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Assessing the air temperature and rainfall trend over the undulating red and lateritic zone of West Bengal using Mann-Kendall test and Innovative trend analysis

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सार– इस अध्ययन का उद्देश्य भारत के पश्चिम बंगाल के तरंगित लाल और लैटेराइट क्षेत्र में और मासिक, ऋतुनिष्ठ और वार्षिक पैमाने पर वर्षा की अधिकतम और न्यूनतम तापमान प्रवृत्ति का आकलन करना था। "टेराक्लाइमेट" मासिक अधिकतम और न्यूनतम वायु तापमान और वर्षा के आंकड़े 1958- 2021 की अवधि के लिए गूगल क्लाइमेट इंजन प्लेटफॉर्म से एकत्र किए गए। प्रवृत्ति का पता लगाने के लिए पारंपरिक मान-केंडल (एमके) परीक्षण, सेन के ढलान अनुमानक और अभिनव प्रवृत्ति विश्लेषण (आईटीए) का प्रयोग किया गया। परिणामों ने स्पष्ट रूप से संकेत दिया कि लाल और लैटेराइट क्षेत्रों ने पिछले छह दशकों के दौरान महत्वपूर्ण तापमान वृद्धि का अनुभव किया। सेन के ढलान अनुमानक और आईटीए दोनों ने दर्शाया कि फरवरी का न्यूनतम वायु तापमान सबसे अधिक वार्षिक दर से बढ़ा और उसके बाद मार्च और नवंबर का स्थान रहा। एमके परीक्षण और आईटीए दोनों द्वारा पुष्टि की गई है कि अध्ययन क्षेत्र में वार्षिक वर्षा में नगण्य वृद्धि की प्रवृत्ति पाई गई। मासिक और मौसमी वर्षा वितरण प्रवृत्ति में बदलाव पाया गया। अध्ययन क्षेत्र में दक्षिण-पश्चिम मॉनसून का स्थानांतरण देखा गया जिसके कारण जून में वर्षा में कमी तथा अक्टूबर में वर्षा में वृद्धि हुई। आईटीए ने वायु तापमान और वर्षा की एकरस और गैर-एकरस प्रवृत्ति का सफलतापूर्वक पता लगाया। आईटीए द्वारा प्रचंड मौसम मूल्यों की ऐतिहासिक प्रवृत्ति का पता लगाया गया। नवंबर की वर्षा के उच्च मूल्यों ने सकारात्मक प्रवृत्ति दिखाई। इसके विपरीत, मॉनसून पूर्व वर्षा के निम्न मूल्यों के लिए एक सकारात्मक प्रवृत्ति का पता चला। इस अध्ययन ने संकेत दिया कि लाल और लैटेराइटिक क्षेत्र में तापमान और वर्षा प्रवृत्ति में महत्वपूर्ण परिवर्तन हुए। इस अध्ययन के निष्कर्षों का उपयोग मौसम मापदंडों की भविष्य की प्रवृत्ति का आकलन करने और इस जलवायु और सामाजिक-आर्थिक रूप से कमजोर क्षेत्र में योजना और टिकाऊ प्रबंधन के लिए किया जा सकता है।

ABSTRACT. The present study aimed to assess the trend of maximum and minimum temperature at monthly scale and rainfall at monthly, seasonal and annual scale over the undulating red and lateritic zone of West Bengal, India. "TerraClimate" monthly maximum and minimum air temperature and rainfall data was collected from Google climate engine platform for the period 1958- 2021. The traditional Mann-Kendall (MK) test, Sen's slope estimator and Innovative trend analysis (ITA) were implemented to detect the trend. The results clearly indicated that the red and lateritic zones experienced significant temperature increase during the last six decades. Both the Sen's slope estimator and ITA showed that the minimum air temperature of February increased at the highest annual rate followed by March and November. Annual rainfall over the study area followed non- significant increasing trend as confirmed by both the MK test and ITA. The monthly and seasonal rainfall distribution pattern changed. A shift of the South-west monsoon was realized over the study zone characterized by decreasing rainfall in June and increasing rainfall in October. The ITA successfully detected the monotonic and non-monotonic trend of air temperature and rainfall. Historical trend of the extreme weather values were detected by ITA. Higher values of November rainfall showed positive trend. On the contrary, a positive trend was detected for the lower values of pre-monsoon rainfall. The present study indicated that the red and lateritic zone experienced significant changes in the temperature and rainfall pattern. The findings of the present study can be used for assessing the future trend of the weather parameters and planning and sustainable management in this climatologically and socio-economically vulnerable zone.

Keywords – Red and lateritic zone, Temperature and rainfall trend, Change point, Sen's slope, Innovative trend analysis.

1. Introduction

Climate change is the harsh reality now-a-days across the world. It can be indicated by the "long-term change in the average weather patterns that have come to define Earth's local, regional and global climates" (Teressa, 2021). For investigating climate variability and change in any region, temperature and rainfall are considered as the two prime factors due to their impact on natural and socio-economic status of the region (Serencam, 2019). The Intergovernmental Panel on Climate Change (IPCC) reported an increase in the global mean temperature and spatiotemporal change in the rainfall. According to the fifth Assessment Report (AR5) of IPCC, global mean surface temperature increased by 0.89°C in between 1901 and 2012 (IPCC, 2013). The projection of IPCC (2021) showed that the global surface temperature will likely increase by 1.2 to 1.9 °C, 1.2 to 3.0 °C and 1.0 to 5.7 °C in near-term (2021-2040), mid-term (2041-2060) and long-term (2081-2100) period, respectively than the average surface temperature in the period extending from 1850 to 1900 (Phuong *et al*., 2022). During the last decade, the period from 2015-2019 was observed to be the warmest since 1850 according to the World Meteorological Organization (2019) (Marak *et al*., 2020). Increased anthropogenic activities and thereby increased concentration of greenhouse gases in the atmosphere caused the global temperature rise. Global warming not only increases the evapotranspiration but also increase the moisture holding capacity of the air. Increased atmospheric moisture content enhances the intensity of precipitation. Further, the world-wide warming affects the hydrological cycle and induces the occurrence of extreme climatic events like flood, drought, cyclone *etc*. (IPCC, 2018; Marak *et al*., 2020). Intensity and distribution of rainfall changed due to global warming. The frequency of extreme rainfall increased in many sites in the world. The increased frequency of intense precipitation was strongly related with the increased mean surface temperature (Berg *et al*., 2013).

The variability in the air temperature and rainfall intensity and distribution pattern greatly influences the farming activities especially where the rain-fed agriculture is the backbone of economy (Sarkar *et al*., 2020). Crop growth and production is largely affected by the changing pattern of weather factors. Climate change alters the agricultural production and thereby affects the livelihood of the global population (Jha *et al*., 2021). The increased frequency of floods due to intense rainfall was observed in many places over India. It was also reported that reduced rainfall for extended period of time caused drought (Marak *et al*., 2020). The undulating red and lateritic agro-climatic zone of the West Bengal state is a drought-prone region. This agro-climatic zone covers six districts of West Bengal viz. Bankura, Birbhum, Jhargram, Paschim Bardhaman, Paschim Midnapore and Purulia districts occupying about 34 % of the total area of the state. The trend of the weather parameters helps to determine the optimum cropping windows and reduce crop loss by escaping prolonged exposures of the crops under stressed environment (Mukherjee and Banerjee, 2009).

Assessing the time trend of meteorological factors helps the planners and decision makers for suggesting useful adaptation and mitigation strategies to combat the climate change (Ali and Abubaker, 2019). Agroclimatic potentiality of any region can be determined by analyzing the meteorological factors (Ghosh *et al*., 2021). To assess the impact of the climate change on agricultural production, one must have to analyze the climatic data. Several researchers performed the time series analysis of temperature and rainfall to detect the historical trend present in the monthly, seasonal and annual series of data in many sites all over world. The non-parametric Mann-Kendall (MK) and Sen's slope estimator are most popular time series analysis procedure adopted by most of the researchers for detecting the significant or non-significant monotonic trends of meteorological and hydrological data (Mandal *et al*., 2019). The MK test assumes the normal distribution of data, independent structure and length of the time series. Furthermore, this test cannot estimate the contribution of the high, medium and low values in the trend. Auto-correlation in the time series affects the performance of MK test (Caloiero *et al*., 2018). To eliminate the autocorrelation in the time series data, the pre-whitening approach may be followed but this approach is also suffers from some limitations. Sometimes the pre-whitening method can eliminate the actual trend. The effectiveness of the pre-whitening approach was reported to be doubtful in the presence of serial correlation and large sized data (Marak *et al*., 2020). To overcome these problems in time series analysis, recently several researchers are using the Innovative Trend Analysis (ITA) approach proposed by Sen (2012). Unlike the MK test, the ITA approach does not depend on any restrictive assumptions and it detects the monotonic as well as non-monotonic trends very easily. The ITA approach successfully deals with the autocorrelation present in the

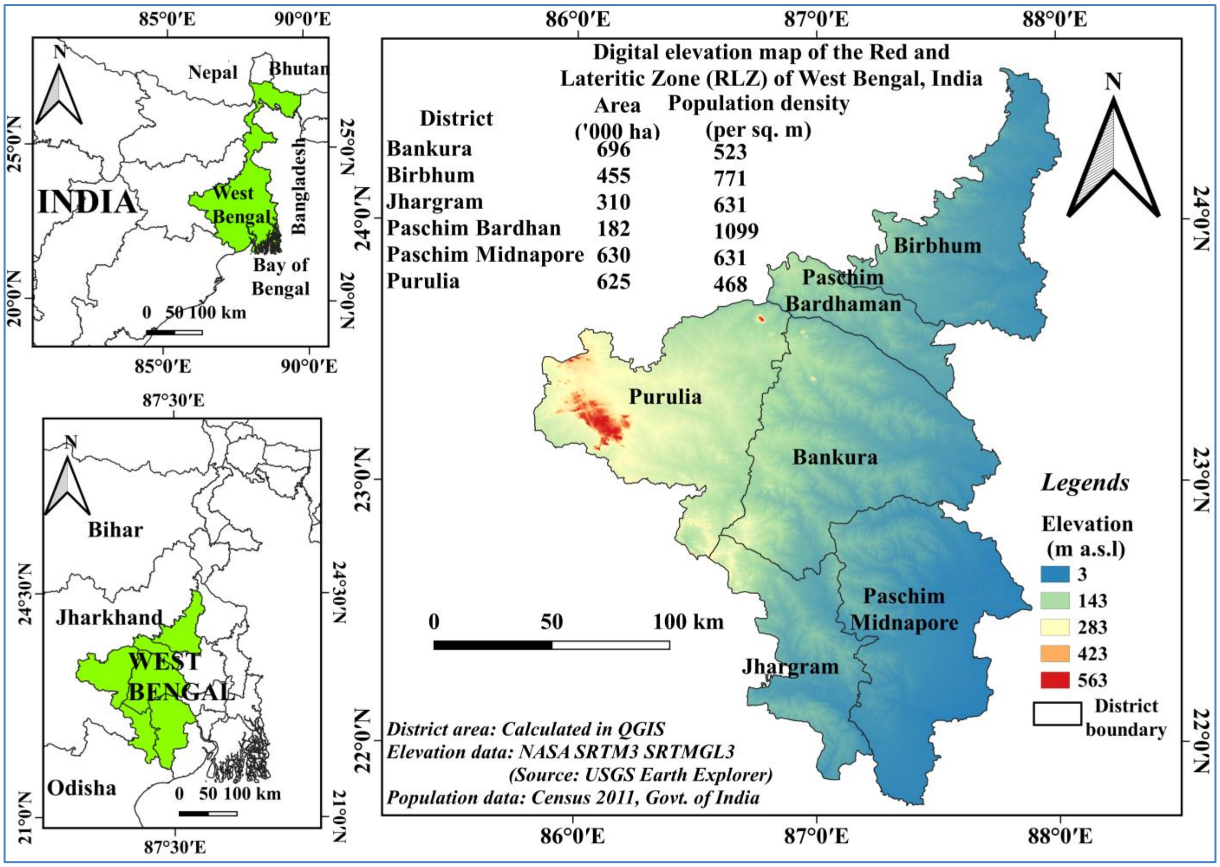

Fig. 1. Geographical location of the Red and Laterite zone of West Bengal

time series data; assesses the trend of high, medium and low values in the time series data and describe the presence of temporal clusters (Caloiero *et al*., 2018). Several studies reported the advantages of ITA approach over the traditional MK test (Sen, 2014).

Although the historical trend of temperature and rainfall of some part of the red and lateritic zone was analyzed earlier, a comprehensive report on the temperature and rainfall trend of the entire red and lateritic zone is still lacking. To bridge the gap, the present study was aimed to assess the trend of monthly maximum (T_{max}) and minimum temperature (T_{min}) and monthly and seasonal rainfall (R) of the undulating Red and Lateritic agro-climatic zone. Traditional MK test was used to detect the significant or non-significant trend in the time series data. Sen's slope estimator was used to estimate the annual increasing or decreasing rate temperature and rainfall. Further, the ITA approach was applied to identify the presence of stable or unstable monotonic trend in the monthly and seasonal time series data. Secondly, the change points where significant shift in the temperature and rainfall pattern occurred was identified through three change point analysis approaches *viz*. Pettitt's test, Buishand's Range Test and Buishand U test.

2. Data and methodology

2.1. *Study area*

The undulating red and lateritic zone is located in the western part of the West Bengal state & extends from 22° N to 24.5° N and from 86° E to 87.5° E. This zone is surrounded by Jharkhand state in the West, Odisha state and East-Midnapore district of West Bengal state in the South (Fig. 1). This zone covers about one third of the cultivated area of Purulia, Bankura, Jhargram, Paschim Medinipur, Paschim Bardhaman & Birbhum districts of West Bengal (Pradhan *et al*.,2012; Haldar *et al*., 2018). The red & lateritic zone, a part of the Eastern Plateau and Hill region experiences the hot sub-humid climate. There are three distinct seasons *viz*. monsoon (June, July, August & Sept.), post-monsoon or winter (October, November, December, January & February) & pre-monsoon or summer season (March, April and May). This zone is considered as the most backward and under developed region of the state because of its climate, mainly characterized by drought proneness, unfavourable for agriculture especially during winter and summer (Mishra, 2012). Agriculture is predominated by the rainfed mono-cropping of *kharif* paddy. Cropping intensity (125-130%)

TABLE 1

Root Mean Square Error (RMSE) values between Terra Climate and IMD gridded data

		Bankura	Birbhum	Paschim Bardhaman	Paschim Midnapore	Purulia	Jhargram
Rainfall	Jan	5.07	8.67	3.74	12.39	3.11	6.03
	Feb	15.60	15.51	10.76	12.93	12.36	11.27
	Mar	20.49	11.91	14.62	19.73	16.55	15.27
	Apr	23.16	21.13	21.46	24.53	18.05	18.30
	May	56.17	71.60	72.89	56.31	74.01	60.33
	Jun	69.49	71.05	56.24	95.89	101.29	90.33
	Jul	91.67	95.89	63.12	92.29	111.72	74.20
	Aug	77.72	95.67	87.78	77.15	92.25	80.33
	Sep	58.31	67.07	66.83	92.59	91.42	75.33
	Oct	60.97	62.85	86.00	116.29	39.58	49.26
	Nov	14.19	15.98	13.37	14.38	7.41	9.06
	Dec	9.08	15.53	9.53	4.30	15.18	8.21
	MON	135.09	215.97	157.66	220.28	276.56	195.63
	POST	65.81	63.18	104.69	124.64	100.90	75.24
	PRE	81.50	81.94	78.45	74.48	94.47	69.31
	Annual	205.86	241.87	196.31	311.36	355.83	259.32
Air temperature	T_{min}	2.63	1.36	1.86	1.64	3.16	1.97
	T_{max}	2.39	4.53	2.25	2.42	4.53	2.22

is lesser than the state average (Brahmachari *et al*., 2019). The lateritic soil is red in colour and infertile, though little vegetation can grow with availability of proper irrigation facilities.

2.2. *Data and source*

Monthly series of mean maximum and minimum temperature and rainfall data from 1958 to 2021 was analyzed in the present study. "TerraClimate" monthly maximum and minimum temperature and rainfall data with 4 km X 4 km spatial resolution was collected for the six different districts from the Google climate engine (https://app.climateengine.com/climateEngine). This data have been generated using climatically aided interpolation combining finer spatial resolution climatological normals from the WorldClim dataset with coarser spatial resolution and time-varying data from Climatic Research Unit (CRU) Time series version 4.0 (Ts4.0) and the Japanese 55-year Reanalysis (JRA55) (Abatzoglou *et al*., 2018).

Descriptive statistics consisting of mean and coefficient of variation (CV) of the monthly maximum (T_{max})& minimum temperature (T_{min}) & monthly, seasonal and annual rainfall over the study period (1958-2021) were calculated and presented in the Appendix table A.

In order to validate the "TerraClimate" climate data, air temperature and rainfall data of India Meteorological Department (IMD) were used. IMD gridded daily data were downloaded with 0.25° X 0.25° and 1° X 1° spatial resolution for rainfall and air temperatures, respectively. Both data sets were compared in-terms the Root Mean Square Error (RMSE) values and the results so obtained in the Table 1. The "Terra Climate" data was also applied in four other districts outside the Red and Laterite regions of West Bengal and the districts were Jalpaiguri (Terai zone), Dakshin Dinajpur (Old Alluvial zone), South 24 Pgs. (Coastal saline zone) and Kolkata (New Alluvial zone). Long term trend (1958- 2021) of monthly and annual rainfall and monthly maximum and minimum air temperature was determined.

2.3. *Mann-Kendall (MK) test*

The presence of increasing or decreasing trend in the time series of various weather parameters was tested with the nonparametric Mann-Kendall test. Mann-Kendall test is suitable for cases where the trend may be assumed to be monotonic and thus no seasonal or other cycle is present in the data. It is therefore assumed that the variance of the distribution is constant in time. The test statistics (S) of the MK test is calculated by the following formula adopted by Marak *et al*. (2020) and Das *et al*. (2021).

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sign(x_j - x_i)$$

where, x_i and x_j are the sequential data points of time i and$j$, N is the length of the data series, and

$$sign(x_j - x_i) = \begin{bmatrix} 1 & if\ sign(x_j - x_i) & > 0 \\ 0 & if\ sign(x_j - x_i) & = 0 \\ -1 & if\ sign(x_j - x_i) & < 0 \end{bmatrix}$$

When the number of observations is equals to or more than 8 (N ≥ 8), the trend statistics (S) is said to follow normal distribution (Mann (1945) and Kendall (1938). The variance of S is calculated using the following the formula:

$$VAR(S) = \frac{1}{18}\{n(n-1)(2n+5) - \sum_{j=1}^{g} t_j(t_j - 1)(2t_j + 5)\}$$

where, g is the number of the tied groups' number and t_j indicates the extent of jth tied number. The tied groups are the set of sample data with similar values.

The Kendall's τ (tau) is calculated by the following formula:

$$\tau = \frac{S}{B}$$

$$B \sqrt{\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{g} t_j(t_j - 1)} \sqrt{\frac{1}{2}n(n-1)}$$

The test statistics (S) and the variance of S is calculated to determine the standardized test measurement (Z) using the following formula when n > 10

$$Z = \begin{bmatrix} \frac{S-1}{\sqrt{V(S)}} & if\ S & > 0 \\ 0 & if\ S & = 0 \\ \frac{S+1}{\sqrt{V(S)}} & if\ S & < 0 \end{bmatrix}$$

The positive and negative values of Z indicate the increasing and decreasing trend, respectively. If the value of Z becomes zero then the time series is said to be trendless. In the present study, the MK test was performed at four significance levels (p = 0.001, 0.01, 0.05 and 0.1). MAKESENS, a macro enabled spreadsheet programme was used to perform Mann-Kendall test in the present study.

2.4. *Sen's slope estimator*

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method (Sen, 1968) was used in the present study. The Sen's method uses a linear model to estimate the slope of the trend and the variance of the residuals should be constant in time. The Sen's slope is a measure of the strength of the trend or in other word the rate of change of the parameter. The Sen's slope is estimated by the following formula stipulated by Marak *et al*. (2020).

$$\beta = Median\left[\frac{Y_i - Y_j}{i - j}\right] for\ all\ j < i$$

where, β is the median of all slope estimates, Y_i and Y_j are data values at time steps i and j, respectively. The positive and negative value of β denotes the increasing and decreasing trend, respectively. In the present study, MAKESENS was used to compute Sen's slope.

2.5. *Innovative trend analysis (ITA)*

Innovative trend analysis (ITA) method was first proposed by Sen (2012). It is a graphical non-parametric method that can detect the monotonic or non-monotonic trend of the time series. The ITA can also detect the sub-trends and different combination of trends at different time period. The trend of high, medium and low category data can also be detected by the ITA. It can efficiently handle the autocorrelation and outliers in the time series data. The length of the time series does not affect the performance of the ITA (Das *et al*., 2021). In order to carry out the ITA over a time series data, the full time series is to be divided into two equal sub-series. The two sub-series are to be arranged in ascending order and plotted against each other together in a scatter diagram with the first half of the time series plotted along the X axis and second half of the time series along the Y axis. A straight line, called 1: 1 line is to be drawn at a 45° angle in the scatter diagram. The points fall on the line indicate a trendless series. If the points fall above the 1: 1 line *i.e*. in the upper triangle of the diagram, the time series follows positive trend. On the other hand, negative trend is detected when the points fall below the 1: 1 line *i.e*. in the lower triangle of the scatter diagram (Cui *et al*., 2017). The monotonic and non-monotonic feature of the trend is identified by the distribution of the points with respect to the 1:1 line. The slope (B) of the ITA method is calculated by using the following formula used by Das *et al*. (2021):

$$B = \frac{1}{n}\sum_{i=1}^{n}\frac{10(x_j - x_k)}{\bar{x}}$$

where, n is the extent of individual sub-series, x_j and x_k are the values of the consecutive sub-series, and $\bar{x}$ is the mean of the 1st sub-series (x_k). The upper and lower confidence limit (CL) of the trend slopes are calculated using the formula:

$$CL_{1-\alpha} = 0 \pm S_{cri}\sigma_s$$

where, α is the significance level and $\sigma_s$is the slope standard deviation.

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1 - \rho_{\overline{x_i}\overline{x_j}}}$$

where,$\overline{x_i}\overline{x_j}$ is the cross correlation coefficient between two sub-series. In the present study, the ITA method was performed in R studio using the "trend change" package.

2.6. *Change point analysis*

In the present study, three change point analysis procedures viz. Pettitt's test, Buishand's Range Test and Buishand U test were carried out for assessing the period from where significant change has occurred in a time series (Jaiswal *et al*., 2015). The change points were determined at the probability level P = 0.05. The "trend" package of R studio was used to perform the change point analysis in the present study.

3. Results

3.1. *MK trend and annual change rate of air temperature and rainfall*

The historical monotonic trend of the maximum (T_{max}) and minimum (T_{min}) air temperature at monthly scale and rainfall at monthly, seasonal and annual scales over the red and lateritic zone was estimated using the MK test and the results so obtained have been summarized in the Table 2. Four confidence levels ($p \leq 0.1$; ≤ 0.05; ≤ 0.01 and ≤ 0.001) was chosen to assess the significance of the trend statistics (Z) obtained from MK tests. The rate of change of the meteorological parameters under study at different temporal scales over the last six decades was calculated using the Sen's slope estimator. The variations in the change rate of air temperature and rainfall over the study area have been presented in the form of thematic maps in Figs. 2 to 5.

The results clearly stated that T_{max} during the months of January, April and May decreased during the study period though the trends were insignificant. On the contrary, T_{max} in June showed non-significant rising trend over all the six districts. Significant rising trend of the monthly T_{max} was estimated from July to December month over the entire study zone. The annual decreasing rate of T_{max} in January was ranged from 0.005 to 0.01 °C per year as shown in the Fig. 2. The decreasing rate of T_{max} in May was estimated as comparatively higher (0.01- 0.015 °C per year) than that was in January and April. The annual increasing rate of T_{max} ranged between 0.005 and 0.015 °C per year from June to September. Further increase in the rising rate of T_{max} was observed in October and November (0.015- 0.025 °C per year) over the study zone. Finally, in the month of December T_{max} increased at the rate of 0.005- 0.015 °C per year. The present study revealed the significant increase of T_{min} in all the months except January, April and May where non-significant rise in T_{min} was observed. It was estimated that T_{min} of February, March and November increased at the highest annual rate (0.015- 0.025 °C per year) (Fig. 3). The increasing rate of T_{min} was slightly lower in the months of August, October and December (0.01- 0.015 °C per year).

The trend statistics (TestZ) of monthly, seasonal and annual rainfall showed that the rainfall of May significantly increased during the study period over the entire red and lateritic zone. However, the rate of increase in the May rainfall was not uniform over the study zone. Paschim Midnapore district recorded the highest increasing rate (2.5 mm per year) of rainfall as against Birbhum district where the lowest increasing rate (0.39 mm per year) was recorded (Fig. 4). Further, April and June rainfall also showed increasing trend though the trend was not significant. On the contrary, July rainfall showed non-significant declining trend in four out (Birbhum, Jhargram, Paschim Midnapore and Purulia) of six districts. October rainfall showed non-significant decreasing trend during the last sixty four years of study in all the six districts. In Jhargram and Paschim Midnapore districts rainfall during November did not follow any trend. The rest four districts showed a non-significant negative trend of November rainfall. Considering the seasonal scale of rainfall in the red and lateritic zone, the pre-monsoon (March, April and May) rainfall showed a significant increasing trend in all the six districts. The pre-monsoon rainfall increased at the rate of 0.6- 0.9 mm per year in Birbhum, Paschim Bardhaman and Purulia districts while at the rate of 0.3- 0.6 mm per year in Bankura, Jhargram and Paschim Midnapore districts (Fig. 5). Monsoon rainfall also showed an increasing trend but the trends were not significant. On the contrary, a declining trend of the post-monsoon rainfall

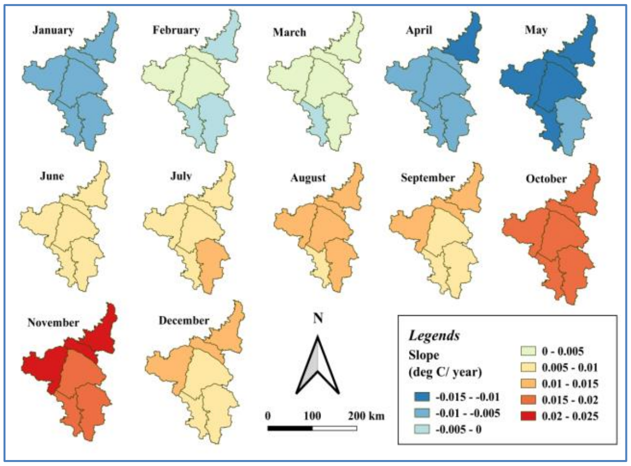

Fig. 2. Annual increasing/ decreasing rate of monthly maximum air temperature over the red and laterite zone.

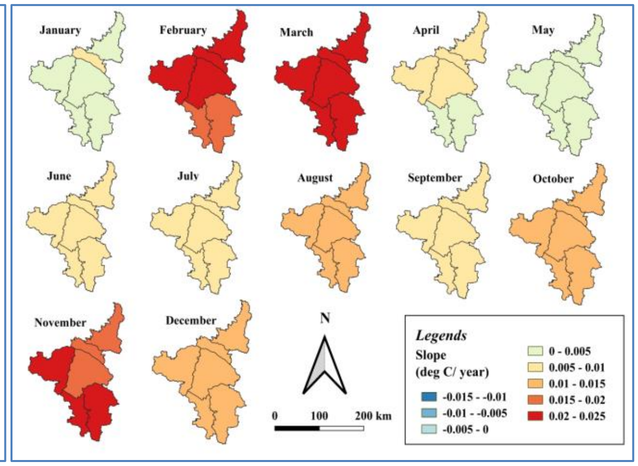

Fig. 3. Annual increasing/ decreasing rate of monthly minimum air temperature over the red and laterite zone.

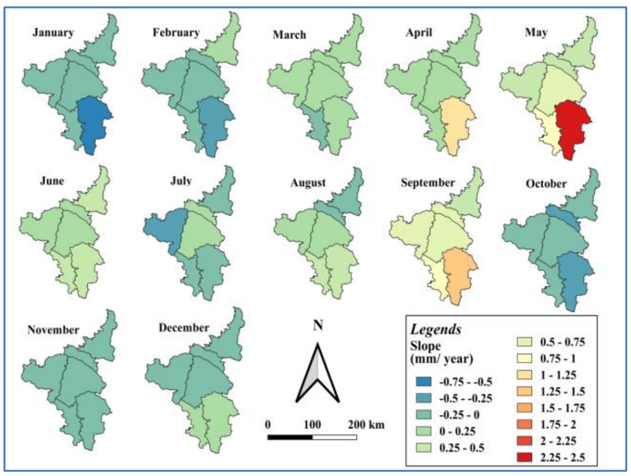

Fig. 4. Annual increasing/ decreasing rate of monthly rainfall over the red and laterite zone.

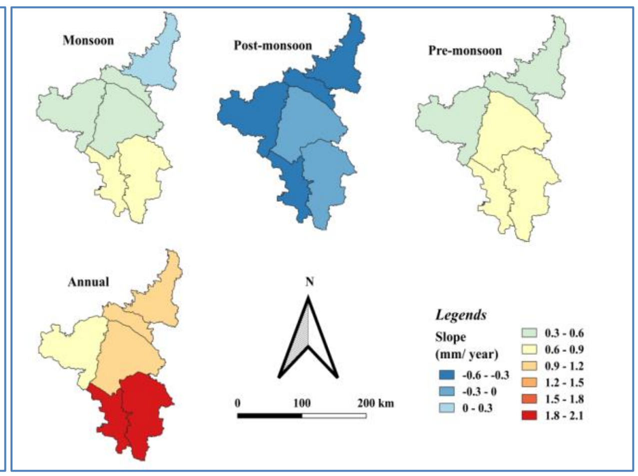

Fig. 5. Annual increasing/ decreasing rate of seasonal and annual rainfall over the red and laterite zone

was recorded in each district. The Sen's slope estimator calculated the decreasing rate of post-monsoon rainfall as 0.1- 0.5 mm per year. While studying the annual scale of rainfall, a non-significant increasing trend was observed over the entire red and lateritic zone. The southern part of the red and lateritic zone (Paschim Midnapore and Jhargram districts) recorded the highest increasing rate of both monsoon (0.6- 0.9 mm per year) and annual rainfall (1.8- 2.1 mm per year). A gradual decrease in the increasing rate of pre-monsoon, monsoon and annual rainfall in the northern direction was observed. The similar result was obtained for the monthly scale of rainfall also.

Besides the Red & Laterite zone of West Bengal, the monthly & annual rainfall & monthly air temperature over the districts of Jalpaiguri, Dakshin Dinajpur, South 24 Pgs. & over Kolkata was estimated and given in Table 3. Temperature trend varied among the districts. Maximum air temperature increased in all months except in January and April over Kolkata. On the other hand minimum air temperature increased in all months except in April, May, July and September over Kolkata. Annual rainfall decreased over Jalpaiguri and Dakshin Dinajpur and increased over South 24 Pgs. and Kolkata. Monthly rainfall over Kolkata showed a decreasing trend from January to July and December. Rainfall showed a rising trend from August to November.

3.2. *ITA of air temperature and rainfall*

Innovative trend analysis (ITA) was performed to detect the hidden monotonic or non-monotonic trend in the maximum (T_{max}), minimum (T_{min}) air temperatures and rainfall at various scales. The estimated trends and slope parameters including slope, trend indicator, & upper & lower confidence level at 95% have been given in Table 4 and 5. To investigate the stability of the air temperature &

TABLE 2

Trend statistics (Z) of maximum and minimum air temperature and rainfall obtained from Mann-Kendall trend analysis

Weather parameters	Districts	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
Maximum temperature	Bankura	-1.11	0.11	0.34	-0.74	-1.31	1.18	2.11*	3.83***	3.59***	3.51***	3.66***	1.75 +	1.44
	Birbhum	-0.82	-0.02	0.31	-1.25	-1.21	1.33	2.15*	3.83***	3.63***	3.19**	4.00***	1.79+	1.44
	Jhargram	-1.18	-0.04	-0.08	-0.88	-1.55	1.04	2.25*	3.60***	3.48***	3.49***	3.54***	1.69+	1.06
	Paschim Bardhaman	-0.81	0.16	0.59	-0.74	-1.41	1.16	1.94+	3.82***	3.59***	3.30***	3.92***	1.87*	1.55
	Paschim Midnapore	-1.29	0.01	0.12	-0.89	-1.30	1.20	2.47*	3.79***	3.44***	3.49***	3.42***	1.50	0.98
	Purulia	-1.16	0.12	0.13	-0.75	-1.58	0.90	1.85+	4.00***	3.82***	3.68***	3.69***	1.94+	1.41
Minimum temperature	Bankura	0.71	3.05**	3.39***	1.11	0.16	2.02*	1.99*	3.56***	2.84**	2.38*	2.43*	2.18*	4.12***
	Birbhum	0.85	2.66**	3.13**	0.59	0.10	2.39*	2.32*	3.40***	2.94**	2.53*	2.40*	2.01*	4.14***
	Jhargram	0.18	2.90**	2.72**	1.04	0.30	1.80+	2.07*	3.48***	2.88**	2.28*	2.60**	2.25*	4.02***
	Paschim Bardhaman	1.01	3.04**	3.43***	1.12	0.13	1.94+	2.03*	3.45***	3.10**	2.51*	2.49*	2.17*	4.21***
	Paschim Midnapore	0.13	2.90**	2.90**	0.90	0.34	2.06*	2.29*	3.48***	2.79**	2.24*	2.45*	1.85+	3.86***
	Purulia	0.78	3.08**	3.19**	1.18	0.19	1.62	1.87+	3.67***	3.04**	2.49*	2.62**	2.57*	4.43***
Rainfall	Bankura	-0.89	-0.11	0.46	1.48	2.55*	0.20	0.24	0.09	1.33	-0.26	-0.61	0.86	
	Birbhum	-0.67	0.37	0.67	1.73+	2.14*	0.49	-0.04	-0.05	1.07	-0.62	-0.72	-0.02	
	Jhargram	-0.75	-0.58	-0.10	1.13	2.72**	0.46	-0.39	0.53	1.40	-0.39	0.00	1.22	
	Paschim Bardhaman	-0.82	0.00	0.74	1.52	2.49*	0.20	0.10	-0.03	1.32	-0.63	-0.85	-0.02	
	Paschim Midnapore	-0.71	-0.43	0.14	1.15	2.47*	0.36	-0.01	0.49	1.27	-0.32	0.00	1.79	
	Purulia	-0.94	-0.19	0.35	0.90	2.74**	0.36	-0.55	0.01	1.11	-0.59	-0.74	-0.03	

Weather parameters	Districts	Monsoon	Post-monsoon	Pre-monsoon	Annual
Seasonal and annual rainfall	Bankura	0.47	-0.55	2.22*	1.14
	Birbhum	0.25	-1.07	2.11*	0.71
	Jhargram	0.94	-0.90	2.37*	1.44
	Paschim Bardhaman	0.32	-0.94	2.06*	0.88
	Paschim Midnapore	0.72	-0.43	2.03*	1.49
	Purulia	0.26	-1.14	1.87*	0.64

+: $p \leq 0.1$; *: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$

rainfall trend, Double- Innovative trend analysis (D-ITA) was carried out and the ITA plots for air temperatures and rainfall have been presented in the Appendix figures: Fig. A, B, C and D.

It was found that T_{max} of January, February, March and April did not show trend. However, negative slopes and trend indicators were estimated for the T_{max} of January and April while positive slopes and trend indicators were estimated for the T_{max} of February and March (Table 3). A non-monotonic decreasing trend was shown by the T_{max} of May. Over the study area, the June rainfall was associated with the positive slope values as obtained from the ITA. In case of July months the T_{max} showed non-monotonic decreasing trend. The higher values in the time series showed no trend. The T_{max} of September and November was found to follow a monotonic increasing trend associated with positive values of slopes and trend indicators. On the other hand, the T_{max} of October and December followed non-monotonic increasing trend with positive values of slopes and trend indicators. The results further revealed that the two halves of the time series exhibited very high correlation in all months. Very little variations between the slopes estimated by Sen's Slope

TABLE 3

Trend statistics (obtained from MK test) of air temperature and rainfall over Dakshin Dinajpur, Jalpaiguri, South 24 Pgs. and Kolkata

Parameters	Time scale	Dakshin Dinajpur		Jalpaiguri		South 24 Pgs.		Kolkata	
		Test Z	Q	Test Z	Q	Test Z	Q	Test Z	Q
Maximum air temperature	Jan	-0.16	0.000	0.19	0.003	-2.39	-0.025	-0.90	-0.013
	Feb	1.05	0.017	0.93	0.016	-0.38	-0.004	0.88	0.016
	Mar	0.65	0.012	0.50	0.009	1.11	0.011	0.97	0.017
	Apr	-0.50	-0.010	-0.05	0.000	0.77	0.008	-0.46	-0.007
	May	0.56	0.006	-0.01	0.000	1.58	0.013	0.21	0.000
	Jun	1.51	0.014	1.07	0.012	1.29	0.009	1.28	0.012
	Jul	2.60	0.021	2.36	0.021	1.67	0.011	1.50	0.014
	Aug	2.26	0.016	2.19	0.020	1.69	0.009	2.23	0.013
	Sep	3.42	0.025	2.76	0.022	1.21	0.009	1.88	0.012
	Oct	1.11	0.010	1.51	0.019	1.21	0.011	0.34	0.000
	Nov	0.47	0.004	1.02	0.010	0.06	0.000	0.59	0.003
	Dec	1.04	0.015	0.68	0.011	-0.62	-0.006	0.43	0.005
	Annual	1.69	0.009	2.02	0.008	0.75	0.004	0.91	0.004
Minimum air temperature	Jan	-1.29	-0.014	-0.04	0.000	-0.78	-0.011	0.61	0.006
	Feb	0.34	0.004	0.85	0.011	0.81	0.013	2.57	0.027
	Mar	0.74	0.009	1.10	0.012	0.88	0.015	1.62	0.025
	Apr	-0.14	0.000	0.72	0.007	-0.22	0.000	-0.60	-0.006
	May	1.22	0.010	1.76	0.018	0.22	0.000	-1.05	-0.011
	Jun	1.74	0.011	3.39	0.021	1.39	0.013	0.31	0.000
	Jul	3.26	0.016	4.00	0.023	1.11	0.009	-0.29	0.000
	Aug	1.77	0.011	3.32	0.021	1.91	0.012	0.81	0.003
	Sep	2.00	0.014	2.47	0.017	1.73	0.010	-0.53	0.000
	Oct	1.49	0.015	2.03	0.026	0.12	0.000	0.45	0.000
	Nov	-0.03	0.000	0.85	0.009	0.07	0.000	2.56	0.037
	Dec	-0.42	-0.004	-0.16	0.000	0.23	0.000	0.90	0.010
	Annual	1.57	0.007	2.75	0.014	1.19	0.005	2.24	0.010
Rainfall	Jan	-1.63	-0.130	-0.58	-0.030	-1.8	-0.140	-2.03	-0.170
	Feb	-0.41	-0.060	-0.22	-0.030	-1.79	-0.370	-1.57	-0.240
	Mar	-0.42	-0.080	0.01	0.000	-0.82	-0.250	-0.74	-0.210
	Apr	0.92	0.310	0.81	0.540	0.01	0.000	0.22	0.130
	May	0.21	0.130	0.48	0.690	-1.03	-0.670	-0.33	-0.220
	Jun	-0.66	-0.450	-0.85	-2.000	-0.13	-0.220	-0.06	-0.090
	Jul	-1.12	-1.100	-0.84	-2.000	-0.26	-0.350	-0.12	-0.140
	Aug	-0.9	-1.070	-0.43	-0.850	0.7	1.000	0.94	1.500
	Sep	-0.99	-1.000	-0.36	-0.790	1.78	1.810	1.52	1.850
	Oct	0.03	0.030	0.33	0.420	0.74	0.780	1.02	0.880
	Nov	-1.16	-0.060	-2.17	-0.130	0.39	0.000	0.47	0.030
	Dec	-1.64	0.000	-1.52	0.000	-0.55	0.000	-0.54	0.000
	Annual	-1.19	-3.450	-0.26	-1.100	0.05	0.420	0.75	2.360

TABLE 4

Trend statistics of monthly maximum and minimum air temperature obtained from the Innovative trend analysis (ITA)

	Dist.	Bankura			Birbhum			Jhargram			Paschim Bardhaman			Paschim Midnapore			Purulia		
	Month	slope	TI	CL(±)	slope	TI	CL(±)	slope	TI	CL(±)	slope	TI	CL(±)	slope	TI	CL(±)	slope	TI	CL(±)
Maximum air temperature	Jan	-0.006	-0.069	0.002	-0.003	-0.037	0.002	-0.008	-0.090	0.002	-0.003	-0.033	0.002	-0.008	-0.097	0.002	-0.004	-0.052	0.002
	Feb	0.008	0.086	0.002	0.008	0.087	0.002	0.006	0.064	0.002	0.009	0.100	0.002	0.006	0.070	0.002	0.009	0.095	0.002
	Mar	0.006	0.058	0.002	0.006	0.059	0.002	0.004	0.033	0.002	0.008	0.076	0.002	0.004	0.038	0.002	0.007	0.065	0.002
	Apr	-0.002	-0.019	0.004	-0.006	-0.047	0.004	-0.003	-0.027	0.004	-0.002	-0.020	0.003	-0.003	-0.029	0.004	-0.001	-0.012	0.003
	May	-0.007	-0.055	0.001	-0.006	-0.055	0.001	-0.008	-0.068	0.001	-0.006	-0.054	0.001	-0.007	-0.059	0.001	-0.007	-0.055	0.002
	Jun	0.006	0.055	0.001	0.006	0.056	0.001	0.005	0.041	0.002	0.006	0.052	0.002	0.006	0.055	0.002	0.005	0.044	0.001
	Jul	0.009	0.087	0.001	0.008	0.082	0.001	0.009	0.091	0.001	0.008	0.085	0.001	0.009	0.096	0.001	0.009	0.087	0.001
	Aug	0.009	0.094	0.002	0.009	0.095	0.001	0.008	0.085	0.001	0.010	0.097	0.001	0.009	0.092	0.001	0.010	0.101	0.001
	Sept	0.011	0.110	0.001	0.011	0.113	0.001	0.011	0.115	0.001	0.012	0.116	0.001	0.011	0.110	0.001	0.012	0.126	0.001
	Oct	0.013	0.133	0.002	0.014	0.140	0.002	0.011	0.118	0.002	0.014	0.142	0.002	0.011	0.117	0.002	0.015	0.154	0.002
	Nov	0.018	0.206	0.001	0.021	0.230	0.001	0.017	0.186	0.001	0.021	0.231	0.001	0.016	0.178	0.001	0.021	0.237	0.001
	Dec	0.010	0.119	0.001	0.011	0.129	0.001	0.008	0.102	0.001	0.011	0.137	0.001	0.008	0.099	0.001	0.012	0.152	0.001
	Annual	0.005	0.047	0.001	0.005	0.054	0.001	0.004	0.037	0.001	0.005	0.052	0.001	0.003	0.034	0.001	0.006	0.062	0.001
Minimum air temperature	Jan	0.005	0.134	0.002	0.006	0.152	0.002	0.003	0.076	0.002	0.007	0.182	0.002	0.003	0.073	0.002	0.007	0.181	0.002
	Feb	0.026	0.534	0.002	0.024	0.538	0.003	0.024	0.473	0.002	0.026	0.552	0.002	0.024	0.486	0.002	0.026	0.558	0.002
	Mar	0.021	0.331	0.002	0.019	0.329	0.002	0.018	0.281	0.001	0.022	0.354	0.002	0.019	0.291	0.001	0.021	0.346	0.001
	Apr	0.009	0.119	0.003	0.006	0.081	0.002	0.008	0.104	0.002	0.009	0.120	0.002	0.008	0.101	0.002	0.010	0.128	0.002
	May	0.009	0.112	0.002	0.009	0.113	0.002	0.009	0.104	0.001	0.009	0.111	0.002	0.010	0.118	0.002	0.009	0.111	0.002
	Jun	0.013	0.159	0.002	0.013	0.157	0.001	0.012	0.146	0.001	0.013	0.157	0.001	0.013	0.157	0.001	0.013	0.156	0.002
	Jul	0.009	0.117	0.001	0.009	0.114	0.001	0.010	0.123	0.002	0.009	0.117	0.001	0.010	0.121	0.001	0.010	0.126	0.002
	Aug	0.013	0.162	0.001	0.013	0.159	0.001	0.013	0.168	0.001	0.013	0.165	0.001	0.013	0.162	0.001	0.014	0.178	0.001
	Sept	0.010	0.124	0.001	0.010	0.126	0.001	0.011	0.138	0.001	0.011	0.135	0.001	0.010	0.124	0.001	0.012	0.154	0.001
	Oct	0.011	0.152	0.001	0.012	0.171	0.001	0.011	0.153	0.001	0.012	0.168	0.001	0.010	0.139	0.001	0.013	0.189	0.001
	Nov	0.016	0.310	0.002	0.015	0.300	0.002	0.018	0.337	0.001	0.016	0.326	0.002	0.016	0.296	0.002	0.019	0.378	0.002
	Dec	0.010	0.246	0.002	0.010	0.247	0.001	0.010	0.236	0.002	0.011	0.277	0.002	0.008	0.201	0.002	0.013	0.349	0.002
	Annual	0.012	0.178	0.001	0.011	0.178	0.001	0.012	0.173	0.001	0.012	0.177	0.001	0.011	0.159	0.001	0.013	0.203	0.001

estimator and ITA were observed for all the months. According to ITA, the highest increasing rate of T_{max} was observed in November (0.016- 0.021 °C per year) (Table 3). The direction of change obtained from the ITA was confirmed by the D-ITA but the D-ITA plots showed that the increasing or decreasing trends of T_{max} were unstable (Appendix Fig. A).

The results indicated a trendless time series for the T_{min} of January, April, May and December though the slopes and trend indicators exhibited positive values in all six districts (Table 3). The T_{min} of February and March was observed to follow a monotonic increasing trend. On the other hand, a non-monotonic positive trend of T_{min} during June and July was found. August T_{min} showed a monotonic declining trend while the September, October and November T_{min} showed a non-monotonic declining trend. It was observed that the higher values in the time series of November T_{min} followed no trend. The two halves of the time series were strongly correlated as obtained from the ITA. The annual rate of change of T_{min} did not show much variation from the rate obtained from the Sen's Slope estimator. The annual increasing rate of T_{min} was found to be the highest in Feb. (0.024- 0.026 °C per year) closely followed by March (0.018- 0.022 °C per year) and November (0.015-0.019 °C per year) (Table 3). From the D-ITA it was found that the T_{min} of July, August, September and October showed unstable monotonic positive trend. A stable monotonic positive trend was observed for the T_{min} of June month (Appendix Fig. B).

The ITA of the rainfall at monthly scale showed no trend for rainfall in January, February and March (Appendix Fig. C). It was found that very high and low

TABLE 5

Trend statistics of monthly, seasonal and annual rainfall obtained from the Innovative trend analysis (ITA)

Dist.	Bankura			Birbhum			Jhargram			Paschim Bardhaman			Paschim Midnapore			Purulia		
Month/ seasons	slope	TI	CL (±)	slope	TI	CL(±)	slope	TI	CL(±)	slope	TI	CL(±)	slope	TI	CL(±)	slope	TI	CL(±)
Jan	-0.001	-0.031	0.015	0.020	0.456	0.024	0.001	0.042	0.013	-0.002	-0.061	0.019	0.007	0.219	0.012	-0.010	-0.303	0.015
Feb	0.028	0.679	0.019	0.031	0.951	0.014	-0.018	-0.356	0.026	0.022	0.506	0.018	0.007	0.146	0.020	0.002	0.032	0.016
Mar	-0.014	-0.232	0.029	-0.003	-0.066	0.023	-0.048	-0.680	0.036	-0.004	-0.074	0.020	-0.024	-0.327	0.035	-0.016	-0.263	0.027
Apr	0.119	1.316	0.043	0.149	1.969	0.038	0.209	1.946	0.050	0.099	1.459	0.032	0.212	1.828	0.054	0.032	0.523	0.018
May	0.362	1.985	0.046	0.278	1.533	0.042	0.640	2.537	0.077	0.334	2.014	0.034	0.555	2.130	0.053	0.323	2.636	0.036
Jun	-0.102	-0.160	0.186	-0.084	-0.124	0.169	0.055	0.086	0.227	-0.135	-0.217	0.177	0.007	0.219	0.012	-0.119	-0.191	0.195
Jul	0.145	0.179	0.127	0.105	0.102	0.152	-0.018	-0.019	0.097	0.078	0.087	0.141	0.185	0.214	0.114	-0.378	-0.397	0.135
Aug	-0.150	-0.165	0.107	-0.261	-0.263	0.112	0.173	0.179	0.101	-0.286	-0.298	0.152	0.039	0.045	0.091	-0.198	-0.202	0.166
Sept	0.713	1.051	0.160	0.475	0.773	0.200	0.837	0.979	0.224	0.642	0.979	0.203	0.855	1.069	0.235	0.402	0.528	0.160
Oct	0.310	1.100	0.145	0.336	0.968	0.153	0.324	0.917	0.169	0.246	0.801	0.159	0.315	0.989	0.149	0.117	0.413	0.134
Nov	0.020	0.622	0.031	-0.022	-0.662	0.029	0.069	1.388	0.056	-0.013	-0.428	0.021	0.080	1.726	0.063	-0.012	-0.464	0.020
Dec	-0.001	-0.149	0.011	-0.016	-2.101	0.010	-0.003	-0.354	0.016	-0.016	-1.843	0.011	-0.002	-0.277	0.013	-0.009	-1.348	0.007
Monsoon	0.042	0.013	0.343	-0.279	-0.082	0.418	0.864	0.250	0.235	-0.280	-0.087	0.423	0.615	0.188	0.270	-0.697	-0.207	0.411
Post-monsoon	0.349	0.885	0.094	0.442	0.945	0.162	0.287	0.573	0.129	0.277	0.645	0.134	0.404	0.882	0.100	0.052	0.129	0.116
Pre-monsoon	0.407	1.194	0.086	0.380	1.214	0.060	0.730	1.647	0.091	0.353	1.224	0.063	0.713	1.543	0.117	0.242	0.961	0.058
Annual	0.798	0.208	0.335	0.543	0.130	0.380	1.881	0.428	0.232	0.351	0.089	0.432	1.732	0.413	0.262	-0.403	-0.100	0.363

TI: Trend indicator; CL: Confidence limit at 95% level

values of rainfall in April, May & September did not show any trend. Otherwise, a non-monotonic positive trend was found for April, May and September rainfall. June rainfall followed a non-monotonic decreasing trend and the negative slope values supported this trend in the four (Bankura, Birbhum, Paschim Bardhaman and Purulia) out of six districts. For the other months the rainfall time series was observed to be trendless. A non-monotonic rising trend was shown by the November rainfall. It was found that the higher values of rainfall increased in November. Rising trend of the July rainfall was observed in Bankura, Birbhum, Paschim Bardhaman, Paschim Midnapore districts. The slope values obtained from ITA showed that the September month's rainfall increased at the highest rate (0.402-0.855 mm per year) (Table 4). The monthly rainfall trends were found to be unstable as indicated by the D-ITA. Unstable negative trend was found for February, March & November rainfall.

Lower intensity pre-monsoon rainfall showed increasing trend while higher intensity pre-monsoon rainfall showed declining trend. The ITA indicated absence of any definite trend in the annual rainfall over Bankura and Birbhum districts. It was observed that the higher values of annual rainfall followed a rising trend over Jhargram and Paschim Midnapore districts. On the contrary, the high annual rainfall over Paschim Bardhaman and Purulia districts showed a declining trend. The ITA slope showed that pre-monsoon rainfall increased at the rate of 0.242- 0.730 mm per year (Table 4) over the red and lateritic zone. The instability of the non-monotonic rainfall trend at seasonal and annual scales was indicated by the D-ITA (Appendix Fig. D).

3.3. *Change points of air temperature and rainfall pattern*

In order to investigate the change points of air temperature and rainfall, three change point detection tests *viz*. Pettitt's test (Pt), Buishand's Range Test (BR) and Buishand U test (BU) were performed. The results so obtained have been summarized in the Table 5 and 6. It was observed that the BR test and BU test detected same year as the change point in the T_{max} series of every month (Table 6). For the time series of March and April, 2003 and 1970, respectively were found to be the change points over the red and lateritic zones of West Bengal. The year 2000 was detected as the change point (significant at 5% level) in the time series of September over all the districts except Jhargram where the BR and BU tests found 1997 as the change point. In case of October month, the year 1980 was identified as the change point by the BR and BU tests overall the six districts except Birbhum, Jhargramand Paschim Midnapore where 1973, 1978 and 1978,

TABLE 6

The Change points of monthly maximum and minimum air temperature using Pettitt's test (Pt), Buishand's Range Test (BR) and Buishand U test (BU)

	Dist.	Bankura			Birbhum			Jhargram			Paschim Bardhaman			Paschim Midnapore			Purulia		
	Month	Pt	BR	BU	Pt	BR	BU	Pt	BR	BU	Pt	BR	BU	Pt	BR	BU	Pt	BR	BU
Maximum air temperature	Jan	1973	2010	2010	2010	2010	2010	1973	2010	2010	1965	2010	2010	1973	2010	2010	1973	2010	2010
	Feb	2000	2000	2000	1969	2000	2000	1970	2000	2000	1997	1997	1997	1970	2000	2000	2000	2000	2000
	Mar	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003
	Apr	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970	1970
	May	1970	1972	1972	1970	1972	1972	1970	1972	1972	1972	1970	1970	1970	1972	1972	1972	1970	1970
	Jun	2008	2008	2008	2004	2008	2008	2008	2008	2008	2008	2008	2008	1994	2008	2008	2008	2008	2008
	Jul	1990	2008	2008*	2008	2008	2008*	1990	2008	2008*	2008	2008	2008	1990	1990	1990*	1990	2008	2008
	Aug	2002*	1999*	1999*	2002*	1999*	1999*	1984*	1984	1984*	1999*	1999*	1999*	1984*	1984*	1984*	1999*	1999*	1999*
	Sept	2000*	2000*	2000*	2000*	2000*	2000*	2000*	1997*	1997*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*
	Oct	1980*	1980*	1980*	1973*	1980*	1980*	1978*	1980*	1980*	1980*	1980*	1980*	1978*	1980*	1980*	1980*	1980*	1980*
	Nov	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*	1975*
	Dec	1997	1997	1997	1997	1997*	1997	1997	1997	1997	1997	1997	1997	1997*	1997*	1997*	1997*	1997*	1997*
Minimum air temperature	Jan	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978	1978
	Feb	1986*	1986*	1986*	1986*	1987*	1987*	1986*	1986*	1986*	1986*	1986*	1986*	1986*	1986*	1986*	1986*	1986*	1986*
	Mar	1984*	1982	1982*	1982*	1982	1982*	1984	1984	1984	1982*	1982*	1982*	1984	1984	1984*	1984*	1982	1982*
	Apr	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998
	May	1993	1993	1993	1993	1993	1993	2000	1993	1993	1994	1993	1993	1994	1993	1993	1994	1993	1993
	Jun	2001*	2001*	2001*	2001*	2001*	2001*	2001	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001	2001*	2001*
	Jul	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*	2001*
	Aug	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*
	Sept	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*	2000*
	Oct	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*	1997*
	Nov	1972*	1972*	1972*	1972*	1972*	1972*	1972*	1972*	1972*	1975*	1972*	1972*	1972*	1972*	1972*	1975*	1975*	1975*
	Dec	1977*	1977*	1977*	1977*	1977*	1977*	1977*	1977*	1977*	1977*	1977*	1977*	1977	1977	1977	1977*	1977*	1977*

*significant at 95% level

respectively were identified as the change point by the Pt test. The year 1975 was detected as the significant change point in the November time series of T_{max} over the entire red & lateritic zone. On the other hand, 1997 was shown as the change point in the December time series. In case of T_{min} of January, all the three change detection tests confirmed the year 1978 as the change point though the result was not significant. For February month, T_{min} pattern changed in the year 1986 over five (except Birbhum) out of six districts under study. It was found that the pattern of T_{min} in June & July significantly shifted after 2001 while the pattern of T_{min} in August & October significantly shifted after 1997. The years 2000, 1972 & 1977 was identified as the change point in the time series of September, November & Dec., respectively (Table 6).

Considering the monthly time series of rainfall, different change points were obtained over different districts. It was observed that the rainfall pattern of January changed after 1998 (Table 7). On the other hand, the rainfall pattern of February also changed after 1998 in five (except Birbhum) out of six districts of the study zone. In case of May rainfall, 1972 was detected as the change point over the stud area except in Purulia where 2005 was detected as the change point. The change point analysis over the seasonal rainfall showed that the monsoon rainfall pattern changed after 2005 in Jhargram, Paschim Midnapore and Purulia districts and after 1967 in Birbhum districts as confirmed by all the three change point detection tests. It was evident from the results that the post-monsoon rainfall pattern over the red and lateritic zone of West Bengal shifted after 2004. Considering the pre-monsoon rainfall pattern, the year 1971 was identified as the change point in Birbhum and Paschim Midnapore districts. On the other hand, the year 1974 was detected as the change point for pre-monsoon rainfall pattern over Paschim Bardhaman district. The annual rainfall pattern shifted after 1967 over Bankura, Birbhum, Paschim

TABLE 7

The Change points of monthly, seasonal and annual rainfall using Pettitt's test (Pt), Buishand's Range Test (BR) and Buishand U test (BU)

Dist.	Bankura			Birbhum			Jhargram			Paschim Bardhaman			Paschim Midnapore			Purulia		
Month/ seasons	Pt	BR	BU	Pt	BR	BU	Pt	BR	BU	Pt	BR	BU	Pt	BR	BU	Pt	BR	BU
Jan	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998
Feb	1998	1998	1998	1998	1975	1975	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998	1998
Mar	1977	2005	2005	1977	2005	2005	1983	2005	2005	1977	2005	2005	2005	2005	2005	1977	1966	1966
Apr	1980	1980	1980	1980	1980	1980	1976	2011	2011	1980	1980	1980	1980	1980	1980	1975	2010	2010
May	1972	1972	1972*	1972	1972	1972*	1975	1972	1972*	1972	1972	1972*	1972	1972	1972*	2005	2005	2005*
Jun	1987	1996	1996	1987	1967	1967	1983	1983	1983	1987	1996	1996	1983	1983	1983	1976	1994	1994
Jul	1973	1973	1973	1967	1967	1967	1993	1992	1992	2014	1967	1967	1973	1973	1973	1990	1990	1990
Aug	1972	1972	1972	1972	1972	1972	2005	2005	2005	1972	1972	1972	2005	2005	2005	1972	1972	1972
Sept	2003	2003	2003	1960	1968	1968	2003	2003	2003	2005	2005	2005	2003	2003	2003	2003	2005	2005
Oct	1975	2016	2016	1964	1964	1964	1975	2016	2016	2004	1964	1964	1975	2016	2016	2004	2016	2016
Nov	2003	2003	2003	2003	2003	2003	2003	1985	1985	2003	2003	2003	2003	1985	1985	2003	2003	2003
Dec	1991	1972	1972	1976	1972	1972	1976	1972	1972	1976	1972	1972	1976	1972	1972	1991	1972	1972
Monsoon	2005	1967	1967	1967	1967	1967	2005	2005	2005	2005	1967	1967	2005	2005	2005	2005	2005	2005
Post-monsoon	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004	2004
Pre-monsoon	1971	1974	1974	1971	1971	1971	1995	1974	1974	1974	1974	1974	1971	1971	1971	1995	1975	1975
Annual	1967	1967	1967	1967	1967	1967	1983	1983	1983	1967	1967	1967	1967	1967	1967	2005	1967	1967

*significant at 95% level

Bardhaman and Paschim Midnapore districts as confirmed by all the three change detection tests. Over Jhargram districts, annual rainfall pattern shifted after the year 1983.

4. Discussion

The historical trend of maximum and minimum air temperature at monthly scale and rainfall at monthly, seasonal and annual scale were detected in the present study using MK test, Sen's slope estimator and ITA. Both the MK test and ITA confirmed the increasing trend of T_{max} and T_{min} in June. Although, the pre-monsoon rainfall showed increasing trend during the last six decades under study (1958-2021) the total pre-monsoon rainfall accounted for only 6-12% of the total annual rainfall over the entire region. Considering the monthly scale, the rainfall in June showed non-significant increasing trend in MK test while it showed decreasing trend in ITA. The rising temperature of June might be attributed to the decreasing rainfall (Mukherjee and Bannerjee, 2009). The combined effect of increased temperature and decreased rainfall causes meteorological drought. Goswami (2017) reported the maximum occurrence of meteorological drought in June month over Bankura district during 1910-2009 period. Further, the meteorological drought occurred in June was reported to follow a rising trend. Limited water conservation measures might cause increased drought. Das *et al*. (2013) estimated about 29- 40% and 19- 65% of the total geographical area of Bankura district as the moderate and severe drought area, respectively during 2000- 2010 period. It was also stated that the undulating topography with dry climate, industrialization, lack of natural water resources made a major part of the Bankura district vulnerable to the agricultural drought. Bhunia & Maiti, 2014 reported that mild drought condition occurred once in three years over Bankura district during 1885-2013 period.

The present study revealed that the South-west monsoon caused the maximum rainfall during July-September period and accounted for 77- 83% of the annual rainfall which was in closed agreement with the findings of Bera, 2016. The occurrence of meteorological drought in August and September was less frequent due to rising trend of rainfall (Goswami, 2017). The present study identified a changed monsoon behaviour associated with declining post-monsoon rainfall and significantly increasing pre-monsoon rainfall. Monsoon rainfall was observed to follow non-significant rising trend. ITA showed declining trend of June rainfall and rising trend of October rainfall in the northern and central part of the red and lateritic zone (Bankura, Birbhum, Paschim Bardhaman and Purulia). Sometimes, the delayed onset and cessation of the South-west monsoon was associated with the mid-season break as detected by the declining August rainfall. The shift of rainfall distribution pattern in the study area was confirmed by Mukherjee and Bannerjee (2009). Jhargram and Paschim Midnapore districts received comparatively more rainfall due to the geographical nearness to the Bay of Bengal. The rising trend of pre-monsoon rainfall was also reported in the adjoining Odisha state (Prabhakar *et al*., 2018). The study area receives rainfall during November mainly due to the post - monsoon cyclones formed over the Bay of Bengal (Bhardwaj and Singh, 2020).

The result clearly stated that the red and lateritic zones experienced significant temperature rise during the last six decades. The rising trend of air temperatures over the red and lateritic zone was reported by Mukherjee and Bannerjee (2009) who identified the increasing trend of minimum temperature observed at different weather stations in the red and lateritic zone. Increased relative humidity and decreased insolation cause decrease in evapotranspiration which leads to the increase in the atmospheric moisture content. Moisture absorbs the insolation and counter radiation and thus the air temperature increases (Choudhury *et al*., 2012). The trends of maximum and minimum air temperature varied among different months. Maximum air temperature decreased in pre-monsoon months while increased significantly in the post-monsoon months. On the contrary, minimum air temperature significantly increased in all the months. Considering the annual scenario, both the average maximum and minimum temperature increased during the study period showing a clear indication of global warming in the last six decades in the Red and Laterite zone of West Bengal. Annual rise in the minimum air temperature was observed over Kolkata also which was closely confirmed by Naskar (2022).

In the present study, ITA was able to detect the positive trend of higher rainfall in November. Double ITA clearly detected the stability and instability of the air temperature and rainfall. It was demonstrated that ITA and D-ITA provide more in-depth information about the trend in any time series data as compared to the fully MK and partial MK tests, respectively (Güçlü *et al*., 2018).

The present study identified the break points of temperature and rainfall change. Temperature in most of the months showed similar results in different tests though dissimilarities were also observed among the results obtained from different tests. Similar findings were reported from other parts of India (Jaiswal *et al*. 2015; Machiwal *et al*. 2016). Chakraborty *et al*. (2017) demonstrated that the steady increase in the concentration of greenhouse gases and alteration of land use might cause the break in the trend of air temperature in a given region. The changes in the trend of air temperature after 1970 over India due to increased greenhouse gas concentration were reported by.

5. Conclusions

The incidence of warming over the entire region was evident from the present study which revealed the significant increasing trend of maximum and minimum air temperature during the last six decades over the Red and Laterite zone of West Bengal.

Maximum temperature notably decreased in the months of April and May and increased in November. Minimum temperature notably increased in the months of February, March and November

Although the total annual rainfall did not follow any significant trend, the intensity and distribution pattern of monthly and seasonal rainfall was changed.

A shift of the South-west monsoon was realized over the study zone.

Summer season minimum air temperature increased while maximum air temperature declined. However, annual mean minimum air temperature significantly increased.

The air temperature and rainfall trends were found to be mostly unstable as detected by the D-ITA.

Based on the findings, the present study suggests some necessary actions to be taken to adapt and mitigate the changing climatic conditions. Importance must be given in the rain water harvesting to store the excess rainfall and use in the dry period. The crops and cultivars should be selected carefully so that the crops can cope with the changed weather pattern. Crops having low water requirement are to be selected during winter season as the post-monsoon rainfall cannot meet the ET demand. More attention should be paid on the summer season crop production because the increased rainfall in the months of April and May can damage the crop. Cropping window must be adjusted according to the changed pattern of the weather variables. Various types of water conservation technologies like zero tillage, mulching, micro-irrigation etc. may be adopted in the crop fields. Finally, the results of the present study can be used for assessing the future trend of the weather parameters and planning and sustainable management in this climatologically and socio-economically vulnerable zone.

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Authors' contributions

Argha Ghosh: Conceptualized the research, analyzed the data, wrote, reviewed and edited the manuscript.
Dillip Kumar Swain: Planned and conceptualized the research and reviewed the manuscript.
Chandraprakash: Reviewed and edited the paper.
Suchismita Tripathy: Reviewed and edited the paper.

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Appendix

TABLE A

Descriptive statistics of monthly maximum and minimum temperature and monthly and seasonal rainfall over different districts

Parameters	Districts	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Maximum temperature (°C)	Bankura	25.9 (3.9)	29.4 (4.7)	34.8 (3.2)	38.5 (3.3)	37.6 (2.6)	35.4 (2.7)	32.0 (1.8)	31.8 (1.4)	31.9 (1.6)	31.1 (2.3)	28.7 (2.8)	26.2 (3.4)
	Birbhum	25.8 (3.9)	29.0 (4.9)	34.2 (3.4)	38.0 (3.5)	36.8 (2.7)	34.9 (2.6)	32.4 (1.8)	32.1 (1.5)	32.3 (1.6)	31.5 (2.3)	29.1 (2.8)	26.4 (3.5)
	Jhargram	26.8 (3.8)	30.1 (4.5)	34.9 (3.1)	38.0 (3.2)	37.8 (2.4)	35.0 (2.7)	31.8 (1.9)	31.7 (1.4)	31.8 (1.6)	31.1 (2.2)	29.1 (2.7)	26.8 (3.1)
	Paschim Bardhaman	25.7 (3.9)	29.1 (4.8)	34.7 (3.3)	38.8 (3.4)	38.3 (2.6)	35.7 (2.7)	32.2 (1.8)	31.9 (1.4)	32.1 (1.6)	31.4 (2.3)	28.9 (2.8)	26.2 (3.5)
	Paschim Midnapore	26.5 (3.8)	29.7 (4.6)	34.4 (3.2)	37.4 (3.3)	36.6 (2.5)	34.6 (2.7)	31.8 (1.9)	31.8 (1.4)	32.0 (1.7)	31.2 (2.2)	29.1 (2.7)	26.8 (3.2)
	Purulia	25.6 (3.8)	29.1 (4.7)	34.6 (3.2)	38.9 (3.3)	39.3 (2.5)	35.8 (2.9)	31.6 (1.9)	31.3 (1.4)	31.6 (1.6)	30.8 (2.2)	28.3 (2.8)	25.9 (3.3)
Minimum temperature (°C)	Bankura	12.4 (6.8)	15.8 (6.2)	20.3 (4.9)	24.4 (3.7)	26.6 (3.1)	26.0 (2.6)	25.6 (1.9)	25.7 (1.9)	25.1 (2.0)	22.5 (3.5)	16.7 (6.6)	13.0 (6.8)
	Birbhum	11.7 (7.0)	14.7 (6.8)	18.9 (5.2)	23.5 (3.9)	25.7 (3.2)	26.0 (2.4)	25.9 (1.8)	25.9 (1.9)	25.3 (2.0)	22.5 (3.6)	16.5 (6.5)	12.7 (7.2)
	Jhargram	13.2 (6.7)	16.7 (5.8)	21.0 (4.7)	25.0 (3.5)	26.8 (2.2)	26.4 (2.6)	26.0 (2.0)	25.9 (2.0)	25.6 (2.0)	23.0 (3.3)	17.1 (6.7)	13.3 (6.7)
	Paschim Bardhaman	12.2 (6.8)	15.5 (6.5)	20.0 (5.0)	24.4 (3.7)	26.5 (3.2)	26.2 (2.6)	25.7 (1.9)	25.7 (1.9)	25.2 (2.0)	22.5 (3.6)	16.4 (6.7)	12.7 (7.1)
	Paschim Midnapore	13.1 (6.6)	16.4 (5.9)	20.7 (4.7)	24.6 (3.6)	26.4 (3.0)	26.3 (2.5)	25.9 (2.0)	26.0 (1.9)	25.6 (2.0)	23.1 (3.3)	17.4 (6.5)	13.6 (6.5)
	Purulia	12.1 (7.0)	15.5 (6.3)	20.1 (5.0)	24.4 (3.7)	26.5 (3.2)	26.0 (2.9)	25.1 (2.1)	25.1 (2.0)	25.0 (2.0)	21.9 (3.6)	16.1 (6.9)	12.5 (7.1)

Rainfall (mm)	Bankura	9.6 (99.7)	13.6 (93.6)	18.7 (90.2)	30.8 (68.0)	64.1 (41.5)	201.7 (39.6)	261.6 (28.8)	287.4 (23.2)	228.6 (36.0)	95.1 (58.2)	10.7 (125.9)	2.0 (184.6)
	Birbhum	14.1 (99.8)	10.9 (90.1)	15.4 (89.9)	26.6 (66.3)	62.5 (39.7)	216.8 (38.5)	333.8 (27.1)	313.3 (24.9)	204.2 (33.0)	116.2 (60.3)	10.3 (128.2)	2.1 (173.2)
	Jhargram	10.4 (104.3)	16.2 (93.1)	21.7 (94.3)	37.8 (69.7)	91.0 (45.0)	206.1 (37.3)	299.0 (25.5)	310.8 (22.1)	287.1 (30.8)	118.1 (53.9)	17.1 (123.6)	2.7 (186.8)
	Paschim Bardhaman	11.4 (98.8)	14.0 (91.7)	15.2 (91.7)	23.2 (70.2)	58.4 (44.0)	197.1 (40.6)	291.1 (28.6)	303.0 (24.0)	220.1 (34.3)	102.1 (60.0)	9.7 (123.7)	2.5 (168.3)
	Paschim Midnapore	10.7 (104.9)	16.0 (95.5)	22.8 (93.9)	40.5 (70.6)	92.3 (42.8)	213.0 (38.4)	279.2 (28.3)	280.4 (23.0)	269.4 (34.6)	106.9 (54.2)	16.1 (129.3)	2.2 (191.5)
	Purulia	10.3 (93.1)	15.5 (89.6)	19.5 (90.1)	19.8 (70.9)	44.4 (52.6)	197.2 (42.0)	298.5 (26.9)	309.4 (22.4)	250.3 (31.2)	92.9 (57.8)	8.3 (114.1)	1.9 (156.2)

Seasonal and annual rainfall (mm)		Monsoon		Post-monsoon		Pre-monsoon		Annual	
	Bankura	975.7	(15.1)	129.4	(42.2)	114.4	(36.1)	1219.4	(12.9)
	Birbhum	1067.5	(15.8)	153.1	(46.1)	105.1	(34.6)	1325.7	(13.7)
	Jhargram	1100.5	(13.4)	161.8	(39.5)	151.6	(36.1)	1413.9	(11.7)
	Paschim Bardhaman	1008.2	(15.8)	138.9	(44.0)	97.4	(37.4)	1244.5	(13.7)
	Paschim Midnapore	1038.8	(14.5)	150.1	(39.4)	156.7	(36.9)	1345.6	(12.5)
	Purulia	1053.1	(14.8)	127.4	(42.1)	84.3	(42.6)	1264.7	(13.1)

The values in the parenthesis represent the CV (%) values.

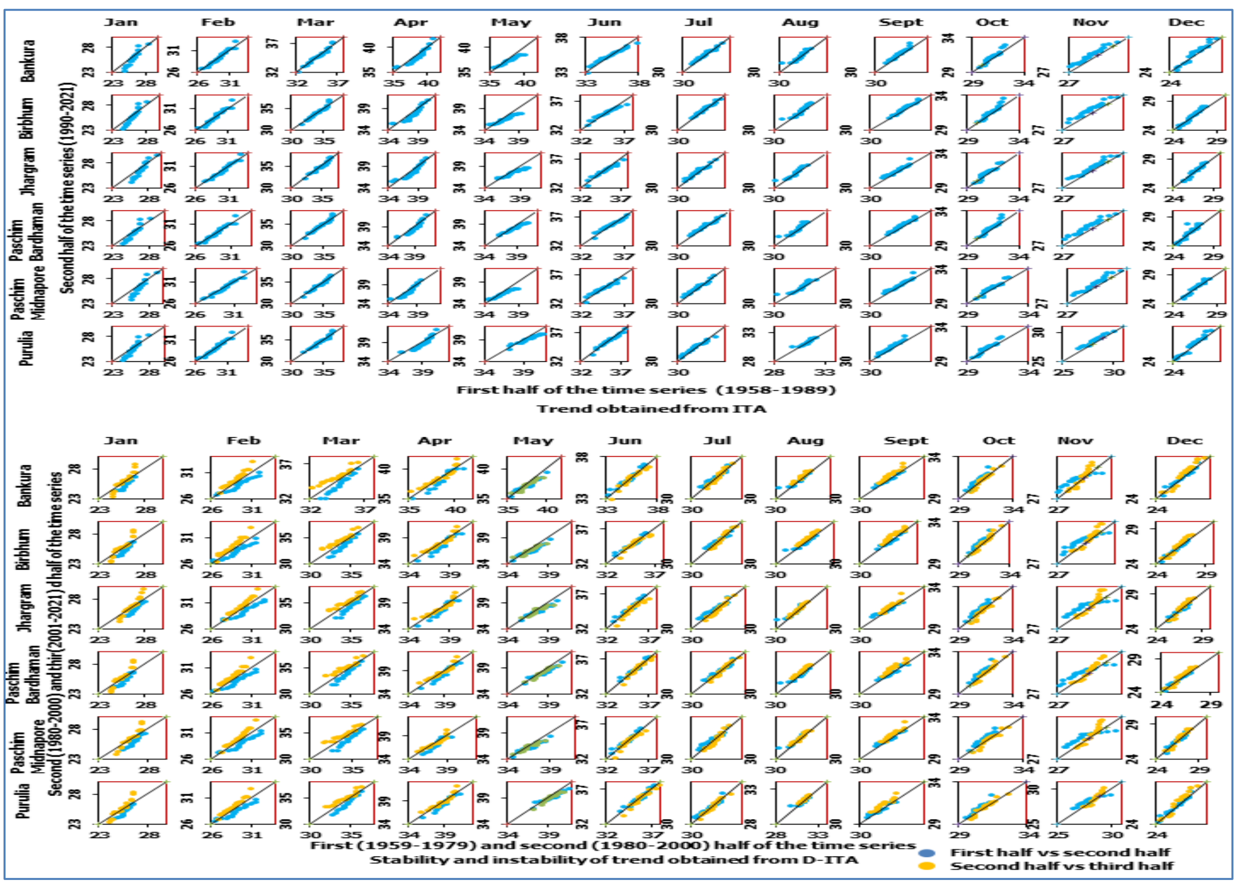

Fig. A. The ITA and D-ITA plots of monthly maximum air temperature (°C) over the red and laterite zone

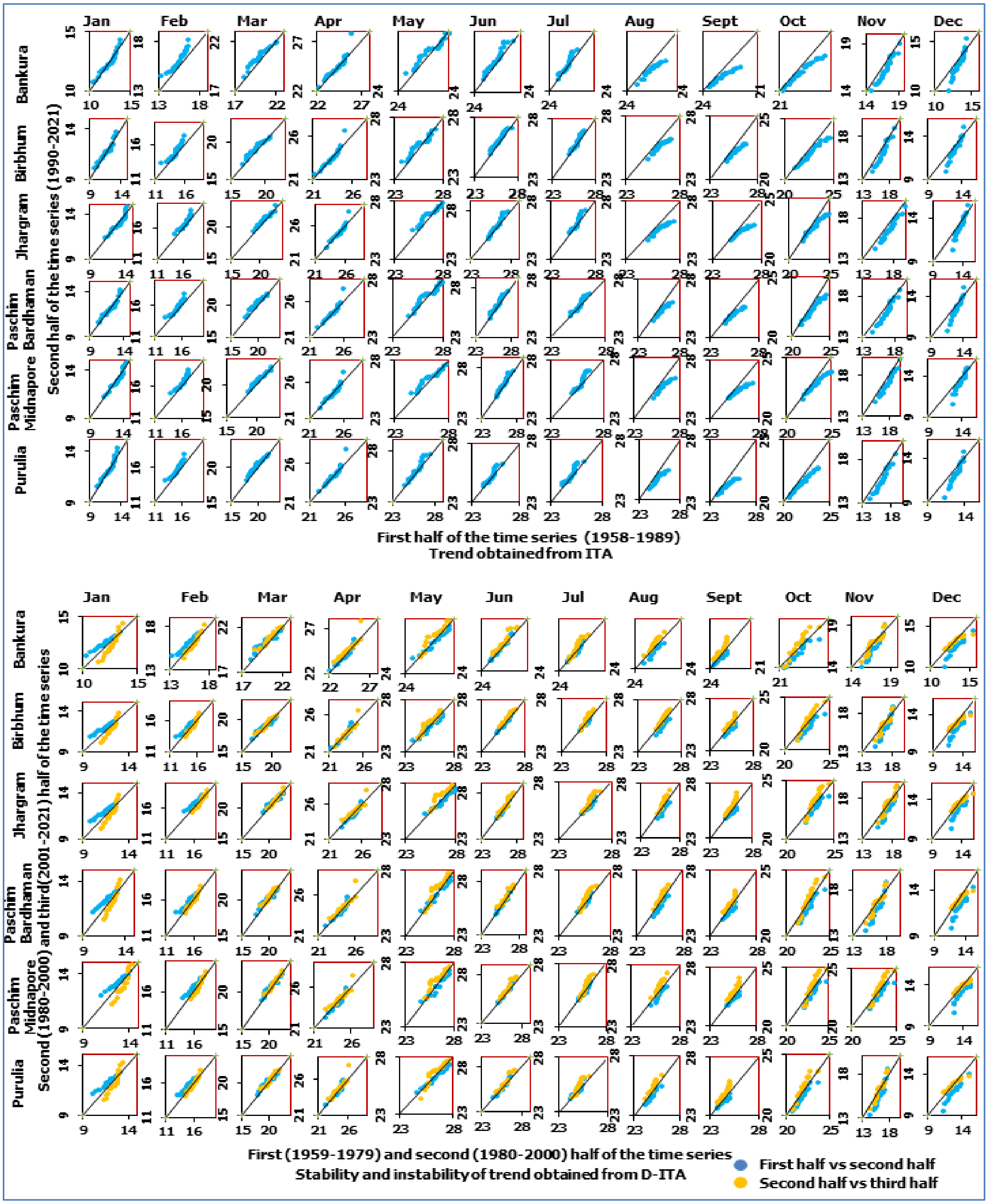

Fig. B. The ITA and D-ITA plots of monthly minimum air temperature (°C) over the red and laterite zone

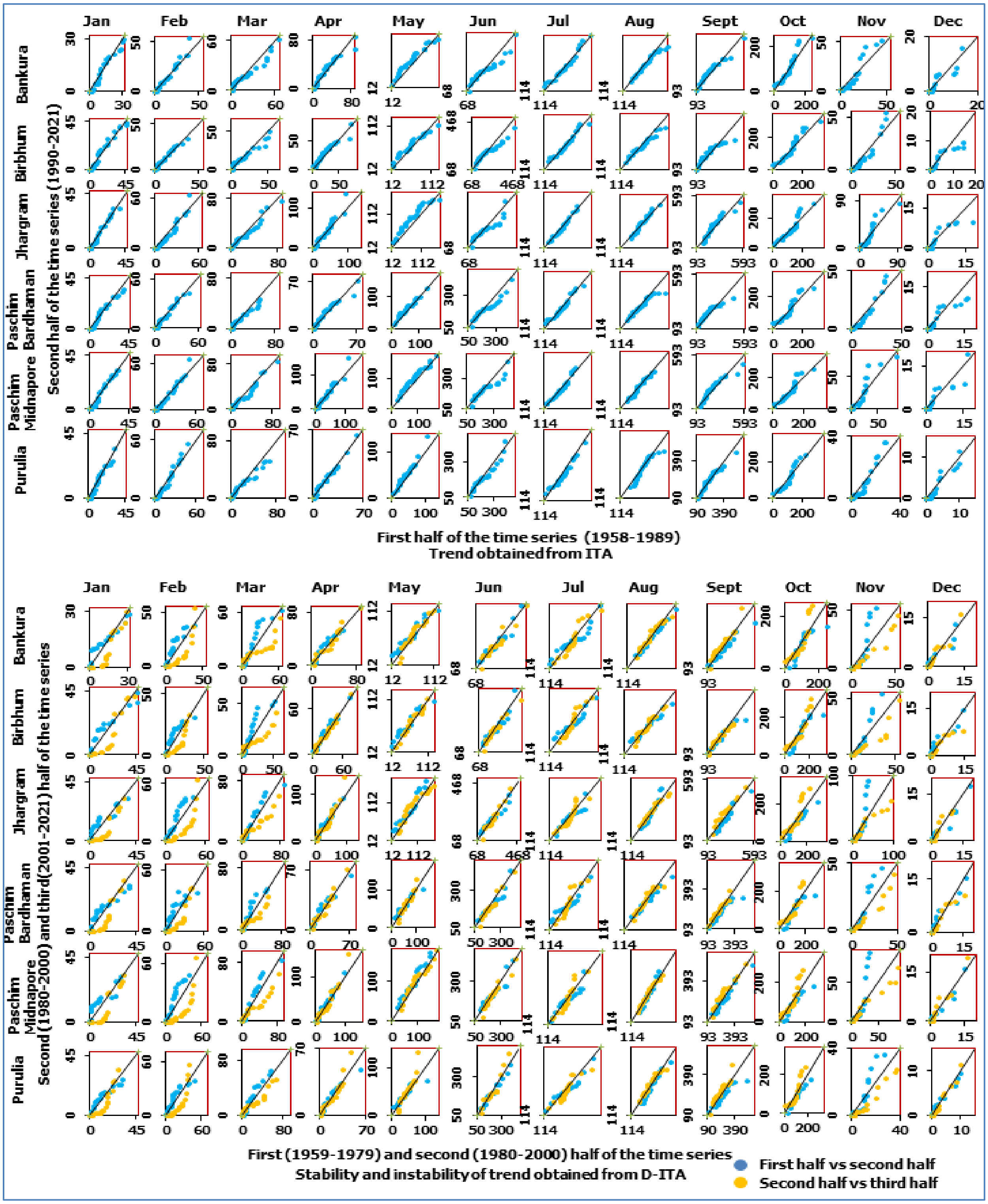

Fig. C. The ITA and D-ITA plots of monthly rainfall (mm) over the red and laterite zone

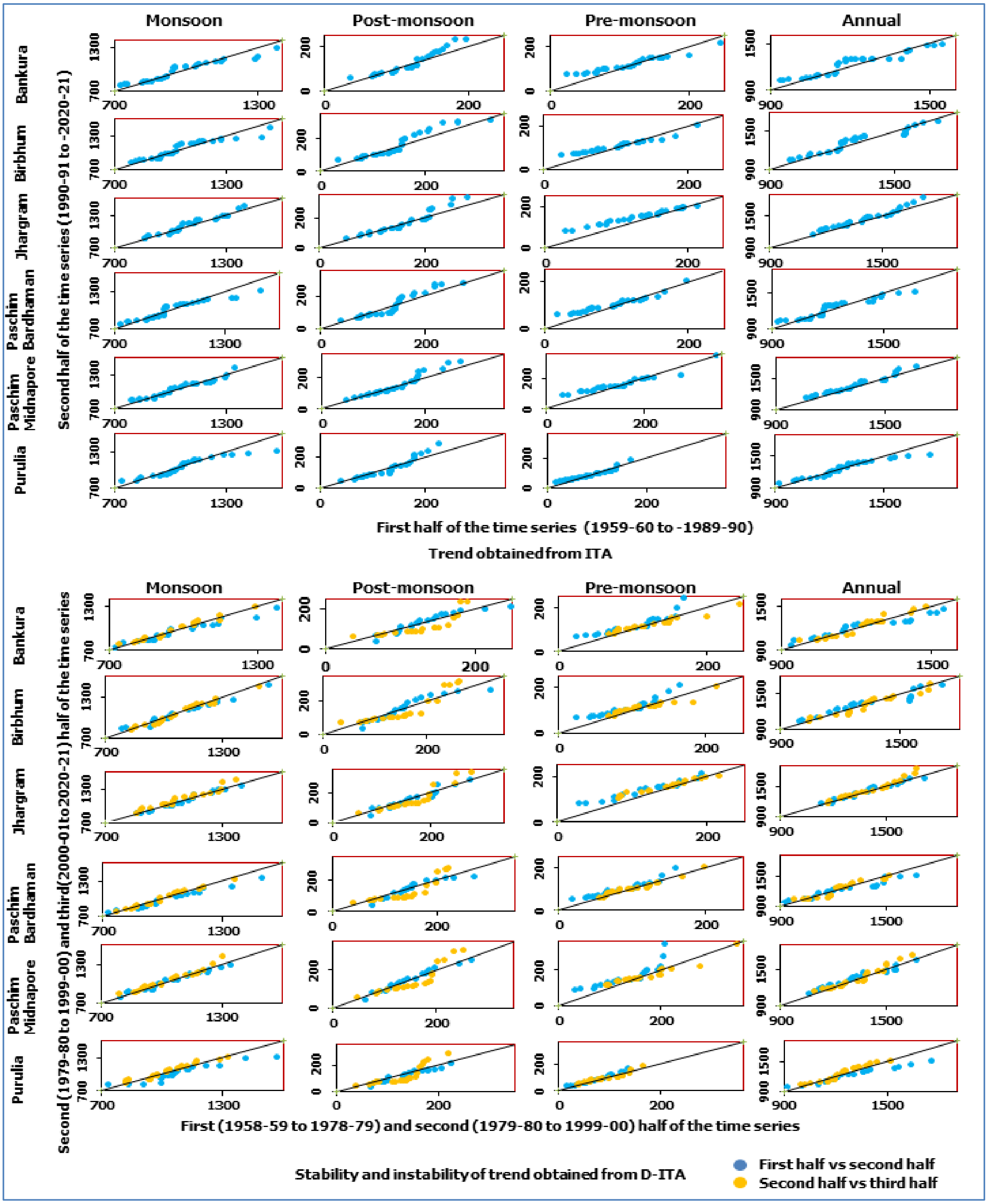

Fig. D. The ITA and D-ITA plots of seasonal and annual rainfall (mm) over the red and laterite zone