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Analysis of Rainfall Trend along with Change-point: Study on Purulia District, West Bengal, India

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Abstract

Although, the rainfall and scarcity of rainfall is critically important issue for the Purulia; but the analysis of rainfall is far from the proper conclusive statement till date. In this research, an attempt has been made to analyze the annual and seasonal rainfall trends along with the change point of annual rainfall in the Purulia District for 35 years (1979 to 2013) using the monthly rainfall data of seven meteorological stations. The Mann-Kendall test was used to identify the trend in rainfall data and Theil-Sen's slope estimator was utilized to assess the magnitude of trend. Trend-free pre-whitening method was used to eliminate the influence of significant lag-1 correlation from the series. Change in magnitude was derived in terms of percentage change over mean rainfall. The Pettitt and Lanzante test had been used in the annual rainfall series to identify the most probable change point for the series of annual rainfall. After analysis, a significant trend was found at one station in annual rainfall. The seventh, fifth and third stations were identified with the highest positive change in magnitude for the annual, pre-monsoon, monsoon and post-monsoon series respectively. The highest negative change was portrayed in the first station during the Winter phase. The most probable change point was identified at 1987-1988 for all meteorological stations. In the pre-change point phase, the highest positive change was found in the southern sections and the lowest positive change was marked in the northern portions of the study area. In contrary, completely a reversed scenario was marked in the post change point phase. Therefore, it can be concluded that the tendency of rainfall was shifted in the northern portions after the change point. The findings presented in this research can be a helpful tool for the planners to strategize local level agricultural planning of the Purulia District.

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1. Introduction

The changing pattern of the rainfall (or precipitation) in the context of climate change has substantial impact on a region's socioeconomic situation (Arnell et al., 2016). Precipitation often fluctuates in time and space as a result of anthropogenic causes (Malik & Kumar, 2020). Indian agriculture, is heavily reliant on rains provided by the southwest monsoon (Das, Akhtar, Dutta, & Meher, 2015). In India, the monsoonal rainfalls are crucial for irrigation during months of low rainfall as well as for agricultural production during the monsoon season. The "Indian summer monsoon," a crucial part of the Asian monsoon system, is renowned for its' wide range of variability in diurnal, interannual and decadal, time scales (Rajeevan, Gadgil, & Bhate, 2010). Additionally, India's interannual monsoon rainfall variability causes widespread droughts and floods, having a significant impact on the nation's food grain output and economy (Mirza, 2011)**.** Therefore, the fate of Indian farmers would be directly impacted by variations in monsoon seasons.

Researchers have recently been concentrating more on the analysis of rainfall variability at various spatiotemporal scales. Chakraborty, Pandey, Chaube & Mishra (2013) analyzed the spatiotemporal variability of rainfall trends of Chhattishgarh state, India for 49 years (1960-2008). Overall, downward trend was detected for annual and seasonal rainfalls. The inter-annual variation of rainfall was detected as 22%. Huang, Sun and Zhang (2013) identified upward trends of rainfall (in Jiangxi Province, China) during the winter and summer, while significant falling (declining) trends were detected throughout October. Bari, Rahman, Hoque and Hussain (2016) discovered a downward seasonal rainfall trend (in Bangladesh) for the majority of the stations in the early 1990s using the sequential Mann-Kendall test. Numerous research work on the trend of rainfall in India showed that there was either a declining or an increasing tendency of annual and seasonal rainfall in different regions of the nation. Malik and Kumar (2020) analysed the rainfall trends of 13 districts of the Uttarakkhand state. The spatial variation was tested for the annual and seasonal time series data. By applying the Theissen Polygon method the authors plot the data in GIS platform and found decreasing trend for the annual series and increasing trend for the Winter series for almost all meteorological stations. Sinha, Nageswarao, Dash, Nair and Mohanty (2019) found a significant decreasing trend (at every season) for rainfall (across India). While analyzing the spatio-temporal trend and concentration of monsoon precipitation time series in the state of West Bengal, India, from 1901 to 2002, Chatterjee, Khan, Akbari and Wang (2016) discovered a monotonic trend with increasing precipitation in the state's mountain and coastal regions. Additionally, the monsoon arrives in the North Bengal before South Bengal, where the rainfall becomes dispersed more evenly in the North Bengal. They concluded that the monsoon rainfall trend in the Gangetic West Bengal corresponds to the pattern of India. More importantly, they stress over the micro-level assessment of the rainfall trend, which was missing in the previous pieces of literature. Further, at the micro-level, the change point assessment produces a quick overview of the variability of the rainfall trend. In previous pieces of literature, such an approach is completely missing. Therefore, the analysis of rainfall trends along with the change point in the Purulia District is a noble attempt.

Researchers from all around the world have frequently used both parametric and nonparametric tests to pinpoint the direction, size, and change point of trends in hydrologic and meteorological variables. When the hydrological data series deviates from the normal distribution, the nonparametric test performs better than the parametric one (Totaro, Giaoia, & lacobellis, 2020). Mondal, Khare and Kundu (2015) utilized the rainfall data for 141 years (1871-2011) to analyze the trend of the rainfall over India. The decreasing annual and monsoonal rainfall trend was discovered by the authors in several portions of India. The long-term spatio-temporal changes of the rainfall (1901-2015) trend was analyzed by Praveen et al. (2020) by using the MK test and Sen's slope. They found significant increasing rainfall trend during the period of 1901 to 1950 and a significant declining trend was detected after 1951, especially for the eastern portions of the country. Radhakrishnan, Sivaraman, Jena, Sarkar and Adhikari (2017) evaluate the rainfall pattern all over the India during 1901 to 2015 using the Mann-Kendal test and Sen's Slope. The yearly and summer rainfall were found with a significant downward trend over the past 30 years. In addition, there comparatively less variations were identified for the annual, summer, and monsoon rainfall and the winter and post-monsoon seasons were detected with comparatively more variability. This study found that rainfall was decreasing quickly, especially in the last 30 years. Saini et al. (2020) used innovative trend analysis and Sen's slope to detect the tendency of rainfall in the East coast plain of India. Results show that January, July, August, September, as well as the Winter season, have positive rainfall trends. Rainfall decreased between January and July, which was the only noteworthy trend. All of the seasons obtained monotonic trends but the July was noticed with the highest trend magnitude. While the winter season exhibited a monotonically dropping rainfall pattern with relatively low magnitudes, the months of August and September, which together account for 30% of the annual rainfall, exhibited an increasing monotonic trend with large amplitude. The rainfall trend of Central India was investigated by Sanikhani, Kisi Mirabbasi and Meshram (2018) by using the innovative MK test and Sen's slope. The findings of the ITM test showed that the majority of the stations have declining trends in the annual, summer, and monsoon seasons, whereas the winter and post monsoon seasons generally show a rising tendency. Saha, Chakraborty, Paul, Samanta and Singh (2018) analyzed the disparity of the rainfall trend across India for 158 years. Along with a rising tendency over southern peninsular India, the north mountainous region of India had a substantial declining wetness trend. The findings of this investigation confirmed that India's rainfall anomaly exhibits substantial spatial variability. Further, for complete and efficient understanding they stressed over the micro level assessment of trend of hydrometeorological variables., which is still absent in previous literatures.

Therefore, it will be highly beneficial to study on the spatiotemporal rainfall patterns in the sub-regional and local scales. More importantly, estimation of change point at the micro level is missing in the recent literatures. Therefore, the objective of the research is as follows:

A) to assess the spatiotemporal rainfall trends in the annual, monsoon, pre-monsoon, post monsoon and winter phases in the Purulia District and,
B) And to estimate the change point and percentage change of the rainfall trend.

2. Study area

Purulia is one of the westernmost districts of West Bengal and it is an extended tract of Rarh terrain (Ghosh, Bandyopadhyay & Jana, 2016). This region is affected by the shortage of precipitation and due to the poor water holding capacity of the soil, 50% of its precipitation passes away as runoff (Bhunia, Das & Maiti, 2020). Average annual precipitation varies between 1100 to 1500 mm within Purulia. 75% to 90% relative humidity is observed in the monsoon season. According to SAFE (2011), Purulia was the worst hit by scanty rainfall, and agricultural production was falling by 27% in the year 2010. Due to the scanty rainfall, around 280,000 hectares of agricultural land were lying vacant during 2010-2011. Most of the families of Purulia (almost 70-75%) were dependent upon the paddy cultivation and the abrupt decreasing rainfall of 2010 had put an end to their only means of livelihood (Palchaudhuri & Biswas, 2016). Therefore, an assessment of the trends of rainfall with respect to its' change points is desperately needed here. Figure 1 depicts the location map of the study area.

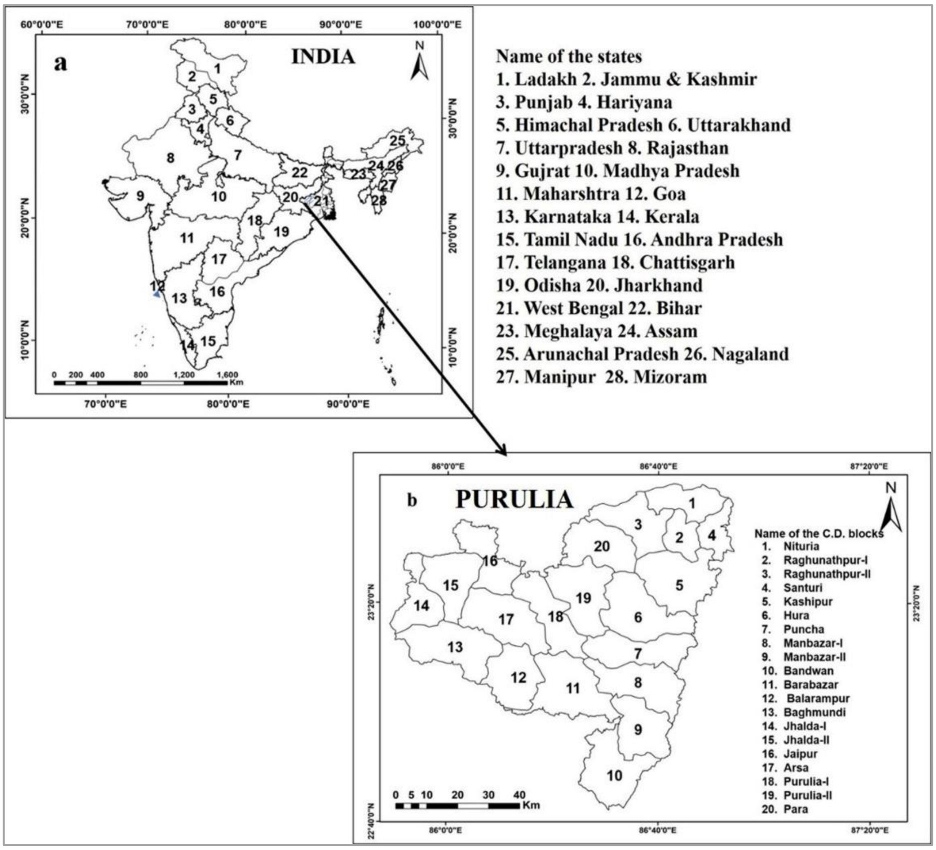

Fig. 1. Location map of the study area.

3. Methodology

Figure 2 determines the methodological framework applied in this research. Here, the methodology has been applied in the 5 steps; which are discussed as follows:

3.1 1st Step: Collection of the rainfall data

The first step of the research is marked with the collection of rainfall data. The rainfall data was downloaded from the SWAT (globalweatherdata.tamu.edu). SWAT is basically an open access and flexible dataset. The origin of the data is marked by the integrated project of the Climate Forecast System Reanalysis (CFSR), which was completed over the 36 years from 1979 through 2013. After downloading the daily data; it has been converted to the monthly total. The CFSR was created as a global, high-resolution, coupled system of the atmosphere, ocean, land surface, and sea ice (Dile & Srinivasan, 2014). The whole analysis was done according to the recommendation of the Indian Meteorological Department (IMD) as the annual (i.e., an average of the January to December months), pre-monsoon (i.e., an average value of the March to May months), monsoon (i.e., an average value of the June to September months), post-monsoon (i.e., an average value of October to December months) and the winter phases (i.e., an average value of the January and February months). A total of seven meteorological stations were found in the study area (Figure 3, Table 1).

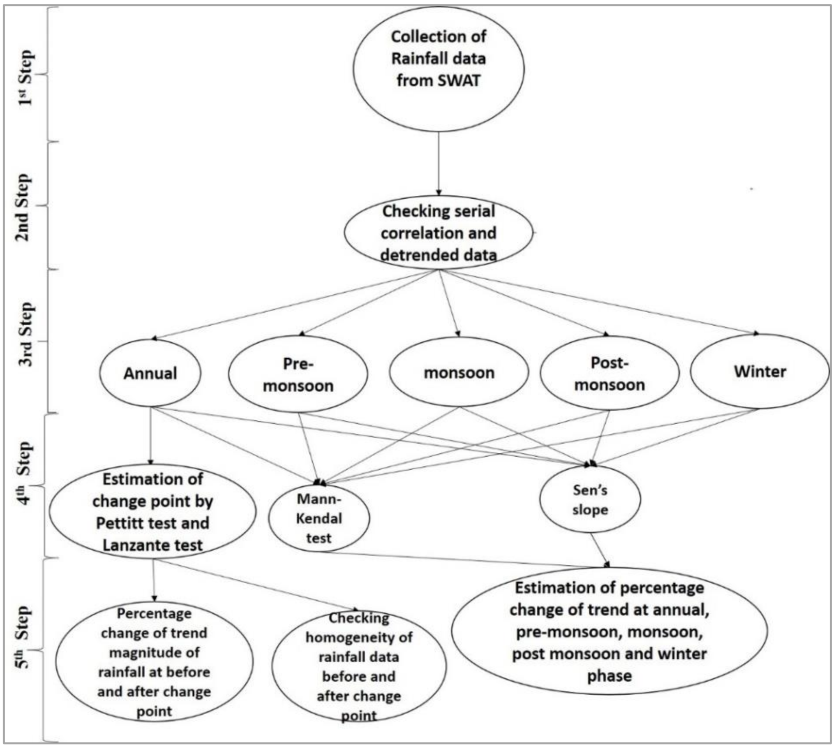

Fig. 2. Methodology.

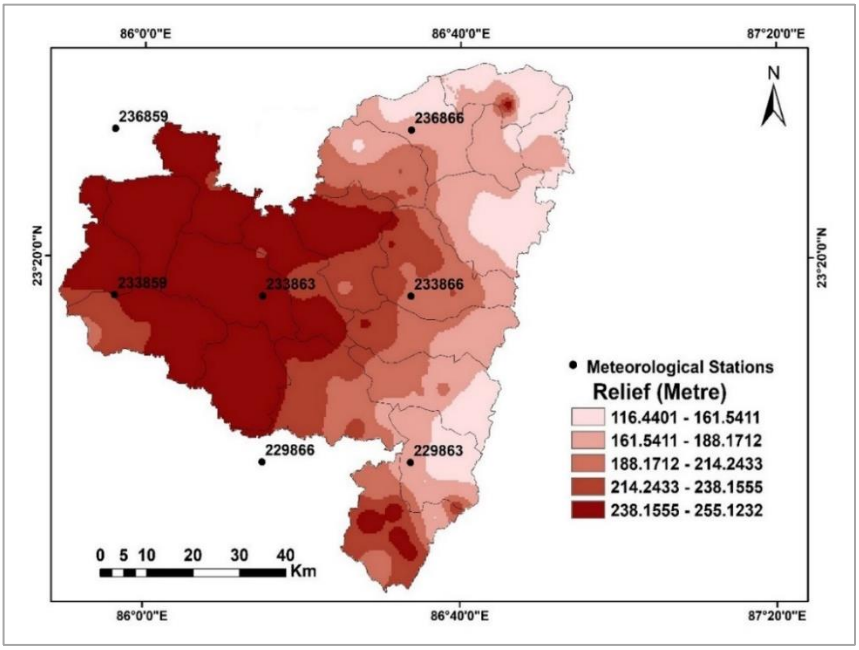

Fig. 3. Meteorological stations in the study area.

Table 1. Station wise descriptive statistics of annual, mean, standard deviation and coefficient of variation of rainfall (1979-2013).

Station Code**	Season	Mean Rainfall (mm.)	Standard Deviation (SD)	Coefficient of Variation (CV)
229863 (1st Station)	Annual	156.8496	34.7843	22.1768
	Pre-Monsoon	15.8995	18.4772	116.2124
	Monsoon	416.1263	96.2225	23.1234
	Post-Monsoon	49.6485	30.3173	61.0638
	Winter	10.5229	9.1645	87.0913
229866 (2nd Station)	Annual	175.6605	40.1905	22.8796
	Pre-Monsoon	20.8142	23.7224	113.9720
	Monsoon	457.9272	109.0638	23.8169
	Post-Monsoon	59.4618	35.3040	59.3726
	Winter	11.4778	9.7767	85.1790
233859 (3rd Station)	Annual	146.7596	32.4327	22.0992
	Pre-Monsoon	13.5460	15.0693	111.2457
	Monsoon	386.5694	90.9230	23.5205
	Post-Monsoon	47.4064	32.0657	67.6399
	Winter	15.9903	11.6343	72.7587
233863 (4th Station)	Annual	158.4968	38.9767	24.5915
	Pre-Monsoon	15.9579	18.4423	115.5688
	Monsoon	418.6780	108.9738	26.0281
	Post-Monsoon	50.9168	32.9734	64.7593
	Winter	13.3128	10.4929	78.8181
233866 (5th Station)	Annual	173.6260	44.1702	25.4398
	Pre-Monsoon	19.3614	22.2658	115.0010
	Monsoon	455.1654	117.7346	25.8663
	Post-Monsoon	58.4021	36.8978	63.1789
	Winter	14.7799	10.0065	67.7033
236859 (6th Station)	Annual	112.0326	30.3396	27.0810
	Pre-Monsoon	10.3617	12.4456	120.1116
	Monsoon	292.7285	85.9713	29.3689
	Post-Monsoon	37.2977	27.5230	73.7927
	Winter	15.2493	10.9993	72.1302
236866 (7th Station)	Annual	131.5526	37.4437	28.4629
	Pre-Monsoon	15.2968	19.0904	124.8006
	Monsoon	341.5455	101.3892	29.6854
	Post-Monsoon	45.9671	33.0490	71.8972
	Winter	14.3290	10.3730	72.3917

This research uses SWAT data which is basically a raster data; therefore, station name is not available. Only station code available. For the analysis, the authors have renamed it as first station, second station, third station and so on.

3.2 2nd Step: Checking the serial correlation and detrended data

The principle assumption of the Mann Kendal trend test is that the data should be independent, randomly ordered and no trend exists within the data set. But most of the hydrological time series bear significant autocorrelation. Here, the time series is tested for serial autocorrelation using the following equation:

$$\left(\frac{-1-1.645\sqrt{n-2}}{n-1}\right) \leq r_1 \leq \left(\frac{1+1.645\sqrt{n-2}}{n-1}\right) \quad (1)$$

where, r_1 is the lag-1 autocorrelation coefficient and n are the number of observations in the dataset. If the r_1 falls within the above-specified range the time series is assumed to be independent. In cases, where r_1 falls outside the above-specified interval, the data will be serially correlated. Additionally, if the autocorrelation coefficient of a time series data is within the blue dotted lines in figure 6 the data set is considered to be an independent series and if above 5% of the time series observation falls outside the blue dotted lines the dataset should be considered as the serially dependent or correlated dataset. For that case, the 'prewhittened' procedure must be applied for that time series data. Initially, Storch (1995) proposed the 'pre-whitened approach to remove autocorrelation from the time series data. However, this Pre-Whitening procedure is inappropriate for the time series data having negative autocorrelations. A 'trend-free pre-whitening approach was developed by Yue, Pilon, Phinney and Cavadias (2002) which is applicable for the time series having positive or negative serial correlations. Therefore, this procedure was applied in this research, where, the serially correlated data was found. After computation of the Sen's slope (β) from the original series, the following procedure was applied (Yue et al., 2002):
The detrended series is calculated first as follows:

$$M_i{}' = M_i - (\beta \times i) \tag{2}$$

where, $M_i{}'$is the calculated series; M_i is the original time series of rainfall, β is the Sen's slope and i is the row. Here, the lag-1 serial correlation is calculated. If r_1 falls outside the range specified in equation (1), the detrended pre-whitened series is calculated as follows:

$$N'_i = M_i{}' - r_1 \times M'_{i-1} \tag{3}$$

The $(\beta \times i)$ is again added with equation (3) to get the final equation of the detrended series:

$$N_i = N'_i + (\beta \times i) \tag{4}$$

The N_i is the pre-whitened series.

3.3 3rd Step-Detrended data for annual, pre-monsoon, monsoon, post-monsoon, and winter series

In the third step, equation (1) was applied separately for each station and each series i.e., Annual, pre-monsoon, monsoon, post-monsoon, and winter. If any of the series was found with serial correlation, the annual series is estimated by the equation (3). Similarly, for every month separately the r_1 is checked and if found outside the range, that respective phase is determined using the TFPW series in the equation (3).

3.4 4th Step- Estimation of Mann Kendall test (MK), Sen's slope, and change point

3.4.1 MK Test

To detect the long-term seasonal and annual rainfall trends the MK test is applied in this research (Mann, 1945; Kendall, 1975). In this trend test, the null hypothesis (H_0) was that there is no trend exist in the time series data and the alternative hypothesis (H_1) was that there is an increasing or decreasing trend exist within the time series data set. For time series, in which less than ten data points exist, the S test was used and for the time series in which ten or more than ten data points exist; the normal approximation technique was followed (Kundu & Mondal, 2019). The Mann Kendal S statistic was calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(M_j - M_i) \tag{5}$$

where, M_j is the original rainfall time series; n is the length of the data set and

$$sgn(t) = \begin{cases} 1 & for\ t > 0 \\ 0 & for\ t = 0 \\ -1 & for\ t < 0 \end{cases} \quad (6)$$

The value of S indicates the upward (positive) or downward (Negative) trend. In the MK test, when n ≥ 8; the test statistic S is normally distributed with mean and variance as follows:
$E(S) = 0$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad (7)$$

where *m* is the number of tied groups; t_i is the size of the i-th tied group. The standardized test statistics Z is computed as follows:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & for\ S > 0 \\ 0 & for\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & for\ S < 0 \end{cases} \quad (8)$$

The positive value of Z_{MK} imply the positive trend and the negative value of Z_{MK} imply the negative trend. In the present study, a significance level of 0.05 is used.

3.4.2 Sen's slope estimator

The magnitude of trends in the rainfall time series was estimated using Theil Sen's slope estimator (Theil, 1950; Sen, 1968) in the following process:

$$\beta = median(\frac{M_i - M_j}{i-j}) \quad (9)$$

where *β* is the median slope; and *M* is the rainfall time series.

3.4.3 Estimation of the change point

Pettitt Mann-Whitney test

The Pettitt test was implemented (in this research) as given by Verstraetan, Poesen, Demarée and Salles (2006), where the ranks (r_1, r_2,…….r_n) and the original dataset (M_i,……..M_n) are used for the statistic:

$$U_k = 2\sum_{i=1}^{k} r_i - k(n+1) \qquad k = 1,2,\ldots\ldots,n \quad (10)$$

The test statistic is the maximum of the absolute value of the vector:

$$\widehat{U} = max|U_k| \quad (11)$$

Thereafter, the probable change point *k* is located, where $\widehat{U}$ is maximum. The appropriate probability for a two-sided test is calculated according to the following formula:

$$p = 2exp^{-6K^2/(T^3+T^2)} \quad (12)$$

This test is really suitable one to detect the change in the middle portion of the time series (Mallakpour & Villarini, 2016).

The Lanzante test

The Lanzante test is a non-parametric test to detect the central tendency in the time series data. Here, the null hypothesis was no shift in the central tendency of the time series data set and the alternative hypothesis considers its' reverse.

Let, *M* is a continuous random variable then the model of single shift is as follows (Lanzante, 1996):

$$M_i = \begin{cases} \theta + \varepsilon_i & i = 1,2, \ldots \ldots, m \\ \theta + \Delta + \varepsilon_i & i = m+1, \ldots \ldots . n \end{cases} \quad (13)$$

with $\theta(\varepsilon) = 0$; The null hypothesis, $H: \Delta = 0$ was tested against the alternative hypothesis $A: \Delta \neq 0$.First, the data was arranged with the increasing ranks for each of the series and the adjusted rank sum (U_k)is computed as follows:

$$U_k = 2\sum_{i=1}^{k} r_i - k(n+1) \qquad k = 1,2, \ldots \ldots .., n \quad (14)$$

where, r_i is the rank of the data points; n is the number of observations.
The probable change point is located in the maximum of the statistic

$$m = k(max|U_k|) \quad (15)$$

where, m is the probable change point; U_k is the adjusted rank sum statistics.

3.5 5th Step: Estimation of percentage change of slope and homogeneity test

3.5.1 Estimation of percentage change at station L

To make the change (B_L) comparable in different stations; the percentage increase and decrease of mean ($E(M^L)$) of the time series of the rainfall data over the observation period *T* at station *L* was estimated by the following formula (Yue & Hashino, 2003):

$$B_L = 100 \times \frac{T\beta}{E(M^L)} \% \quad (16)$$

3.5.2 Homogeneity test

F-test

The F-test is applied for the two sample for variances assuming the null hypothesis that the variances are equal $H_0: \partial_1^2 = \partial_2^2$. The alternate hypothesis is that the variances are unequal $H_0: \partial_1^2 \neq \partial_2^2$; here, ∂_1^2 and ∂_2^2 are the variances of the time series data of before and after change point. The F distribution is estimated as follows:

$$F - Statistic = \frac{\partial_1^2}{\partial_2^2} \quad (17)$$

where, ∂_1^2 is assumed to be the variance of the rainfall data at after change point; ∂_2^2 is assumed to be the variance of the rainfall data at before change point. In this research, the F-test is checked at 95% confidence interval. If the P value is less than 0.5 the F-statistic is supposed to be significant and then the alternative hypothesis is accepted. Otherwise, null hypothesis is accepted and the alternative hypothesis is rejected at 95% confidence interval.

T-test

Further, the homogeneity test is done using T-test by assuming the equal variances for the two-time series (i.e., time series for the before change point and time series for after change point). The null hypothesis assumes that the variance of the before change and after change series (At the annual scale) is equal. If those are not equal; it is considered as the alternative hypothesis. In this research, the T-test is checked at 95% confidence interval. If the P value is less than 0.5 T-test is supposed to be significant and then the alternative hypothesis is accepted. Otherwise, null hypothesis is accepted and the alternative hypothesis is rejected at the 95% confidence interval.

4. Result

4.1 Descriptive statistics of the annual and seasonal rainfall

Station wise descriptive statistics of rainfall at annual, pre-monsoon, monsoon, post-monsoon and winter series were portrayed in the table 1. The average annual rainfall was comparatively high (175.6605 mm) at the second station, and it was low (112.0326 mm) at the sixth station. The standard deviation of rainfall at the annual series was relatively high at the fifth station and the standard deviation value of the annual series was the lowest at the sixth station. The coefficient of variation of rainfall was comparatively high at the seventh station (i.e.,28.46%) and the CV of the rainfall was comparatively low at the first station (i.e., 22.18%).

The average pre-monsoonal rainfall was highest (i.e., 20.8142 mm) at the second station and it was lowest (i.e.,13.5460 mm) at the third station. The standard deviation of rainfall was highest (i.e.,23.7224mm) at the second station and it was the lowest (i.e.,12.4456 mm) at the sixth station. At the pre-monsoon phase, the coefficient of variation of rainfall was comparatively high at the seventh station with 124.80% variability. The variation was comparatively low for the 3rd station with 111.25% variability of rainfall. The average monsoonal rainfall was comparatively high (i.e., 457.9272mm.) at the second station and it was comparatively low at the sixth station (i.e., 292.7285mm.). The standard deviation of rainfall was comparatively high (i.e., 117.7346) at the fifth station and it was lowest at the sixth station (i.e., 85.9713). At this phase, the first station was noticed with the lowest variability in rainfall amount (i.e., 23.12%) and the seventh station was marked with the highest variability in the rainfall amount (i.e., 29.68%). The average post-monsoonal rainfall amount was comparatively high (i.e., 59.4618mm.) for the second station and it was comparatively low (i.e., 37.2977mm.) for the sixth station. The standard deviation of the rainfall was high for the fifth station and it was comparatively low at the sixth station. The variability of the rainfall was low (59.37% variability) at the second station and it was much higher (73.79%variability) at the sixth station. At the Winter season, the average rainfall was high at the third station and it was low at the first station. The standard deviation of rainfall was comparatively low at the first station and comparatively high at the third station. The coefficient of variation of rainfall was relatively low (67.70% variability) at the fifth station and it was comparatively high (87.09% variability) for the first station. Figure 4 determines the monthly rainfall variation within the meteorological stations. In each case, the time span of June to September (i.e., monsoon season) experience much higher rainfall and the October to February (i.e., post monsoon and Winter seasons) time span experience comparatively low rainfall (Figure 4a to 4g).

Figure 5 represents the boxplot of annual and seasonal rainfall in the study area during 1979 to 2013. The thick line inside the boxes represents median (50 percentile) and the upper and lower thin lines of the boxes represent 75 and 25 percentiles, respectively. The median value for the average annual rainfall lied within the 100 mm and 150 mm rainfall except for the first, second and fifth station (Figure 5a). The median value for the average pre-monsoonal rainfall lied within the 0 to 20mm. rainfall (Figure 5b). In case of monsoon, the median value for the rainfall lied within the 300 to 600 mm. rainfall (Figure 5c). For the post monsoon the median rainfall value lied close to 40mm to 60mm rainfall (Figure 5d). For the Winter series, the rainfall varied from the 10mm to 20mm rainfall value (Figure 5e). Overall, the median rainfall was high for the monsoon series and comparatively low for the Winter season.

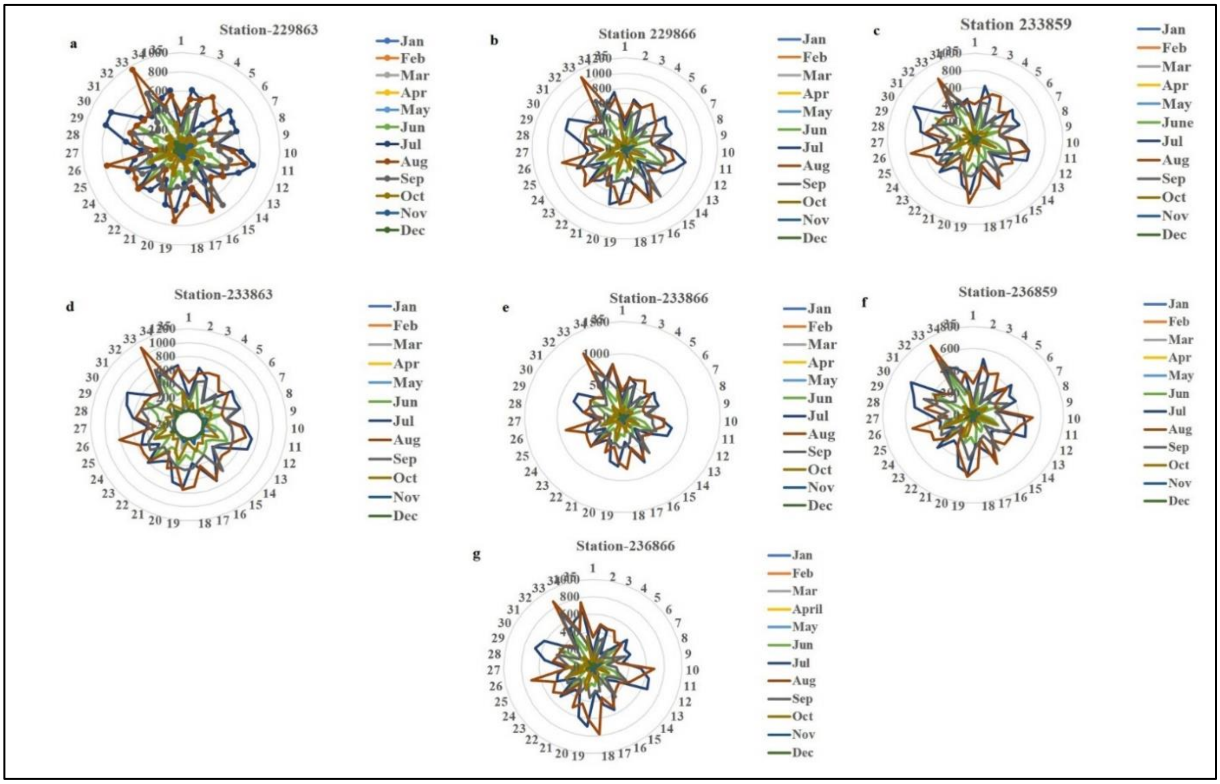

Fig. 4. Station wise monthly rainfall.

4.2 Percentage change of the rainfall data

Spatial variability of magnitude as percentage of mean rainfall during 1979 to 2013 were portrayed in the figure 5. For the annual series, the percentage change in the Sen's slope varied from +16.97% to +25.42% (Figure 7a). For this phase, all of the stations were noticed with the upward trend. At the annual phase, comparatively higher change (positive) were found in the northern portions and negative change (decreasing) were marked in the Western portions of the study area. The sixth and third stations were identified with the highest (+24.75%) and lowest positive change (+16.97%) in magnitude in annual series respectively. For the pre-monsoon phase, the percentage change in the Sen's slope varied from -12.25% to +9.04% (Figure 7b). Most of the stations were marked with either upward or downward trend, which are non-significant at 95% confidence interval. At this phase, Western portions were marked with the negative change (decreasing) and the northern sections were noticed relatively high percentage change in the Sen's slope. The seventh and fifth station were marked with the highest negative (-16.97%) and highest positive change (+9.04%) respectively at this phase.

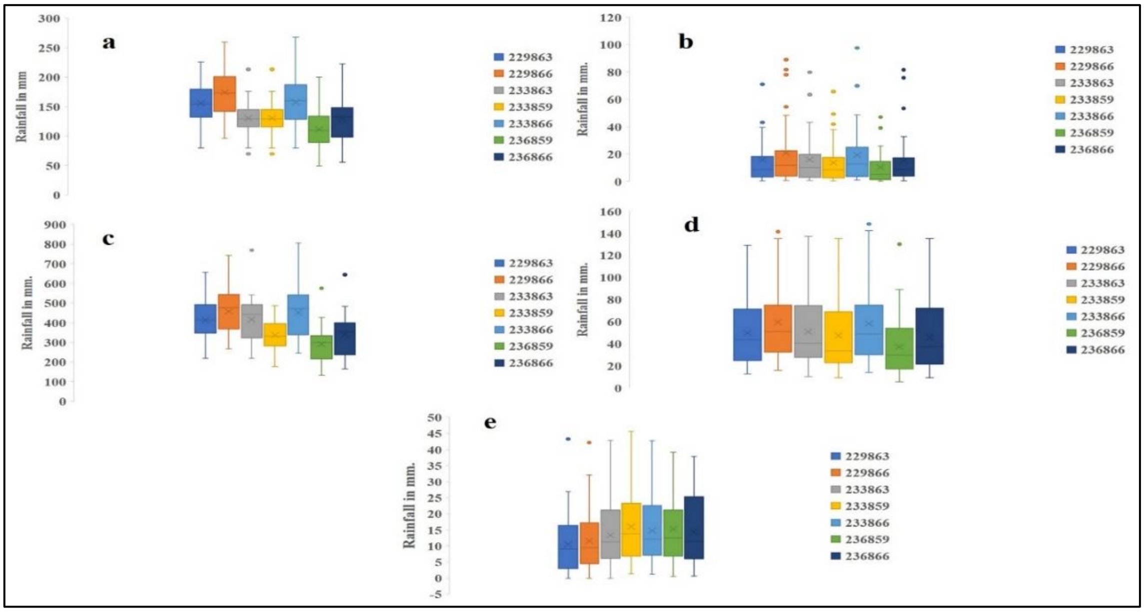

Fig. 5. Boxplot of Annual and Seasonal rainfall time series during 1979-2013 in the Purulia District a. Annual series b. Pre-monsoon series c. Monsoon series d. Post-Monsoon series e. Winter series.

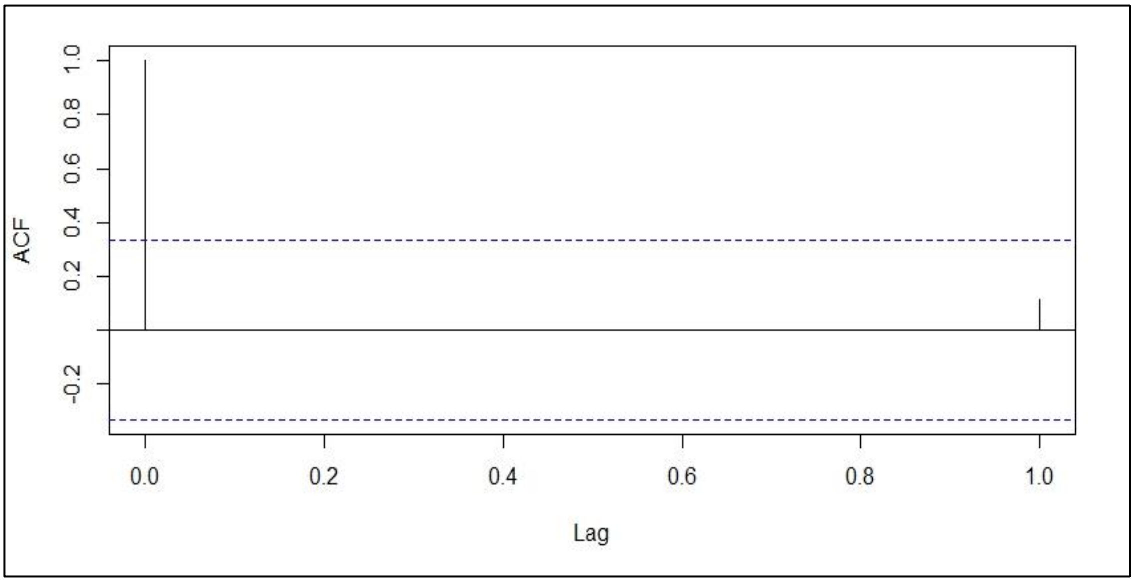

Fig. 6. The autocorrelation function in Lag-1 (Example from the seventh station at Winter series).

For the monsoon phase, the percentage change in the Sen's slope varied from 20.32% to 29.97%. (Figure 7c) All the stations were marked with the upward trend, in this phase. Southern and Western sections were marked with negative change (decreasing) in the Sen's slope and Northern portions were marked with its' reverse at the Monsoon phase. The fifth and first stations were marked with the highest (+29.96%), and lowest positive change (+20.32%) in the magnitude of rainfall in the monsoon series respectively. For the post-monsoon phase, all meteorological stations were noticed with the upward trend, which were not significant at 95% confidence interval. For the post-monsoon phase, the Sen's slope varied from 21.22% to 44.36% within the study area (Figure 7d). At the Post-monsoon season, the Western sectors were marked with the positive percentage change in the Sen's slope and the southern and northern sections were identified with negative change (i.e., decreasing) in the Sen's slope. For the post-monsoon series, the lowest positive change (+21.22%) was marked at the seventh station and the highest positive change (+44.36%) was identified at the third station. For the Winter phase, the Sen's slope varied from -57.94% to -25.23% (Figure 7e). In this phase all meteorological stations were marked with the downward trend, which were not significant at 95% confidence interval. Northern, eastern and southern sections were marked with the positive change (increasing) in the magnitude and the Western sections were identified with negative change (decreasing) in the magnitude of rainfall. The highest negative change (-57.94%) were portrayed in the fourth station and the lowest negative change was found at the seventh station (-25.23%) in the Winter phase.

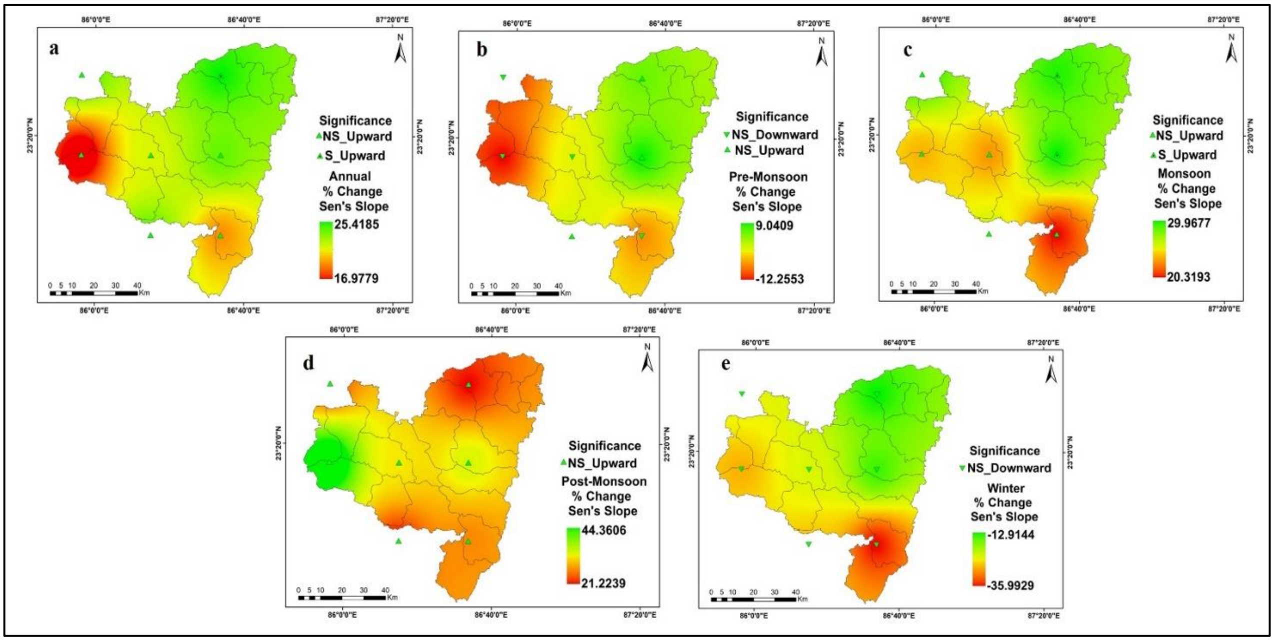

Fig. 7. Spatial variability of change magnitude as percentage of mean rainfall during 1979 to 2013 a) Annual series b) Pre-monsoon series c) Monsoon series d) Post-monsoon series e) Winter series (NS-Not significant; S-Significant).

4.3 Change point and percentage change of the rainfall

Here, Pettitt Mann-Whittney and Lanzante test confirm that the change point is 1987-1988. Therefore, the pre-change point phase is 1979 to 1986 and the post change point phase is 1989 to 2013 (Table 2). Further, the T-test and F-test proves that for all the stations pre-change point and post change point series is almost homogeneous in character (Table 3). During the pre-change point phase, the Sen's slope varied from 20.46% to 46.90% in the study area. The North-eastern sections of the study area were identified with negative change in magnitude and the south-eastern portions were marked with positive change in the magnitude of the rainfall (Figure 8a). In the post change point phase, a completely reversed picture was identified. Negative or decreasing nature of change was identified in the south-eastern portions of the study area and higher change was marked at the northern sections of the study area. Overall, the percentage change in the Sen's slope varied from the -8.60% to 8.10% in the Purulia District after the change point (Figure 8b). Therefore, it could be concluded that comparatively high rainfall dominates in the northern portions of the Purulia District after the change point.

Table 2. Pettitt-Mann Whitney test and Lanzante test result for change point in Annual series.

Station name	**Annual series (Change point) (Pettitt test and Lanzante test)**	**Change point taken**	**Before change point series**	**After change point series**
229863	1988	1987-1988	1979-1986	1989-2013
229866	1988		1979-1986	1989-2013
233859	1988		1979-1986	1989-2013
233863	1988		1979-1986	1989-2013
233866	1988		1979-1986	1989-2013
236859	1987		1979-1986	1989-2013
236866	1987		1979-1986	1989-2013

Table 3. F-test and T-test for checking the homogeneity of the series.

Station Id	**F Test two sample for variances**	**P value****	**T-test assuming equal variances**	**P value****	**Homogeneity**
229863	1.0414	0.5187	1.9902	0.0277	Homogeneous
229866	1.2876	0.3872	2.0406	0.0249	Homogeneous
233859	0.9775	0.4408	2.0822	0.0228	Homogeneous
233863	0.8273	0.4252	2.1539	0.0391	Homogeneous
233866	1.4975	0.3030	2.1459	0.0199	Homogeneous
236859	1.2462	0.4066	2.0483	0.0245	Homogeneous
236866	1.3574	0.3568	2.5098	0.0087	Homogeneous

**95% confidence interval

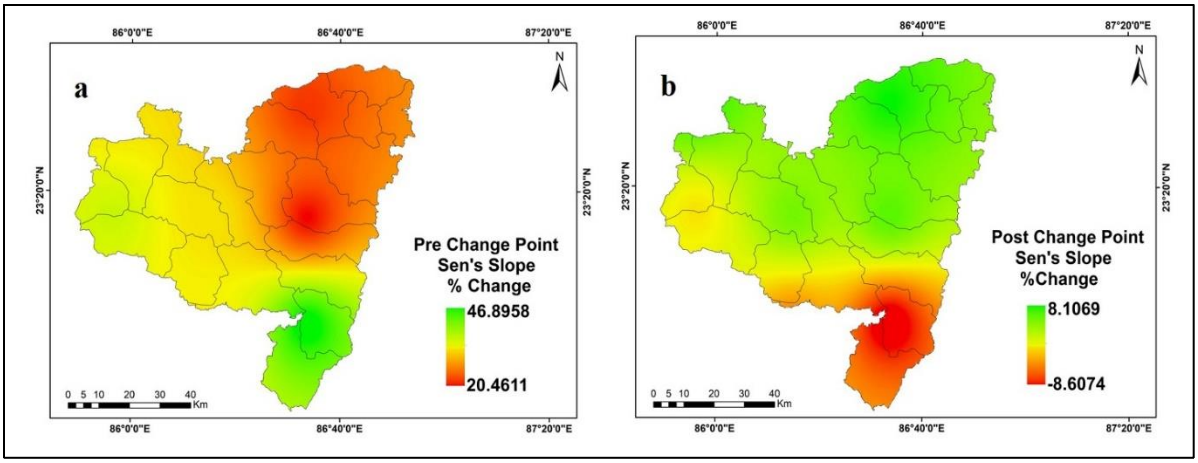

Fig. 8. Spatial variability of change magnitude as percentage of mean rainfall at a) Pre-change point phase (1979-1986) b) Post-change point phase (1989-2013).

5. Discussion

Rainfall patterns in the Purulia District are consistent with the rainfall patterns of both West Bengal and across all India. Potential causes of this tendency may be closely related to geo-environmental factors like global climate change. The association between India's monsoon patterns and ENSO changed around 1990 and reached its peak positivity in the past ten years and therefore it demonstrates a recent deterioration in the relationship between ENSO and the monsoon (Bhardwaj, Shah, Aadhar & Mishra, 2020). Walker circulation shifts southward as a result of global warming, and greater surface temperatures are the real cause of such a relationship (Kundu & Mondal, 2019). Therefore, a single ENSO event is unable to fully explain the rainfall pattern in the context of Purulia. From a wide viewpoint, the weakening of the easterly jet stream and the warming of the equatorial ocean are two local level elements that typically influence the increasing tendency of rainfall at eastern regions of the region (Naidu et al.,2009). The study of trend of rainfall in the Purulia is devoted to micro level variability of rainfall at seven meteorological stations. Thereafter, role of ENSO and other phenomena has not been assessed here. The local level aspects, such as the topography, altitude, gradient, etc., and modifications in agricultural property due to the introduction of irrigated agriculture, deforestation, and growing urban expansion are what this research had fundamentally implied (Kundu & Mondal, 2019).

The Purulia has crystalline bedrock that were once part of a granitic environment and was thinly covered by a worn mantle (Nag & Ghosh, 2013). Purulia's dispersed shallow rupture zones are unable to hold enough groundwater (Dolui, Das, Guchhait, & Roy, 2021). According to Nayak, Mukhopadhyay, Mitra and Chakraborty (2020), the weathered fracture zone restricts the amount of groundwater in Purulia. The fracture zone exhibits secondary porosity, which denotes the development of a thick profile of in porous material. The hard, cemented rock is getting weathered continuously and as a result the secondary porosity is noticed. Generally, the western portions of Purulia has experienced comparatively low rainfall and the eastern portions experiences its' reverse (Raha & Gayen, 2019; Raha & Gayen, 2021). As a matter of fact, percentage change of rainfall was relatively high in the southern sections and low at the northern portions of the district at the pre-change point phase. The pattern was reversed from 1990s and percentage change in magnitude was comparatively high for the northern portions and low at the southern portions of the study area.

The result presented in this research is also easily comparable with other research activities done in other portions of the West Bengal. Mukhopadhyay, Kulkarni, Kulkarni & Dutta (2016) estimated the change point of the rainfall time series for all over West Bengal and found increasing trend for the annual rainfall series for every station except South-24-Pargana District. In case of monsoon months, this research found the non-significant increasing trend for every station. The majority districts were noted with very small changes in the rainfall trends in the non-monsoon months. Praveen et al. (2020) calculated the change point in the rainfall time series for whole India by using the Pettitt test, Buishand Rang test and Artificial Neural Network model during 1901 to 2015. Monsoon, Summer and Winter season were marked with the non-significant decreasing trend; while the Pre-monsoon phase was identified with the non-significant positive trends of rainfall. Guhathakurta and Revadekar (2017) found the increasing trend of rainfall for the Gangetic West Bengal for the Annual, Pre-monsoon, monsoon, Post-monsoon and Winter phase. Guhathakurta, Rajeevan, Sikka, and Tyagi (2015) found the multidecadal epochal variability of rainfall for all over India during 1901 to 2011 and found significant change for the south-west monsoonal rainfall. Overall, for all cases, the upward trend was recorded by the authors. Nandargi and Barman (2018) found the 1990 as the change point in the rainfall time series for the West Bengal and found the downward trend of the rainfall during 2001 to 2016. Ghosh (2018) estimated the rainfall trends of the Gangetic West Bengal, Eastern India and found a delayed tendency of onset and withdrawal of the monsoon in this tract. In the Rarh portion, Ghosh (2018) found the decreasing rainfall trend during monsoon season and observed its' reverse during post monsoon season. Similar findings are also noted in the research work of Kundu and Mondal (2019).

The Western Rarh was highlighted with the decreasing trend while the northern portion was highlighted with the increasing trend of rainfall after the change point. According to the findings, a significant trend is seen at five sites for yearly rainfall, six stations for monsoon rainfall, and eight stations for postmonsoon rainfall. Maldah station has the largest degree of negative change in annual rainfall (14 %) and monsoon rainfall (20.48%). The South 24 Parganas rainfall station has the largest yearly (+ 13.98%) and monsoon (+ 13.27%) rainfall change in magnitude. Post-monsoon rainfall shows a positive change in magnitude at 16 rainfall sites, with Birbhum station (+ 40.07%) showing the largest change. Chatterjee et al. (2016) analysed the rainfall trends for 1901 to 2002 and found that the monsoon arrives earlier in the North Bengal than in the South Bengal. Decreasing trend was marked both at before and after change point for the Rarh Bengal. The eastern Gangetic West Bengal was marked with the increasing tendency of rainfall. Datta and Das (2019) found the decreasing rainfall trends in the monsoon season and found the upward rainfall trends in the annual phase. Therefore, by analysing the above research works the following findings are more or less common:

1) The northern portions of the West Bengal i.e., Darjeeling, Jalpaiguri, Cooch Behar have upward rainfall trend during the monsoon season.
2) 1990s is the most probable change point for the West Bengal and Gangetic West Bengal.
3) During post monsoon and winter season, the districts of the north Bengal experience decreasing trend of rainfall.
4) On the contrary, the eastern portions of the South Bengal experience upward rainfall trend during annual and monsoon season.
5) Decreasing rainfall trend is noticed for the south Bengal during the Winter season.
6) The Rarh Bengal is found with decreasing trend of rainfall but it has abrupt micro level variability. The northern portions of the Rarh are noticed with the increasing trend of rainfall, while the Western portions have the decreasing rainfall trend.

Our research work also found the decreasing rainfall trend in the Western portion of the Purulia during the pre-monsoon season. But for the other phases, the positive trend was identified. Significant positive changes in the rainfall trend was marked in the northern portions of the Purulia for the annual and monsoon seasons. The non-significant positive trend in the rainfall was identified in the northern portions of the Purulia. The Winter season was noticed with non-significant downward trend for every station. Therefore, the present research work completely supports the findings of the research done by all of the above researchers. The assessment of change point is also perfect in this research as Nandargi and Barman (2018) found the similar result for the West Bengal and Gangetic West Bengal. The present research is a perfect example of micro-level assessment of rainfall trend along with the change point.

6. Conclusion

This research is devoted to assess the rainfall trends of the Purulia District along with the changepoint during 1979 to 2013. To do this, a 5-step approach had been followed. At the first step, rainfall data was collected from the free, online, flexible SWAT sources; in the second step, the serial correlation was checked and trend free pre-whitening procedure was applied to exclude the influence of lag-1 correlation from the time series. The detrended series was estimated individually for each station and for each series in the third stage. The fourth stage was portrayed by the Mann-Kendall test and Sen's slope to identify the trend and magnitude of trend in the rainfall time series data. The Pettitt-Mann-Whitney and Lanzante test had been used to identify change point in the annual rainfall series. The percentage change in the magnitude of the rainfall data and homogeneity were checked using F test and T test in the fifth stage of the methodology. A significant trend was found at one station in annual rainfall, and for two stations in the monsoonal rainfall. The sixth and third stations were identified with the highest (+24.75%) and lowest positive change (+16.97%) in magnitude of the annual series respectively. The third and fifth station were marked with the highest negative (-12.25%) and highest positive change (+9.04%) respectively at the pre-monsoon phase. The fifth and first stations were marked with the highest (+29.96%), and lowest positive change (+20.32%) in the magnitude of rainfall for the monsoon series respectively. For the post-monsoon series, the lowest positive change (+21.22%) was marked at the seventh station and the highest positive change (+44.36%) was marked at the third station. The highest negative change (-35.99%) was portrayed in the first station during the Winter phase. The most probable change point is identified at 1987-1988 for all meteorological stations. In the pre-change point phase, the highest positive change was found in the southern sections and the lowest positive change is marked in the northern portions of the study area. In contrary, completely reversed scenario was marked in the post change point phase. Therefore, it can be concluded that the tendency of rainfall was shifted in the northern portions after the change point. The findings presented in this research can be a helpful tool for the planners to strategize local level agricultural planning of the Purulia District.

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