Long period trend analysis of annual and seasonal rainfall in West Bengal, India (1901- 2020)

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Research Article

Keywords: Seasonal rainfall, Persistency, Pre Whitening, Mann-Kendall test, Sen's slope estimator, West Bengal

Posted Date: November 11th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2222429/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Theoretical and Applied Climatology on August 19th, 2023. See the published version at https://doi.org/10.1007/s00704-023-04577-z.

Abstract

The present study assessed long period (1901–2020) trends and magnitudes of seasonal and annual rainfall across districts of West Bengal. The non-parametric Mann-Kendall test and Sen's slope estimator applied on the gridded (0.5˚ × 0.5˚) rainfall dataset. We used von Neumann ratio test ($p < 0.05$) for data homogenization. Tested autocorrelation using lag-1 autocorrelation coefficient (r_1) at $p < 0.05$ and removed serial correlations if any using trend-free pre whitening (TFPW) technique. Results revealed that, both the annual and seasonal rainfall of West Bengal increased (at 0.02 mm year^{-1} to 0.04 mm year^{-1}) non significantly ($p > 0.05$), except winter rainfall which decreased at 0.01 mm year^{-1}. Annual rainfall across the districts of sub Himalayan West Bengal (SHWB) declined. On the contrary, significant ($p <$ 0.05) increase of annual rainfall observed across most of the districts of Gangetic West Bengal (GWB) at the rate of 1.8 mm year^{-1} to 2.9 mm year^{-1}. Monsoon rainfall increased significantly ($p < 0.05$) over Gangetic West Bengal (GWB) at 1.4 mm year^{-1} to 2.1 mm year^{-1}, while declined significantly ($p < 0.05$) in Dakshin Dinajpur district at 3.2 mm year^{-1} of SHWB. Post-monsoon rainfall increased significantly ($p <$ 0.05) over GWB at the rate of 0.2 mm year^{-1} to 0.6 mm year^{-1}. The winter rainfall decreased non-significantly across all the districts except Dakshin Dinajpur, where significant ($p < 0.05$) decrease (@ 0.10 mm year^{-1}) observed. Thus, the derived location specific information on seasonal rainfall trends have immense utility in devising crop planning as well as livelihood security in West Bengal.

1 Introduction

In recent time, climate change is a serious environmental issue posing serious threats to human being. Though, the natural change of climatic parameters (e.g. rainfall, temperature, humidity) follow a naturalistic rhythm, but rapid anthropogenic greenhouse gas (GHGs) emissions since post-industrial era in particular causing global warming as well as climate change (IPCC 2014,Sam and Chakma 2019). As a consequence global surface temperature has increased nearly 0.6 ± 0.2°C in the 20th century since 1861 (Kumar et al. 2014).In association with the global warming the rainfall changes have already been recorded across the globe. Several global studies (IPCC 2014, Ren et al. 2013, Adler et al. 2017) reported increasing rainfall trend with an increasing inconsistency. However, such change may not be identical at regional level, since both the increasing and decreasing trends have reported from different parts of the world (Bhutiyani et al. 2010; Rana et al. 2012). Decreasing trend of rainfall observed in Tanzania (Gebrechorkos et al. 2019), north and central Ethiopia (Asfaw et al. 2018), North China (Su et al. 2020), middle India (Duhan and Pandey 2013), Pakistan (Salma et al. 2012) and in Bangladesh (Khan et al. 2019). On the contrary, increasing trends reported from Southern and Central China (Choi et al. 2009), Srilanka (Nisansala et al. 2020), and arid East-Central Asia (Hong et al. 2014). Such changes in rainfall adversely affected regional crop production system as well as food security, biodiversity, livelihood and human health (Connell 2015).

As a principle elements of hydrological cycle, rainfall directly affects runoff, fresh water availability and thus water demand in various sectors (drinking, domestic, irrigation, industry, hydro-power generation) of a region (Padron et al. 2020). Voudouris et al. (2012) estimated that a decrease in rainfall by 20% will reduce runoff by 29–32% in Crete region and subsequent dearth of freshwater availability of the region. Any abrupt change in annual rainfall affect spatio-temporal allocation of runoff, moisture content in the soil, ground water storage, stream flow and water quality (Das et al. 2014). Besides, anomalies in rainfall distribution bring series of environmental consequences such as soil erosion, landslide, flood, and drought etc. (Gupta et al. 2014). Having low resiliency and adaptive capacity developing countries are the hardest hit of climate changes, since majority of the population relay on the climate sensitive economic activities like agriculture, fishing and tourism etc. (Mandal et al. 2018).

In India, agrarian economy largely depends on the normal distribution of rainfall, more than 80% of which occurs during monsoon months (June to September). Spatio-temporal anomalies in the Southwest Monsoon rainfall (SWM) pose serious threats to the agricultural production system *vis-à-vis* Indian economy. The SWM rainfall over India was in decreasing trend during 21st centuries, while increasing trend observed in pre-monsoon and post-monsoon season (Ghosh and Dutta 2020). It was evident that the deficit of 23% in SWM rainfall (2009–2010) adversely affected *Kharif* production and thus decline of agricultural GDP by 0.2% compare to the previous year in India (Aggarwal 2010). Another report warns that the crop production will reduce by 31.3% with the reduction of rainfall by 2030 in India (Vyankatrao 2017). However, at sub-regional scale Das et al. (2014) reported increasing trend in summer monsoon rainfall and rainy days over east coast and Deccan Plateau, while decreasing trend in west coast, eastern part, western desert region and northeastern region of India during 1971 to 2005. Guhathakurta and Rajeevan (2008) reported significant decrease in annual rainfall for the subdivisions of Konkan and Goa, Madhya Maharashtra, North Interior Karnataka, Rayalseema, coastal Andhra Pradesh, Gangetic West Bengal, Assam, Meghalaya and Jammu and Kashmir.during 1901 to 2003. However, for the country as a whole the annual and monsoon rainfall decreased and winter rainfall increased during 1871 to 2005 (Kumar et al. 2010). In a study of 236 districts rainfall data (1901–2000), Bera (2017) showed that the half of the Ganga basin experienced decrease in annual rainfall, while significant declining trend in annual, pre-monsoon and post-monsoon rainfall over Kosi, Gandak and Sone sub-basins. Basistha et al. (2009) reported increase of annual rainfall over Indian Himalayan region during 1902–1964, while decrease in between 1965–1980. Narayanan et al. (2016) reported rise in pre-monsoon rain over Ajmer, Bikaner, Indore, Kolkata and fall in Minicoy, Belgaum during 1949–2009. Kamal and Pachauri (2019) observed negative trend in annual rainfall over northeast India during (1901–2015), though the state of Meghalaya and Mizoram experienced significant positive trend in SWM rainfall and Arunachal Pradesh, Assam, Nagaland and Sikkim felt significant decrease.

Likewise, in West Bengal wide variation of annual as well as seasonal rainfall occurrences likely to be observed and any abrupt change in rainfall distribution affected predominant agricultural system. Thus, the proper knowledge of inter annual and seasonal rainfall variability, their trends and anomalies through the sound analysis of long period rainfall dataset would be of immense utility in devising agricultural planning and water resource management. However, literatures available in public domain for the lower Gangetic plains (Chatterjee et al. 2016; Mukhopadhyay et al. 2016; Kundu and Mondal 2019; Ghosh and Dutta 2020) are with shorter data period excluding resent years data. Though the availability of long term observed rainfall dataset is another challenge especially in West Bengal, where well spaced rain gauge stations, preservation of long period data, and data availability in public domain is rare. Secondly quality control of available data and data analysis with standard methods is another challenge. Keeping this in mind, we aimed at analysing the spatio-temporal anomalies in rainfall occurrences, annual and seasonal trends and magnitude of rainfall distribution across the districts of West Bengal, India. We used long period grided ($0.5^{o}\times 0.5^{o}$) rainfall dataset (1901–2020) and employed Mann-Kendal (Mann 1945; Kendall 1975) non-parametric trend test and Sen's slope estimator (Sen 1968).

2 Materials And Methods

2.1 Study Area

West Bengal is one of the 28 states of India, located at eastern part of the country (21° 25' 02" to 27° 13' 15" N latitudes and 85° 49' 20" to 89° 53' 04" E longitudes) by occupying nearly 88Th km^2 land area (Fig. 1). Altitudes varies from 3,636 metres (Sandakphu at Singalila range) in the north to < 3 metres (Sagar island) in the south with an average of 44 metres from mean sea level (MSL). Due to wide altitudinal variation and diverse physiographic setting West Bengal experiences varied climatic condition from tropical wet-dry in the south to humid subtropical in the north (Kundu and Mandal 2019). The Indian Meteorological Department (IMD) has categorized the state into two homogeneous climatic regions i.e. the sub-Himalayan West Bengal (SHWB) and the Gangetic West Bengal (GWB) (Parthasarathy et al. 1995) and four seasons e.g. summer or Pre-monsoon (March-May), Southwest monsoon (June - September), Post-monsoon (October- December) and Winter (January- February) (Mandal et al., 2013). Average temperature goes up to 43°C during summer months, while in winter it goes down to 10°C. *Rarh* Bengal in the west experiences heat weave (> 45°C) in the summer months, while cold wave and snowfall (< 0°C) observe during winter months in the sub-Himalayan West Bengal (SHWB) region. Southwest monsoon (SWM) contributes > 80% of the annual rainfall (1750 mm). Frequent occurrences of severe cyclonic storms along with heavy downpour during pre-monsoon and monsoon months cause flooding, inundation and livelihood devastation in the districts of Gangetic West Bengal (GWB). Predominant *Kharif* (rice) cultivation solely depends on sufficient and timely occurrence of SWM rainfall, though in recent time early and or delay onset and or recession including wide anomalies in SWM rainfall causes frequent crop failure *vis-à-vis* livelihood insecurity of the resource poor farmers (Mandal et al. 2015; Mandal et al. 2018).

2.2 Dataset

We used long term (1901–2020) gridded ($0.5^{\circ}\times 0.5^{\circ}$) rainfall dataset covering 19 districts of West Bengal. The dataset was sourced from the India Meteorological Department (IMD), Pune through the Water Resource Information System (WRIS) interface (https://indiawris.gov.in/wris/#/rainfall). Monthly dataset for each of the district was categorized into Pre monsoon (March-May), Monsoon (June-September), Post monsoon (October- December) and winter (January-February) (Mandal et al. 2013). Generally the IMD converts station data to a regular space-time gridded data after removing all kinds of errors by validating and multi stage quality control of the observed data. Such errors include suspicious values, repeated values, location errors, ambiguity in recorded date and duplication of monthly or sub-monthly record that is affected by correlation coefficient, outliers, unknown errors and human errors arising at various levels from field measurement (Hamada et al. 2011). The IMD used the inverse distance weighting interpolation (IDW) method to obtain gridded data.

2.3 Data analysis

We tested long period (1901–2020) trend and magnitude (in %) of both the annual and seasonal rainfall time series across districts as well as for the state as a whole by employing nonparametric Mann-Kendalltest (Mann 1945; Kendall 1975). Magnitudes of such trends were estimated using Sen's slope estimator (Sen 1968). We followed the entire computational procedures path as- i) data homogenization ii) test the autocorrelation affects in the rainfall data, iii) removal of positive serial correlation if any by pre-whitening method, iv) detection of Mann-Kendal trend,v) Sen's slope estimation v) estimation of magnitude in percent (%).

2.3.1 Data homogenization

Though, the IMD ensures homogeneity and quality of data still we tested the homogeneity in annual rainfall series of each district as a precautionary measure. For data homogenization we applied von Neumann ratio test at $p < 0.05$ significant level through a Monte Carlo simulation experiments. Homogeneity test revealed the district level annual rainfall data series are homogeneous as the estimated test statistics are greater than the critical values 1.67 ($p \leq 0.05$) (Table 1). The critical values assumed for a 100 years and long data based on the asymptotic normal distribution of N (Buishand 1981).

Table: 1 Homogeneity tests of the annual rainfall time series and autocorrelation tests of both the annual and seasonal rainfall time series across all the districts of West Bengal (1901 2020).

District Name	Homogeneity test		Auto correlation coefficient (rl)				
	N	Homogeneity status	Annual	Pre monsoon	Monsoon	Post monsoon	Winter
Bankura	2.033	homogeneous	-0.0142	0.0965	-0.0162	0.0223	-0.0172
Barddhawan	1.970	homogeneous	-0.0044	0.0448	0.0114	-0.0842	0.0588
Birbhum	1.746	homogeneous	0.1162	0.0044	0.1051	0.0152	0.0033
Coch Behar	1.861	homogeneous	0.0156	-0.1144	0.0159	0.0600	0.1667
Dakshin Dinajpur	1.867	homogeneous	**0.3728**	-0.0965	**0.2867**	0.0776	0.0422
Darjelling	1.770	homogeneous	0.1058	-0.0101	0.0654	-0.0119	0.1220
Hoarah	2.048	homogeneous	-0.0220	-0.0042	-0.0308	-0.0075	-0.0248
Hugli	1.932	homogeneous	0.0377	-0.0211	0.0218	-0.0221	0.0275
Jalpaigudi	1.863	homogeneous	0.0612	-0.0465	0.0701	0.0555	0.1590
Kolkata	1.883	homogeneous	0.0570	0.0098	0.0639	0.0060	0.0256
Malda	1.868	homogeneous	**0.3339**	0.0351	**0.3012**	**0.0342**	0.0973
Murshidabad	1.704	homogeneous	0.1219	0.0093	0.1399	-0.0403	0.0264
Nadia	1.732	homogeneous	0.1061	0.0628	0.1204	-0.1208	0.0477
N 24 Parganas	1.872	homogeneous	0.0670	-0.0214	0.0725	0.0217	0.0289
Paschim Mednapur	2.105	homogeneous	-0.0712	0.0010	0.0452	0.0334	-0.0293
Purbo Mednapore	2.182	homogeneous	-0.1156	-0.0143	0.0249	0.0030	-0.0956
Purulia	2.092	homogeneous	-0.0576	0.0385	0.0180	0.0316	-0.0420
S 24 Parganas	2.003	homogeneous	-0.0034	0.0169	0.0255	0.0081	-0.0328
Uttar Dinajpur	1.769	homogeneous	0.1210	-0.0822	0.1018	-0.0273	0.1075
West Bengal	2.108	homogeneous	-0.0281	0.0227	-0.1106	-0.0211	-0.0577

Assumed critical value of homogeneity for >100years period is 1.67 at $p<0.05$. Critical limit of autocorrelation test is -0.1873<r1>0.1873 at $p<0.05$. Values beyond the critical limit marked in bold.

2.3.2 Testing autocorrelation

Major problem in trend detection of rainfall time series is the effect of autocorrelation or serial correlation. Existence of any positive or negative serial correlation underestimates the trend result (Hamed and Rao 1998; Yue et al. 2002). Nonparametric test generally detects significant trend if there exist positive autocorrelation, however there may exist no actual trend at all. Rainfall timeseries data often shows a tendency to be correlated automatically, which strengthens the probability of trend detection in nonparametric test (Kulkarni and Von Storch 1995).Therefore it is essential to remove serial correlation effect from the data series. In the rainfall time series datasets we tested serial correlation using lag-1 autocorrelation coefficient (r_1) at $p < 0.05$ significant level using two tailed test (Table 1). We computed lag-1 serial correlation coefficient following Kendall and Stuart (1968) and Salas (1980).

$$E\left(x_1\right)=\frac{1}{n}\sum_{i=1}^{n}X_i \ (1)$$

Where, $E\,x(i)$ is the mean of sample data and n is the sample size.

$$r_1=\frac{\frac{1}{n-1}\sum_{i=1}^{n-1}\left(X_i-E_{(X)}\right).\left(X_{(i+1)}-E_{(X_i)}\right)}{\frac{1}{n}\sum_{i=1}^{n}X_i-E\left(X\right)\big)^2}(2)$$

To check the significance of serial correlation the autocorrelation coefficient (r_1) was tested against the null hypothesis at a 95% confidence interval using a two tailed test.

$$r_1\,(95\%) = \frac{-1 \pm 1.96\sqrt{(n-2)}}{n-1}\,(3)$$

When, r_1 concentrated within the confidence interval then the data consideredas serially independent, otherwise for significant correlation pre-whitening approach applied to remove serial correlations in the nonparametric test (Yue et al. 2002).

2.3.3 Trend free pre-whitening

In order to minimize the effects of serial correlations in the dataset trend-free pre whitening (TFPW) method was applied prior to nonparametric test following Yue et al. (2002). Following are the steps of TFPW method applied in this study.

i. At first we calculated the lag-one autocorrelation coefficient (r_1) using the Eq. 4. If the r_1 value exceeded the upper and lower limits of confidence level then the trend free pre-whitening approach applied before Mann-Kendall (MK) Test (as mention earlier).

ii. The slop of n pairs of data point is computed by using the equation 1, then the trend was removed from the series to acquire a detrended series using the following equation 6.

$$X\prime_i = X\prime_i - (Q \times i)\,(4)$$

(iii)Computed the lag-1 serial correlation coefficient for the detrended series (r_1) by using Eq. 4.

(iv) Removed the lag-one autoregressive component (AR (1)) from the detrended series to get a residual series as given below

$$\text{Y}\prime_i = X\prime_i - r1 \times X\prime_{i-1}\,(5)$$

(v) Again the value of the trend (Q ×i) is added to the residual series to get a new data series as described below.

$$\text{Y}_i = \text{Y}\prime_i + (Q \times i)\,(6)$$

The new Y_i series is then considered for the Mann-Kendall (MK) trend analysis.

2.3.4 Mann-Kendall test

The nonparametric Mann-Kendall test (Mann 1945; Kendall 1975) extensively used to detect the significant monotonic trends in hydro-meteorological time series. In recent times researcher across the globe extensively used the method to detect trends in rainfall dataset (Kamruzzaman et al. 2018; Das and Bhattacharya 2018). In this study we used nonparametric Mann-Kendall trend test to detect statistically significant ($p < 0.05$) trend in the long term (1901–2020) annual and seasonal rainfall data series following standard method.

2.3.5 Sen's slope estimation

We used Sen's slope estimator to estimate the true slop (change per unit of time) of a liner trend (Sen 1968). The method is widely used in magnitude estimation in hydro-meteorological time series trend (Mandal et al. 2013; Jain et al. 2013; Kumar et al. 2014). The slope (Q) of N pairs data isobtained from Eq. 1.

$$Q_i = \frac{x_i - x_k}{j - k}\mathrm{i} = 1{,}2\ldots\ldots N\,(7)$$

Were, x_i and x_k represent data values at times j and k respectively and obviously $j > k$.

Now, the median of N values of Q_i is represented as Sen's slope (Q), which determines the magnitude of trend and is calculated following Eq. 2.

$$Q = Q(N+1)/2\mathrm{when}'N'\mathrm{isodd}$$

$$Q = [Q(\,N/2) + Q(N+2)/2]/2\mathrm{when}'N'\mathrm{iseven}$$

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When, positive value of Q_i indicated increasing trend and negative value expressed decreasing trend.

2.3.6 Change magnitude in percent (%)

We computed the change magnitudes in percent (%) for annual and seasonal rainfall over mean rainfall during 1901–2020. To estimate change in % following equation is used (Some'e et al. 2012).

$$\text{Percentage Change (\%)} = \frac{Q \times \text{Period length} \times 100}{\text{Mean}} \qquad (9)$$

Where, Q refers to slop derive from Sen's Slope Estimator.

Spatial distribution maps of the annual and seasonal rainfall occurrences and their trends and changes in % prepared using inverse distance weighting (IDW) interpolation method in Arc-GIS v 10.2 software environments.

3 Results

3.1 Persistency in rainfall series

All the long-term (1901 to 2020) annual and seasonal rainfall time series across different districts of West Bengal were checked for autocorrelation coefficient (r1) at $p < 0.05$ significant level (Table 1). Results revealed that the annual (r1:0.3728) and monsoon (r1: 0.2867) rainfall series of Dakshin Dinajpur and annual (r1: 0.3339), monsoon (r1: 0.3012) and post-monsoon (r1: 0.0342) rainfall series of Malda district showed significant lag-1 autocorrelation as their value felled outside the critical limit (-0.1873 < r1 > 0.1873). So, in the case of significant correlation or persistency observed in the seasonal and annual rainfall series of Dakshin Dinajpur and Malda district, the trend free pre-whitening test is applied to eliminate the effect of autocorrelation from the data series. Either the annual or seasonal time series of other districts showed no serial or autocorrelation. This indicated no successive value in the time series and they are not influenced by their antecedent values, rather they are independent data values.

3.2 Descriptive statistics of seasonal and annual rainfall

The state of West Bengal received nearly 1824.8 ± 715.0 mm rainfall annually during the past century (1901–2020); though the spatial distribution widely varied among districts and followed the north-south altitudinal gradient. As a result comparatively higher mean annual rainfall recorded in the districts of sub Himalayan West Bengal (SHWB) and lower in the districts of Gangetic West Bengal (GWB). Average annual rainfall varied from 3777.3 ± 636.2mm in Jalpaigudi district followed by Darjeeling (3238.3 ± 431.3mm) in the SHWB to as low as 1331.2 ± 224.3mm in Purulia district followed by Bankura (1371.4 ± 229.2mm) in the western plateau region (Table 2). Median of annual rainfall remained in between 2000mm to 3000mmin most of the districts in North Bengal, while in south Bengal it ranged from 1500 to 2000mm (Fig. 2a). In general the annual rainfall in GWB was more variable (CV:16.5% in west Mednapore to 24.6% in Kolkata) than SHWB(CV: 13.3% in Darjelling to 16.9% in Jalpaigudi). Most of the districts showed positive Skewness (Sk) with low Kurtosis (Ku) value, which affirmed that the annual rainfall is distributed asymmetrically and lies to the right of the mean with lack or minimum outliers (Fig. 2a). The Sk and Ku of Kolkata (1.06, 5.01), South 24 Parganas (1.08, 4.56) and Howrah (1.09, 4.79) showed a highly positive skewed distribution with a heavy tails compare to other districts (Table 2). During the study period 49% of the year (59) experienced negative rainfall anomaly, while 51% showed positive rainfall anomaly (Fig. 3a)

Likewise, seasonal rainfall varied widely among districts. Pre-monsoon rainfall recorded as low as 126.4 ± 53.1mm in Purulia district of western plateau fringe to maximum of 606.0 ± 183.6mm in Jalpaigudi district of SHWB (Table 2). Rainfall during the pre monsoon months highly varied in Malda district (CV: 52.1%) and most consistent in Darjeeling district (CV: 28.4%). Median of pre-monsoon rainfall was higher in the SHWB (200 to 600 mm); while it was lower (50 to 200 mm) in the western and southern part of the GWB (Fig. 2b).West Bengal as a whole received 254.1 ± 69.8mm pre-monsoon rainfall with 27.5% variability and 53% year deviated towards negative rainfall (Fig. 3b). Monsoon months (June-September) rainfall highly accumulated over sub Himalayan region (1358.2 ± 357.0 mm in Dakshin Dinajpurto 2939.7 ± 525.1 mmin Jalpaigudi district) (Table 2). On the contrary Gangetic West Bengal received comparatively lower monsoon rainfall 986.9 ± 232.4mm (Nadia district) to 1242.3 ± 249.7mm (East Mednapore)during 1901–2020. (Table 2 and Fig. 2c). Apart from this, the median of monsoon rainfall remained higher over sub Himalayan region (2000 mm to 3000 mm), which was closer to 1000 mm in Gangetic West Bengal (Fig. 2c). The occurrence of monsoon rainfall over the state as a whole was

1391.8 ± 165.9mm with the variability of 11.9%. Nearly 70% year received normal monsoon rainfall, while 16% year deficit and 14 year surplus rainfall (Fig. 3f).
Lowest accumulation of post-monsoon rainfall recorded in western plateau fringe area (Purulia: 108.4 ± 75.1mm) and highest inJalpaigudi district (193.9 ± 107.5mm) of SHWB (Fig. 2d). Post-monsoon rainfall was more consistent in Jalpaigudi (CV: 55.4%) district and highly variable in Maldah district (CV: 83.6%). The median of post-monsoon rainfall remained closer to 150mm in every district, though considerable numbers of outliers exists (Fig. 2d). During the study period (1901–2020) Purba Medinipur district experienced highest winter rainfall (42.1 ± 38.16mm), while Uttar Dinajpur (21.8 ± 19.4mm) received the lowest. Similar to post-monsoon rainfall considerable numbers of outliers exists in winter rainfall (Fig. 2e). Occurrence of winter rainfall (33.0 ± 24.7) found to be highly variable (75%) compared to all seasons of the state (Table 2).

3.4 Trend and magnitude of seasonal and annual rainfall

Mann-Kendall trend statistics revealed that, in the past century annual rainfall across the districts of sub Himalayan West Bengal (SHWB) declined (Table 3). Significant ($p < 0.05$) decrease occurred in the district of Dakshin Dinajpur at 3.6mm year^{-1}. Darjelling is the exception among SHWB districts where significant ($p < 0.05$) increase (3.3 mm year^{-1}) observed. On the contrary, significant ($p < 0.05$) increase of annual rainfall observed in most of the districts of Gangetic West Bengal (GWB: Purba Midnapore, Kolkata, Howrah, South 24 Parganas and North 24 Parganas) at the rate of 1.8 mm year^{-1} to 2.9 mm year^{-1}(Table 3, Fig. 4a). Pre-monsoon rainfall significantly ($p < 0.05$) increased in the districts of Darjeeling, Purulia at the rate of 0.3 mm year^{-1} to 0.7mm year$^{-1,}$ while significant decline occurred in Nadia district at 0.6 mm year^{-1} (Fig. 4b). Monsoon rainfall contributed nearly76% of the annual rainfall of West Bengal. Monsoon rainfall increased significantly ($p < 0.05$) over North 24 Parganas, Darjeeling, South 24 Parganas, Kolkata, Purba Medinipur and Howrah at 1.4 mm year^{-1} to 2.1 mm year^{-1}, while declined significantly ($p < 0.05$) in Dakshin Dinajpur district at 3.2 mm year^{-1} (Fig. 4c). Post-monsoon rainfall increased significantly ($p < 0.05$) over GWB (e.g. North 24 Parganas, South 24 Parganas) at the rate of 0.2 mm year^{-1}to 0.6 mm year^{-1}(Fig. 4d).The winter rainfall decreased non-significantly across all the districts except Dakshin Dinajpur, where significant ($p < 0.05$) decrease (@ 0.10 mm year^{-1})observed (Fig. 4e).

During the past century (1901–2020) both the annual as well as seasonal rainfall of West Bengal as a whole increased (at 0.02mm year^{-1} to 0.04mm year^{-1}) non significantly ($p > 0.05$) except winter rainfall, which decreased at 0.01mm year^{-1} (Table 3)

3.5 Percentage change of seasonal and annual rainfall

Percentage change of annual rainfall respective to the long period (1901–2020) average found to be positive across districts of GWB ranging from 7.7% (Paschim Mednapore) to 22.7% (North 24 Parganas). Conversely across SHWB districts negative deviation observed from − 25% (Dakshin Dinajpur) to -1.9% (Birbhum) (Table 3, Fig. 5a). Pre-monsoon rainfall in most of the districts deviated negatively ranging from 3.8–33.7%, however for the entire state it increased by 1.1% (Fig. 5b). Percentage change in both the monsoon and post monsoon rainfall across GWB deviated positively from 6.1–25.4% and 10.1–44.4%. Conversely it showed negative deviation across districts of SHWB for both the monsoon and post monsoon season (Fig. 5c-d). Post monsoon rainfall for the state as a whole showed maximum positive deviation (15.6%) from rest of the seasons, while winter season showed declining change during the study period (23.8%) (Fig. 5e). Besides, all the districts experienced declining deviation of winter rainfall from 10.8% (Birbhum) to 48% Dakshin Dinajpur (Table 3).

4 Discussions

Analysis of long period (1901–2020) rainfall revealed wide spatial variation in the distribution of annual and seasonal rainfall across West Bengal. Most of the districts of the GWB experienced more variability in seasonal and annual rainfall than the districts of SHWB. Exceptionally the post monsoon rainfall showed more evenness over the districts of SHWB. The coastal districts of GWB (e.g. South 24 Parganas, Kolkata, Howrah, Purba and Paschim Medinipur) received more winter rainfall compared to the SHWB and western plateau fringe area. This might be because of the cyclonic disturbances over coastal areas caused by the westerly wind from the Mediterranean region (Dimri et al. 2015; Hunt et al. 2018). Besides,a trough of retreating monsoon over the SHWB form convergence zone between the western disturbances and easterly wind from the Bay of Bengal. Due to the shifting of the trough towards Bay of Bengal (BOB) gains moist air from the ocean which causes heavy rain and thundershower over the coastal regions of Bengal (Attri and Tyagi 2010). At the same time the SHWB gets precipitation from the western disturbance in the form of snowfall (Chatterjee et al. 2016).

Most of the districts of GWB exhibited decreasing trend in pre-monsoon rainfall, while districts of SHWB and western part of West Bengal (Rarh Bengal: Purulia, Bankuraand Paschim Medinipur) revealed non-significant increasing trend.This corroborated with the findings of Choudhury et al.(2012) from mid altitude Meghalaya. Based on 1454 rain gauge station data (1951–2010) across India, Rathore et al. (2013) also reported increase in pre-monsoon rainfall across different sub Himalayan states of Northeast India e. g. Manipur, Mizoram, Nagaland, Meghalaya, Tripura and West Bengal. Extrapolated results from the analysis of long period (1871–2008) data based on 32 meteorological subdivisions covering entire country, Jain and Kumar (2012) reported an increasing trend in the pre-monsoon rainfall including SHWB. Our findings contradicted with Datta and Das (2019), and Mandal et al. (2013) but corroborated with Kundu and Mondal (2019), who reported decreasing pre-monsoon rainfall in all parts of GWB and increasing in all districts of SHWB. Besides, our findings of increasing trend in Rarah Bengal were supported by Mukhopadhyay et al. (2016).

Trend of annual rainfall declined in the SHWB and in the northern part of GWB (Bardhhaman, Birbhum, Nadia, and Murshidabad).Annual rainfall in the lower Gangetic plane or coastal Bengal and two districts of SHWB (Darjeeling and Cooch Behar) experienced increased annual rainfall. Likewise, monsoon rainfall trend followed the similar pattern as annual rainfall. Jhajharia et al. (2012) also reported a decreasing trend of monsoon rainfall from Assam in Northeast India (NEI). Previous researchers also reported a decreasing trend in monsoon rainfalls from different parts of India (Choudhury et al. 2012; Jain et al. 2013; Dash et al. 2015). Similarly, Nair et al. (2018) using high resolution IMD and Global Rainfall Climatology Project (GPCP) dataset also revealed comparable trends with our findings in pre-monsoon and monsoon rainfalls for SHWB region. Such declining trend in monsoon rainfall might be partially from the decrease in vertically integrated moisture transport (VIMT) over the BOB (Konwar et al. 2012).Apart, the weakening of monsoon might be because of the warmer tropical ocean, especially the central eastern Pacific and the western Indian Ocean (Roxy, 2015; Bidyabati et al. 2018).Our findings corroborated with Datta and Das (2019) who reported positive trend of monsoon and annual rainfall for the coastal districts of GWB and negative trend for SHWB. However, our trends of pre monsoon and monsoon rainfall for GWB contradicted with the findings of Mandal et al. (2013). This might be because of their single point and short period (1980–2010) of data analysis.

In case of post monsoon rainfall the districts of SHWB, except Darjeeling were experienced declining trend, while GWB revealed increasing trend. The finding contradicted with Datta and Das (2019) and Kundu and Mondal (2019), however supported by Mukhopadhyay et al. (2016). The winter rainfall was non significantly decreased over the entire state, which was supported by several researchers (Jain et al. 2013; Mukhopadhyay et al. 2016).

Our findings showed that the pre monsoon, monsoon and post monsoon rainfall in Darjeeling district increased significantly. This might be associated with the complex hilly terrain led orographic rainstorm.Moreover, dense forest cover of the district allowed higher volume of evapotranspiration, which might favored increasing rainfall. Mukhopadhyay et al. (2016) reported similar increasing trend of seasonal rainfall from the region by analyzing the dataset from 1901 to 2000. Similar to our findings significant decreasing trend in monsoon rainfall in Dakshin Dinajpur district was observed by Datta and Das (2019). In addition to this the non-significant negative trend of annual rainfalland winter rainfall in the district was documented by Kundu and Mondal (2019).

Increasing trend of pre monsoon rainfall over SHWB might be associated with the higher amount of aerosol concentration in this season, which largely responsible for heating up the regional atmosphere and thereby enhancd pre-monsoon rainfall by intensifying moisture gaining mechanism (Lau and Kim 2006). Similarly, decrease in aerosol concentration in the SHWB during monsoon season might be responsible for the declining trend in monsoon rainfall (Sarkar et al. 2015). In reverse, increasing events of severe cyclonic storms (SCS) as a consequence of global warming over north Indian ocean increased rainfall during the monsoon and post-monsoon seasons in different parts of West Bengal (Dong et al. 2016). Besides, insufficient moisture supply in SCS at post landfall stage owe to the decreasing trend in post monsoon rainfall over SHWB compared to GWB. Again the declining sea surface temperature and southward shifting of the Inter-Tropical Convergence Zone (ITCZ) accompanying by decreasing frequency of cyclones during the winter months in Bengal, which may responsible for the insignificant decline of winter rainfall (Khullar 2011).

Conclusions

The trend analysis of seasonal and annual rainfall by Mann-Kendall test statistics and Sen's slope estimator concluded that the spatio-temporal distribution of rainfall was drastically changed in West Bengal over the last 120 years. The significant increasing trend in annual and seasonal rainfall in the coastal districts of Gangetic West Bengal (annual: 1.8 mm year^{-1} to 2.9 mm year^{-1}, monsoon: 1.4 mm year^{-1} to 2.1 mm year^{-1} and post monsoon: 0.2 mm year^{-1} to 0.6 mm year^{-1}) and western drier region (although non significant) of West Bengal would be beneficial for rainwater harvesting and would help to overcome the water crisis and crop water stress in the regions. Moreover, such increasing trend over the coastal districts further raised the probabiliy of flood, inundation, land erosion, water stagnation and thus crop failure. The decreasing trend in pre monsoon rainfall and increasing trend in post monsoon rainfall over the districts of GWB indirectly indicated that the monsoon is being delayed on its arrival as well as its withdrawal, which has subsequent impacts on cropping cycles as well as agricultural economy. An increase in the post monsoon rainfall in every districts of GWB might be detrimental for Kharif crop harvesting. On the other hand most of the districts of sub Himalayan West Bengal (SHWB) showed a non-significant declining trend in annual as well as seasonal rainfall. The winter rainfall showed a clear reduction (0.01 mm year^{-1}) over the entire state during the study period, which alarmed the water crisis during winter crop cultivation. Overall, a decrease in annual and seasonal rainfall across the districts increased the possibility of drier condition and water scarcity. As a result, the agrarian economies as well as livelihood of the resource poor farming communities need to be coping up with the changing rainfall pattern *vis-à-vis* changing climate. Thus, the rational use of water resource, gradual shifting of crop calendar and cropping cycle is imperative in sustaining agricultural economy. Besides, the findings of this study will help in understanding the seasonal water budget, which is essential for devising crop planning, water security and overall livelihood security of the resource poor framers of the state.

Declarations

CRediT authorship contribution statement

P Halder conceptualized the work, collected data, adopted methodology, prepared spatial maps, and wrote preliminary draft.

R K Dey collected data and adopted methodology, statistically analyzed the data, prepared spatial maps, and wrote preliminary draft.

S Mandal contributed by statistical analysis, preparing tables and graphs, Writing -original draft, Writing - review & editing of final manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics approval

The authors ensure that the research followed necessary ethics approval norms and no waiver enjoyed for the study.

Consent to participate

Appropriate consent was obtained from the participants if any and will submit on request.

Consent for publication

All the authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript. Due consent of the affiliated institutions authors submit the manuscript for publication.

Data availability statement

The data that support the findings of this study are available in https://indiawris.gov.in/wris/#/rainfall

Acknowledgements

We thank to the Water Resource Information System (WRIS), Government of India for providing the data with free of cost.

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Table 2 and 3

Table 2 and 3 is available in the Supplementary Files section.

Figures

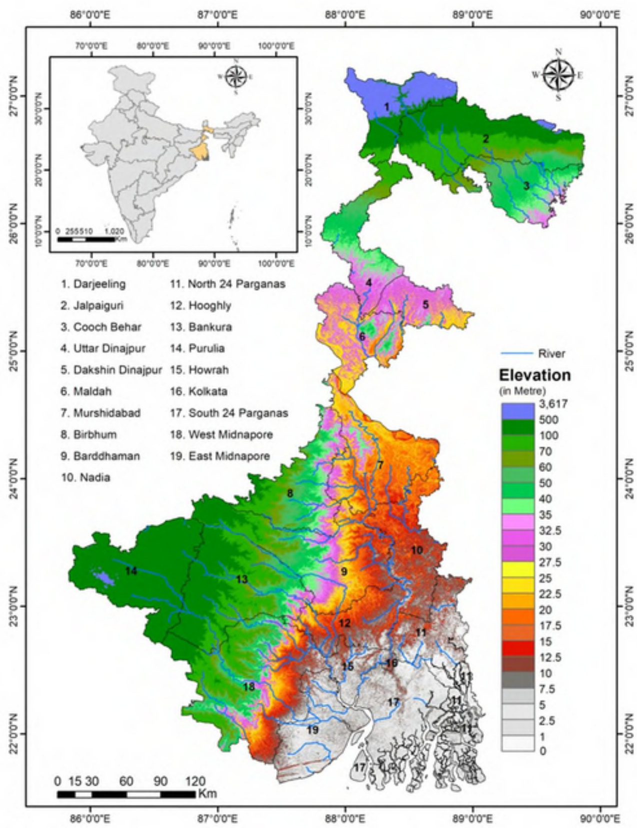

Figure 1

Location map of the study area (West Bengal) showing (a) district map (generated from http://www.diva-gis.org/gdata), and (b) elevation and river map (obtained from the Digital Elevation Model of Shuttle Radar Topography Mission, obtained from https://earthexplorer.usgs.gov/).

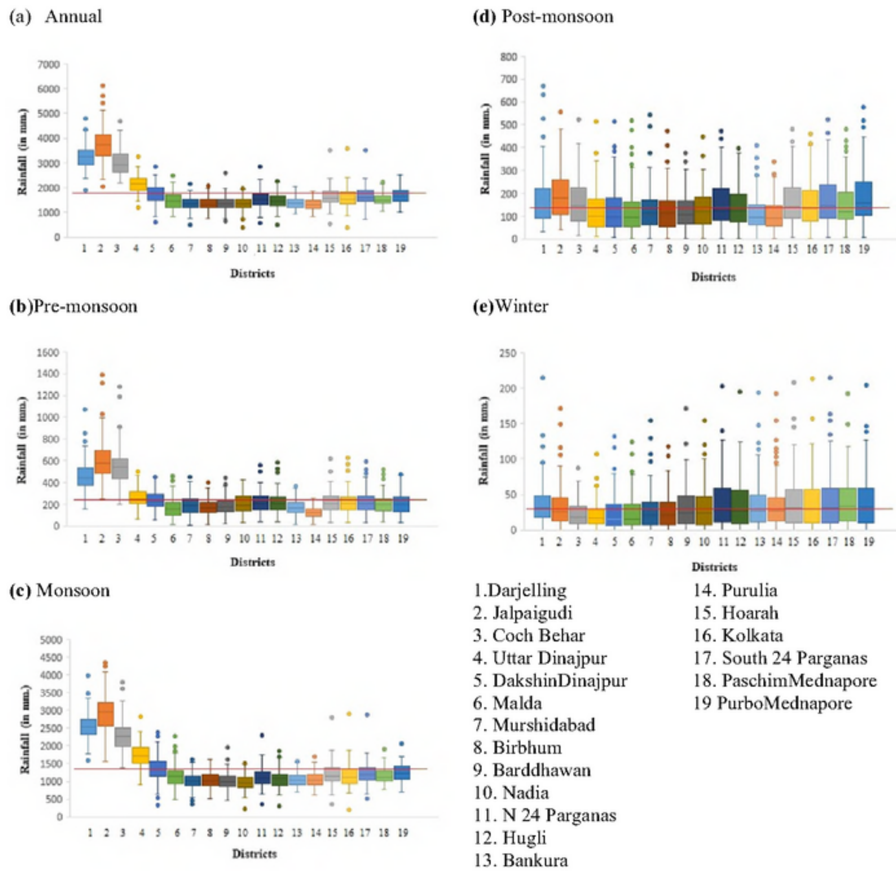

Figure 2

Box plots of annual (a) and seasonal (b-e) rainfall time series across all districts of West Bengal during 1901-2020.

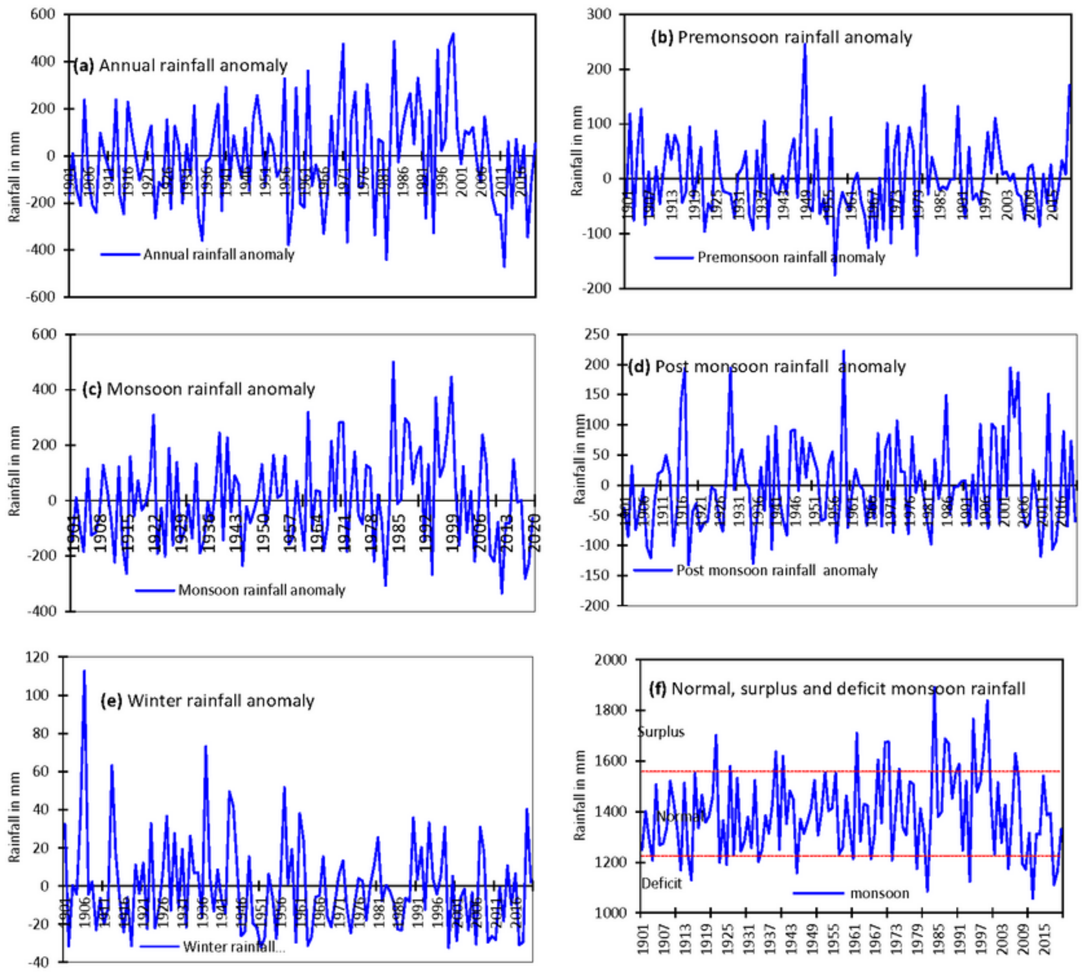

Figure 3

(a-e) Annual and seasonal rainfall anomaly respect to long period mean; **(f)** Normal, surplus and deficit monsoon rainfall during 1901-2020 in West Bengal

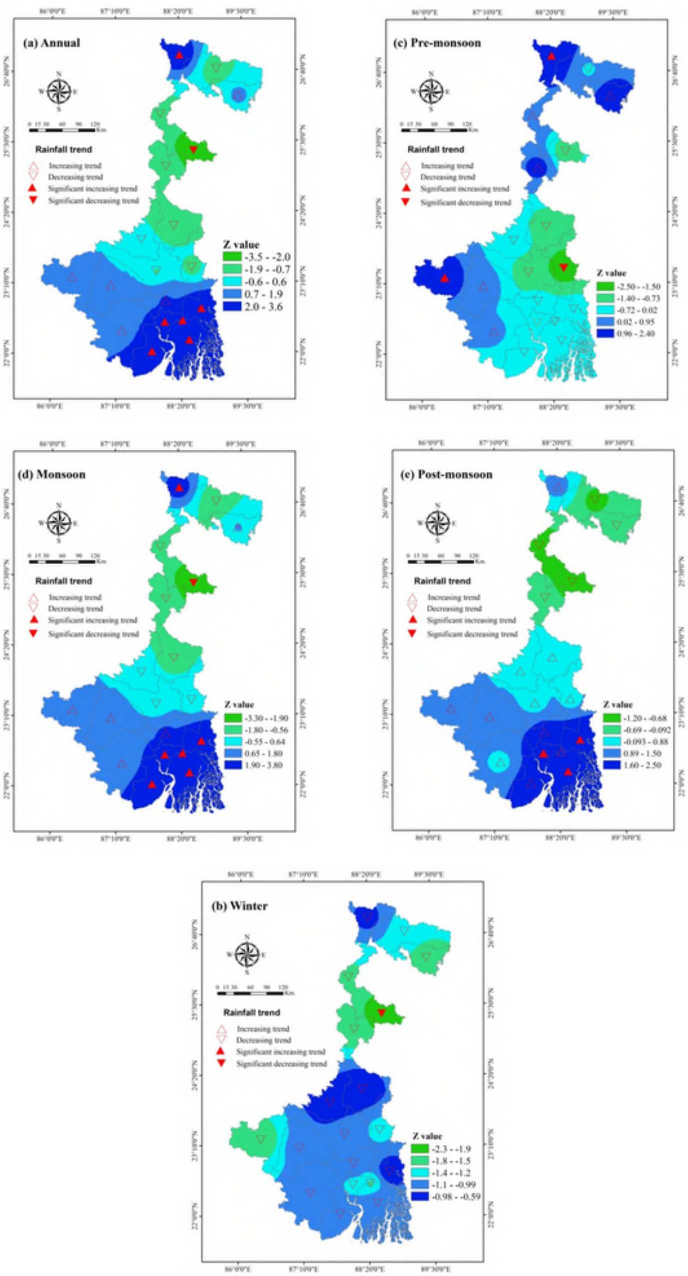

Figure 4

Nonparametric trend of annual (a) and seasonal (b-e) rainfall across different districts of West Bengal during 1901-2020

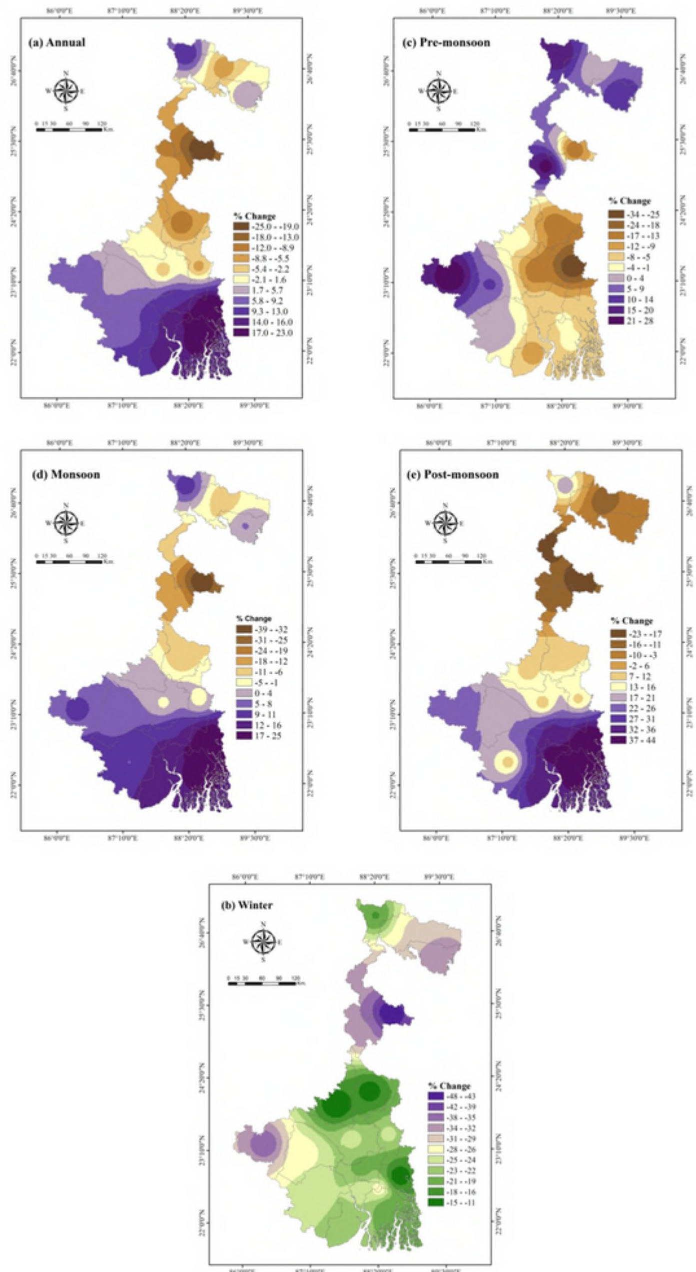

Figure 5

Percentage change of annual and seasonal rainfall respect to longperiod (1901-2020) average across 19 districts of West Bengal.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table2and3.docx
- Supplementarydata.xlsx