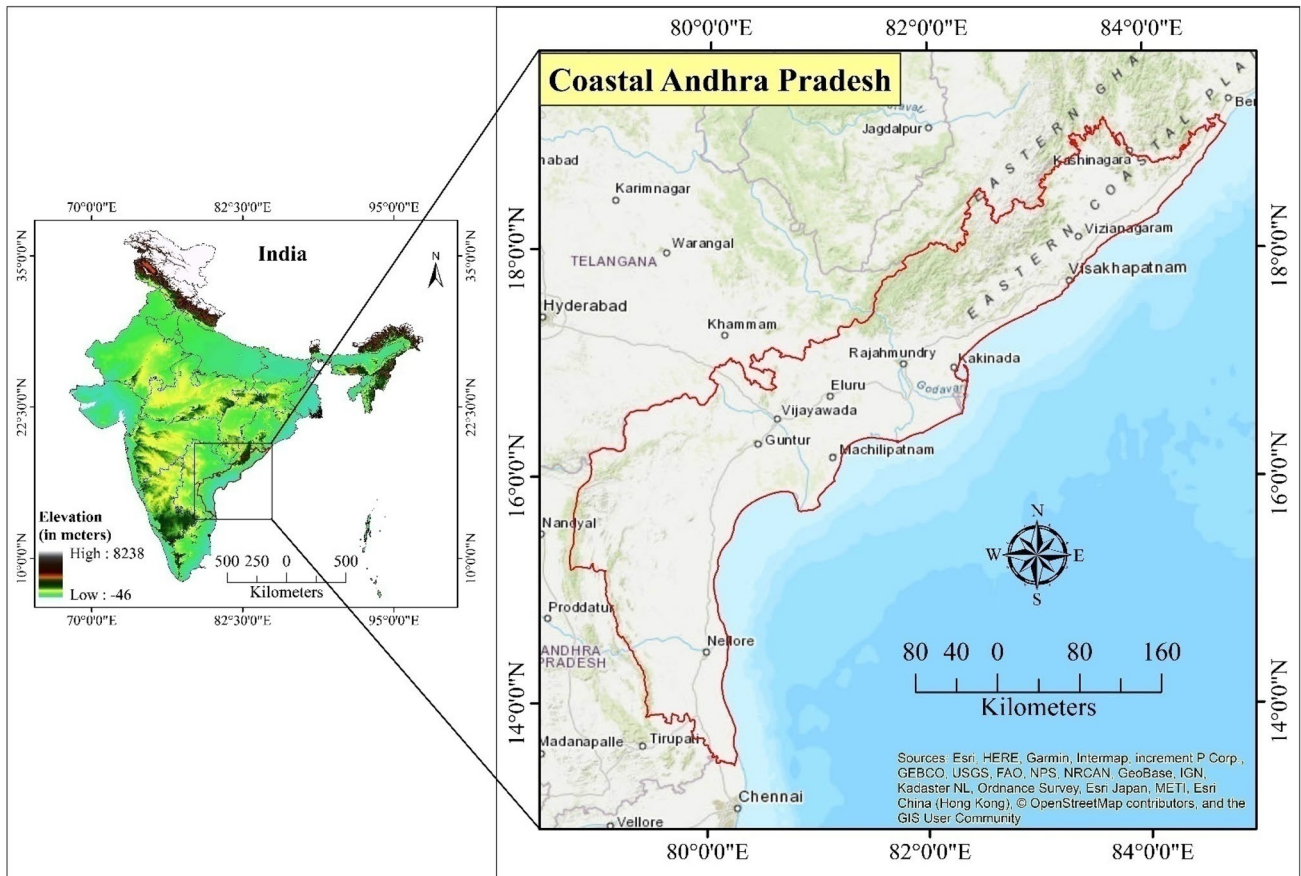


Fig. 1 Locational aspect of the study area

Table 1 Database and sources

S. no.	Data	Spectral bands	Years	Sources
1	Mean monthly temperature	–	1991–2018	India Meteorological Department
2	Annual temperature	–	1991–2018	India Meteorological Department
3	Landsat 4–5 (TM+MSS)	7	1991 and 2011	http://www.earthexplorer.usgs.gov
4	Landsat 7 (TM+ETM)	8	2001	http://www.earthexplorer.usgs.gov
5	Landsat 8 OLI	9	2018	http://www.earthexplorer.usgs.gov
6	Study area shape file	–	–	http://www.bhuvan.nrsc.gov.in

Mann–Kendall test

Mann–Kendall test, a non-parametric test has been used to assess the significance of trends in time series of selected climatic data e.g., rainfall (Ahmad et al. 2015; Gaponov et al. 2019; Praveen et al. 2020). In this test, the null hypothesis assumes that there is no significant trend in data series and vice versa for the research hypothesis (Ahmad et al. 2015; Islam et al. 2020b). The precipitation trend is considered to be significant when the null hypothesis is

rejected. The significance level at 0.05 is determined by the interval $- 1.96 \leq Z \leq 1.96$ which shows no significant trends and it comes under the acceptance region. Value of $Z < - 1.96$ means the trend is significantly decreasing and when $Z > 1.96$, then it shows a significant increasing trend where Z is a normalized test statistic (Zhang et al. 2020).

$$z = \frac{S - \text{sign}(S)}{\text{VAR}(S)^{0.5}} \tag{2}$$

where,

Fig. 2 Flowchart of the methodology

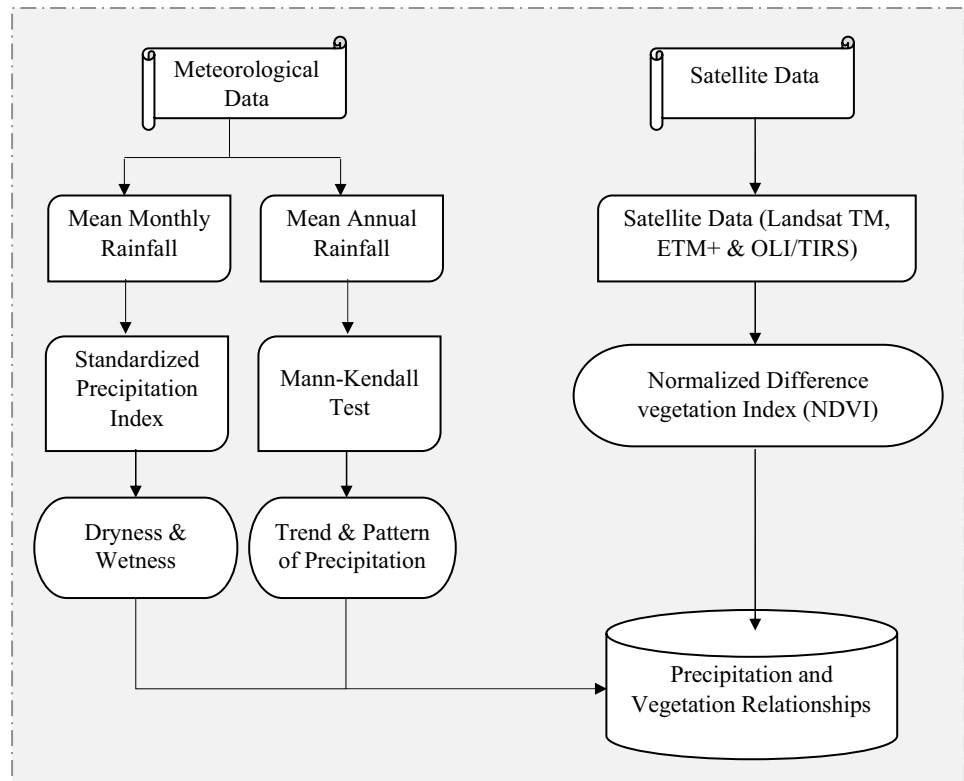


Table 2 Standardized precipitation values based on Mckee et al. (1993)

S. no.	Rating	Value
1	Extreme wetness	≥ 2
2	Severe wetness	$< 2 \geq 1.5$
3	Moderate wetness	$\geq 1 < 1.5$
4	Mild wetness	$\geq 0.5 < 1$
5	Normal	< 0.5
6	Normal	> -0.5
7	Mild dryness	$\geq -0.5 < -1$
8	Moderate dryness	$\geq -1 < -1.5$
9	Severe dryness	$> -2 \leq -1.5$
10	Extreme dryness	≤ -2

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \tag{3}$$

where, $J > K$ and $K = 1, 2, \dots, n - 1$ $j = 2, 3, \dots, n$ and ‘ n ’ is the number of data.

$$\text{Sign}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases}$$

$$\text{VAR}(S) = \frac{1}{18} [n(n - 1)(2n + 5)].$$

With the help of SPI and Mann–Kendall, the rainfall data of coastal Andhra Pradesh has been used for further analysis and assessment of trends and patterns as well as dryness and wetness year. Sen’s slope value is -1.27 which means that rainfall is declining trend at the rate of -1.27 cm per year.

Normalized difference vegetation index (NDVI)

Normalized difference vegetation index (NDVI) is one of the widely used vegetation indexes to observe greenery worldwide (Xue and Su 2017; Shahfahad et al. 2020). NDVI is calculated using Eq. (4); the positive NDVI value shows good health of vegetation whereas negative values indicate bad health (Shahfahad et al. 2021):

$$\text{NDVI} = (\text{NIR} - R) / (\text{NIR} + R). \tag{4}$$

In Landsat 4–7, $\text{NDVI} = (\text{Band } 4 - \text{Band } 3) / (\text{Band } 4 + \text{Band } 3)$.

Whereas in Landsat 8, $\text{NDVI} = (\text{Band } 5 - \text{Band } 4) / (\text{Band } 5 + \text{Band } 4)$.

Karl Pearson's coefficient of correlation between NDVI and mean annual rainfall

Correlation is an index of relationship which measures the degree of association or relationship between two variables quantitatively and it is also termed as co-efficient of correlation (Asuero et al. 2006). The two variables are related and to what extent the variations in one variable can cause a change in another is also described by the technique. It is symbolized either by r or (Rho). Value of r indicates the degree or extent of the relationship between two variables used for the study. If the value of ' r ' is positive then the correlation is positive and if ' r ' is negative then vice-versa. Therefore, the sign of coefficient indicates the kind of relationship and values of ' r ' varies from +1 and -1 (Asuero et al. 2006). Mean NDVI and mean annual rainfall of the year 1983, 1990, 2001, 2011 and 2018 have been used to find the relationship between these two using Karl Pearson's coefficient of correlation using Statistical Package for the Social Sciences Software (SPSS) version 20 (Tables 8 and 9).

Linear regression

Linear regression is a statistical technique that models the relationship between dependent and independent variables with a linear approach. It models the relationship between one or more explanatory variables. In simple linear regression, there is a relationship between one variable and for more than one variable, the method may be called multiple linear regressions (Davies and Hutton 1977; Li et al. 2016). In multivariate linear regression technique, where multiple correlated dependent variables are predicted, rather than a single scalar variable (Ludbrook 2012).

In simple linear regression,

$$y = a + bx \quad (5)$$

where ' y ' is the dependent variable or can be called as the predicted value and ' x ' is the independent variable. The letters ' a ' and ' b ' discuss the y -axis intercept and also the slope of the line mentioned. The goodness of fit of the model is represented by R^2 whose value lies between 0 and 1. The higher value of R^2 shows that the model's fitness is higher and vice-versa. After the correlation between mean NDVI and mean annual rainfall a regression analysis has been done in the SPSS.

Rainfall anomaly index

Rainfall anomaly index (RAI) was developed by Van Rooy (1965) to analyse the intensity and frequency of dryness and

wetness in terms of rainfall. The annual rainfall average is used to calculate RAI for the study area. RAI constitutes the following equations:

$$RAI = 3 * \left[\frac{N - \bar{N}}{\bar{M} - \bar{N}} \right] \quad \text{for positive anomalies} \quad (6)$$

$$RAI = -3 * \left[\frac{N - \bar{N}}{\bar{X} - \bar{N}} \right] \quad \text{for negative anomalies} \quad (7)$$

where: N = current monthly/yearly rainfall, in order words, of the month/year (cm); \bar{N} = monthly/yearly average rainfall of the historical series (cm); \bar{M} = average of the ten highest monthly/yearly precipitations of the historical series (cm); \bar{X} = average of the ten lowest monthly/yearly precipitations of the historical Series (cm).

Results

Trend analysis of precipitation for 36 years

According to standard precipitation index, coastal Andhra Pradesh has shown variation in trends of precipitation for 36 years. Depending on the SPI values 36 years have been categorised into wetness and dryness groups. On the basis of average data, the years have been categorised into normal, moderate and extreme wetness and dryness. Severe dryness was witnessed in the years 2018 and 2011 whereas moderate dryness has been recorded in 2002, 2012 and 2014. Mild dryness is found in the year 2017. Normal precipitation has been experienced by the area in the years 1983, 1991, 1992, 1993, 1994, 1996, 1997, 1999, 2000, 2004, 2006, 2007, 2008, 2009, 2013, 2015 and 2016. Moderate wetness was recorded in the year 1998, 2003 and 2005. 1995, 2005 and 2010 were the years in which coastal Andhra Pradesh has recorded severe wetness (Table 3 and Figs. 3 and 4).

For analysis of rainfall, data was collected for about 36 years and is presented in Table 2. There is a declining trend along with fluctuations of average rainfall from 1983 to 1990. Furthermore, there is a declining trend of rainfall from 147.71 cm in 1991 to 141.41 cm in 1994 and it rises in 1995 to 174.9 cm. Again, the downward trend is noticed from 131.7 cm in 1996 to 141.3 cm in 2000 and with a sharp increase of 181.11 cm in 2001. In 2002 there is a decline in rainfall of 111.16 cm which was lowest in terms of the previous record. Furthermore, the trend rises and rainfall increases to 163.0 cm in 2003 and it fluctuates till 2009. In 2010 the rainfall rises to 175 cm. A sudden rainfall dropped to 90 cm in 2011 is observed. It fluctuates till 2015 and again increases to 128 cm in 2015. From 2016 the rainfall started

Table 3 Analysis of mean annual rainfall pattern of coastal Andhra Pradesh for 36 years

S. no.	Years	Rainfall (X)	\bar{A}	SD	$X - \bar{A}$	$SPI = X - \bar{A}/SD$	RAI
1	1983	161.32	136.18	24.38	25.14	1.03	1.87
2	1984	160.97	136.18	24.38	24.79	1.02	1.83
3	1985	185.32	136.18	24.38	49.14	2.02	4.23
4	1986	157.97	136.18	24.38	21.79	0.89	1.54
5	1987	144.77	136.18	24.38	8.59	0.35	0.24
6	1988	170.70	136.18	24.38	34.52	1.42	2.79
7	1989	153.01	136.18	24.38	16.83	0.69	1.05
8	1990	178.30	136.18	24.38	42.12	1.73	3.54
9	1991	147.71	136.18	24.38	11.53	0.47	0.53
10	1992	124.51	136.18	24.38	- 11.67	- 0.48	- 1.78
11	1993	139.00	136.18	24.38	2.83	0.12	- 0.34
12	1994	141.49	136.18	24.38	5.32	0.22	- 0.09
13	1995	174.93	136.18	24.38	38.75	1.59	3.21
14	1996	131.79	136.18	24.38	- 4.38	- 0.18	- 1.05
15	1997	124.60	136.18	24.38	- 11.58	- 0.47	- 1.77
16	1998	170.47	136.18	24.38	34.29	1.41	2.77
17	1999	128.75	136.18	24.38	- 7.43	- 0.30	- 1.35
18	2000	141.38	136.18	24.38	5.2	0.21	- 0.10
19	2001	181.11	136.18	24.38	44.94	1.84	3.82
20	2002	111.16	136.18	24.38	- 25.02	- 1.03	- 3.10
21	2003	163.01	136.18	24.38	26.83	1.10	2.03
22	2004	147.26	136.18	24.38	11.09	0.45	0.48
23	2005	167.94	136.18	24.38	31.76	1.30	2.52
24	2006	138.11	136.18	24.38	1.93	0.08	- 0.42
25	2007	145.30	136.18	24.38	9.13	0.37	0.29
26	2008	126.61	136.18	24.38	- 9.57	- 0.39	- 1.57
27	2009	126.93	136.18	24.38	- 9.25	- 0.38	- 1.53
28	2010	175.05	136.18	24.38	38.87	1.59	3.22
29	2011	90.67	136.18	24.38	- 45.5	- 1.87	- 5.14
30	2012	104.82	136.18	24.38	- 31.36	- 1.29	- 3.73
31	2013	141.70	136.18	24.38	5.53	0.23	- 0.07
32	2014	108.18	136.18	24.38	- 28	- 1.15	- 3.40
33	2015	128.43	136.18	24.38	- 7.75	- 0.32	- 1.39
34	2016	127.63	136.18	24.38	- 8.55	- 0.35	- 1.47
35	2017	113.46	136.18	24.38	- 22.72	- 0.93	- 2.87
36	2018	91.00	136.18	24.38	- 45.17	- 1.85	- 5.11

X observed annual rainfall, \bar{A} mean rainfall of 36 years, *SD* standard deviation, *SPI* standardized precipitation index, *RAI* rainfall anomaly index

decreasing to 127 cm, 113 and 91 in 2016, 2017 and 2018, respectively (Fig. 3).

Periodic analysis of rainfall pattern

In the study area, we have calculated the SPI along with the Mann–Kendall test for 36 years. The results show that the precipitation is not normal throughout the years taken for the study. A decreasing trend in rainfall for the entire coastal Andhra region is noticed from 1983 to 2018.

Trend of precipitation from 1983 to 2000

The mean annual rainfall of coastal Andhra Pradesh from 1983–1990 is depicted in Fig. 5, which shows that the mean annual rainfall is erratic. The highest rainfall occurred in 1985 with 185 cm and the minimum was recorded in 1987 with 144.7 cm rainfall. Rainfall was moderate to normal in the years 1983, 1984, 1986, 1988, 1989 and 1990. On the whole, the period has a very high irregular nature of precipitation (Table 3).

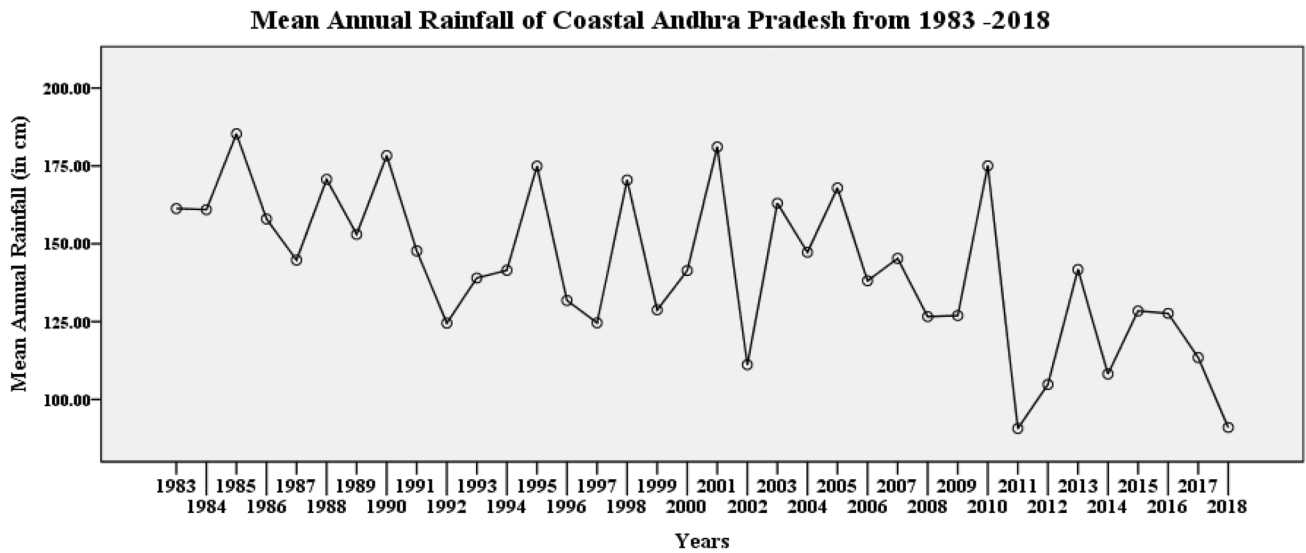


Fig. 3 Mean annual rainfall of Coastal Andhra Pradesh during 1983 to 2018

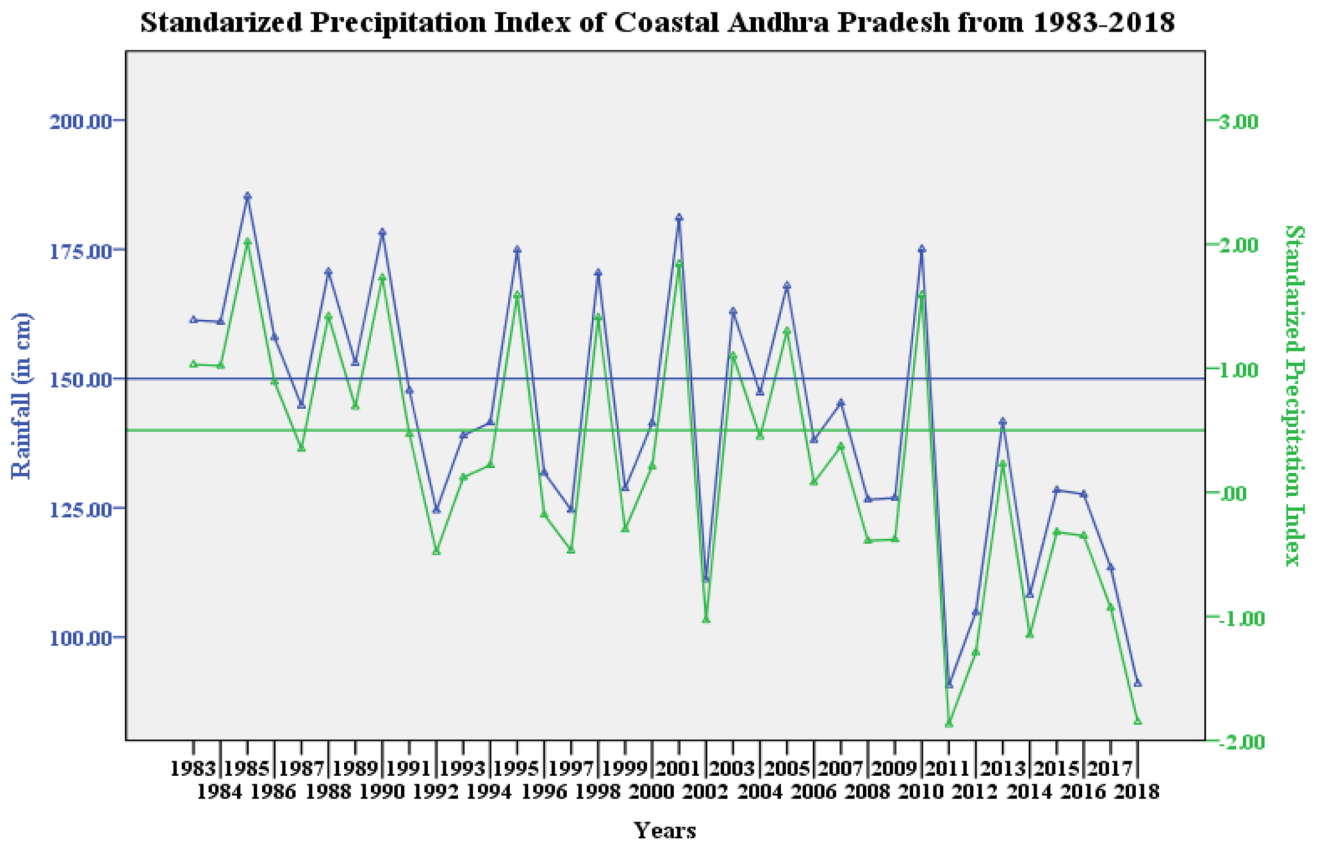


Fig. 4 Standardized precipitation index of Coastal Andhra Pradesh from 1983 to 2018

Trend of precipitation from 1991 to 2000

The mean annual rainfall of coastal Andhra Pradesh from 1991–2000 is shown in Fig. 4. The rainfall pattern is

fluctuating with the highest rainfall in years 1995 and 1998 with the value of approximately 175 cm. In this decade lowest rainfall was recorded in the years 1992, 1997 and 1999 which was close to 125 cm. Precipitation varies in the range

Mean Annual Rainfall of Coastal Andhra Pradesh (1983–1990)

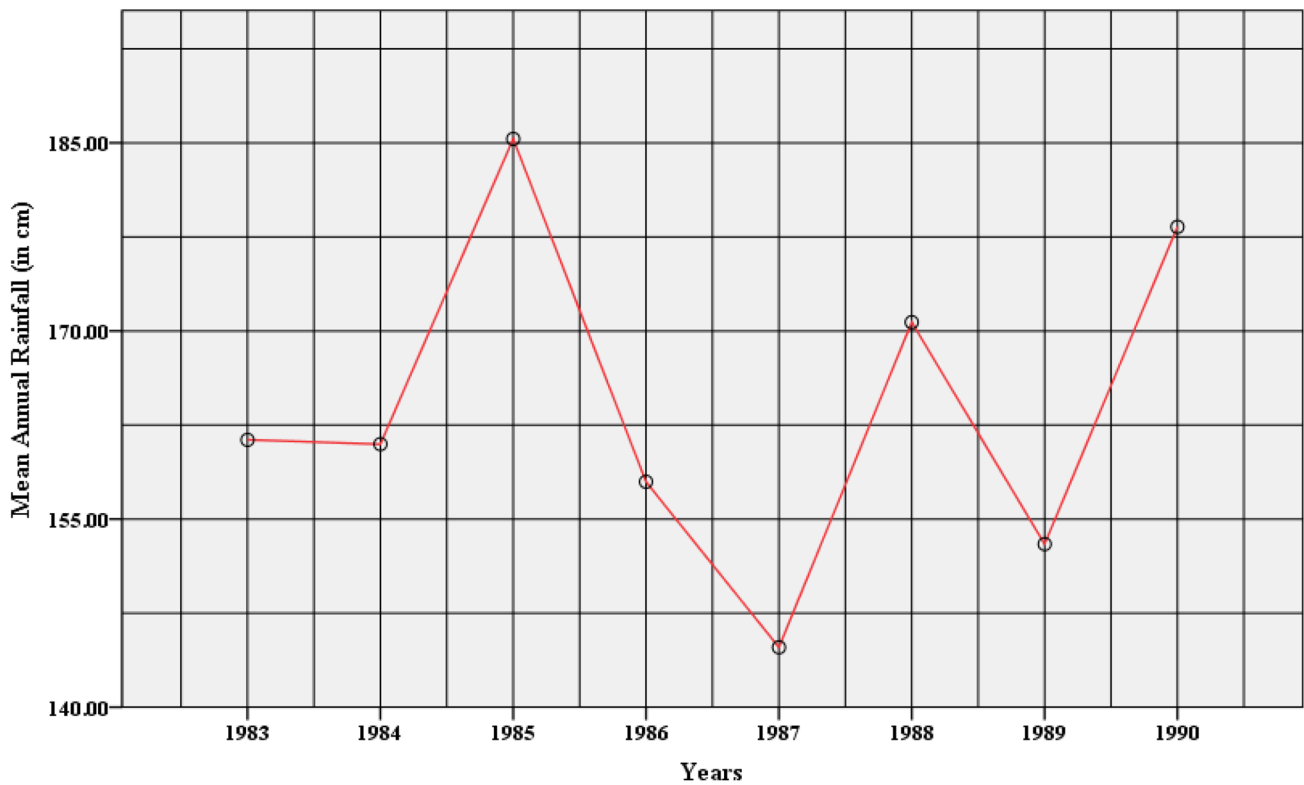


Fig. 5 Mean annual rainfall of Coastal Andhra Pradesh (1983–1990)

125–150 in the years 1993, 1994, 1996 and 2000. The study shows inconsistent nature of average rainfall in all periods (Table 3 and Figs. 4, 6).

Trend of precipitation from 2001 to 2010

The decadal period of 2001–2010 portrays an irregular trend of precipitation as compared to the previous decade (1991–2000). The highest value of rainfall reaches more than 175 cm in the years 2001 and 2011. The lowest rainfall was recorded in the year 2002. In the years 2008 and 2009 the precipitation was above 125 cm and then a sharp increase in rainfall is noticed in the year 2010. An inconsistent nature of precipitation is observed from the year 2002 to 2009 (Table 3 and Figs. 4, 7).

Trend of precipitation from 2011 to 2018

From the year 2011 to 2018 the rainfall shows a drastic change with fluctuations in rainfall patterns and trends in coastal Andhra. The lowest value is observed in the year 2011 and 2018 which is below 90 cm. In this period the maximum rainfall (141 cm) is observed in the year 2013 whereas, approximately 128 cm precipitation has been observed in the years 2015 and 2016. After 2016 the precipitation started

declining as mentioned in the Mann–Kendall test also. In 2012 and 2014 the rainfall was recorded close to 105 and 110 cm respectively (Table 3). Coastal belts of the Bay of Bengal and the Arabian Sea are vulnerable to low-pressure systems (LPS). In the Bay of Bengal, LPS are generated either in situ or due to downstream amplification of waves from the western Pacific Ocean (Rajamani and Sikdar 1989; Meera et al. 2019). The formation of LPS whose occurrence is dependent on the Pacific Ocean has shown a declining trend recently which makes the prediction of LPS and consequent rainfall very difficult thereby weakening the monsoon (Meera et al. 2019). Thus, these unfavourable LPS and weak monsoon over the years can result in the increased frequency of droughts and floods in the coastal regions (Shewale and Kumar 2005; Jena and Azad 2021) (Fig. 8).

Mean annual rainfall of years 1991, 2001, 2011 and 2018 in the coastal Andhra Pradesh

The mean average rainfall of coastal Andhra Pradesh is not uniform in the years 1983, 1991, 2001, 2011 and 2018. There is variation in rainfall patterns in the area due to the climate change scenario. In 1983 the highest value of mean rainfall is 267.12 while the lowest value goes to 13.21 (Fig. 9a). In 1991 the maximum range of mean annual

Mean Annual Rainfall of Coastal Andhra Pradesh (1991–2000)

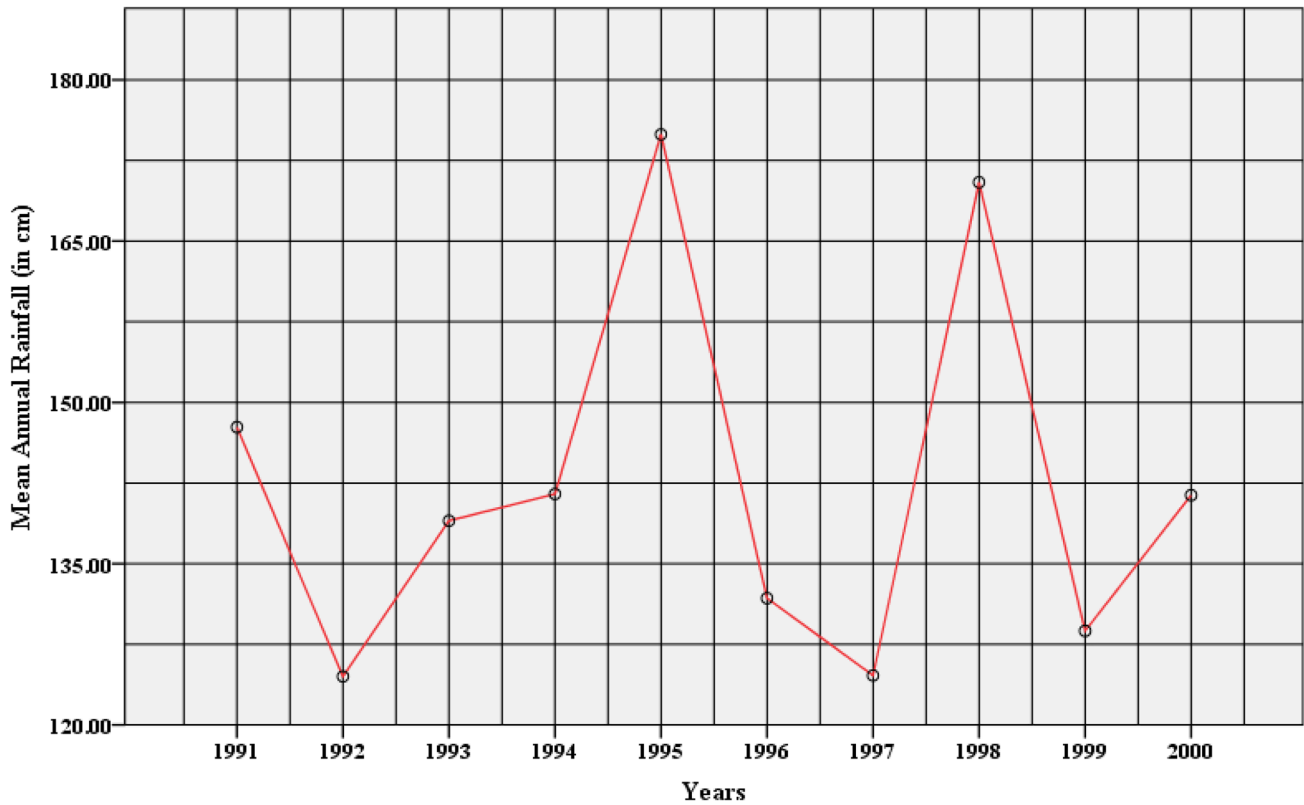


Fig. 6 Mean annual rainfall of Coastal Andhra Pradesh (1991–2000)

rainfall is 253 cm and the minimum are about 0.32 cm in the study area (Fig. 9b). In 2001 the average annual rainfall of the area reaches 338 and the minimum recorded was around 4.07 whereas 167.83 cm was maximum and 61.52 was minimum in 2011 (Fig. 9c, d). The year 2018 has little enhancement in terms of precipitation which shows that the maximum annual mean rainfall value was 218.91 cm and the minimum is 33.21 (Fig. 9e).

The annual average rainfall of coastal Andhra Pradesh

On the whole average annual rainfall of Coastal Andhra Pradesh ranges from 262.53 to 81.21 (Fig. 10a) and a district-wise map was also prepared for the 36 years of precipitation. Srikakulam, Vizianagaram, Vishakhapatnam and East Godavari have shown a better picture in terms of recorded mean annual precipitation data whereas other districts have shown low mean annual precipitation such as West Godavari, Krishna, Guntur, Prakasam, and Nellore (Fig. 10b). Although the precipitation is a major parameter for agriculture and related activities in this region as most of the coastal districts coastal plain rely on agriculture economy (Tables 4 and 5).

Overall trend and pattern of rainfall in the coastal Andhra Pradesh

Coastal Andhra Pradesh shows changes in trends and patterns in terms of precipitation. Rainfall data has been analysed with the help of the SPI and Mann–Kendall test and a fluctuating trend with decreasing nature of precipitation was observed in the coastal Andhra region. The results of the Mann–Kendall test show that at 95% confidence level the value of z is -2.07 which is less than -1.5 , hence the null hypothesis is rejected and the alternate hypothesis is accepted. Hence it can be concluded that rainfall has a significantly decreasing trend.

NDVI of 1983, 1991, 2001, 2011 and 2018 has been calculated for the study area. NDVI value of 1983 ranges from 0.87 to -0.57 and in 1991 it ranges from 0.83 to -0.64 (Fig. 11a, b). In 2001, the maximum value is 0.99 and the minimum is also close to -0.99 (Fig. 11c). In 2011 and 2018 due to less annual precipitation the NDVI values range between 0.70 to -0.51 and 0.78 and 0.57 respectively (Fig. 11d, e).

Mean Annual Rainfall of Costal Andhra Pradesh (2001–2010)

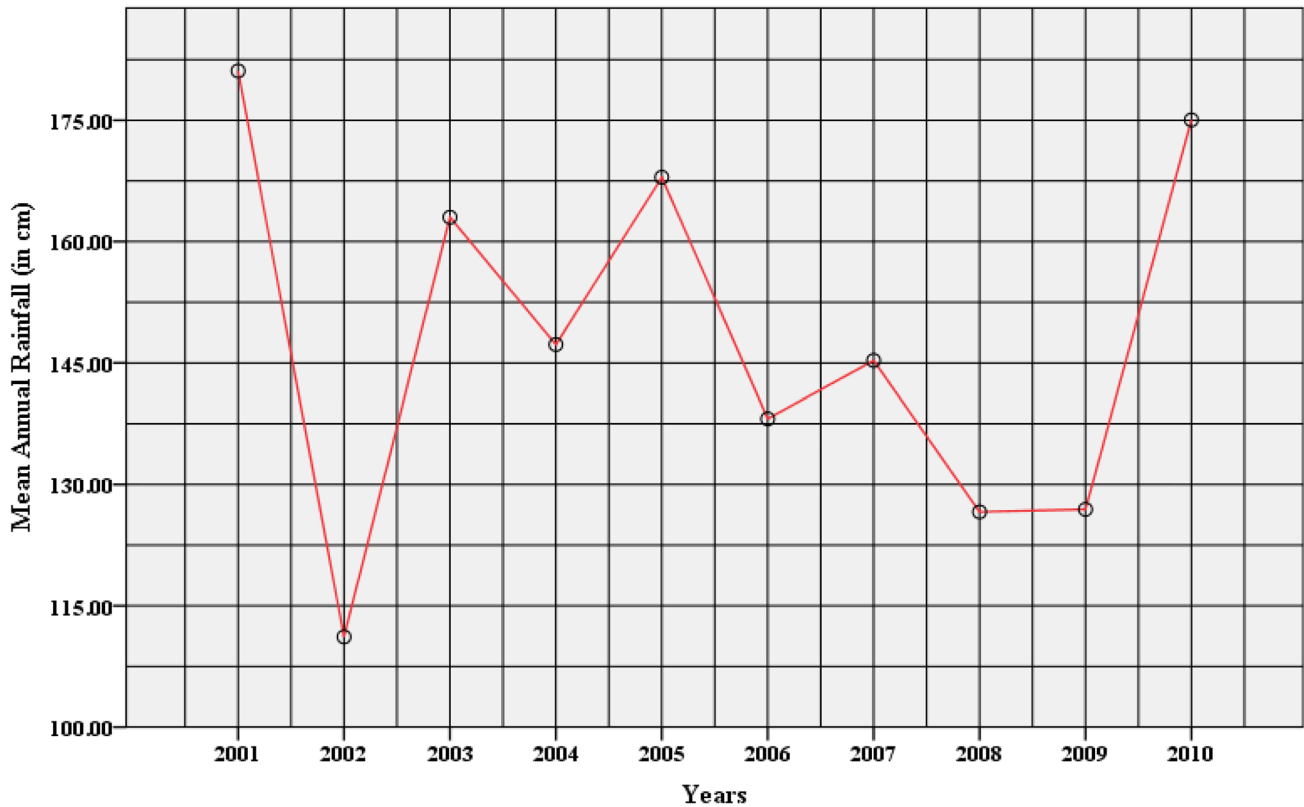


Fig. 7 Mean annual rainfall of Coastal Andhra Pradesh (2001–2010)

Karl Pearson's coefficient of correlation and regression

Coefficient of correlation between mean NDVI and mean annual rainfall has been calculated using SPSS. With the 0.01 significance level of confidence, the correlation is highly positive between mean NDVI and mean annual rainfall. The result hence shows that NDVI and mean annual rainfall is positively related. If rainfall is high then the value of NDVI also goes up (Table 9). The regression line shows that the value $y=0.002x+0.07$ and $R^2=0.98$, so the value of R^2 is higher as such the model is a good fit and there is more variation in the relationship of independent and dependent variables (Fig. 11). Mean NDVI is 0.42 and rainfall is 134.3 cm and standard deviation is 0.10 and 41.41 respectively (Table 6). As per model summary, R is 0.91 and R^2 is 0.98 and adjusted R^2 is 0.97 and Std. The error of the estimate is 0.01 (Table 7) which means that 97.6% variability in NDVI is explained by precipitation. ANOVA test shows that the model is significant as $F(1,3)=160.92$, $p=0.001$ which is significance value (Table 8). Table 9 discusses the slope $y=0.002x+0.07$ which is significant with 0.001 along with that ' t ' is 12.6 which too has a significant level of 0.001. In terms of residuals statistics for predicted value minimum, maximum, mean and Std.

deviation are 0.29, 0.52, 0.40, 0.10 and residuals' minimum, maximum, mean and Std. deviation are -0.01 , 0.02 , 0.00 , 0.013 (Table 10, Fig. 12).

Rainfall anomaly index (RAI)

The RAI is below -4 for the year 2011 and 2018, which may be classified as extremely dry. The years 2002, 2012, 2014 and 2017 have been categorized in very dry with RAI value between -4 and -2 . Dry years are being observed in about 8 years mentioned in Table 3 with a RAI value of -2 to 0 . Humid intensity of rainfall with a RAI value of 0 to 2 is also observed in 8 years (Table 11). Extremely humid intensity is recorded only in 1985 with RAI value above 4 (Fig. 13). Both SPI and RAI are collectively shown in Fig. 13 which also depicts that both the indices increase at the same pace and shows a slight variation in output obtained. There is strong correlation between SPI and RAI with 0.01 significance level (Table 12).

Mean Annual Rainfall of Coastal Andhra Pradesh (2011–2018)

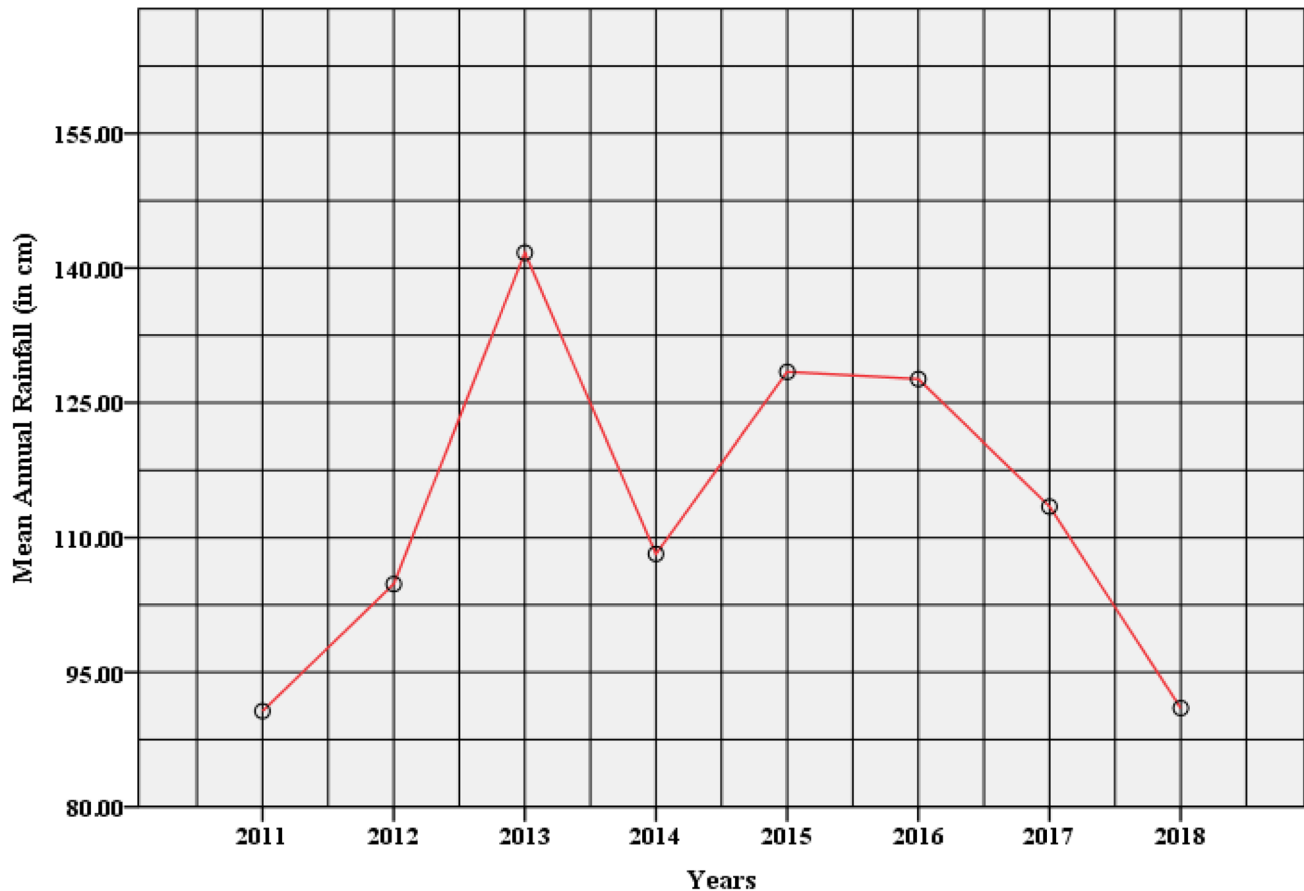


Fig. 8 Mean annual rainfall of Coastal Andhra Pradesh (2011–2018)

Discussion

The study shows that the precipitation trend is declining in coastal Andhra Pradesh because of various factors. The declining trend of rainfall is maybe because of the weakening of the southern oscillation index and relaxed longitudinal gradient of temperature has resulted in the decline of rainfall intensity Naidu et al. (2009). The other factors are since Andhra Pradesh has seen a decline in forest cover by about 25% from 1990 to 2017 and such a large-scale deforestation result in the decline of evapotranspiration and that results in a subsequently lower amount of rainfall (Paul et al. 2016). The results of the study are in line with the results of other studies conducted in India and Andhra Pradesh (Rupakumar et al. 1992; Kulkarni et al. 2020; IMD 2020). Kulkarni et al. (2020) found a decreasing trend in annual and monsoon rainfall in coastal Andhra Pradesh. Further, India Meteorological Department (IMD 2020) reported a decreasing trend in annual rainfall in the coastal districts of Andhra Pradesh namely Guntur, Nellore and Prakasam. The decreasing trend of the rainfall can be attributed to the decline in the amount

of precipitation from the monsoon due to various reasons (Guhathakurta et al. 2014). During monsoon primary source of rainfall in coastal Andhra Pradesh is the LPS from the Bay of Bengal whose frequency has increased recently but only a few of them get intensified into rain-bearing depression and above stages (Naidu et al. 2009; Meera et al. 2019).

Dryness and wetness can be assessed in terms of rainfall trends and patterns and there can be more parameters that influence the rate and intensity of precipitation (Asfaw et al. 2018). In addition to this, the drought and rainfall conditions could be evaluated and assessed accordingly. Severe dryness was witnessed in the years 2018 and 2011 and moderate dryness has been recorded in 2002, 2012 and 2014 in coastal Andhra Pradesh. The severity of rainfall depends on various parameters like duration of rainfall, intensity, frequency and magnitude (Zope et al. 2016; Mallick et al. 2021). During these years the intensity of rainfall was very high due to tropical cyclones namely Bay of Bengal 06 (BOB 06), Pyarr and Laila which made landfalls on coastal Andhra Pradesh in 1995, 2005 and 2010, respectively (Telangana Times 2021; The Hindu 2010). IMD (2020) reported that the frequency

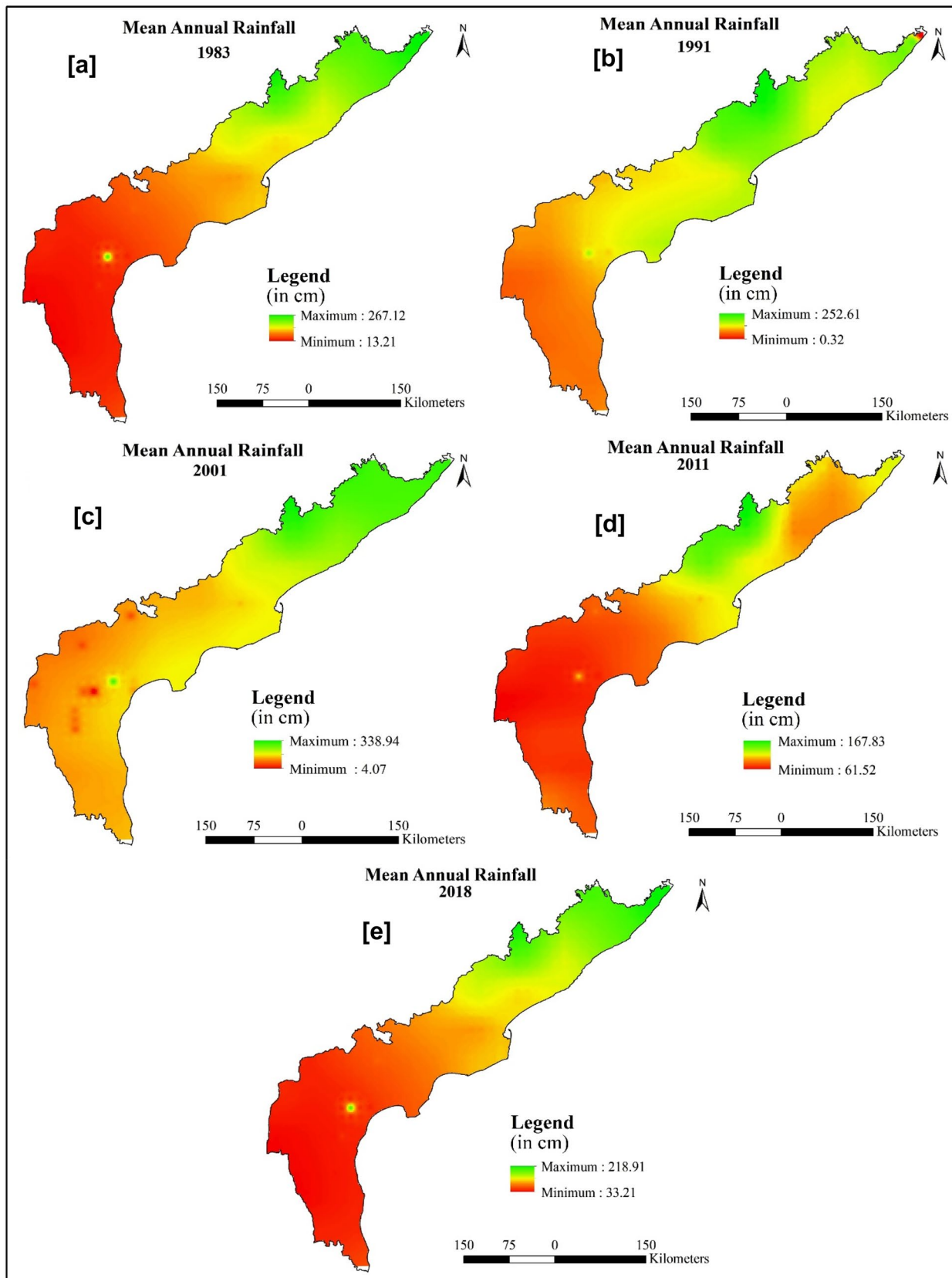


Fig. 9 Mean annual rainfall in the coastal Andhra Pradesh during 1983–2018

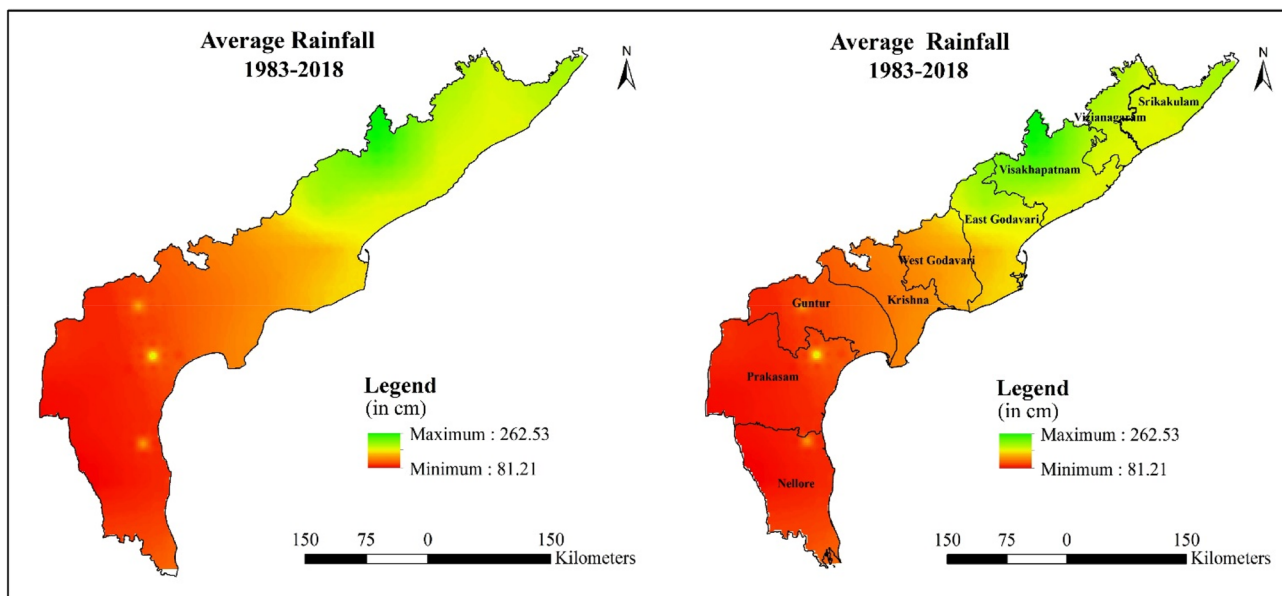


Fig. 10 Average annual rainfall for 36 years in Coastal Andhra Pradesh

Table 4 Mean annual rainfalls and mean NDVI during (1983–2018)

S. no.	Years	Mean annual rainfall (in cm)	Mean NDVI
1	1983	161.32	0.49
2	1991	147.71	0.42
3	2001	181.11	0.51
4	2011	90.67	0.29
5	2018	91.0	0.30

Table 5 Correlation between mean annual rainfall and NDVI

Pearson correlation		
	Rainfall	NDVI
Rainfall		
Pearson correlation	1	0.991**
Sig. (2-tailed)		0.001
N	5	5
NDVI		
Pearson correlation	0.991**	1
Sig. (2-tailed)	0.001	
N	5	5

**Correlation is significant at the 0.01 level (2-tailed)

of moderate rainfall days in coastal Andhra Pradesh Districts was higher from 1989 to 2018 which may be attributed to the normal rainfall during this period. Andhra Pradesh receives

rainfall from both South-West and North-East monsoon and coastal Andhra is considered to be the most rained region of the state (Guhathakurta et al. 2005). Normal precipitation has been experiencing by the study area in the years from 1991–1997 and then in 1999 after few years the years 2000, 2004, along with 2006, 2007, 2008, 2009, 2013, 2015 and 2016. Moderate wetness was recorded in the year 1998, 2003 and 2005. In 1995, 2005 and 2010 coastal Andhra has recorded severe wetness due to ample amount of precipitation throughout the years as mentioned previously.

The study depicts that low mean annual rainfall of 90 cm has been witnessed in 2011 and 2018 and maximum mean rainfall was recorded in the years 1985, 1995, 1998 and 2010 which is more than 170 cm in coastal Andhra Pradesh. In the study area, the NDVI value of 2011 and 2018 was low as compared to 1983, 1991 and 2001 which somehow validate the pattern and trend of rainfall in the study region. The NDVI also signifies the health of plants and vegetation and it can also be used as indicators for dryness and wetness and in addition to monitoring of droughts and famine simultaneously (Xue and Su 2017; Geleta and Deressa 2020). Precipitation is considered to be one of the important factors in the growth of vegetation (Nafus et al. 2017) and crops as precipitation lead to the increment of soil moisture and minerals solution in soil which enhance fertility. Higher NDVI shows that plenty of precipitation has been recorded in the study area and hence the drought or dryness would be less as compared to when the NDVI value is low (Faridatul and Ahmed 2020; Rousta et al. 2020).

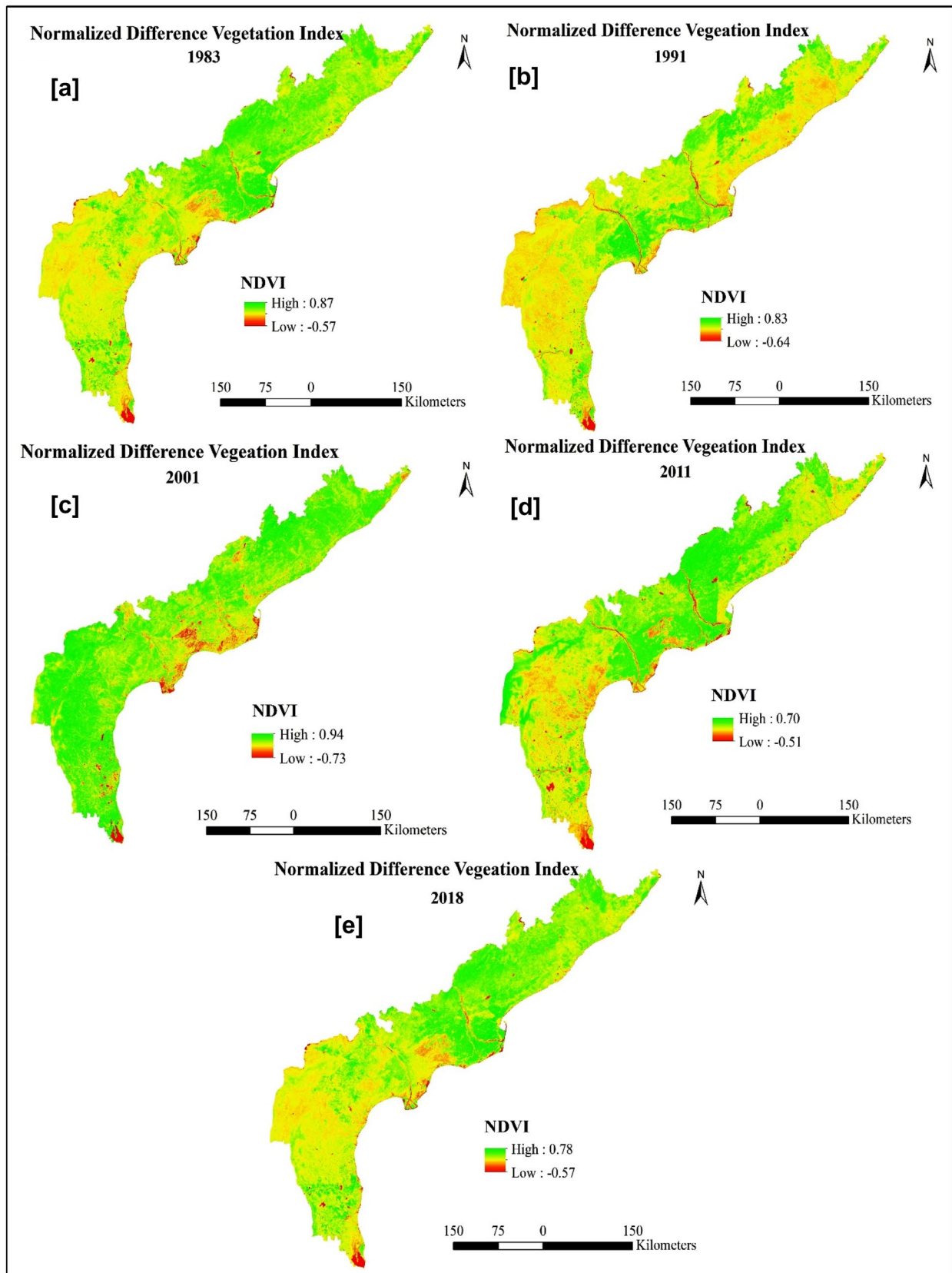


Fig. 11 Pattern of normalized difference vegetation index (NDVI) of coastal Andhra Pradesh

Table 6 Descriptive statistics of regression

Descriptive statistics			
	Mean	Std. deviation	<i>N</i>
NDVI	0.4020	0.10330	5
Rainfall	134.3620	41.47147	5

Table 7 Model summary of regression

Model summary ^b				
Model	<i>R</i>	<i>R</i> ²	Adjusted <i>R</i> ²	Std. error of the estimate
1	0.991 ^a	0.982	0.976	0.01614

^aPredictors: (constant), rainfall

^bDependent variable: NDVI

Rainfall is determining factor for agriculture and allied activities and coastal Andhra Pradesh has been the most favourable condition in terms of growing crops (Poornima and Pushpalatha 2019). In this study, a trend and pattern of precipitation have been calculated which may be helpful in planning and formulation of policies especially in the agricultural, horticulture and allied activities in the study area. The results can also be used for irrigation management and also for infrastructure development, for example setting irrigation facilities during dry years.

Table 10 Analysis of residuals

Residuals statistics ^a					
	Minimum	Maximum	Mean	Std. deviation	<i>N</i>
Predicted value	0.29	0.52	0.40	0.10	5
Residual	−0.015	0.02	0.00	0.01	5
Std. predicted value	−1.05	1.13	0.00	1.00	5
Std. residual	−0.92	1.33	0.00	0.86	5

^aDependent variable: NDVI

Conclusion

The study focuses on the trends and pattern of precipitation along with the identification of dryness and wetness years for 36 years of the coastal Andhra Pradesh. The Mann–Kendall test is used for the study of the trend in rainfall. The SPI and RAI are used for the identification of dryness and wetness in the region. The results from the Mann–Kendall test show that rainfall in coastal Andhra Pradesh has a declining trend which is at the rate of 1.27 cm per year. The decline in the rainfall trend may be attributed to lower monsoon rainfall, uneven formations of LSP in the Bay of Bengal and a decrease in forest cover in Andhra Pradesh. SPI results show that less than 50% of years have normal rainfall. Severe dryness is witnessed in 2 years (2011 and 2018), severe wetness is found in 4 years (1990, 1995, 2001, 2010) and extreme wetness is seen in a single year (1985). Similarly, the results of the RAI show that the years 2011 and 2018 are extremely dry, 8 years (1988, 1990, 1995, 1998, 2001, 2003, 2005 and 2010) are very humid and the year 1985 is extremely humid.

Table 8 ANOVA test

ANOVA ^a						
Model		Sum of squares	<i>df</i>	Mean square	<i>F</i>	Sig.
1	Regression	0.042	1	0.042	160.928	0.001 ^b
	Residual	0.001	3	0.000		
	Total	0.043	4			

^aDependent variable: NDVI

^bPredictors: (constant), rainfall

Table 9 Coefficients of regression

Coefficients ^a								
Model		Unstandardized coefficients		Standardized coefficients	<i>t</i>	Sig.	95.0% confidence interval for <i>B</i>	
		<i>B</i>	Std. error				Beta	Lower bound
1	(Constant)	0.070	0.027		2.597	0.081	−0.016	0.157
	Rainfall	0.002	0.000	0.991	12.686	0.001	0.002	0.003

^aDependent variable: NDVI

Fig. 12 Association between NDVI and rainfall in Coastal Andhra Pradesh

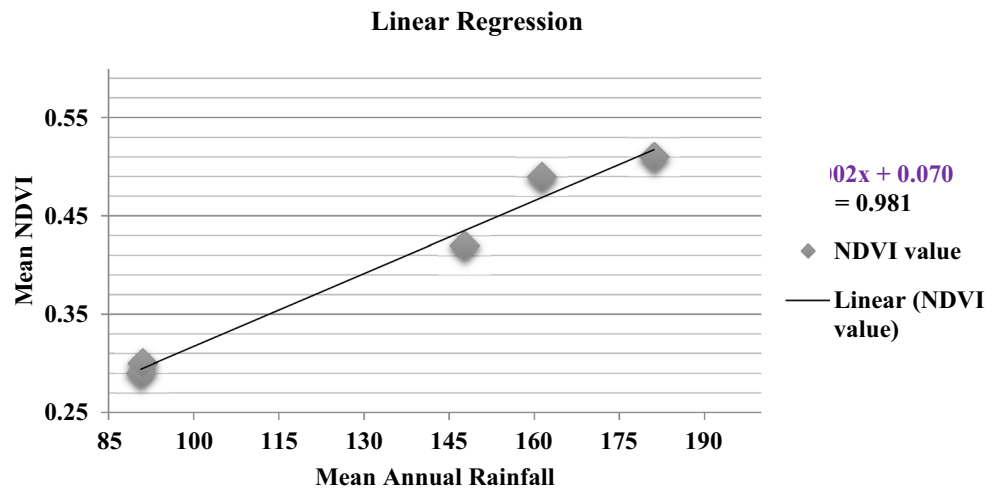


Table 11 Classification of rainfall anomaly index intensity

RAI range	Classification
Above 4	Extremely humid
2 to 4	Very humid
0 to 2	Humid
-2 to 0	Dry
-4 to -2	Very dry
Below -4	Extremely dry

For the validation of dryness and wetness years correlation between NDVI and rainfall has been calculated. The correlation between NDVI and mean annual rainfall is highly significant with a Pearson correlation coefficient of 0.99. The results of the study on precipitation may be useful for the farmers and fishermen as well as regional planners and developers in sustainable management of coastal areas in the socio-economic development of the people.

RAI and SPI of Coastal Andhra Pradesh from 1983- 2018

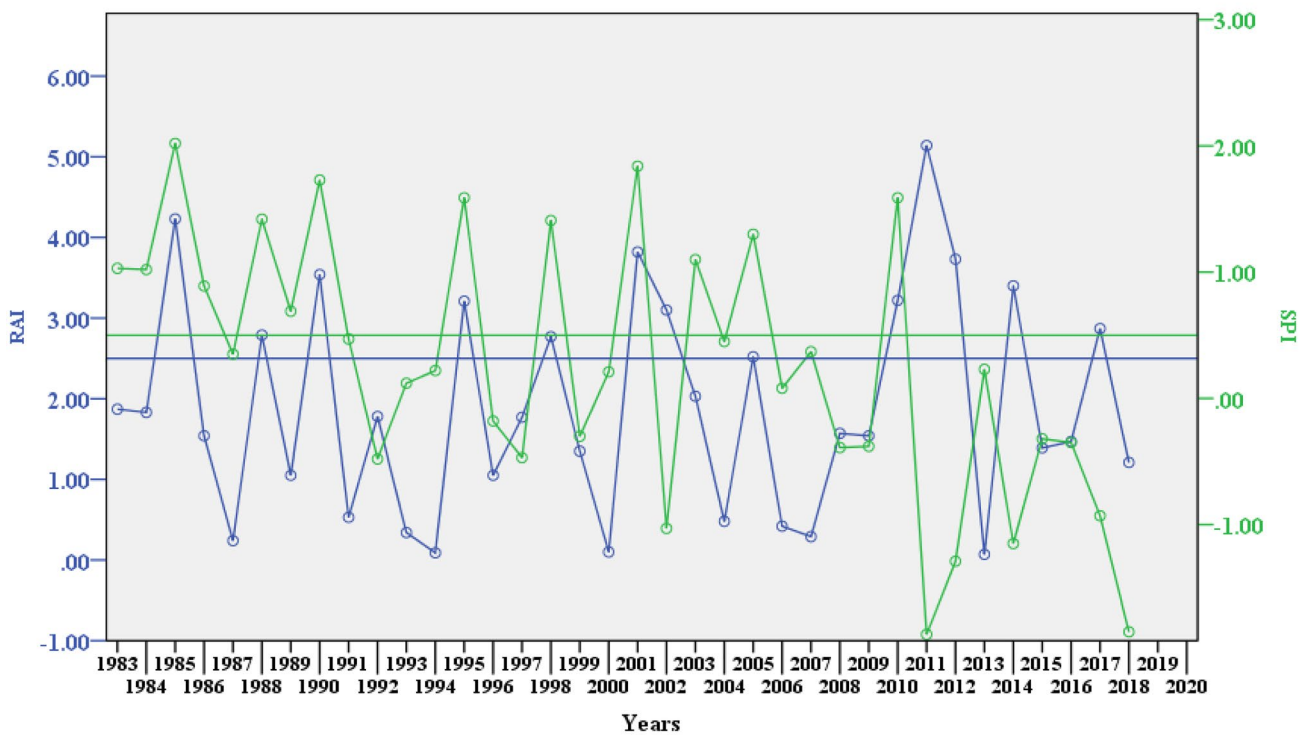


Fig. 13 RAI and SPI of Coastal Andhra Pradesh from 1983–2018

Table 12 Correlations between rainfall anomaly index and standardized precipitation index

Correlations		RAI	SPI
RAI	Pearson correlation	1	1.000**
	Sig. (2-tailed)		0.000
	<i>N</i>	36	36
SPI	Pearson correlation	1.000**	1
	Sig. (2-tailed)	0.000	
	<i>N</i>	36	36

**Correlation is significant at the 0.01 level (2-tailed)

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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