Evaluation of district-level rainfall characteristics over Odisha using high-resolution gridded dataset (1901–2013)

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Abstract

In the present global warming era, exploring the regional/district-level changes in rainfall patterns/events is highly essential for understanding the diverse characteristics of rainfall, which will be value added for the policy planning for rainfed agricultural-based states like Odisha, a region that is also highly prone to flood and droughts. Since most of the global and continental scale climate studies rarely contribute for such planning of agro-economic states of India like Odisha, there is a colossal necessity for the analysis of rainfall characteristics at regional/district level. In the present study, the rainfall characteristics at district level over Odisha are extensively evaluated for winter (JF), pre-monsoon (MAM), monsoon (JJAS) and post-monsoon (OND) using India Meteorological Department high-resolution gridded rainfall analysis dataset for the period 1901–2013. The El Nino Southern Oscillation (ENSO) influence on the district-level seasonal rainfall during four distinctive seasons has also been studied. The results suggest that the frequency of various categorical rainfall events and associated seasonal rainfall patterns over Odisha is highly heterogeneous and varies from season to season in magnitude and similar statements can be highlighted for inter-annual variability and coefficient of variation. Although the seasonal rainfall time series is significantly persistent in most of the districts during all the seasons, it is manifested to the normal distribution in majority of districts only for JJAS. Statistical analysis infers that most of the districts possess reasonable abrupt changes in seasonal rainfall during mid- and late twentieth century. A significant increasing (decreasing) trend in the frequency of high-intensity (low-intensity and wet days) rainfall events over most parts of Odisha is observed for all the seasons. A notable decreasing trend in seasonal rainfall is perceived over southern districts during MAM (7–21 mm) and OND (23–49 mm), western districts during MAM (2–41 mm) and JJAS (6–309 mm) and most of the districts during JF (6–46 mm), while increasing trend is prominent over coastal and northern Odisha during MAM (7–46 mm), northern coastal Odisha during JJAS (25–175 mm), northern and northern coastal Odisha during OND (2–64 mm). It has been noticed that the ENSO influence on seasonal rainfall is insignificant during summer monsoon, while it is notable during the other seasons. This study is very useful in determining the effects and assists the risk management for various sectors in acclimating innovative technologies for a sustainable future in the present global warming era.

Keywords Seasonal rainfall · Rainfall events · District level · Regional change · Statistical analysis · ENSO

1 Introduction

The temperature of the earth's surface is sharply rising since last few decades due to global warming [1] and causes changes in the amount, intensity, duration and

frequency of precipitation for all types of events (such as snow, fog, ice, rain, etc.) over different regions of the globe. The surface warming of an about 1 °C leads to increase the water holding capacity by 7% of the atmosphere. The increased water vapor content causes significant changes

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of the weather and climate events, particularly in the amount, intensity and duration of the rainfall at regional scale [2–4] and its impact on the various sectors associated with the societal development. Climate change and climate variability are posed the challenges in ascertainment, identification and quantification of trends in rainfall and their implications on different sectors, viz. agriculture, hydro power, etc., the in formulation of adaptation measures through appropriate strategies for water resources management at regional/district level [5–7]. During recent decades, the rainfall over the Indian Himalayas has been decreased in the last century and a sudden shift in rainfall trend has also been noticed in the recent decades [4, 8]. Furthermore, a decreasing trend in wet days and associated accumulated annual rainfall have been found for 15 out of 22 basins in India [9]. Even, consolidation of recent studies has been carried out on analysis of rainfall, which is the key input into the hydrological system; there are conclusive evidences that rainfall is decreasing in Asia [10–15]. An ample number of investigators [16–20] have reported that the anthropogenic influence is causing significant changes in trends and variability of the climatic variables and their studies found that south Asia is the most vulnerable to the present global warming. Analysis of trends in rainfall that plays vital role in controlling the hydrological system is an important factor for studying the impacts of climate change and climate variability on water resources and associated planning and management [21]. It is well known that the global or continental scale observations of historical climate are less useful for local or regional scale planning [8, 22, 23]. Thus, the evaluation of long-term trends on a local scale is needed. In this study, an attempt has been made to study the trends in district-level rainfall over Odisha, the most vulnerable to the climate extremes in India [24], for four different seasons (http://imdpune.gov.in/Weather/Reports/forecaster_guide.pdf), i.e., winter (January–February, JF), pre-monsoon (March–May, MAM), monsoon (June–September, JJAS) and post-monsoon (October–December, OND) for the period of 113 years (1901–2013).

In recent years, there has been a radical increase in attempts to understand the variations in the precipitation over India and its global teleconnections with large-scale atmospheric and oceanic circulation features. The El Niño–Southern Oscillation (ENSO) phenomenon plays a significant role on variations of various seasonal variables of local climate in different parts of the globe, and in particular, its role has been crucial over the Northern Hemisphere and its influence varies from region to region as well as season to season. A plenty number of research studies [4, 25–33] enlightened the ENSO influence on various seasonal rainfall over the Indian sub-continent. The ENSO is negatively correlated with the Indian summer

monsoon rainfall (ISMR) [30, 34], while it is positively correlated with NWI winter precipitation, and northeast monsoon precipitation over India [4, 30–33]. However, all the previous studies have been only intended to understand the variability and trends in the rainfall at the country scale of India and no such studies are available at district level using advanced high-resolution gridded rainfall analysis dataset of India Meteorological Department (IMD), which is more useful for planning and management in various sectors, viz. agriculture, hydropower, water management, etc. In India, Odisha is one of the most vulnerable states to natural disaster and district-level rainfall analysis is highly essential.

A number of studies are available on the characteristics of rainfall over Odisha [35–38], and it is reported that variations in summer monsoon rainfall during 1980–1999 are more in most parts of the Odisha when compared with the long-term average for the period of 1901–1990 [36]. Analysis of the rainfall trend over Odisha (1871–2006) by using both parametric and nonparametric tests indicates that the annual and monsoon rainfall has decreased insignificantly, whereas post-monsoon rainfall trend has increased over Odisha [38]. The information and analysis of rainfall trends at smaller spatial scales such as district level for different seasons are highly needed for planning and implementation in various sectors, viz. agriculture, water resources, water management, hydro power, etc. Therefore, an attempt has been made in this study to find out the characteristics of different seasonal rainfall at district level over Odisha by using high-resolution ($0.25^\circ \times 0.25^\circ$) gridded observed rainfall analysis dataset of IMD for the long period of 113 years (1901–2013). This study will be useful for a better understanding of climate change, rainfall variations and its global teleconnections to prepare better strategies for water resources management, disaster preparedness and flood control measures at smaller regional scale, particularly district level.

2 Study area, data, and methods

Odisha is one of the most flood and drought-prone coastal state in India, lying in the eastern margin of the Indian Peninsula that shares 480 km of coastline with the Bay of Bengal and lies between the latitudes 17.78°N , and 22.73°N , and between longitudes 81.37°E and 87.53°E [39]. It is mainly an agricultural-based state, the agriculture is the lifeline of the state's economy, more than 65% of the population is dependent on agriculture, and it contributes about 15% of Gross State Domestic Product (<http://odihort.nic.in/agriculturepolicy>). Therefore, the growth rate in agriculture sector is very crucial for the socio-economic development of the state. However, the climate

change impact on agriculture is being witnessed all over the world, but countries like India are more vulnerable in view of the high population depending on agriculture and excessive pressure on natural resources particularly over Odisha. The information and analysis of rainfall characteristics and trends in the rainfall during four distinctive seasons at each 30 districts of Odisha (Fig. 1) are highly needed for planning and implementation of new adaptive technologies on various sectors for sustainable development over this region in the present global warming era. Various abbreviations of 30 districts are frequently used in this manuscript which is represented in Fig. 1.

The high-spatial-resolution ($0.25^\circ \times 0.25^\circ$) IMD daily gridded rainfall analysis dataset from 1901–2013 is used in this study and is available in the archive of National Data Center, IMD, Pune [40, 41]. For the development and preparation of this dataset, 6955 rain gauge station records in India with varying availability periods are used. Out of 6955 rain gauge station records, 547 records from IMD observatory stations, 494 records from Hydro-meteorological observatories, 74 records from Agro-met observatories and 5845 records from stations maintained by the state governments. However, the spatial density of the station points was not uniform (Fig. 2) and it varies with time and about 1450 in the first year 1901 to about 3950 during the period 1991–1994 throughout the country [40]. The density of stations was relatively higher (≥ 3100 stations per day) from 1951 onwards except in the last 2–3 years when the density reduced to about 1900

stations per day [40]. On an average, about 2600 stations per year were available for the preparation of daily grid point data and more details of the development of this data set are available in [40]. The previous studies confirm that the IMD high-resolution ($0.25^\circ \times 0.25^\circ$) daily gridded rainfall dataset is better and statistically indistinguishable in producing the long-term features of the Indian summer monsoon rainfall [40] and winter precipitation over north-west India [42]. Moreover, it is also reported the superiority of this dataset, in a realistic representation of heavy precipitation over the Western Ghats and northeast and low precipitation over the leeward side of the Western Ghats during summer monsoon; and heavy precipitation over the Himalayan region during winter [40, 42]. Therefore, the IMD high-resolution dataset is the best choice for finding the realistic climatological mean, inter-annual variability, trend and relationships of the seasonal rainfall at district level over Odisha.

To investigate the changes in the frequency of various rainfall events (Table 1) and associated rainfall at grid point as well as district level over Odisha for different seasons, a year is divided into four seasons: winter (January–February, JF), pre-monsoon (March–May, MAM), southwest monsoon (June–September, JJAS) and post-monsoon (October–December, OND). The time series of area-weighted averages of seasonal rainfall for each of the thirty districts in Odisha during four distinctive seasons have been analyzed. To understand the characteristics of various rainfall events and associated seasonal rainfall over Odisha, the

Fig. 1 Districts of Odisha state of India

Locations of Rain gauge Stations

Fig. 2 Network of 6955 rain gauge stations used for development of India Meteorological Department (IMD) high-spatial-resolution gridded rainfall analysis dataset. *Source:* Pai et al. (2014a)

climatological mean, inter-annual variability (IAV) and coefficient of variation (CV) are calculated for the long term of 113 years from 1901 to 2013.

To study the important characteristics of changes and quantifying its acceptance in the district-level seasonal

rainfall over Odisha several statistical methods, i.e., normality, homogeneity, persistence and abrupt changes, statistical tests such as Shapiro–Wilk normality test (SWNT), Hurst exponent (H), Pettit's test (PTT), Buishand range test (BRT), Buishand U test (BUT) and standard normal

Table 1 Various rainfall events categorized by India Meteorological Department

Rainfall category	Short form	Range of rainfall
Wet days	Wet	Wet > 0 mm
Very light rain	VLR	$0.1 < \text{VLR} \leq 2.4$ mm
Light rain	LR	$2.5 \text{ mm} \leq \text{LR} < 7.5$ mm
Moderate rain	MR	$7.6 \text{ mm} \leq \text{MR} < 35.5$ mm
Rather heavy rain	RHR	$35.6 \text{ mm} \leq \text{RHR} < 64.4$ mm
Heavy rain	HR	$64.5 \text{ mm} \leq \text{HR} < 124.4$ mm
Very heavy rain	VHR	$124.5 \text{ mm} \leq \text{VHR} < 244.4$ mm
Extremely heavy rain	EHR	$\text{EHR} > 244.5$ mm

homogeneity test (SNHT) are applied on the district-level seasonal rainfall during four distinctive seasons for the period of 113 years (1901–2013). Shapiro–Wilk normality test checks whether the district-level seasonal rainfall time series of each 30 districts of Odisha are normally distributed or not at 95% confidence level [43, 44]. Four homogeneity tests such as PTT, BRT, BUT and SNHT are used to test the homogeneity of the district-level seasonal rainfall over Odisha [45]. It can be noted that the SNHT is sensitive in detecting the breaks near the beginning and the end of the series, while BRT, BUT and PTT test easier to use to detecting the break in the middle of the series [45].

The Hurst-exponent (H) test is one suitable examination to quantifying the persistent or anti-persistent behavior of district-level seasonal rainfall time series over Odisha and also determines whether the time series is completely random or has some long-term memory. For calculating the Hurst exponent, one must estimate the dependence of the rescaled range on the time span of observations. Several techniques have been adopted for calculating Hurst exponent [46–48]. The oldest and well-known method to estimate the Hurst exponent (H) is R/S analysis [49–51]. The range of the H value is 0 to 1. Based on the H value, the time series of district-level seasonal rainfall categorized at 95% confidence level [52]: if $H = 0.5$ then the time series of district-level seasonal rainfall is random series (no memory of previous values); if $0 < H < 0.5$ then the time series of district-level seasonal rainfall is an anti-persistent series (negative autocorrelation), which means an up value is more likely followed by a down value, and vice versa; if $0.5 < H < 1$ then the time series of district-level seasonal rainfall is a persistent series (positive autocorrelation), which means the direction of the next value is more likely the same as current value.

The trends in the frequency of various rainfall events and associated seasonal rainfall at grid point level over Odisha for all the four distinctive seasons are computed, and the significance is tested by the nonparametric test Mann–Kendall (MK) test. This analysis also extended for

each of 30 district of Odisha for seasonal scale rainfall. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of an increasing or decreasing trend [53–57].

The relationships of district-level rainfall for different seasons with simultaneous ENSO have also been examined. For this purpose, correlation coefficients are calculated at district-level seasonal rainfalls with simultaneous Niño–3.4 region sea surface temperature (Niño–3.4 region SSTs) and the Southern Oscillation Index (SOI) for the study period (1901–2013) during the different seasons. The datasets of Niño–3.4 region SSTs and SOI are obtained from the Climate Research Unit (CRU), University of East Anglia (<http://www.cgd.ucar.edu/cas/catalog/climind>). Student's t test is used to examine the significance of these correlations at different confidence levels (90, 95 and 99%).

3 Results

The IMD new high-resolution rainfall gridded analysis dataset is used for analyzing the characteristics of various rainfall events and associated seasonal rainfall at each grid point as well as district level over Odisha during the four distinctive seasons, and the results are discussed in the following subsections.

3.1 Statistical characteristics of monthly rainfall of Odisha as a whole

Figure 3 depicts the monthly distribution of climatological mean, inter-annual variability (IAV) and coefficient of variation (CV) of rainfall for Odisha as a whole to understand the annual variation for the study period of 113 years (1901–2013). The monthly mean rainfall is maximum during the southwest monsoon (JJAS) and particularly peak in August (345 mm) followed by July (340 mm), September (242 mm) and June (208 mm), while it is minimum during the winter season months December (6 mm), January (13 mm) and February (22 mm) (Fig. 3a). It is noticed that the southwest monsoon contributes 80% of the annual rainfall, while the post-monsoon (OND) 11.1%, winter season (JF) 2.4% and pre-monsoon (MAM) 8.5% contribute to the annual rainfall. Monthly distribution of IAV rainfall is commensurate with the pattern of monthly mean rainfall distribution (Fig. 3b). The maximum IAV is found during southwest monsoon (JJAS) and particularly more in July (86 mm) followed by August (80 mm), June (75 mm) and September (66 mm). It is indeed interesting to note that the IAV of October monthly rainfall is higher than that of IAV of August, June and September monthly rainfall, whereas the amount of monthly rainfall for October is lesser than that of August, June and September monthly

Fig. 3 Statistical analysis of all Odisha rainfall (mm) at monthly scale **a** climatological mean **b** interannual variability and **c** coefficient of variation (in %) for the long period of 1901–2013

rainfall. The CV of monthly rainfall is less (27–36%) during the southwest monsoon (JJAS), while it is more (66–205%) during post-monsoon followed by winter (111–123%) and pre-monsoon (62–106%) seasons.

3.2 Statistical characteristics of seasonal rainfall at grid point level over Odisha

Figure 4a–l depicts the patterns of statistical features of seasonal rainfall such as climatological mean, inter-annual variability (IAV) and coefficient of variation (CV) at grid

point over Odisha during four distinctive seasons for the study period of 113 years (1901–2013). It is remarkably noticed that the spatial pattern of rainfall varies from one season to another (Fig. 4a, d, g, j). The maximum rainfall contribution over entire Odisha is observed during the summer monsoon (JJAS) followed by the post-monsoon, pre-monsoon and winter seasons.

The climatological patterns of seasonal rainfall indicate the rainfall gradient from south to northern parts of Odisha during winter and summer monsoon. In particular, winter rainfall is more over the northern and northeastern parts of Odisha and the summer monsoon rainfall is more over western parts of Odisha. In the other hand, the pre-monsoon and post-monsoon seasonal rainfall is strangely decreasing from south to northern parts of Odisha. In case of IAV of the seasonal rainfall, similar kind of patterns in IAV is found like climatological mean pattern of seasonal rainfall during the corresponding season (Fig. 4b, e, h, k). The greater values of climatological mean and IAV of seasonal rainfall during the summer monsoon season than the other seasons are mainly due to the development of a number of low pressure systems (LPS) over northwest Bay of Bengal (NWBoB), Gangetic West Bengal (GWB) and northern Odisha regions that lead to the number of heavy-to-extreme rainfall events over Odisha during summer monsoon season [58]. The values of climatological mean and IAV of summer monsoon rainfall increase from south to northern Odisha and are mainly associated with the increase in the occurrences of heavy-to-extreme rainfall events from south to northern part of Odisha by the interaction of basic monsoon flow and the LPS mostly over NWBoB, GWB and north Orissa with the monsoon trough from the system extending to west–northwest–erly direction [58]. The most of the post-monsoon rainfall over Odisha is mainly associated with the development of cyclonic disturbances in BoB that propagates north/northwestward and wind reversal during mid-September. The climatological mean and IAV of post-monsoon rainfall are relatively higher over coastal than the interior districts of Odisha because the influence of cyclonic disturbances formed over the BoB is higher over coastal regions than the interior parts of Odisha. However, the pattern of CV is in reverse of the climatological mean and IAV during all the seasons (Fig. 4c, f, i, l). The CV of seasonal rainfall is higher during winter in most parts of Odisha followed by post-monsoon, pre-monsoon and summer monsoon. The higher CV of seasonal rainfall during winter than the other seasons is due to the value of ratio between IAV, and climatological mean of seasonal rainfall during winter is relatively higher than the other seasons.

For analyzing the frequency of various rainfall events and its long-term trends over Odisha during four distinctive seasons for the study period, the rainfall events

Fig. 4 Statistical analysis of seasonal rainfall at grid point level over Odisha during four distinctive seasons JF (row 1), MAM (row 2), JJAS (row 3) and OND (row 4) for the period of 113 years (1901–2013). The seasonal mean rainfall in mm (**a, d, g, j**), inter-annual

variability (IAV) in mm (**b, e, h, k**) and coefficient of variation (CV) in % (**c, f, i, l**) of seasonal rainfall for four distinctive seasons have been shown in columns 1 to 3, respectively

are categorized into seven categories as per IMD criteria (<http://imd.gov.in/section/nhac/termglossary.pdf>) and shown in Table 1 [20]. From Fig. 5a–af, the spatial patterns of various rainfall events over Odisha during the four distinctive seasons reveal that the frequency of all types events and the total number of wet days are significantly more over the entire Odisha during the monsoon season (JJAS) and these results support to the findings in the above analysis on seasonal rainfall patterns. It is demonstrated from the figure that in a particular season, the spatial distribution of frequencies in various rainfall events exhibits a similar pattern with a lower magnitude

in south Odisha and greater magnitude in northern Odisha. The frequency of various rainfall events during winter, pre-monsoon and summer monsoon remarkably increases from south to northern parts of Odisha, and particularly, the frequency of various rainfall events during winter over northern and northeastern, pre-monsoon over northeastern and summer monsoon over western parts of Odisha is relatively more as compared to the other parts of Odisha. In the other hand, the post-monsoon seasonal rainfall strangely decreases from coastal to the interior parts of Odisha. It is interestingly noticed that during the winter and pre-monsoon seasons, the frequency of VLR

Fig. 5 Spatial distribution of frequency of various rainfall events such as Wet days (a–d), VLR (e–h), LR (i–l), MR (m–p), RHR (q–t), HR (u–x), VHR (y–ab) and EHR (ac–af) at grid point level over Odisha during four distinctive seasons JF (column 1), MAM (column 2), JJAS (column 3) and OND (column 4) for the period of 113 years (1901–2013)

events over most parts of Odisha is greater followed by LR, MR, RHR, HR and VHR events. However, there was no EHR event during winter over the entire Odisha, while the frequency of VHR events during winter and EHR during pre-monsoon occurs in a very few places. It is also noticed that during winter and pre-monsoon, the frequency relatively increases toward the coast with increase in the rainfall intensity category. During the summer monsoon, the frequency of MR events (22–40) in most parts of Odisha is more followed by VLR (18–32), LR (17–28), RHR (2–7), HR (1–3), VHR and EHR events. The frequency relatively increases from east to western parts of Odisha with increase in the intensity of rainfall category. In case of post-monsoon, the frequency of VLR (4–9) is high followed by MR (3–8), LR (3–7), RHR, HR, VHR and EHR events. It is observed that during post-monsoon season, the frequency relatively increases from the interior parts to coastal parts of Odisha with increase in the intensity of rainfall category.

3.3 Statistical characteristics of seasonal rainfall at district level over Odisha

Figure 6 portrays the climatological features of district-level seasonal rainfall over Odisha during four distinctive seasons for the study period of 113 years (1901–2013). From Fig. 6a–d, it is observed that the district-level seasonal rainfall varies from one season to another with the maxima during the summer monsoon (JJAS) followed by post-monsoon, pre-monsoon and winter seasons.

The climatological patterns of seasonal rainfall during four distinctive seasons indicate that the seasonal rainfall during winter, pre-monsoon and summer monsoon seasons remarkably increases from south to northern districts, and particularly, the seasonal rainfall is more over northern and northern coastal districts during winter, northern districts during pre-monsoon and western Odisha districts during summer monsoon (Fig. 6a, c), while the seasonal rainfall strangely decreases from south to northern districts of Odisha during post-monsoon (Fig. 6b, d). In case of IAV of seasonal rainfall, similar patterns in IAV are found like climatological mean pattern of seasonal rainfall during the corresponding season (Fig. 7a–d), while the patterns of CV of seasonal rainfall during four distinctive seasons are in reverse of the climatological mean (Fig. 8a–d). The CV is higher during winter followed by post-monsoon,

pre-monsoon and summer monsoon in the most of districts (Fig. 8). The statistical analysis of various rainfall events and associated seasonal rainfall at grid point level over Odisha also supports the district-level seasonal rainfall analysis (Figs. 4, 5).

Statistical analysis with Shapiro–Wilk normality test (SWNT), Hurst exponent (H), Pettit's test (PTT), Buishand range test (BRT), Buishand U test (BUT) and standard normal homogeneity test (SNHT) on district-level seasonal rainfall time series has been carried out to explore the normality, homogeneity, persistence and abrupt changes in the seasonal rainfall. The SWNT is involved with the normality test, and if the p value is > 0.05 (< 0.05) then the associated district-level seasonal rainfall follows (not following) the normal distribution at 95% confidence level (Table 2). The analysis of SWNT reveals that the seasonal rainfall series computed for each of the 30 districts as well as Odisha as a whole not follow the normal distribution at 95% confidence level during winter, pre-monsoon and post-monsoon seasons, while it is indeed interesting that the seasonal rainfall during summer monsoon over GPT, KLH, NPD, ANG, BLS, DEO, KNDP, KNJHR, SMBLR, GJM, KNM, NGRH, KHD, CTC, JSR, BDH, SNR, BRG districts as well as Odisha as a whole follows the normal distribution (Table 2).

The Hurst exponent (H) quantifies the relative tendency of a time series of district-level seasonal either to regress strongly to the mean or to cluster in a direction (Fig. 9). From Fig. 9, it is interestingly noticed that the time series of seasonal rainfall in most of the districts during all the seasons are persistent ($H > 0.5$) at 95% confidence level. However, the time series of district-level seasonal rainfall are not persistent for MKG, JHSGD, SNR and BRG during pre-monsoon, MYBHG during summer monsoon, GJM, NGRH, CTC and JSR during winter and JSR during post-monsoon. The time series of seasonal rainfall for KRP, NBR, SUND and SMBLR during pre-monsoon, KLH during winter and SMBLR during post-monsoon is random.

For identifying the most probable change-point year in the seasonal rainfall time series, the PTT, BRT, BUT and SNHT have been adopted and the change-point years with 90%, 95% and 99% confidence levels are depicted in Table 3. The detected break-point years in district-level seasonal rainfall time series over Odisha by four tests have also been compared. In terms of change-point analysis, the PTT confirms that the entire Odisha state has experienced 7 different change-point years for different districts (1924–2, 1948–20, 1963–2, 1968–2, 1977–1, 1988–1 and 1998–2 districts, respectively) during winter, while the BRT, BUT and SNH tests confirm the 12 (1923–1, 1924–1, 1926–1, 1937–1, 1938–1, 1944–7, 1945–4, 1947–1, 1948–4, 1962–1, 1967–1 and 1968–4 districts), 11 (1923–2, 1924–1, 1926–1, 1938–2, 1944–7, 1945–4, 1947–1, 1948–5, 1962–1, 1965–1 and

Fig. 6 The climatological mean of seasonal rainfall (mm) at district level over Odisha for four distinctive seasons **a** JF **b** MAM **c** JJAS and **d** OND for the period 1901–2013. The all Odisha (AO) on the each figure indicates climatological seasonal mean rainfall for Odisha as a whole

1967-1 districts) and 12 (1901-9, 1906-3, 1911-1, 1919-1, 1923-2, 1926-2, 1938-1, 1944-2, 1945-1, 1948-4, 1968-2 and 1998-1 districts) different change-point years during the winter, respectively. It is noteworthy that the change in district-level winter seasonal rainfall is confirmed by PTT, BRT, BUT and SNHT and significant at 90% confidence is for 11, 3, 13 and 12 different districts of Odisha, respectively (Table 3). The winter seasonal rainfall for Odisha as a whole the change-point years 1948, 1944, 1944 and 1901 (at 95% confidence level) which is confirmed by PT, BRT, BUT and NSHT tests, respectively, is observed (Table 3). All the tests assert that the abrupt change in the winter seasonal rainfall is confined between 1946 and 1982 in the majority of the districts of Odisha (Table 3).

On the other hand, during pre-monsoon, 16, 16, 16 and 18 different change-point years for district-level seasonal rainfall of 30 districts of Odisha are confirmed by PTT, BRT, BUT and SNHT, respectively (Table 3). Moreover,

the changes in the pre-monsoon seasonal rainfall significant at 90% confidence level confirmed for 7, 10, 6 and 4 different districts of Odisha by PTT, BRT, BUT and SNHT, respectively (Table 3). Although, the change-point year of pre-monsoon seasonal rainfall for Odisha as a whole is 1976 by PTT and 1980 by BRT, BUT and SNHT has been confirmed. The most common period from 1951 to 1989 for the abrupt changes in the pre-monsoon seasonal rainfall over the majority of districts of Odisha is endorsed by all the four tests (Table 3). For the summer monsoon, 19, 20, 20 and 15 different change-point years in time series are confirmed by PTT, BRT, BUT and SNHT, respectively. Moreover, the change-point years for summer monsoon seasonal rainfall are significant at 90% confidence level for 12, 16, 13 and 16 different districts of Odisha are inveterate by PTT, BRT, BUT and SNHT, respectively, while the change-point year of summer monsoon seasonal rainfall for Odisha as a whole has found in 1961 that is confirmed

Fig. 7 Inter-annual variability (IAV) of seasonal rainfall (mm) at district level over Odisha for **a** JF **b** MAM **c** JJAS and **d** OND seasons for the period 1901–2013. The AO on the each figure indicates inter-annual variability (IAV) of seasonal rainfall for Odisha as a whole

by all four tests. It has notably observed that the most common period from 1943 to 1990 is found by all the four tests for abrupt changes in the summer monsoon seasonal rainfall in majority of the districts of Odisha. In the case of post-monsoon seasonal rainfall, 10, 11, 11 and 7 different change-point years in time series of post-monsoon seasonal rainfall of 30 districts are confirmed by PTT, BRT, BUT and SNHT, respectively, while the change-point year for Odisha as a whole can find the year 1963 by PTT, BRT and BUT, 2012 (at 90% confidence level) by SNHT. Moreover, the abrupt changes in the post-monsoon seasonal rainfall are significant at 90% confidence level for 4, 5, 1 and 9 different districts of Odisha are confirmed by PTT, BRT, BUT and SNHT, respectively. It has remarkably noticed that the most common period from 1948 to 1984 is found by PTT, BRT and BUT for abrupt changes in the post-monsoon seasonal rainfall in majority of the districts of Odisha, while the abrupt changes in the district-level post-monsoon

seasonal rainfall are confirmed in the years 2011 and 2012 for 23 districts out of 30 districts of Odisha by SNHT.

From the above analysis, it is confirmed that the abrupt changes in district-level seasonal rainfall for the four seasons have found from 1943 to 1990 in majority districts of Odisha as well as Odisha as whole. However, the relative comparison between the four tests for indemnifying the abrupt changes in the district-level seasonal rainfall for four seasons shows that the sensitivity in detecting the abrupt changes near the beginning and the end of the time series of district-level seasonal rainfall over Odisha is more for SNHT than the PTT, BRT and BUT [45].

3.4 Trends in various rainfall events and associated seasonal rainfall at grid point level over Odisha

Figure 10 depicts the trends in seasonal rainfall (mm/113 years) at grid point level over Odisha during four

Fig. 8 Coefficient of variation (%) of seasonal rainfall at district level over Odisha for **a** JF **b** MAM **c** JJAS and **d** OND seasons for the period 1901–2013. The AO on the each figure indicates coefficient of variation (%) of seasonal rainfall for Odisha as a whole

distinctive seasons for the period of 113 years (1901–2013). The trend analysis illustrates that the winter seasonal rainfall has decreased in all parts of Odisha (Fig. 10a). Moreover, these decreasing trends in winter seasonal rainfall (10–40 mm) are significant at 90% confidence level over western, northwestern, northern and northeastern parts of Odisha. From Fig. 10b, it is noticed that there is an insignificant decreasing trend in the pre-monsoon seasonal rainfall over most of parts of western and central Odisha (0–50 mm), while an increasing trend is detected over coastal and northern parts of Odisha (0–50 mm). Moreover, the increasing trend in pre-monsoon seasonal rainfall (> 50 mm) is significant at 90% confidence level over RGD and DHKL region. In case of summer monsoon season, it is noticed that there is a significant increasing trend in the summer monsoon seasonal rainfall at 90% confidence level over northeastern (> 250 mm), central-coastal (100–250 mm), NBR, RGD, GPT, DEO regions

(> 250 mm), while a significant decreasing trend in the summer monsoon seasonal rainfall at 90% confidence level is observed over SMBLR and SNR regions. During the post-monsoon season, an insignificant decreasing trend in the post-monsoon seasonal rainfall over most parts of south and southwestern Odisha is observed, while there is an insignificant increasing trend in the post-monsoon seasonal rainfall over most parts of coastal, northern and northwestern parts of Odisha.

The trend analysis has also been carried out on the frequency of various categorical rainfall events at grid point level over Odisha during four distinctive seasons for a long period of 113 years (1901–2013) and depicted in Fig. 11a–af. From Fig. 11, it is observed that there is a remarkable decreasing trend in the frequency of wet days over the most parts of Odisha during all the seasons (Fig. 11a–d). Moreover, the decreasing trends in the frequency of wet days are significant at 90% confidence

Table 2 Shapiro–Wilk normality test (SWNT) for testing the normality of district-level seasonal rainfall over Odisha during the four distinctive seasons for the period of 113 years (1901–2013)

District	<i>p</i> values of Shapiro–Wilk normality test			
	JF	MAM	JJAS	OND
MKG	0.000	0.000	0.000	0.000
KRP	0.000	0.000	0.000	0.000
RGD	0.000	0.000	0.000	0.001
GPT	0.000	0.000	0.063	0.000
NBR	0.000	0.000	0.003	0.000
KLH	0.000	0.000	0.386	0.000
NPD	0.000	0.000	0.072	0.000
ANG	0.000	0.000	0.616	0.000
BLS	0.000	0.000	0.081	0.000
BHD	0.000	0.000	0.001	0.000
DHKL	0.000	0.000	0.001	0.000
DEO	0.000	0.000	0.125	0.000
JPR	0.000	0.000	0.034	0.000
JHSGD	0.000	0.000	0.037	0.000
KNDP	0.000	0.013	0.344	0.000
KNJHR	0.000	0.000	0.148	0.000
MYBHG	0.000	0.012	0.045	0.000
SUND	0.000	0.051	0.009	0.000
SMBLR	0.000	0.004	0.814	0.000
GJM	0.000	0.000	0.379	0.000
KNM	0.000	0.000	0.507	0.000
PURI	0.000	0.000	0.000	0.000
NGRH	0.000	0.000	0.082	0.000
KHD	0.000	0.000	0.545	0.000
BNGR	0.000	0.000	0.019	0.000
CTC	0.000	0.000	0.348	0.000
JSR	0.000	0.000	0.053	0.000
BDH	0.000	0.000	0.594	0.000
SNR	0.000	0.000	0.554	0.000
BRG	0.000	0.000	0.203	0.000
Odisha	0.000	0.000	0.483	0.001

The *p* value is > 0.05 (< 0.05) with bold (without bold) indicates that the associated district-level seasonal rainfall is following (not following) the normal distribution

level over the western and northwestern parts of Odisha during winter, west, central and southwestern parts of Odisha during pre-monsoon, southern and a few parts of northern Odisha during summer monsoon, central and southwestern parts during post-monsoon seasons, while a significant increasing trend in the frequency of wet days is noticed only over RGD region during summer, pre-monsoon and post-monsoon seasons. In case of VLR events, a significant decreasing trend in the frequency of VLR events at 90% confidence level is observed over central, western and northwestern parts of Odisha during winter, central, western, northeastern and southwestern

parts of Odisha during pre-monsoon, most parts of Odisha during summer monsoon, central and southwestern parts of Odisha during post-monsoon (Fig. 11e–h). However, a significant increasing trend in the frequency of VLR events is also noticed over southeastern parts of Odisha during summer, pre-monsoon and post-monsoon seasons. In the other hand, a notable decreasing trend in the frequency of LR events is found over northwestern parts of Odisha during winter, central and southwestern parts of Odisha during pre-monsoon, central, north-coastal and northern parts of Odisha during summer monsoon seasons, while trend in the LR events is insignificant for all the seasons (Fig. 11i–l). In case of MR events, a notable decrease in the frequency of MR events is observed over the western parts of Odisha during winter, western, southwestern and north-coastal parts of Odisha during summer monsoon, a significant increasing trend in the frequency of MR events is evident only over west-central part of Odisha (Fig. 11m–p).

It is interesting to notice that there is a significant increasing trend in the frequency of high-intensity rainfall events (RHR, HR, VHR and EHR events) in most parts of Odisha, while there is a remarkable decreasing trend (at 90% confidence level) in the frequency of low-intensity rainfall events in most parts of Odisha during the summer monsoon season. This infers that the increasing trend leads to more flood situations in the state of Odisha. It is indeed a troubling fact that a notable increase trend in the frequency of EHR events is observed (> 244.5 mm/day) over the northeastern part of Odisha during pre-monsoon, southern tip of Odisha during pre-monsoon, western parts of Odisha during summer monsoon, which leads to flash floods and highly impact to various sectors (Fig. 11q–af). There is a significant increasing trend in the frequency of high-intensity rainfall events such as RHR, HR and VHR in most parts of Odisha during pre-monsoon, while a significant decreasing trend is observed in the frequency of low-intensity rainfall events as well as frequency of wet days in most parts of Odisha during post-monsoon.

From the above analysis, it is remarkably seen that there is a significant decreasing trend in the frequency of wet days in most parts of Odisha for all the seasons. It is mainly due to a significant decreasing trend in the frequency of low-intensity rainfall events (VLR, LR and MR events) in most parts of Odisha during all the seasons which events where contributed maximum frequency to the wet days. However, the low-intensity rainfall event's contribution to the associated seasonal rainfall over most parts of Odisha during summer, pre-monsoon and post-monsoon is lesser than the high-intensity rainfall events. The increasing trend in the seasonal rainfall during summer, pre-monsoon and post-monsoon seasons in most parts of Odisha is mainly due to a significant increasing trend in the frequency of high-intensity rainfall events

Fig. 9 Hurst exponent (H) of district-level seasonal rainfall time series over Odisha during four distinctive seasons for the study period 1901–2013. The Hurst-exponent values on the figure, $H > 0.5$, $H < 0.5$ and $H = 0.5$ values indicate that the time series of dis-

trict-level seasonal rainfall is persistent (positive autocorrelation), anti-persistent (negative autocorrelation) and random (no memory of previous values) time series, respectively

(RHR, HR, VHR and EHR) which events where the contribution of events to associated seasonal rainfall is higher than the low-intensity rainfall events.

3.5 Trends in various seasonal rainfall at district level over Odisha

Figure 12 depicts the trends in the district-level seasonal rainfall (mm/113 years) for each of 30 districts of Odisha during four distinctive seasons for the period of 113 years (1901–2013). During the winter, there is a decreasing trend in the winter seasonal rainfall for all the districts of Odisha (Fig. 12a). Moreover, the decreasing trends are significant over NPD (27 mm), SMLR (24 mm), SUND (46 mm), KHJR (42 mm) and MYBHG (33 mm) districts at 99% confidence level and BNGR (21 mm), BRG (23 mm), SNR (22 mm), JHSGD (25 mm), DEO (37 mm), ANG (29 mm), DHKL (24 mm), KHD (22 mm), KNDP (35), JPR (28 mm), BHD (35 mm), BLS (26 mm) and MKG (10 mm) districts at 90% confidence level, while insignificant decreasing trends have been noticed over the other districts.

From Fig. 12b, it has been noticed that there is a decreasing trend in pre-monsoon seasonal rainfall in most of the districts of south and western Odisha (2–41 mm), while there is an increasing trend detected in pre-monsoon seasonal rainfall over the districts of coastal and northern Odisha (7–46 mm). Moreover, the decreasing trend of pre-monsoon rainfall is a significant over NPD (41 mm) at 99% confidence level, BHD (45 mm) and KNDP (33 mm) at 90% confidence level, while there is a significant increasing trend in the pre-monsoon seasonal rainfall

over KNJHR (26 mm), CTC (46 mm), JSR (43 mm) and GPT (41 mm) districts (Fig. 12b).

There is an increasing trend in the summer monsoon seasonal rainfall over MYBHG (92 mm), BLS (155 mm), DEO (58 mm), DHKL (129 mm), JPR (69 mm), KNDP (26 mm), JSR (126 mm), CTC (175 mm), NGRH (25 mm), PURI (31 mm), GJM (76 mm), GPT (98 mm), KLH (154 mm) and RGD (94 mm) districts, while there is decreasing trend noticed for the same over other districts of Odisha (7–309 mm) (Fig. 12c). Moreover, the increasing trend in the summer monsoon seasonal rainfall is significant at 90% confidence level over BLS, DHKL, CTC, GJM, GPT and RGD districts, while the decreasing trend in the summer monsoon seasonal rainfall is significant over SUND (198 mm) and JHSGD (309 mm) at 99% confidence level and BDH (154 mm) and NPD (150 mm) at 90% confidence level (Fig. 12c). On the other hand, the post-monsoon seasonal rainfall has a decreasing trend over most districts of south and western Odisha (4–49 mm). In addition to these districts, decreasing trend in the post-monsoon seasonal rainfall is also observed over GPT (23 mm), KNM (34 mm), PURI (31 mm) and KHD (56 mm) districts, while increasing trend is perceived in the other districts (2–64 mm) during the post-monsoon (Fig. 12d). Moreover, the decreasing trend in the post-monsoon seasonal rainfall is significant (at 90% confidence level) over MKG (39 mm), NBR (34 mm), RGD (49 mm) and KHD (56 mm) districts, while significantly increased at 90% confidence level in the post-monsoon rainfall is noticed only over JSR (64 mm) (Fig. 12d). The trend analysis in the frequency of various rainfall events and associated seasonal rainfall is supported to the trend

Table 3 Years identified as change points by four change-point detection tests (Pettit's test (PTT), Buishand range test (BRT), Buishand U test (BUT) and standard normal homogeneity test (SNHT)) in seasonal rainfall at district level over Odisha during four distinctive seasons for the period of 113 years (1901–2013)

District	JF				MAM			
	PTT	BRT	BUT	SNHT	PTT	BRT	BUT	NSHT
MKG	1948	1937	1937	1937	1958	1958	1958	1958
KRP	1944	1944	1944	1911	1971	1958	1958	2011
RGD	1944	1944	1944	1944	1966	1979	1979	1979
GPT	1977	1938	1938	1938	1976**	1976*	1976*	1976*
NBR	1988	1944	1944	1919	1919	1919	1919	1919
KLH	1924	1926	1926	1926	1919	1919	1919	1909
NPD	1945	1944	1944**	1901***	1951**	1951	1951**	1919*
ANG	1968*	1967	1967*	1901	1915	1989	1989	1989
BLS	1944	1948	1948	1948	1975	1975**	1975	1975
BHD	1948**	1948	1948**	1948*	1951**	1950**	1950*	1950
DHKL	1948	1968	1968	1901	1975*	1975**	1975*	1980*
DEO	1968*	1968	1968**	1901***	1920	1920	1920	1915
JPR	1948*	1948	1948*	1948	1980	1980*	1980	1987
JHSGD	1962*	1962	1962**	1901**	1924	1924	1924	2006
KNDP	1948**	1948	1948**	1948*	1951	1946*	1946	1946
KNJHR	1948**	1948*	1948**	1906**	1976*	1976*	1976	1976
MYBHG	1948*	1944	1944**	1906*	1975*	1975***	1975	1975
SUND	1945**	1945*	1945***	1906***	1952	1952	1952	1909
SMBLR	1945	1945	1945*	1901**	1952	1999	1999	2006
GJM	1963	1923	1923	1901	1976	1980	1980	1980
KNM	1944	1944	1944	1926	1952	1980	1980	1918
PURI	1998	1924	1924	1998	1985	1985	1985	1987
NGRH	1924	1968	1968	1968	1987	1987*	1987	1989
KHD	1948	1968	1968	1968	1918	1985	1985	1987
BNGR	1945	1945	1945*	1901***	1920	1999	1999	1999
CTC	1948	1968	1968	1923	1980*	1980**	1980**	1966***
JSR	1998	1923	1923	1923	1985	1980	1980*	1985
BDH	1948	1944	1944	1944	1980	1980	1980	1987
SNR	1945*	1945*	1945*	1945*	2006	1980	1980	2006
BRG	1945*	1947	1947**	1901***	2006	1952	1952	2006
Odisha	1948	1944	1944**	1901**	1976	1980	1980	1980
District	JJAS				OND			
	PTT	BRT	BUT	SNHT	PTT	BRT	BUT	NSHT
MKG	2002	2002**	2002	2004***	1977	1963	1963	1977
KRP	1959***	1959***	1959*	2005**	1963	1963**	1963	1963
RGD	1952	1952	1952	2005*	1963*	1963***	1963*	1963*
GPT	1977**	1977**	1977**	1977**	1963	1968	1968	2012
NBR	1999	1999	1999	2002*	1962*	1962	1962	1962
KLH	2000	1989	1989	2000**	1963	1963	1963	2012
NPD	1961***	1961***	1961**	1961**	1964	1964	1964	1964
ANG	1963	1963	1963	1963	1963	1963	1963	2012
BLS	1925**	1925	1925*	1925*	1922	1914	1914	2012**
BHD	1947	1947***	1947*	1947	1922	1914	1914	2012
DHKL	1982*	1982	1982*	1982	1963	1914	1914	2012**
DEO	1982	1982	1982	1982	1963	1963	1963	2012
JPR	1924	1924*	1924	1924	1922	1914	1914	2012*

Table 3 (continued)

District	JJAS				OND			
	PTT	BRT	BUT	SNHT	PTT	BRT	BUT	NSHT
JHSGD	1961***	1961***	1961***	1961***	1927	2002	2002	2012
KNDP	1925	1925*	1925	1912	1914	1914	1914	1914
KNJHR	1946	1946**	1946	1946	1963	1956	1956	2012*
MYBHG	1925	1970	1970	2005	1956	1914	1914	2012***
SUND	1953***	1961**	1961**	1961**	1963	1948	1948	2012
SMBLR	1946	1961	1961	1961	1923	1914	1914	2012
GJM	1974*	1974	1974*	2005*	1914	1914	1914	2012*
KNM	1916	1916	1916	1907	1956*	1958*	1958	2012
PURI	1979	1979	1979	1990	1959	1959*	1959	2012
NGRH	2000	2000*	2000	2000***	1963	1914	1914	2012
KHD	1948	1948**	1948	2000	1956*	1956**	1956	2012
BNGR	1961*	1961*	1961	1961	1964	1964	1964	2012
CTC	1979**	1979	1979**	2000***	1914	1914	1914	2012**
JSR	1959	1959	1959*	2000*	1914	1914	1914	1914
BDH	1946*	1963**	1963**	1963*	1963	1984	1984	2012**
SNR	1946	1943**	1943	2002	1922	1984	1984	2011
BRG	1961**	1961***	1961**	1961**	1922	1984	1984	2011
Odisha	1961	1961	1961	1961	1963	1963	1963	2012*

*, **, ***Indicates that the abrupt changes in the seasonal rainfall is significant at 90, 95 and 99% confidence levels, respectively

analysis of district-level seasonal rainfall for the four distinctive seasons (Figs. 10, 11).

3.6 ENSO relationship with seasonal rainfall at district level over Odisha

It is noteworthy to investigate the relationship between the district-level seasonal rainfalls with simultaneous Nino3.4 region SST for the four distinctive seasons, and the same is depicted in Fig. 13. It is noticed that the district-level seasonal rainfall is in inverse relationship with Nino3.4 region SST for winter and post-monsoon for most of the districts, while the relationship is in the phase for the pre-monsoon seasonal rainfall in most of the districts of Odisha. Moreover, this inverse relationship of Nino3.4 region SST is a significant over SUND and SMBLR at 99% confidence level, BRG, KNJHR and JSR at 90% confidence level for the winter seasonal rainfall, only MKG at 90% confidence level for summer monsoon seasonal rainfall and entire northern and coastal districts of Odisha for post-monsoon seasonal rainfall. The positive relationship of district-level pre-monsoon seasonal rainfall with Nino3.4 region SST is a significant over BLS, DEO, ANG, BDH, BNGR and NGRH at 90% confidence level and KNM at 99% confidence level. It is troubling to notice that coastal Odisha rainfall has an insignificant positive relationship with Nino3.4 region SST, while there is an insignificant inverse

relationship found for the other districts during the summer monsoon.

From Fig. 14, it is noticed that the district-level seasonal rainfall is in phase with Southern Oscillation Index (SOI) for winter, and post-monsoon for most of the districts, while the SOI is in inverse relationship pre-monsoon seasonal rainfall in most of the districts of Odisha. The positive relationship of SOI is a significant over the districts SUND, SMBLR, SNR and CTC at 99% confidence level, JHSGD, BRG, KNJHR and JSR at 90% confidence level for the winter seasonal rainfall; DEO, ANG, DHKL, JPR and JSR at 99% confidence level and MYBHG, BLS, JHSGD, SMBLR, SNR, NPD, NBR and BDH districts at 90% confidence level for post-monsoon seasonal rainfall. Interestingly, the post-monsoon seasonal rainfall of Odisha as a whole exhibits a significant positive relationship with SOI, while the relationship is insignificant for the other seasons. It is clearly emanated from the analysis that the ENSO does show any significant relationship with summer monsoon seasonal rainfall neither at district levels nor at Odisha as a whole.

4 Discussion

Odisha is mainly an agricultural-based coastal state of India having the most flood and drought situations. On the other hand, the agriculture is the lifeline of the state's economy. The results of this study reveal that the rainfall

Fig. 10 Trend analysis of seasonal rainfall (mm/113 years) at grid point level over Odisha for four distinctive seasons for the long period of 113 years from 1901 to 2013 **a** JF **b** MAM **c** JJAS and **d**

OND seasons. The area enclosed with solid/dotted closed contours indicates the significant increasing/decreasing trend in the seasonal rainfall at 90% confidence level

distribution over Odisha is highly heterogeneous in space and time, which in turn significantly influences on various sectors such as hydrological system, agriculture and water resource management. The most of the variability in the agricultural production is highly impacted by the variations in the rainfall over this region [59]. The summer monsoon (JJAS) itself contributes 78% of annual rainfall over Odisha with a coefficient of variation 13% and is mainly because of the coalition of southwest wind from the Arabian Sea with the low-level convergent wind from the Bay of Bengal and a huge amount of consistent moisture transport by development of a number of low pressure systems (LPS) over northwest Bay of Bengal (NWBoB), Gangetic West Bengal (GWB) and northern Odisha regions that lead to producing enormous rainfall to this region which is an important ingredient for Kharif crops [58].

The post-monsoon season (OND) is the second highest contribution (11%) to the annual rainfall over this region with 57% of coefficient of variation. The highest

coefficient of variation in this seasonal rainfall is mainly because of cyclonic disturbances that developed mostly over the Bay of Bengal and propagate north/northwestward and wind reversal during mid-September [20]. The rainfall associated with cyclonic disturbances during post-monsoon adversely affects various sectors, particularly on agricultural and hydrological system, sometimes causes to loss of lives and also property damages over this region [60].

On the other hand, the pre-monsoon contributes 8.5% annual rainfall over this region and this is mainly due to severe thunderstorm activities or cyclonic disturbances in the Bay of Bengal [61], while January and February months are mostly dry and contributes only 2.4% annual rainfall. The post-monsoon rainfall is more over the coastal districts and it is due to the influences of cyclonic disturbances in the Bay of Bengal, while the pre-monsoon rainfall is more over the northern districts of Odisha and this rainfall is due to severe thunderstorm activities over this region.

Fig. 11 Trend analysis of various rainfall events such as Wet days (a–d), VLR (e–h), LR (i–l), MR (m–p), RHR (q–t), HR (u–x), VHR (y–ab) and EHR (ac–af) at grid point level over Odisha for four distinctive seasons JF (column 1), MAM (column 2), JJAS (column 3) and OND (column 4) for the long period of 113 years from 1901 to 2013. The area enclosed with solid/dotted closed contour indicates the significant increasing/decreasing trend in the frequency of particular categorical rainfall events at 90% confidence level

The Shapiro–Wilk normality test confirms that the district-level seasonal rainfall series of all the 30 districts as well as Odisha as a whole during winter, pre-monsoon and post-monsoon seasons are not following the normal distribution, while the district-level seasonal rainfall during summer monsoon for most of the districts as well as Odisha as a whole follows the normal distribution. The Hurst exponent is quantifying the persistent or anti-persistent behavior of district-level seasonal rainfall time series over Odisha and also determines whether the time series is completely random or has some long-term memory. It has found that the time series of district-level seasonal rainfall are persistent at 95% confidence level in most of the districts during all the seasons. The abrupt changes in the district-level seasonal rainfall over Odisha for four seasons have been found during mid- and late twentieth century (1943 and 1990) in the majority of districts and confirmed through several tests such as PTT, BRT, BUT and SNHT. It has also found that the SNHT is more sensitive in detecting the abrupt changes near the beginning and the end of the time series, while PTT, BRT and BUT detects most of the abrupt changes in the middle of the time series [45].

There is a significant decreasing trend in the frequency of wet days in most parts of Odisha for all the seasons, and it is mainly due to a significant decreasing trend in the frequency of low-intensity rainfall events in most parts of Odisha during all the seasons. It is also noticed that an increasing trend in the seasonal rainfall during summer, pre-monsoon and post-monsoon seasons in most parts of Odisha is mainly due to a significant increasing trend in the frequency of high-intensity rainfall events and the contribution of these events to associated seasonal rainfall is higher than the low-intensity rainfall events. The significant increasing trend in the frequency of high-intensity rainfall events is mainly due the warming of the Indian Ocean in the recent period, and it is evident that the Indian Ocean is relatively warmer during extreme rainfall events over Odisha compared to the dry events [62]. The increasing trend in the frequency of high-intensity rainfall events in the recent years causes serious destructive floods over Odisha. The significant decreasing trend in the frequency of low-intensity rainfall events and wet days in the recent warming era may lead to a significant decrease in the food production over Odisha (Economic Survey of Government of Odisha 2009–2010, 2012–2013) [59].

The district-level analysis reveals that there is a notable increasing trend in summer monsoon seasonal rainfall over the coastal districts of Odisha, while a significant decreasing trend is noticed over districts of Western Odisha. Moreover, a significant decreasing trend in post-monsoon rainfall over MKG, NBR, RGD, and KHD districts while notable increasing is observed only over JSR. The changes in the summer and post-monsoon rainfall at district level over Odisha which together almost contributes 90% of annual rainfall are significantly impact on the hydrological system and Kharif crop patterns over this region in the present global warming era. A remarkable decrease in winter rainfall is also noticed over most of the districts over Odisha, while an increasing trend is detected over the districts of coastal and northern Odisha. The pre-monsoon rainfall has been decreased in most of the districts of south and western Odisha, while the significant increasing trend is detected over the districts of coastal and northern Odisha. The significant increasing trend in pre-monsoon rainfall over coastal and northern Odisha is due to the increase in thunderstorm activity over this region in the recent periods. The relationships of Nino3.4 region SST and SOI with district-level rainfall over Odisha during four distinctive seasons indicate that the ENSO does not have any significant influence on summer monsoon rainfall neither at district levels nor at Odisha as a whole, while it is indeed influencing on other seasonal rainfall at district level as well as Odisha as a whole. Moreover, the influence of ENSO on post-monsoon rainfall is highly significant at district level as well as Odisha as a whole particularly over north and north-coastal Odisha. The finding changes in various seasonal rainfalls at district level over Odisha will be useful in determining climate change and climate variability effects on various sectors such as agriculture, hydro power, hydrological systems and applying advanced adaptive techniques at district level for sustainable development in the present changing climate.

5 Summary and conclusions

The results suggest that the frequency of various rainfall events and associated seasonal rainfall over Odisha is highly heterogeneous spatially as well as seasonally and the highest rainfall is found in most of the districts during the summer monsoon (78%) followed by post-monsoon (11.1%), pre-monsoon (8.5%) and winter (2.4%) seasons. It is interesting to notice that the frequency of various rainfall events and the associated seasonal rainfall during winter and summer monsoon is more in the northern parts of Odisha and is decreased toward south, while the frequency and associated seasonal rainfall is in reverse pattern during pre-monsoon and post-monsoon seasons. It is

Fig. 12 Trends in the seasonal rainfall (mm/113 years) at district level over Odisha for the long-term period of 113 years from 1901 to 2013 **a** JF **b** MAM **c** JJAS and **d** OND seasons. The different sym-

bols on the figures indicate the trends significance. The AO on the each figure indicates trend in seasonal rainfall of Odisha as a whole

noticed that the frequency of various categorical rainfall events and associated seasonal rainfall is more over the coastal districts during post-monsoon and it is due to the influence of cyclonic disturbances in the Bay of Bengal, while the frequency of various categorical rainfall events and associated seasonal rainfall during pre-monsoon is more over the northern districts of Odisha and it may be due to the severe thunderstorm activities over this region. The IAV distribution of seasonal rainfall follows the similar patterns of climatological mean. However, the October IAV is higher particularly toward coast than that of August, June and September because the October is the dreadful month for the Odisha since more number of cyclones hit that state during this month which stretching the variability in the rainfall amount and so the IAV.

The district-level seasonal rainfall time series for most of the districts is significantly persistent for each of the four

seasons, but it is manifested to the normal distribution in majority of districts only for JJAS. The abrupt changes in the district-level seasonal rainfall over Odisha for four seasons have been found during mid- and late twentieth century (1943 and 1990) in the majority of districts, and these changes are confirmed by several tests such as PTT, BRT, BUT and SNHT. The trend analysis infers that a significant increasing trend in the frequency of high-intensity rainfall events (RHR, HR, VHR and EHR events) is evident, while a reverse nature in trend is prominent for low-intensity rainfall events (VLR, LR and MR) as well as wet days in most parts of Odisha for all the seasons. A substantial reduction in winter rainfall is observed over many districts due a remarkable decreasing trend in the frequency of all types of rainfall events during that season, while an increasing trend is perceived over many districts during summer monsoon season. A remarkable decreasing (south

Fig. 13 The relationship (correlation coefficient) of Nino3.4 region's SST with district-level seasonal rainfall over Odisha for **a** JF **b** MAM **c** JJAS and **d** OND seasons for the period 1901–2013. The different

symbols on the figures indicate the relationship significance. The AO on the each figure indicates Nino3.4 region SST relationship with all Odisha seasonal rainfall

and western Odisha) and increasing (coastal and northern Odisha) trends in pre-monsoon seasonal rainfall are also observed. It is noticed that the Nino3.4 region SST is an inverse relationship with winter, and post-monsoon seasonal rainfall in most of the districts, while the relationship is in the phase for the pre-monsoon rainfall in most of the districts of Odisha and it is interestingly noticed that the relationships of SOI with district-level rainfall are in reverse of Nino3.4 region SST relationship. Although the ENSO has a significant correlation with the al-India summer

monsoon rainfall, it has been noticed that the ENSO influence is insignificant for rainfall at district level and Odisha as a whole.

This study is very useful in determining the effects on various sectors such as agriculture, hydro power and hydrology in the formulation of adaptation measures through appropriate strategies for water resources management at regional/district level over Odisha and for a sustainable future in the present global warming era.

Fig. 14 The relationship (correlation coefficient) of Southern Oscillation Index (SOI) with district-level seasonal rainfall over Odisha for **a** JF **b** MAM **c** JJAS and **d** OND seasons for the period 1901–2013.

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The different symbols on the figures indicate the relationship significance. The AO on each figure indicates SOI relationship with all Odisha rainfall.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this article.

References

- IPCC (2013) Climate change 2013: the physical science basis. contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge. <https://doi.org/10.1017/cbo9781107415324>
- Dore MHI (2005) Climate change and changes in global precipitation patterns: what do we know? *Environ Int* 31:1167–1181. <https://doi.org/10.1016/j.envint.2005.03.004>

3. Trenberth KE (2011) Changes in precipitation with climate change. *Clim Res* 47:123–138. <https://doi.org/10.3354/cr00953.0>
4. Nageswararao MM, Mohanty UC, Ramakrishnan SSVS, Nair A, Kiran Prasad S (2016) Characteristics of winter precipitation over Northwest India using high-resolution gridded dataset (1901–2013). *Global Planet Change* 147:65–87. <https://doi.org/10.1016/j.gloplacha.2016.10.017>
5. De Luis M, Raventós J, González-Hidalgo JC, Sánchez JR (2000) Cortina J (2000) Spatial analysis of rainfall trends in the region of Valencia (east Spain). *Int J Climatol* 20(12):1451–1469. [https://doi.org/10.1002/1097-0088\(200010\)20:12%3c1451::AID-JOC547%3e3.0.CO;2-0](https://doi.org/10.1002/1097-0088(200010)20:12%3c1451::AID-JOC547%3e3.0.CO;2-0)
6. Nageswararao MM, Dhekale BS, Mohanty UC (2018) Impact of climate variability on various Rabi crops over Northwest India. *Theor Appl Climatol* 131(1–2):503–521. <https://doi.org/10.1007/s00704-016-1991-7>
7. Dhekale BS, Nageswararao MM, Nair Archana, Mohanty UC, Swain DK, Singh KK, Arunbabu T (2018) Prediction of kharif rice yield at Kharagpur using disaggregated extended range rainfall forecasts. *Theor Appl Climatol* 133(3–4):1075–1091. <https://doi.org/10.1007/s00704-017-2232-4>
8. Barsugli J, Anderson C, Smith JB, Vogel JM (2009) Options for improving climate modeling to assist water utility planning for climate change. White Paper, Water Utility Climate Alliance
9. Kumar V, Jain SK (2011) Trends in rainfall amount and number of rainy days in river basins of India (1951–2004). *Hydrol Res* 42(4):290–306. <https://doi.org/10.2166/nh.2011.067>
10. Khan TMA, Singh OP, Sazedur Rahman MD (2000) Recent sea level and sea surface temperature trends along the Bangladesh coast in relation to the frequency of intense cyclones. *Mar Geodesy* 23:103–116. <https://doi.org/10.1080/01490410050030670>
11. Shrestha AB, Wake CP, Dibb JE, Mayewski PA (2000) Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters. *Int J Climatol* 20:317–327. [https://doi.org/10.1002/\(SICI\)1097-0088\(20000315\)20:3%3c317::AID-JOC476%3e3.0.CO;2-G](https://doi.org/10.1002/(SICI)1097-0088(20000315)20:3%3c317::AID-JOC476%3e3.0.CO;2-G)
12. Mirza MQ (2002) Global warming and changes in the probability of occurrence of floods in Bangladesh and implications. *Glob Environ Change* 12:127–138. [https://doi.org/10.1016/S0959-3780\(02\)00002-X](https://doi.org/10.1016/S0959-3780(02)00002-X)
13. Lal M (2003) Global climate change: India's monsoon and its variability. *J Environ Stud Policy* 6:1–34
14. Min SK, Kwon WT, Parkand EH, Choi Y (2003) Spatial and temporal comparisons of droughts over Korea with East Asia. *Int J Climatol* 23:223–233. <https://doi.org/10.1002/joc.872>
15. Goswami BN, Venugopal V, Sengupta D, Madhusoodanam MS, Xavier PK (2006) Increasing trends of extreme rain events over India in a warming environment. *Science* 314(5804):1442–1445. <https://doi.org/10.1126/science.1132027>
16. Cayan DR, Peterson DH (1989) The influence of north Pacific atmospheric circulation on stream flows in the west. *Geophys Monogram Ser* 55:375–397. <https://doi.org/10.1029/GM055p0375>
17. Lins HF, Slack JR (1999) Stream flow trends in the United States. *Geophys Res Lett* 26(2):227–230. <https://doi.org/10.1029/1998GL900291>
18. Jain S, Lall U (2000) Magnitude and timing of annual maximum floods, trends and large scale climatic associations for the Black smith Fork River, Utah. *Water Resour Res* 36(12):3641–3651. <https://doi.org/10.1029/2000WR900183>
19. Sinha P, Nageswararao MM, Dash GP, Nair A, Mohanty UC (2018) Pre-monsoon rainfall and surface air temperature trends over India and its global linkages. *Atmos Phys, Meteorol.* <https://doi.org/10.1007/s00703-018-0621-6>
20. Nageswararao MM, Sannan MC, Mohanty UC (2019) Characteristics of various rainfall events over South Peninsular India during northeast monsoon using high-resolution gridded dataset (1901–2016). *Theor Appl Climatol* 132(1–2):181–207. <https://doi.org/10.1007/s00704-018-02755-y>
21. Haigh MJ (2004) Sustainable management of headwater resources: the Nairobi headwater declaration (2002) and beyond. *Asian J Water Environ Pollut* 1(1–2):17–28
22. Brekke LD, Kiang JE, Olsen JR, Pulwarty RS, Raff DA, Turnipseed DP, Webb RS, White KD (2009) Climate change and water resources management: a federal perspective. US Geological Survey Circular, 1331, 65p. <http://pubs.usgs.gov/circ/1331>
23. Raucher RS (2011) The future of research on climate change impacts on water: a workshop focused on adaption strategies and information needs. Water Research Foundation. http://www.floridawca.org/wp-content/uploads/2018/06/Water-Research-Foundation-Report-7-Future_of_Research_Climate_Change.pdf
24. Swain M, Pattanayak S, Mohanty UC (2018) Characteristics of occurrence of heavy rainfall events over Odisha during summer monsoon season. *Dyn Atmos Oceans* 82:107–118. <https://doi.org/10.1016/j.dynatmoce.2018.05.004>
25. Pant GB, Parthasarathy B (1981) Some aspects of the association between southern oscillation and Indian Summer Monsoon. *Arch Meteorol Geophys Bioclimatol Ser B* 29(3):245–252. <https://doi.org/10.1007/BF02263246>
26. Mooley DA, Parthasarathy B (1984) Indian summer monsoon and east equatorial Pacific SST. *Atmos Ocean* 22(1):23–35. <https://doi.org/10.1080/07055900.1984.9649182>
27. Webster PJ, Yang S (1992) Monsoon and ENSO: selectively interactive systems. *Q J R Meteorol Soc* 118:877–926. <https://doi.org/10.1002/qj.49711850705>
28. Krishna kumar K, Rajagopalan B, Cane MA (1999) On the weakening relationship between Indian monsoon and ENSO. *Science* 284:2156–2159. <https://doi.org/10.1126/science.284.5423.2156>
29. Kumar P, Rupakumar K, Rajeevan M, Sahai AK (2007) On the recent strengthening of the relationship between ENSO and northeast monsoon rainfall over South Asia. *Clim Dyn* 28(6):649–660. <https://doi.org/10.1007/s00382-006-0210-0>
30. Yadav RK, Rupa Kumar K, Rajeevan M (2009) Increasing influence of ENSO and decreasing influence of AO/NAO in the recent decades over northwest India winter precipitation. *J Geophys Res* 114:D12112. <https://doi.org/10.1029/2008JD011318>
31. Dimri AP (2013) Relationship between ENSO phases with Northwest India winter precipitation. *Int J Clim* 33(8):1917–1923. <https://doi.org/10.1002/joc.3559>
32. Nageswararao MM, Mohanty UC, Osuri Krishna K, Ramakrishna SSVS (2016) Prediction of winter precipitation over northwest India using ocean heat fluxes. *Clim Dyn* 47(7–8):2253–2271. <https://doi.org/10.1007/s00382-015-2962-x>
33. Nageswararao MM, Mohanty UC, Nair A, Ramakrishna SSVS (2016) Comparative evaluation of performances of two versions of NCEP climate forecast system in predicting winter precipitation over India. *Pure Appl Geophys* 173(6):2147–2166. <https://doi.org/10.1007/s00024-015-1219-2>
34. Krishna Kumar K, Balaji Rajagopalan, Martin Hoerling, Gary Bates, Mark Cane (2006) Unraveling the mystery of Indian monsoon failure during El Nino. *Science* 314(5796):115–119. <https://doi.org/10.1126/science.1131152>
35. Mohapatra M, Mohanty UC, Behara S (2003) Spatial variability of daily rainfall over Orissa, India, during the southwest summer monsoon season. *Int J Climatol* 23:1867–1887. <https://doi.org/10.1002/joc.974>
36. Mohapatra M, Mohanty UC (2006) Spatio-temporal variability of summer monsoon rainfall over Orissa in relation to low pressure systems. *J Earth Syst Sci* 115(2):203–218. <https://doi.org/10.1007/BF02702034>

37. Mohapatra M, Mohanty UC (2007) Interannual variability of summer monsoon rainfall over Orissa in relation to tropospheric circulation features. *Curr Sci* 90(9):1218–1229
38. Patra JP, Mishra A, Singh R, Raghuwanshi NS (2012) Detecting rainfall trends in twentieth century (1871–2006) over Orissa State, India. *Clim Change* 111(3–4):801–817. <https://doi.org/10.1007/s10584-011-0215-5>
39. Beura D (2009) Cyclone disaster management with special reference to Orissa Coast, India. In: Geological hazards, New India Publishing House, New Delhi, pp 133–153
40. Pai DS, Latha Sridhar, Rajeevan M, Sreejith OP, Satbhai NS, Mukhopadhyay B (2014) Development of a new high spatial resolution ($0.25^\circ \times 0.25^\circ$) long period (1901–2010) daily gridded rainfall dataset over India and its comparison with existing datasets over the region. *Mausam* 65(1):1–18
41. Pai DS, Latha Sridhar, Badwaik MR, Rajeevan M (2015) Analysis of the daily rainfall events over India using a new long period (1901–2010) high-resolution ($0.25^\circ \times 0.25^\circ$) gridded rainfall dataset. *Clim Dyn* 45(3–4):755–776. <https://doi.org/10.1007/s00382-014-2307-1>
42. Nageswararao MM, Mohanty UC, Ramakrishna SSVS, Dimri AP (2018) An intercomparison of observational precipitation datasets over Northwest India during winter. *Theor Appl Climatol* 132(1–2):181–207. <https://doi.org/10.1007/s00704-017-2083-z>
43. Oztuna D, Elhan AH, Tuccar E (2006) Investigation of four different normality tests in terms of type 1 error rate and power under different distributions. *Turk J Med Sci* 36(3):171–176
44. Peat J, Barton B (2005) Medical Statistics: A guide to data analysis and critical appraisal. Blackwell Publishing, Hoboken
45. Wijngaard JB, Klein Tank AMG, Ko Nnen GP (2003) Homogeneity of 20th century European daily temperature and precipitation series. *Int J Climatol* 23:679–692
46. Mandelbrot BB, Van NJ (1968) Fractional Brownian motions, fractional noises and applications. *SIAM Rev* 10:422–437
47. DeGrauwe P, Dewachter H, Embrechts M (1993) Exchange rate theory chaotic models of foreign exchange markets. Blackwell Publishers, London
48. Peitgen HO, Saupe D (1988) The science of fractal images. Springer, New York
49. Mandelbrot B, Wallis JR (1969) Robustness of the rescaled range R/S in the measurement of noncyclic long-run statistical dependence. *Water Resour Res* 5:967–988
50. Hurst H (1951) Long-term storage capacity of reservoirs. *Trans Am Soc Civ Eng* 6:770–799
51. Samuel SR, Umarani PR, Vimal Priya SP, Mahalakshmi N (2011) Fractal dimensional analysis of geomagnetic as index. *Int J Curr Res* 3:146–147
52. Alina Barbulescu, Serban Cristina, Maftei Carmen (2007) Evaluation of Hurst exponent for precipitation time-series. *Latest Trends Comput* 2:590–595
53. Onoz B, Bayazit M (2003) The power of statistical tests for trend detection. *Turk J Eng Environ Sci* 27(4):247–251
54. Novotny EV, Stefan HG (2007) Stream flow in Minnesota: indicator of climate change. *J Hydrol* 334:319–333. <https://doi.org/10.1016/j.jhydrol.2006.10.011>
55. Helsel DR, Hirsch RM (1992) Statistical methods in water resources. Elsevier, New York
56. Hirsch RM, Helsel DR, Cohn TA, Gilroy EJ (1993) Statistical analysis of hydrologic data. In: Maidment DR (ed) The handbook of hydrology. McGraw-Hill Inc, New York
57. Kendall MG (1975) Rank correlation methods, 4th edn. Charles Griffin, London
58. Mohapatra M, Mohanty UC (2005) Some characteristics of very heavy rainfall over Orissa during summer monsoon season. *J Earth Syst Sci* 114:17–36
59. Mishra D, Sahu NC, Sahoo D (2016) Impact of climate change on agricultural production of Odisha (India): a Ricardian analysis. *Reg Environ Change* 16:575–584. <https://doi.org/10.1007/s10113-015-0774-5>
60. Nadimpalli R, Osuri Krishna K, Pattanayak S, Mohanty UC, Nageswararao MM, Kiran Prasad S (2016) Real time prediction of movement, intensity and storm surge of very severe cyclonic storm Hudhud over Bay of Bengal using High resolution dynamical models. *Nat Hazards* 81(3):1771–1795. <https://doi.org/10.1007/s11069-016-2155-x>
61. Das Y (2015) Some aspects of thunderstorm over India during pre-monsoon season: a preliminary report-I. *J Geosci Geomat* 3(3):68–78. <https://doi.org/10.12691/jgg-3-3-3>
62. Swain MS, Sinha P, Mohanty UC, Pattnaik S (2019) Dominant large-scale parameters responsible for diverse extreme rainfall events over vulnerable Odisha state in India. *Clim Dyn*. <https://doi.org/10.1007/s00382-019-04949-0>

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