

Article

Trends and Variabilities of Thunderstorm Days over Bangladesh on the ENSO and IOD Timescales

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Abstract: Thunderstorms (TS) are one of the most devastating atmospheric phenomena, which causes massive damage and adverse losses in various sectors, including agriculture and infrastructure. This study investigates the spatiotemporal variabilities of TS days over Bangladesh and their connection with El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). The TS, ENSO and IOD years' data for 42 years (1975–2016) are used. The trend in TS days at the spatiotemporal scale is calculated using Mann Kendall and Spearman's rho test. Results suggest that the trend in TS days is positive for all months except December and January. The significant trends are found for May and June, particularly in the northern and northeastern regions of Bangladesh. In the decadal scale, most of the regions show a significant upward trend in TS days. Results from the Weibull probability distribution model show the highest TS days in the northeastern region. The connection between TS days and ENSO/IOD indicates a decrease in TS activities in Bangladesh during the El Niño and positive IOD years.

Keywords: thunderstorm; variability; trend; ENSO; IOD; Bangladesh

1. Introduction

Thunderstorms (TS) are a severe hazard in Bangladesh that cause immense death and adverse loss in agriculture, infrastructure and livestock during pre-monsoon and monsoon months. In the most severe situation, it can also create very destructive tornadoes [1], due to hot and humid air in the lower atmosphere from the southeastern direction and the opposite cold and dry air from the northwestern direction. TS predominantly occur in Bangladesh during the premonsoon and monsoon seasons, with the maximum frequency in May. The country experienced TS strikes an average of nine days in May before 1981, but later, it increased to 12 days. According to the Bangladesh Meteorological Department (BMD), a total number of 1476 people have died in Bangladesh by TS since 2010. The Comprehensive Disaster Management Programme under the Ministry of Disaster Management and Relief reported 180 deaths by TS only in 2016. The Government of Bangladesh

declared TS as natural disasters on 17 May 2016 by considering their significant impacts on human life and economy [2].

El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are associated with monthly or seasonal climate anomalies at many places around the globe [3,4]. They might have an effect on TS activity over Bangladesh due to its tropical climate. Therefore, further understanding the effects of ENSO on TS variations over Bangladesh is necessary for disaster prevention and mitigation. Some studies have performed globally to investigate the effects of ENSO on TS activity [5–10]. Manohar et al. [5] found the influences of El Niño on thunderstorm occurrences during the Indian monsoon season. Allen and Karoly [7] showed a significant influence of ENSO on the spatial distribution of thunderstorms in Australia. Yuan and Di [11] found a decrease in thunderstorms in Eastern China during ENSO episodes. Pinto [10] found an increasing tendency in thunderstorm activity in Southern Brazil during the ENSO warm phase.

A substantial number of studies have been conducted on thunderstorms worldwide in recent years, e.g., Kunkel et al. [12] in the USA, Mir et al. [13] in Pakistan, Kunz et al. [14] in Germany, Pinto et al. [9,10] in Brazil, Enno et al. [15] in Europe, Allen and Karoly [7] in Australia, Zheng et al. [16] in China, Singh and Bhardwaj [17] in India, Saha and Quadir [2] in Bangladesh and Araghi et al. [18] in Iran. Most of the earlier studies focused on the synoptic, dynamic and physical aspects of TS events, as well as modelling or predicting TS occurrence. However, the spatiotemporal variabilities of TS days linked to ENSO and IOD have been less investigated in the prevailing literature.

A few studies have also been conducted to explore the TS events in Bangladesh [2,19,20]. These prior studies mostly investigated time and space variations and the origin and frequency of TS over Bangladesh. However, these earlier works in Bangladesh were very limited to a specific site or a short period like the premonsoon season only. The spatial variabilities in the occurrence of TS days for different timescales and the relation of TS days with ENSO and IOD are not clear yet for Bangladesh. The present study would contribute to filling this knowledge gap by investigating the spatiotemporal variabilities in monthly, seasonal, annual and decadal TS days and exploring the link between TS days and ENSO/IOD over Bangladesh.

2. Data and Methods

2.1. Study Area

Bangladesh is a South Asian country located between 20.57° N to 26.63° N and 88.02° E to 92.68° E with a tropical and subtropical monsoon climate [21]. Bangladesh often faces severe natural disasters during the premonsoon, monsoon and postmonsoon seasons. Geographically, the Indian States of West Bengal, Assam, Meghalaya and Tripura border Bangladesh in the west, north and east, respectively. Myanmar forms the southern part of the eastern frontier. The Bay of Bengal is on the southern side. The topography of Bangladesh is extreme lowlands, with most of the land below 10 m above the mean sea level. The Brahmaputra, Ganges (Padma) and the Meghna influence the main river system of Bangladesh. There are four seasons in Bangladesh: pre-monsoon (March–May), monsoon (June–September), post-monsoon (October and November) and winter (December–February). Southwest and northeast monsoons have a major influence on the country's climate, resulting in marked seasonal rainfalls and temperatures. In this study, we selected 29 weather stations (Figure 1).

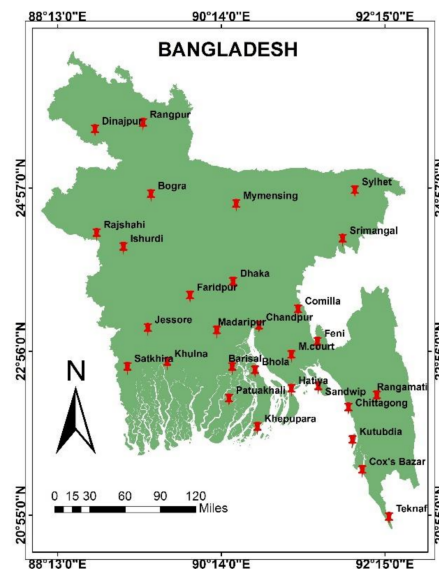


Figure 1. Meteorological stations over Bangladesh used in this study.

2.2. Data Source and Quality Control

Daily thunderstorm data are collected from the BMD for the period of 42 years (1975–2016). A storm with thunder and lightning formed by the rapid upward movement of warm moist air is considered as a thunderstorm. The mechanism of thunderstorm formation is different for different seasons in Bangladesh. Therefore, thunderstorm data are analyzed separately for each season in this paper. ENSO and IOD data are collected from the National Oceanic and Atmospheric Administration (NOAA) for the same period, which are represented in Table 1. These years are selected based on the definition of the NOAA. Meteorological data often contain inhomogeneity, which results in erroneous and false analysis and prediction. Data collection techniques, data processing methods, relocation of the stations, lack of proper equipment and the drift of equipment are the causes of data inhomogeneity [22]. In this study, the Standard Normal Homogeneity Test (SNHT) was used to assess the homogeneity in the collected TS data. Data for all the stations found homogeneity at a significance level of 95% or more.

Table 1. Identified years under various climate modes during 1975–2016.

Climate Modes	Years
El Niño	1976, 1977, 1986, 1987, 1988, 1997, 1998, 2006, 2007, 2014
La Niña	1975, 1983, 1984, 1985, 1989, 1996, 1999, 2000, 2001, 2005, 2008, 2010, 2012, 2013
Normal	1978, 1991, 1992, 1994, 1995, 2002, 2003, 2004, 2005, 2009, 2015, 2016
IOD-positive	1982, 1983, 1994, 1997, 2006, 2012, 2015
IOD-negative	1975, 1981, 1989, 1992, 1996, 1998, 2010, 2014, 2016

2.3. Methods

2.3.1. Mann–Kendall (MK) Trend Test

The trend in a data series is most popularly detected using the Mann–Kendall (MK) test [23]. Wilks et al. [24] identified the following equations from the original version of the MK test:

$$s_t = \sum_{c=1}^{n-1} \sum_d^n \text{sign}(x_d - x_c) \quad (1)$$

where

$$\text{sign}(x_d - x_c) = \begin{cases} +1 & \text{if } (x_d - x_c) > 0 \\ 0 & \text{if } (x_d - x_c) = 0 \\ -1 & \text{if } (x_d - x_c) < 0 \end{cases} \quad (2)$$

The trend significance is estimated using Z statistics,

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (3)$$

where

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)}{18} \quad (4)$$

where n represents the data size, m represents the tied groups with repeated values that are indicated by j and t_j is the number of repeated values in and t_i represents the number of data in the tied group, i .

The existence of serial correlation and a seasonality pattern in a time series data can have a major effect on the results of the MK test. Autocorrelation estimation is one of the simplest methods to check for the existence of seasonality patterns or serial correlations in any time series. Plotting autocorrelation coefficients versus lags are called a correlogram, which is usually used for detecting seasonality patterns and serial correlations in a time series. The autocorrelation coefficient for lag can be calculated as:

$$r_k = \frac{\sum_{i=1}^{n-k} [(x_i - x_-)(x_{i+k} - x_+)]}{\sqrt{\left[\sum_{i=1}^{n-k} (x_i - x_+)^2\right]} \sqrt{\left[\sum_{i=k+1}^n (x_i - x_+)^2\right]}} \quad (5)$$

The subscripts “−” and “+” in Equation (6) indicate the sample averages over the first and last $n - k$ values in the time series, respectively. To judge, if the time series is serially correlated, the significance of the lag-1 autocorrelation coefficient at a significance level of $\alpha = 0.10$ of the two-tailed t -test is assessed using Equation (6).

$$\frac{-1 - 1.645 \sqrt{n-2}}{n-1} \leq r_k \leq \frac{-1 + 1.645 \sqrt{n-2}}{n-1} \quad (6)$$

If the time series has a positive (negative) lag-1 autocorrelation coefficient, then the variance estimation will be less (more) than the actual value and based on Equation (7); this will increase or decrease the MK Z -value erroneously. When the lag-1 autocorrelation coefficient is significant, or, in other words, when there is serial correlation in a time series, then the modified version of the MK test should be used as follows:

$$\text{var}(S') = \frac{1}{18} [n(n-1)(2n+5)] \left[\frac{n}{n_e} \right] \quad (7)$$

$$\frac{n}{n_e} = 1 + \left(\frac{2}{n^3 - 3n^2 + 2n} \right) \sum_{f=1}^{n-1} (n-f)(n-f-1)(n-f-2) \rho_e(f) \quad (8)$$

$$\rho(f) = 2 \sin \left[\frac{\pi}{6} \rho_e(f) \right] \quad (9)$$

2.3.2. Weibull Probability Distribution Model

Wallodi Weibull invented the Weibull distribution for parameter estimation of the frequency distribution of data. Weibull distribution is commonly used in the probability density function. The detailed information regarding Weibull probability distribution can be found in Islam et al. [20].

2.3.3. Spearman's Rho Test

The Spearman's rho (SR) test is a technique with uniform power for linear and nonlinear trends [20]. It is commonly used to verify the absence of trends. The null hypothesis (H_0) of the test is that all the data in the time series are independent and identically distributed, while the alternative hypothesis (H_1) is that increasing or decreasing trends exist. Positive values of the standardized test statistic, SR_Z , indicate upward trends, while the negative values of SR_Z indicate downward trends in the time series. The SR is calculated by the following Equation (10),

$$R = 1 - \frac{6 \sum d^2}{n^3 - n} \quad (10)$$

where R denotes the spearman's rank correlation, d denotes the difference in the rank and n is the total number of data.

3. Results

3.1. Monthly and Seasonal Variation of TS Days

The monthly and seasonal variabilities of TS days over Bangladesh are presented in Figures 2 and 3, respectively. The highest average TS days are observed in May, while the lowest in December (Figure 2). The least TS activity is found during the postmonsoon and winter seasons because of low temperatures and lower moisture. The premonsoon and the monsoon seasons have comparatively higher TS days than that of the winter season (Figure 3). The average monthly value of TS days in the monsoon and pre-monsoon seasons is 7.96 and 7.95, respectively, while the average TS days in the postmonsoon and cold winter are four and one, respectively. The seasonal variation of TS days during 1975–2016 shows a sharp increasing trend in TS days during the monsoon, with $R^2 = 0.41$, and almost no change during the premonsoon season.

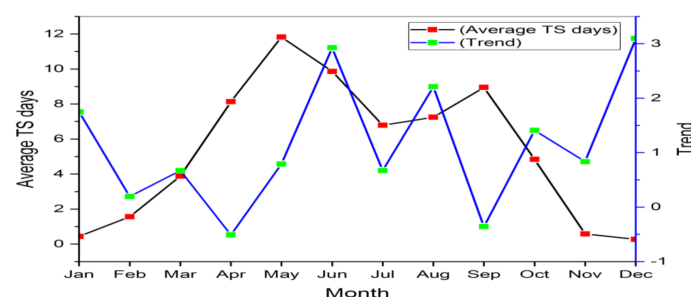


Figure 2. Average monthly thunderstorm (TS) days in Bangladesh during 1975–2016.

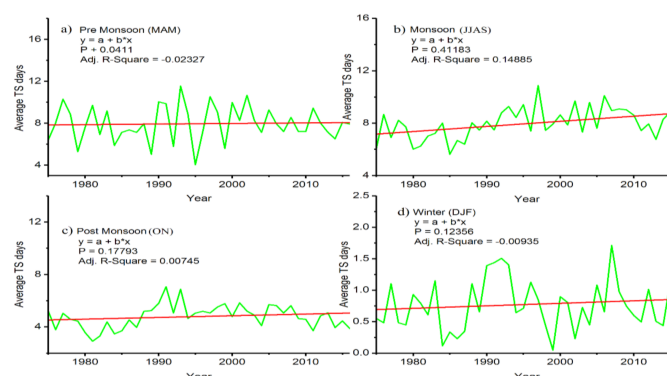


Figure 3. Seasonal variation days (a) premonsoon (March–May (MAM)); (b) monsoon (June–September (JJAS)); (c) postmonsoon (October–November (ON)); (d) winter (December–February (DJF)) of TS days in Bangladesh during 1975–2016.

3.2. Annual Variation of TS Days

More than 60% of stations revealed an upward trend of TS days in most parts of Bangladesh, except in the southwest and the northeast. Atmospheric disturbance, unstable temperature and uneven rainfall variability may be the possible reasons for TS day variability in Bangladesh. The annual average TS days in Bangladesh over the study period are shown in Figure 4. The total number of annual TS days in Bangladesh is 65. The descriptive statistics for the total number of annual TS days are given in Table A1. The TS days in the country vary from zero in Taknaf to 7.5 days per decade in Sylhet (Table A1).

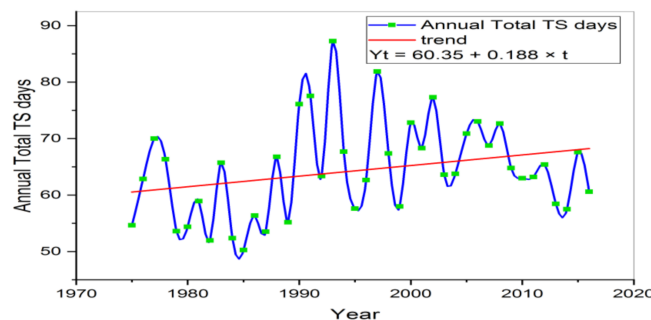


Figure 4. Same as Figure 3, but for annual variation.

3.3. Spatial Distribution of TS Days

Monthly Spatial Distribution of TS Days

Spatial distributions of average TS days in Bangladesh for different months are shown in Figure 5. It can be observed that TS mainly happen in the eastern and south-central regions of the country. However, it dominates in the eastern, central and southeastern parts during the premonsoon and monsoon months (March–August). Faridpur experiences the highest number of TS days, with 2.95 and six in January and February, respectively. The maximum TS days during March and April are found in the northeast, north and south-central parts. Sylhet located in the northeastern part of Bangladesh experiences the highest TS days (average 9.85 days) during these months. The maximum amount of TS days, 22.7, 19.7 and 15.8, are noticed at Sylhet, Mymensingh and Rangpur stations, respectively, in May. The highest number of TS days in June are noticed at Sylhet (21.5) and Jessore (15.3), while the highest TS days are observed at Sylhet, Srimangal and Mymensingh (17.6, 14 and 13.4, respectively, in July and 19.8, 16.5 and 13.2, respectively, in August). The TS days are found more in the south and east of Bangladesh during October. The number of TS days was nearly zero in most of the country during November and December. Only a few TS days (less than two days on average) are found in the coastal region during these two months. Figure 6 shows the spatial distributions of the average TS days in Bangladesh for the ENSO (and Figure 7, the IOD) years for different seasons. It can be observed that the highest TS mainly happen in the eastern regions of the country for all seasons, except winter for both the ENSO and IOD years. Among all four seasons, the monsoon season contributes the highest.

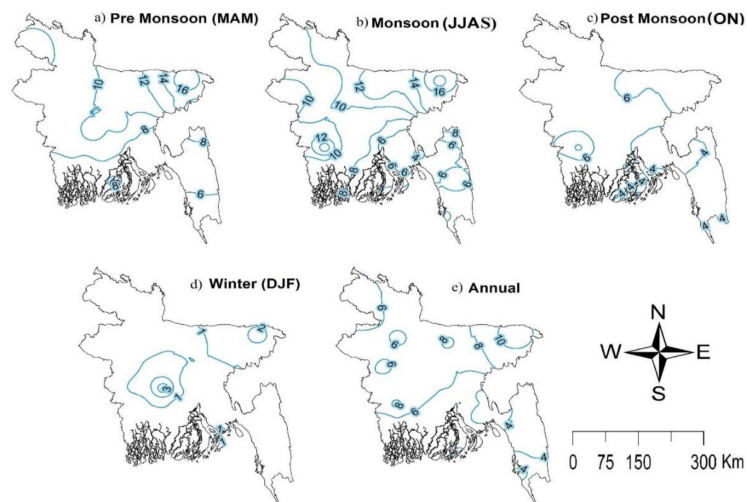


Figure 5. The average number of TS days (a) premonsoon (March–May (MAM)); (b) monsoon (June–September (JJAS)); (c) postmonsoon (October–November (ON)); (d) winter (December–February(DJF)); (e) annual during 1975–2016 in Bangladesh.

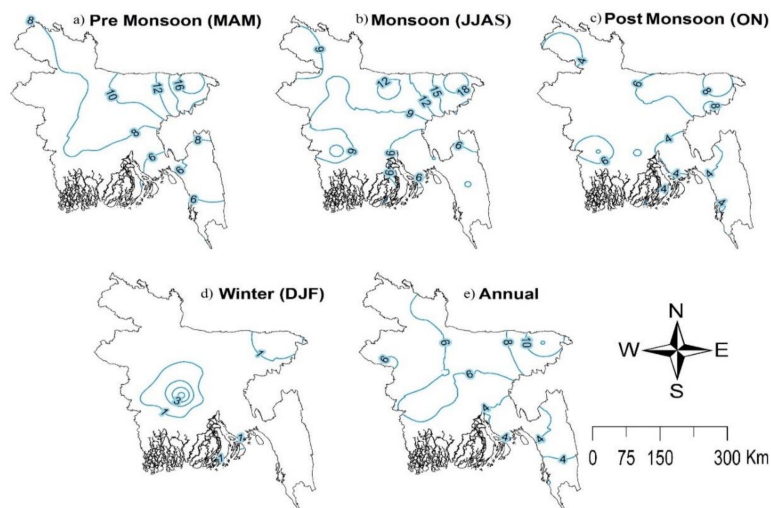


Figure 6. Spatial distribution of TS days (a) premonsoon (March–May (MAM)); (b) monsoon (June–September (JJAS)); (c) postmonsoon (October–November (ON)); (d) winter (December–February(DJF)); (e) annual in the ENSO years.

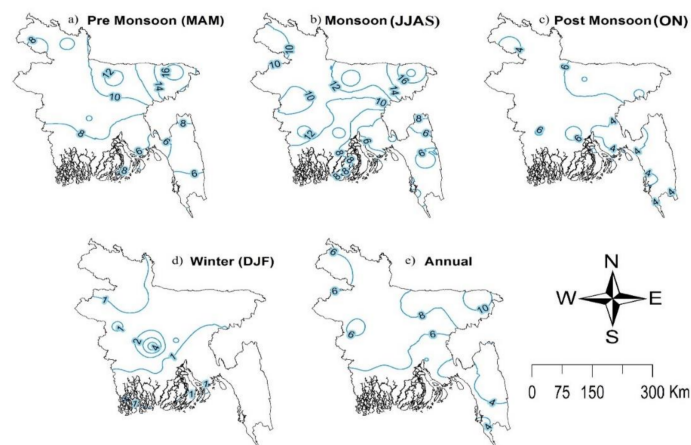


Figure 7. Same as Figure 6, but for IOD.

3.4. Spatiotemporal Pattern of TS Days

Spatial Patterns in the Monthly Trends of TS Days

Most parts of the country, except the central part, show a negative insignificant trend in TS days in December, November, January and February (Figure 8). A positive insignificant trend, indicating a slight ascension in TS days, is noticed in the northern part (Rangpur and Dinajpur). The TS days in March are noticed to increase significantly at the Faridpur, Rangamati and Hatiya Stations, while a mix of insignificant trends ($p > 0.05$) are noticed in the northeast and northwest parts. The TS days in April and May in most parts of the country are observed to increase significantly. It is also found to increase significantly in June over a large area in the northeastern and some eastern regions. A similar trend is observed in July and August in the northern region and some parts of southern stations, including Patuakhali, Khepupara and M. Court. In October, a significant positive trend is detected only in M. Court Station and a negative trend in Faridpur Station.

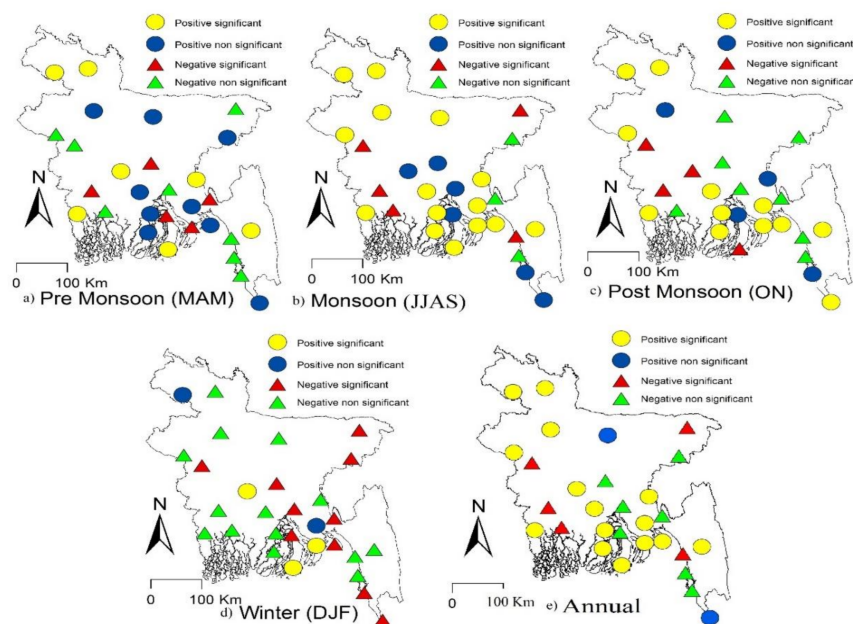


Figure 8. Distributions of the trends in monthly TS days (a) premonsoon (March–May (MAM)); (b) monsoon (June–September (JJAS)); (c) postmonsoon (October–November (ON)); (d) winter (December–February (DJF)); (e) annual in Bangladesh during 1975–2016. Positive significant (insignificant) is shown as yellow (blue) color and negative significant (insignificant) is shown as red (green) color.

3.5. Probability of TS Days over Bangladesh

The Weibull distribution model with a plotting position method was applied to estimate the probable maximum number of TS days for 5, 10, 15 and 20 years in Bangladesh. The results are shown in Table A2 and Figure 9. The results showed the maximum number of TS days in the northeastern region, whereas the lowest was in the southwestern parts of the country close to the coastal area. The results indicate that northeast Bangladesh as most prone to TS.

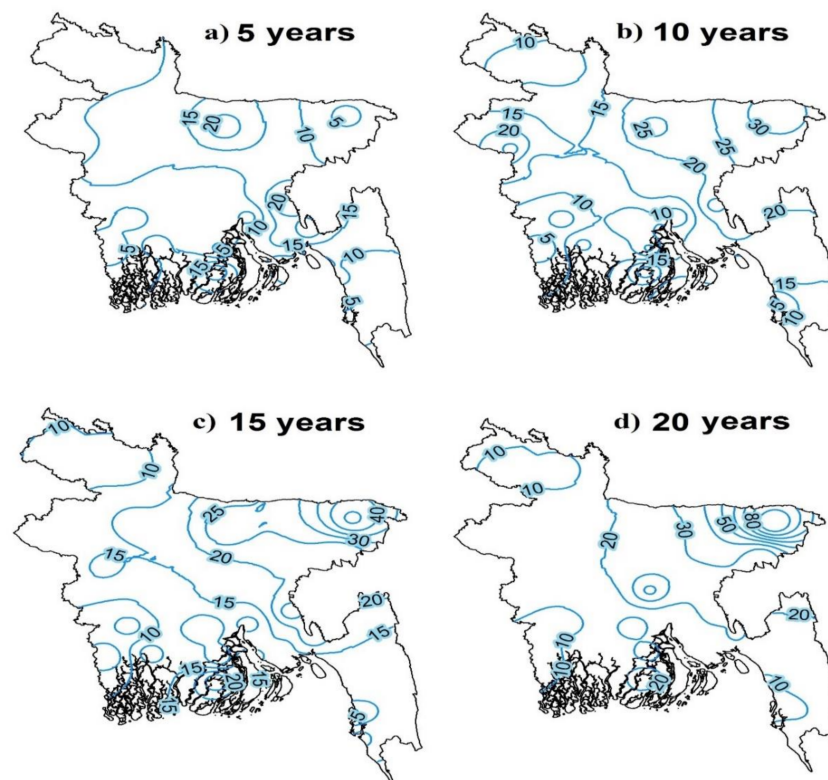


Figure 9. Probability of maximum annual TS days for different periods (a) 5 years; (b) 10 years; (c) 15 years; (d) 20 years in Bangladesh estimated using the data from 1975 to 2016.

3.6. The Relationship between ENSO/IOD and TS Days

The annual averages and anomalies of TS days in the El Niño, La Niña and neutral years are shown in Figures 10 and 11, respectively. A smaller number of average premonsoon TS days compared to neutral years is observed for the La Niña years, while a higher number of average premonsoon TS days compared to neutral years is noticed in the El Niño years. The anomalies of TS days (Figure 11) revealed a large positive anomaly in the pre-monsoon season in the La Niña years and a large negative anomaly in the monsoon season in the El Niño years.

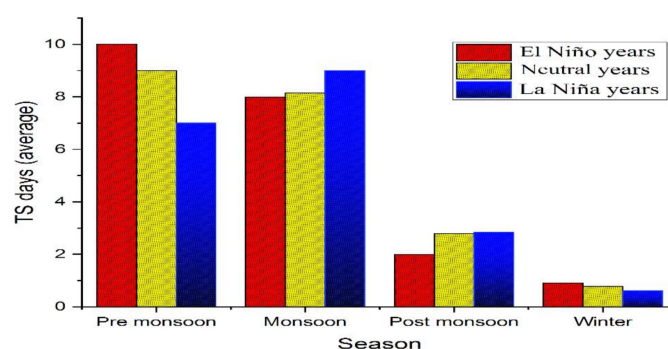


Figure 10. Seasonal (premonsoon, monsoon, postmonsoon and winter) variation of annual average TS days during the El Niño (indicated as red), neutral (yellow) and La Niña (blue) years.

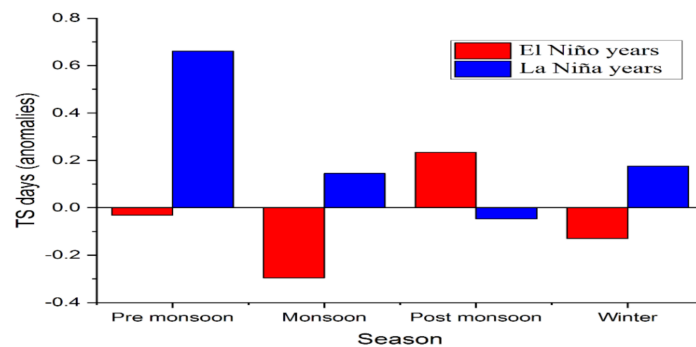


Figure 11. Same as Figure 10, but for composite anomalies of the average TS days during the El Niño (indicated as red color) and La Niña (blue) years.

The annual averages and anomalies of TS days in the positive, negative and neutral IOD years are shown in Figures 12 and 13, respectively. The average premonsoon TS days are found less in the IOD-negative years compared to the IOD-neutral years, while they were not found to vary for the IOD-positive and IOD-neutral years. The influence of IOD on the average monsoon TS days is found much less. Almost no variation in the average monsoon TS days was noticed for IOD-positive and negative years. The anomalies of the average TS days in IOD-positive and negative years (Figure 13) show a large increase in premonsoon TS days in negative IOD years, while a decrease in monsoon TS days during IOD-positive years.

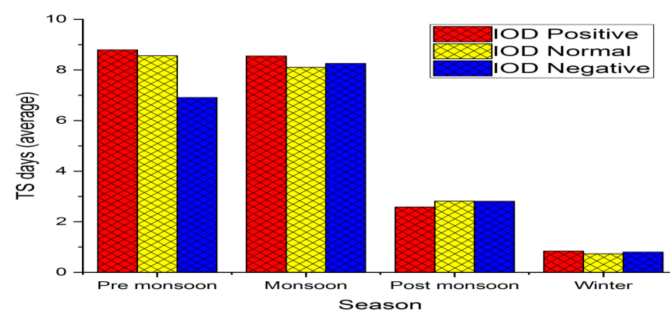


Figure 12. Same as Figure 10, but for IOD.

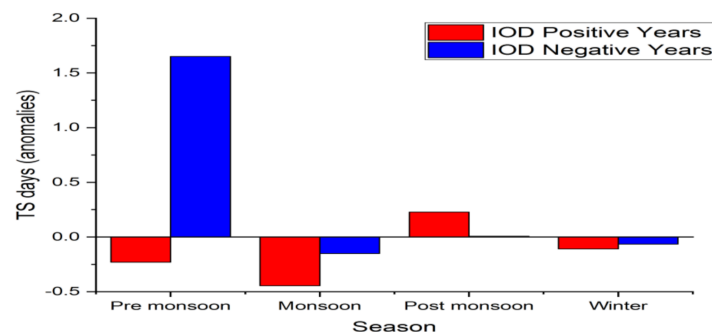


Figure 13. Same as Figure 11, but for IOD.

4. Discussion and Conclusions

The mean annual TS days at the studied 29 stations in Bangladesh vary between 2.8 and 11.8. The annual monthly mean value for TS days for the studied stations is approximately 7.1. The heating of the lower atmosphere moist air during the summer makes the air lighter and move upward through convection and form clouds. A thunderstorm occurs when any atmospheric activity causes a rapid upward movement of air. Generally, moist air from the Bay of Bengal acts as the trigger of a

thunderstorm. An interaction of moist air from the Bay of Bengal with the hills in the north causes a rapid uplifting of air and triggering of thunderstorms [25]. The topography and wind regimes made Bangladesh and Northeast India bordering Bangladesh highly favorable for the occurrence of thunderstorms [26]. Therefore, the region experiences the maximum thunderstorm activities compared to other parts of South Asia. A higher number of thunderstorms in Bangladesh are noticed in the northeast region due to the proximity to uplifted land.

Our study shows that the annual average TS days in Bangladesh are increasing by about 1.9 days/decade, which is consistent with an earlier study by Saha et al. [2] and Islam et al. [20]. These outcomes support the findings of the MK test of this study. However, it contradicts the findings in most of India, where a declination of both premonsoon and monsoon thunderstorms was reported by Bhardwaj and Shingh [27]. However, Singh et al. [25] also reported increasing TS days in some parts of West Bengal on the western border of Bangladesh. Bhardwaj and Shingh [27] also reported an increasing trend in thunderstorm-related rainfall activity in Northeast India, despite a decrease in the rest of India. The present study reports an increase in the annual number of TS days mainly due to an increase in TS days in monsoon season. The higher surface temperature caused an increase in the convective available potential energy (CAPE) in the region [28,29]. However, an increasing number of TS days in Bangladesh may be due to an increased number of thunderstorms triggering moist air circulation from the Bay of Bengal. Stronger and more continuous winds from the Bay of Bengal in recent years due to the increase of sea surface temperature have been reported. Glazer et al. [29] evaluated the changes in thunderstorms in Bangladesh due to climate change and reported an increase in severe TS days in most parts of the country.

The monthly spatial distribution of TS shows that TS days are high in the south-central region and very little in the northeastern and northern regions during November–February. This is due to the low sea surface temperature and northeast wind direction from the Bay of Bengal and vapor flux availability in the regions. In March to October, most TS occur in the northeast part of Bangladesh. Besides, high TS days are detected in the north, central, southwest and south of Bangladesh. The higher number of TS days in May and June is noticed in the northeast region, near to Cherapunji, where the cloud formation is the maximum and the mountain ranges produce a large amount of vapor flux and rainfall. Most TS occurs in May, when the average TS days are more than 11 days. The spatial distribution of the annual TS days obtained in this study was found to be consistent with earlier studies [2,20]. For instance, Bangladesh showed an increase in the monthly, seasonal annual and decadal TS days during the last four decades. It has been shown that the increment of TS days is strongly correlated with the strengthening of the sunspot and East Asian summer monsoon, which is the key source of moisture and dynamic force conducive for the premonsoon season climate across the Bay of Bengal.

The monthly, seasonal, decadal and annual trend patterns of TS days show an insignificant decreasing trend at most of the stations in November to February due to the little amount of TS days. By contrast, in May, a positive trend is detected in the southern, northeastern and northern regions. A high positive trend is also found in June. The seasonal and annual trend patterns are similar to the previous observations of Saha et al. [2]. The southeastern air masses when it passes the equator and turns into a southwestern monsoon due to Ferrell's law, which carries a huge amount of water vapor from the Bay of Bengal. This warm and cold monsoon air produces a higher number of TS in Bangladesh in this period [2,19]. The results of the TS days are validated with the earlier literature observed around the world in the last four decades. Most of the stations show an increasing trend in TS days over Bangladesh. This is probably due to the rising CAPE and moisture contents in the Bay of Bengal [15].

The trend of TS days was mostly positive in all months except December and January. The trends were significant in May and June. The linear regression and Weibull distribution model showed a higher number of annual total TS days at almost all stations, except Teknaf and Sawndip. The highest number of TS occurred in May, whereas the lowest in December. This was expected, as the higher surface temperatures and soil moistures in May make the period favorable for the formation of thunderstorms,

while the low surface temperatures and less soil moistures make December the least favorable for the formation of thunderstorms.

The magnitude of the average TS days anomaly for the monsoon and premonsoon seasons are found positive for the La Niña years and negative for the El Niño years. This indicates a decrease in TS activities in Bangladesh in the El Niño years. Similar results are found in India and the nearby regions. Kulkarni et al. [6] evaluated the association of TS days over India with the ENSO and showed a reduction of TS days during the El Niño episodes. Yuan and Di [11] found a decrease in thunderstorms in Eastern China during the ENSO episodes. Kulkarni et al. [6] explored the teleconnections between TS days and ENSO for the period 1998–2013 and reported a decrease in TS days during the ENSO years. The anomalies of the average TS days in IOD–positive and negative years also show a large increase in premonsoon TS days in negative IOD years, while a decrease in monsoon TS days during IOD–positive years. This indicates a negative influence of the IOD on TS activities in Bangladesh. A decrease in moist air supply from the Bay of Bengal due to a reduction of monsoon depression during the ENSO and IOD warm phases has been reported in several studies by Bhardwaj and Singh [27], Krishnamurthy and Krishnamurthy [30] and Dash et al. [31]. A decrease in thunderstorms triggering moist air circulation of the Bay of Bengal in ENSO and IOD–positive years may be the cause of a decrease in TS activities in Bangladesh.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Descriptive statistics of the annual average TS days over Bangladesh during 1975–2016.

Station	Mean	Median	Standard Deviation	Maximum	Minimum	1st Quartile	3rd Quartile	Variation per Decade
Dhaka	6.1	6.1	1.0	8.8	4.4	5.3	6.6	3.3
Madaripur	6.0	6.3	1.8	10.0	1.8	4.9	7.1	4.6
Faridpur	7.1	7.4	2.0	11.2	2.2	5.6	8.5	5.8
Mymensingh	8.2	8.3	1.6	11.8	4.1	7.3	8.9	5.5
Srimangal	9.8	9.9	1.6	13.1	6.0	8.7	11.1	6.5
Sylhet	11.8	11.9	1.6	16.2	9.1	10.5	12.8	7.5
Bogura	5.7	5.6	1.3	8.5	2.9	4.9	6.8	2.3
Rajshahi	6.3	6.4	1.2	9.0	4.4	5.2	7.2	3.5
Ishwardi	5.5	5.6	1.4	8.4	2.8	4.7	6.3	2.2
Dinajpur	4.6	4.7	1.7	7.6	1.0	3.3	6.0	3.2
Rangpur	6.3	6.3	1.6	9.0	2.7	5.3	7.3	4.2
Jessore	7.9	8.1	1.5	10.3	2.6	7.0	9.0	2.1
Khulna	5.2	5.2	1.4	8.2	1.8	4.3	6.1	2.5
Satkhira	5.1	5.5	1.6	8.5	1.8	4.1	6.0	2.3
Barishal	4.9	5.3	1.6	7.3	1.7	3.8	6.3	3.3
Bhola	4.3	4.2	1.0	6.4	2.5	3.6	5.1	1.1
Khepupara	4.4	4.6	1.8	8.5	1.3	3.1	5.5	1.2
Patuakhali	5.2	5.3	1.3	7.8	2.1	4.2	6.1	0.5
Chandpur	4.3	4.0	1.3	7.5	2.5	3.3	5.1	3.1
Chattogram	4.3	4.4	1.1	6.7	1.3	3.6	5.0	2.5
Comilla	3.9	4.0	1.3	6.8	1.4	3.0	4.6	3.5
Cox's Bazar	4.2	4.0	1.0	6.7	2.4	3.4	4.9	2.5
Feni	3.2	3.0	1.2	6.5	0.7	2.3	4.2	2.3
Hatiya	4.8	4.4	1.7	8.8	2.0	3.6	5.7	1.4
Kutubdia	3.1	3.2	1.2	5.5	0.7	2.1	3.8	1.9
M.court	3.2	3.5	1.4	6.3	0.3	2.1	4.2	3.3
Rangamati	4.5	4.8	1.5	7.1	0.6	3.6	5.5	1.2
Sandwip	3.3	3.1	1.4	6.9	0.6	2.4	4.3	1.0
Teknaf	2.4	2.5	1.2	5.2	0.3	1.4	3.2	0

Table A2. Probability of maximum number of TS days for different periods at different locations of Bangladesh.

Year	5	5	10	10	15	15	20	20
Station Name	Maximum	3rd Quartile	Maximum	3rd Quartile	Maximum	3rd Quartile	Maximum	3rd Quartile
Dhaka	>7	3	>19	10	>18	6	>42	4
Madaripur	>5	4	>5	3	>5	4	>5	4
Faridpur	>10	8	>12	9	>15	9	>17	8
Mymensingh	>22	16	>26	12	>28	12	>26	20
Srimangal	>9	8	>28	13	>20	12	>23	12
Sylhet	>4	3	>33	4	>46	15	>100	10
Bogra	>13	12	>14	12	>16	14	>18	13
Rajshahi	>8	2	>26	7	>13	6	>15	6
Ishurdi	>14	8	>14	10	>16	10	>18	12
Dinajpur	>7	5	>9	5	>8	5	>8	6
Rangpur	>9	5	>7	5	>7	5	>7	5
Jessore	>3	2	>3	2	>3	1	>4	2
Khulna	>12	8	>16	10	>17	17	>19	19
Satkhira	>2	2	>2	2	>2	2	>2	2
Barisal	>3	3	>4	2	>5	3	>4	2
Bhola	>13	7	>15	10	>18	14	>18	13
Khepupa	>13	5	>11	8	>16	7	>12	9
Patuakhali	>24	18	>28	25	>30	23	>28	24
Chandpur	>3	2	>6	5	>8	5	>10	4
Chittagon	>11	7	>17	6	>15	6	>8	5
Comilla	>25	23	>27	25	>28	25	>26	24
Cox's Bazar	>8	6	>10	8	>16	8	>12	4
Feni	>24	17	>23	20	>24	22	>21	19
Hatiya	>7	6	>17	7	>12	8	>14	7
Kutubdia	>3	2	>3	2	>3	2	>3	2
M.court	>17	13	>20	12	>14	11	>18	12
Rangamat	>8	6	>18	8	>11	8	>16	7
Sandwip	>6	4	>14	5	>6	3	>12	5
Teknaf	>12	4	>13	2	>16	5	>12	5

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