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Rainfall Pattern Analysis to Depict the Affects of Climate Change in West Bengal

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ABSTRACT

The spatiotemporal trends of rainfall at a seasonal and annual scale in 23 districts of West Bengal during the 1991-2020 had been evaluated by Mann-Kendall and Theil-Sen's slope estimates. Both annual and monsoon rainfall had expressed a decreasing trend in all the districts of the southern part of the state whereas total summer rainfall increased across the state. Post-monsoon rainfall had been decreased while winter rainfall exhibited a positive trend in most of the districts. The maximum negative change was reported in Paschim Medinipur on annual basis, while the highest positive was recorded in Darjeeling. South 24 Parganas has the highest negative change of magnitude in monsoon, whereas Darjeeling has the highest positive change of magnitude. The magnitude of change confirmed the affect of climate change in the state.

Keywords Rainfall trend, Magnitude of change, Mann kendall test

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INTRODUCTION

Rainfall has been established as one of the most important climatic variables, with spatial pattern as well as differs from daily to decadal and expresses longer-term variations (Jonah *et al.* 2021, Juan-Carlos *et al.* 2009, Sinha *et al.* 2018) Rainfall trends in the context of climate change have significant socio-economic implications for a region, state, country and contingents level (Towfiqul Islam *et al.* 2020, Roccati *et al.* 2020) Large number of studies have examined the rainfall distribution, variability and trends at global, national and regional scales (Dash *et al.* 2007, Zhai *et al.* 2005, Guhathakurta *et al.* 2008, Islam *et al.* 2019, Singh *et al.* 2020). Mann-Kendall (MK) and Sen's slope estimator have been widely exploited in studies on spatio-temporal trends for meteorological time series data at regional and national scales (Michaelides *et al.* 2009, Igweze *et al.* 2014, Kundu and Mondal 2019). A decreased rain fall trend was observed over the state Jharkhand, irrespective of the change in seasons by Sharma and Singh (2017). A significant negative trend of rainfall observed by Portela *et al.* (2020) over Mainland Portugal in the last five decades. A significant decreasing trend in winter and pre-monsoon rainfall had reported in all the districts of Maharashtra by Singh *et al.* (2020) whereas monsoon, post-monsoon and annual rainfall had shown both significant increasing and decreasing trends in different districts. A decrease trend in annual and seasonal rainfall was found in southwest part of Rwanda accompanied by an increase in northeast part by Jonah *et al.* (2021). The present study looked at the seasonal and annual rainfall trends in West Bengal, India, from 1991 to 2020.

MATERIALS AND METHODS

The secondary data on the monthly rainfall of 23 districts of West Bengal during the period from 1991 to 2020 has been utilized. Rainfall data have been collected from online web services of 'Solar Radiation Data (SoDa) - Solar energy services for professionals' (http://www.soda-pro.com/web-services/meteo-data/merra). The monthly data has been classified into four seasons as per the IMD (1) winter (December to February), (2) summer/pre-monsoon (March to May), (3) southwest monsoon (June to September) and (4) post-monsoon (October to November).

Mann-Kendall S statistic calculated as

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

where X_i and X_j were climate variables in the year i and j respectively, given j>i.

$$\operatorname{sign}(x_j - x_i) = \begin{cases} -1 \text{ if } X_j < X_i \\ 0 \text{ if } X_j = X_i \\ 1 \text{ if } X_j > X_i \end{cases}$$

For number of observations more than 10, the statistic assumed to be followed a normal distribution with variance equal to

$$\sigma 2 = \frac{n(n-1)(2n+5)}{18}$$

Sen's slope estimator test was used to quantify the significant linear trends in time series. In general, the slope Q between any two values of a time series X was estimated from:

$$Q = \frac{X_j - X_k}{j-k}, k = j$$

N = n (n-1)/2 values of Q can be determined for a time series X with n observations. The overall estimate of slope, according to Sen's method, is the median of these N values of Q. Q* is the overall slope estimator:

$$Q^* = \left\{ \begin{array}{ll} \frac{Q_N + 1}{2} & \text{N is odd} \\ \frac{\frac{Q_N}{2} = \frac{Q_N + 2}{2}}{2} & \text{N is even} \end{array} \right\}$$

The Q* represents the data trend, while the value denotes the trend's steepness. The confidence interval of Q* at a specific probability should be obtained to assess if the median slope was statistically different from zero.

$$\text{Percentage change} = \frac{\text{Theil-Sen^' s median slope} \times \text{length of the period}}{\text{mean}} \times 100$$

RESULTS AND DISCUSSION

Descriptive statistics

The mean, standard deviation and coefficient of variation in seasonal and annual rainfall data for 23 districts of West Bengal from 1991 to 2020 were depicted in Table 1. The mean and SD during the winter season ranged from 21.25 mm (Coochbehar) to 47.95 mm (Purulia) and 20.44 mm (Coochbehar) to 39.21 mm (Purulia), respectively. Summer/pre-monsoon rainfall mean and SD values varied from 73.75 mm (Uttar Dinajpur) to 514.16 mm (Kalimpong) and 242.12 mm (Kalimpong) to 53.66 mm (Malda), respectively. The mean monsoon rainfall ranged from 1038.77 mm (Uttar Dinajpur) to 2935.81 mm (Kalimpong), with SD ranging from 252.86 mm (Dakshin Dinajpur) to 648.68 mm (Kalimpong). During the post-monsoon season, mean rainfall ranged from 80.73 mm in Uttar Dinajpur to 227.92 mm in South 24 Parganas, with SD ranging from 64.95 mm in Uttar Dinajpur to 132.96 mm in South 24 Parganas (Kolkata).The maximum and minimum of mean annual rainfall in the region were found in Kalimpong (37.16.19 mm) and Uttar Dinajpur (1217.87 mm), respectively. The standard deviation for annual rainfall ranged from 289.97 mm (Dakshin Dinajpur) to 809.29 mm (Kalimpong).

With the exception of Kalimpong, Darjeeling, Jalpaiguri and Alipurduar in the extreme northern part of the state, the median value of annual rainfall was close to 1500 mm for most of the districts. The median of monsoon rainfall was 1000 mm for the most part of the state except extreme northern part. Expect extreme northern part of the state, the median of summer rainfall was 100 mm frequent extreme

Table 1. Rainfall statistics of the districts of West Bengal during 1991-2020. SD= Standard deviation, CV= Coefficient of variation.

District	Winter			Summer			Monsoon		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Kalimpong	42.84	24.84	57.97	514.16	242.12	47.09	2935.81	648.68	22.10
Darjeeling	41.78	25.22	60.36	419.67	205.90	49.06	2596.58	597.29	23.00
Jalpaiguri	34.75	22.56	64.93	327.61	172.44	52.64	1972.31	454.19	23.03
Alipurduar	36.54	21.22	58.07	474.93	224.81	47.34	2115.96	452.33	21.38
Coochbehar	21.25	20.44	96.16	156.83	124.24	79.22	1241.18	302.51	24.37
Uttar Dinajpur	24.63	20.68	83.98	73.75	56.74	76.93	1038.77	270.89	26.08
Dakshin Dinajpur	25.47	26.49	104.01	89.66	57.40	64.02	1163.33	252.86	21.74
Malda	27.77	28.75	103.51	76.32	53.66	70.32	1124.21	261.55	23.27
Murshidabad	32.88	35.61	108.32	88.94	56.40	63.41	1226.92	271.46	22.13
Nadia	32.11	28.91	90.06	117.77	74.01	62.85	1349.99	315.93	23.40
Purba Bardhaman	38.8	34.06	87.78	95.57	58.71	61.43	1253.43	305.89	24.40
Paschim Bardhaman	41.39	34.42	83.15	78.49	56.94	72.54	1218.95	281.24	23.07
Birbhum	36.96	34.56	93.52	86.13	55.73	64.70	1231.76	296.19	24.05
Bankura	42.46	35.76	84.22	97.94	72.89	74.42	1250.24	292.10	23.36
Purulia	47.95	39.21	81.78	77.45	75.99	98.11	1327.07	287.51	21.67
Howrah	34.18	28.11	82.23	133.51	70.78	53.02	1442.46	343.43	23.81
Hooghly	33.58	27.34	81.42	122.19	66.00	54.01	1385.25	328.95	23.75
Kolkata	32.94	27.11	82.30	137.18	71.54	52.15	1484.87	358.14	24.12
North 24 Parganas	32.78	26.81	81.81	135.98	70.96	52.18	1479.08	355.87	24.06
South 24 Parganas	33.6	29.19	86.90	156.18	70.65	45.23	1571.06	369.91	23.55
Purba Medinipur	36.25	31.39	86.59	161.50	74.39	46.06	1556.62	348.21	22.37
Paschim Medinipur	36.79	30.95	84.13	128.23	70.43	54.93	1383.07	308.29	22.29
Jhargram	39.6	34.46	87.03	110.86	72.22	65.14	1317.11	290.88	22.09

Table 1. Continued.

District	Post monsoon			Annual		
	Mean	SD	CV	Mean	SD	CV
Kalimpong	223.37	94.46	42.29	3716.19	809.29	21.78
Darjeeling	195.21	87.83	44.99	3253.24	719.51	22.12
Jalpaiguri	166.43	77.17	46.37	2501.10	542.81	21.70
Alipurduar	186.10	78.80	42.34	2813.54	588.32	20.91
Coochbehar	110.82	84.60	76.34	1530.09	339.75	22.20
Uttar Dinajpur	80.73	64.95	80.46	1217.87	309.45	25.41
Dakshin Dinajpur	111.37	79.89	71.73	1389.82	289.97	20.86
Malda	113.60	78.39	69.00	1341.90	297.17	22.15
Murshidabad	153.02	104.17	68.08	1501.76	323.85	21.56
Nadia	187.64	112.44	59.92	1687.50	377.55	22.37
Purba Bardhaman	172.30	111.32	64.61	1560.10	371.11	23.79
Paschim Bardhaman	148.87	96.61	64.89	1487.70	341.07	22.93
Birbhum	156.84	102.92	65.62	1511.69	360.69	23.86
Bankura	172.29	114.39	66.40	1562.93	356.79	22.83
Purulia	152.03	103.36	67.99	1604.49	338.11	21.07
Howrah	203.33	131.56	64.71	1813.48	395.13	21.79
Hooghly	198.53	129.03	64.99	1739.55	386.46	22.22
Kolkata	211.49	132.96	62.87	1866.48	413.99	22.18
North 24 Parganas	211.10	132.19	62.62	1858.95	412.87	22.21
South 24 Parganas	227.92	131.63	57.75	1988.76	430.70	21.66
Purba Medinipur	212.44	124.80	58.75	1966.82	397.92	20.23
Paschim Medinipur	189.09	119.10	62.99	1737.18	352.83	20.31
Jhargram	185.01	119.34	64.50	1652.58	334.67	20.25

rainfall events were common during those seasons.

Seasonal and annual rainfall variability

Assessment of rainfall variability is becoming increasingly essential for strategic agricultural water management due to frequent weather aberrations and demand on water resources. Figure 1 depicted the variation in seasonal and annual rainfall in all West Bengal districts during the last 30 years. Winter, summer, monsoon and post-monsoon rainfall variability varied from 57.97 to 108.32 %, 45.23 to 98.11 %, 21.38 to 23.55 % and 42.29 to 76.34 %, respectively. Winter had the highest range of variability (108.32 %), followed by summer (98.11 %), post-monsoon (76.34 %) and monsoon (23.55 %). The annual variability ranged from 20.91 to 22.37 %. In the winter, summer and post-monsoon seasons, rainfall variability was quite high, with CV above 40% in all districts.

For winter and post-monsoon, the minimum

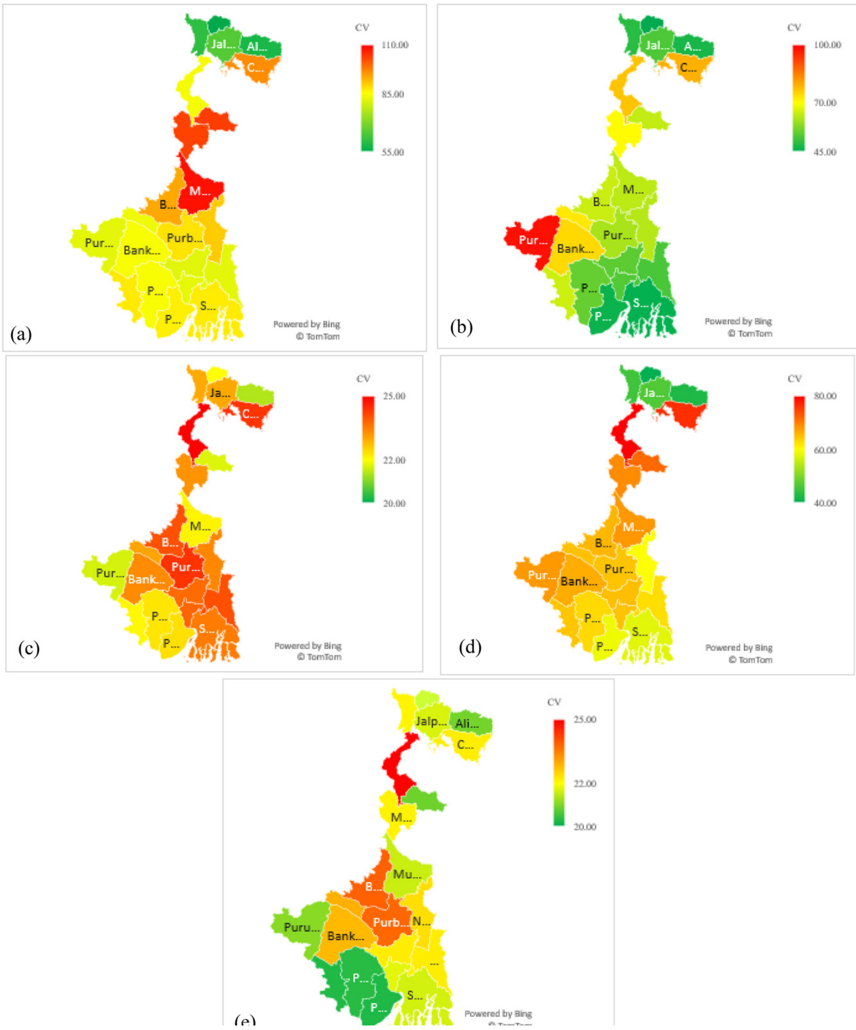

Fig. 1. Spatial variability of seasonal and annual rainfall in West Bengal during 1991-2020
a) winter, b) summer, c) Monsoon, d) Postmonsoon and e) annual.

seasonal variability was found in Kalimpong, whereas pre-monsoon was found in South 24 Parganas and monsoon in Alipurduar. Murshidabad, Purulia, South 24 Parganas and Coochbehar, for winter, summer, monsoon and post-monsoon, respectively, had the maximum seasonal rainfall variability. Nadia had the highest annual variability, whereas Alipurduar had the lowest.

Seasonal and annual rainfall trend

M-K test Table 2 was used to identify trends in seasonal and annual rainfall and also illustrated the percentage changes in annual and seasonal rainfall values. Winter rainfall shows increase trend in all the districts except Coochbehar and Uttar Dinajpur with significant value at 10% level of significance observed in Alipurduar, Purba Medinipur and Paschim Medinipur characterized with percentage change of magnitude +74.75%, 87.83% and 62.66%, respectively. Summer rainfall showed increasing trend in all the districts of the state while significant trend at 1% level of significance was observed in Jalpaiguri, Alipurduar, Coochbehar, Uttar and Dakshin Dinajpur with percentage change of magnitude +75.40%, +67.33%, +76.80%, +98.77% and +76.18%, respectively. In Kalimpong, Darjeeling and Malda, significant trend was observed at 5% level of significance with percentage change of magnitude +80.54%, +84.85% and +72.78%, respectively. Monsoon rainfall accounted for largest share of annual rainfall and showed decreasing trend in southern part of the state. A significant decrease trend at 1% level of significance was observed in Howrah, South 24 Parganas, Paschim Medinipur and Jhargram with percentage change of magnitude -34.18%, -42.23%, -36.44% and -37.96%, respectively and 5% level of significance observed in Hooghly, Kolkata, North 24 Parganas and Purba Medinipur with percentage change of magnitude -35.46%, -37.80%, -36.58% and -32.14%, respectively. Nadia and Bankura expressed significant decrease trend with percentage change of magnitude -28.19% and -30.79%, while Darjeeling and Alipurduar exhibited significant increasing trend with percentage change of magnitude +27.18% and +25.17% at 10% level of significance. Post-monsoon rainfall shows non significant decreasing trend in all the districts except extreme northern part (i.e. Kalimpong, Darjeeling, Jalpaiguri and Alipurduar). A significant increasing trend at 5% level of significance was observed in Kalimpong with percentage change of magnitude +64.83%.

Annual rainfall achieved a decreasing trend in the similar manner of monsoon rainfall. A significant decrease trend at 5% level of significance was observed in Howrah, Hooghly, Kolkata, North 24 Parganas, Purba Medinipur, Paschim Medinipur and Jhargram with percentage change of magnitude -33.46%, -25.59%, -31.53%, -30.78%, -37.36%, 41.06% and -34.22%, respectively while in South 24 Parganas, significant at 1% level of significance with percentage change of magnitude -36.53%. At 10% level of significance, Bankura showed decrease trend with percentage change of magnitude -30.72%, while Darjeeling, Jalpaiguri and Alipurduar showed increasing trend with percentage change of magnitude +27.42%, +25.05% and +18.62%, respectively.

Figure 2 illustrated the percentage change of magnitude in monsoon and annual series during the last thirty years was positive in the southern part of the state, but negative in the northern part. During the summer season, the percent change of magnitude was considerably higher and Uttar Dinajpur district had the highest rising trends of rainfall in terms of percentage change.

CONCLUSIONS

Analysis of spatio-temporal variability in rainfall figures over the state West Bengal indicated wide variations in annual and seasonal rainfall pattern as mentioned by Sushant *et al.* 2015. In the southern part of the state, both annual and monsoon rainfall had showed a decreasing trend in all districts. Bankura, Howrah, Hooghly, Kolkata, North 24 Parganas, South 24 Parganas, Purba Medinipur, Paschim Medinipur, and Jhargram districts had achieved a significant decrease trend in annual rainfall. Except for Murshidabad, Purba Bardhaman, Paschim Bardhaman, Birbhum and Purulia, all districts in the southern parts had expressed a significant decrease trend in monsoon

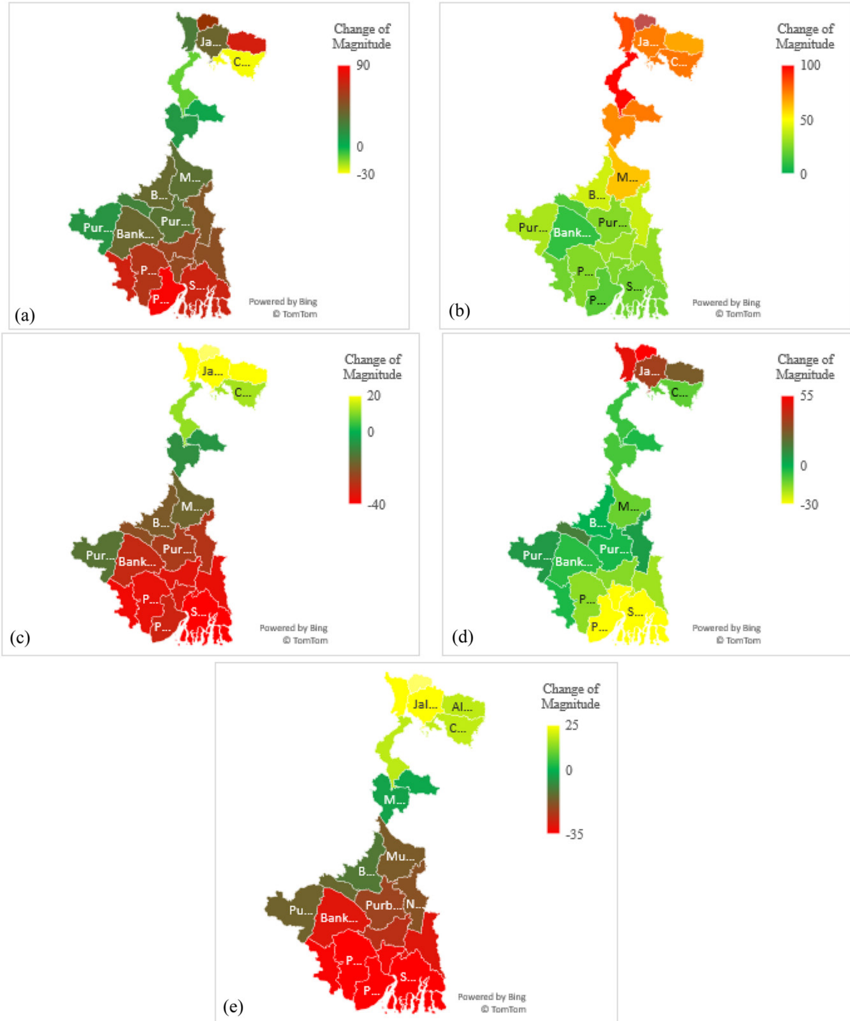

Fig. 2. Percentage change of magnitude for rainfall in West Bengal during 1991-2020 a) winter, b) summer, c) monsoon, d) postmonsoon and e) annual.

rainfall. All of the districts in the northern part of the state had registered a significant increase trend in summer rainfall. Post-monsoon rainfall exhibited a non-significant declining trend in all districts except the extreme northern part of the state (i.e. Kalimpong, Darjeeling, Jalpaiguri and Alipurduar), in contrast to an increasing trend was found in the extreme northern part. The study would be helpful for regional crop-water management and effective execution of rain water harvesting program of the West Bengal.

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Table 2. M-K test, Sen's slope estimate and percentage change of magnitude in West Bengal during 1991-2020. Z= Kendall tau, Q= Sen's slope, %= Percentage change of magnitude ***, ** and * represent significant at 1%, 5% and 10% level of significance, respectively.

District	Winter			Summer			Monsoon		
	Z	Q	%	Z	Q	%	Z	Q	%
Kalimpong	0.136	0.717	50.19	0.306**	13.803	80.54	0.209	20.792	21.25
Darjeeling	0.090	0.376	26.96	0.315**	11.870	84.85	0.218*	23.512	27.18
Jalpaiguri	0.099	0.441	38.10	0.343***	8.234	75.40	0.214	15.953	24.26
Alipurduar	0.231*	0.911	74.75	0.356***	10.659	67.33	0.223*	17.753	25.17
Coochbehar	-0.076	-0.205	-28.89	0.343***	4.015	76.80	0.090	5.342	12.91
Uttar Dinajpur	-0.021	-0.097	-11.79	0.402***	2.428	98.77	0.117	4.045	11.63
Dakshin Dinajpur	0.011	0.046	5.44	0.343***	2.277	76.18	-0.057	-2.357	-6.08
Malda	0.039	0.115	12.44	0.320**	1.852	72.78	-0.062	-2.818	-7.52
Murshidabad	0.094	0.357	32.60	0.255	1.825	61.57	-0.122	-7.050	-17.24
Nadia	0.126	0.490	45.75	0.182	1.519	39.70	-0.232*	-12.683	-28.19
Purba Bardhaman	0.076	0.405	31.31	0.090	0.831	26.07	-0.214	-11.140	-26.66
Paschim Bardhaman	0.057	0.324	23.50	0.057	0.404	15.45	-0.159	-9.081	-22.35
Birbhum	0.117	0.447	36.31	0.140	1.172	40.80	-0.149	-8.000	-19.49
Bankura	0.103	0.529	37.40	0.030	0.322	9.86	-0.241*	-12.831	-30.79
Purulia	0.053	0.226	14.16	0.117	0.862	33.40	-0.145	-6.098	-13.78
Howrah	0.205	0.595	52.24	0.126	1.123	25.23	-0.338***	-16.433	-34.18
Hooghly	0.140	0.611	54.57	0.122	1.228	30.16	-0.329**	-16.374	-35.46
Kolkata	0.186	0.604	54.96	0.136	1.282	28.04	-0.324**	-18.711	-37.80
North 24 Parganas	0.172	0.541	49.50	0.131	1.295	28.57	-0.320**	-18.034	-36.58
South 24 Parganas	0.200	0.806	71.95	0.136	1.154	22.16	-0.343***	-22.117	-42.23
Purba Medinipur	0.237*	1.061	87.83	0.117	0.932	17.31	-0.315**	-16.679	-32.14
Paschim Medinipur	0.223*	0.769	62.66	0.103	1.105	25.85	-0.356***	-16.798	-36.44
Jhargram	0.195	0.963	72.97	0.090	0.812	21.97	-0.347***	-16.666	-37.96

Table 2. Continued.

District	Postmonsoon			Annual		
	Z	Q	%	Z	Q	%
Kalimpong	0.292**	4.827	64.83	0.182	27.613	22.29
Darjeeling	0.205	3.234	49.71	0.223*	29.730	27.42
Jalpaiguri	0.136	1.946	35.07	0.251*	20.888	25.05
Alipurduar	0.131	1.631	26.30	0.246*	17.459	18.62
Coochbehar	-0.034	-0.406	-10.98	0.149	9.653	18.93
Uttar Dinajpur	-0.021	-0.178	-6.63	0.205	7.489	18.45
Dakshin Dinajpur	-0.021	-0.127	-3.42	-0.030	-0.854	-1.84
Malda	-0.034	-0.317	-8.36	-0.030	-1.255	-2.81
Murshidabad	-0.053	-0.629	-12.32	-0.113	-8.449	-16.88
Nadia	0.025	0.369	5.90	-0.163	-10.561	-18.78
Purba Bardhaman	-0.011	-0.153	-2.66	-0.168	-11.182	-21.50
Paschim Bardhaman	0.053	0.764	15.39	-0.113	-7.089	-14.30
Birbhum	-0.002	-0.021	-0.41	-0.094	-5.642	-11.20
Bankura	-0.007	-0.272	-4.74	-0.237*	-16.002	-30.72
Purulia	0.016	0.359	7.08	-0.140	-8.230	-15.39
Howrah	-0.113	-2.343	-34.56	-0.324**	-20.228	-33.46
Hooghly	-0.048	-1.041	-15.73	-0.260**	-14.838	-25.59
Kolkata	-0.057	-1.727	-24.51	-0.283**	-19.614	-31.53
North 24 Parganas	-0.053	-1.329	-18.88	-0.274**	-19.071	-30.78
South 24 Parganas	-0.094	-2.444	-32.17	-0.333***	-24.216	-36.53
Purba Medinipur	-0.113	-2.662	-37.59	-0.310**	-24.492	-37.36
Paschim Medinipur	-0.048	-1.048	-16.62	-0.324**	-23.775	-41.06
Jhargram	-0.011	-0.193	-3.13	-0.297**	-18.850	-34.22

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