Assessment of regional-level long-term gridded rainfall variability over the Odisha State of India

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Abstract

Odisha State is located in eastern part of India which is blessed with sufficient amount of rainfall. Major part of the state is covered by Mahanadi river basin; Mahanadi river basin originated from Sihawa town and disposed out to Bay of Bengal near Sambalpur, Odisha State. The distribution pattern is erratic and uneven due to climate, topography, hydrology and geomorphology of the state. Catchment area of the Mahanadi is vast; therefore, drainage order is also high (about six); due to these features large amount of water has generated, and it will be appeared as flood at downstream through deltaic region to Bay of Bengal. In this connection, water resources planning and management are one of the crucial issues. For any hydrological study, it is necessary to identify the characteristics and climatic variability of the catchment. In the present study, long-term (1901–2013) rainfall time series has been utilized for rainfall variability analysis using nonparametric tests, viz. Mann–Kendall (MK), modified Mann–Kendall (MMK) and Theil–Sen's slope. The average annual rainfall of the Odisha State is to be found as about 1438 mm; out of them, about 78% occurs in the monsoon season. In the present study, it was found that the maximum and minimum rainfalls occurred at Bhadrak and Puri districts, respectively. As per change point detection, it was found to be as 1945 is shift change year. Further, it was noticed that most of the districts are showing positive trends before change point and vice versa. Similar results are estimated in the monsoon season because most of the rainfall has occurred in the monsoon season. Both positive and negative trends have been found in Odisha State; detailed study has been carried out for rainfall behavior identification of the state. The present study is useful for agricultural and water resources planning and mitigation.

Keywords Mann–Kendall · Modified Mann–Kendall test · Rainfall variability · IMD gridded data

Introduction

Increase in water demand with an increase in population in India along with improvement in quality of life and climatic variability has attracted the attention of scientist and engineers to estimate availability of water at a place for sustainability. The primary source for river flow in India is rainfall. Extreme variability in rainfall could result in extreme hydrological events such as drought and floods (Kalra and Ahmad

2012). Deficiency in rainfall from average annual rainfall of the area has an ultimate impact on agricultural produce. More than 60% of India's population is based on agriculture which generates about 20% of the national gross domestic product (GDP). The climate changes in recent years have led to more variability in rainfall pattern. However, the effect is not uniform throughout the Earth.

The uncertainty and non-uniformity associated with rainfall characteristics could result in severe impact on agricultural production in India as the farmers mostly depend on rainfall. Therefore, precipitation is an essential variable along with other hydro-climatic variables, viz. temperature, evapotranspiration and humidity (Chowdhury et al. 2014). Thus, there is an acute need to study the changed rainfall patterns and its effect on water resources. Available literature associated with global warming effects strongly indicates that at global scale there are significant changes in rainfall pattern (Diaz et al. 1989; Hulme et al. 1998). Various other

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authors (Rind et al. 1989; Mearns et al. 1996) have also highlighted the future climate changes and its influence on rainfall trends. Studies analyzing rainfall characteristics, variability and trends have reported that there will be extreme variations in precipitation intensity, spatial and temporal rainfall patterns in most regions of India (Goswami et al. 2006; Kumar et al. 2010) and China (Wang and Zhou 2005) in future.

Various authors (Mirza 2002; Goswami et al. 2006; Dash et al. 2007) reported that many parts of Asia would witness an increase in intense rainfall events, while a reduction in the total rainy days and total annual rainfall. Studies based on daily values of rainfall from 1951 to 2000 reported the rising trends in magnitude and frequency of extreme events of precipitation as well as noticeably decrease in the frequency of the usual occurrences (Goswami et al. 2006) during the monsoon over central India. Mirza et al. (1998) conducted an extensive analysis of Ganga and Brahmaputra river basins and reported that in Ganga basin rainfall pattern shows stability largely, while Brahmaputra basin shows increasing rainfall pattern. A study of annual rainfall of nine river basins of central India and northwest (Singh et al. 2008) indicated increasing trend in annual rainfall in the majority of the basins. For the entire northwest and central India, the annual rainfall increased by 5.2% of mean per 100 years. Sinha Ray and De (2003) found that all-India rainfall shows no significant trend, except for some periodic behavior. Sinha Ray and Srivastava (1999) established that the frequency of heavy rainfall events during the southwest monsoon shows an increasing trend over certain parts of India. However, a decreasing trend has been observed during winter, pre-monsoon and post-monsoon seasons.

Gradual or abrupt (steep change) in trend or more complex spatial and temporal variations may occur in rainfall (Kundzewicz and Robson 2004). Such changes will affect statistical properties (mean, median, variance, kurtosis, skewness, autocorrelation, etc.) of rainfall with time. The difference in observational process and natural climatic phenomena may result in sudden or gradual changes in climatic variables. From the latest Intergovernmental Panel on Climate Change (IPCC) report, it has been observed that massive precipitation events are likely to increase disproportionately in comparison with mean differences between the years 1951 and 2003 for many midlatitude regions. Also, the reduction in the total annual precipitation is reported by Liuzzo et al. (2015). Based on the study of monthly rainfall data series of 135 years in 30 subdivisions (regions) in India from the year 1871–2005, Kumar et al. (2010) reported rising trends in annual precipitation in 50% of the subdivisions. Mondal et al. 2012 have found rising and decreasing trend of precipitation in months in Cuttack District, Odisha.

Based on mathematical tools/methods, the works reported for rainfall trend analysis may be grouped into

two types (Zhang et al. 2006; Kundzewicz and Robson 2004). The first method is named as a parametric method (linear and residual models), while the second is termed as a nonparametric method (Mann 1945; Kendall 1975b), viz. Mann–Kendall (MK), modified Mann–Kendall (MMK) and the Sen's slope estimator (1968). Out of these methods, the use of a nonparametric approach (Kalumba et al. 2013; Sabzevari et al. 2015) is more appropriate for an analysis of distributed data involving uncertainty, which is observed in hydrometeorological time series. Sen (1968) extended the work reported by Thiel (1950) and developed a procedure unaffected by outliers and gross data errors which are called as Sen's slope estimator. Several researchers (Yu et al. 1993; Yue and Hashino 2003; Palizdan et al. 2015; Chandniha et al. 2016; Prabhakar et al. 2017; Mondal et al. 2018) reported their works regarding detecting a hydrological and hydrometeorological trend in the time series by the MK test and Sen's slope estimator.

In this study, MK/MMK test method and Sen's slope estimator for 30 districts of the state have been used for trend analysis of the long-term rainfall record of Odisha, India, available from the year 1901 to 2013 on the annual and seasonal basis. Different seasons considered for study are monsoon, pre-monsoon, post-monsoon and winter. Standard normal homogeneity test (SNHT) and Mann–Whitney–Pettitt (MWP) test are used to investigate the change point in the long-term rainfall time series. The annual and seasonal rainfall variability, viz. coefficient of variation (CV), including cross- and autocorrelations have also been examined for the time series.

Study area and data availability

The geographical area of Odisha State is about 156,077 km², which has 30 districts. The gridded (resolution of 0.25° latitude × 0.25° longitude) daily rainfall data for the study have been procured from Indian Meteorological Department (IMD), Pune, from the year 1901 to 2013. The long-term rainfall of the state varies between 961 and 1872 mm. However, the normal annual rainfall of the state is about 1438 mm. The overall weather of the Odisha State is highly humid with medium-to-high rainfall, tropical and short winter with mild temperature. The varying intensities of cyclones, drought and flood occur almost every year in most of the districts. The maximum temperature in summer season goes above 40 °C hovering between 40 and 46 °C in western districts, viz. Sundargarh, Sambalpur, Balangir, Kalahandi and Mayurbhanj. The minimum temperature goes down to 1.02 °C. Figure 1 shows the map of Odisha State along with locations of 30 districts.

Fig. 1 Odisha State along with locations of 30 districts

Methodology

For investigating the spatial and temporal changes in rainfall, the whole year is categorized into different seasons, mainly winter (December–February), pre-monsoon (March–May), monsoon (June–September) and post-monsoon (October–November). IMD gridded (resolution of 0.25° latitude $\times$ 0.25° longitude) daily rainfall has been converted into weighted average rainfall time series for different districts of Odisha as per administrative boundary of the districts. The daily rainfall series are used to form monthly, seasonal and annual series for the trend analysis. The rainfall series varied spatially and temporally. Factors like instruments, observing practices, station environment situation and location of the station may impact the uniformity of rainfall data time series (Huang et al. 2015).

As discussed above, the long-term rainfall series may even have successive autocorrelations, and therefore, before conducting further investigations, the rainfall series is analyzed for homogeneity in time series by using SNHT. SNHT has been used for checking the homogeneity of long-term data series at 5% significance level

(Alexandersson 1986; Alexandersson and Moberg 1997). The critical values of SNHT test statics (T_0) for various sample sizes (10–250) were initially developed using short Monte Carlo simulations with the different critical percentage (Khaliq and Ouarda 2007).

Further, MWP test was used to detect the possible breakpoint (Pettitt 1979) in long-term monthly data sets of each district of Odisha. After that, change percentages have been carried out from magnitude for both the data sets before and after breakpoint individually. Nonparametric MK and MMK tests have been used (Jain and Kumar 2012; Kendall 1975b; Kumar et al. 2010; Mann 1945) for the identification of monotonic trend as it is considered better than parametric tests (Kendall 1975a; Mann 1945). So in the present study, these tests have been used for the long-term rainfall trend analysis. The magnitude of trend has been quantified by Theil–Sen’s estimator (Jhajharia et al. 2012; Tabari et al. 2011; Jain and Kumar 2012) found that different values of the magnitude of a trend in hydrometeorological time series. The relevant details of the foresaid tests and methods are summarized in the following sections.

Mann–Kendall (MK) test

The MK statistical test requires sample data which should be serially independent (Yue and Wang 2004). The MK statistic, S , is defined as:

$$S = \sum_{j=1}^{m-1} \sum_{k=j+1}^m \text{sign}(x_k - x_j), \quad (1)$$

where x_j and x_k are the j th and k th term in the sequential data of sample size m and for $x_k - x_j = \theta$

$$\text{Sign}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases}. \quad (2)$$

Assuming independent data with identically scattered, the variance and mean of the S statistic in Eq. (2) may be calculated as given by (Kendall 1975a; Dinpashoh et al. 2011):

$$E[S] = 0, \quad \text{Var}(S) = \frac{m(m-1)(2m+5)}{18}.$$

However, for ties in the data set the expression for $\text{Var}(S)$ becomes:

$$\text{Var}(S) = \frac{m(m-1)(2m+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)}{18}, \quad (3)$$

where m is the number of tied (zero difference between compared values) groups and t_i is the number of data points in the i th tied group. The standard normal deviate (Z statistics) is then computed

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases}. \quad (4)$$

The Z values greater than ± 1.96 represent 5% level of significant positive/negative trend in the time series, respectively.

Modified Mann–Kendall (MMK) test

The modified variance of S is used in MMK statistical test for minimizing the influence of significant autocorrelation coefficients from the time series as reported by the authors (Hamed and Rao 1998). The modified spatial and temporal variance of S , labeled as $\text{Var}(S)^*$, is expressed as follows:

$$\text{Var}(S)^* = \text{Var}(S) \frac{m}{m^*}, \quad (5)$$

where m^* = adequate sample size. Based on the work reported by Hamed and Rao (1998), the m/m^* ratio may be defined as

$$\frac{m}{m^*} = 1 + \frac{2}{m(m-1)(m-2)} \sum_{i=1}^{m-1} (m-1)(m-i-1)(m-i-2)ri, \quad (6)$$

where m = actual number of sample data and ri = lag- i represents the significant autocorrelation coefficient of rank I of time series. The computed values of $\text{Var}(S)^*$ (Eq. 5) are used for the $\text{Var}(S)$ in Eq. (3). The results are compared with threshold levels at 5%, and the values above ± 1.96 are significant level.

Theil–Sen's slope estimator

Sen (1968) gave nonparametric procedure for a linear trend in time series in terms of slopes. The slope estimates (Q_i) of m pairs of data are calculated using the following expression as:

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1, 2, 3, \dots, m. \quad (7)$$

The median of Q_i is derived from:

$$\beta = \begin{cases} Q(m+1)/2 & m \text{ is odd} \\ \frac{1}{2}(Q(m/2) + Q(m+2)/2) & m \text{ is even} \end{cases}. \quad (8)$$

The results are compared with threshold levels at 5%, and the β values above ± 1.96 are significant (increasing/decreasing) trends.

Mann–Whitney–Pettitt test

The sample time series $X = (x_1, x_2, \dots, x_m)$, partition X such that $Y = (x_1, x_2, \dots, x_{m1})$ and $Z = (x_{m1+1}, x_{m2+1}, \dots, x_{m1+m2})$. The Mann–Whitney–Pettitt test statistics are given as

$$Z_c = \frac{\sum_{i=1}^{m1} r(x_i) - m_1(m_1 + m_2 + 1)/2}{[m_1 m_2 (m_1 + m_2 + 1)/12]^{1/2}}, \quad (9)$$

where $r(x_i)$ is the rank of observations. The null hypothesis H_0 is accepted if $-Z_{1-\alpha/2} \leq Z_c \leq Z_{1-\alpha/2}$, where $\pm Z_{1-\alpha/2}$ are the $1 - \alpha/2$ quantiles of standard normal distribution corresponding to significance level α for the test.

Standard normal homogeneity test (SNHT)

The SNHT test (Alexandersson 1986) is used to detect a change in a rainfall time series, viz. $R(s)$ ($s = 1, \dots, n$). The time series $R(s)$ to compare the mean value of the initial s years of the record with that of last $n - s$ years is:

$$R(s) = s\bar{z}_1^2 + (n-s)\bar{z}_2^2, \quad (10)$$

where

$$\bar{z}_1 = \frac{1}{s} \sum_{i=1}^s \frac{(Y_i - \bar{Y})}{\sigma_R} \quad \text{and} \quad \bar{z}_2 = \frac{1}{n-s} \sum_{i=s+1}^n \frac{(Y_i - \bar{Y})}{\sigma_R}.$$

If any break point exists in S year in the time series, then $R(s)$ approaches its maximum nearly at $s = S$. This test result, $R(s)$, is illustrated in the graphs. The test statistic To is defined as:

$$To = \max_{1 \leq s < n} R(s). \quad (11)$$

Coefficient of variation (CV%)

The coefficient of variation (CV) statistically measures relative variability in the time series. It shows the individual data position differing from the mean value. Higher values of CV specify the high variability. The annual and seasonal rainfall variability (CV%) (Landsea and Gray 1992) has been investigated for 30 districts of the Odisha State from the entire time series by the inverse distance weighted (IDW) technique in Arc-Map 9.3 which is shown in Fig. 2.

Results and discussion

The annual and seasonal rainfall for 113 years of the state has been analyzed. The statistical parameters such as mean, standard deviation (SD) and coefficient of variations (CV) have been estimated using Excel.

Rainfall characteristics during the years 1901–2013

The average annual rainfall of the state is found as 1438 mm with a minimum value of 961 mm and a maximum value of 1872 mm. The standard deviation is approximately 190 mm. Seasonal rainfall values range from 40 to 376 mm with SD of 54 mm (pre-monsoon); 750–1532 mm with SD of 155 mm (monsoon); 16–440 mm with SD of 96 mm (post-monsoon); and 1–141 mm with SD of 31 mm (winter). This statistic indicates that the regions with more rainfall have less variability than the areas with relatively lower rainfall. Monthly rainfall characteristics for Odisha State (1901–2013) are shown in Table 1. These rainfall characteristics represent that how much rainfall will probably be available and their confidence level could be used in deciding the cropping pattern.

The mean annual rainfall at different confidence levels, viz. 75, 90 and 95%, has been computed for different districts of Odisha State. These confidence levels may be useful in

deciding the cropping pattern, planning of agricultural practices, industrial and domestic uses and other water resource needs. The highest rainfall occurs in Bhadrak District with average magnitude = 1610.9 mm, and the lowest rainfall in Puri District with average magnitude = 1139.9 mm. The average annual rainfall at 75, 90 and 95% of confidence level is found in Bhadrak District as 1339.3, 1195.2 and 1098.0 mm, respectively. In Puri District, these are 973.1, 841.0 and 753.3 mm, respectively. These values for all districts are shown in Fig. 3.

The change point detection in the time series

Homogeneity test has been applied to the time series using SNHT with the significance level of 5% (Alexandersson 1986; Alexandersson and Moberg 1997). H_0 represents the homogeneous series, and H_a represents the heterogeneous series. The change point (P values) has been obtained after 10,000 Monte Carlo simulations. Considerable change or shift point in series has been detected by both MWP and SNHT tests. The change point years in Odisha using MWP and SNHT tests are shown in Table 2. These two analyses indicated that the year 1945 is the most likely change point year in time series for the state. The possible reason for the change in rainfall pattern from the year 1945 onwards is due to the beginning of current warming period (around 1950) from the past cooling period (1891–1950) (Mohanty et al. 2012).

The rainfall season-wise autocorrelation analysis of Odisha State

Autocorrelation analysis of the state has been done by varying lag from 1 to 24. Figure 4a–e shows the lag number versus autocorrelation functions for annual rainfall, pre-monsoon, monsoon, post-monsoon and winter. Two autocorrelations have been found for the pre-monsoon season at lags 17 and 22. One autocorrelation exists for the monsoon season at lag 17. Similarly, one autocorrelation exists for the post-monsoon season at lag 11. And three autocorrelations exist for the winter season at lags 9, 14 and 24. These significant autocorrelation coefficients would influence the Z statistic values from MK and MKK tests.

Rainfall trend analysis with seasonal and annual time steps

Rainfall trend analysis has been performed for seasonal (pre-monsoon, monsoon, post-monsoon and winter) and annual data series consisting of all data from 1901 to 2013, data up to pre-change point year (1945) and data from change point year to 2013. Z statistics have been estimated using MK and

Fig. 2 Intra-annual variability of CV (%) of rainfall and its trends: **a** annual; **b** pre-monsoon; **c** monsoon; **d** post-monsoon; and **e** winter seasons

Table 1 Monthly rainfall characteristics for Odisha State (1901–2013)

Year	Mean (mm)	SD (mm)	CV (%)	75%	90%	95%	% Contribution to annual
<i>Confidence level</i>							
Jan	12.3	15.4	125.0	0.1	0.0	0.0	0.9
Feb	21.7	24.5	113.2	1.6	0.1	0.0	1.5
Mar	21.2	22.9	108.1	2.8	0.3	0.0	1.5
Apr	32.1	22.9	71.3	12.1	4.9	3.0	2.2
May	65.6	43.2	65.9	33.5	20.3	14.0	4.6
Jun	204.0	75.9	37.2	132.6	95.8	79.2	14.2
Jul	335.5	88.9	26.5	249.7	197.9	174.0	23.3
Aug	341.7	82.6	24.2	258.4	208.4	179.2	23.8
Sep	239.3	66.2	27.7	177.5	136.4	117.9	16.6
Oct	126.0	84.6	67.2	53.0	28.0	19.1	8.8
Nov	33.4	44.5	133.4	1.1	0.1	0.0	2.3
Dec	5.9	12.2	207.5	0.0	0.0	0.0	0.4
Annual	1438.6	190.2	13.2	1251.9	1111.1	1029.5	100.0

MMK tests at 5% of a significant level. Theil–Sen's slope has also been estimated using Eq. (8) for the state.

Annual and seasonal rainfall analysis

Results of Z statistic values for all districts for annual and seasonal rainfalls are shown in Fig. 5. From the period 1901 to 2013, it is seen that in annual data the positive trend has been shown by 13 districts out of 30 and remaining districts show negative trend. At 5% significance level, four districts, viz. Baleshwar, Cuttack, Dhenkanal and Jagatsinghpur, are having positive trend, four districts, viz. Jharsuguda, Koraput, Nuapada and Sundargarh, show negative trend and rest do not show any significant trend. Further, in pre-monsoon season, only negative trend has been obtained in all districts with two districts, viz. Balangir and Nuapada, having significant trend. For monsoon season, only four districts (Baleshwar, Cuttack, Dhenkanal and Ganjam) have significant positive trend. In post-monsoon, no significant trend has been found. In winter season also only negative trend has been obtained in all districts with six districts (Angul, Jajpur, Kendrapara, Keonjhar, Mayurbhanj and Nuapada) having significant negative trend.

Similarly, from the year 1901 to 1945, it is seen that in annual data the positive trend has been shown by 27 districts out of 30 and remaining districts show negative trend. At 5% significance level, eight districts, viz. Baleshwar, Bhadrak, Boudh, Jajpur, Jharsuguda, Kendrapara, Keonjhar and Sambalpur, are having positive significant trend.

Further, in pre-monsoon season, only negative trend has been obtained in all districts with three districts, viz. Cuttack, Keonjhar and Mayurbhanj, having significant trend. For monsoon season, nine districts, viz. Baleshwar, Bargarh,

Bhadrak, Boudh, Jajpur, Kendrapara, Keonjhar, Mayurbhanj and Nuapada, have significant positive trend. In post-monsoon season, six districts, viz. Baleshwar, Bhadrak, Jajpur, Kendrapara, Keonjhar and Sundargarh, have positive significant trend. In winter season, most of the districts showed negative trend with six districts having no significant trend.

Likewise, from the year 1946 to 2013, it is seen that in annual data the positive trend has been shown by 23 districts out of 30 and remaining districts show negative trend. At 5% significance level, three districts, viz. Cuttack, Dhenkanal and Jagatsinghpur, are having positive significant trend. Further, in pre-monsoon season, most of the positive trend has been obtained in all districts with three districts, viz. Cuttack, Gajapati and Jajpur, having positive significant trend. For monsoon season, six districts, viz. Cuttack, Deogarh, Dhenkanal, Gajapati, Ganjam and Jagatsinghpur, have significant positive trend and one district, viz. Jharsuguda, has significant negative trend. In post-monsoon, only negative trend has been obtained in all districts with one district, viz. Khordha, having significant negative trend. In winter season, there is no significant trend.

Theil–Sen's slope for annual and seasonal rainfall

The majority of the districts are showing negative trend from the analysis of annual rainfall series from the year 1901 to 2013. This suggests that availability of total rainfall is declining with years. This warrants special attention of water resources planner. However, within the year with different seasons there are both positive and negative variations, e.g., pre-monsoon rainfall shows increasing trend, whereas post-monsoon, monsoon and winter show decreasing trends.

Fig. 3 District-wise dependable rainfall and its deficit variability at different probability exceedance: **a** 75% dependable rainfall; **b** deficit rainfall at 75% level of confidence; **c** 90% dependable rainfall; **d** deficit rainfall at 90% level of confidence; **e** 95% dependable rainfall; **f** deficit rainfall at 95% level of confidence; **g** average annual rainfall during 1901–2013

Before change point years, it is seen that majority of the districts are showing positive trend from the analysis of annual rainfall series from the year 1901 to 1945. This suggests that availability of total rainfall is increasing with years. And within the year with different seasons there are both positive and negative variations, e.g., pre-monsoon and winter rainfalls show decreasing trend, whereas post-monsoon and monsoon show increasing trends.

After the change point years, it can be observed from the analysis that majority of the districts are showing less positive trend for the annual rainfall series from the year 1946 to 2013. This suggests that availability of overall rainfall is decreasing with years. However, within a year with different seasons there are both positive and negative variations, e.g., post-monsoon and winter rainfalls show decreasing trend, whereas pre-monsoon and monsoon show less increasing trends. The magnitude of change in rainfall trend is shown in Fig. 6 for different periods of analysis. The figure shows box plot of the Theil–Sen's slopes for monthly rainfall time series (a) 1901–2013; (b) 1901–1945; (c) 1946–2013; annual and seasonal rainfall time series (d) 1901–2013; (e) 1901–1945; (f) 1946–2013 of Odisha State. The central box line represents median, and the upper and lower lines

Table 2 Change point years in Odisha using MWP and SNHT tests

Districts/state	MWP test			SNHT test		
	<i>P</i> value	Year	Trend	To value	Year	Trend
Angul	0.34	1963	H_o	4.13	1963	H_o
Baleshwar	0.15	1924	H_o	6.81	1912	H_o
Bargarh	0.01	1961	H_a	11.63	1961	H_a
Bhadrak	0.14	1952	H_o	8.41	1946	H_o
Balangir	0.04	1961	H_a	5.12	1961	H_o
Boudh	0.05	1944	H_a	8.37	1963	H_o
Cuttack	0.01	1989	H_a	13.33	2000	H_a
Deogarh	0.26	1982	H_o	4.76	1982	H_o
Dhenkanal	0.00	1982	H_a	13.62	1982	H_a
Gajapati	0.55	1977	H_o	4.27	1979	H_o
Ganjam	0.46	1976	H_o	6.37	2012	H_o
Jagatsinghpur	0.02	1989	H_a	10.32	1989	H_o
Jajpur	0.21	1924	H_o	5.77	1924	H_o
Jharsuguda	0.00	1952	H_a	14.68	1961	H_a
Kalahandi	0.37	1989	H_o	6.52	2000	H_o
Kandhamal	0.23	1963	H_o	4.47	1933	H_o
Kendrapara	0.47	1912	H_o	5.18	1912	H_o
Keonjhar	0.32	1946	H_o	4.00	1946	H_o
Khordha	0.14	1989	H_o	6.31	1989	H_o
Koraput	0.00	1962	H_a	10.34	1962	H_o
Malkangiri	0.10	1959	H_o	11.14	2002	H_o
Mayurbhanj	0.68	1970	H_o	5.76	2012	H_o
Nabarangpur	0.26	1947	H_o	5.58	2002	H_o
Nayagarh	0.08	1989	H_o	7.94	2000	H_o
Nuapada	0.00	1961	H_a	14.35	1961	H_a
Puri	0.31	1989	H_o	4.79	1989	H_o
Rayagada	0.91	1913	H_o	2.86	1908	H_o
Sambalpur	0.04	1946	H_a	7.51	1961	H_o
Sonepur	0.11	1944	H_o	4.51	1944	H_o
Sundargarh	0.00	1953	H_a	15.27	1953	H_a
Odisha State	0.27	1945	H_o	3.96	1945	H_o

Fig. 4 Lag number versus autocorrelation functions (ACF) for time series of 113 years: **a** annual rainfall; **b** pre-monsoon; **c** monsoon; **d** post-monsoon; and **e** winter

Fig. 5 Z statistic (MMK) values of annual, pre-monsoon, monsoon, post-monsoon and winter rainfall of all districts during 1901–2013 (a–e), 1901–1945 (f–j), and 1946–2013 (k–o)

Fig. 6 Box plot of Theil–Sen's slope values for monthly rainfall time series during **a** 1901–2013; **b** 1901–1945; **c** 1946–2013; annual and seasonal rainfall time series **d** 1901–2013; **e** 1901–1945; **f** 1946–2013 over Odisha State

rainfall events show the decrease trend in rainfall (Goswami et al. 2006). The deferential pressure generation due to the current warming period would also cause the uneven distribution of rainfall in most districts of Odisha State.

Conclusion

The following are the important conclusions derived from the study:

- The average annual rainfall of the state is found as 1438 mm with standard deviation of ± 190 mm with about 78% of rainfall in monsoon.
- The highest rainfall occurs in Bhadrak District with average magnitude of about 1610.9 mm, and the lowest rainfall in Puri District with average magnitude of about 1139.9 mm. The average annual rainfall at 75, 90 and 95% of confidence level is found in Bhadrak District as 1339.3, 1195.2 and 1098.0 mm, respectively.
- The year 1945 is the most likely change point year in time series for the state due to the beginning of current warming period. It is observed that the rainfall trend is having decreasing trend beyond this year.
- One autocorrelation exists for the monsoon season at lag 17. Similarly, one autocorrelation exists for the post-monsoon season at lag 11. And three autocorrelations exist for the winter season at lags 9, 14 and 24.
- Annual rainfall is decreasing at 5% significance level, with three districts, viz. Cuttack, Dhenkanal and Jagatsinghpur, having positive significant trend. Further, in pre-monsoon season, most of the positive trend has been obtained in all districts with three districts, viz. Cuttack, Gajapati and Jajpur, having positive significant trend. For monsoon season, six districts, viz. Cuttack, Deogarh, Dhenkanal, Gajapati, Ganjam and Jagatsinghpur, have significant positive trend and one district, viz. Jharsuguda, has significant negative trend. In post-monsoon, only negative trend has been obtained in all districts with one district, viz. Khordha, having significant negative trend. In winter season, there is no significant trend.

As the rainfall plays the most vital role in the hydrological analysis and water balance studies, the results of this study may provide useful inputs for the planning and management in context of agricultural and water resource areas.

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represent the 75th and 25th percentile, respectively. Also, the upper and lower lines represent the maximum and minimum values of rainfall slopes.

Discussion

In this study, vast data have been processed for behavior identification long-term time series. Initially, entire daily time series has been extracted from IMD gridded data; further, it has been converted into monthly basis. Thereafter, it will be converted into weighted average rainfall time series and seasonal time series for each district. Change detection year has been found as 1945. Hence, entire time series has been converted into two segments 1901–1945 and 1946–2013. Further, nonparametric trend analysis has been utilized, for all the time series 1901–2013, 1901–1946 and 1946–2013. In 1901–2013, most of the districts have been showing the negative trend in annual time series analysis, whereas in 1901–1945 and 1946–2013, it was noticed that most of the districts have been showing positive trends. Similar results were found by the various researchers at eastern region of India (Kumar et al. 1992; Patra et al. 2012; Mondal et al. 2015). In various places in India, it was found that the annual and monsoon time series having similar results in trend analysis even the level of significance is also matched (Patra et al. 2012; Chandniha et al. 2016; Pal et al. 2019). The insignificantly decreasing trends in pre-monsoon and post-monsoon rainfall are found in the majority of districts of Odisha during 1901–2013. Chandrasekhar (2010) suggested that the occurrence of temporary lows pressure over the eastern regions of India, and it would be the possible region of occurrence of rainfall in pre-monsoon seasons. The rainfall occurs from the moisture laden wind coming from Bay of Bengal during non-monsoon seasons through the differential pressure generated between the land sea areas. The rise in air temperature over the past decade may diminish the low-pressure zone over land area and would reduce the pre-monsoon and post-monsoon rainfall in most of the districts of Odisha State. On the other hand, the winter season showed the same pattern in rainfall (Jain and Kumar 2012; Warwade et al. 2018; Nema et al. 2018). Most of the districts of the Odisha State have shown the significant increasing rainfall trend in annual and monsoon rainfall for the period 1901–1945. The possible reason for the change in rainfall pattern from the year 1945 onwards is due to the beginning of current warming period (around 1950) from the past cooling period (1891–1950) (Mohanty et al. 2012). The air temperature rises more in the current warming period and would reduce the rainfall for the period 1946–2013. The magnitude and frequency of extreme rainfall events would increase, and moderate

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