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20th Century District-level Spatio-Temporal Annual Rainfall Changes Over West Bengal

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Abstract: Present study attempted to quantify district wise annual rainfall change statistics over the West Bengal State using the monthly rainfall data from the Indian Meteorological Department during 1901-2000. The characteristic of mean annual rainfall varies abruptly from ~1491±301 mm in the thirteen south Bengal districts to ~2532±486 mm in six North Bengal districts. 30 years mean rainfall climatology indicates that the mean rainfall normally varies 3100-3900 mm in the sub-Himalayan districts namely Darjeeling, Cooch Behar and Jalpaiguri while it varies 1454-1505 mm in the south Bengal districts viz. Bardhaman, Nadia, Purulia and Bankura. Mann Kendall trend analysis shows that North Bengal has a consistent increasing slope during 1920s to 1980s as well as in the centennial time period (1901-2000). The rainfall trend has shifted from a negative slope to a highly positive slope during the transition of 1950s to 1980s for most of the districts of South Bengal. Percentage of annual rainfall change with respect to 1901-30 period indicates a deficient rainfall (1-10%) for the districts like Jalpaiguri, North and South Dinajpur, Malda, Burdwan, Nadia and Purulia, while, Darjeeling, Cooch Behar, Bankra, Hooghly, Midnapur and all others have shown an increasing trend of rainfall by 2-20% in the periods of 1931-60, 1961-90 and 1901-2000. So future crop planning has to be adjusted keeping in view deficient rain over North Bengal districts and surplus rain over South Bengal districts.

Keywords: Annual Rainfall; West Bengal; Trend.

Introduction

Now-a-days local level Government and other multi-level stake holders are planning to introduce many developmental related issues particularly implementing some new adaptation and mitigation strategies without knowing the exact past and future climate change information at district or local scale. All these attempts of developments and new strategies are more useful if we have long-term as well as short-term climate change information from a reliable source. Therefore, creating climate change information at local scale is of the top most priority research work for the climate scientists for helping multi-level stakeholders including Government agencies. There are huge evidences that unlike other climatic variables, rainfall is highly erratic in nature, which is changing its patterns and magnitudes within few kilometres apart. Indian summer monsoon (ISM) is the major component of the Asian summer monsoon, which significantly affects the lives of more than 60% of the world's population (Wang and Linho, 1990). ISM provides more than 80% of the total annual rainfall in India and directly relates to water resources, agriculture, ecosystem, health, and food security (Turner and Annamalai, 2012). Climate change may have significant impacts on the distribution of rainfall pattern over local, regional and global scale, which will in turn affect different sectors, and hence assessing the impacts of

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climate change on rainfall is a high-priority task. Global climate shift, reduction of forest cover and increasing aerosol due to human activity are the probable causes of change in rainfall pattern (Basistha et al., 2009).

Regional averaged rainfall analysis over the whole Indian subcontinent reveals that the annual and seasonal rainfall is free from any significant trend and typically random in nature (Kumar et al., 2010; Krishnamurthy and Krishnamurthy, 2014). Rainfall in annual and monsoon has decreased while there is a sign of increment in the winter, pre-monsoon and post-monsoon seasons. In the context of West Bengal (WB) state of India, trend analysis of rainfall shows that regional averaged monsoon rainfall in the Southern part (South Bengal) has a significant increasing trend (Slope = +91.0 mm/100 years) and the Sub-Himalayan WB has a non-significant increasing trend (Slope = 57.2 mm/100 years) during the period 1901-2003 (Guhathakurta and Rajeevan, 2008). A similar type of study by Naidu et al. (2009) showed that South Bengal has an increasing trend while Sub-Himalayan WB has a decreasing trend of monsoon rainfall during the period 1871-2005. No long-term trends were found for the premonsoon rainfall over Gangetic WB and its neighbourhood during the period 1901–1992 (Sadhukhan et al., 2000), while during the period 1901-2003 Guhathakurta and Rajeevan (2008) reported a non-significant decreasing trend (Slope = –6.7 mm/100 years) of premonsoon rainfall over South Bengal whereas Sub-Himalayan WB has a non-significant increasing trend (slope = +10.5 mm/100 years). During the winter and postmonsoon season the same study has reported a non-significant decreasing trend of rainfall for Sub-Himalayan WB, whereas South Bengal has shown increasing trend in postmonsoon and decreasing trend in winter. The total annual rainfall over the state has an overall non-significant increasing trend. Das et al. (2012) reported an increase in the annual rainfall during the period 1901-2000 over the Gangetic West Bengal and its neighbourhood.

Seasonal rainfall distribution over WB shows that winter is the driest season of the year which contributes only 1-3.5% of the average annual rainfall. The hottest premonsoon season receives 8-17% of average annual rainfall, which is mostly associated with the premonsoon thunderstorm or 'Norwester' also popularly known as '*Kalbaisakhi*'. Bay of Bengal branch of the Indian Ocean monsoon brings 73-80% rainfall to the state from June to September. Monsoon rainfall has played a vital role in the last three decades as during 1970-2000 there has been a significant increase in productivity of food grains over the state of WB, and the state now has a surplus of food (Raychaudhuri and Das, 2005). The post-monsoon season shares 5-15% of average annual rainfall.

There have been plenty of studies based on the distribution of rainfall over the whole of WB and its neighbourhood in different seasons. But, there is a scattered picture of exact rainfall distribution at district level, which is essential for implementing any suitable adaptation and mitigation strategies by the local district level government to combat climate change effect. In this paper we have explicitly divided 19 districts of WB into two separate and distinct regions on the basis of amount of annual rainfall received and the geographical location. Six districts from Northern part namely Darjeeling, Jalpaiguri, Cooch Behar, North Dinajpur, South Dinajpur and Malda collectively are named as North Bengal (Annual rainfall >1580 mm) while rest of the thirteen districts of Southern part namely Birbhum, Murshidabad, Bardhaman, Nadia, Purulia, Bankura, Hooghly, North 24 Parganas, West Midnapore, Howrah, Kolkata, South 24 Parganas and East Midnapore are together termed as South Bengal (Annual rainfall mostly <1500). The main objective of the study is to address the statistical distribution of rainfall in terms of mean climatology, trend analysis and percentage change of rainfall over different districts of WB in annual scale for a better understanding of the stakeholders, scientific community and for the general public.

Materials and Methods

Description of the Study Area and Data Used

The present study was carried out over the state of WB, extending from 21.20° N to 27.32° N latitude and 85.50° to 89.52° E longitudes in the eastern part of India (Figure 1). The total area of the state is 88,752 sq.km, which is 2.7% of the total area of the country. Monthly total rainfall data for 19 districts of WB state have been collected from India Meteorological Department (IMD), Pune during the period 1901-2000. This data has been used as observational data for the present study.

Methodology

Time series analysis was carried out for each district and their regional average under North Bengal and South. Statistics namely Mean and Coefficient of Variance (CV) were used to define the rainfall distribution over the study region while Mann Kendall trend test was employed to find out monotonic trend in the rainfall time series. Subsequently percentage change of annual

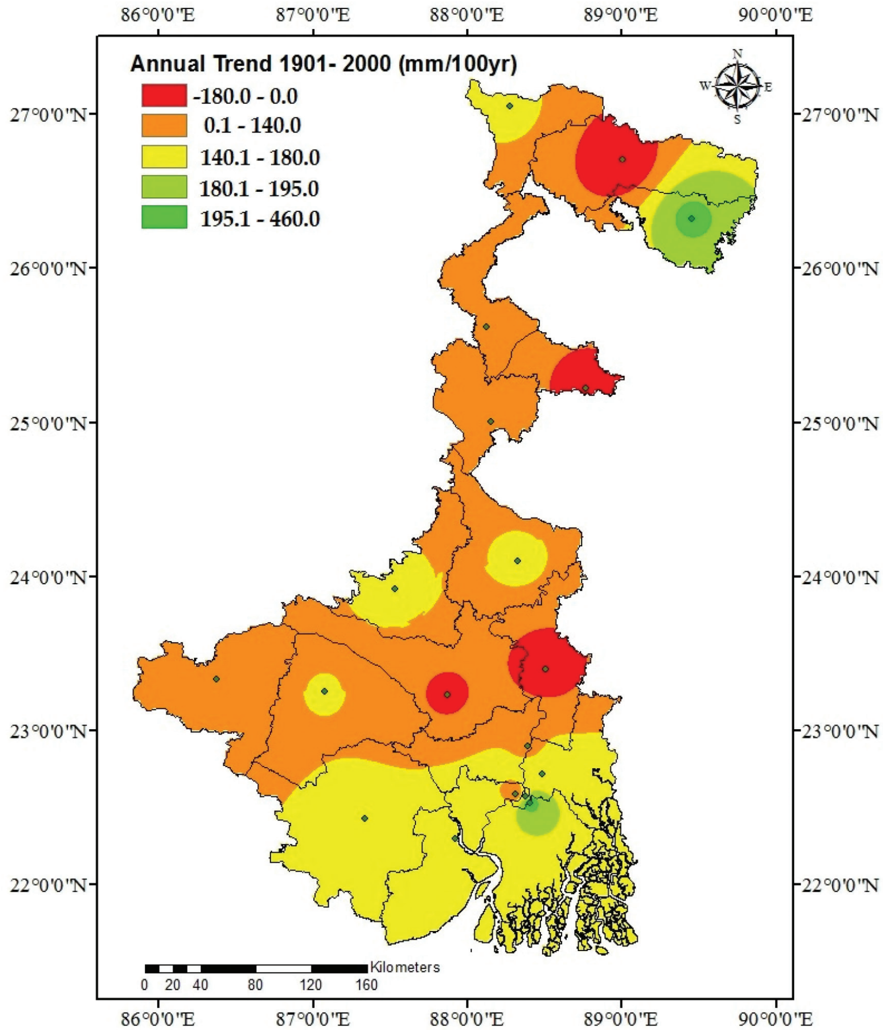

Figure 1: Spatial variation of long-term annual rainfall trends during 1901-2000 period estimated for the 19 different districts over West Bengal.

rainfall has been calculated for two short-term periods (1931-60 i.e. 1950s and 1961-1990 i.e. 1980s) and the long-term period (1901-2000) to visualize the climate change over WB with respect to the first period of 1901-30 which is termed as reference period. The expression of calculation is:

Percentage change = ((target period – reference period)/ reference period) × 100

Mann-Kendall Trend Test

Mann Kendall test is a non-parametric test for detection of monotonic trend in the time series of any frequency distribution. It is based on the test statistics S defined as (Yue et al., 2002a):

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}\left(x_{\mathrm{j}} - x_{\mathrm{i}}\right)$$

Here, x_{j} are the sequential data values, N is the length of the data set (for our case N = 11) and

$$\operatorname{sgn}(y) = \begin{cases} 1 & \text{if} \quad (y > 0) \\ 0 & \text{if} \quad (y = 0) \\ -1 & \text{if} \quad (y > 0) \end{cases}$$

For $N \geq 8$, the statistic S is approximately normally distributed with mean $\mu = 0$ and variance is

$$V(S) = \frac{N(N-1)(2N+5) - \sum_{i=1}^{M} t_{\mathrm{i}}\left(t_{\mathrm{i}}-1\right)\left(2t_{\mathrm{i}}+5\right)}{18}$$

where M is the number of tied groups and t_{i} is the size of the i^{th} tied group. The standardized test statistic Z is computed by

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{V(S)}} & \text{when } S > 0 \\ 0 & \text{when } S = 0 \\ \dfrac{S+1}{\sqrt{V(S)}} & \text{when } S < 0 \end{cases}$$

Sen's Slope Estimator Test

The magnitude of trend is predicted by the Sen's estimator. Here, the slope (T_i) of all data pairs is computed as (Sen, 1968)

$$T_i = \frac{x_j - x_k}{j - k}, \text{ for } i = 1, 2 \ldots, N.$$

Here x_j and x_k are considered as data values at time j and k ($j > k$) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is computed as

$$Q_{med} = T_{(N+1)}/2$$

if N appears odd, and it is considered as

$Q_{med} = [T_{N/2}+T_{(N+2)/2}]/2$ if N appears even. At the end, Q_{med} is computed by a two sided test at 100 (1 – α) % confidence interval and then a true slope can be obtained by the non-parametric test. Positive value of Q_i indicates an upward or increasing trend and a negative value of Q_i gives a downward or decreasing trend in the time series.

Results and Discussion

Analysis of District-wise Rainfall

The district-wise mean annual rainfall along standard deviation (±SD) and Coefficient of Variation (C.V. in %) during three distinct 30-years periods namely 1901-30 (1920s), 1931-60 (1950s), 1961-90 (1980s) in addition to a centennial scale of 1901-2000 period were computed and results were summarized in Table 1. These multi-temporal scale information provide the detailed pictorial insight about district level accurate rainfall fluctuations and patterns. In addition to district, the regional averaged rainfall statistics for North Bengal and South Bengal are also presented in Table 1.

The annual rainfall of all 19 districts for the first period of 1901-1930 ranged from 1331.1 to 3992.0 mm, the maximum was received in Jalpaiguri and minimum was received in Bankura. The SD varied from 187.9 to 630.7 mm. The CV ranged from 11.0 to 25.5%. Among 19 districts of WB, the mean maximum annual rainfall (3992.0±630.7 mm) was recorded in Jalpaiguri district among the six North Bengal districts while from 13 south Bengal districts, Kolkata received the maximum annual rainfall (1641.2±258.9 mm). The SD was highest in Jalpaiguri, and minimum in West Midnapore which showed the departure of rainfall from the normal. The CV was highest in South Dinajpur indicating the high variability of rainfall. The variability of rainfall was lowest at Darjeeling because it received rain throughout the year. Similarly, during the period of 1931-60, the mean annual rainfall slightly decreased in three districts like Darjeeling, Cooch Behar and North Dinajpur over North Bengal and nine districts from south Bengal (Table 1). The increased mean rainfall during this period from the previous three decades (1901-30) were 3.3, 125.5, and 30.5 mm for Jalpaiguri, South Dinajpur, and Malda districts of North Bengal respectively. In South Bengal, South 24 Parganas, Howrah, Hooghly and Murshidabad districts received 59.5, 120.5, 114.6 and 7.4 mm higher rainfall respectively than 1901-30. The SD and CV were highest in Jalpaiguri (559.0 mm) and North Dinajpur (23.9%) respectively indicating the presence of a large number of rainless days and variability of rainfall in north Bengal.

Similarly during the period of 1961-90, the mean rainfall did not follow a similar trend to that of the previous periods. In this period rainfall increased only in two districts namely in Darjeeling and Cooch Behar of North Bengal but in South Bengal, rainfall amount was increased in eight districts (North 24 Parganas, South 24 Parganas, Bankura, Birbhum, Bardhaman, East Midnapore, Kolkata, and West Midnapore), except Howrah, Hooghly, Murshidabad, Nadia and Purulia. Out of the 19 districts, Jalpaiguri received maximum rainfall (3802.6±687.6 mm) and Nadia received minimum rainfall (1271.0±370.4 mm). Only South 24 Parganas district recorded increasing amount of rainfall and North Dinajpur, Nadia and Purulia districts received decreasing trend during the 90 years (1901-1990) study. High SD value indicated the existence of a large number of days without rainfall. The CV ranged from 14.7 to 30.1% indicating the variability of rainfall in the different districts under study. The maximum and minimum variability were recorded in Malda and Darjeeling respectively.

During the long-term time period (1901-2000), the maximum mean rainfall was recorded in Jalpaiguri (3930.2±641.9 mm) while the minimum was recorded in Nadia (1319.1±326.3 mm). The high SD values indicated the persistence of dry spells. The CV ranged from 13.9 to 25.7% indicating variability in annual rainfall pattern.

Table 1: Variation of district-wise annual rainfall statistics of north and south Bengal districts in different climatological time periods along with regional and state averaged

S No.		Lat (ºN)	Lon (ºE)	1901-30			1931-60			1961-90			1901-2000		
				Mean (mm)	*SD (+/-)*	*CV (%)*	*Mean (mm)*	*SD (+/-)*	*CV (%)*	*Mean (mm)*	*SD (+/-)*	*CV (%)*	*Mean (mm)*	*SD (+/-)*	*CV (%)*
North Bengal															
1.	Darjeeling	27.05	88.27	3094.7	341.9	11.0	3036.0	369.7	12.2	3153.2	462.1	14.7	3123.3	435.2	13.9
2.	Jalpaiguri	26.70	89.00	3992.0	630.7	15.8	3995.4	559.0	14.0	3802.6	687.6	18.1	3930.2	641.9	16.3
3.	Cooch Behar	26.32	89.45	3249.9	567.8	17.5	3079.1	420.5	13.7	3756.5	827.2	22.0	3347.0	678.5	20.3
4.	N Dinajpur	25.62	88.12	1581.8	362.5	22.9	1544.7	369.1	23.9	1511.9	261.3	17.3	1571.6	403.1	25.7
5.	S Dinajpur	25.22	88.76	1717.9	438.1	25.5	1843.4	395.6	21.5	1606.1	325.9	20.3	1721.3	392.6	22.8
6.	Malda	25.00	88.15	1496.9	339.5	22.7	1527.4	268.5	17.6	1360.5	409.4	30.1	1493.2	369.4	24.7
Regional average of North Bengal				**2522.2**	**446.8**	**19.2**	**2504.3**	**397.1**	**17.2**	**2531.8**	**495.6**	**20.4**	**2531.1**	**486.8**	**20.6**
South Bengal															
1.	Birbhum	23.92	87.53	1345.7	206.7	15.4	1312.5	253.0	19.3	1377.4	308.0	22.4	1374.7	280.6	20.4
2.	Murshidabad	24.10	88.32	1375.2	225.5	16.4	1382.6	288.9	20.9	1367.8	262.8	19.2	1410.4	299.1	21.2
3.	Bardhaman	23.23	87.87	1404.7	218.3	15.5	1281.9	215.2	16.8	1311.2	252.4	19.3	1341.2	238.8	17.8
4.	Nadia	23.40	88.50	1378.7	210.4	15.3	1333.1	313.2	23.5	1271.0	370.4	29.1	1319.1	326.3	24.7
5.	Purulia	23.33	86.37	1353.9	215.2	15.9	1326.3	216.9	16.4	1282.1	277.6	21.6	1331.3	239.8	18.0
6.	Bankura	23.25	87.07	1331.1	198.0	14.9	1266.3	213.6	16.9	1390.9	304.8	21.9	1343.7	249.2	18.5
7.	Hooghly	22.90	88.39	1415.6	210.4	14.9	1530.2	322.9	21.1	1458.1	365.5	25.1	1479.0	303.6	20.5
8.	N 24 Parganas	22.72	88.48	1568.2	232.9	14.9	1549.7	362.7	23.4	1689.5	388.1	23.0	1611.3	332.9	20.7
9.	W Midnapore	22.43	87.33	1488.0	187.9	12.6	1474.7	265.5	18.0	1575.8	311.3	19.8	1525.5	266.7	17.5
10.	Howrah	22.59	88.31	1576.9	281.5	17.9	1697.5	337.2	19.9	1569.6	341.6	21.8	1616.2	319.7	19.8
11.	Kolkata	22.57	88.37	1641.2	258.9	15.8	1580.7	286.9	18.1	1729.5	351.6	20.3	1673.2	314.9	18.8
12.	S 24 Parganas	22.53	88.40	1582.8	230.9	14.6	1642.2	309.6	18.9	1942.1	568.8	24.8	1762.2	444.2	25.2
13.	E Midnapore	22.30	87.92	1562.5	262.1	16.8	1527.2	293.1	19.2	1609.1	311.1	19.3	1597.4	308.6	19.3
Regional average of South Bengal				**1463.4**	**226.1**	**15.5**	**1454.2**	**283.0**	**19.4**	**1505.7**	**339.5**	**22.1**	**1491.2**	**301.9**	**20.2**
West Bengal as a whole				**1797.8**	**295.7**	**16.6**	**1785.8**	**319.0**	**18.7**	**1829.7**	**388.8**	**21.6**	**1819.6**	**360.3**	**20.3**

The bold figures represent the regional averaged

South Bengal district received annual rainfall from 1454 mm to 1641 mm compared to higher rainfall from 2504-2623 mm while all Bengal annual rainfall varies 1785 mm to 1955 mm.

Analysis of District-wise Rainfall Trends

The district-wise rainfall change trends as calculated from the Sen's slope are presented in Table 2 for different temporal periods. During the time period from 1901-1930, highly increasing trend of the rainfall was observed in Jalpaiguri (Slope = 565.5 mm/30 years) and Malda (Slope = 460.5 mm/30 years) districts. The increasing slope of rainfall ranging from 17.4 to 185.8 mm/30 years was observed in North 24 Parganas, Cooch Behar, Darjeeling, South Dinajpur, Bankura, Howrah and Purulia districts. All the districts of North Bengal have shown increasing trend during the 1920s while in South Bengal, most of the districts (9 numbers) showed decreasing trend of the rainfall. The districts Birbhum (Slope = –243.7 mm/30 years) and Murshidabad (Slope = –183.0 mm/30 years) districts showed highly decreasing trend. Table 2 shows that during the 1920s the South Bengal has a non-significant decreasing slope, while the North Bengal and the West Bengal as a whole has non-significant increasing slope. During 1931-1960, the highly increasing trend was observed in Nadia, South Dinajpur and Jalpaiguri districts (Slope = 197.7 to 475.0 mm/30 years). Most of the districts of South Bengal (11 numbers) showed the decreasing trend (Slope = –10.4 to –318.7 mm/30 years) of the rainfall except in Nadia and Purulia districts. During the 1950s North Bengal has shown an increasing trend (Slope = 49.4 mm/30 years) while South Bengal and West Bengal as a whole has shown non-significant decreasing trend. During next 30 years period (1961-1990), most of the districts of West Bengal (16 numbers) has shown mostly significant (at 5%) and high increasing trend (Slope = 126.2 mm/30 years to 780.5 mm/30 years).

Table 2: District-wise annual rainfall change trends (mm/time period) calculated from Mann-Kendall trend test and Sen's slope in different 30-year climatological periods and the long term time period

S.No.	*District Name*	*1901-30*	*1931-60*	*1961-90*	*1901-2000*
North Bengal					
1.	Darjeeling	+54.4	+184.5	-757.7*	+130.3
2.	Jalpaiguri	+565.5	+475.0	-120.0	-97.0
3.	Cooch Behar	+36.6	-332.5	+459.4	+393.8*
4.	North Dinajpur	-80.5	-30.0	+127.6*	0.0
5.	South Dinajpur	+66.6	+227.3	+556.6*	-43.3
6.	Malda	+460.5*	-304.5	+328.4	-11.9
Regional average of North Bengal		**+140.4**	**+49.4**	**+224.2**	**+90.6**
South Bengal					
1.	Birbhum	-243.7	-219.0	+548.1*	+185.6
2.	Murshidabad	-183.0	-78.0	+283.2*	+137.8
3.	Bardhaman	-63.3	-242.5	+154.2	-79.5
4.	Nadia	-141.2	+197.7	-125.1	-178.9
5.	Purulia	+185.8	+0.4	+396.9*	+34.5
6.	Bankura	+93.4	-226.3	+526.1*	+155.8
7.	Hooghly	-107.3	-66.9	+288.1	+120.4
8.	North 24 Parganas	+17.4	-13.6	+473.1	+177.3
9.	West Midnapore	-17.5	-10.4	+456.1*	+146.6
10.	Howrah	+140.9	-59.3	+18.2	+19.3
11.	Kolkata	-44.5	-243.9	+440.6	+194.7*
12.	South 24 Parganas	-37.5	-318.7	+780.5*	+458.2*
13.	East Midnapore	-20.3	-190.8	+126.2	+184.4
Regional average of South Bengal		**-40.3**	**-91.0**	**+333.1***	**+151.0***
West Bengal as a whole		**+62.5**	**-45.9**	**+303.9***	**+134.7**

The Darjeeling, Nadia and Jalpaiguri districts only shown high decreasing trend (Slope = –120.0 mm/30 year to –757.7 mm/100 year) during this time period. Table 2 reveals that North Bengal, South Bengal and West Bengal as a whole have shown increasing trends during the 1980s, reflecting a clear signal of rainfall change pattern from the 1920s and 1950s.

During the long-term period from 1901-2000 only two districts namely Cooch Behar and South 24 Parganas showed the highly increasing trend (Slope = 393.8 and 458.2 mm/30 years respectively) (Figure 2, Table 2). In the whole West Bengal during this time period, most of the districts (13 numbers) showed the increasing trend of annual rainfall except Jalpaiguri, South Dinajpur, Nadia, Bardhaman, Malda (Figure 2, Table 2). The increasing trend of rainfall in the districts Howrah, Purulia, Hoogly, Darjeeling, Murshidabad, West Medinapur, Birbhum and Kolkata varies from 19.3 to 194.7 mm/100 years.

Detection of Climate Change Signal

The regional averaged annual rainfall over the whole of West Bengal during the three consecutive periods of 1901-30, 1931-60 and 1961-90 are 1797.8 mm, 1785.8 mm, 1829.7 mm respectively indicating an increasing rainfall after 1950s over the study region. The trend

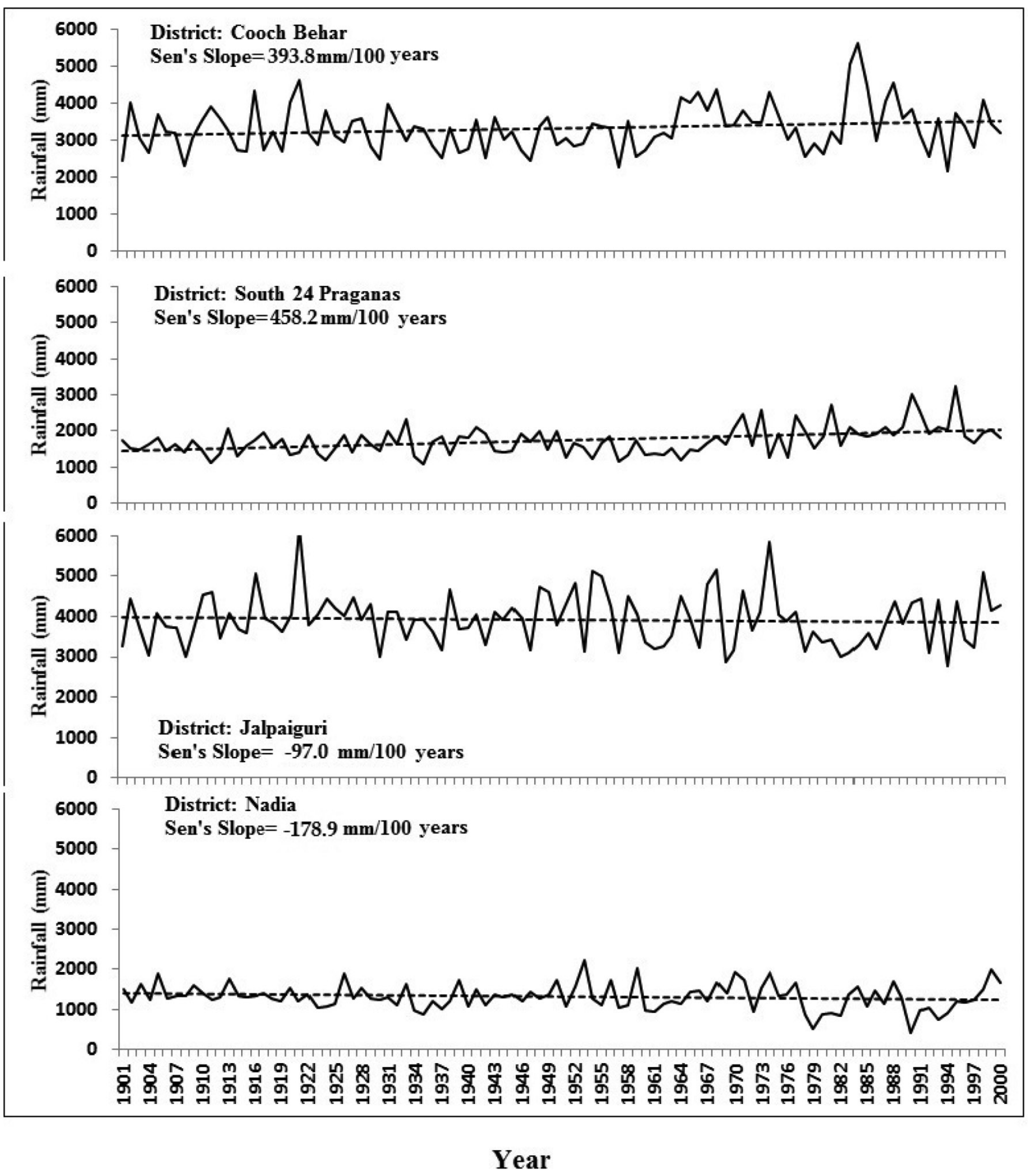

Figure 2: Variation of temporal annual rainfall during 1901-2000 period for two selected districts having maximum increasing rainfall trends in south (South 24 Paraganas) and north (Cooch Behar) Bengal along with two districts receiving maximum decreasing rainfall trends in south (Nadia) and north (Jalpaiguri) Bengal.

analysis of annual rainfall shows irregular characteristics over West Bengal as a whole. The annual rainfall has an increasing slope during the 1920s, which reversed during the 1950s and again suddenly changed to a high increasing slope during the 1980s. From 1950s to 1980s the rainfall trend has shown a sudden shift over most of the districts, North Bengal, South Bengal and West Bengal as a whole. Figure 3 shows the percentage change of annual rainfall during 1950s, 1980s and the long-term time period 1901-2000 with respect to the mean annual rainfall received during 1901-30. Over whole of West Bengal rainfall is found to be both increased (1.5-2%) and decreased (1%) during the period 1961-90, 1901-2000 and 1931-60 respectively. Similar results were found for South Bengal. In north Bengal the rainfall has not shown any drastic change during 1961-90 and 1901-2000 while decreased (1%) during 1931-60. In north Bengal, Cooch Behar district has shown a 5% decrease and 15% increase of rainfall during 1931-60 and 1961-90 respectively whereas a 3% increase during the long term time period 1901-2000 is found over the same district. In south Bengal, South 24 parganas has shown 3% and 23% increase of rainfall during 1920s and 1950s respectively whereas the long term increase is ~11%. In South Bengal, except Bardhaman, Nadia and Purulia all other districts have shown a surplus (1-23%) of rainfall during the 1980s and the long term 1901-2000 time period. In the North Bengal, except Cooch Behar and Darjeeling most of the districts have shown deficient rainfall (5-10%) during the different time period.

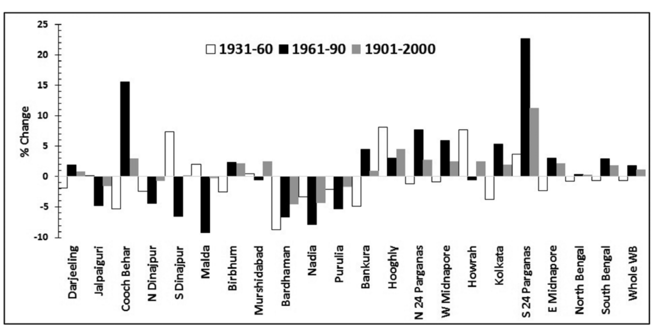

Figure 3: District-wise percentage change (in %) of annual rainfall for different time periods with respect to 1901-30.

Conclusion

The regional average rainfall over North Bengal region (~2532 mm) is higher than South Bengal region (~1492 mm). The mean annual rainfall during the periods of 1961-90, 1901-2000 over whole of West Bengal was shown a surplus (1.5-2%) whereas it was deficient (1%) during the period 1931-60 with respect to the mean annual rainfall received during 1901-30. In South Bengal, except Bardhaman, Nadia and Purulia all other districts have shown a surplus (1-23%) of rainfall during the 1980s and the long term 1901-2000 time periods. In North Bengal, except Cooch Behar and Darjeeling most of the districts have shown deficient rainfall (5-10%) during different time periods. The reason may be decrease of thunderstorm activity during pre-monsoon and western disturbances in the winter as well as weakening southwest monsoon over North Bengal as compared to South Bengal, which needs to be further studied. The districts namely Darjeeling, Jalpaiguri and Cooch Behar falling under North Bengal has received rainfall more than 3000 mm whereas South Bengal districts namely North 24 Parganas, Howrah, Kolkata, South 24 Parganas and East Midnapore have received annual rainfall of greater than 1600 mm. The regional averaged annual rainfall over the whole of West Bengal during the three consecutive periods of 1920s, 1950s and 1980s are 1797.8 mm, 1785.8 mm, 1829.7 mm respectively indicating an increasing rainfall over the study region. Mann-Kendall trend analysis shows that the rainfall over North Bengal has a consistent increasing slope from 1920s to 1980s through 1950s as well as in the centennial time period (1901-2000).

Some irregularities in the rainfall trend were found in South Bengal and West Bengal regional rainfall i.e. the rainfall trend has shifted from a negative slope to a highly positive slope during the transition of 1950s to 1980s. On the other hand the increasing trend of rainfall in the long term time period 1901-2000 has dominated the short term decreasing trends of 1920s, 1950s and 1980s. In South Bengal districts rainfall has increased by ~150 mm/100 years during 1901-2000 while in North Bengal it increased only by 90 mm but South Bengal has shown an decreasing trend in 1901-30 and 1931-60 periods. Why rainfall has increased in the last century both in North and South Bengal has to be investigated but primary reason may be increased amount of urbanization, deforestation and land use activities etc. over the West Bengal region which may have enhanced more warming resulting in more evaporation and more rainfall. The variation of rainfall between North and South Bengal may have arisen due to local geographical variation mainly due to topographical influences in the North Bengal and presence of sea in extreme South Bengal and other small scale features like soil characteristic and small size mountains in the western part of South Bengal where water resources are very limited and scanty.

References

Basistha, A., Arya, D.S. and Goel, N.K., 2009. Analysis of historical changes in rainfall in the Indian Himalayas. *International Journal of Climatology*, **29(4):** 555-572.

Das, L., Banerjee, S., Saha, G., Saha, A. and Rai, S.K., 2012. 20th century rainfall change over Gangetic West Bengal and its neighbourhood. *Journal of Agrometeorol*, **14:** 58-66.

Guhathakurta, P. and Rajeevan, M., 2008. Trends in the rainfall pattern over India. *International Journal of Climatology*, **28(11):** 1453-1470.

Krishnamurthy, L. and Krishnamurthy, V., 2014. Decadal scale oscillations and trend in the Indian monsoon rainfall. *Climate Dynamics*, **43(1-2):** 319-331.

Kumar, V., Jain, S.K. and Singh, Y., 2010. Analysis of long-term rainfall trends in India. *Hydrological Science Journal*, **55(4):** 484-496.

Naidu, C.V., Durgalakshmi, K., Muni Krishna, K., Ramalingeswara Rao, S., Satyanarayana, G.C., Lakshminarayana, P. and Malleswara Rao, L., 2009. Is summer monsoon rainfall decreasing over India in the global warming era? *Journal of Geophysical Research: Atmosphere*, **114(D24)**.

Raychaudhuri, A. and Das, T.K., 2005. WB Economy: Some Contemporary Issues. Allied Publishers.

Sadhukhan, I., Lohar, D. and Pal, D.K., 2000. Premonsoon season rainfall variability over Gangetic WB and its neighbourhood, India. *International Journal of Climato*logy, **20(12):** 1485-1493.

Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the Americal Statistical Association*, **63(324):** 1379-1389.

Turner, Andrew G. and Annamalai, S.H. 2012. Climate Change and the South Asia Summer Monsoon. *Nature Climate Change*, **12:** 587-595.

Wang, B. and Rui, H.L., 1990. Synoptic climatology of transient tropical intraseasonal convective anomalies: 1975-1985. *Meteorology and Atmospheric Physics*, **44:** 43–61.

Yue, S., Pilon, P. and Cavadias, G., 2002. Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology*, **259(1):** 254-271.