MAUSAM, **68**, 4 (October 2017), 713-722

556.121 : 556.162 “32” (540.33)

Annual and seasonal variability of wet day frequency in West Bengal, India

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(*Received 29 September 2016, Accepted 13 July 2017*)

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सार - वार्षिक, मॉनसून पूर्व, मॉनसून, मॉनसूनोत्तर और शीत ऋतु की प्रवृत्तियों के साथ दशकों में वार्षिक और मौसमी परिवर्तनशीलता को जानने के लिए 1901 से 2000 तक की अवधि में पश्चिम बंगाल के मासिक आर्द्र दिनों के आवृत्ति आँकड़ों का विश्लेषण किया गया है। गैर-प्राचलीय पद्धति (मान-केंडल) से पता चला कि अधिकांश जिलों में मॉनसून के दौरान कमी की प्रवृत्ति तथा मॉनसून पूर्व, मॉनसूनोत्तर और शीत ऋतु के दौरान वृद्धि की प्रवृत्ति रही। विभिन्न दशकों में सांख्यिकीय प्राचलों (माध्य, एस डी, स्कयूनेस और कुर्टोसिस का गुणांक) में देखे गए परिवर्तन पश्चिम बंगाल में आर्द्र दिनों की आवृत्ति के बदलते पैटर्न को दर्शाते हैं।

ABSTRACT. The monthly wet day frequency data of West Bengal for period 1901-2000 were analyzed to know annual and seasonal variability over decades along with annual, pre-monsoon, monsoon, post-monsoon and winter trends. The non-parametric approach (Mann-Kendall) revealed that the most of the districts shows the decreasing trend during monsoon and increasing trend during pre, post monsoon and in winter season. The changes observed in the statistical parameters (mean, SD, coefficient of skewness and kurtosis) during different decades which reflect the changing pattern of wet-day frequency in West Bengal.

Key words – Trend analysis, Sen’s method, Mann-Kendall test,

1. Introduction

Detection of changes in long time series of hydrological data is an important and of increasing interest. The analysis considering the distribution-free methods that are particularly suited to hydrological data is quite useful in a wide range of situations under minimal data assumptions.

Scientific evidences show there is a changing pattern of monsoonal period in India and in present scenario it is difficult to predict the exact monsoon season (Parthasarathy *et al.*, 1988; Ramanathan *et al.*, 2005; Auffhammer *et al.*, 2006).

Brunetti *et al.*, 2001, studied Changes in total precipitation, rainy days and extreme events in Northeastern Italy found negative trend in the number of wet days associated with an increase in the contribution of heavy rainfall events to total precipitation.

Alexander *et al.*, 2006 found precipitation indices show a tendency toward wetter conditions throughout the 20th century.

Kumar and Jain, 2010, found all the stations in Kashmir Valley in the Last Century experienced a decreasing trend in monsoon and winter rainy days.

Kumar and Jain, 2011, studied trends in annual and seasonal rainfall and rainy days over different river basins across India for the period 1951-2004. They found four river basins experienced increasing (non-significant) trend in annual rainy days; three basins did not show any change in annual rainy days whereas 15 basins have shown a decreasing trend in annual rainy days. The decreasing trend in three basins was statistically significant. Most of the basins have shown the same direction of trend in rainfall and rainy days at the annual and seasonal scale.

Studies by Joshi and Pandey (2011) have observed no trend in annual precipitation over the entire Indian Territory and specific Indian regions for a study period of 100 years (1901-2000).

Mondal *et al.* (2012) have analyzed the mean monthly precipitation data for the period 1971 to 2010 along Birupa River in Orissa, India for possible trend in data. The result shows there is either non-significant increase or decrease in precipitation trend in the various months of the year.

Jain *et al.*, 2012, examined trends in monthly, seasonal, annual rainfall and temperature of northeast region on subdivision and regional scale. They found that only few hydro-meteorological subdivisions show the seasonal trend in rainfall over 1871-2008.

Skansi *et al.*, 2013 studied changes in climate extreme indices over South America for periods 1950-2010 and 1969-2009 found warming and wetting signals using high-quality daily maximum and minimum temperature and precipitation series.

Keggenhoff *et al*., 2014 observed the contribution of very heavy and extremely heavy precipitation to total precipitation increased between 1971 and 2010, whereas the number of wet days decreases.

Variations in total precipitation can be caused by a change in the frequency of precipitation events, or in the intensity of precipitation per event or a combination of both. In order to improve the understanding of precipitation behavior as an indicator of climate changes in the last century, wet day frequency series must be analyzed. Wet day frequency is one day with rainfall of at least 0.1 mm and dry and wet spell which affects the agricultural practice as well as social life. The study of wet day frequency analysis used to know occurrence of flood, drought along with occurrence of pest and disease on crops which reduces crop yield. Future changes in the number of dry days per year can either reinforce or counteract projected increases in daily precipitation intensity as the climate warms.

However, there are very few studies about this topic, probably because of the lack of high-quality daily data.

The present piece of study deals with change and trend detection in wet day frequency over decades for the 18 districts of West Bengal over a period of 102 years.

2. Data and methodology

The monthly wet-day frequency data for period of 1901-2000 over West Bengal obtained from http://www.indiawaterportal.org. Annual and seasonal wet-day frequency series were constructed using monthly data of 18 districts of West Bengal.

3. Trend analysis

Trend analysis of a time series consists of the magnitude of a trend and its statistical significance in a time series. Different workers have used different methodologies for trend detection. Kundzewicz (2004) has discussed the change detection methodologies for hydrological data.

In general, the magnitude of trend in a time series is determines either using regression analysis (parametric test) or using Sen's estimator method (non-parametric). Both these methods assume a linear trend in the time series.

4. Sen's method

The Sen's slope estimator is a linear slope estimator that works most effectively on monotonic data. Unlike linear regression, it is not greatly affected by data errors, outliers, or missing data. Sen's slope estimator has been widely used for determining the magnitude of trend. The approach involves computing slopes for all the pairs of ordinal time points using the median of these slopes as an estimate of the entire overall slope. Sen's method proceeds by calculating the slope as a change in measurement per change in time.

$$Q = \frac{x_j - x_k}{j - k}$$

where, Q = slope between data points x_j and x_k; x_j and x_k are data points at time j and k ($j > k$) respectively.

5. Mann-Kendall test

Many researchers (Douglas *et al.*, 2000; Yue *et al.*, 2002; Burn *et al.*, 2004; Singh *et al.*, 2008(a&b); Kumar & Jain, 2011) employed non-parametric Mann-Kendall (MK) test to ascertain the presence of statistically significant trend in wet-day frequency. Since there is fluctuation presents in the weather parameters, non-parametric Mann-Kendall test is useful because its static is based on the sign of differences, not directly on the values of random variable and therefore trends determined is less affected by the fluctuations. Mann-Kendall test is applicable to the detection of monotonic trend in time series. It checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

The test statistic S is calculated using the formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(x_j - x_k\right)$$

$$sgn\left(x_j - x_k\right) = \begin{cases} +1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases}$$

where, n is the number of observed data series, x_j and x_k are the values in periods j and k respectively, $j > k$. For $n \geq 10$, the sampling distribution of S is as follows:

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases}$$

where, VAR(S) is determined as

$$\mathrm{VAR(s)} = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{\mathrm{p=1}}^{\mathrm{q}} t_p(t_p-1)(2\,t_p+5) \right]$$

where, p = 1, 2,…, q is the number of tied groups and t_p is the number of data values in the p^{th} group.

Changes in the wet-day frequency have been studied using the descriptive statistical parameters such as mean, standard deviation (SD), coefficient of skewness and kurtosis. Also changes in these statistical parameters have seen plotting the histogram over different periods.

6. Results

The magnitude of trend in annual and seasonal wet-day frequency as determined by the Sen's slope estimator with Mann-Kendall test is given in Table 1.

6.1. *Annual wet-day frequency trends*

Seven districts had decreasing trend and ten districts had the increasing trend, whereas Murshidabad district had no trend over 102 years. The increase in annual wet-day frequency varied between 0.001 (for Cochbihar) and 0.029 (for North 24 pragnas); the decrease was maximum for Maldah (-0.042) and minimum for Bankura. Annual wet-day frequency of only three districts showed significant trend and the trend for majority of the districts were non-significant.

6.2. *Seasonal wet-day frequency trends*

6.2.1. *Pre-monsoon (March-May)*

Only Midnipur shows deceasing trend and other showed the increasing trend, whereas Howrah and North 24 pragnas had no trend. The increase in pre-monsoon wet day frequency varied between 0.001 (for Bankura, Kolkata and South 24 prgnas) and 0.052 (for Jalpaiguri). The Mann-Kendall test indicates that wet-day frequency during pre-monsoon insignificant over102 years in all the districts of West Bengal.

6.2.2. *Monsoon (June-Sepember)*

Seven districts had increasing trend and eleven districts had the decreasing trend over 102 years. The increase in monsoon wet-day frequency varied between 0.006 (for Jalpaiguri) and 0.045 (for Hugali); the decrease was maximum for Utterdinajpur (-0.112) and minimum for Nadia (-0.001). Monsoon wet-day frequency of only three districts showed significant decreasing trend and the trend for majority of the districts were non-significant.

6.2.3. *Post-monsoon (October-November)*

Three districts had decreasing trend and 15 districts had the increasing trend over 102 years. The decrease in post-monsoon wet-day frequency varied between -0.005 (for Cochbihar) and -0.007 (for Darjiling and Jalpaiguri); the increase was maximum for Bankur, Bardhman, Birbhum and Midnipur (0.010) and minimum for Utterdinajpur (0.002). Post-Monsoon wet-day frequency of only three districts showed significant increasing trend and the trend for majority of the districts were non-significant.

6.2.4. *Winter (December-February)*

Five districts showed the decreasing trend and nine districts had the increasing trend, whereas four districts had no trend over 102 years. The Mann-Kendall test indicated that the seasonal wet-day frequency during winter statistically non-significant.

6.3. *Annual and seasonal wet-day frequency during different periods*

To know the behavior change of annual and seasonal wet-day frequency, the wet-day frequency analysis performed for each district of west Bengal over different periods and results are provided in Table 2 and Fig. 1. It shows that the changes occurred in annual and seasonal wet-day frequency over state during the different periods. The graphical approach (Fig. 1) shows the changes in pattern of wet-day frequency in districts during different periods.

6.4. *Annual (January-December)*

The maximum annual wet-day frequency observed in Jalpaiguri 84.63±6.5 (period 1981-2000) and minimum

TABLE 1

Trend analysis of annual and seasonal wet day frequency of West Bengal

S. No.	District	Annual			Pre-monsoon			Monsoon			Post-monsoon			Winter		
		Tau	S	Z	Tau	S	Z	Tau	S	Z	Tau	S	Z	Tau	S	Z
1	Bankura	-0.011	-0.003	-0.162	0.010	0.001	0.150	-0.067	-0.013	-0.989	**0.123u**	0.010	1.833	0.015	0.001	0.220
2	Bardhaman	0.013	0.003	0.185	0.018	0.003	0.266	-0.056	-0.011	-0.838	**0.121u**	0.010	1.804	0.030	0.002	0.445
3	Birbhum	-0.031	-0.008	-0.463	0.030	0.003	0.445	**-0.117d**	-0.025	-1.735	0.107	0.010	1.596	0.018	0.001	0.263
4	Cochbihar	0.004	0.001	0.058	0.844	0.007	0.844	-0.231	-0.003	-0.231	-0.054	-0.005	-0.798	0.030	0.001	0.451
5	Dakshindinajpur	0.025	0.005	0.376	0.029	0.002	0.428	-0.043	-0.043	-0.636	0.034	0.004	0.497	0.054	0.002	0.795
6	Darjiling	**-0.121d**	-0.030	-1.798	0.042	0.004	0.625	-0.102	-0.021	-1.521	-0.102	-0.007	-1.521	-0.080	-0.004	-1.183
7	Howrah	0.109	0.025	1.619	0.003	< 0.001	0.040	0.079	0.012	1.174	0.103	0.008	1.538	0.044	0.003	0.653
8	Hugali	0.083	0.020	1.226	0.011	0.001	0.165	0.006	0.045	0.671	0.108	0.009	1.602	0.047	0.003	0.691
9	Jalpaiguri	-0.050	-0.010	-0.746	0.052	0.052	0.769	0.045	0.006	0.012	-0.086	-0.007	-1.272	-0.022	-0.001	-0.321
10	Kolkata	0.104	0.026	1.544	0.005	0.001	0.075	-0.045	-0.009	-0.665	0.101	0.008	1.504	0.062	0.004	0.925
11	Maldah	-0.042	-0.042	-0.619	0.022	0.002	0.330	0.075	0.011	1.110	0.069	0.006	1.029	0.006	< 0.001	0.084
12	Midnipur	0.089	0.021	1.330	-0.006	-0.001	-0.081	-0.100	-0.018	-1.480	**0.112u**	0.010	1.671	0.024	0.002	0.359
13	Murshidabad	< 0.001	< 0.001	< 0.001	0.020	0.002	0.295	0.062	0.011	0.914	0.096	0.008	1.428	-0.002	< 0.001	-0.026
14	Nadia	0.067	0.013	0.000	0.021	0.021	0.312	-0.005	-0.001	-0.069	0.096	0.009	1.423	0.013	0.001	0.197
15	North24p	**0.114u**	0.029	1.694	0.001	< 0.001	0.017	0.095	0.017	1.411	0.103	0.009	1.527	-0.002	< 0.001	-0.029
16	Purulia	-0.066	-0.017	-0.983	0.009	0.002	0.133	**-0.129d**	-0.025	-1.920	0.109	0.009	1.619	-0.007	< 0.001	-0.098
17	South24p	**0.137u**	0.025	2.041	0.008	0.001	0.113	0.107	0.016	1.596	0.097	0.007	1.446	0.017	0.001	0.252
18	Utterdinajpur	-0.051	-0.008	-0.758	0.038	0.003	0.567	**-0.112d**	-0.112	-1.660	0.025	0.002	0.364	0.026	0.001	0.385

Bold values indicate the presence of significant trend at 5% level of significance,
u = upward trend, d = downward trend, tau = Mann Kendall tau value,
S = Sen slope estimator, Z = z statistics to test trend.

observed at South 24 prgnas district 53.62±3.0 (period 1901-1920). The districts Bankura, Jalpaiguri & Puruliya shows the positive skewness (except in period 1941-1960) while Utterdinajpur shows no skewness in period 1961-1980 and other districts shows the negative skewness. Cochbihar, Jalpaiguri and Utterdinajpur show positive kurtosis, *i.e.*, leptokurtic nature (except periods 1921-1940, 1921-1940 and 1961-1980 respectively) while others shows the negative kurtosis, *i.e.*, platykurtic nature.

6.5. *Pre-monsoon (March-May)*

Cochbihar shows the maximum pre-monsoon wet-day frequency16.84±2.06 (period 1981-2000) and minimum 7.87±1.81 at South 24 prgnas district (period 1941-1960). The districts Bankura, Maldah shows no skewness in 1961-1980 period and other districts shows the negative skewness. Almost all the districts show the negative kurtosis, *i.e.*, platykurtic nature.

6.6. *Monsoon (June-Sepember)*

The maximum monsoon wet-day frequency observed in Jalpaiguri 60.85±4.22 (period 1941-1960) and minimum observed at South24prgnas district 37.35±2.43 (period 1901-1920).The districts Bankura, Midnipur and Nadia shows the positive skewness whileother districts shows the negative skewness in more than one period. South 24 prgnas shows positive kurtosis *i.e.*, leptokurtic nature (except period 1981-2000) while others shows the negative kurtosis, *i.e.*, platykurtic nature in more than one periods.

6.7. *Post-monsoon (October-November)*

During period 1941-1960 Midnipur district shows the maximum post-monsoon wet-day frequency 7.12±1.78 while Darjiling district shows the minimum 4.2±1.37. Midnipur shows the no skewness while other districts

TABLE 2

Decadal changes in annual and seasonal wet day frequency over districts of West Bengal

Period	Annual				Pre-monsoon				Monsoon				Post-monsoon				Winter			
	Mean	SD	Skew	Kurt	Mean	SD	Skew	Kurt	Mean	SD	Skew	Kurt	Mean	SD	Skew	Kurt	Mean	SD	Skew	Kurt
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
BANKURA																				
1901-1920	70.81	3.68	0.42	-1.07	10.73	2.37	-0.13	-0.45	51.69	2.86	0.08	-0.36	5.13	2.14	0.26	0.09	3.25	1.39	0.55	0.61
1921-1940	71.57	4.12	0.05	-1.05	9.75	2.36	-0.25	-1.06	52.68	3.61	0.09	0.17	5.44	1.54	-0.81	1.34	3.72	0.84	0.9	0.65
1941-1960	71.55	5.51	-0.09	0.96	9.8	2.42	-0.28	-0.13	52.62	3.65	0.41	-0.33	5.94	1.61	0.04	-1.27	3.19	1.19	-0.25	-0.95
1961-1980	71.10	7.11	0.81	1.19	9.85	3.22	0	-0.99	52	4.23	0.95	2.18	5.68	1.29	-0.23	-0.82	3.57	1.42	0.22	0.4
1981-2000	71.56	5.10	0.36	0.72	10.8	2.03	0.33	-0.4	51.46	4.04	0.56	-0.93	5.83	1.86	0.23	0.56	3.48	0.92	-0.1	-0.46
BARDHAMAN																				
1901-1920	68.53	3.28	0.55	-0.57	10.88	2.09	-0.13	-0.39	49.51	2.64	-0.1	-0.05	5.07	2.05	0.34	0.16	3.06	1.19	0.35	0.09
1921-1940	68.79	3.67	-0.29	-0.69	9.78	2.08	-0.41	-1.11	50.3	3.39	-0.06	0.26	5.16	1.46	-0.78	1.37	3.55	0.7	0.58	0.42
1941-1960	69.12	4.52	-0.4	0.63	9.86	2.22	-0.21	0.66	50.59	2.9	0.11	-0.69	5.74	1.64	0.16	-1.14	2.94	1.16	-0.51	-1.03
1961-1980	68.51	6.69	0.59	0.32	9.94	3.01	-0.02	-1.25	49.57	3.98	0.85	1.37	5.59	1.26	-0.27	-0.93	3.41	1.29	0.09	-0.09
1981-2000	69.48	5.1	-0.1	-0.14	11.01	1.94	0.36	-0.18	49.4	3.74	0.49	-1.27	5.66	1.83	0.13	0.53	3.41	0.85	-0.22	-0.71
BIRBHUM																				
1901-1920	67.97	3.36	0.26	-0.69	9.76	1.82	-0.34	-0.54	50.24	2.76	-0.58	0.13	5.03	2.11	0.4	-0.2	2.94	1.19	0.08	-0.18
1921-1940	68.47	3.34	-0.08	-1.1	8.7	1.93	-0.3	-1.02	51.17	3.19	-0.1	-0.25	5.05	1.53	-0.57	1.09	3.54	0.73	0.63	0.23
1941-1960	68.84	4.58	-0.35	0.73	8.88	2.01	-0.11	0.17	51.49	3.09	0.23	-0.36	5.66	1.65	0.21	-0.88	2.81	1.15	-0.4	-1.24
1961-1980	67.89	6.88	0.75	0.61	8.97	2.8	0.15	-1.14	50.04	4.28	0.97	1.95	5.56	1.34	-0.34	-0.55	3.32	1.26	0.21	0
1981-2000	68.13	4.73	-0.03	0.28	9.94	1.76	0.28	-0.14	49.25	3.65	0.67	-0.78	5.56	1.77	0.33	0.83	3.38	0.77	-0.15	-0.65
COCHBIHAR																				
1901-1920	80.69	3.87	0.32	0.88	16.34	2.13	-0.15	-0.02	56.62	3.14	1.08	0.84	5.28	1.78	0.23	-0.85	2.45	0.91	-0.69	1.85
1921-1940	80.45	5.02	-0.02	-0.27	15.51	2.63	-0.58	-0.11	56.67	3.68	-0.06	-1.43	5.4	1.37	-1.57	4.94	2.87	0.6	-0.39	-1.25
1941-1960	80.77	5.58	-1.1	0.82	15.62	2.47	0.08	-0.19	57.05	3.95	-0.41	-0.58	5.38	1.94	0.42	-0.95	2.73	1.07	-0.31	-0.91
1961-1980	79.19	5.03	0.23	0.1	15.74	2.42	0.07	-0.63	55.49	3.11	-0.12	-0.62	5.52	1.78	0.64	-0.36	2.43	0.68	0.21	-0.1
1981-2000	81.75	5.96	0.71	1.3	16.84	2.06	-0.31	-0.83	57.01	4.67	0.54	0.45	4.82	1.45	0.6	0.51	3.09	0.91	0.25	-1.29
DAKSHINDINAJPUR																				
1901-1920	66.34	3	-0.4	-0.26	10.57	1.5	0.01	-0.64	47.54	2.21	-0.27	-0.55	5.29	2.06	0.23	-0.64	2.93	0.88	-0.23	-0.27
1921-1940	66.57	3.31	-0.25	0.48	9.7	1.72	-0.8	-1.01	48.1	2.8	-0.25	-0.92	5.37	1.5	-0.81	2.19	3.41	0.74	-0.53	-0.58
1941-1960	66.52	4.34	-1	0.66	9.71	1.92	-0.38	0.78	48.42	2.68	-0.39	-1.12	5.67	1.88	0.35	-0.88	2.72	1.23	-0.35	-0.75
1961-1980	65.23	4.94	0.36	-0.11	9.76	2.02	-0.03	-0.71	46.91	3.01	0.29	-0.46	5.5	1.61	0.2	-0.76	3.06	1.21	0.64	-0.84
1981-2000	67.49	4.2	-0.28	0.57	10.83	1.4	0.39	-0.65	47.58	3.73	0.47	-0.41	5.44	1.51	-0.1	-0.11	3.64	1	0.5	0.1
DARJILING																				
1901-1920	75.38	3.83	-0.12	0.58	13.21	1.85	0.71	0.97	54.87	3.1	0.34	-0.32	4.33	1.14	0.92	0.19	2.97	0.61	-0.07	0.16
1921-1940	75.05	4.26	0.09	-1.14	12.57	1.82	-0.68	-0.29	55.01	3.81	0.11	-1.49	4.35	1.06	-0.8	3.94	3.12	0.53	-0.1	1.12
1941-1960	74.95	5.14	-1.09	1.12	12.19	2.28	0.08	-0.71	55.68	3.7	0.01	-0.65	4.2	1.37	0.16	-1.1	2.88	1	-0.63	0.65
1961-1980	72.34	5.04	-0.05	-0.88	12.59	2.7	0.01	-0.83	53.12	3.47	-0.26	-1.21	4.22	1.58	0.41	-0.35	2.41	0.79	-0.16	0.56
1981-2000	74.12	6.18	0.94	1.03	13.51	1.93	-0.29	-1.37	53.82	5.1	0.81	0.12	3.63	1.43	1.09	0.51	3.15	1	0.14	-0.92

TABLE 2 (*Contd.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
HOWRAH																				
1901-1920	67.24	3.5	0.53	-0.85	11.68	2.5	0.4	0.37	47.06	2.76	0.97	1.32	5.53	2.02	0.2	0.43	2.96	1.19	0.67	0.61
1921-1940	67.6	4.36	-0.11	-0.86	10.6	2.15	-0.53	-1.15	47.86	3.74	0.38	0.2	5.74	1.44	-0.99	1.34	3.4	0.84	0.12	-0.09
1941-1960	67.31	4.51	-0.5	-0.03	10.33	2.38	-0.22	0.12	47.75	2.86	-0.11	-0.46	6.36	1.65	0.23	-1.29	2.86	1.19	-0.22	-1.44
1961-1980	67.75	5.65	0.32	0.13	10.46	2.83	-0.14	-1.5	48.07	3.28	0.68	0.75	5.96	1.27	0.13	-0.94	3.26	1.3	-0.28	-0.45
1981-2000	69.67	5.17	-0.12	-0.29	11.64	2	0.62	-0.21	48.54	3.66	0.39	-1.12	6.18	2.01	-0.15	0.21	3.31	0.95	-0.08	-0.3
HUGALI																				
1901-1920	69.24	3.45	0.63	-0.68	12.04	2.48	0.3	0.21	48.8	2.7	0.68	0.86	5.43	2.05	0.24	0.4	2.97	1.13	0.62	0.37
1921-1940	69.37	4.2	-0.2	-0.87	10.9	2.19	-0.52	-1.14	49.55	3.73	0.22	0.39	5.54	1.44	-0.98	1.54	3.38	0.73	0.45	0.13
1941-1960	69.33	4.51	-0.5	0.3	10.72	2.46	-0.19	0.33	49.62	2.79	-0.14	-0.55	6.15	1.69	0.15	-1.32	2.85	1.14	-0.39	-1.03
1961-1980	69.44	6.13	0.45	0.02	10.83	3.04	-0.12	-1.46	49.5	3.53	0.77	0.64	5.85	1.28	-0.01	-1.16	3.27	1.26	-0.11	-0.33
1981-2000	71.33	5.42	-0.15	-0.36	12.04	2.14	0.46	-0.27	49.95	3.8	0.39	-1.23	6.03	1.99	-0.02	0.19	3.3	0.84	0.1	-0.53
JALPAIGURI																				
1901-1920	84.45	4.27	0.27	0.77	16.35	2.1	0.15	-0.03	60.31	3.56	0.89	0.64	5	1.5	0.38	-0.67	2.78	0.86	-0.51	0.73
1921-1940	84.07	5.08	0.17	-0.65	15.64	2.52	-0.45	-0.1	60.28	4.06	-0.07	-1.36	5.05	1.29	-1.4	4.09	3.1	0.59	-0.15	-0.26
1941-1960	84.2	5.78	-0.95	0.64	15.49	2.52	0.11	-0.6	60.85	4.22	-0.21	-0.88	4.95	1.83	0.29	-1.11	2.9	0.95	-0.24	-0.39
1961-1980	82.3	5.22	0.2	0.26	15.89	2.64	0.01	-0.76	58.91	3.47	-0.23	-1	5.07	1.77	0.66	-0.18	2.44	0.75	-0.14	-0.3
1981-2000	84.63	6.5	0.81	0.83	16.77	2.12	-0.34	-0.93	60.21	5.2	0.71	0.26	4.37	1.42	0.83	0.74	3.28	1.08	0.08	-1.18
KOLKATA																				
1901-1920	67.21	3.49	0.61	-0.61	11.91	2.43	0.43	0.31	47.15	2.71	0.87	1.06	5.33	1.95	0.24	0.5	2.82	1.09	0.69	0.39
1921-1940	67.33	4.23	-0.17	-0.69	10.76	2.09	-0.57	-1.09	47.86	3.75	0.18	0.47	5.4	1.41	-0.96	1.3	3.31	0.71	0.26	-0.3
1941-1960	67.21	4.3	-0.46	0.11	10.53	2.33	-0.07	0.51	47.93	2.68	-0.31	-0.38	6.02	1.64	0.17	-1.31	2.73	1.14	-0.32	-1.1
1961-1980	67.54	5.77	0.36	-0.03	10.62	2.82	-0.13	-1.57	47.99	3.38	0.69	0.59	5.76	1.25	0.05	-1.12	3.18	1.25	-0.2	-0.5
1981-2000	69.57	5.35	-0.26	-0.33	11.86	2.12	0.41	-0.32	48.58	3.69	0.34	-1.14	5.89	1.98	-0.06	0.07	3.25	0.84	-0.04	-0.49
MALDAH																				
1901-1920	66.06	3.44	-0.42	-0.5	9.68	1.54	0.02	-0.05	48.51	2.65	-0.74	-0.11	5.12	2.02	0.32	-0.55	2.75	0.83	-0.42	-0.03
1921-1940	66.43	3.02	-0.35	-0.27	8.74	1.7	-0.6	-1.16	49.35	2.88	-0.13	-0.73	5.19	1.52	-0.73	2.01	3.16	0.64	0.01	-0.39
1941-1960	66.5	4.15	-1	1.88	8.77	1.93	-0.12	-0.01	49.61	2.51	-0.51	-0.25	5.56	1.71	0.24	-0.83	2.56	1.08	-0.26	-0.76
1961-1980	64.9	5.32	0.03	-0.55	8.78	2.16	0.03	-0.84	47.84	3.09	-0.01	-0.53	5.42	1.59	0.03	-0.52	2.87	0.83	0.55	-0.88
1981-2000	66.13	4.14	0.05	0.03	9.9	1.45	0.43	-0.9	47.74	3.64	0.67	-0.29	5.42	1.56	0.31	0.58	3.08	0.68	-0.18	0.47
MIDNIPUR																				
1901-1920	71.41	3.77	0.24	-1.21	11.84	2.73	0.4	0.45	50.36	3	0.8	1.19	6.03	2.34	0.03	0.08	3.17	1.3	0.57	0.62
1921-1940	72.15	4.81	-0.05	-1.02	10.84	2.51	-0.41	-1.21	51.34	3.85	0.38	-0.32	6.42	1.57	-1.01	0.97	3.54	0.96	0.02	-0.02
1941-1960	71.71	5.47	-0.37	0.8	10.61	2.66	-0.54	0.13	50.9	3.66	0.37	-0.6	7.12	1.78	0.27	-1.23	3.08	1.26	-0.06	-1.43
1961-1980	72.12	6.1	0.4	0.68	10.62	3.21	-0.17	-1.21	51.49	3.54	0.57	1.21	6.56	1.38	0	-0.97	3.45	1.41	0.08	-0.02
1981-2000	73.77	5.07	0.29	0.07	11.79	1.95	0.67	0.09	51.65	3.76	0.43	-1.31	6.9	2.18	-0.03	0.27	3.42	1.06	-0.07	-0.62
MURSHIDABAD																				
1901-1920	67.45	3.16	0.28	-0.67	10.83	1.8	-0.09	-0.64	48.41	2.45	-0.66	0.14	5.22	2.1	0.29	-0.4	2.99	1.01	0.22	-0.32
1921-1940	67.46	3.05	-0.45	-0.5	9.66	1.95	-0.6	-1.17	49.23	2.78	-0.02	0.08	5.18	1.51	-0.69	1.77	3.39	0.64	-0.01	0.14
1941-1960	67.72	4.29	-0.55	0.06	9.75	2.1	-0.33	0.88	49.52	2.61	0.34	-1.36	5.75	1.8	0.38	-0.72	2.7	1.12	-0.51	-1.11
1961-1980	66.67	5.89	0.32	-0.07	9.77	2.61	0	-1.2	48.2	3.58	0.33	0.02	5.57	1.42	-0.13	-1.06	3.13	1.03	0.45	-0.22
1981-2000	67.95	4.5	-0.32	-0.22	10.98	1.78	0.4	-0.08	48.06	3.38	0.35	-1.42	5.68	1.8	0.17	0.88	3.22	0.79	-0.12	-0.41

TABLE 2 (*Contd.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
NADIA																				
1901-1920	68.51	3.17	1.11	0.59	11.82	2.05	0.33	-0.28	48.2	2.37	0.03	0.21	5.46	2.1	0.24	-0.17	3.02	1.01	0.43	-0.16
1921-1940	68.27	3.46	-0.5	-0.11	10.66	1.95	-0.69	-1.08	48.86	3.15	0.21	0.25	5.43	1.47	-0.87	1.75	3.34	0.6	0.1	0.25
1941-1960	68.48	4.32	-0.32	-0.01	10.53	2.26	-0.42	1.38	49.1	2.58	0.19	-1.15	6.08	1.82	0.32	-0.93	2.77	1.17	-0.59	-0.99
1961-1980	67.86	5.88	0.33	-0.05	10.58	2.75	-0.1	-1.35	48.33	3.5	0.42	-0.42	5.86	1.42	-0.06	-1.57	3.09	1	0.32	-0.27
1981-2000	70.06	5.12	-0.28	-0.47	11.93	1.92	0.46	0.01	48.87	3.65	0.21	-1.15	6	2.03	-0.15	0.85	3.26	0.83	-0.32	-0.7
NORTH 24 P																				
1901-1920	68.19	3.58	0.93	-0.11	11.55	2.35	0.49	0.32	47.78	2.81	0.87	0.81	5.8	2.06	0.32	0.19	3.08	1.03	0.56	-0.02
1921-1940	67.97	4.25	-0.34	0.27	10.38	1.93	-0.46	-1.13	48.42	3.88	0.42	0.28	5.86	1.41	-0.95	1	3.31	0.84	0.07	-0.74
1941-1960	68.06	4.34	-0.03	-0.2	10.16	2.22	-0.08	0.28	48.54	2.82	-0.3	0.13	6.63	1.69	0.29	-1.2	2.73	1.26	-0.43	-0.93
1961-1980	68.14	5.35	-0.22	0.06	10.21	2.43	-0.11	-1.58	48.76	3.27	0.2	-0.09	6.21	1.32	0.2	-1.05	2.97	1.12	-0.44	-0.72
1981-2000	70.53	5.34	-0.3	-0.43	11.51	2.04	0.46	-0.1	49.45	3.87	0.18	-0.82	6.34	2.09	-0.38	0.95	3.24	0.93	-0.14	-0.61
PURULIA																				
1901-1920	68.18	4.19	0.38	-0.89	9.43	2.37	0.05	-0.57	50.55	3.09	-0.26	-0.73	4.55	2.12	0.21	-0.43	3.65	1.45	0.75	0.81
1921-1940	69.69	3.69	0.42	-0.57	8.6	2.33	-0.18	-0.94	52	3.3	0.14	-0.31	4.91	1.54	-0.84	1.05	4.18	0.86	0.58	0.21
1941-1960	69.52	6.03	-0.05	0.32	8.59	2.27	-0.17	-0.38	51.88	4.04	0.3	-0.18	5.35	1.47	-0.09	-1.32	3.7	1.16	-0.35	-0.58
1961-1980	68.59	7.2	1.05	1.46	8.67	2.93	0.14	-0.83	50.82	4.46	0.73	1.73	5.05	1.29	-0.25	-0.89	4.05	1.66	0.48	-0.04
1981-2000	68.14	4.95	0.59	2.33	9.46	1.95	0.07	-1.02	49.62	3.98	0.8	0.32	5.26	1.71	0.47	0.93	3.8	1.08	-0.49	-0.62
SOUTH 24 P																				
1901-1920	53.62	3	0.56	-0.67	8.99	1.97	0.47	0.34	37.35	2.43	1.04	1.22	4.79	1.65	0.3	0.34	2.49	0.96	0.4	0.29
1921-1940	53.88	3.73	-0.19	0.04	8.15	1.62	-0.46	-1.05	38	3.16	0.58	0.05	4.99	1.15	-0.83	0.63	2.74	0.83	-0.21	-0.54
1941-1960	53.67	3.54	-0.31	-0.64	7.87	1.81	-0.21	-0.18	37.88	2.38	-0.29	0.2	5.61	1.29	0.41	-1.19	2.31	1.01	-0.3	-0.96
1961-1980	54.11	4.24	-0.24	0.4	8	1.94	-0.19	-1.51	38.46	2.56	0.33	0.27	5.13	1.09	0.13	-0.37	2.52	1.09	-0.43	-0.65
1981-2000	55.87	4.12	-0.32	-0.3	8.94	1.52	0.68	-0.16	38.9	3.03	0.22	-0.79	5.31	1.68	-0.52	0.88	2.72	0.82	-0.24	-0.63
UTTERDINAJPUR																				
1901-1920	66.19	3.43	-0.36	0.17	10.12	1.56	0.25	0.21	48.87	2.71	-0.27	-0.91	4.63	1.74	0.33	-0.56	2.57	0.75	-0.8	0.8
1921-1940	66.48	3.49	-0.37	0.25	9.4	1.64	-0.71	-1.01	49.47	3.23	-0.14	-1.01	4.68	1.3	-0.63	2.32	2.93	0.58	-0.15	-1.06
1941-1960	66.73	4.24	-1.23	2	9.33	1.92	-0.01	-0.07	49.91	2.6	-0.56	0.07	4.87	1.53	0.16	-1.09	2.61	1.12	-0.28	-0.6
1961-1980	64.52	4.75	0	-0.52	9.42	2.06	-0.14	-0.74	47.64	2.79	-0.17	-1.1	4.82	1.55	0.31	-0.52	2.64	0.87	0.37	-1.08
1981-2000	66.37	4.89	0.72	1.49	10.49	1.39	0.21	-1.33	48.16	4.37	0.79	0.47	4.71	1.42	0.68	-0.22	3.02	0.78	-0.04	-0.52

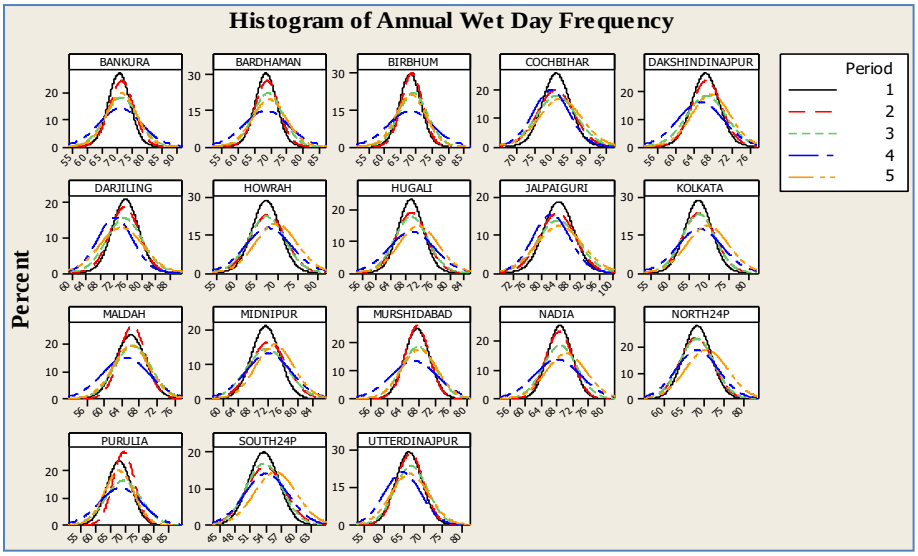
shows the negative skewness in more than one period. Almost all districts show the negative kurtosis, *i.e.*, platykurtic nature in more than one period.

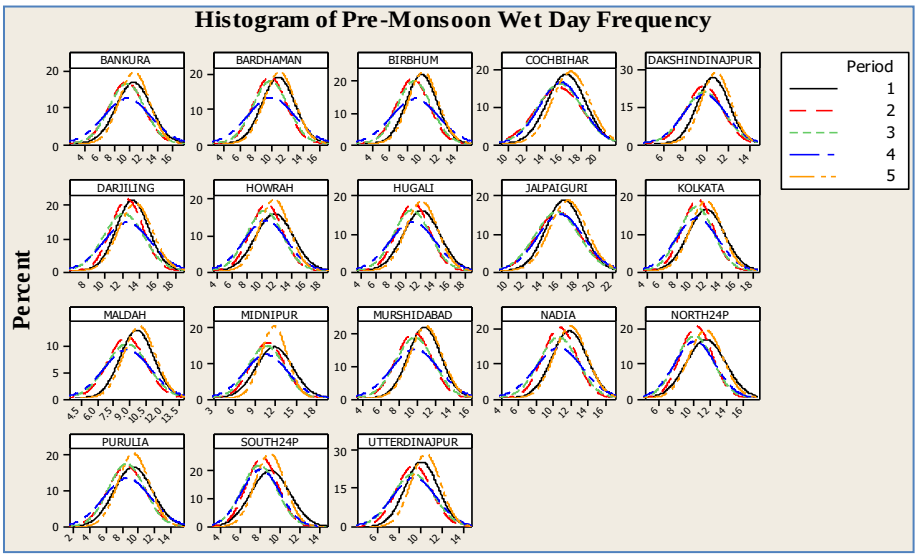
6.8. *Winter (December-February)*

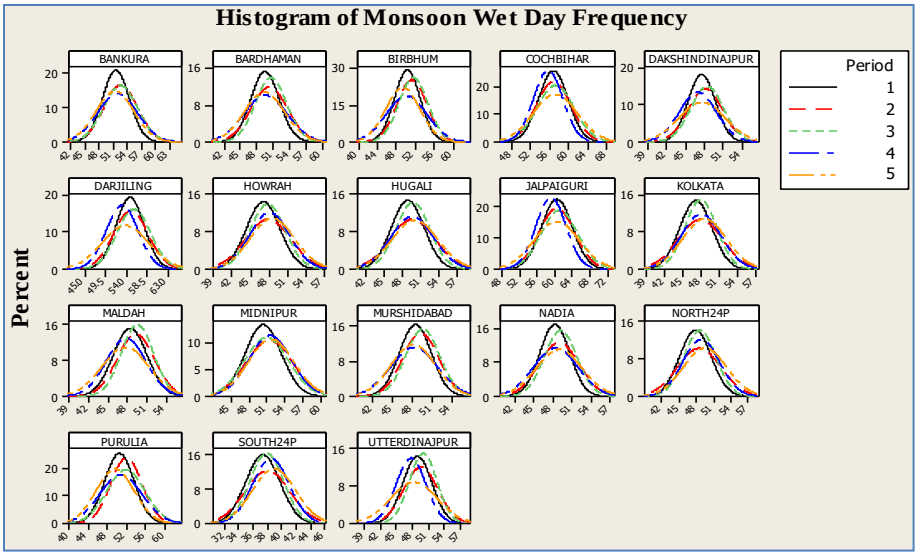
The maximum post-monsoon wet-day frequency 4.18±0.86 observed in Purulia district during period 1921-1940 while South 24 prgnas district shows the minimum 2.31±1.01 during 1941-1960.Generally all the districts shows the negative skewness in more than one period. Birbhum shows the no kurtosis, *i.e.*, mesokurtic nature during 1961-1980 and almost all districts shows the negative kurtosis, *i.e.*, platykurtic nature in more than one periods.

7. Summary

Long term monthly wet day shows annual and seasonal variability over decades. The non-parametric


Histogram of Annual Wet Day Frequency
Percent
BANKURA
BARDHAMAN
BIRBHUM
COCHBIHAR
DAKSHINDINAJPUR
DARJILING
HOWRAH
HUGALI
JALPAIGURI
KOLKATA
MALDAH
MIDNIPUR
MURSHIDABAD
NADIA
NORTH24P
PURULIA
SOUTH24P
UTTERDINAJPUR
Period
1
2
3
4
5


Histogram of Pre-Monsoon Wet Day Frequency
Percent
BANKURA
BARDHAMAN
BIRBHUM
COCHBIHAR
DAKSHINDINAJPUR
DARJILING
HOWRAH
HUGALI
JALPAIGURI
KOLKATA
MALDAH
MIDNIPUR
MURSHIDABAD
NADIA
NORTH24P
PURULIA
SOUTH24P
UTTERDINAJPUR
Period
1
2
3
4
5


Histogram of Monsoon Wet Day Frequency
Percent
BANKURA
BARDHAMAN
BIRBHUM
COCHBIHAR
DAKSHINDINAJPUR
DARJILING
HOWRAH
HUGALI
JALPAIGURI
KOLKATA
MALDAH
MIDNIPUR
MURSHIDABAD
NADIA
NORTH24P
PURULIA
SOUTH24P
UTTERDINAJPUR
Period
1
2
3
4
5

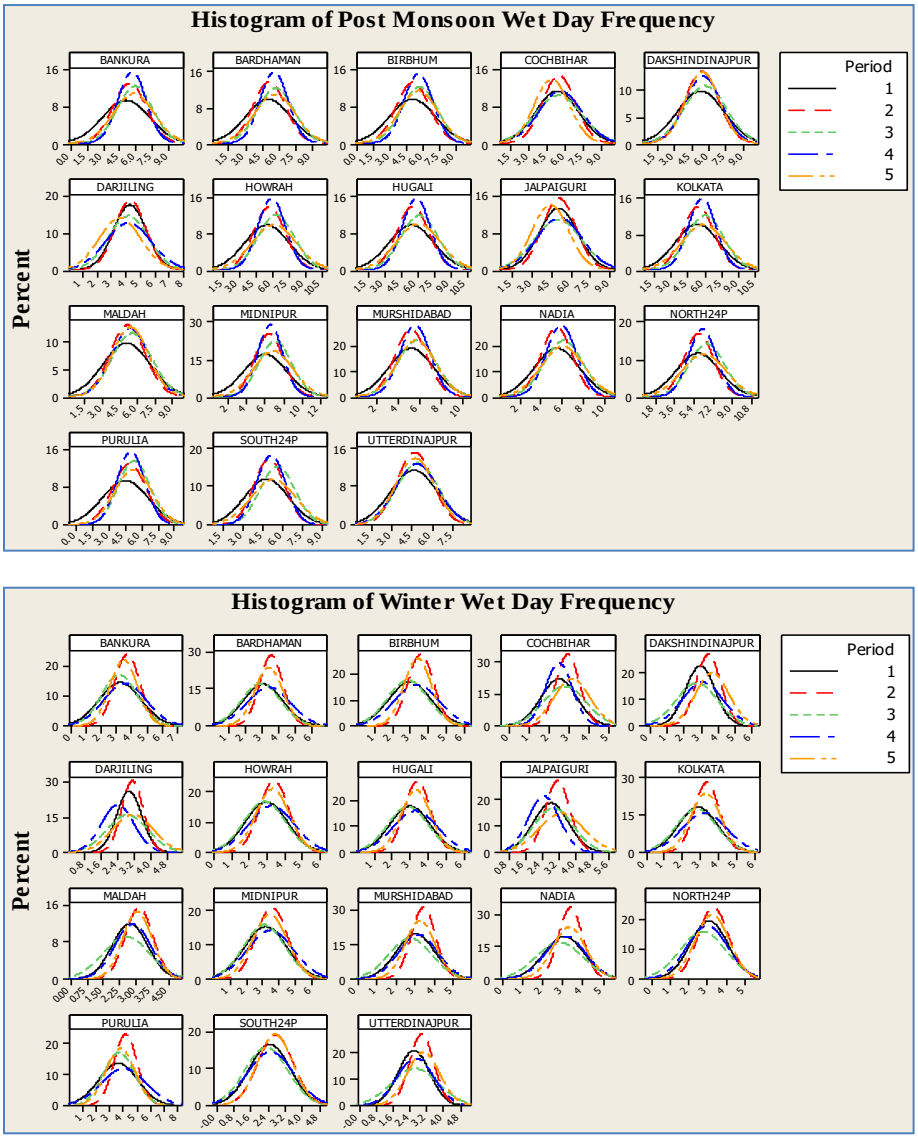


Fig. 1. Decadal changes in wet day frequency of districts of West Bengal

approach (Mann-Kendall) revealed that the few districts shows significant trend. Darjiling and Purulia shows decreasing trend in annual, monsoon, post monsoon and in winter season whereas Howrah, Hugali, South 24 prgnas shows increasing trend in annual and four seasons.

Almost all districts show the normally distributed curve with little changes in shapes revels that variability observed over decades. The changes observed in the statistical parameters (mean, SD, coefficient of skewness and kurtosis) during different periods which reflect the changing pattern of wet-day frequency in West Bengal.

Present study help to know the change occurred over decades which can be used to relate different climatic factors ultimately to shifting agricultural cropping pattern. Farmers are advised to overcome the pre and post shifting of monsoon and also to monitor the pest and disease attack due to wet/dry spell during different crop stage.

Acknowledgement

The authors are grateful to the referee for his valuable comments that have helped in improving the paper. The contents and views expressed in this research article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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