



Understanding Thunderstorm Patterns and Risk from It by Investigating Thunderstorms Causalities of Bangladesh in 2018

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Abstract

The changing perspective of climate causes the increasing of natural disasters all over the world. The calamity of thunderstorms is also a consequence of these global alterations. Thunderstorms are more frequent in countries of tropical regions. People of Bangladesh are significantly vulnerable to such kind of natural disaster due to their geographical location and their daily activities. It occurs scatteredly and causes numerous fatalities across the country. Therefore, it is essential to understand the patterns and frequencies of thunderstorm occurrence to mitigate the risk from it. This is why this study aims to identify and map thunderstorm incidence in Bangladesh with investigating climatic factors and relevant reasons in 2018. Information about the weather, like gusty and squall winds, temperature, and cloud cover, was collected from the Bangladesh Meteorological Department (BMD), and secondary data on deaths and injuries caused by thunderstorms was gathered from national newspapers. The result indicates there were 136 deaths in 2018, with the most deaths in Sylhet Division because of its geography and climate, which make it more likely to have convective activity. May recorded the most thunderstorms during the pre-monsoon season, known for its high temperatures and humidity. Most of the fatalities occurred between late morning and early afternoon, when most of them were farmers and fishermen who worked outside. Northwesterly squall winds, high temperatures before the occurrence, and a lot of cloud cover all contributed to the thunderstorm occurrence. The results will help to improve early warning systems and community-level disaster preparedness.

Subject Areas

Earth and Environmental Science (Geography)

Keywords

Thunderstorm, GIS, Meteorology, Lightning

1. Introduction

Thunderstorms are one of the most dazzling phenomena triggered by the instability of air mass. The unstable conditions of air mass can occur when there is a significant difference between upper and lower layers of clouds [1]. The formation of thunderstorms is the result from the combination of atmospheric phenomena like air and condensation. The formation is influenced by various factors, including meteorological conditions, geographical features, and even anthropogenic changes [2]. The rise of warm, humid air followed by cooling contributes to the formation of cumulonimbus clouds, leading to lightning and thunderstorms due to their distinct charge regions [3]. Thunderstorms can be classified based on their duration and intensity [4]. Thunderstorms can result in fatalities and destruction globally due to lightning, intense rainfall, hail, cloud cover and severe winds [5]. Climate changes and environmental factors, such as rising temperatures and humidity, can intensify thunderstorms and influence lightning severity, affecting local and regional weather patterns [6]. It is estimated that for every increase of 0.1°C in surface temperature, the average number of thunderstorm days increases by one [7]. Thunderstorms have both direct and indirect effects on human health, causing death to number of people each year globally [8]. Outdoor workers, particularly those in agriculture, construction, and landscaping, face a significant risk of lightning-related injuries and fatalities [9]. Thunderstorms also cause monetary losses by significantly damaging social infrastructure. For instance, in the United States, among all the weather-related hazards, thunderstorms alone can disrupt 47 percent of power delivery [10]. A large area of forest cover was lost by the destructive winds during thunderstorms in Finland in 2021 [11]. Thunderstorms can also damage the environmental conditions by affecting daily atmospheric ozone. In some regions like north Florida, thunderstorms are significantly responsible for increasing the level of ozone, particularly during early summer, spring and late winter. The fluctuations of ozone levels sometimes reach a certain level that can cause ecological damage [12]. Researchers have found a strong connection between the occurrence of thunderstorms and climate change. It is also verified by some researchers that the strong wind gusts from thunderstorms are intensified by the changing effects of climate. According to a study, areas in the U.S. Midwest that were affected by strong straight-line winds in 1980 were found to have an expansion of damage by 4.8% during 2022 [13]. It is expected that frequency of severe thunderstorms will increase by the end of 21st century, as demonstrated by several climatic models [8].

Thunderstorms are common weather phenomenon in Bangladesh and its neighboring countries like India, Myanmar and Sri Lanka. However, the frequency of

thunderstorm varies from country to country based on their climatic conditions and geographical location. In every year, India witnessed of 100 to 120 days of thunderstorms, indicating a high frequency of thunderstorm occurrence, particularly in Assam and Sub-Himalayan West Bengal in the east, and the Jammu region in the north. In the plains of Gangetic West Bengal and Bangladesh, the frequency stands between 80 and 100 thunderstorm days annually [14]. The occurrence of thunderstorm is also frequent in Myanmar every year, especially during the pre-monsoon and post-monsoon seasons. But this phenomenon is more frequent in the months of May, June and September [15]. Lightning is very common in Sri Lanka, causing around 50 fatalities annually throughout the country. The average days of thunderstorm occurrence in Sri Lanka is approximately 76 days in one year [16]. Thunderstorms, influenced by the monsoon trough and local heat lows, generate strong winds (gusty and squally) that can cause damage and fatalities. Wind dynamics are crucial in their development and severity, as evidenced by long-term studies on wind, precipitation, and storm patterns [17]. Thunderstorms are more frequent during warmer months, especially from late spring to early autumn, due to increased atmospheric instability caused by rising temperatures [18]. Lightning in the Indian subcontinent peaks in the warm season, especially pre-monsoon, occurring between 1200 and 1400 UTC [19].

Research shows that impoverished communities, especially in regions like Bangladesh, are more vulnerable to lightning strikes, which can worsen their socio-economic conditions [20]. Climatic variability, including temperature and humidity changes, significantly influences the prevalence of thunderstorms in Bangladesh, with anomalies playing a crucial role, especially in specific seasons [21]. Severe thunderstorms in Bangladesh bring high gusty and squally winds, along with thunder, hail, lightning, and heavy rain. Squally winds, often exceeding 50 - 60 km/h, contribute significantly to storm intensity and destruction. The annual mortality rate from lightning strikes in Bangladesh has been reported at approximately 2.4 deaths per million people [21]. In May 2016, a newspaper reported that 81 individuals died in thunderstorm over two days, leading to the declaration of a natural disaster in Bangladesh [22]. Thunderstorms in Bangladesh peak from March to May during the pre-monsoon season, but also remain prevalent in the monsoon season from June to July. Thunderstorm occurrences in Bangladesh vary by region and time, with central areas experiencing them in the late afternoon or evening, the north at night or early morning [23]. Lightning strikes pose a significant risk in rural areas, especially for farmers, leading to numerous fatalities, particularly in the northeast [18].

The storms are closely monitored using advanced meteorological models, which capture various atmospheric parameters and help predict thunderstorm events [24]. Monitoring these winds and their maximum speeds is crucial for predicting their impact and assessing storm severity [25]. Rising global temperatures due to climate change may lead to more frequent and intense thunderstorms, as warmer air holds more moisture, a key factor in thunderstorm formation [26].

This study aims to identify 2018 pre-monsoon and monsoon period thunderstorm casualties, their frequencies, and spatial distribution across Bangladesh, while investigating the connection between these incidents and climatic variability. The main objective of the study is to identify the casualties and analyze their relationship, on a date-wise basis, with three climatic elements: gusty and squally wind, temperature, and cloud cover. Moreover, the outcome will help in developing strategies to mitigate injuries and fatalities caused by lightning strikes.

2. Data and Methods

2.1. Study Area

Bangladesh is located in the northeastern region of South Asia, approximately between 20° 34' to 26° 38' north latitude and 88° 01' to 92° 41' east longitude. The neighboring countries of Bangladesh include India on west, north and east side, and Myanmar to the southeast side. There is no land adjacent to the south side of Bangladesh except a bay, called Bay of Bengal. Climatic conditions of Bangladesh are mainly characterized by the tropical monsoon (rainy season), represented by moderate to substantial precipitation, elevated relative humidity, and high temperatures.

This climatic condition is ideal for intensive local convective storms, such as tornadoes and hail due to increased moisture influx from the Bay of Bengal and atmospheric instability [27]. The monsoon typically extends from June to October and an

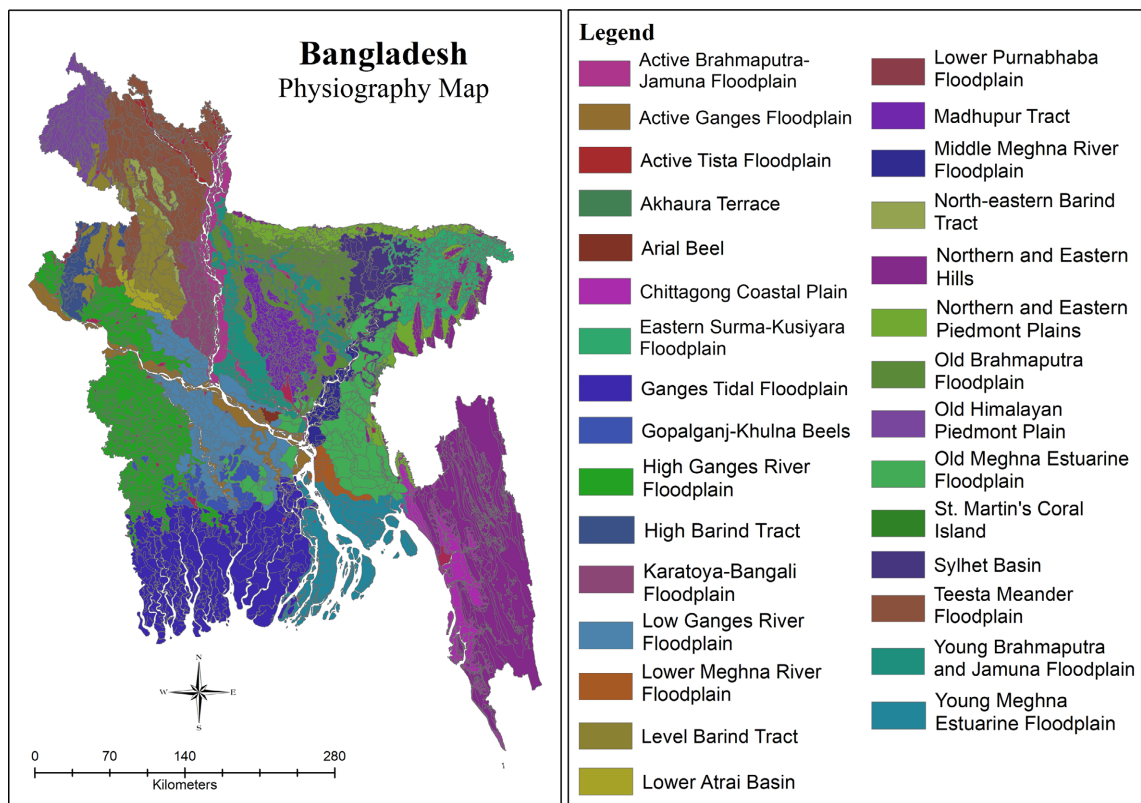


Figure 1. Physiographic map showing different types of land in Bangladesh.

increase in climatic hazards is noticeable during this season [28]. The Pre-Monsoon extends from March to May and winter extends from November to February.

The physiography of Bangladesh (**Figure 1**) can be categorized into thirty different regions and is dominated by the floodplains (80%) from some major rivers of this country. The central and southern part of this country is covered with floodplains like active Brahmaputra-Jamuna floodplain, active Ganges floodplain and old Meghna estuarine floodplain. Terraces and Hills (12%) are the second most dominated landscape of Bangladesh after floodplains. Hills are located in the north-eastern and southeastern parts of this country. Madhupur tract, Barind tract and Akhaura terrace (8%) are some examples of terraces of Bangladesh. The physiography of Bangladesh is very diverse and the occurrence of climatic hazards is not the same in different physiographic regions.

2.2. Data

The method of data collection was different for both of the selected objectives, and a secondary source of data was used for conducting the research. Data for the first objective was collected from different types of newspapers, particularly those published in Bengali, such as Prothom Alo, Noya Diganta, and Somokal. Some data were also gathered from reports regarding the statistical information of thunderstorm occurrence and consequences in different districts of Bangladesh. After collecting these scattered data from different sources, it was then carefully organized and categorized to get concrete and meaningful information about thunderstorms in Bangladesh during 2018, which was used for further analysis and graphical representation. The categorization summarized the data into different small groups, including Name (affected person), Age, Occupation, Date and Time of Thunderstorm occurrence, Event, Injury Type, Village/Mauza, Union, Upazila, and District. This spatially coordinated, time-interval database covers the Mauza to District levels.

The climatic data, including gusty and squall winds, thunderstorm days, temperature, relative humidity, and cloud cover extent, were used for the objective 2 analysis. All the climatic variables were daily average and monthly total collected from the Bangladesh Meteorological Department (BMD). During 2018, there were 35 weather stations providing meteorological data, which did not cover the whole of Bangladesh. The data were then organized into a spreadsheet and made a connection with the thunderstorm casualties' data. This allowed to see the relationship between climatic variables and thunderstorm occurrence.

2.3. Methods

The methodology of this work was divided into sections (**Figure 2**) based on the two different objectives. The study first tried to assess the impacts of thunderstorms on people at different ages and occupations, and other types of variables related to thunderstorm casualties. The assessment mainly relied on gathering such kinds of data and successfully categorized them to create meaningful information. Data

cleaning and correcting were performed using different methods, including Google Earth Pro to fill up missing information about thunderstorm occurrence places. Direct contact with the local people through mobile calls was conducted to double-check and correct wrong information where needed. All the corrected data were joined spatially to the national administrative dataset using ArcMap. This allowed to visualize the data by maps portraying thunderstorm effects in different administrative boundaries of Bangladesh.

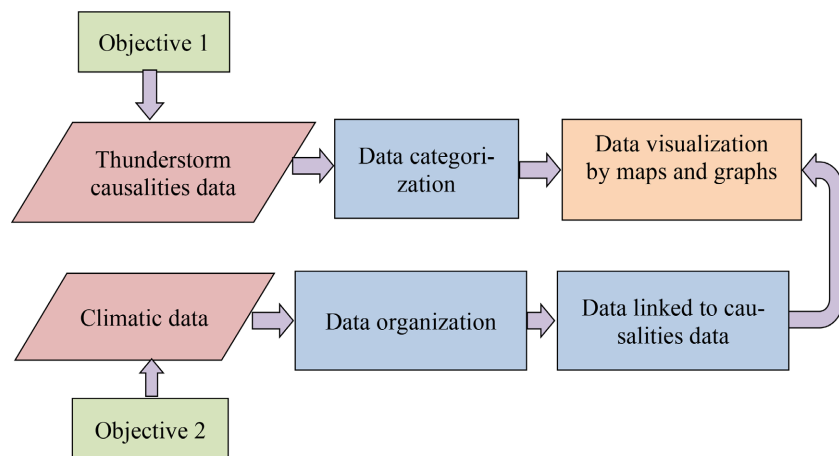


Figure 2. Methodological framework of analyzing thunderstorm causalities.

The second and most important task for this study was analyzing the thunderstorms causalities with response to different climatic variables, including gusty and squall winds, thunderstorm days, temperature, relative humidity, and cloud cover extent. When thunderstorms occur, the meteorological factors of that day and the previous two days, date of occurrence and next day's temperature are very important to take into consideration. Therefore, different meteorological factors were closely observed during the occurrence of thunderstorms and tried to find out the pattern of those variables related to thunderstorm occurrence.

The linkage between thunderstorm causalities and meteorological variables was created in ArcMap by joining two different information based on unique data like location and time. The data on lightning victims was correlated with meteorological data from BMD to ascertain the association between the two variables. The casualty-related climatic variability information was obtained from the weather station geographically nearest to each location. This method ensured that the meteorological conditions linked to each fatal incident were shown as precisely as possible, given the existing monitoring network. Then some interactive graphs and tables were created to expose the relationship between thunderstorm causalities and selected climatic variables.

3. Results

3.1. Total Death from Thunderstorms in 2018 over Eight Divisions

Thunderstorms caused death of around 136 people (As per collecting database)

during 2018 over eight different divisions of Bangladesh, showing in **Figure 3**. In this year, the number of fatalities that occurred in the Sylhet division was 42, which is the highest to be recorded compared to other divisions. The number of people who died from thunderstorms in the Dhaka division was almost half of Sylhet, making it the second most affected area of Bangladesh by thunderstorms in 2018. Fewer people died from thunderstorms in that year in Khulna, Rajshahi, Mymensingh, and Rangpur divisions: 18, 17, 14, and 13, respectively. Chittagong and Barisal divisions experienced minimal fatalities from the thunderstorms, where 7 people died in Chittagong division. In terms of death counts from thunderstorms in Bangladesh for the year 2018, Barisal division had 2 people, which was the lowest compared to any other division of Bangladesh in that year.

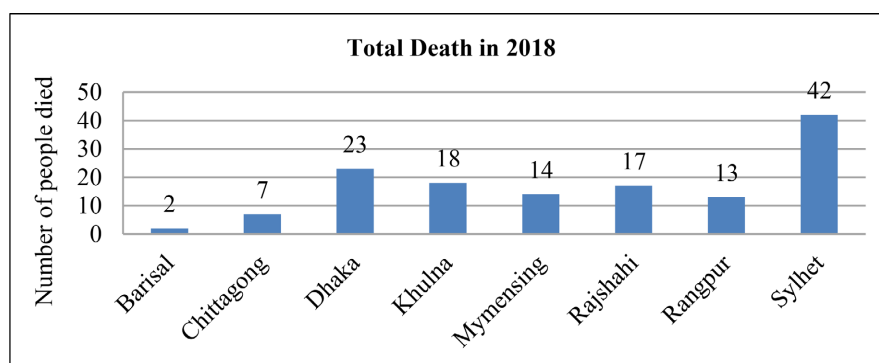


Figure 3. Division-wise total death by Thunderstorm in 2018.

The district-wise thunderstorms fatalities map (**Figure 4**) demonstrates a detail about number of died from thunderstorms in 2018 across Bangladesh. The four most northeastern districts of Sylhet division, Habiganj, Moulvibazar, Sunamganj and Sylhet had the highest record of fatalities from thunderstorms. Sunamganj district experienced more death about 21 people and 11 people died in Habiganj district, darkest red shades, compared to all other districts of Bangladesh. The neighboring districts, such as Netrokona and Kishoreganj, also witnessed of moderate to high death of people by thunderstorms in 2018, indicating severe thunderstorm occurrence in these regions. Conversely, districts in southern divisions of Bangladesh, particularly in Bagerhat, Barguna and Patuakhali, had very few fatalities from thunderstorms, ranging from 1 to 2 people.

The spatial distribution of thunderstorm casualties varied across different regions of Bangladesh, concerning the frequency of thunderstorms and deaths from thunderstorms. The fatalities from thunderstorms during 2018 in Bangladesh are considerably high in the central, north-central and northeastern regions. It is widely known that due to the elevated topography, high humidity and substantial moisture coming from the Bay of Bengal, pre-monsoon convective storms occur in the northeastern part of Bangladesh, especially in the Sylhet region. The presence of this circumstance generally causes intense lighting and extreme gusty winds; both can lead to likelihood fatalities.

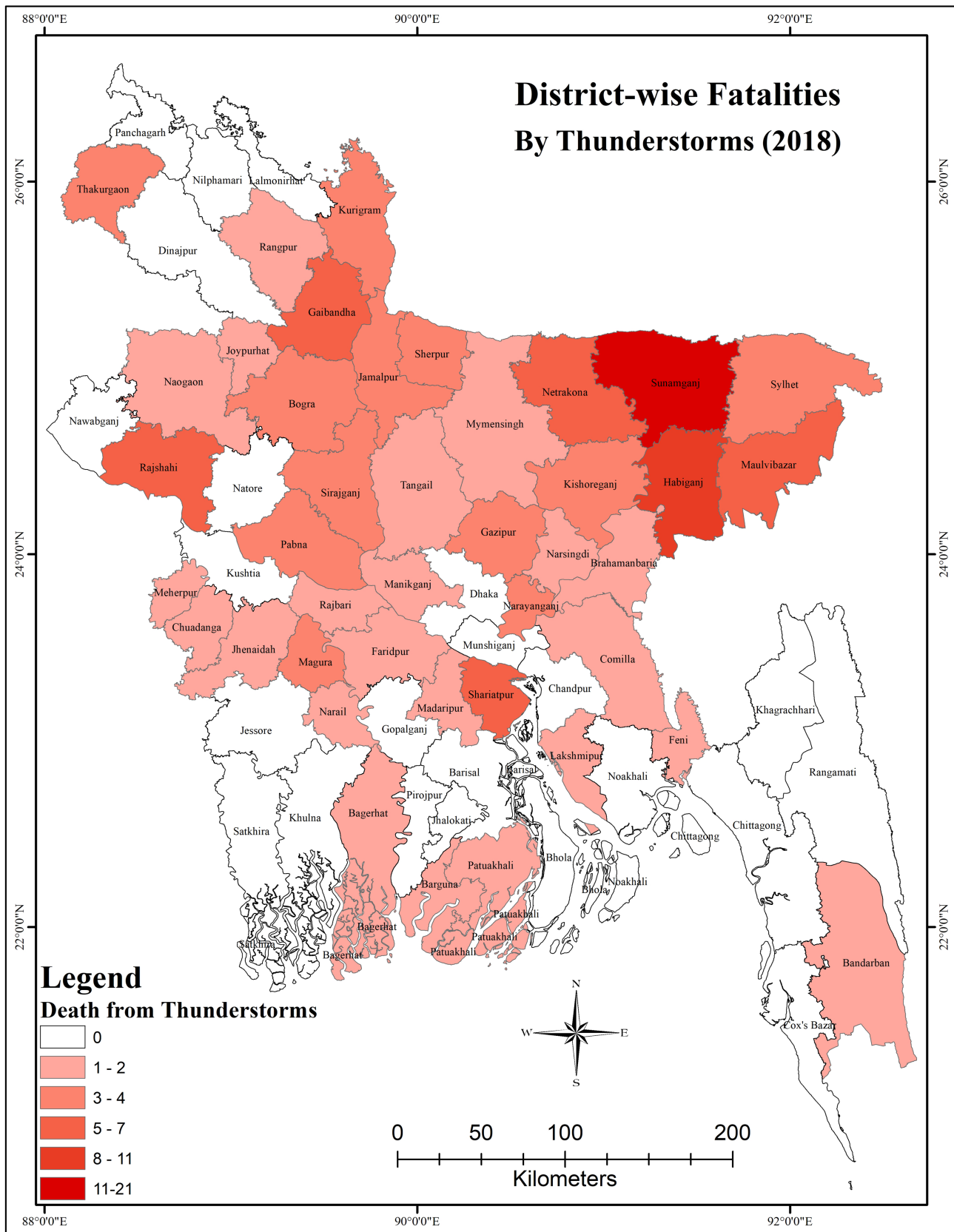


Figure 4. District-wise total death from the thunderstorm.

3.2. Number of Thunderstorm-Related Fatalities from March to September in 2018

Lightning does not strike all the year in Bangladesh except from few months. **Figure 5** illustrates a record for number of lightning strikes from March to September in 2018 across Bangladesh, when the skies are generally erupted in electrical fury. There were approximately 136 lightning counted in different districts of Bangladesh within these seven-months period of 2018. Initially, few lightning strikes in March, there were 78 lightning strikes in the month of May, which is higher to be counted. In September, the last month from lightning in 2018, Bangladesh experienced 20 lightning across the country. Moderate to fewer number of lightning was recorded in April, June, and July, around 16, 10 and 8 lightning strike, respectively. The lowest number of lightning strikes was found in August, only one lightning strike in this month.

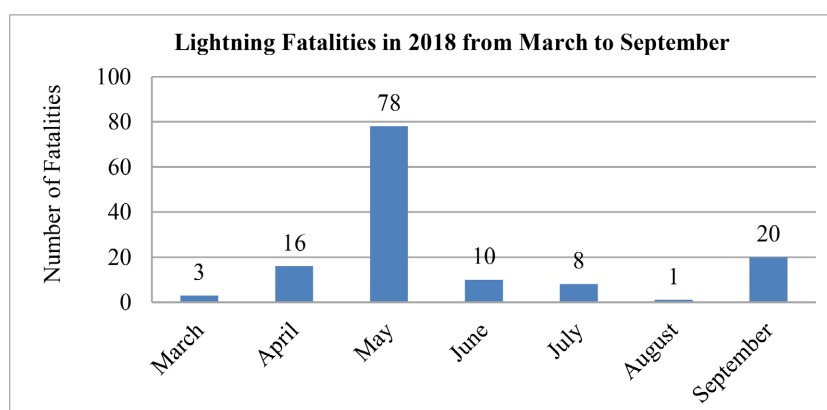


Figure 5. Monthly distribution of fatalities resulting from thunderstorm incidences in Bangladesh during 2018.

The lightning strikes often in monsoon seasons (pre-monsoon, monsoon and post-monsoon) in Bangladesh. Pre-monsoon starts from March, so as the lightning starts to strike from this month, according to the bar diagram too. The spring begins in the mid of April to May and the “Kalbaishakhi” or “Nor’westers” occurs at that time. During the time of “Kalbaishakhi” most of the lightning strikes over Bangladesh (April 16 and May 78 as shown in the diagram). The time between April to June often known as lightning season to the local people of Bangladesh. During this time period, people who works outside for example; day laborers, farmers and fishermen are more vulnerable to the strikes of lightning. The monsoon starts to let up by the end of September, causing less amount and intense of rainfall. At this time, atmospheric energy also slowly fades away. Therefore, fewer lightning strikes at this time period. However, there is still possibility of lightning occurrence, as shown in the diagram (August and September). Although the worst is over, the sky sometimes releases stinging outbursts every once in a while.

3.3. Where Does Thunderstorm Occur?

The distribution of fatalities from thunderstorms (**Figure 6**) in Bangladesh is highly

uneven across different places during 2018. Most of the death, around 78, were linked to “Working at Agricultural Field/Open Area” in that year. This significantly indicates how vulnerable farmers and other laborers towards thunderstorms suggesting these places are highly susceptible to thunderstorms. “Catching Fish at Open Area” and being “On the Road/Way” both counted as 20 fatalities each and are the second most vulnerable activities during the occurrence of thunderstorms. Being near the open water bodies for catching fish and moving on the road are considered as danger zones since there is no place for a safe shelter. “Working at Yard/Roof and Excessive Sound” poses moderate risk from thunderstorms, responsible for 13 deaths in 2018. This actually suggests even places near home are not safe when they are in open space. The last hotspot for thunderstorm occurrence listed as “Take shelter under tree and Tong”, counted a number of 5 deaths from this natural disaster during this year.

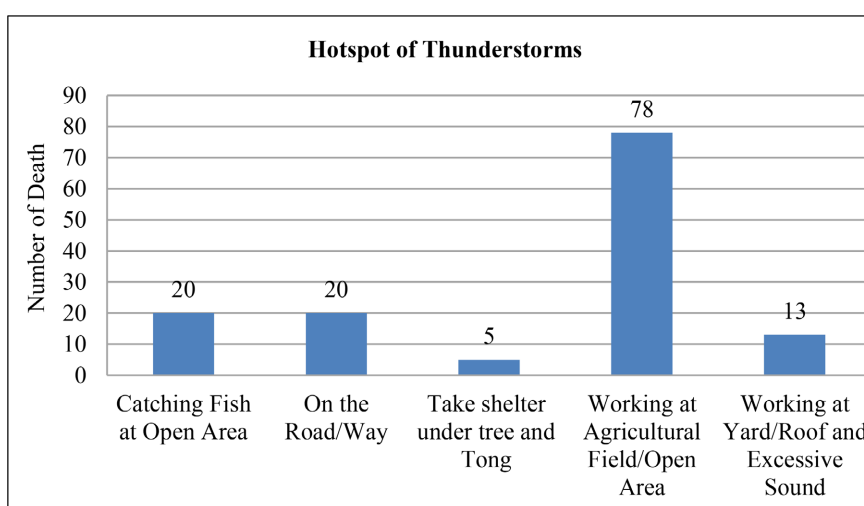


Figure 6. Hotspot and event of thunderstorm incidence in 2018.

Thunderstorms in Bangladesh predominantly occur in open or exposed areas. During the daytime, an individual situated outdoors is extremely vulnerable to lightning strikes because convective thunderstorms are prominent in this time. People involved in activities such as agricultural fields, haors, yards, and river side offer limited protection against lightning. The uses of Mobile phones and metal tools make them more prone to thunderstorms. Taking shelter of any building or vehicle may reduce the risk from thunderstorms. From April to June, farmers in Bangladesh are more susceptible to thunderstorms because at this time they need to harvest rice from agricultural land and lightning also occurs more during this time period, as shown in **Figure 5**.

3.4. When Does Thunderstorm Occur?

There was a certain time of a day when thunderstorms caused more fatalities in 2018, as shown in **Figure 7**. More than 60 people died within the two hours period of noon (12 pm to 2 pm), making it the deadliest hour for lightning strikes of

a day. The risk from thunderstorms is more during this mid-day period. The morning period, which is from 6:00 am to 11:59 am, also recorded very high number of fatalities (exactly 39 deaths) by thunderstorms. The majority of the thunderstorm fatalities occurred between morning to noon (6:00 am to 2:00 pm) due to the human's outdoor activity in this time period. The number of tragedies dropped in the afternoon (2:00 pm to 5:00 pm) period, recorded deaths of 20 people during this time. The fatalities counted even lower in evening (6:00 pm to 8:00 pm) and night (8 pm to 4 am), respectively, 8 and 5 people died during these two-time periods. The lowest death was recorded (3 people) at the early morning (4 am to 6 am), demonstrating people's high vulnerability towards thunderstorms during the core workday hours compared to other times of a day.

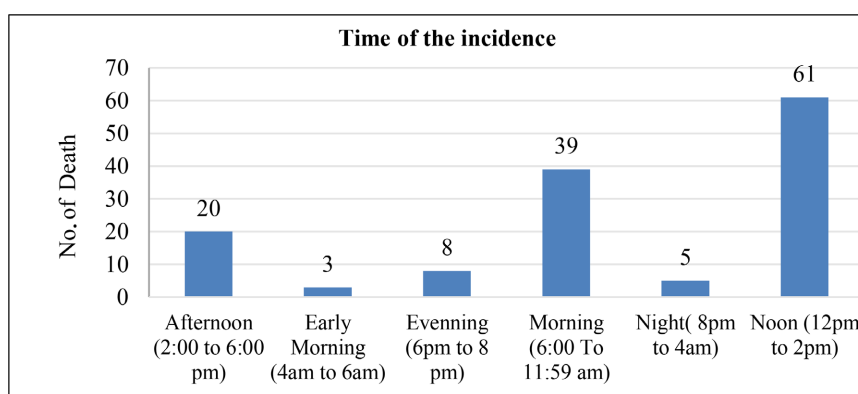


Figure 7. Time of the thunderstorm occurrence in 2018.

Thunderstorm mainly occurs in the noon, morning and afternoon. Thunderstorms are more frequent during noon and afternoon hours in Bangladesh, coinciding with the maximum solar heating of the day. In pre-Monsoon period of Bangladesh, sun shines vertically and day length is relatively large, resulting in significant surface heating. During this period, the moisture content of the air increases, resulting in higher precipitation, which facilitates the formation of cumulonimbus clouds. Both cumulonimbus and mammatus clouds are associated with lightning strikes. Morning and noon are the highest casualties found because this is the peak period of outdoor human activities. Early morning, evening and night, lightning strike casualties are less than others during this time because fewer people are staying outdoor.

3.5. Frequency of Thunderstorm Occurrence

Table 1 shows that thunderstorms occurred all year long, although the number of thunderstorms and fatalities they caused changed a lot from month to month. In February, there were 47 thunderstorms, and by March, there were 166. In May, the number of thunderstorms hit its highest peak, which was 1231. This peak happens during the pre-monsoon season, which is known for having high temperatures, strong convection, and plenty of precipitation. These conditions make it easier for powerful thunderstorms to form. In the local community, these storms are

called “Kalbaishakhi”.

Table 1. Monthly distribution of thunderstorm days recorded at thirty-four meteorological stations across Bangladesh.

Month	Number of Thunderstorm
January	1
February	47
March	166
April	990
May	1231
June	852
July	386
August	376
September	595
October	74
November	9
December	2

There were 990 thunderstorms in April, and many people died as a consequence. This shows that April was a month before the monsoon, with weather that wasn't consistent. May experienced the most thunderstorms and the most deaths caused by these phenomena. After May, thunderstorms occurred less and less often, with 852 in June and 386 in July. The trend was also the same for the number of deaths when the full monsoon started to set in and the weather began to calm down. There were, however, a lot of thunderstorms that lasted into August and September (376 and 595, respectively). These storms may have been driven by localized convection and disturbances related to the monsoon. From October to December, the number of thunderstorms dropped a lot, and few people died on that time. This was because the weather was cooler and more steady.

The frequencies of thunderstorm, as shown in **Figure 8**, are quite high in few months, like April, May and June, when the fatalities rate was also high (**Figure 5**). There was a clear rise in the number of thunderstorms that happened starting in March (3.51%), then an enormous increase in April (20.93%), and finally a peak in May (26.02%), when more than a quarter of the year's thunderstorms happened. The peaks of this season occur at the same time as the pre-monsoon season in Bangladesh, which is known for its hot weather, strong convection, and plenty of rainfall. These are the conditions that are perfect to develop extremely severe thunderstorms. The frequency began to decline significantly after May, hitting 18.02% in June and 8.16% in July. This happened as the monsoon season started to show up and the weather started to become much more stable. Because thunderstorms were happening throughout the monsoon months, even if they were less violent

than they were before the monsoon, there was still moderate activity in August (7.95%) and September (12.57%). The winter months (November to February), on the other hand, featured very few thunderstorms, less than one percent, because the weather was dry and steady, which stops convection.

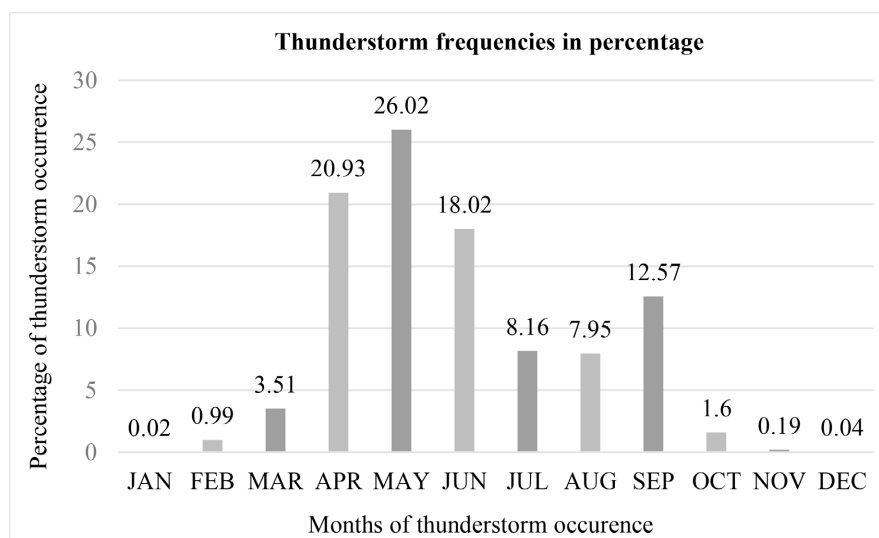


Figure 8. Monthly average thunderstorm frequency over Bangladesh.

4. Climatic Variability and Their Relationships with Thunderstorm

The relationship of thunderstorms causalities with climatic variables, including squall and gusty wind, cloud cover and temperature, was analyzed to see how these variables influence the thunderstorm frequency.

4.1. Wind and Thunderstorm

There were 16 people died (**Figure 5**) from thunderstorms across Bangladesh during the month of April in 2018. The lightning mainly struck on two days (11/04/2018 and 30/04/2018) at this month. **Table 2** shows all the important information of wind when lightning struck. Type of wind (squall or gusty), speed of the wind, wind direction and what time the lightning struck are the important

Table 2. Information about wind for March 2018 from six weather stations of Bangladesh.

Date	Station	Squall/Gusty	Wind Speed	Direction	Time (utc)
11-04-18	Sayedpur	Squall	30 kts/56 kph	N ^l y	0115 - 0117 utc
30-04-18	Rajshahi	Squall	30 kts/56 kph	NW ^l y	0200 - 0230 utc
30-04-18	PBO Dhaka	Gusty	29 kts/54 kph	NW ^l y	0540 utc
30-04-18	Khulna	Squall	26 kts/48 kph	NW ^l y	0500 - 0530 utc
30-04-18	Faridpur	Squall	25 kts/46 kph	NW ^l y	0430 - 0500 utc
30-04-18	Comilla	Squall	32 kts/59 kph	NW ^l y	0630 - 0700 utc

factors of wind to analyze its relationship with thunderstorms.

The wind on 11th April in 2018 was categorized as squall type of wind with a speed of 56 kph flowed from Northerly part of Bangladesh as recorded by Sayedpur weather station. The thunderstorm of that day caused one fatality in Netrokona named Masud Mia, was a farmer in occupation. On April 30th, highest wind speed was recorded simultaneously by weather stations of Comilla and Rajshahi. The wind speed on that day was 59 kph and both of the station classified the wind as a squall wind flowed from Northwesterly (NW^{ly}) direction. The PBO Dhaka station recorded multiple gusty wind with 54 kph wind speed having same wind directions on the same day. Though, the wind speed was lower for weather stations in Faridpur and Khulna, 46 kph and 48 kph respectively. The wind type was squall and direction was Northwesterly (NW^{ly}) direction recorded by both of the stations. On this day 15 people died from the thunderstorms in different places of the country.

Most of fatalities from thunderstorms during 2018 occurred in May throughout Bangladesh. Exactly, 78 people died (**Figure 5**) from the strikes of lightning in different days of this month. The wind properties mainly recorded in five different days of May, 03/05/2018, 09/05/2018, 11/05/2018, 15/05/2018, and 18/05/2018, as shown in **Table 3**. Most of the casualties were recorded on 9th May of 2018 in PBO Dhaka, Mymensingh, and Rangpur stations. MMO Chittagong weather station recorded two different days of wind properties data. In May, 33 people died in Sylhet, while 11 people died in the Mymensingh, both of the divisions are located in the northeastern part of the country. Thunderstorms killed a total of 34 people in other regions of Bangladesh. Most of the people who have died have been found in the Rangpur and Rajshahi divisions, which are in the northern and northwestern portions of the country.

Table 3. Wind direction and its intensity observations during May 2018 from eleven weather stations across Bangladesh.

Date	Station	Squall/Gusty	Wind Speed	Direction	Time (utc)
03-05-18	MMO Chittagong	Squall	25 kts/46 kph	NW ^{ly}	0830 - 0900 utc
03-05-18	MMO Chittagong	Squall	25 kts/46 kph	NW ^{ly}	2345 - 2350 utc
05-05-18	PBO Dhaka	Gusty	18 kts/33 kph	NE ^{ly}	0908 utc
08-05-18	Nikli	Squall	35 kts/65 kph	NW ^{ly}	0200 - 0230 utc
09-05-18	Rangpur	Squall	29 kts/54 kph	NW ^{ly}	0230 utc
09-05-18	Mymensingh	Squall	35 kts/65 kph	NW ^{ly}	0500 - 0530 utc
09-05-18	PBO Dhaka	Gusty	28 kts/52 kph	NE ^{ly}	0745 utc
11-05-18	Khulna	Squall	35 kts/65 kph	WNW ^{ly}	1110 - 1112 utc
11-05-18	MMO Chittagong	Gusty	46 kts/85 kph	NW/W ^{ly}	1244 utc
15-05-18	PBO Dhaka	Gusty	35 kts/65 kph	N ^{ly}	2140 utc
18-05-18	MMO Chittagong	Squall	32 kts/59 kph	NNW ^{ly}	0955 - 1007 utc

The properties winds that were recorded by the different weather stations of Bangladesh have a wide range of variations in different days, in different places even on the same day. There were two squalls on May 3rd, both coming from the northwestern direction and with winds of 46 kilometers per hour recorded by the MMO Chittagong stations in different times. The MMO Chittagong station observed these squalls happen in the morning and late at night. The PBO Dhaka station recorded that on May 5th, a strong wind of 33 kilometers per hour was coming from the northeastern direction of the country. On May 8th, only a few days later, a strong squall caught by Nikli station, coming from the northwest at a speed of 65 kilometers per hour. On May 9th, stations in Rangpur and Mymensingh both found squalls wind blowing from the northwest at speeds of 54 and 65 kilometers per hour, respectively. These two places were both in the state of Mymensingh. The PBO Dhaka also recorded that on the same day, there were strong winds from the northeast that reached speeds of 52 kilometers per hour. On May 11th, Khulna had a squall that came from the west-northwest and blew at 65 kilometers per hour. MMO Chittagong had an even stronger gusty wind that came from the northwestern to the western direction and blew at 85 kilometers per hour. Strong winds of different strengths hit each of these stations. Dhaka reported another strong wind from the north on May 15th at a speed of 65 kilometers per hour. On May 18th, Chittagong saw a strong wind coming from the north-northwestern direction with a speed of 59 kilometers per hour.

Table 4. Squally and gusty wind characteristics observation in June 2018 from two weather stations at Khepupara in Patuakhali and Dhaka district.

Date	Station	Squall/Gusty	Wind Speed	Direction	Time (utc)
09-06-18	Khepupara	Squall	25 kts/46kph	NW'ly	1420 - 1450 utc
10-06-18	PBO Dhaka	Gusty wind	20 kts/37 kph	SW'ly	1108 utc

In June 2018 only one day's wind information was available for only two weather stations (**Table 4**), Khepupara, and PBO Dhaka. During this month 10 people died from the lightning strikes as shown before in **Figure 5**. The First wind blow was recorded on 6th of June by Khepupara weather stations. The stations found a squall type of wind coming from northwesterly direction with a speed of 46 kilometers per hour. On June 10th, a gusty wind was recorded at a speed of 37 kilometers per hour and the wind direction was southwesterly part of Bangladesh. This caused a fatality of 10 people in different regions of Bangladesh including southern, southwesterly and southeasterly parts of this country, particularly in Barguna, Patuakhali, and Satkhira districts. When gusty and squall wind goes toward the southern and southeastern part of Bangladesh its losses speed, so that the casualties are seen limited in this area.

4.2. Temperature and Thunderstorms

The occurrence of thunderstorms is dramatically related to the air temperature of

thunderstorm occurrence day, two days before of thunderstorm occurrence, one day before of thunderstorm occurrence and day after the thunderstorm occurrence. The relationship between temperature and thunderstorms for several months of 2018 are shown in **Table 5** since within these months most of the fatalities occurred from the lightning strikes.

Table 5. Information about temperature varieties associated with lightning occurrence during April, May, June, July and September 2018 from twenty-three weather stations of Bangladesh.

Station Name	Date (2 Days before) Temperature (°C)	Date (1 day before) Temperature (°C)	Date of Lightning Occurrences Temperature (°C)	Date (1 Day after) Temperature (°C)
Chuadanga	28-April	29-April	30-Aprill	01-May
	28.3	25.8	23.2	26.5
Comilla	28-April	29-April	30-Aprill	01-May
	28.4	22.7	22.5	25.8
Srimangal	28-April	29-April	30-Aprill	01-May
	27.4	21.4	20.6	24.7
Rajshahi	28-April	29-April	30-Aprill	01-May
	28.2	24.9	22.8	26.5
Tangail	01-May	02-May	03-May	04-May
	26.1	22.4	26.5	24.7
Faridpur	03-May	04-May	05-May	06-May
	26.7	26.3	26.9	29.4
Mymensingh	05-May	06-May	07-May	08-May
	25.4	27.6	24.4	24.8
Sylhet	06-May	07-May	08-May	09-May
	25.1	24.3	24.2	22.9
Srimangal	07-May	08-May	09-May	10-May
	24.5	24.1	24	22
Dhaka	07-May	08-May	09-May	10-May
	27.2	29.6	27.8	24.4
Rajshahi	07-May	08-May	09-May	10-May
	30.1	30.2	29.1	27.7
Sylhet	07-May	08-May	09-May	10-May
	24.3	24.2	22.9	21.9
Feni	09-May	10-May	11-May	12-May
	26.2	24.7	24.1	27.2

Continued

Mymensingh	09-May	10-May	11-May	12-May
	24	23.8	24.9	26.7
Rajshahi	13-May	14-May	15-May	16-May
	26.2	26.9	26.9	24.4
Satkhira	16-May	17-May	18-May	19-May
	24.7	28.9	26.5	30.1
Tangail	22-May	23-May	24-May	25-May
	27.3	26.9	28.8	29.2
Sylhet	24-May	25-May	26-May	27-May
	25.2	24.5	26.6	29
Patuakhali	07-June	08-June	09-June	10-June
	30.9	30.5	28.9	27.4
Rangpur	05-June	06-June	07-June	08-June
	30.9	29.7	28.4	29
Satkhira	23-June	24-June	25-June	26-June
	29	29	26.7	28.1
Chuadanga	22-July	23-July	24-July	25-July
	27.5	27.2	26.9	27.5
Faridpur	10-September	11-September	12-September	13-September
	29.3	27.7	29	28

Most of the weather stations, such as Rajshahi, Faridpur, Tangail, and Patuakhali, recorded a gradual increase in temperature two days before the thunderstorm and till the day before the event. In tropical regions, warming happens before a rainstorm because the sunlight heats the land a lot throughout the day. As the air at the surface heats up and rises, the moisture that comes from nearby bodies of water, such rivers within the country and the Bay of Bengal, makes the atmosphere less stable. When humidity and heat come together in the right manner, they provide the best conditions for growing cumulus clouds, causing thunderstorms. So, the rise of temperature before the storm may be interpreted as a sign that convective activity was about to start. The temperature during the thunderstorm occurrence day, temperature dropped suddenly as recorded by different weather stations across Bangladesh. For instance, the temperature in Chuadanga dropped from 26.5 degrees Celsius the day before to 23.2 degrees Celsius during the lightning day. Stations in Srimangal and Sylhet also observed the same fluctuations. This drop in temperature is caused by the downdrafts and rain that come with thunderstorms. When raindrops fall over layers of dry air, some of the water evaporates, which cools the surface. During the thunderstorm, cold

air from higher altitudes moves down to the surface, displacing the warm air that is already there. This makes the temperature drop even further. So, the thunderstorm works as a way to cool things down, making the weather cools from the hot and humid weather that was there before the thunderstorms. After the thunderstorm, the temperature pattern of the next at different stations is quite different from each other. The temperature in the next day of thunderstorm occurrence rises again in several places, including Dhaka, Rajshahi, and Faridpur. This demonstrated that the temperature rises again quickly once the storm has gone and the sky has cleared. After a storm, the sun warms up the surface again, which makes the temperature and humidity go up for a short time. On the other hand, the temperature stays rather low in certain places, including Sylhet and Tangail, even after the storm. This is most likely because of clouds that stay in the sky or the rain that keeps falling make it hard for the ground to warm up quickly.

There are also significant differences in how the temperature fluctuates from one region to another. Northeastern areas like Rajshahi and Chuadanga tend to experience higher temperature variations because they are located far away from the coast and have a more continental climate. On the contrary, places in the north-east of the country, including Sylhet and Srimangal, did not experience as many temperature variations because of more rain and humidity, which helps keep the temperature fairly stable in such places. Also, the temperature in regions adjacent to the Bay of Bengal like Satkhira and Patuakhali see modest changes in temperature because the Bay keeps the temperature from changing too much by acting as a moderating force.

4.3. Cloud Cover and Thunderstorm

The correlation between cloud cover and thunderstorms in Bangladesh reveals a complicated interaction, wherein increased cloud coverage, particularly certain cloud types and their attributes, frequently connects with the frequency and severity of thunderstorms [29] [30].

Table 6 demonstrates the cloud information during March of 2018 in Bangladesh. On March 31st, the Ishurdi weather station in the Pabna district measured the average amount of clouds was six octas, which means that clouds covered about three-quarters of the sky on that day based on the weather at the time. This indicated that the sky was quite cloudy, which is an indication that the atmosphere is moist and unstable. A thick layer of clouds is a solid indication that there will be convective activity in the area, which is important when considering thunderstorms. When the sky is mostly overcast (usually between 5 and 8 octa), it usually means that there are cumulonimbus clouds or thick convective clouds, which are closely related to thunderstorms, heavy rain, lightning, and strong winds. The fact that there was a lot of cloud cover in Ishurdi that day suggests that the area probably had conditions that were good for thunderstorms to form.

Table 6. Average cloud cover (in octa) on the dates of thunderstorm occurrences in March 2018.

Date	Average Amount of Cloud (octa)	Station	District
31-03-2018	6	Ishurdi	Pabna

Table 7 showed the average cloud cover for April 2018 from many meteorological stations in various regions of Bangladesh. The octa number from three to seven indicates certain regions are cloudier than others. Dhaka (Narayanganj), Ishurdi (Rajshahi), Mymensingh (Jamalpur), Chuadanga, and Sylhet (Sunamganj) were among of the stations that recorded fairly high cloud cover (6 - 7 octa). This means that most of the sky was clouded on those particular days. On the contrary, Mymensingh (Netrakona) had 3 octas of clouds, which means that the sky was either partly cloudy or mostly clear.

Table 7. Average cloud cover (in octa) on the dates of thunderstorm occurrences in April 2018.

Date	Average Amount of Cloud (octa)	Station	District
30-Apr	6	Chuadanga	Chuadanga
30-Apr	5	Comilla	Comilla
30-Apr	5	Srimangal	Habiganj
30-Apr	6	Mymensingh	Jamalpur
30-Apr	5	Srimangal	Maulvibazar
30-Apr	7	Dhaka	Dhaka
11-Apr	3	Mymensingh	Netrakona
30-Apr	6	Rajshahi	Rajshahi
30-Apr	6	Sylhet	Sunamganj

The different amounts of cloud cover in Bangladesh in April are due to the different weather conditions in different parts of the country. The monsoon season starts in the month of April, which is known for thunderstorms that often happen in this month. There is a lot of convective activity in the central, western, and northeastern parts of the country, causing frequent thunderstorms on those regions. This is shown by the fact that there are more clouds, which vary from five to seven Octobers. Cumulonimbus clouds, which cause lightning, heavy rain, and strong winds, are commonly seen in the thick cloud layers that are prevalent around this time. So, the information that was illustrated in **Table 7** exposed that areas like Dhaka, Rajshahi, Chuadanga, and Sylhet were under conditions that were suitable for thunderstorms to occur. Conversely, areas with less cloud cover, like Netrakona, may have seen fewer or less intense thunderstorms over the same timeframe.

The octa values range from three to eight, indicating the cloudiness varied from

moderate to very high in the different locations of Bangladesh in May 2018 (**Table 8**). There were a lot of thunderstorms in the country at this period, and many people died as a result. Notably, some stations, including those in Sylhet (Sunamganj and Sylhet), Mymensingh (Netrakona, Sherpur), and Srimangal (Habiganj, Maulvibazar), reported 7 to 8 octa cloud, which suggest that the sky was very gloomy or overcast at that time. These areas are known for having strong convection before the monsoon and storms happened.

Table 8. Average cloud cover (in octa) on the dates of thunderstorm occurrences in May 2018.

Date	Average Amount of Cloud (octa)	Station	District
2-May	7	Sylhet	Sunamganj
3-May	3	Chandpur	Lakshmipur
3-May	4	Tangail	Tangail
4-May	6	Mymensingh	Jalpur
4-May	6	Srimangal	Maulvibazar
4-May	8	Sylhet	Sunamganj
5-May	6	Faridpur	Faridpur
5-May	5	Jessore	Jhenaidah
5-May	8	Sylhet	Sunamganj
7-May	8	Srimangal	Maulvibazar
7-May	8	Srimangal	Habiganj
7-May	8	Mymensingh	Mymensingh
7-May	8	Mymensingh	Sherpur
7-May	8	Sylhet	Sunamganj
8-May	8	Mymensingh	Netrakona
8-May	8	Sylhet	Sunamganj
9-May	6	Srimangal	Habiganj
9-May	7	Mymensingh	Jalpur
9-May	7	Dhaka	Manikganj
9-May	7	Sylhet	Sylhet
9-May	7	Dhaka	Narsingdi
9-May	5	Rajshahi	Rajshahi
9-May	7	Sylhet	Sunamganj
11-May	6	Feni	Feni
11-May	5	Srimangal	Habiganj
11-May	6	Rangpur	Kurigram
11-May	4	Chuadanga	Meherpur

Continued

11-May	5	Rajshahi	Naogaon
11-May	6	Mymensingh	Netrakona
15-May	7	Mymensingh	Netrakona
15-May	3	Rajshahi	Rajshahi
18-May	5	Jessore	Narail
18-May	7	Satkhira	Satkhira
24-May	8	Sylhet	Sunamganj
24-May	7	Tangail	Tangail
26-May	8	Sylhet	Sylhet
26-May	6	Syedpur/Saidpur	Thakurgaon

The high cloud cover values that are seen in the northeastern and central parts of Bangladesh during the month of May are a result of the strong convective activity that happens during the pre-monsoon season. This is when moisture-laden air from the Bay of Bengal meets rising warm air over land. During this month the cumulonimbus clouds, which cause heavy thunderstorms, lightning, and squalls wind, often form. For example, the Sylhet and Mymensingh districts, which regularly had cloud covers that reached 8 octa, are the places in the country where thunderstorms are most common. This is why a lot of fatalities from thunderstorms occurred at this month. On the other hand, other places, including Rajshahi and Chandpur, saw less clouds (3 to 5 octa), which means that clouds aren't growing as much and storms aren't as strong as they are in the north and northeast. Accordingly, there is a strong link between dense cloud cover and thunderstorms. It is quite likely that the places that experienced a lot of severe thunderstorms were the same places that had a lot of thick clouds between seven and eight octa.

5. Discussion

The primary aim of this research was to identify casualties resulting from thunderstorms in Bangladesh from March to September 2018, and to examine the associated meteorological conditions. The results show that the Sylhet Division in the northeastern regions of the country had the number of deaths from thunderstorms. This could be because of the area's high rate of orographic precipitation (when moisture content air encounters an elevated terrain along its path) or the fact that there is local convective activity. This region is surrounded by hilly terrains, including Meghalaya in India, which enhances orographic uplift and results in an increased incidence of thunderstorms.

The most deaths from thunderstorms were reported in May, which was the month before the monsoon season. Most of the people who died were farmers and day laborers who were working outside during the morning, noon, and afternoon hours, when convective activity is at its peak. Farmers, fishermen and outdoor workers

are particularly vulnerable because they spend extended durations working outdoors and often lack access to safe shelters during sudden storm events. The absence of early warnings in rural regions and owing to their unstable socio-economic status, they continue in their daily work despite hazardous weather conditions, further increasing their risk of lightning-related fatalities. A study of [31] also observed that the Sylhet Division frequently exhibits a high incidence of thunderstorm-related fatalities.

Thunderstorms are closely related to a number of weather conditions, such as strong and squally winds, temperature, and cloud cover. The results of [32] and [33] support the observation that gusty and squally winds from the northwest were particularly common on days characterized by thunderstorms. [34] found that the temperature climbed in the days before thunderstorms, which made the atmosphere even more unstable and led to the formation of convective clouds. There is a strong link between thunderstorms and cloud cover, which usually ranged from six to eight oktas. This relationship showed that there were conditions that led to a lot of convective or orographic cloud formation.

However, much of the information about casualties came from secondary sources, such as newspapers, which may not be able to give a full picture of what happened, especially in rural areas. The investigation was limited to a single year (2018), complicating the assessment of patterns over an extended timeframe. Moreover, the results of this study have tangible implications for organizations tasked with disaster management and meteorological forecasting. Bangladesh Meteorological Department (BMD) are not able to provide every fatality area climatic database due to lack of functional or active weather stations in 2018. The frequency's database was provided monthly total, if the database found date wise and hourly data it would be more helpful to correlate with casualties database.

A better understanding of the spatiotemporal patterns and climatic drivers of thunderstorms can help the Bangladesh Meteorological Department (BMD) build early warning systems, especially for rural areas, Haor, and other places that are likely to be affected by thunderstorms. By raising community knowledge and building localized shelter infrastructure near agricultural areas, it is possible to greatly lower the number of future deaths.

6. Conclusions

This study examined the geographical and temporal distribution of thunderstorms and their associated deaths in Bangladesh from March to September 2018, utilizing geospatial techniques and meteorological data. The data shows that thunderstorms happen a lot in Bangladesh, and they may be deadly. This is particularly true in April and May, which are the months before the monsoon season starts. The Sylhet Division in the northeastern part of the country was found to be the most vulnerable because of its geography, unstable convection, and moisture coming in from the Bay of Bengal. It had the highest fatalities. This was largely because it was the place where the most people died. There was a strong link between the quantity

of thunderstorms and a variety of weather conditions, such as squalls and gusty winds, changes in temperature, and cloud cover. Before the storm started, the temperature rose, and then it dropped dramatically throughout the storm. Thick clouds and squall winds from the northwest also formed. Most of the deaths occurred around noon, which was when people were most active outdoors and the weather was most hazardous. This was particularly true for those who work in open spaces, such as those in farming and fishing. Specifically, the study shows the usefulness of geospatial analysis in gaining knowledge of thunderstorm patterns and pinpointing locations that are at a high risk. The Bangladesh Meteorological Department (BMD) and other disaster management groups might use this information to improve their early warning systems, initiatives to get people involved in their communities, and efforts to raise public awareness. Thunderstorm-related fatalities during the pre-monsoon period, especially between 12:00 and 14:00, focused early warning communications directed at agricultural communities could significantly decrease mortality rates. Divisions like Sylhet in high-risk regions must be emphasized to improve the effectiveness of the national warning system.

In the future, localized shelters, real-time lightning detection, and the use of Geographic Information Systems (GISs) to combine weather forecasts with vulnerability mapping could greatly cut down on the number of deaths and property damage.

Conflicts of Interest

The authors declare no conflicts of interest.

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