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Pre-Monsoon Thunderstorm Activity Over Bangladesh From 1983 to 1992

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ABSTRACT

Daily and 3-hourly weather information in code figures and daily rainfall data from 19 stations in Bangladesh for the months of March through May, from 1983 through to 1992, have been analysed to give some understanding to the space/time distributions as well as to the nature of the thunderstorms throughout the country. The Statistical characteristics of these disturbances are presented.

It turns out that over Bangladesh thunderstorm (TS) occurrence has a wide variation in terms of both space and time. Whereas in Sylhet TS days make up 50% of the premonsoon season, in Maijdee they comprise only 10%. However, in Maijdee precipitation per TS day is abnormally high. In central Bangladesh, the most dominant time of TS occurrence is either late afternoon or early evening, unlike that in the north where the corresponding time is either night or early morning. In general, the frequency of TSs as well as the amount of precipitation are greatest in the month of May almost all over the country with the average rainfall per TS day being quite high though dry TS days are still quite numerous.

(Key words: Pre-monsoon thunderstorm, Nor'wester, Correlation co-efficient, Spatial Contour)

1. INTRODUCTION

Bangladesh is a land of rivers and branching of these rivers and the canals is widespread throughout the country (Figure 1) leading to the conclusion that, to a large extent, they control the weather and climate of the country. The usual wind patterns in the Bangladesh region are north-east trade winds on the surface and the upper air westerlies. Nonetheless, Bangladesh also falls within the Indian southwest monsoon system, and the surface winds during the monsoon time are SW/S/SE, though the upper wind remains westerly. The premonsoon phase

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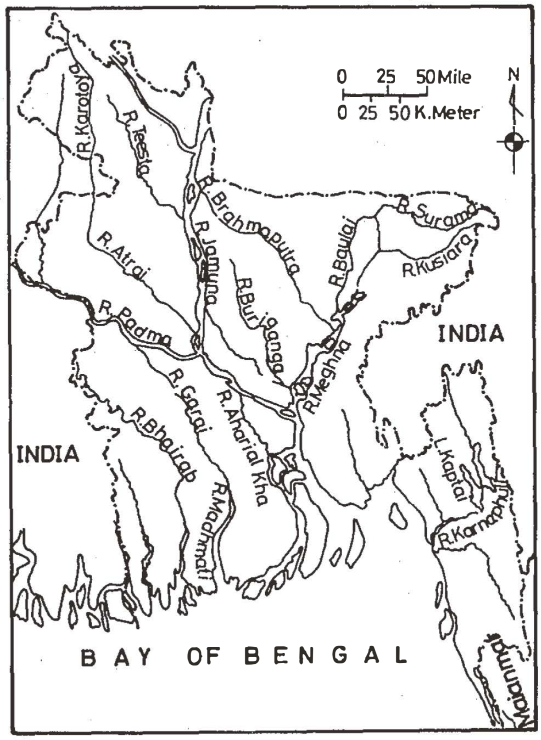

Fig. 1. Rivers and canals of Bangladesh.

i.e. March through May, is a transition phase, when many a violent thunderstorm (TS) affect the region. During this period, the subtropical high shifts to the Bay of Bengal with two other heat lows falling around Bangladesh. One is in the Assam region in the east and the other is dominantly in the Madhya Pradesh region of India to the west. In their wake, the surface winds are, in general, SW/S in south Bangladesh, while the surface winds in the northern region are easterlies due to the topography. During this period, a strong westerly jet appears over the country at the upper tropospheric level which generates associated atmospheric instabilities.

This phase is characterized by high surface temperatures and convective developments because of copious moisture support and the presence of atmospheric instabilities. In some developments, giant cumulonimbus clouds are produced resulting in severe thunderstorms which cause huge losses in terms of property and lives. However, these thunderstorms also provide principal rainfall patterns during the period and are the main source of rains until the southwest monsoon sets in.

In fact, the TS activity in the Bangladesh region is supposed to have three distinct causes:

In the southern part, as stated previously, the surface wind during the premonsoon period is SW/S in general. With this wind comes sea moisture. Besides this, the southern land area is covered by a large number of rivers, creeks and water bodies in various forms. All these give enough moisture support for TS activity.

In the adjacent western part of the country lies the Gangetic plain of West Bengal. There, the cause of the TS activity is mainly the instabilities produced in the hilly tracts of the adjacent states of Bihar and Orissa. As the downdrafts meet the sea moisture-laden SE surface winds of the region, successive TS developments occur. It appears as if the disturbances are propagating from the NW direction, resulting in the premonsoon TS activity in Gangetic west Bengal being popularly known as Nor'westers (local name of SLS). Incidentally, in the middle region of Bangladesh many of the downdrafts of Nor'westers arrive and, with the help of moisture from large rivers like Padma and Meghna, these disturbances regenerate into TS activity.

The northern part of Bangladesh is greatly influenced by the wind system of the foothill zones of the Himalayas. The surface winds are usually easterly here, and due to the orography, these easterlies frequently cause TS developments. Additionally, sometimes a western disturbance strengthens and its influence supposedly makes TS developments occur.

The average surface pressure and wind patterns for the month of April are presented in Figure 2. However, a sharp demarcation of the three zones for all three months cannot be expected.

Various aspects of TS activity have been studied and published in journals by such authors as Rai Sircar (1953), Koteswaran and Srinivasan (1958), Sen and Gupta (1961), De and Sen (1961), Nandi and Mukherjee (1966), Mukherjee and Bhattacharya (1972) and Mukherjee *et al.* (1977). In all these studies, a number of important results have been obtained with regards to the formation,structure, timing and devastations of Nor'westers. However, almost all of these studies focus on India. In fact,as for Bangladesh, only a limited number of research works on thunderstorms done by the Bangladesh Meteorological

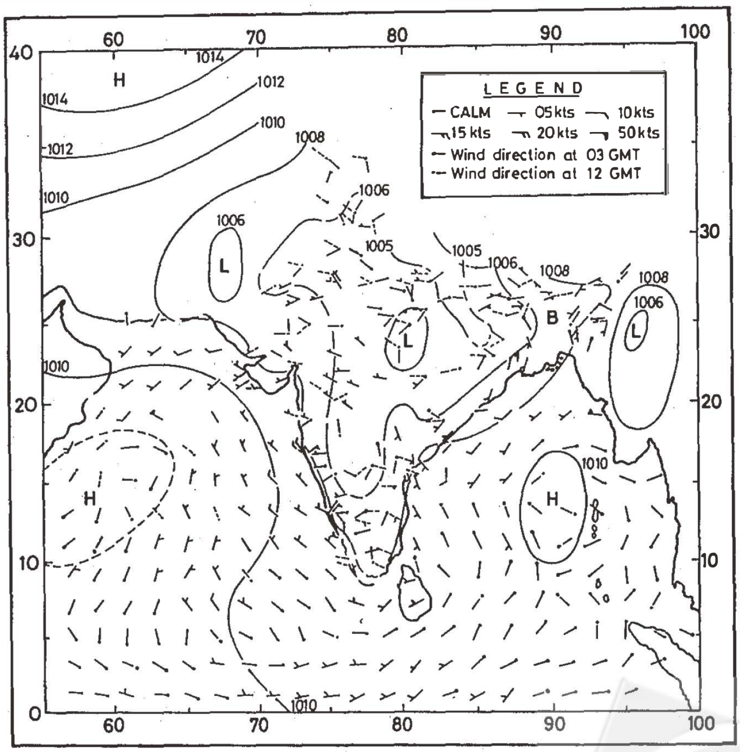

Fig. 2. Pattern of mean pressure (mb) and surface winds in April. B indicates Bangladesh.

Department was presented in the seminar on "SEVERE LOCAL STORMS" organized by the South Asian Association for Regional Co-operation (SAARC) countries.

The present study is the first of its kind in the context of Bangladesh, and it is believed that the results (of this study) will be useful in making objective forecasts of TSs in the country.

In the present study, 3-hourly interval surface observational data as well as daily rainfall data have been analysed over a ten-year interval (1983-92) for 19 stations scattered all over Bangladesh. The study has essentially been confined to the three-month period before the onset of monsoons i.e. March, April and May.

2. GEOGRAPHICAL LOCATION OF BANGLADESH

Bangladesh extends from 20°-45'N to 26°-40'N and 88°-05'E to 90°-40'E. Most of the country is flat except for hills in the southeastern parts. In fact, the country is surrounded by the Assam Hills to the east and by the Meghalaya Plateau (i.e. Shillong Plateau) to the north, with the lofty Himalayas beyond. The Bay of Bengal lies to the south of the country. To the west is the contiguous Plain of west Bengal and the Gangetic Plain of India. The geographical setting of Bangladesh and the location of the observational stations in the present study with their heights are shown in Figure 3.

3. DATA AND STATION LOCATION

Daily and 3-hourly weather information data in code figures for the months of March through May, and daily rainfall data for the same months, for the period from 1983 to 1992 for 19 stations in Bangladesh were obtained from the Bangladesh Meteorological Department (BMD). It should be noted that the present study is confined to surface observations which include pressure, dry bulb temperature, dewpoint temperature, wind velocity and direction, the present weather as well as that in the past three hours at every three-hour interval starting from oo GMT. The stations have been chosen in such a way as to represent almost every zone of the country.

Starting from the north of the country, the following stations are considered for the study:

Rangpur (RNP 859), Dinajpur (DNP 862), Bogra (BGR 883), Rajshahi (RJSH 856), Ishurdi (ISDI 907), Mymensingh (MYMS 886), Sylhet (SLT 891), Comilla (CML 933), Dhaka (DCA 923), Faridpur (FDP 929), Jessore (JSR 936), Khulna (KLN 947), Barisal (BSL 950), Patuakhali (PTKI 955), Khepupara (KPRA 984), Maijdee (MJD 934), Chittagong (CTG 971), Rangamati (RMGT 943) and Cox's Bazar (C'BZR 992). The code name and the station codes are given within brackets. The last three digits begin with 41.

Though the two stations, Srimangal and Satkhira are shown on the map, because of the lack of data, they are excluded from this analysis.

4. ANALYSES

In the present work, the following statistical studies are presented to provide an understanding of the space/time distributions as well as the nature of thunderstorms over Bangladesh.

(1) Monthly and biweekly frequency distributions of TSs during the premonsoon months.

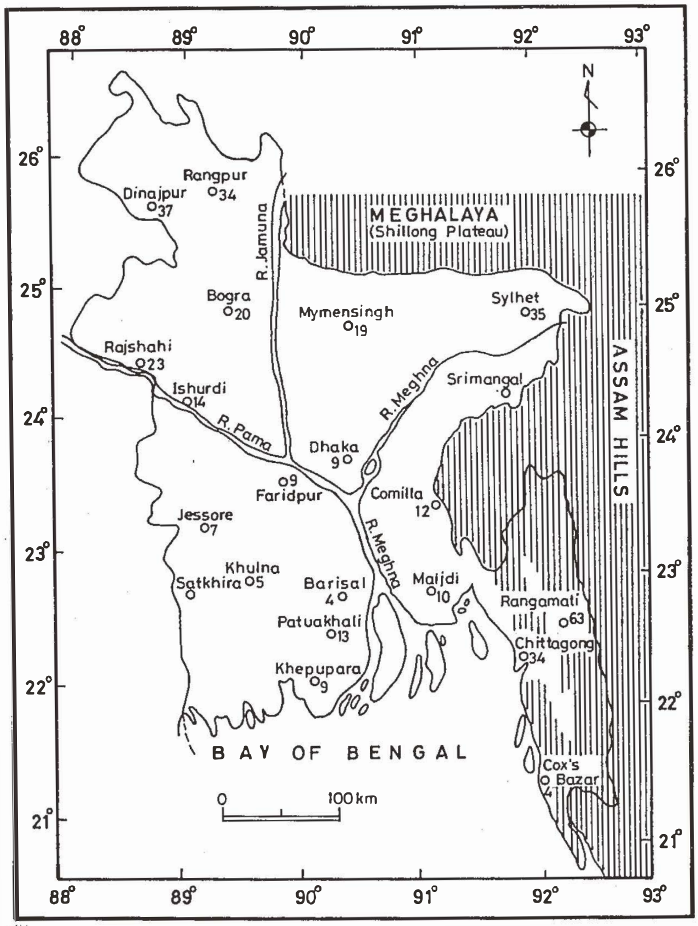

Fig. 3. Geographical setting of Bangladesh. The circles and numerical values indicate the location and height (above mean sea level in meters) of the stations used in this study. Shaded areas are in excess of 250 meters above sea level. Some elevations are in excess of 1000 meters (Assam Hills and the Meghalaya Plateau).

(2) Correlations of the number of annual TS days over premonsoon months of different stations with three representative stations viz., DCA, RNP and KPRA.
(3) Percentage occurrence of TS at different 3-hourly time intervals per day.
(4) Average rainfall distribution per TS day over each biweekly interval.

4.1. TS Frequency Analysis

In this analysis, the identification of TS days has been made from weather information. By international agreement, a "thunderstorm" day is defined as a local calender day on which thunder is heard, regardless of the actual number of thunderstorms (WMO, 1953).

Monthly and two-week frequency distributions of TS days are shown in Table 1. From this and from Figure 4, it is evident that an unusually high number of TS days occur in Sylhet

Monthly and two-week frequency distributions of TS days are shown in Table 1. From this and from Figure 4, it is evident that an unusually high number of TS days occur in Sylhet (SLT). SLT is just at the foot of the Meghalaya Hills, and this orographical feature plays an important role in enhancing TS days.

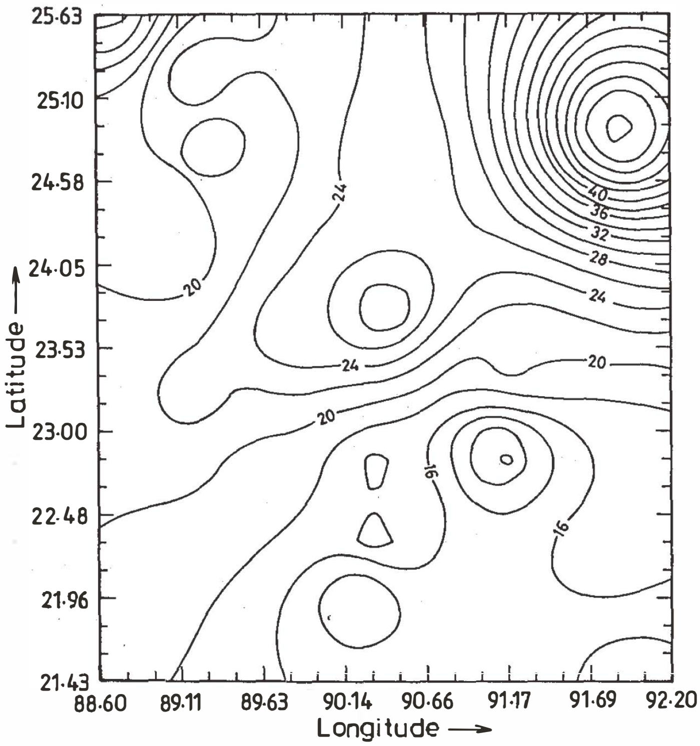

Fig. 4. Frequency distribution of TSs over Bangladesh in the pre-monsoon season from 1983-1992.

The lowest frequency of TS is in Maijdee. In twelve other stations, 20% or more of the days considered agree well with the average TS days. For all the stations, the monthly TS frequency increases systematically from March to May. This is quite expected as sun becomes more overhead from March to May, thereby increasing the temperature as well as evaporation. As all of Bangladesh is covered by innumerable water bodies, the moisture support increases from March to May. This is distinctly seen in the present study.

From Table 1, it also clear that, in general, during March and April, the number of TS days in the second two-week period is more than in the first. The exception occurs only in five stations in March. However, in twelve stations TS frequency is highest in the first half of May. Another notable feature, TS frequency sharply rises at RNP and MYMS from the second half of April. Such an increase in TS days in the first half of May at most of the stations is not unexpected, as the number of western disturbances is high during this period. The number shows a decline with the approach of a monsoon.

The information of TS frequency on the two-week scale is important for Bangladesh which is still predominantly an agrarian state.

Table 1. Biweekly and monthwise frequency distributions of TS days. I, II and T represent 1st half, 2nd half and the total of the monthly frequency distributions, respectively.

Station	March			April			May		
	I	II	T	I	II	T	I	II	T
RNP	1.2	1.5	2.7	1.5	5.0	6.5	7.6	7.0	14.6
DNP	0.6	0.5	1.1	0.9	2.0	2.9	3.3	3.7	7.0
BGR	1.0	1.5	2.5	2.1	3.4	5.5	5.7	5.6	11.3
RJSH	1.2	1.9	3.1	1.9	3.7	5.6	4.8	5.9	10.7
ISDI	1.2	1.2	2.4	2.0	3.8	5.8	5.0	5.2	10.2
MYMS	1.2	1.9	3.1	1.9	5.7	7.6	7.2	6.5	13.7
SLT	3.9	6.1	10.0	9.7	10.4	20.1	10.7	10.1	20.8
CML	1.6	2.4	4.0	2.6	3.9	6.5	5.2	4.7	9.9
DCA	1.9	3.3	5.2	3.2	5.3	8.5	6.2	6.0	12.2
FDP	2.0	2.8	4.8	3.5	4.7	8.2	6.8	6.2	13.0
JSR	2.2	1.8	4.0	2.1	4.5	6.6	6.2	5.9	12.1
KLN	1.8	1.6	3.4	2.8	3.3	6.1	5.3	4.9	10.2
BSL	1.5	1.8	3.3	2.1	3.1	5.2	3.5	3.4	6.9
PTKI	1.8	1.7	3.5	1.9	3.7	5.6	5.6	4.4	10.0
KPRA	0.8	1.6	2.4	1.2	2.0	3.2	3.3	2.9	6.2
MJD	0.9	0.8	1.7	0.9	2.1	3.0	2.5	2.1	4.6
CTG	0.8	2.0	2.8	1.8	4.0	5.8	4.1	4.5	8.6
RMGT	1.2	1.4	2.6	2.7	3.5	6.2	3.7	3.8	7.5
C'BZR	0.5	0.7	1.2	1.2	2.5	3.7	3.5	4.2	7.7

4.2 Correlation Study of Annual TS Days Over Premonsoon Months With Three Representative Stations

Dhaka, the capital of Bangladesh is considered the central point of the country by the Bangladesh Meteorological Department and also representative of the middle region of Bangladesh, where the origin of TSs may be mostly due to the same cause. This is strongly supported by a similar frequency of occurrence of TS over a large region of the middle of the country as discussed in Section 4.3. Thus, an attempt has been made to understand the correlation of TS days between Dhaka and the rest of the stations of the country on the basis of monthly occurrence over the ten-year period. In Figure 5, the spatial contour of correlation co-efficient of TS days with respect to Dhaka is presented.

Pearson's correlation co-efficients between three representative stations, DCA, KPRA and RNP of three regions of Bangladesh, and the rest of the stations are listed in Table 2.

If the correlation co-efficient for Dhaka and any station is greater or equal to 0.5 for all three months, then that station may be considered well correlated with Dhaka. On the other hand, when the correlation co-efficient for all three months is above 0.45, the station may be taken as good correlation with Dhaka.

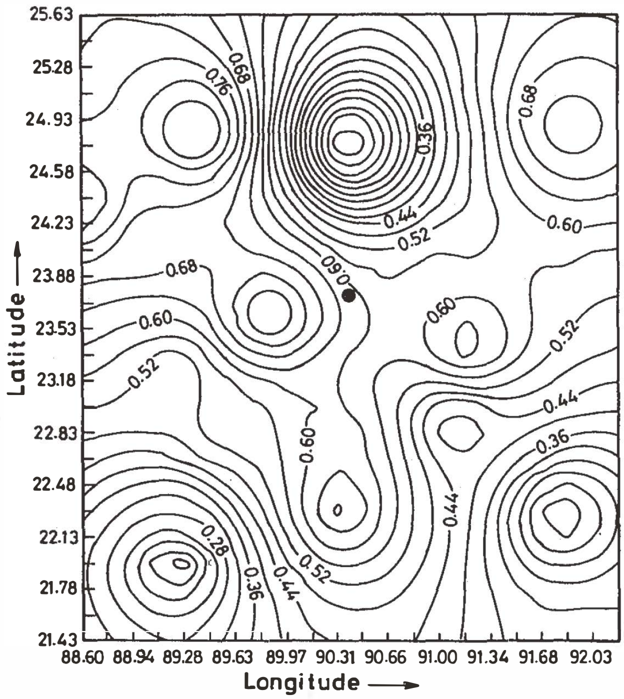

Fig. 5. The spatial Contour of Correlation co-efficients of various stations with Dhaka in the pre-monsoon season from 1983-1992. Dhaka is marked with a dot.

With these rules, it turns out from Table 2 that BGR, RJSH, SLT, CML, FDP and RMGT are well correlated with Dhaka, whereas ISDI and MJD have a good correlation. This simple correlation study possibly indicates the extent of the middle region of Bangladesh from the standpoint of TS activity over all three months. But this study also shows that in the month of March, TS activity in all regions is highly interrelated. In fact March is a highly transitional month when surface easterlies are slowly withdrawing from the lower part of the country and the two heat lows around the nation are not so prominent.

A similar correlation study can be carried out with a representative station of the northern part of Bangladesh and another representative station in the southern part. Such studies are conducted with RNP and KPRA. As expected, both these stations bear good correlation with all stations of Bangladesh in the month of March. But in the case of KPRA, stations like C'BZR, CTG bear correlation co-efficients greater than 0.5 for all three months. In contrast, stations like JSR, KLN, PTKI and BSL bear good correlation for the months of March and May, but the corresponding co-efficient is less in the month of April (Table 2). In the case of RMGT, the co-efficient is very poor in the month of May, but it has a high value in the other two months. For the other stations, the correlation co-efficient with KPRA is erratic, making them not worthy of presentation in Table 2.

In the case of RNP, the northern stations like DNP, BGR, RJSH, ISDI bear good correlation co-efficients in the month of April also (Table 2). But the situation drastically changes in the month of May. This shows the complexity of the wind pattern, moisture availability and the role of local orography in the northern part as the monsoon approaches.

Table 2. Correlation co-efficients between three representative stations, DCA, KPRA and RNP and the rest of the other stations.

Station	March	April	May
RNP-DNP	0.52	0.49	0.03
DNP-DCA	0.51	0.16	0.56
BGR-DCA	0.63	0.80	0.85
RJSH-DCA	0.61	0.53	0.52
ISDI-DCA	0.72	0.63	0.40
MYMS-DCA	0.53	-0.01	0.57
SLT-DCA	0.77	0.77	0.84
CML-DCA	0.97	0.63	0.65
FDP-DCA	0.91	0.88	0.72
JSR-DCA	0.79	0.45	-0.04
KLN-DCA	0.92	0.42	-0.34
BSL-DCA	0.79	0.87	0.16
PTKI-DCA	0.67	0.65	0.07
KPRA-DCA	0.55	0.44	-0.07
MJD-DCA	0.65	0.46	0.47
CTG-DCA	0.68	0.73	0.12
RMGT-DCA	0.61	0.59	0.75
C'BZR-DCA	0.51	0.40	0.10
JSR-KPRA	0.53	0.49	0.66
KLN-KPRA	0.80	0.27	0.52
BSL-KPRA	0.81	0.40	0.83
PTKI-KPRA	0.84	0.30	0.67
CTG-KPRA	0.61	0.60	0.66
RMGT-KPRA	0.76	0.91	0.17
C'BZR-KPRA	0.82	0.50	0.84
DNP-RNP	0.74	0.62	-0.07
BGR-RNP	0.73	0.58	-0.05
RJSH-RNP	0.72	0.68	0.18
ISDI-RNP	0.78	0.70	0.32

4.3 TS Occurrence at Different Three Hour Intervals of a Day

In this section the percentage of occurrence of TS in each 3-hour interval during the months of March, April and May is studied for each station over the concerned period of ten years. The time stated in Table 3A and 3B is local Bangladesh time i.e. six hours are added to G.M.T. In this analysis, if the occurrence is 75% or above for a 12-hour period and if it is 50% or above for a 6-hour period and if it is 25% or above for a 3-hour interval, then

Table 3A. Percentage occurrence of TS in each three-hour interval.

STATION	00-03hrs.	03-06hrs.	06-09hrs.	09-12hrs.	12-15hrs.	15-18hrs.	18-21hrs.	21-24hrs.
RNP	19.0	18.6	12.7	8.8	8.5	7.9	9.6	14.9
DNP	11.5	23.5	15.7	12.6	9.0	10.8	5.4	11.5
BGR	14.2	11.7	12.8	9.6	10.3	12.5	11.4	17.5
RJSH	4.1	5.1	7.3	6.6	13.9	27.8	23.1	12.1
ISDI	7.1	5.0	7.7	7.1	13.4	22.0	20.7	17.0
MYMS	12.5	12.8	9.4	9.2	11.8	17.2	13.0	14.1
SLT	15.8	15.3	11.7	10.7	8.2	10.3	12.0	16.0
CML	7.1	7.5	6.9	8.6	14.3	21.8	20.3	13.5
DCA	8.7	6.4	5.4	5.2	12.3	23.5	23.2	15.3
FDP	6.5	5.1	5.7	4.9	14.1	27.1	23.5	13.1
JSR	6.6	5.3	3.7	4.8	13.8	23.0	27.8	15.0
KLN	8.0	5.5	6.1	5.8	12.2	24.3	25.0	13.1
BSL	6.2	3.5	5.8	5.1	14.8	27.2	26.5	10.9
PTKI	7.2	7.2	6.0	12.0	14.8	22.0	18.1	12.7
KPRA	7.9	10.8	8.4	10.8	17.7	17.3	16.8	10.3
MJD	4.6	7.7	4.7	16.3	10.9	29.4	15.5	10.9
CTG	16.7	14.1	10.6	9.4	10.0	11.4	10.5	17.3
RMGT	9.3	9.2	9.0	12.0	14.2	17.6	15.1	13.6
C'BZR	10.7	14.5	15.9	11.2	11.7	11.2	14.5	10.3

Table 3B. 12 hrs, 6 hrs and 3 hrs of maximum TS activity with respective percentage of occurrence.

Station	Maximum periods of occurrence	Total hours	Maximum % of occurrence
RNP :	21 hrs.- 09 hrs.	12 hrs.	65.2
	00 hrs.- 06 hrs.	6 hrs.	37.6
	00 hrs.- 12 hrs.	3 hrs.	19.0
DNP :	00 hrs.- 12 hrs.	12 hrs.	63.3
	03 hrs.- 09 hrs.	6 hrs.	39.2
	03 hrs.- 06 hrs.	3 hrs.	23.5 (V)
BGR :	15-18, 21-24, 00-03 & 06 - 09 hrs.	12 hrs.	56.9
	21 hrs.- 03 hrs.	6 hrs.	31.7
	21 hrs.- 24 hrs.	3 hrs.	17.4
RJSH :	12 hrs.- 24 hrs.	12 hrs.	76.9 (I)
	15 hrs.- 21 hrs.	6 hrs.	50.9 (I)
	15 hrs.- 18 hrs.	3 hrs.	27.8 (I)

Table 3B. (Continued.)

Station	Maximum periods of occurrence	Total hours	Maximum % of occurrence
ISDI :	12 hrs.- 24 hrs.	12 hrs.	74.1 (V)
	15 hrs.- 21 hrs.	6 hrs.	43.7
	15 hrs.- 18 hrs.	3 hrs.	22.0 (V)
MYMS :	15-24, 3-6 hrs.	12 hrs.	57.1
	15-18, 21-24 hrs.	6 hrs.	31.4
	15 hrs.- 18 hrs.	3 hrs.	17.2
SLT :	18 hrs.- 06 hrs.	12 hrs.	59.1
	21 hrs.- 03 hrs.	6 hrs.	31.8
	21 hrs.- 24 hrs.	3 hrs.	16.0
CML :	12 hrs.- 24 hrs.	12 hrs.	69.9
	15 hrs.- 21 hrs.	6 hrs.	42.1 (V)
	15 hrs.- 18 hrs.	3 hrs.	21.8 (V)
DCA :	12 hrs.- 24 hrs.	12 hrs.	74.3 (V)
	15 hrs.- 21 hrs.	6 hrs.	46.7 (V)
	15 hrs.- 18 hrs.	3 hrs.	23.5 (V)
FDP :	12 hrs.- 24 hrs.	12 hrs.	77.9 (I)
	15 hrs.- 21 hrs.	6 hrs.	50.6 (I)
	15 hrs.- 18 hrs.	3 hrs.	27.1 (I)
JSR :	12 hrs.- 24 hrs.	12 hrs.	79.6 (I)
	15 hrs.- 21 hrs.	6 hrs.	50.8 (I)
	18 hrs.- 21 hrs.	3 hrs.	27.8 (I)
KLN :	12 hrs.- 24 hrs.	12 hrs.	74.7 (V)
	15 hrs.- 21 hrs.	6 hrs.	49.4 (V)
	18 hrs.- 21 hrs.	3 hrs.	25.0 (I)
BSL :	12 hrs.- 24 hrs.	12 hrs.	79.4 (I)
	15 hrs.- 21 hrs.	6 hrs.	53.7 (I)
	15 hrs.- 18 hrs.	3 hrs.	27.2 (I)
PTKI :	12 hrs.- 24 hrs.	12 hrs.	67.5
	15 hrs.- 21 hrs.	6 hrs.	40.1 (V)
	15 hrs.- 18 hrs.	3 hrs.	22.0 (V)
KPRA :	09 hrs.- 21 hrs.	2 hrs.	62.6
	12 hrs.- 18 hrs.	6 hrs.	35.0
	12 hrs.- 15 hrs.	3 hrs.	17.7
MJD :	09 hrs.- 21 hrs.	2 hrs.	72.1 (V)
	09-12, 15-18 hrs.	6 hrs.	45.7 (V)
	15 hrs.- 18 hrs.	3 hrs.	29.5 (I)
CTG :	00-06, 15-18 & 21 hrs.- 24 hrs.	12 hrs.	59.5
	21 hrs.- 03 hrs.	6 hrs.	34.0
	21 hrs.- 24 hrs.	3 hrs.	17.3
RMGT :	12 hrs.- 24 hrs.	12 hrs.	60.5
	15 hrs.- 21 hrs.	6 hrs.	32.7
	15 hrs.- 18 hrs.	3 hrs.	17.6
C'BZR :	03-09, 12-15 & 18 hrs.- 21 hrs.	12 hrs.	56.5
	03 hrs.- 09 hrs.	6 hrs.	30.4
	06 hrs.- 09 hrs.	3 hrs.	15.9

these periods are termed intensive periods of thunderstorm activity. On the other hand, if the coresponding percentage are above 70, 40 and 20% respectively, then these periods are termed vulnerable periods of thunderstorm activity.

Table 3A presents the percentage of occurrence of TS in each 3-hour interval. Table 3b presents 12 hours, 6 hours and 3 hours of maximum thunderstorm activity, with the respective percentage of occurrence and indicates whether it is intensive, vulnerable or otherwise.

It is observed that ten out of 19 stations have 12 hours maximum thunderstorm activity from 12.00 hours to 24.00 hours. These ten stations lie mostly in central Bangladesh. These ten stations, namely RJSH, ISDI, DCA, FDP, JSR, KLN, BSL, CML and PTKI all have the identical six hours of maximum thunderstorm activity i.e. 15 hours to 21 hours. However, of the ten stations, 8 have the same 3 hours of maximum thunderstorm activity i.e. from 15 hours to 18 hours. The two exceptions, namely JSR and KLN have a different 3 hours of maximum thunderstorm activity i.e. 18 hours to 21 hours. The notable point about these ten stations is that all the different periods of maximum thunderstorm activity fall either into the intensive or vulnerable class with few exceptions.

Of the 9 stations having different 12 hour maximum thunderstorm activity, five, (namely DNP, RNP, BGR, MYMS and SLT) are located in north Bangladesh. On the other hand, the other four stations namely MJD, CTG, C'BZR and KPRA are located mostly in the extreme southern part. Stations CTG and C'BZR are located on the Hill tract and, as already mentioned, station SLT is just at the foot of the Meghalaya Plateau. Hence, orography plays an important role in the thunderstorm activity of these three stations. However, KPRA is located on a plain.

Of the five northern stations above, four have a 3-hour period of maximum thunderstorm activity either at night or in the early morning. The only exception is MYMS where a 3-hour period of maximum activity is from 15 hours to 18 hours, like most stations in the central region.

Of the four southern Bangladesh stations,each have a distinct 3-hour period of maximum thunderstorm activity. In CTG, night time (21 hours to 24 hours) thunderstorm is active, but morning (06 hours to 09 hours) thunderstorm is dominant in C'BZR. In KPRA the corresponding period is just after noon (12 hours to 15 hours). The most notable thing is in the case of MJD, where the corresponding period is in the afternoon (15 hours to 18 hours) under intensive class with nearly 30% of all thunderstorms occurring within this short span.

In fact, the 9 stations in northern and extreme southern areas have hardly any period of thunderstorm activity which might fall in either the intensive or vulnerable class.

The notable exception is MJD where all 3 periods of different durations come either under intensive or vulnerable class. The only exception is DNP where the 3 hours of maximum thunderstorm activity in the early morning hours (03 hours to 06 hours) are included in the vulnerable category.

Now, when the correlation study and the different periods of maximum thunderstorm activity are compared, it seems that the origin of most of the thunderstorms for DCA, RJSH, ISDI, CML and FDP is identical. Apparenly RMGT may also be included in this family, but many of the thunderstorms there also have a different origin as the thunderstorms there are more evenly distributed over a day. On the other hand, it can be concluded that most of the thunderstorms of JSR and KLN are expected to have a common origin.

4.4 Rainfall Per TS Day

In the present study, any rainfall from March to May is assumed to be due to TS activity only. In Table 4, rainfall in mm per TS day over each two-week period and averaged over the ten-year interval is presented.

It is evident that the tendency for rainfall/TS days in general increase from March to May even biweekly, though there are many departures from this. In fact, such a uniform rise over each successive two-week is observed only in DCA and DNP.

In 14 out of 19 stations, the maximum rainfall/TS occurred in the second half of May. In 3 stations this occurred in the first half of May. But station C'BZR has some exceptional behaviour since the maximum rainfall/TS occurred in the first half of March. There the rainfall/TS day in the second half of March is very low compared to the rainfall/TS day in other halves.

A notable feature occurs in the case of MJD where the rainfall/TS day is always very high and it increases up to 82.8 mm/TS day in the second half of May. This amount is almost twice that during highest rainfall/TS day as that of any other station. On the other hand, MJD has the lowest frequency of TS occurrence, which shows that TS occurrence is comparatively a rare phenomena but whenever it does occur, it generates huge precipitation.

Lastly, it should be pointed out that, in principle, the rainfall/TS day is greater in the second half of a month, but it is obvious from Table 4 that there are many departures.

Table 4. Rainfall (mm) per TS day.

Station	March		April		May	
	I	II	I	II	I	II
RNP	9.5	13.4	11.5	18.6	15.2	26.8
DNP	14.6	15.4	18.2	19.4	26.4	40.7
BGR	6.2	3.5	4.8	14.7	28.2	17.0
RJSH	6.5	3.4	8.4	8.7	13.2	15.8
ISDI	11.0	16.1	8.6	0.6	17.8	21.1
MYMS	13.9	9.4	23.2	11.8	25.1	34.2
SLT	8.7	27.0	17.0	20.8	23.8	34.8
CML	8.3	22.8	21.1	16.9	30.4	33.4
DCA	6.6	16.4	19.2	20.8	23.9	30.0
FDP	7.8	19.6	13.5	17.1	17.9	27.4
JSR	10.3	14.0	7.3	8.1	8.4	18.1
KLN	12.9	9.9	4.7	19.2	19.5	22.7
BSL	11.2	10.9	16.8	18.7	34.4	35.4
PTKI	18.7	6.9	18.7	13.6	38.0	25.3
KPRA	27.3	9.4	13.6	27.8	29.9	33.8
MJD	28.1	39.3	53.7	48.4	71.8	82.8
CTG	13.6	12.0	35.2	23.5	27.1	33.4
RMGT	13.4	22.5	33.0	25.1	42.8	32.3
C'BZR	40.4	6.9	39.8	23.6	29.5	28.5

4.5 Percentage Occurrence Of Different Types Of TS

The occurrence of TSs may be classified according to the WMO code. The TS with codes 17 and 29 may be considered dry, where those with codes 91-99 are termed wet. Any code from 96-99 may also be taken as a severe TS.

Accordingly, all TSs occurring at a particular station over a ten-year period are grouped by the percentage of occurrence under three columns in Table 5.

Table 5. Different types of TS occurrence in Bangladesh (in % form).

Station		TS 17 & 29	TS 91 - 95	TS 96 - 99
RNP :	March	70.5	25.0	4.5
	April	58.4	33.3	8.3
	May	61.0	36.4	2.6
DNP :	March	78.6	14.3	7.1
	April	64.1	23.1	12.8
	May	60.2	34.5	5.3
BGR :	March	53.7	43.9	2.4
	April	70.5	25.6	3.9
	May	64.8	29.6	5.6
RJSH :	March	68.6	27.2	4.2
	April	61.3	32.5	6.2
	May	65.5	32.4	2.1
ISDI :	March	58.7	27.1	14.2
	April	78.4	18.0	3.6
	May	68.6	25.9	5.5
MYMS:	March	78.4	19.6	2.0
	April	74.2	24.2	1.6
	May	58.6	39.8	1.6
SLT :	March	70.3	25.9	3.8
	April	65.1	32.2	2.7
	May	53.6	45.5	0.9
CML :	March	60.8	32.6	6.6
	April	49.6	48.6	1.8
	May	58.0	37.1	4.9
DCA :	March	47.0	36.1	16.9
	April	59.3	28.0	12.7
	May	45.1	37.9	17.0
FDP :	March	71.1	22.9	6.0
	April	70.5	25.9	3.6
	May	60.4	33.9	5.7
JSR :	March	67.2	26.6	6.2
	April	56.6	38.1	5.3
	May	58.2	38.3	3.5
KLN :	March	60.9	28.2	10.9
	April	68.9	24.3	6.8
	May	51.5	36.8	11.7
BSL :	March	76.5	19.6	3.9
	April	68.3	31.7	0.0
	May	61.0	36.6	2.4

Table 5. (Continued.)

Station		TS 17 & 29	TS 91 - 95	TS 96 - 99
PTKI :	March	47.5	44.0	8.5
	April	58.9	33.7	7.4
	May	47.4	39.6	13.0
KPRA :	March	66.7	30.9	2.4
	April	61.0	39.0	0.0
	May	59.8	39.2	1.0
MJD :	March	58.8	35.3	5.9
	April	26.1	54.3	19.6
	May	43.9	53.0	3.1
CTG :	March	43.5	56.5	0.0
	April	38.1	51.4	10.5
	May	36.4	57.6	6.0
RMGT :	March	66.7	31.1	2.2
	April	49.2	36.9	13.9
	May	59.7	25.5	14.8
C'BZR :	March	60.0	40.0	0.0
	April	37.3	59.7	3.0
	May	38.9	55.7	5.4

In general, the dry TS has dominance over the wet type, but there are 7 stations where the situation differs. Five of the seven stations are in the southern part where moisture support from the sea is copious and two other stations, namely DCA and CML, get enough moisture support from nearby big rivers. In fact, CTG is the only station where wet TSs dominate over dry TSs in all three months, though the severe type dominates only in April.

At four out of the seven stations, namely DCA, PTKI, MJD and C'BZR, in two out of the three months, wet TSs predominate over dry varieties. In MJD, the dry variety nearly reaches only 26% in April, when the severe type wet TS shoots up to nearly 20%. Such a high incidence of the severe variety is not found in any other place. In DCA, the occurrence of severe TSs is equally dominant over all three months. This is unique for DCA. However, in C'BZR the occurrence of the severe variety is very poor all three months.

In RMGT and CML, wet TSs dominate over the dry type in only one month i.e. in April. However in RMGT the incidence of the severe type is quite appreciable during both April and May. ISD is the place where the severe type has a large occurrence only in March. In DNP and KLN, there are periods when the % of occurrence of the severe type exceeds 10%.

5. CONCLUSIONS

In conclusion, it may be said that though Bangladesh is not a large country, the space/time distributions of TSs vary greatly. Among the 19 stations studied, station SLT has the most numerious premosoon TS occurrence: more than 50% the premonsoon season are TS days. On the other hand, corresponding figure drops to 10% in the case of MJD. In the majority of the stations, TS days contribute around 20% to 25%. In contrast in MJD, though the occurrence of TS is comparatively rare, whenever it does occur, the possibility of huge precipitation is very strong.

In central Bangladesh, the most likly time of TS occurrence is early afternoon or evening while in the north it is either night or early morning. In southern areas, there is a wide variation as to the intense period of TS activity.

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REFERENCES

Ahmed, R., and S. Karmakar, 1993: Arrival and withdrawal dates of summer monsoon in Bangladesh. *Int. J. Climat.*, **13**, 727-740.

Chowdhury, M. H. K. (Ed.), 1986: Proc. of the seminar on severe local storms, Bangladesh Meteorological Department, Govt. of the People's Republic of Bangladesh, Dhaka.

Court, A., and J. F. Griffiths, 1982 : Thunderstorms climatology, In: Kessler, E. (Ed.), Thunderstorm Morphology and Dynamics, **2**, U.S. Department of Commerce, NOAA, U.S.A.

De, A. C., and S. N. Sen,1961: A radar study of premonsoon thunderstorms (nor'westers) over Gangetic West Bengal. *Ind. J. Met. Geophys.*, **12**, 51-60.

Fischer, F. E., 1973 : Fundamental Statistical Concepts, Harper and Row, San Francisco, Publishers Inc. 76-82.

Koteswaram, P., and V. Srinivasan, 1958: Thunderstorms over Gangetic West Bengal in the premonsoon season and the synoptic factors favourable for their formation. *Ind. J. Met. Geophys.*, **9** 301-312.

Mukherjee, A. K., and P. B. Bhattacharrya, 1972: An early morning tornado at Diamond Harbour on 21 March, 1969. *Ind. J. Met. Geophys.*, **23**, 223-226.

Mukherjee, A. K., S. Kumar, and G. A. Krishnamurthy, 1977: A radar study of growth and decay of thunderstorms around Bombay during the premonsoon season. *Ind. J. Met. Geophys.*, **28**, 475-478.

Mobassher, A., and M. H. Rashid, 1991: Some climatological characteristics of mean sea level pressure in Bangladesh. *Mausam*, **42**, 195-200.

Nandi, J. and A. K. Mukherjee, 1966: A tornado over north-west Assam and adjoining West Bengal on 19 April, 1963. *Ind. J. Met. Geophys.*, **17**, 421-426.

Rai, Sircar. N. C., 1953: On the use of tephigrams for forecasting Norwes'ters. *Ind. J. Met. Geophys.*, **4**, 269-278.

Sen, S. N., and J. R. Sen Gupta, 1961: A premonsoon thunderstorm with tornadic characteristics at Calcutta. *Ind. J. Met. Geophys.*, **12**, 41-48.

Srinivasan, V., 1954: Thunderstorms in Kutch Saurastra. *Ind. J. Met. Geophys.*, **5**, 249-252.

World Meteorological Organisation (WMO), 1982: International Weather Code.