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Trend Identification of Thunderstorms and Associated Casualties over Hilly Terrain of Jharkhand and Plains of Gangetic West Bengal

Suman Chattopadhyay and Raja Acharya
Regional Meteorological Centre, Kolkata, Alipore
Email: sumanchatterjee1966@gmail.com

ABSTRACT

An attempt is made in the present study to identify the trends of thunderstorms and associated casualties over two regions, namely Jharkhand and Gangetic West Bengal having different orography with 32yrs of observation across 22 meteorological stations. The non-parametric Mann-Kendall test and Sen's slope estimators have been used to calculate the trends. The results show that the frequency of thunderstorms is maximum in the month of April during the pre-monsoon season and in June during the monsoon season over both Jharkhand and Gangetic West Bengal. However, there is variability in the occurrence of thunderstorms over different districts of Jharkhand as well as Gangetic West Bengal. The causalities, on the other hand, during the period 1985 to 2017 over both Jharkhand and Gangetic West Bengal are observed to be maximum in the months of May and August respectively. The trend analyses show that in most of the districts of Jharkhand and Gangetic west Bengal, thunderstorms have increasing trends in both pre-monsoon and monsoon seasons during the study period.

Keywords: *Thunderstorms, Fatalities, Mann-Kendall trend test and Sen's slope estimation.*

1. Introduction

Thunderstorm is a significant recurrent weather phenomenon in the eastern part of India. It is generated over the hilly terrain of Chotanagpur plateau and some parts of sub Himalayan west Bengal due to extensive convective activity. Forecasting weather hazards is the prime concern of the operational meteorological centers around the globe, India is no exception (Chaudhuri and Middey, 2012).

The thunderstorms generate significant damages to the properties and crops, human and animal fatalities through strong surface wind gusts, lightning flashes, large hails, and occasional tornadoes. After coming in contact with the earth's surface, severe wind gusts produced by the thunderstorm downdraft spread out laterally and give rise to a downburst, which is a major threat for aviation hazard (Chaudhuri and Middey, 2011).

The research on pre-monsoon thunderstorms dates back to 1921 when Normand presented the basic thermodynamic parameters especially the wet bulb and wet bulb potential temperatures in understanding the prevalence of thunderstorms (Normand, 1921). Subsequently, Indian meteorologists (IMD, 1941) could appreciate well before the publication of thunderstorm project report in United States (Byers and Braham, 1949) that not only the discontinuities in temperature and moisture in the vertical plane create favorable environment for the genesis of thunderstorms but also the large-scale flow pattern to advect temperature and moisture.

Plethora of literature has been written by several professional scientists on thunderstorms over north eastern region of India dealing with various aspects of the system from different viewpoints. The present study is aimed at identifying the seasonal as well as annual trends of thunderstorms and consequent trends of rainfall over Jharkhand (erstwhile: Chotanagpur) and Gangetic West Bengal.

2. Data and Study Area

Two meteorological subdivisions namely, Jharkhand and Gangetic West Bengal are considered in this study as these places have been observed to encounter maximum number of devastating thunderstorms during two consecutive seasons of pre-monsoon and monsoon. Ten districts/places from Jharkhand namely, Hazaribagh, Jamshedpur, Latehar, Palamu, Gumla, West Singhbhum, Ramgarh, Giridih, Ranchi and Bokaro and twelve districts / places from Gangetic West Bengal namely, Morshidabad, Burdwan, Purulia, Bankura, East Midnapur, West Midnapur, South 24 Parganas, North 24 Paraganas, Birbhum, Hooghly, Howrah and Kolkata are taken as the study locations.

The number of thunderstorms, amount of rainfall and number of causalities are obtained from the weather section, Regional Meteorological Centre (RMC), Kolkata (surface data of class II part time observatories under DVC Met Unit) and from different newspapers. Figures 1-3 show the study locations.

3. Methodology

The monthly total number of thunderstorms have been obtained from daily summary data. The seasonal and annual thunderstorms are calculated from the monthly total values. Similarly, the amount of rainfall and number of causalities have been calculated on seasonal and annual time scales. The method of implementation is shown schematically in Figure 4.

3.1 MK test for trend analysis

The Mann–Kendall (MK) test is a non-parametric trend analysis for identifying the increasing and decreasing patterns in time series of the data. It compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). The MK test is first implemented using the null hypothesis H0 of no trend testing, that is, the observations xi are randomly ordered in time, against the alternative hypothesis, H1, where there is an increasing or decreasing monotonic trend. The data values evaluated as ordered time series are compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is

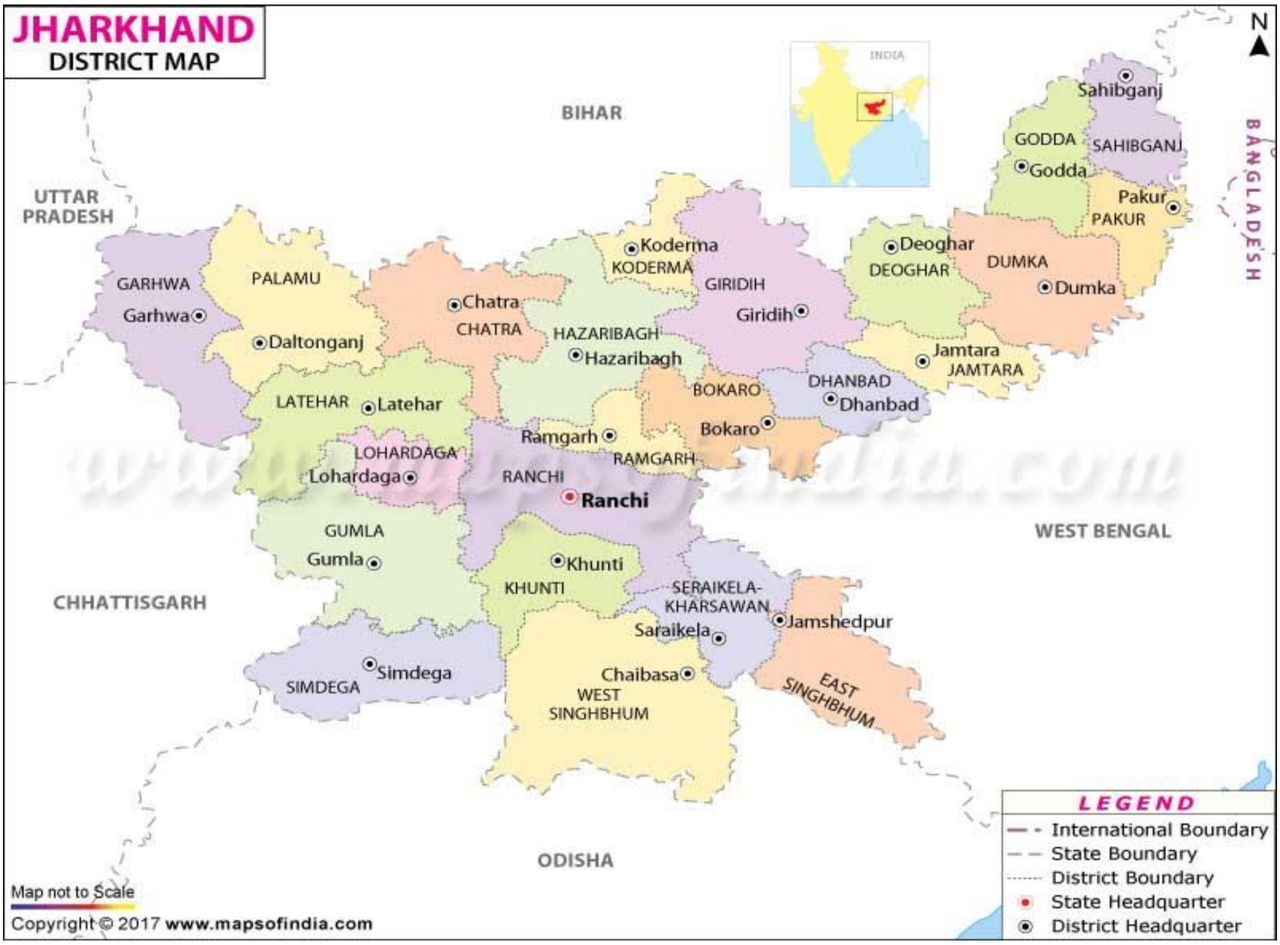

Figure 1: Map showing the districts of Jharkhand under study.

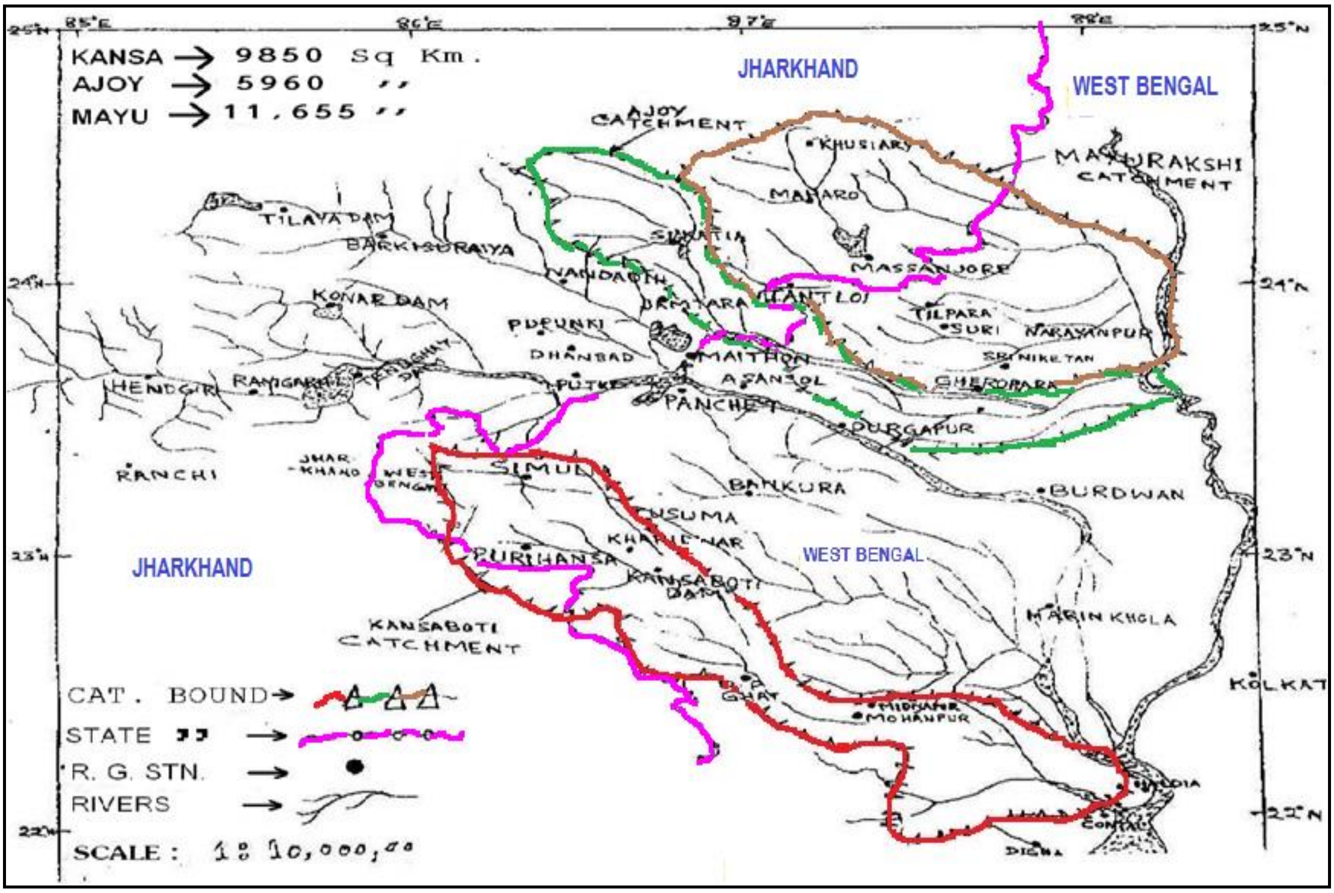

Figure 2: Map showing the districts of Western part of Gangetic West Bengal.

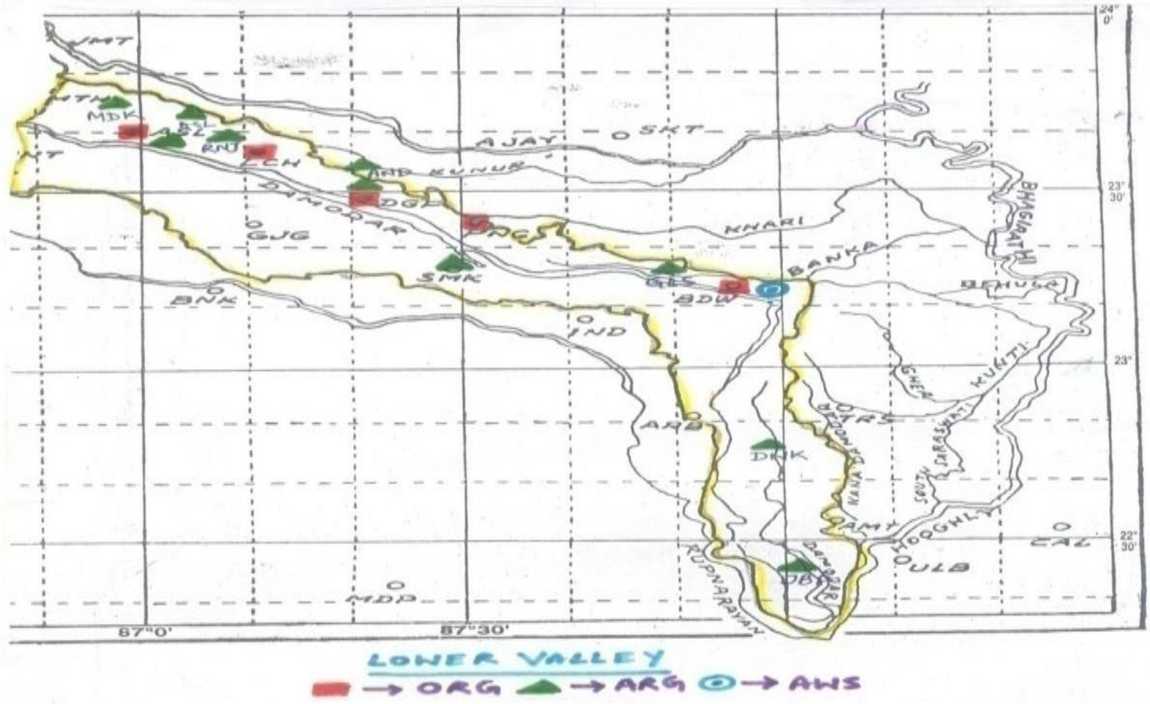

Figure 3: Map showing the districts of Eastern part of Gangetic West Bengal.

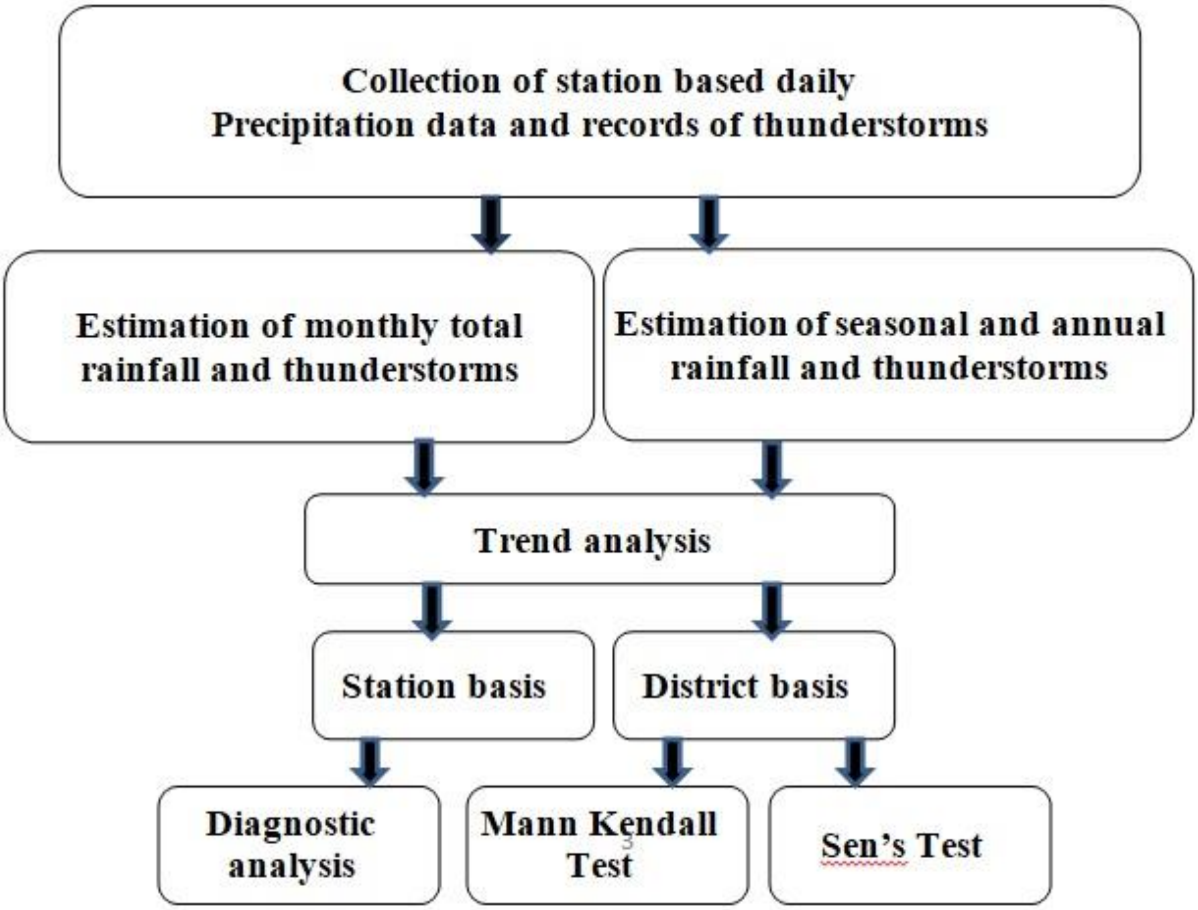

Figure 4. Schematic diagram of the methods followed.

incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all these increments and decrements yields the final value of S (Shahid, 2011; Shrestha et al. 1999; Yue et al. 2002; Domonkos et al. 2003). The MK test statistic S is computed as done by Chaudhuri and Dutta (2014).

$$S = \sum_{k=1}^{n=1} \sum_{j=k+1}^{n} Sgn(x_j - x_k) \tag{1}$$

$$Sgn(x_j - x_k) = \begin{cases} -1 if & (x_j - x_k) < 0 \\ 0 if & (x_j - x_k) = 0 \\ +1 if & (x_j - x_k) > 0 \end{cases} \tag{2}$$

Where x_j and x_k are the annual values in different years j and k, j > k, respectively.

If n < 10 then the value of |S| is compared directly with the theoretical distribution of S that is derived by Mann-Kendall test (Gilbert, 1987). The two tailed test is used. At some probability level H0 is rejected in favour of H1 if the absolute value of S equals or exceeds a specified value Sα/2, where Sα/2 is the smallest S having the probability less than α/2. A positive (negative) value of S indicates an upward (downward) trend (Salmi et al. 2002; Luo et al. 2008).

For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0$$

$$VAR(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)] \tag{3}$$

q is the number of tied groups and t_p is the number of data values in the p th group.

The standard test statistic Z is computed as:

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

The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend.

3.2 Sen's slope estimators

If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). This means that linear model f (t) can be described as

$$f(t) = Qt + B \qquad (4)$$

where Q is the slope B is a constant.

To derive an estimate of the slope Q, the slopes of all data pairs are calculated

$$Q_i = \frac{x_j - x_k}{j-k}, i = 1,2....N, j > k \qquad (5)$$

If there are n values xj in the time series we get as many as $N = \frac{n(n-1)}{2}$ slope estimates Qi.

The Sen's estimator of slope is the median of these N values of Q_i. The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is too much a given measure of heterogeneity

$$Q_{med} = \begin{cases} Q_{[(N+1)/2]} & \text{If N is Odd} \\ Q_{\frac{[N/2]+[(N+2)/2]}{2}} & \text{, If N is even} \end{cases} \qquad (6)$$

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q_{med} at specific probability.

A 100(1-α) % two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution. The method is valid for n as small as 10 unless there are many ties. At first it is computed that,

$$C_\alpha = Z_{1-\frac{\alpha}{2}} \sqrt{Var(S)} \qquad (7)$$

where VAR (S) has been defined in equation (10.3), Z1-α/2 is obtained from the standard normal distribution.

Next $M_1 = (N - C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, Qmin and Qmax, are the M_1th largest and the $(M_2 + 1)$th largest of the N ordered slope estimates Qi. If M_1 and/or M_2 are not a whole numbers, the respective limits are interpolated. To obtain an estimate of B in equation (10.5) the n values of differences $x_i - Qt_i$ are calculated. The median of these values gives an estimate of B (Sirois, 1998). The estimates for the constant B of lines of the 99% and 95% confidence intervals are calculated by a similar procedure. Data were processed using an Excel macro named MAKESENS created by Salmi et al. (2002).

4. Results and Discussion

The present research has dual purposes; firstly to examine the numbers of thunderstorms during two consecutive seasons over two regions (Figures 1–3) with different orography and second purpose is to estimate the measure of casualties due to the consequences of such thunderstorms.

The numbers of thunderstorms occurred during the two consecutive seasons over the two regions have identified and shown in Tables 1-4 & Figures 5-8.

The results of three decades of analysis show that the prevalence of thunderstorm is maximum over both Jharkhand and Gangetic West Bengal in the month of April during the pre-monsoon season whereas maximum thunderstorms is observed to occur in the month of June during the monsoon season over Jharkhand and in the month of July over Gangetic West Bengal. However, there is variability in the occurrence of thunderstorms over different districts of Jharkhand as well as Gangetic West Bengal. The causalities during the period 1985 to 2017 over both Jharkhand and Gangetic West Bengal are reported to be maximum in the month of May during the pre-monsoon season and in the month of August during the monsoon season

Table 1. Number of thunderstorms during February to May over different districts of Jharkhand for the period from 1985 to 2017.

Districts	February	March	April	May	Total	Mean (yearly)
Hazaribagh	32	140	182	137	491	15.3
Jamshedpur(Sereikela)	34	147	191	128	500	15.6
Latehar	30	143	180	131	484	15.1
Palamu	28	148	178	122	476	14.9
Gumla	31	145	184	115	475	14.8
Singhbum(West)	32	143	176	127	478	14.9
Ramgarh	30	151	192	138	511	15.9
Giridih	29	147	188	141	505	15.8
Ranchi	25	150	202	152	529	16.5
Bokaro	27	153	197	142	519	16.2
Total	298	1467	1870	1333		
Mean (yearly)	29.8	146.7	187.0	133.3		

Table 2. Number of thunderstorms during March to May over different districts of Gangetic West Bengal for the period from 1985 to 2017.

Districts	March	April	May	Total	Mean (yearly)
Murshidabad	38	112	92	242	7.6
Burdwan	36	118	98	252	7.9
Purulia	40	122	105	267	8.3
Bankura	39	128	109	276	8.6
West Midnapur	32	119	116	267	8.3
East Midnapur	33	116	112	261	8.2
South 24 Pargana	32	122	124	278	8.7
North 24 Pargana	35	123	122	280	8.7
Birbhum	36	130	120	286	8.9
Hooghly	31	126	116	273	8.5
Howrah	37	128	120	285	8.9
Kolkata	35	124	112	271	8.5
Total	424	1468	1348		
Mean	35.3	122.3	112.6		

Table 3. Number of thunderstorms during June to October over different districts of Jharkhand for the period from 1985 to 2017.

Districts	June	July	August	September	October	Total	Mean (yearly)
Hazaribagh	98	64	96	36	42	336	67.2
Jamshedpur(Sereikela)	108	68	102	32	38	348	69.6
Latehar	102	66	98	34	36	336	67.2
Palamu	96	70	92	30	40	328	65.6
Gumla	105	76	94	34	34	343	68.6
Singhbum(West)	118	78	88	38	42	364	72.4
Ramgarh	110	72	96	32	36	346	69.2
Giridih	112	68	92	30	39	341	68.2
Ranchi	122	70	90	36	37	355	71.0
Bokaro	116	74	98	35	32	355	71.0
Total	1087	706	946	337	376		
Mean	108.7	70.6	94.6	33.7	37.6		

Table 4. Number of thunderstorms during June to October over different districts of Gangetic West Bengal for the period from 1985 to 2017.

Districts	June	July	August	September	October	Total	Mean (yearly)
Murshidabad	87	92	32	26	22	259	8.1
Burdwan	102	104	34	29	26	295	9.2
Purulia	124	106	26	32	20	308	9.6
Bankura	98	100	30	31	21	280	8.7
West Midnapur	105	112	30	34	24	305	9.5
East Midnapur	102	110	28	35	23	298	9.3
South 24 Pargana	96	98	32	32	28	286	8.9
North 24 Pargana	94	100	33	34	27	288	9.0
Birbhum	105	104	26	35	30	300	9.4
Hooghly	93	92	28	29	28	270	8.4
Howrah	97	88	29	31	22	267	8.3
Kolkata	95	93	26	26	23	263	8.2
Tota	1198	1199	354	374	294		
Mean	99.8	99.9	29.5	31.2	24.5		

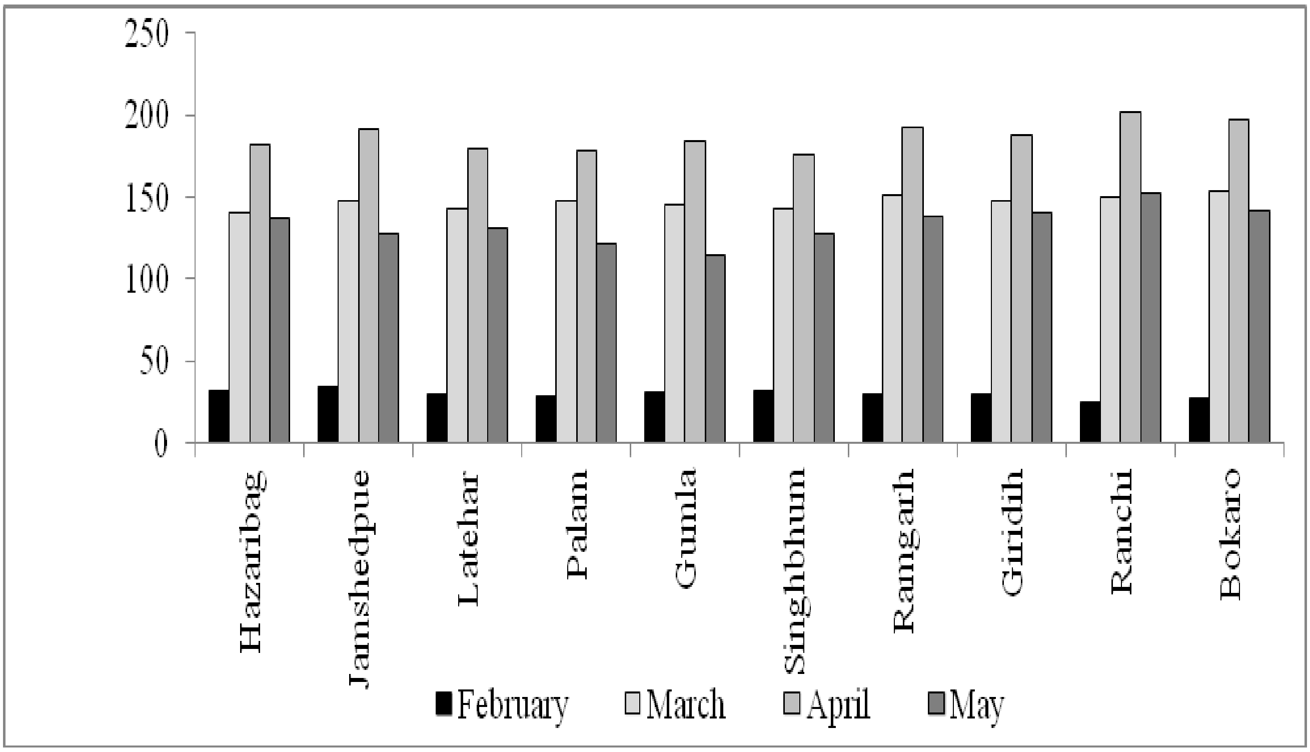

Figure 5: Number of thunderstorms during February to May over Districts of Jharkhand for the period from 1985 to 2017.

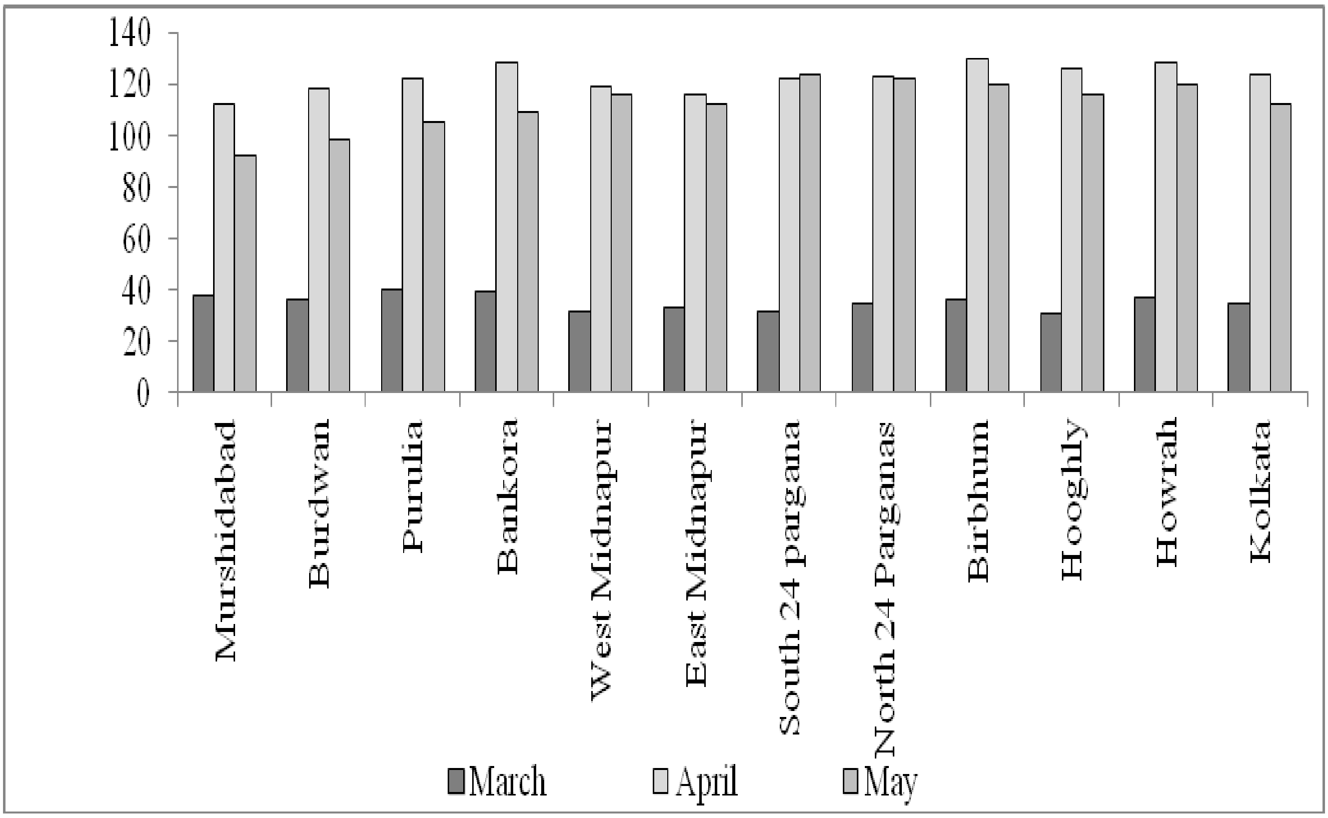

Figure 6: Number of thunderstorms during March to May over Districts of Gangetic West Bengal for the period from 1985 to 2017.

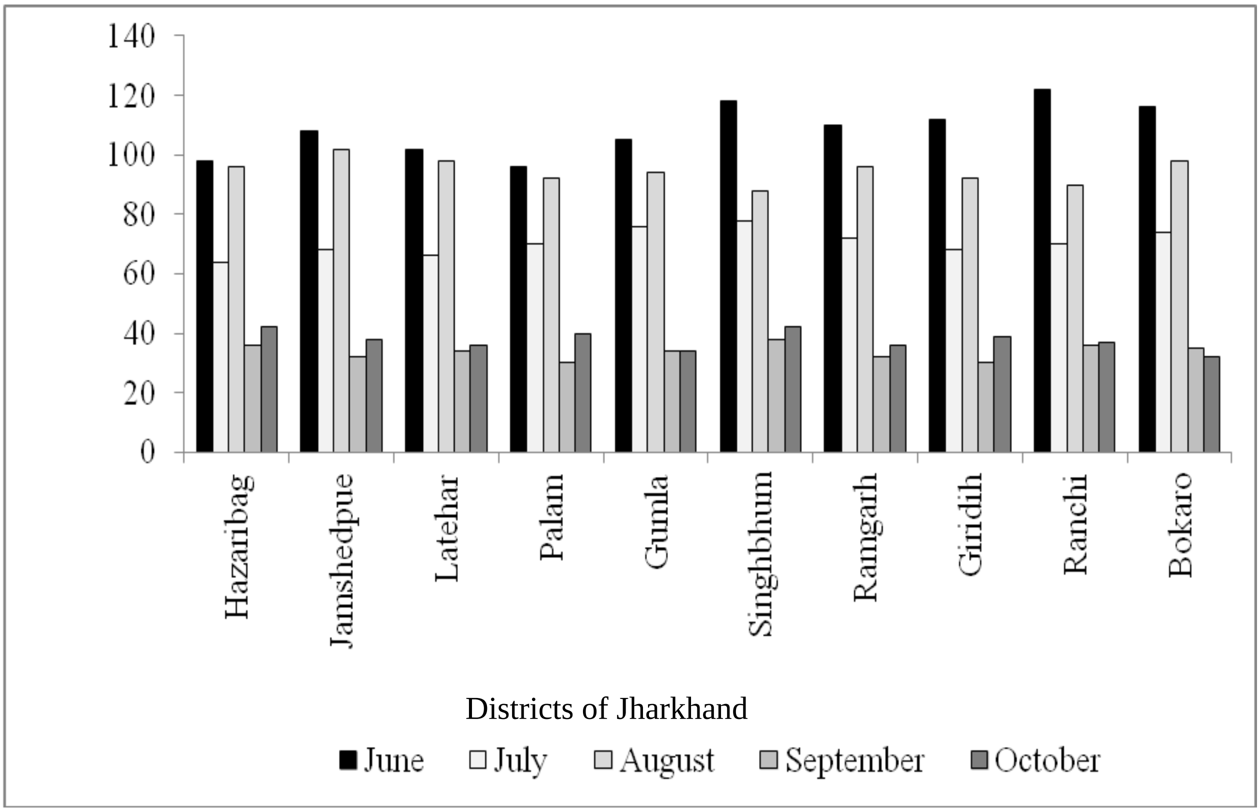

Figure 7: Number of thunderstorms during June to October over Jharkhand for the period from 1985 to 2017.

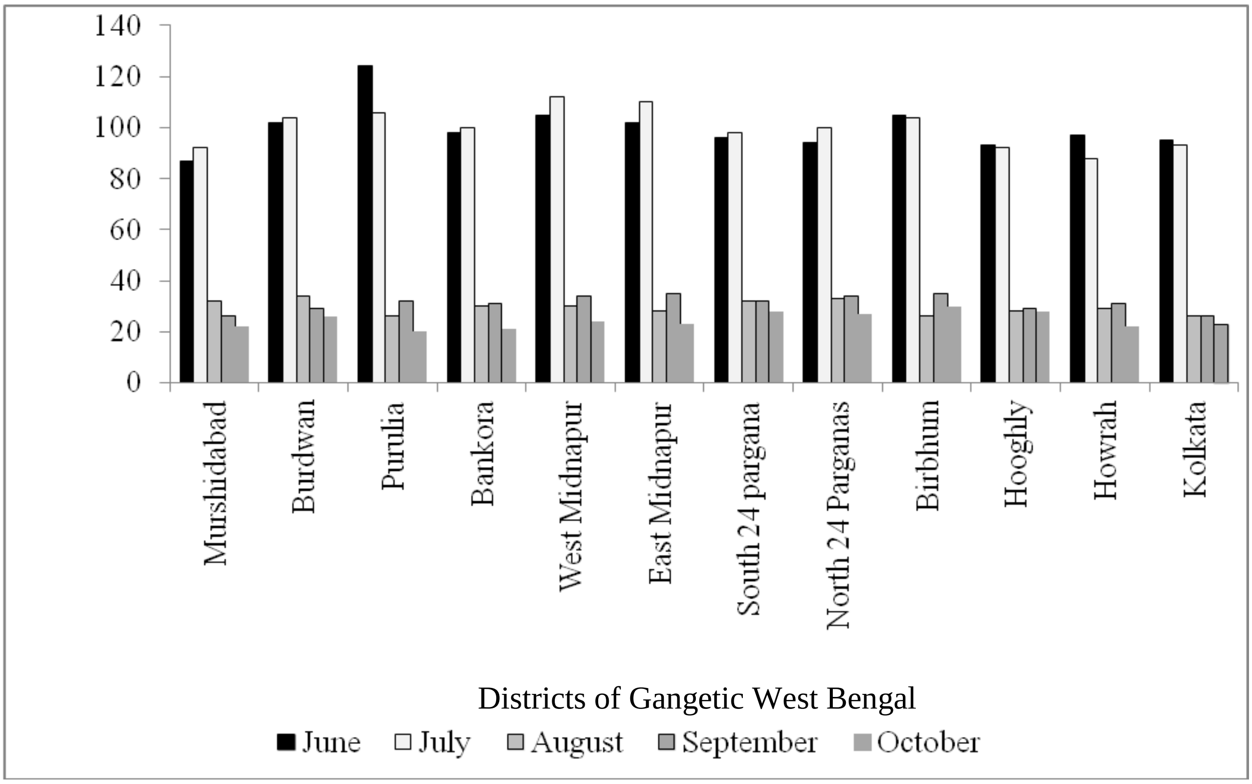

Figure 8: Number of thunderstorms during June to October over Gangetic west Bengal for the period from 1985 to 2017.

Table 5. Causalities reported during February to May over different district of Jharkhand for the period from 1985 to 2017.

Districts	February	March	April	May	Total	Mean (yearly)
Hazaribagh	4	22	147	176	349	10.9
Jamshedpur(Sereikela)	2	27	138	146	313	9.8
Latehar	3	21	112	156	292	9.1
Palamu	4	25	126	198	353	11.0
Gumla	2	23	114	185	324	10.1
Singhbum(West)	2	30	142	174	348	10.9
Ramgarh	5	32	136	202	348	10.8
Giridih	3	28	138	210	379	11.8
Ranchi	6	24	124	214	368	11.5
Bokaro	4	26	119	208	357	11.2
Total	35	258	1296	1869		
Mean	3.5	25.8	129.6	186.9		

Table 6. Causalities reported during March to May over different districts of Gangetic West Bengal for the period from 1985 to 2017.

Districts	March	April	May	Total	Mean (yearly)
Murshidabad	79	132	202	413	12.9
Burdwan	77	138	208	423	13.2
Purulia	82	140	215	437	13.7
Bankura	68	132	219	419	13.0
West Midnapur	76	139	211	426	13.3
East Midnapur	78	138	209	425	13.2
South 24 Pargana	74	127	186	387	12.1
North 24 Pargana	76	129	188	393	12.3
Birbhum	78	137	192	407	12.7
Hooghly	68	132	194	394	12.3
Howrah	82	114	198	394	12.3
Kolkata	83	122	178	383	11.9
Total	921	1580	2400		
Mean	76.7	131.6	200		

Table 7. Causalities during June to October over different districts of Jharkhand for the period from 1985 to 2017.

Districts	June	July	August	September	October	Total	Mean (yearly)
Hazaribagh	72	26	134	78	76	386	12.0
Jamshedpur(Sereikela)	88	32	142	86	77	425	13.2
Latehar	72	34	130	80	64	380	11.8
Palamu	65	38	142	69	68	382	11.9
Gumla	73	42	126	73	72	386	12.1
Singhbum(West)	76	34	140	82	76	408	12.7
Ramgarh	86	36	118	74	67	381	11.9
Giridih	68	32	134	76	69	379	11.8
Ranchi	47	28	128	84	73	360	11.2
Bokaro	56	40	138	80	71	385	12.0
Total	703	342	1332	782	713		
Mean	70.3	34.2	133.2	78.2	71.3		

Table 8. Causalities during June to October over different districts of Gangetic West Bengal for the period from 1985 to 2017.

Districts	June	July	August	September	October	Total	Mean(yearly)
Murshidabad	55	82	115	69	63	384	12.0
Burdwan	68	102	120	73	56	419	13.1
Purulia	85	96	122	81	68	452	14.1
Bankura	64	85	130	78	52	409	12.7
West Midnapur	62	94	134	87	76	453	14.1
East Midnapur	63	96	132	89	74	454	14.2
South 24 Pargana	60	87	138	93	58	436	13.6
North 24 Pargana	73	85	140	89	59	446	13.9
Birbhum	63	98	126	95	68	450	14.0
Hooghly	52	93	118	97	53	413	12.9
Howrah	58	88	114	81	48	389	12.1
Kolkata	56	102	118	84	56	416	13.0
Total	759	1108	1507	737	731		
Mean	63.2	92.3	125.6	61.4	60.9		

Table 9. The trend of thunderstorm occurrence over Jharkhand during the period from 1985 to 2017 (MK test value and Sen's Estimator value).

Districts	**Season (No of TS)**	**MK test (Z test)**	**Trend**	**Result**	**Sen's slope estimator change TS/Year**
Hazaribagh	Pre monsoon	-0.54	↓	NS	-1.78
	Monsoon	0.68	↑	NS	1.32
Jamshedpur (Sereikela)	Pre monsoon	1.28	↑	SIG	3.85
	Monsoon	0.26	↑	NS	0.78
Latehar	Pre monsoon	0.94	↑	SIG	2.24
	Monsoon	0.59	↑	NS	0.96
Palamu	Pre monsoon	0.62	↑	NS	1.12
	Monsoon	0.57	↑	NS	0.93
Gumla	Pre monsoon	1.03	↑	SIG	2.76
	Monsoon	0.68	↑	NS	1.18
Singhbhum (West)	Pre monsoon	-.78	↓	NS	-2.02
	Monsoon	-0.49	↓	NS	0.82
Ramgarh	Pre monsoon	0.22	↑	NS	0.58
	Monsoon	0.89	↑	SIG	1.69
Giridih	Pre monsoon	1.23	↑	SIG	2.54
	Monsoon	0.62	↑	NS	1.25
Dhanbad	Pre monsoon	1.42	↑	SIG	3.68
	Monsoon	0.87	↑	SIG	1.57
Bokaro	Pre monsoon	1.20	↑	SIG	2.14
	Monsoon	0.54	↑	NS	

(NS: Non significant, SIG: Significant)

Table 10. The trend of thunderstorm occurrence over Gangetic West Bengal during the period from 1985 to 2017 (MK test value and Sen's Estimator value).

Districts	**Season (No of TS)**	**MK test (Z test)**	**Trend**	**Result**	**Sen's slope estimator change TS/Year**
Murshidabad	Pre monsoon	0.82	↑	NS	2.10
	Monsoon	1.05	↑	SIG	4.32
Burdwan	Pre monsoon	0.76	↑	NS	1.87
	Monsoon	0.93	↑	SIG	3.05
Purulia	Pre monsoon	0.89	↑	SIG	1.88
	Monsoon	0.72	↑	NS	1.38
Bankura	Pre monsoon	0.77	↑	NS	1.69
	Monsoon	0.68	↑	NS	1.64
West Midnapur	Pre monsoon	0.92	↑	SIG	2.98
	Monsoon	0.42	↑	NS	0.86
East Midnapur	Pre monsoon	0.79	↑	NS	1.25
	Monsoon	1.09	↑	SIG	4.52
South 24 Parganas	Pre monsoon	1.12	↑	SIG	4.62
	Monsoon	0.44	↑	NS	0.72
North 24 Parganas	Pre monsoon	0.75	↑	NS	1.48
	Monsoon	-0.28	↓	NS	-0.46
Birbhum	Pre monsoon	0.98	↑	SIG	3.15
	Monsoon	0.59	↑	NS	1.46
Hooghly	Pre monsoon	0.89	↑	SIG	1.79
	Monsoon	0.92	↑	SIG	2.19
Howrah	Pre monsoon	1.05	↑	SIG	3.76
	Monsoon	0.68	↑	NS	1.59
Kolkata	Pre monsoon	0.54	↑	NS	1.26
	Monsoon	1.02	↑	SIG	2.18

(NS: Non significant, SIG: Significant)

(Tables 5–8). The trend analyses (Tables 9&10) show that in most of the districts of Jharkhand and Gangetic West Bengal, thunderstorms have an increasing trend in both pre-monsoon and monsoon seasons during the study period.

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