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The study of rainfall variability during pre and post monsoon seasons over all India and its different regions in changing climate

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ABSTRACT

This study comprises of the variability analysis of the pre (March to May) and post (October to November)monsoon rainfall over various homogenous regions (northwest, central northeast, west central, northeast and peninsular region) of India, defined by India Meteorology Department (IMD) for the past 143 years (1871-2014). Time series plots of the normalized rainfall anomaly of these regions on tricadal and decadal basis, have been analyzed and compared with the overall rainfall trend in the country. Further, Mann-Kendall trend test has been utilized for any monotonic significant trend (95% and 90% confidence levels), besides Sen's slope estimation for the overall time series and the tricades. The third tricade (1955-1984) of central northeast region for post monsoon season showed significant decreasing trend with Sen's slope being -0.066/year. For the pre monsoon season, the third tricades of west central and peninsular region, both depicted significant negative trend of -0.04 mm/year. Also the all India portrayed significant decreasing slopes of -0.034 mm/year and - 0.038 mm/year respectively during 2nd and 3rdtricades. It was found that the northeast, all India and peninsular regions displayed decreasing rainfall anomaly trend for the present decade 2005-14 for both the pre and post monsoon seasons.These findings will play a vital role in understanding the rainfall pattern over the country.

Keywords: Pre monsoon, Post monsoon, Decadal, Tricadal, Mann-Kendall, Sen's slope, Indian monsoon.

INTRODUCTION

With the rapid increase in human population and due to strained resources, like food production and water supply for people, agriculture, as well as for industrial purposes, the study of the variation in rainfall over different regions is very important. Though, a lot of research had been done on the variability of Indian summer monsoon rainfall and its pattern over the country and its constituent regions (Parthasarathy et al., 1995; Bhatla and Chattopadhyay, 1995; Guhathakurta and Rajeevan, 2006; Turner and Annamalai, 2012; Gadgil, 2003 and Bhatla et al., 2015, 2016a), the post monsoon (October to December; OND) rainfall variability over India and its homogenous regions, still lack significant insight. Its comparison with the pre monsoon rainfall variability is likely to unveil any significant correlation that may exist between them. Sadhukhan et al. (2000) analyzed the rainfall trend of pre monsoon season (March to May; MAM) from 1901-1992 over West Bengal and its neighborhood, but did not find any long term trends. Bhatla et al. (2016b) explained the trend analysis and extreme temperature events during post monsoon season over Varanasi. Kholeand De (2003) stated that thepost monsoon rainfall is higher (lower) than normal rainfall over south-eastern peninsular India during El-Nino (La-Nina) years. It is the major contributor of precipitation in the southern India, especially in the parts of coastal Andhra Pradesh, Rayalaseema and Puducherry. Further, De and Mukhopadhyay (1999) had verified the negative correlation between seasonal SOI index and northeast monsoon (NEM) rainfall over southern peninsular India, with ENSO year being associated with enhanced NEM rainfall with small frequency of cyclonic systems compared to that during anti-ENSO years. A low pressure trough at the beginning of October is developed over Southern Bay of Bengal, associated with southward movement of equatorial maritime air, causing northeast monsoon rainfall (Kripalani and Kumar, 2004). Singh and Sontakke (1999) have gone to the extent of defining the forcing factors operating on the rainfall patterns of the south west and northeast monsoon and stated that same forcing factors work on both the periods. They also determined that the interannual variation of post monsoon wet area, doesn't show significant long term trend and especiallyfor the country as a whole. After mid 1970s, positive relationship between northeast monsoon and ENSO has strengthened and became statistically significant (Kumar et al, 2007). Recently, Sanap et al. (2018) explained the effects of the synoptic feature on the northeast monsoon rainfall over the Indian subcontinent, defining the role of easterly wave on the rainfall events. The intensity of the already developing synoptic systems over Bay of Bengal (BoB), was aided by the dominant easterly wave activity, leading to heavy rainfall events and over Indian Ocean, it plays important role in the occurrence of heavy rainfall during El Nino phase and is weaker during La Nina and neutral phase (43% of heavy rainfall during NEM is associated with El Nino; 31% with La Nina and 26% with neutral years) (Sanap et al., 2018). Also, easterly wave westward propagation is facilitated by above normal SST over Bay of Bengal; strong west-east SST gradient between southwest Bay of Bengal and tropical western Pacific Ocean; and anomalous strong low-level easterly flow over tropical Indian Ocean during El Nino years (Sanap et al., 2018). Inter-annual variations tell us a lot about the rainfall pattern and the seasonal length. Further, onset date variation has greater impact compared to demise date on the seasonal length, seasonal anomalies of rainfall and surface temperature of the northeast monsoon, as suggested by Misra and Bhardwaj (2019). They also analyzed that reduced length of NEM season is associated with warm ENSO with excess seasonal rainfall whereas seasonal deficit rainfall anomalies, are associated with cold ENSO episodes. However, Nageswararao et al. (2019),

verified that during recent decades, relationships of NEM rainfall events have weakened with ENSO, IOD and ISMR. Also the seasonal rainfall has increased over Tamil Nadu, Rayalaseema and south peninsular India, with increase in variability of NEM rainfall. Even sub-seasonal variability was studied by Sen gupta and Nigam (2019), who stated that the ENSO impact was found to be significant that was weak in October and strong in November. Also, the anti-cyclonic flow centered over Bay of Bengal (forced by El Nino related reduction in deep convection over Maritime continent), generated positive anomalies over peninsular India. So we can see that ENSO being a major factor behind the recent changes in NEM, that also lead us to the basic cause as to why ENSO is influencing the NEM in the recent decades. Singh and Achuta rao (2019) also verified the same by finding more rainfall uncertainty in arid northwest region and lesser in the west central region. The increase in rainfall is seen during September-October-November (SON), depicting extended monsoon season. Better understanding of the post monsoon rainfall variability over the different homogenous regions (decadal and tricadal basis), their correlation and interaction with the ENSO phenomena (for further research), has thus become a necessity.

In view of the above, the climate monitoring has become very essential for understanding of the natural climatic changes and for spatial and temporal variability. Analyzing precipitation trends is thus important for the country, whose major portion of the economy is dependent on water availability. The main objective of this study is to analyze the variability trend of annual rainfall along with the variations in each tricade and decade for all India and its sub regions during the analysis period that covers the period from 1871 to 2014. Further, an attempt has been made to study all India and its regions for time series of pre and post monsoon rainfall, to identify various epochs.

DATA AND METHODOLOGY

Based on India Meteorological Department studies, India can be divided into 5 regions; northwest region (NW); west central region (WC); central northeast region (CNE); northeast region (NE) and peninsular region. The monthly rainfall data for these 5 regions, as well as entire India, are taken from official website of Indian Institute of Tropical Meteorology (IITM: http://www.tropmet.res.in) for the period of 143 years (1871-2014). In the present study, we have taken pre monsoon (March to April; MAM) and post monsoon (October to December; OND) seasons, to analyze the variations in the rainfall, based on the decades, tricades along with the annual. The mean and standard deviation of the rainfall data sets were calculated. The pre and post monsoon rainfall is determined (from 1895-2014), for different tricades (from 1895-1924, 1925-1954, 1955-1984 and 1985-2014) and for different decades; for all India as well as other regions. Normalized anomalies are estimated and are plotted with the trend line (added to the series) in order to represent whether the trend is increasing or decreasing. Mann-Kendall trend test and Sen's slope estimator, has been utilized to find the significant increasing and decreasing trend.

To analyze the time series, normalization procedure has been utilized in this study that was proposed by Kraus (1977). Thus, the normalized rainfall anomaly is stated as:

$$A = \frac{X - \mu}{\sigma}$$

Where, X is the observed rainfall for a single year; μ and σ are the mean and standard deviation of the desired series respectively.

The Mann-Kendall Test

Test for significant trends was carried out for the entire time series plots. Statistical significance was estimated at 95% and 90% confidence level by the method proposed by Mann-Kendall (Mann, 1945; Kendall, 1975), which is a rank-based nonparametric test. Equations involving Mann-Kendall Statistics *S, (S)* and standardized statistics *Z* are as given as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(X_j - X_i)\ , \qquad (1)$$

$$sign(X_j - X_i) = \begin{cases} +1 & if(X_j - X_i) > 0 \\ 0 & if(X_j - X_i) = 0 \\ -1 & if(X_j - X_i) < 0 \end{cases} \qquad (2)$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q}(t_p - 1)(2t_p + 5)\right] \qquad (3)$$

$$z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} if S > 0 \\ 0 \qquad\qquad if S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} if S < 0 \end{cases} \qquad (4)$$

In these equations, X_i and X_j are the time series observations in chronological order, n is the length of time series, tp is the number of ties for pth value, and q is the number of tied values. Positive Z indicates increasing trend in the time series; negative Z indicates decreasing trend. The rainfall trend in each series is thus determined for the total period (from 1871-2014), for different tricades and decades.

Sen's slope

For the detection of linear trend in the time series, Sen (1968) developed a simple non-parametric procedure to find the true slope (change per unit time). It can be defined as

$$f(t) = Qt + B \qquad (5)$$

Table 1. Decadal trends (D1-D14) of rainfall variability over All India and its regions during pre and post monsoon seasons.

Period	All India		Northwest India		West Central India		Northeast India		Central Northeast India		Peninsular India	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
D1(1875-1884)	-ve	+ve	-ve	-ve	-ve	+ve	+ve	+ve	-ve	N	-ve	+ve
D2(1885-1894)	+ve	+ve	-ve	+ve	+ve	-ve	+ve	+ve	+ve	+ve	+ve	-ve
D3(1895-1904)	+ve	+ve	+ve	-ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
D4(1905-1914)	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve	-ve	+ve
D5(1915-1924)	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve
D6(1925-1934)	-ve	+ve	+ve	-ve	-ve	+ve	-ve	+ve	-ve	+ve	+ve	+ve
D7(1935-1944)	+ve	+ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	+ve
D8(1945-1954)	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	+ve	-ve
D9(1955-1964)	-ve	-ve	-ve	-ve	-ve	-ve	-ve	-ve	+ve	-ve	-ve	-ve
D10(1965-1974)	+ve	+ve	-ve	+ve	-ve	+ve	+ve	+ve	N	+ve	+ve	-ve
D11(1975-1984)	+ve	-ve	+ve	-ve	-ve	-ve	+ve	-ve	+ve	-ve	-ve	-ve
D12(1985-1994)	+ve	-ve	-ve	-ve	-ve	-ve	+ve	-ve	+ve	-ve	+ve	+ve
D13(1995-2004)	+ve	-ve	-ve	-ve	-ve	-ve	+ve	+ve	-ve	-ve	+ve	-ve
D14(2005-2014)	-ve	-ve	-ve	+ve	-ve	+ve	-ve	-ve	+ve	+ve	-ve	-ve

+ve – Increasing trend; -ve – Decreasing trend; N – No trend

Where, Q is slope and B is constant.

The slopes of all data pairs are calculated

$$Q_i = \frac{x_j - x_k}{j-k}, i = 1,2, \dots \dots N, j > k \quad (6)$$

The median of these N values of Q_i gives us the Sen's estimator of slope. These N values are ranked in increasing order. Sen's estimator of slope is given as

$$Q = \begin{cases} Q_{\frac{N+1}{2}} IfNisodd \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) IfNiseven \end{cases} \quad (7)$$

To find if the Q value (trend) is statistically different from zero, confidence level of the value is obtained at specific probability. Gilbert(1987) defined this confidence interval (about the slope) as

$$C_\alpha = Z_{1-\alpha/2} \sqrt{Var(S)} \quad (8)$$

Where, Var(S) is the variance and the confidence interval is calculated at the alpha level of 5% ($\alpha = 0.05$).

RESULT AND DISCUSSION

Variability of Pre and Post Monsoon Rainfall over All India

The pre monsoon rainfall variability over the Indian region is depicted by Figure 1a, that shows three major positive anomalies, +3.53 (1893), +2.6(1933) and +3.28 (1990). The two of the greater positive anomalies, are followed by the higher negative anomalies of -1.91 (1935) and -1.45 (1992). The epochal behavior is explained by the tricadal and decadal analysis. Figure 1b explains the first tricade (1895-1924) of the All India region, which displays the maximum portion of the rainfall anomaly to be below normal. The second tricade (Figure 1c) spanning 1925-1954 depicted the highest positive peak of +2.6 (1933), followed by the lowest negative anomaly of -1.91 (1935) and trend was not observed. Lesser anomaly variability was observed during the third tricade, spanning 1955-1984 (Figure1d) with no trend. Fourth tricade (Figure 1e) depicted a higher positive peak of +3.28 (1990). The anomaly was found to be consistently decreasing from 2004-2012 during the tricade.

Considering Figure1a, which shows the overall trend of post monsoon rainfall i.e. October, November and December (OND), the average post monsoon rainfall of all India region during period 1871- 2014 was found to be 120.5mm with

standard deviation of 34.3mm. The maximum rainfall recorded was in the year 1956, with a normalized anomaly of +2.60. The peak rainfall anomalies (above the normal) were found to be during the years 1886, 1894, 1903, 1916, 1931, 1946, 1956 and 1997 with normalized anomalies of +1.45, +2.05, +1.95, +2.34, +2.29, +2.46, +2.60 and +2.04 respectively. The scantiest rainfall was recorded in the year 1908, with an anomaly of -2.05. Though the rainfall trend was not significant (Sen's slope of 0.001/year), the years' which are worth mentioning are 2000 and 2011 (beginning of the 21st century) that faced the scantiest rainfall anomaly (-1.67 and -1.62 respectively) after the end of the 19th century (as no negative anomaly of the magnitude ≥1.5 mm was seen during the 20th century). Further, the tricadal analysis revealed the clear picture. The first tricade (Figure 1b), spanning 1895-1924 displayed the slope of 0.03/year (no significant trend as per Mann Kendall trend test) with two greater spikes (+1.95 and +2.34) of positive anomaly during 1903 and 1919 respectively. This tricade (comprising end of the 19th century) displayed the lowest rainfall anomaly of -2.05 (1908). All the other tricades (Figures 1c, 1d and 1e) relatively depicted decreasing rainfall anomaly trend (Sen's slope of -0.03/year, -0.04/year and -0.02/year respectively, as shown in Table 2). The 2nd and 3rd tricades were found to be significant at 90% level of significance. Two greater positive anomalies of +2.29 (1931) and +2.46 (1946) was seen in the 2nd tricade (1925-1954). The decreasing trend (though not significant) of the 3rd decade (1955-1984) is the highest (slope being -0.04/year) among the others, but the decade also displayed the highest positive anomaly of +2.6 (1956). The duration from 1973 to 1979 displays the above normal anomalies. The fourth tricade (1985-2014) showed just a single greater positive anomaly of +2.04 (1997). But this tricade (that marks the beginning of 21st century as well), depicted the two relative greater negative anomalies of -1.67 (2000) and -1.62 (2011), that was seen only at the end of 19th century (here in the 1st tricade). Further, the tricades show decreasing trend. It is quite interesting to note that the years 1886, 1903, 1916 and 1931 are La-Nina years and the years 1891, 1899, 1965 and 1997 are El-Nino years. This signifies the possibility of interplay between the ENSO phenomena and the post monsoon rainfall over all India, affecting its geomorphology.

Table 2. Sen's slope estimation for All India and its regions during pre and post monsoon seasons.

Period	All India		Northwest India		West Central India		Northeast India		Central Northeast India		Peninsular India	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Overall	0.0013	0.0018	0.002	0.0003	0.001	0.001	-0.002	0.002	0.002	-0.0005	0.001	0.001
1st tricade	-0.006	0.03	0.014	0.015	0.012	0.012	0.001	0.011	-0.02	0.025	-0.008	0.027
2nd tricade	0	**-0.034 ****	-0.013	-0.02	-0.005	-0.024	0.01	0.016	-0.006	-0.023	-0.001	-0.03
3rd tricade	-0.02	**-0.038 ****	0.02	-0.008	**-0.04 ***	-0.025	0.006	-0.017	0.04	**-0.066 ***	**-0.04 ***	-0.015
4th tricade	0.008	-0.023	-0.001	-0.011	0.007	-0.014	-0.032	-0.04	-0.008	-0.03	0.03	0

*Significant at 95% level of significance; **Significant at 90% level of significance

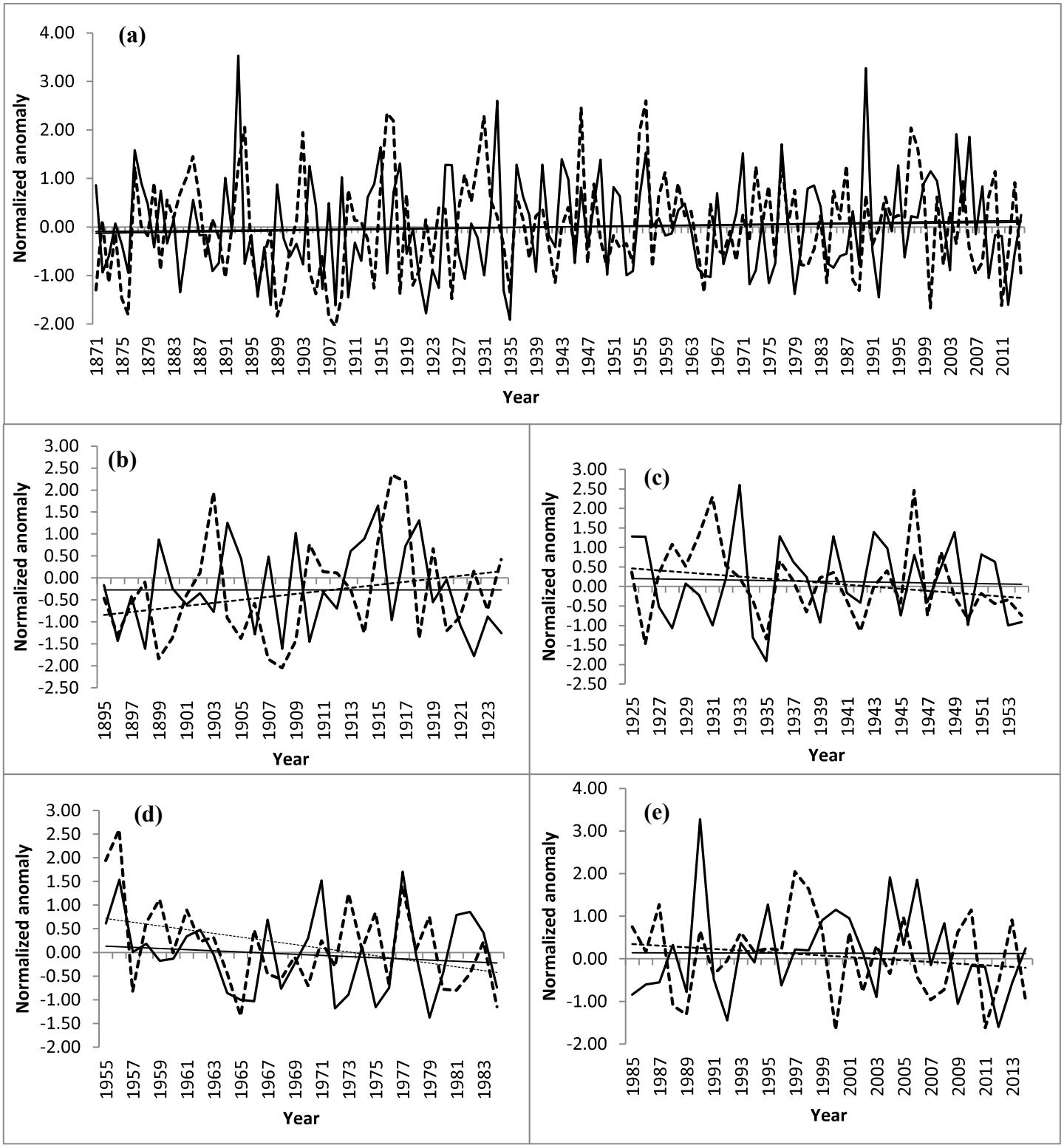

Figure 1. Variation of pre monsoon rainfall (solid line) and post monsoon rainfall (dashed line) over All India during the period (a) 1871-2014; and the tricades: (b) 1895-1924; (c) 1925-1954; (d) 1955-1984; (e) 1985-2014.

Variability of Pre and Post Monsoon Rainfall over Northwest region

Overall, lesser variability and short term epochal behavior is the characteristic feature, as evident from the Figure 2a. Two relatively higher positive anomalies were observed in the time series in the year 1917 (+4.66) and 1982 (+4.88) during pre-monsoon. But a decreasing trend was seen from 1997 to 2014 (recent period). The first tricade (Figure 2b), depicted the single higher positive anomaly of +4.66 (1917), after which the pattern was found to be decreasing till 1924. The second tricade (Figure 2c) displayed lesser variability with only two relatively higher positive anomalies of +2.10 (1926) and +2.76 (1933). An increasing pattern in the rainfall anomaly was seen in the third tricade (Figure 2d), but with lesser overall variability. Highest positive anomaly was found in the year 1982 (+4.88). The fourth tricade (Figure 2e) did not show any significant trend either. But the anomaly is of decreasing nature from 1997 to 2014. Highest positive spike in the tricade was found to be +1.87 (1997).

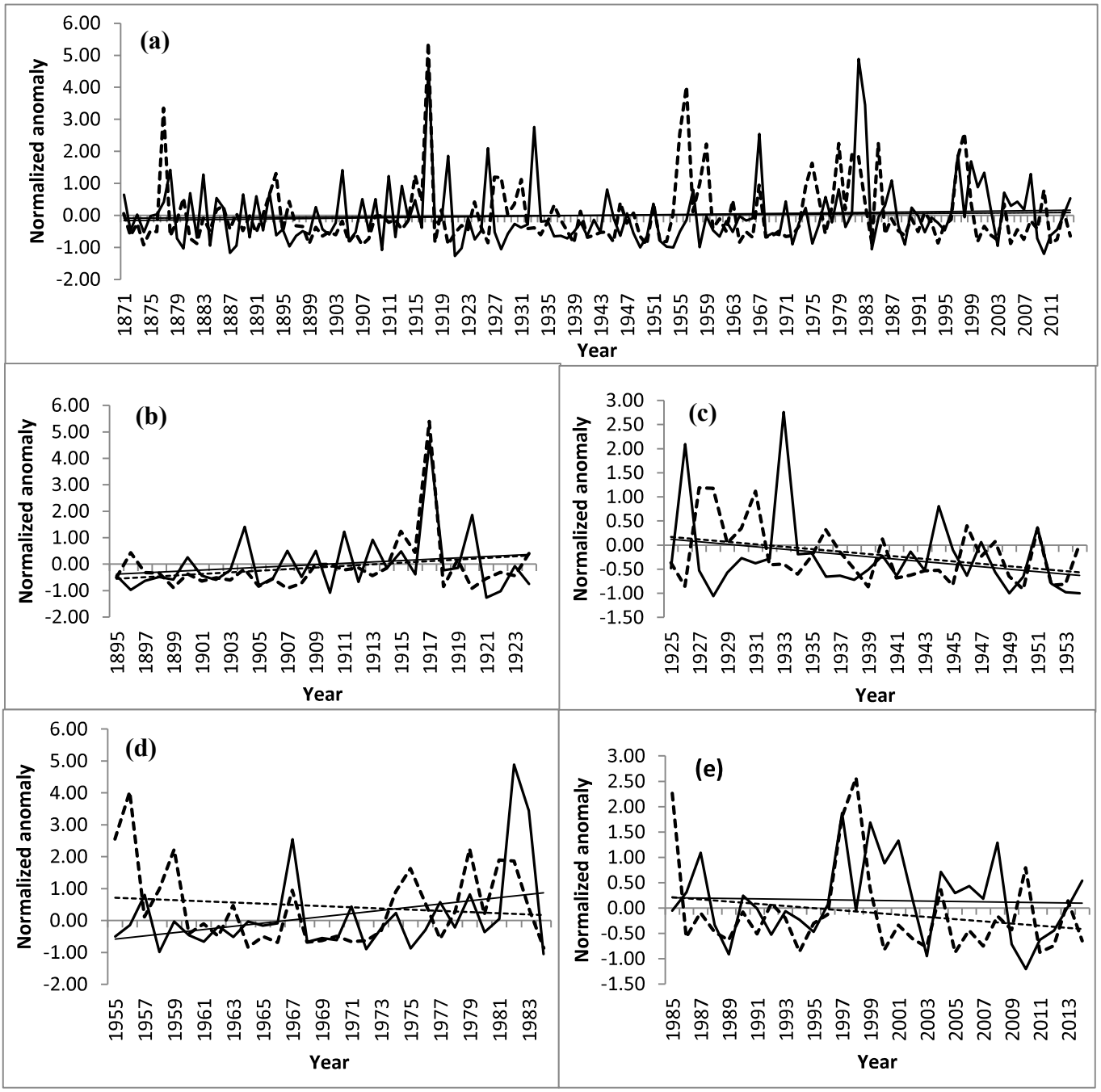

Figure 2. Variation of pre monsoon rainfall (solid line) and post monsoon rainfall (dashed line) over Northwest region during the period (a) 1871-2014; and the tricades: (b) 1895-1924; (c) 1925-1954; (d) 1955-1984; (e)1985-2014.

Figure 2a also reveals that the average post monsoon rainfall of northwest region during period 1871- 2014 is 20.2mm, with standard deviation 21.8mm. This region includes, Haryana, Chandigarh, Delhi, Punjab, West Rajasthan, East Rajasthan, Gujarat and Saurashtra meteorological subdivisions. In the post monsoon period, the maximum rainfall recorded was in the year 1917, with a normalized anomaly of +5.40, whereas the minimum rainfall recorded was in two respective years i.e., 1874 and 1950, with normalized anomaly of -0.92. It is clear that no significant trend was observed (Sen's slope being just 0.0003/year; Table 2). Further, there were three relatively greater positive normalized rainfall anomalies (apart from year 1917) of the order of +2.56 (1998), +3.35 (1877) and +4.03 (1956). While considering the tricades, it was observed that in first tricade i.e., during 1895-1924 (Figure 2b) the rainfall doesn't show any trend (Sen's slope of 0.02/year), and the maximum rainfall anomaly recorded was in the year 1917, with the value of +5.40 and the year with minimum rainfall occurred was in two respective years i.e., 1907 and 1920 with anomaly of -0.92. This tricade depicted lesser variability than the other three tricades. In the second tricade i.e., during 1925-1954 (Figure 2c), the rainfall depicted negative Sen's slope of -0.02/year (Table 2), although trend being not significant. The year from 1932-1934 displayed below normal anomalies that led to the overall decreasing slope. The year when maximum rainfall occurred was in 1927 with anomaly of +1.19 and the year with minimum rainfall was in 1950 with an anomaly of -0.92. In the third tricade i.e. from 1955-1984 (Figure 2d) the rainfall doesn't show any trend and the maximum rainfall occurred was in the year 1956, with an anomaly of +4.03,while minimum rainfall recorded was in the year 1984 with an anomaly of -0.87. The years spanning 1960-1973 displayed the overall rainfall anomaly to be below normal, while the subsequent years showed above normal anomalies. Again in the fourth tricade i.e., during 1985-2014 (Figure 2e), the rainfall is showing negative Sen's slope of 0.011/year (Table 2; but no trend), having a maximum rainfall in the year 1998 with normalized rainfall anomaly of +2.56. In this tricade, minimum rainfall occurred in two years 2005 and 2011 with an anomaly of -0.88. For most of the years (1986-95 and 2000-14), the rainfall anomaly was below normal.

Variability of Pre and Post Monsoon Rainfall over West central region

Relatively higher anomalies were observed in four years in the time series plot spanning from 1871 to 2014 (Figure 3a) during pre monsoon season. These anomalies correspond to +3.96 (1893), +2.81 (1933), +2.91 (1990), and +3.06 (2006). The larger number of below normal anomalies was seen from 1892 to 1910, whereas, more number of above normal anomalies were seen from 1933 to 1962, with relatively decreasing trend (non-significant). Epochal behavior could be seen by analyzing the tricadal time series. The period from 1895 to 1913 (Figure 3b) displays below normal rainfall anomalies. The highest anomaly was seen in 1918 (+2.25) followed by steep decline to -1.48 (1921). Second tricade (Figure 3c) however, displayed greater number of above normal anomalies, with the highest peak seen in 1933 (+2.81) and the trend resembles a decreasing pattern. The third tricade (Figure 3d) too displayed significantly decreasing nature and no higher anomaly peak was observed. Nevertheless, two higher positive peaks were found in the fourth tricade (Figure 3e), viz. +2.91 (1990) and +3.08 (2006).

A decreasing anomaly pattern in the rainfall is observed from the year 1886 to 1899 while considering Figure 3a. The average post monsoon rainfall in the west central region during period 1871- 2014 is 84.9mm with standard deviation of 43.3mm. In the post monsoon period, the maximum rainfall recorded was in the year 1997, with a normalized anomaly of +3.07, after which the succeeding years displayed decreasing slope. The minimum rainfall recorded was in the year 1899, with an anomaly of -1.77. On the tricadal basis, firstly we discussed the rainfall of the first tricade i.e., during 1895-1924 (Figure 3b), where it was observed that the rainfall depicts a positive Sen's slope of 0.01/year (not significant), and the maximum rainfall recorded was in the year 1916 with normalized anomaly of +2.71, with the succeeding years showing below normal rainfall anomaly. The year that showed minimum rainfall was 1899 having anomaly of -1.77. In the second tricade i.e., during 1925-1954 (Figure 3c) Sen's slope was found to be -0.02/year. The year in which maximum rainfall occurred was 1931 with anomaly of +2.99 and the year with minimum rainfall was 1954 with an anomaly of -1.30. Much greater variability was observed during 1942 to 1950, where the anomaly was found to be above normal. Again in the third tricade i.e., from 1955-1984 (Figure 3d), the rainfall depicts negative Sen's slope of -0.03/year (Table 2), which is not significant. The maximum rainfall occurred was in the year 1956 with an anomaly of +1.59 while minimum rainfall recorded was in the year 1965 with an anomaly of -1.39. Below normal variability was seen from the year 1964 to 1972. Again in the fourth tricade of 1985-2014 (Figure 3e), there was negative slope of -0.01/year, with a maximum rainfall in 1997 with a normalized anomaly of +3.07. Similarly, minimum rainfall was in the year 2011 with an anomaly of-1.45. The years succeeding 1997, displayed a gradual decreasing pattern in the anomaly till 2009 (that showed a steep rise in the positive anomaly of +1.54). Only the first tricade (1895-1924) displayed positive slope, whereas all the other tricades displayed decreasing trend in normalized rainfall.

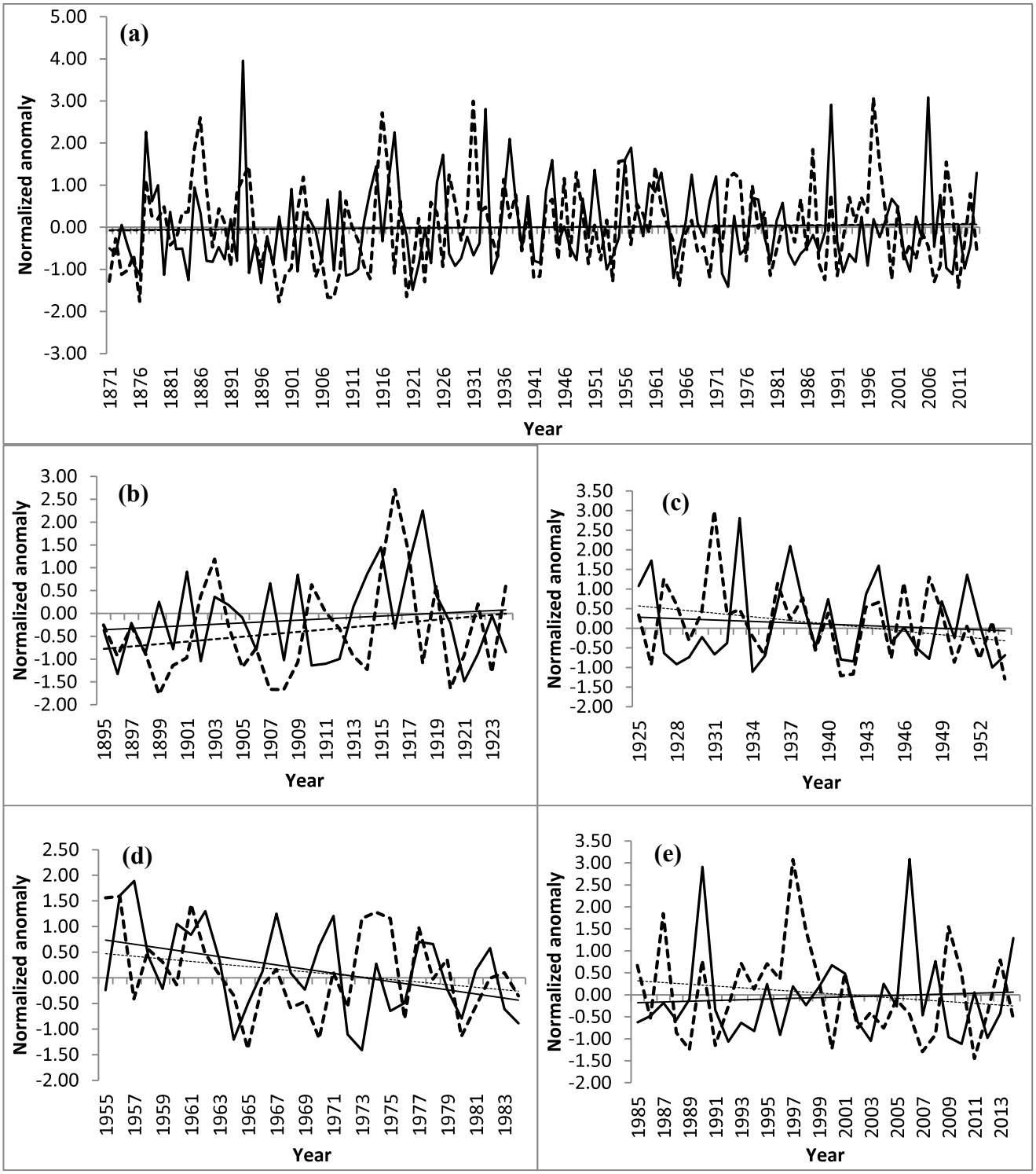

Figure 3. Variation of pre monsoon rainfall (solid line) and post monsoon rainfall (dashed line) over West central region during the period (a) 1871-2014; and the tricades: (b) 1895-1924; (c) 1925-1954; (d) 1955-1984; (e)1985-2014.

Variability of Pre and Post Monsoon Rainfall over Central Northeast region

Analyzing the rainfall pattern during pre monsoon season (Figure 4a), we find the higher positive normalized rainfall anomalies of +3.41 (1893), +2.19 (1914), +2.08 (1971), +2.27 (1990) and +2.41 (1995). We also find the anomalies to be consistently increasing from the year 1894 (-1.46) to 1914 (+2.19). Also, the same increasing trend was observed from the

year 1972 (-1.75) to 1995 (+2.41). After 1995, decreasing trend was seen till 2012 for the region. Tricadal time series explains the epochal behavior. The first tricade (Figure 4b) displayed highest positive peak of +2.19 (1914) and then decreasing trend till 1924. The second tricade (Figure 4c) didn't show any trend. However, the high positive anomaly of +1.68 (1933) was followed by sharp decline in anomaly (-1.59 in 1934). The third tricade (Figure 4d) also displayed the same pattern of the anomaly i.e., a sharp decline in the anomaly (-1.75 in 1972) was observed just after the high positive peak of +2.08 in 1971. There was no trend in both the tricades. The majority of the rainfall anomalies were above normal during the fourth tricade (Figure 4e) with the highest peak occurring in the year 1955 (+2.41).The overall trend in post monsoon rainfall in central northeast region during period 1871- 2014 is clearly depicted by the Figure 4a, where the average rainfall was found to be 92.1 mm with standard deviation of 51.4 mm. The year from 1956 to 1984 displayed a decreasing trend and there was also an abrupt spike in positive anomaly seen in the recent year of 2013 with the normalized anomaly of +2.61. Also the decreasing trend was observed from 1894 to 1915. The maximum rainfall recorded was in the year 1894, with an anomaly of +3.14, whereas the minimum rainfall recorded was in the year 1918, with an anomaly of -1.64. However, Mann-Kendall test did not depict any trend.

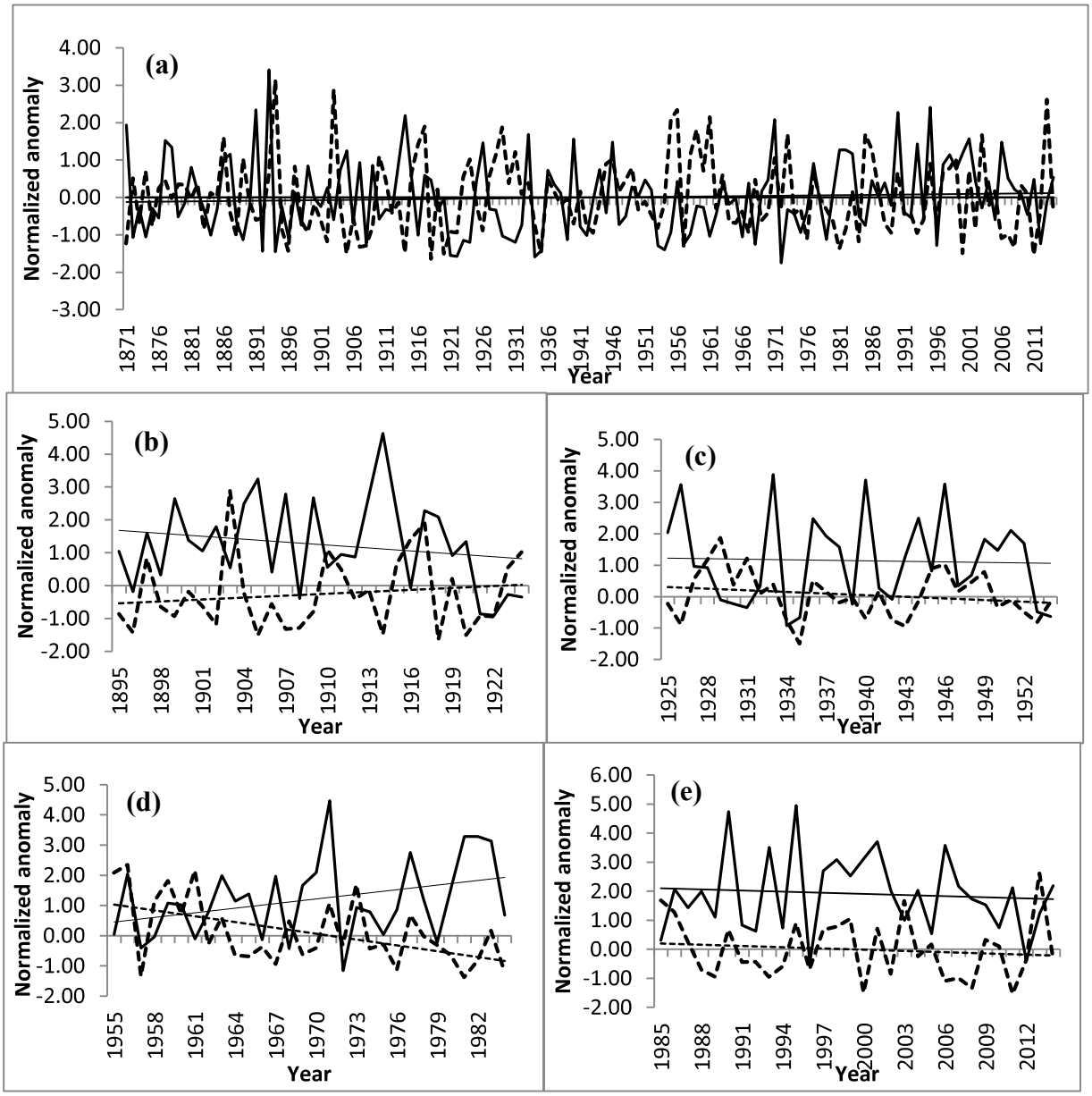

Figure 4. Variation of pre monsoon rainfall (solid line) and post monsoon rainfall (dashed line) over Central Northeast region during the period (a) 1871-2014; and the tricades: (b) 1895-1924; (c) 1925-1954; (d) 1955-1984; (e)1985-2014.

Tricadal analysis of rainfall data of post monsoon period was also done. In the rainfall pattern of the first tricade i.e. during 1895-1924(Figure 4b), we found that the rainfall pattern depicted a positive Sen's slope of 0.02/year (Table 2), with maximum rainfall in the year 1903 with anormalized anomaly of +2.88.The year with minimum rainfall was 1918 together with anomaly of -1.64. The three larger positive anomalies (above normal) during 1903, 1910 and 1917 led to the overall positive trend. In the second tricade (i.e., during 1925-1954) (Figure 4c), the rainfall doesn't show any significant trend. The year when maximum rainfall occurred was in 1929 with a normalized anomaly of +1.87 and the year with minimum rainfall was 1935, with a normalized rainfall anomaly of -1.50. Relative to the first tricade, the 2nd, 3rd and 4th tricade depicted negative slopes of rainfall anomalies. When we consider third tricade (i.e., from 1955-1984) (Figure 4d), the rainfall showed a significant decreasing trend of -0.06/year. The maximum rainfall occurred was in the year 1956, with an anomaly of +2.34. Similarly, minimum rainfall was recorded in the year 1981 with ananomaly of -1.38. However, the fourth tricade of 1985-2014 (Figure 4e) displayed no trend and the recent year 2013, had a maximum rainfall with positive anomaly of +2.61 while the minimum rainfall was in the year 2011, with an anomaly of -1.54. The year from 2011 to 2013 illustrated a steep positive increase in the rainfall anomaly.

Variability of Pre and Post Monsoon Rainfall over Northeast region

Time series analysisof pre monsoon rainfall of the overall northeast region (Figure 5a), revealed the highest positive anomaly of +2.77 (1948) after which it was found to be consistently decreasing till 1966 (-1.33). Highest negative anomaly was found to be in the year 1979 (-2.4), which was preceded by a positive spike of +1.86 (1977). However, the matter of concern is the period from 2000 to 2014 that depicted consistently decreasing rainfall anomaly for the region and no trend was found for the overall northeast region. The first tricade (Figure 5b) illustrated the lesser variability in the rainfall anomaly. The abrupt spike in the positive anomaly of +2.77(1948) was clearly seen in the second tricade spanning 1925-54 (Figure 5c), which was then followed by decreasing anomaly till 1954. The period from 1929 to 1935 (the second tricade) also showed decreasing anomaly from +1.71 to -1.81. Most of the rainfall anomalies in the third tricade (Figure 6d) were found to be below normal with highest spike in the year 1977 (+1.86), followed by the steep decline in the anomaly till 1979 (-2.4). The fourth tricade (Figure 6e) did not depict high variability in the anomaly, but a decreasing pattern from 2000 till 2014 was observed. None of the tricades displayed any trend.

The northeast region is of significant importance while considering the post monsoon rainfall, as it comprises of the flood prone areas of Assam and Meghalaya (that has the place called Mawsynram receiving the highest rainfall in the world). The Figure 6a clearly depicts the trend of the overall post monsoon rainfall that is found to be having Sen's slope of 0.002/year. The average post monsoon rainfall during the period 1871- 2014 is 175.8 mm, while the standard deviation was found to be 71.2 mm. In the post monsoon period, the maximum rainfall recorded was in the year 1946 with an anomaly of +2.78, after which the decreasing slope could be seen till 2014. The scantiest rainfall recorded was in the year 1896, with ananomaly of -2.10. After 1896, relatively greater negative anomaly (2nd highest) was observed in the recent year that was -1.82 (year 2014). A gradual increasing trend is observed from the year 1981 to 1988 with high variability. Further, tricadal analysis revealed the clear picture. The first tricade (Figure 5b) during 1895-1924, the rainfall shows a positive Sen's slope of 0.01/year (Table 2), and the maximum recorded rainfall in 1916 with anormalized rainfall anomaly of +2.24 and the year with minimum rainfall was 1896 with an anomaly of -2.10. The second tricade (Figure 5c) depicts Sen's slope of 0.02/year having maximum rainfall in 1946 with an anomaly of +2.78. The year with minimum rainfall was 1972 with a normalized rainfall anomaly of -1.42. Not much variability was seen in the decade. While, in the third tricade i.e., from 1955-1984 (Figure 6d), the rainfall showed negative slope of -0.02/year. The maximum rainfall occurred in 1959 with ananomaly of +2.62, while minimum rainfall recorded was in the year 1972 with an anomaly of -1.42. To our surprise, the highest negative slope was observed in the fourth tricade (Figure 5e) with the magnitude of 0.04/year (not significant), with the scantiest rainfall anomaly being found in the year 2014 (-1.82). A slightly increasing slope was observed from the year 1997 to 2005. Out of the four tricades, the first two tricades (constituting the first 60 years from 1895 to 1954), displayed positive slope, while the last two tricades (that marks the beginning of 21st century), illustrated the decreasing slope with the high decrease being found in the recent years.

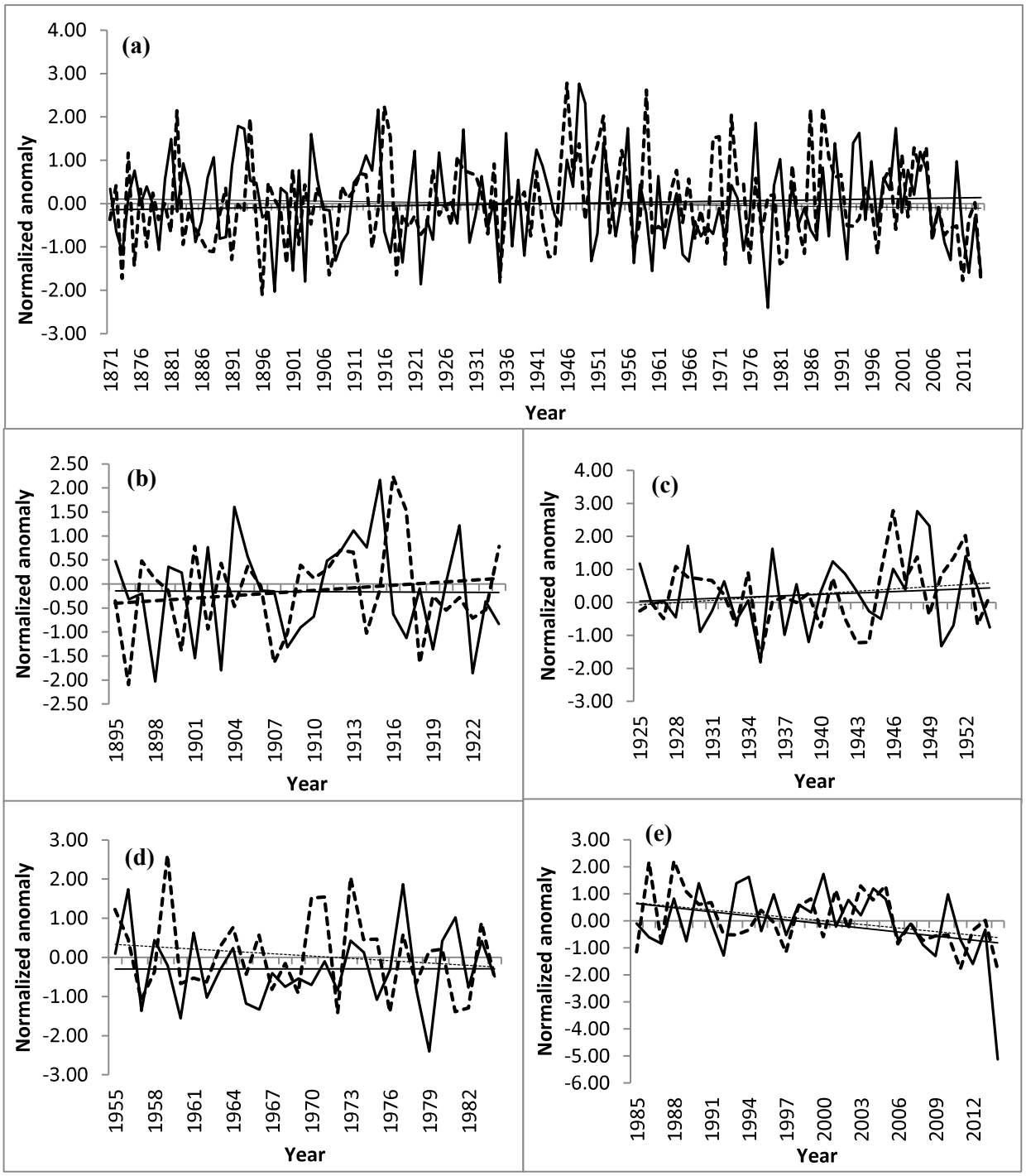

Figure 5. Variation of pre monsoon rainfall (solid line) and post monsoon rainfall (dashed line) over Northeast region during the period (a) 1871-2014; and the tricades: (b) 1895-1924; (c) 1925-1954; (d) 1955-1984; (e)1985-2014.

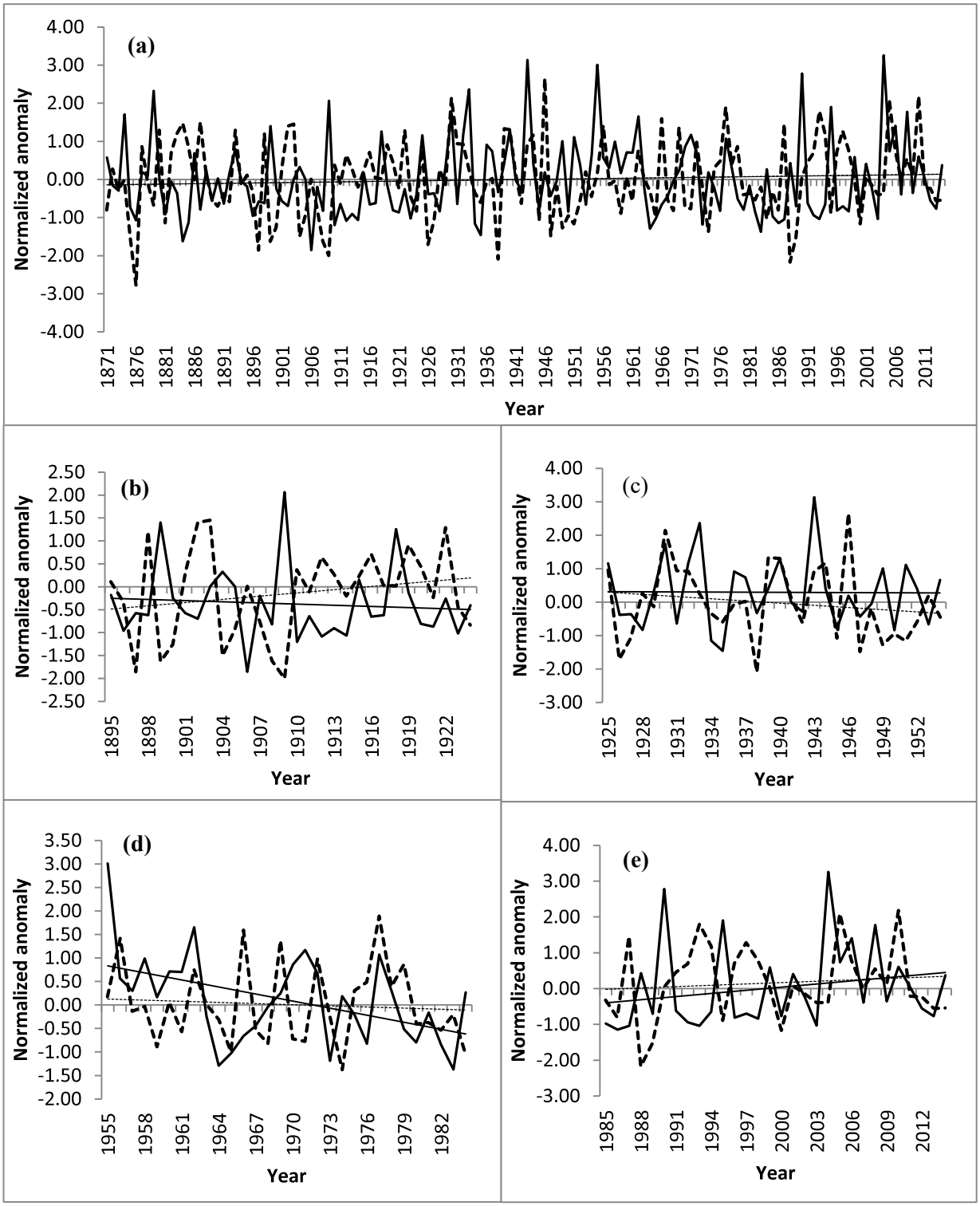

Figure 6. Variation of pre monsoon rainfall (solid line) and post monsoon rainfall (dashed line) over Peninsular region during the period (a) 1871-2014; and the tricades: (b) 1895-1924; (c) 1925-1954; (d) 1955-1984; (e)1985-2014.

Variability of Pre and Post Monsoon Rainfall over Peninsular region

High variability in the normalized rainfall anomaly was observed in the peninsular region (Figure 6a) during the pre monsoon with greater number of positive spikes (above normal anomalies). Highest positive anomaly occurred in the year 2004 (+3.26) and then consistently decreased till 2014. The year from 1925 to 1955 showed an increasing trend of the anomaly (majority of them are above normal). No such overall trend was seen. The period from 1955 to 1984, also displayed decreasing anomaly pattern. Epochal behavior was further analyzed by the tricades. Majority of the rainfall anomalies in the first tricade were below normal (Figure 6b). Lesser variability was observed with the highest anomaly of +2.06 in 1909. The second tricade (Figure 6c) displayed majority of the anomalies to be above normal, with the highest in the year 1943 (+3.14). This tricades barely depicted any trend. A significant decreasing anomaly pattern (-0.06/year) was seen in the third tricade (Figure 6d). Lastly, we could find higher positive anomalies in the fourth tricade (Figure 6e) with the highest in the year 2004 (+3.26). The anomaly pattern decreased from 2004 to the recent years. Peninsular region includes coastal Andhra Pradesh, Rayalseema, coastal Karnataka, south interior Karnataka and Kerala. These coastal parts, especially the Andhra Pradesh and Rayalaseema, are greatly affected by the post monsoon rainfall and thus form an important part of the agro-economy of the regions. Figure 6a, which shows the overall trend of post monsoon rainfall of this region, depicted that the average post monsoon rainfall in peninsular region during period 1871- 2014 is 344.9 mm, with standard deviation 90.6 mm. In the post monsoon period, the maximum rainfall recorded was in the year 1946, with an anomaly of +2.65, whereas the minimum rainfall recorded was in the year 1876, with an anomaly of -2.78. No trend was observed, but a Sen's slope of 0.001/year was found (Table 2). Higher rainfall variability was seen from the year 1959 to 1977, whereas above normal anomalies were seen during the years 1878-91, 1911-21, 1937-48 and 1990-1999. Similarly, below normal anomalies were quite evident during the years 1896-1911 and 1980-1990.

Tricadal analysis of rainfall data of post monsoon period revealed a lot. Firstly, when we observed the rainfall variability in first tricade i.e. during 1895-1924 (Figure 6b), we found that the rainfall doesn't show any trend, but Sen's slope was found to be 0.03/year (Table 2). The maximum rainfall recorded was in the year 1903 with an anomaly of +1.45. Similarly, the above normal rainfall anomalies were seen from 1910-1923. The year that faced minimum rainfall was 1903 with an anomaly of -2.00. In the second tricade i.e. during 1925-1954 (Figure 6c), the rainfall shows negative slope -0.03/year. The year in which maximum rainfall occurred was 1946 with a normalized rainfall anomaly of +2.65 and the year with minimum rainfall was 1938 with an anomaly of -2.10. Not much variability was observed in this tricade but a gradual decreasing trend was found from the year 1930 to 1938. In third tricade i.e. from 1955-1984 (Figure 6d), the rainfall showed negative Sen's slope of -0.02/year (Table 2) and the maximum rainfall occurred was in the year 1977 with an anomaly of +1.89. In this tricade, minimum rainfall was recorded in the year 1974 with an anomaly of -1.38. The normalized rainfall anomaly was found to be decreasing abruptly from 1977 to 1984. Similarly, in the fourth tricade of 1985-2014 (Figure 6e), the rainfall doesn't have a trend, and also Sen's slope is 0. Maximum rainfall occurred in the year 2010 with an anomaly of +2.18, while the minimum rainfall was in 1988 with ananomaly of -2.17.

Decadal variability of Pre and Post Monsoon Rainfall over All India and its regions

Considering Table 1 for the decadal rainfall variability over all India, we found that the decades D2, D3 and D4, showed increasing anomaly trend, followed by the decreasing pattern (D5, D6, D8 and D9) for the pre monsoon season. However, the recent decades (D10, D11, D12, and D13), displayed increasing trends but only the present decade D14, which on the contrary depicted decreasing rainfall trend. For the post monsoon season, consecutive increasing anomalies were observed for the decades D1, D2, D3, D4, D6 and D7 that comprises almost half of the total decades upto year1944. And the rest of the decades that comprises of the recent time periods (D8, D9, D11, D12, D13, D14), showed consecutive decreasing trends over all India.

For the northwest region, the first half of the total decades (D1 to D7), did not show any overall consistent trend for the pre monsoon period. But the other half comprising the recent time period D8 to D14 (1945-54 to 2005-14) displayed consecutive decreasing trends in rainfall. For the post monsoon phase, we could see the decreasing trend dominating the decades D5 to D13 depicting the lesser rainfall faced by the region during the recent times, but the present decade D14 to our surprise, showed the increasing rainfall pattern (Table1). Considering the west central region, the three decades D2, D3 and D4 of the beginning time period, displayed the positive trends, whereas all the rest of the decades (D5 to D14 consisting of the recent time), were dominated by the negative rainfall trends in the pre monsoon season (Table 1) for the west central region. The post monsoon decadal variability however, depicted mixed accent of positive and negative trends for the region with majority of the negative trends towards the other half (D7 to D14) of the total decades. The most recent decade D14 however, displayed increasing pattern compared to the previous three decades.

The beginning decades (D1 to D4) of the northeast region, depicted increasing trends for the pre monsoon season and also

the recent time period comprising of the decades D10 to D13 that displayed positive rainfall anomaly trends. However, the decades D5 to D9 (1915-1924 to 1955-1964), showed the dominant negative trends. Also, the most recent decade D14, displayed decreasing trend. Coming to the post monsoon season, the decades D1 to D4, showed the increasing rainfall trend consecutively over the northeast region. But the rest of the decades (upto the recent times), depicted the mixed accent of positive and negative trends. The present decade however, showed the negative trend relative to the previous decade. Increasing rainfall trends were displayed by the decades D2, D3 and D4 following with decreasing trends (D5 and D6) for the pre monsoon phase in the central northeast region. However, coming to the recent decades, D11 and D12 depicted increasing trends but the decade D13 showed decreasing rainfall. The present decade D14 for the region saw increasing trend relative to the previous decade. The post monsoon phase displayed dominant increasing trend during the beginning of the decades (D2 to D6) whereas, the decades from D7 to D13 depicted overall decreasing anomalies (depicting the dominant decreasing trend in the recent times). The present decade D14 to our surprise, showed increasing rainfall trend over the central northeast region. While the peninsular region displayed mixed accent of increasing and decreasing trends for the pre monsoon phase. Only the three decades D6, D7 and D8, showed consecutive positive trends. But the most recent decade D14 depicted decreasing rainfall trend relative to the previous two decades (D12 and D13).The beginning decades (D3 to D7) of the post monsoon phase depicted the overall increasing trend for the peninsular region. But the latter half of the total decades (D8 to D14), showed the dominant decreasing trend and thus signifying the decreasing rainfall in the present times.

CONCLUSIONS

While studying historic time series (143 years in this case), only the decadal analysis sometimes doesn't provide any specific pattern or trend. So in order to be more precise and for better understanding of the time series variability, we proceeded with the tricades that depict the long term trends. Thus, we can get a clear picture as to what might have resulted to the short term fluctuations in the time series. So, the epochal behavior or sometimes the decadal fluctuations can be better explained by the preceding tricade.

The following conclusion has been drawn from the present study

i. On the basis of the above analysis, we found that all the homogenous regions along with all India, depicted the negative rainfall trend in the 2nd tricade (though not significant) spanning 1925-1954 except for the Northeast region that showed the positive Sen's slope of 0.02mm/year during the post monsoon season.
ii. The fourth tricade of the peninsular region displayed no trend whereas; all other regions for the tricade depicted the negative Sen's slope for the post monsoon season.
iii. An inverse rainfall anomaly pattern was observed between the time series plot of pre and post monsoon season of central northeast and peninsular regions.
iv. For the pre monsoon season, all the regions displayed decreasing rainfall trend for the present decade (2005-2014), except for the central northeast region that depicted the positive trend.
v. The northeast, all India and peninsular regions, displayed decreasing rainfall anomaly trend for the present decade 2005-14 for the pre and post monsoon seasons whereas, on the contrary, only the central northeast region depicted the increasing rainfall trend in the present decade for both the seasons.
vi. The 2nd and 3rdtricades of all India post monsoon season portrayed decreasing rainfall anomaly trends that were found to be significant at 90% significance level.

The indication of delayed rainfall in the post monsoon will pose threat to cropping system in India. Therefore proper study and research is required for the seasonal decadal variability in the rainfall over the entire country. Rainfall variability occurs over a broad range of temporal scales. Critical analysis of such variability can pave the way for better risk management in the agricultural sector thus, saving from greater loss. For the tropical regions, rainfall is an important climatic variable, as it has a high degree of temporal and spatial variability.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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