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Lightning in Northeast Bangladesh: Relation with climatic variables, consequences and adaptation

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Abstract

In Bangladesh, the lightning during a thunderstorm has recently been officially declared as natural disaster, resulting in numerous fatalities each year, especially in the country's northeast. This study aims to look into the relationships between lightning and climatic variables, the spatial distribution of deaths, people's perceptions of the disaster's consequences and adaptation measures, and the influencing factors that make people victims in Sunamganj District. Several statistical approaches, such as descriptive statistics, correlation, and the Mann-Kendall Test, were used to meet the study objectives by examining time series data of climatic variables, lightning events, and household survey data. The data imply that lightning strikes have a positive and statistically significant relationship with climatic variables such as temperature, rainfall, humidity, and air pressure. Moreover, that lightning strikes may become more common in the future as climatic variables increase. The perceived consequences of lightning strikes include disruption of human life, injury, damage and or burning of environmental and infrastructural elements, etc. Going outside during a thunderstorm and/or remaining outside during a thunderstorm are the primary factors contributing to a tragic accident. Those who were engaged in income-generating activities during the monsoon, like agricultural operations such as Boro Rice farming and fishing, were the most vulnerable to this hazard. Therefore, several adaptation strategies, including house safety and facilitating emergency shelter; assisting victim families for recovery and rehabilitation; travelling in covered vehicles during a thunderstorm; and disseminating knowledge about proper lightning safety measures, outside movement during a thunderstorm, and first aid information for initial treatment through awareness building campaign should be implemented to reduce the number of casualties.

1. INTRODUCTION

Lightning refers to the incidence of high voltage natural electric discharge within a cloud and the earth's surface or within a cloud with a bright flash and typically also thunder that lasts for a short period. It can cause a fatality or injury to humans through direct or indirect strikes. Casualties of the lightning incident are considered a global problem these days, depicting one of the vital causes of weather-originated death: tornadoes, flash floods, typhoons, and aridity (Koutroulis *et al.,* 2012). In addition, developing or underdeveloped countries in the tropical and subtropical zones are often encountered by lightning (Ali, 1999).

Unlike other natural hazards in Bangladesh, lightning is not counted as a prioritized disaster, even when it invokes deaths and damage of assets (Dlamini, 2009). The majority of the population relies on agriculture ever since (Holle, 2016), staying without anti-lightning houses and working in unprotected structures (Holle, 2009). Although lightning is not well documented like other calamities in Bangladesh, an estimate (analyzing information from 1990 to 2016) suggests that around 114 fatalities and 89 injuries occur every year on an average basis (Dewan *et al.,* 2017). Karim (1995) estimated the fatality rate and found that lightning causes 0.9 deaths per million people per year, while a recent estimation by Biswas et al. (2016) found that about 3.7 fatal accidents per million per year occur in Bangladesh. According to the United States National Lightning Safety Institute (USNLSI), 25% of universal lightning mortality occurs in Bangladesh each year (Farukh *et al.,* 2017). Victims are generally from rural areas who work in open fields as most of them are peasants (Gomes et al. 2011). Another examination showed that lightning impacts over 25% of the volume of power-related fatalities in Bangladesh (Mashreky *et al.,* 2012). In the 12th and 13th of May 2016, the nation experienced 89 deadly lightning originated deaths, and in May 2017, 59 people were deceased. As the death rate is expanding, the Cabinet of Bangladesh formally announced lightning as a natural disaster (Dewan *et al.,* 2017).

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Lightning is legitimately engaged with ongoing global environmental change. Researchers express that increasingly mild conditions associated with environmental change may cause higher water dissipation from the land and sea. In this way, it generates vapors and precipitation and the potential for a thunderstorm (Bandara, 2004). Usually, April, May, and June are the warmest months in Bangladesh. Humidity immediately increases upward to get together with dry northwesterly breezes to cool and create huge tempest storm clouds (Bandara, 2004). In Bangladesh, lightning happens mainly in long wet stretches of summer and monsoon, which generally endure from March to October-November. Different variables, such as blending of temperature, the abundance of mugginess, and the grating of cold and warm air, significantly impact creating a thunderstorm. Investigation of lightning movement has gained reestablished enthusiasm following raising interest that an uncertain atmosphere, generated by global warming, may prompt more further convection and storms, and hence more lightning (Ushio *et al.,* 2015). Modest variations in normal heat can hit in improved lightning impact (Price and Rind 1994; Williams 2005; Futyan and Del Genio 2007), as the air's affectability to temperature varieties (Williams, 1992; Williams, 2005; Reeve and Toumi, 1999). Celsius increments per degree in global average temperature; for example, lightning would reach out from 5 to past 100% for every degree. (Cost and Rind 1994; Kandalgaonkar *et al.,* 2005; Futyan and Del Genio 2007; Romps *et al.,* 2014). In this way, it is expected to examine the relations of climatic factors with lightning occasions just as the pattern of climatic factors to comprehend the future course of this hazard.

Lightning disaster is not very well explored in Bangladesh as this phenomenon has not got enough concentration in the academic arena. Very few previous studies were found, which are mainly documented the number and nature of fatalities and injuries (e.g., Karim 1995; Gomes *et al.,* 2006; Ono and Schmidlin 2011), characteristics of victims and occurrences as well as the spatial distribution of the events based on the information extracted from newspapers and survey (e.g., Uddin and Suravi 2019; Biswas *et al.,* 2016). However, there is a lack of studies analyzing the relations between local climatic variables and lightning events with a quantitative approach. Furthermore, people's perception in lightning prone areas regarding the consequences of lightning, factors of fatalities, and potential adaptation strategies were not investigated. Moreover, almost all of the previous studies focused on nationwide events. It is essential to study the regional stage's lightning disaster as the characteristics of disaster vary with geographic locations, and insights from one region will enable the policymakers to deal with the disaster in more sophisticated ways, appropriate for that specific region. Moreover, knowing regional observations provides more useful insights and data referring to a policy that addresses the challenge of disaster control in that region (Simane *et al.,* 2016). In this circumstance, this study intends to fill this research gap by investigating the relations between climatic variables and lightning events, lightning frequency and fatalities of previous years, the nature of the consequences, factors of fatalities as well as the adaptation strategies in Sunamganj District—one of the highly lightning-affected regions in the country (Uddin and Suravi 2019; Dewan *et al.,* 2017).

1.1. The Study Area

The study was carried out in the Sunamganj District of Sylhet Division within the northeast Bangladesh. Sunamganj District covers an area of 3,747.18 sq. Km with a population of 2,467,968, according to the 2011 Population Census. The district's climate is dominated by rainfall as it receives 3,334 mm of rain annually, while the temperature extends from 13.6°C to 33.2°C with an average humidity of 78% to 90%. Most of the district is flood-ridden and well known as a lightning prone area because of the number of lightning strikes during pre-monsoon and monsoon. Moist air originated from the sea flowing from the southwest direction carrying a vast amount of moisture and locally formed clouds, and water vapour cannot cross the hills; eventually, the rising air pushes up the hills and then forms orographic thunderstorms. This phenomenon becomes frequent in summer and monsoon when the surface becomes heated. The weather condition of Sunamganj plays a vital role in this case. There is a high temperature during the day that creates a lot of water vapour in the atmosphere, creating thunderclouds. That means the density of the storm increases, and at the end of the day, it leads to lightning. Figure 1 shows a map of the Sunamganj District.

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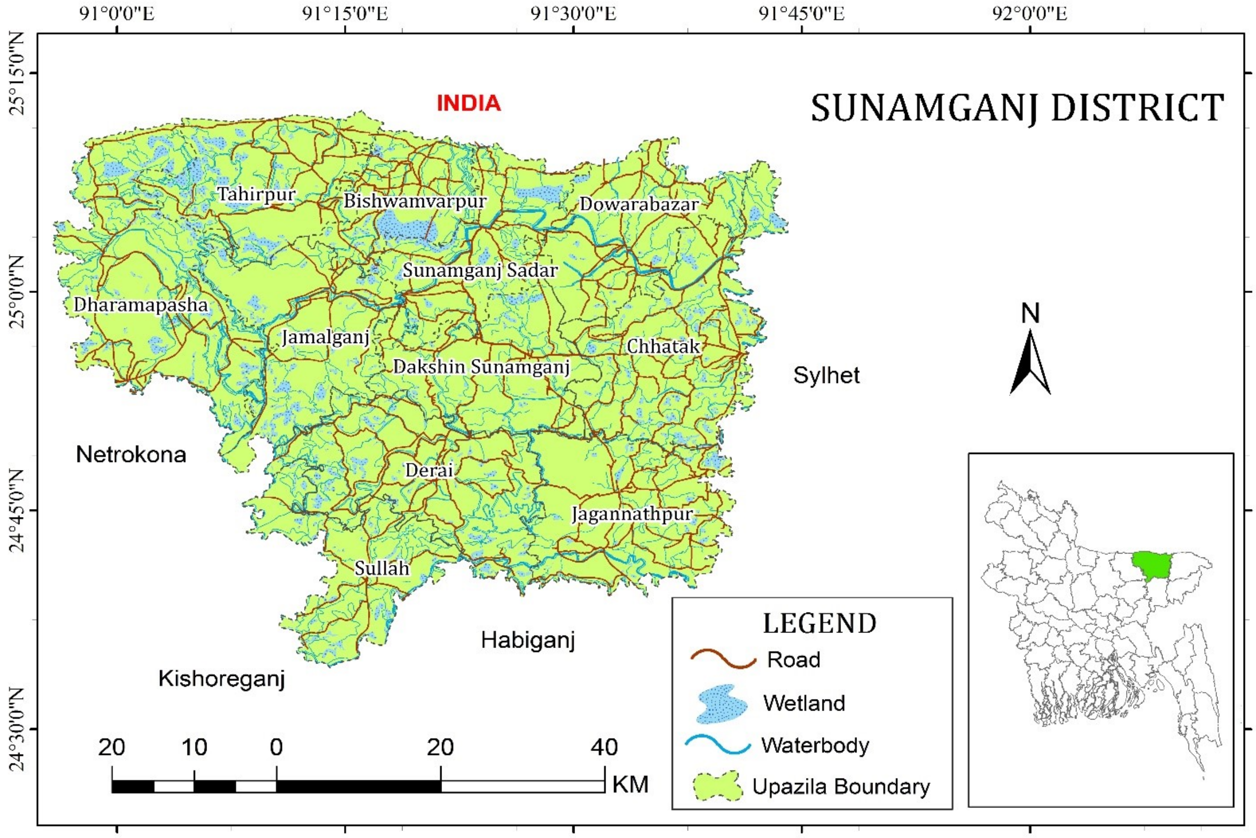

Figure 1: Location of Sunamganj District

2. MATERIALS AND METHODS

2.1 Data

The survey was conducted based on both primary and secondary data. The secondary data includes daily time-series data of different climatic variables, i.e., rainfall, temperature, humidity, air pressure, and lightning event records collected from the Meteorological Department, Bangladesh (BMD). Most of the collected time series data cover the years from 1959 to 2018, except for the monthly time series data of lightning events that include the occurrences from 2012 to 2018. Before 2012, BMD did not keep any record of the lightning event. Since there is no weather station at Sunamganj, climatic and lightning data were collected from Sylhet's nearest station. Moreover, the number of fatalities by a lightning strike was collected from the Office of the District Relief and Rehabilitation Officer, Sunamganj. On the other hand, a household-level survey was conducted to collect primary data, especially people's perception about lightning, consequences, and area of impacts, influencing factors of casualties, options for adaptation, etc., from lightning affected areas of the district.

2.2. Sample Size Estimation

The unit of observation of household-level survey was mainly farmers who live in lightning prone areas. However, the sample size was estimated according to the following equation (Yamane, 1967):

$$n = \frac{N}{1 + Ne^2}$$

Here,
n = Sample size

N = Population (total number of population) = 2,467,968

e = Level of precision (5%) = 0.05

The above formula yields that the sample size stands 399. That means at least 399 households have to cover for the study. However, this study covered 400 households in total. A comprehensive questionnaire was developed and circulated to the participants considering equal men-women ratio to get their perspectives. It had multiple dimensions based on their perceptions of lightning, underpinning driving factors, consequences, and impact and adaptation strategies. Prior to participating in the survey, every respondent was asked to give their consent, and they had the option to opt out at any moment. Moreover, participation in this survey was completely voluntary.

2.3. Analytical Techniques

Various statistical tools and methods had been used to analyze the data. Non-parametric Mann-Kendall

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(MK) test had been used to identify the trend in time series data of climatic variables. The MK Test is a distribution-free test with no need to assume the time series data as a normal distribution. This test was formed by Mann (1945), and the test statistic pattern was provided by Kendall (1975). This method was suggested by frequent use by the World Meteorological Organization (Mitchell et al. 1966). The slope of the trend was calculated by the Sen's Slope Estimator (Sen 1968). The positive estimation of the slope shows an upward, or developing pattern and a negative estimation of the slope indicates a downward or declining pattern in the timeline. Both methods have been executed using MAKESENS_1_0 Excel Macro and R Studio, respectively. Moreover, Pearson's Coefficient of Correlation was used to determine the correlation between time series variables of climatic elements as well as a lightning phenomenon. The *P* value was calculated to measure the significance of the correlation, and the coefficient of determination (r^2) was calculated to decide the dependency rate of dependent variables on independent variables.

3. RESULT AND DISCUSSION

3.1 Relations between Climatic Variables and Lightning Events

The occurrence of lightning events depends on several climatic variables, such as temperature, humidity, air pressure, rainfall, are the determiners for lightning. Pearson's Correlation Coefficient had been measured to learn the presence of any relationship or association of lightning events with local climatic variables of the study area, including temperature, rainfall, humidity, and air pressure. Table 1 shows the summary findings of correlation coefficient (r), coefficient of determination (r^2), and *P* values. According to the values of r, the occurrence of lightning had a strong positive relationship with all of the four climatic variables. Moreover, as per *P* values, all of the correlations were statistically significant as the values were less than α (=.05). This finding, especially in the case of the relation of lightning with rainfall, were validated by previous findings as Koutroulis et al. (2012) reported, there was a strong correlation between accumulated rainfall and lightning activity. The coefficient of determination expressed the portion or percentage of dependent variables that the independent variables explained if other influencing factors remained constant. The findings (r^2 in %) in Table 1 reveal that about 76% of lightning events can be explained by air pressure if other influencing variables remain constant. In case of other climatic variables, the dependency percentages of lightning events were 73%, 75%, and 53% for temperature, rainfall, and humidity, respectively. Since the monthly readings of climatic variables were significantly and strongly associated with lightning events, it could be concluded that the occurrence of lightning events varies with seasonal climatic conditions.

Table 1: Correlation statistics between climatic variables and lightning events

Independent Variable	Dependent Variable	r	*P* Value	r^2	r^2 in %
Mean Monthly Temperature	Monthly Lightning Events	0.84	<.01	0.73	73
Mean Monthly Rainfall		0.87	<.01	0.75	75
Mean Monthly Humidity		0.73	<.01	0.53	53
Mean Monthly Air pressure		0.88	<.01	0.77	76

*Significance level: $p < .05$

3.2 Trend in Climatic Variables

A trend usually represents the general tendency or the course of any time series data over the periods. In this study, the trend of several climatic variables, including temperature, rainfall, humidity, and air pressure, had been investigated. The main reason behind selecting these four climatic variables was that they were directly related to the occurrence of lightning phenomena from the perspective of the climatic system's mechanism. The correlation coefficients between climatic variables and lightning frequency suggested a significant association (Table 1). Therefore, the trend analysis of climatic variables helped understand the future intensity of lightning. Table 2 shows the summary findings of trend analysis. According to the findings, a statistically significant trend exists in mean annual temperature and mean annual air pressure ($P<.05$).

On the other hand, as per the *P* values, the mean total annual rainfall and mean annual humidity did show an upward trend, although they were not statistically significant ($P>.05$). The Sen's slope suggests that the trend line of mean annual temperature and mean annual air pressure headed upward as their slope value was positive. The slope value denotes the average fluctuation rate of the variables by changing per unit time, i.e., year. The average fluctuation rate of annual mean temperature and annual mean air pressure was 0.02°C and 0.01 millibar per year, respectively, with an upward direction. Although the mean annual total rainfall and annual mean humidity did not show a significant trend, Sen's slope suggests a positive fluctuating rate of 0.37 mm and 0.01% per year. Drier weather leads to more lightning cases, as humid convection is considered a warmer climate (Hartmann, 2002). The rise of Global warming due to anthropogenic activities may intensify the prospect of lightning activity in Bangladesh and combining at the level of other natural disasters, e.g., flood. In short, the positive slope of climatic variables, which were significantly associated with the lightning occurrence, suggests the possible increment of frequency and intensity of the lightning event in the coming days. The

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people of the study area's perception also supported these findings, as almost 95% of respondents argued that the intensity of lightning is increasing with time. Moreover, they also sensed the impact of climatic change on thunderstorm and lightning as most of the respondents, almost three-fourth of them, have identified the climatic change as the responsible factor for the increasing intensity of lightning.

Table 2: Trend statistics of climatic variables

Variables	Z Value	*P* Value	Sen's Slope	Significance
Mean Annual Temperature	4.97	<.01	0.02	Yes
Mean Total Annual Rainfall	0.82	.47	0.37	No
Mean Annual Humidity	0.80	.42	0.01	No
Mean Annual Air Pressure	2.18	.02	0.01	Yes

*Significance level: p < .05

3.3 People's Perception about Consequences and Factors of Fatalities

Lightning has adverse impacts on human life, natural elements, and physical infrastructures. This section intends to present the nature of impacts, potential receptors of adverse consequences, factors influencing the fatal incidents, etc., according to the household level survey findings. Most of the respondents reported that lightning events cause delays in their daily works that reduce their economic potentiality and productivity as the respondents are mainly farmers. About one-third of respondents stated that they experience life risk due to lightning while staying outside of their home or any safe shelter. On the other hand, a small portion of respondents – almost 15 percent – reported that they feel mental stress and fear during the thunderstorm that they could be affected by lightning at any time. In short, the people of the lightning prone area in Bangladesh experience a range of consequences, including economic loss, fatalities, and psychological trauma. Lightning not only affects humans but also affects the natural environment as well as infrastructure. According to the study's findings, most of the respondents (almost two-fifth portion) stated that humans are the main receptor of lightning-oriented adversities and difficulties.

On the other hand, about 37 and 20 percent of respondents identified natural environmental elements and infrastructure as the most likely receptor or lightning exposure, respectively. Natural environmental elements include crops, trees, shrubs, animals, etc. that can be burned, torn or injured by lightning strikes. Infrastructure includes mud-built houses, thatch-built houses, polymer, and wood built light vehicles that can be burned and damaged due to lightning events. According to the respondents, the most likely types or consequences of impacts of lightning on humans include disruption of human life, injury, burning, and damage of body organ, i.e., hearing loss (Table 3). Among these consequences, physical injury has been reported as the most likely outcome of a lightning strike by the maximum portion of respondents, followed by burning body skin or other organs. On the other hand, almost the same number of respondents identified the disruption of human life and damage of body organs, i.e., hearing loss as the most likely consequence of the impact of lightning on humans.

This study also intends to present the factors that influenced the people going and outside of their home or shelter during heavy rain and thunderstorm, which caused most of the lightning-oriented fatalities in the study area. The findings show that almost 70% of people who got a strike and were killed by lightning were outside their house or other shelters due to agricultural works (Table 3). Usually, they worked on the agricultural field before the storm and showed an unwillingness to leave the open field immediately after starting the storm. Besides, there are not adequate shelters adjacent to the agricultural field, i.e., a large canopy of trees, roof, etc., for taking refuge during the storm. Nearly 30% of victims were outside of their house to do daily household work and other occupational activities.

On the other hand, about 5% of victims were engaged in other activities like walking, bathing, travelling, etc. The findings suggest that most of the victims were engaged with any sort of income-generating activities during getting hit by lightning, which made them unwilling and delayed their decision to leave the workplace to take protection. This study also investigated the types of agricultural works they were engaged in during accidents. The maximum portion of victims was engaged with Boro Rice cultivation and harvesting activities when they got struck by lightning. In northeast Bangladesh, the period of Boro Rice cultivation is in-between the month of April and June, which explains the high number of fatalities due to lightning during this period. Around one-fifth portion of farmers got killed when they were engaged in fishing. In *haor*[1] areas of Sunamganj, many people get engaged in fishing during the monsoon season from June to October. Since Boro Rice cultivation and fishing mostly take place throughout the period from pre-monsoon to late-monsoon, these two activities experienced the highest number of lightning oriented casualties as the highest number of casualties also takes place during monsoon and late-monsoon period, reported in Figure 2.

[1] A *haor* is a wetland environment in Bangladesh's north-east that is literally a shallow depression in the shape of a bowl or saucer, also known as a backswamp.

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Table 3: People's perception regarding lightning events and factors of fatalities

Variables	%	Variables	%
Adverse consequences of lightning		Exposures of adverse consequences	
Life risk	34.91	Human	41.99
Delay in daily work	51.18	Environment	20.73
Fear	13.91	Infrastructure	37.27
Nature of the impacts on human		Factors influencing the occurrence of fatality	
Disrupt human life	22.31	Agricultural works	67.80
Injury	28.35	Daily works	12.84
Burn	24.15	To earn money	14.53
Damage of body organ	22.05	Others	4.83
Others	3.15		
Type of agricultural engagement during lightning			
Boro Rice Production	67.25		
Fishing	21.50		
Vegetable	4.25		
Others	7.0		

3.4 Frequency of Lightning and Fatalities

The correlation analysis findings in Table 1 of section 3.1 revealed that lightning events vary with month-wise climatic conditions. The frequency of lightning and lightning oriented fatalities is also showing similar results. Figure 2 shows that there is almost no record of lightning and casualty in the winter season. Almost all of the lightning events and casualties took place throughout the monsoon, including pre-monsoon and post-monsoon, in-between the months of March to October. The highest number of lightning events has occurred in August, followed by September and June.

On the other hand, the highest number of fatalities occurred in the month of May, followed by April and June. The findings suggest that the post-monsoon period is most prone to experience lightning, whereas the pre-monsoon season is most prone to cause lightning oriented fatalities. Boro rice farming is the primary source of income in the northeastern region. The harvesting season for Boro begins in April and lasts until June. Comparatively less lightning events cause a higher death rate in this season. Farmers stay outside of their homes during this time and work in open fields, which could be a significant cause of casualties. Though the number of lightning events increases after the harvest season, the number of casualty decreases, indicating that the agricultural pattern of this area is a primary cause of lightning fatalities. Figure 3 shows the geographical distribution (Upazila wise) of the number of fatalities in the study area. Among 11 Upazilas of Sunamganj District, Derai—a southern Upazila of the district, has experienced the highest number of casualties, followed by Tahirpur—a northwestern Upazila. Overall, the northwest-west-southwest-southern belt of the district accounts for the maximum number of fatalities caused by lightning struck. On the other hand, the mid-portion and the eastern belt of the district show the least number of fatalities compared to the portions mentioned above

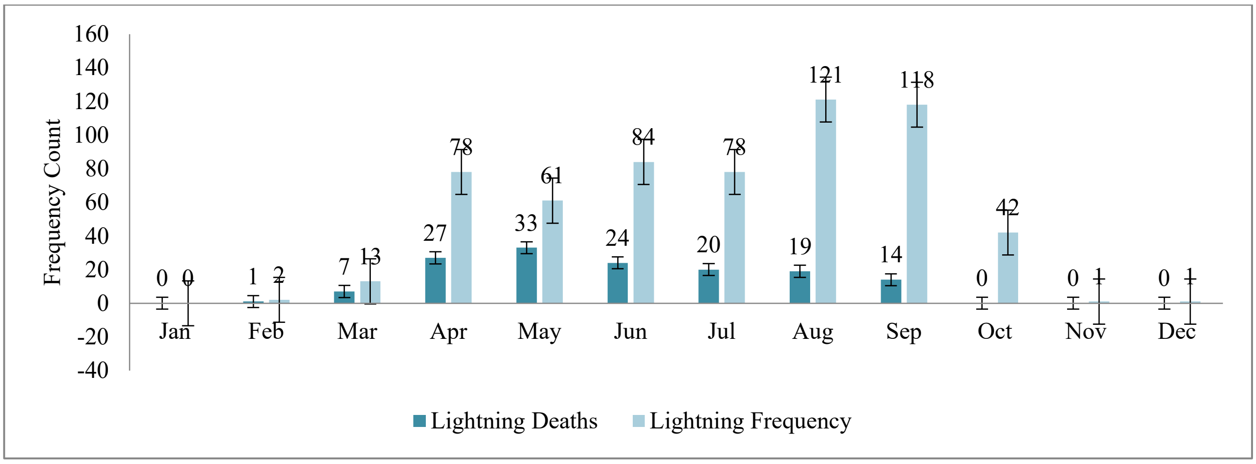

Figure 2: Monthly frequency of lightning and fatalities

3.5 Options for Adaptation

The fatalities, injuries, and other damages caused by lightning can be reduced significantly by implementing appropriate adaptation measures. This section intends to formulate some policy recommendations for possible adaptation based on respondents' opinions and the authors' perception. It is a matter that the nature of adaptation measures highly depends on the geographical characteristics of the study area and available resources. The study's respondents on an open-ended and multiple-answered question mainly opined about five types of adaptation measures shown in Table 4.

The figures in the right column indicate the portion of respondents in favor of corresponding adaptation options. The findings in Table 4 reveal that most of the respondents emphasized the necessity of emergency shelter for self-protection during thunderstorms. The emergency shelter shall be adjacent to agricultural land and roads since most of the fatal incidents occurred while working outside agricultural land. The shelter would be a

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temporary infrastructure, a tall tree, a tree with a large canopy, etc. Plum trees and Banyan trees should be planted beside roads and agricultural land, maintaining a homogeneous distance so that people from the nearer place can take shelter under those trees.

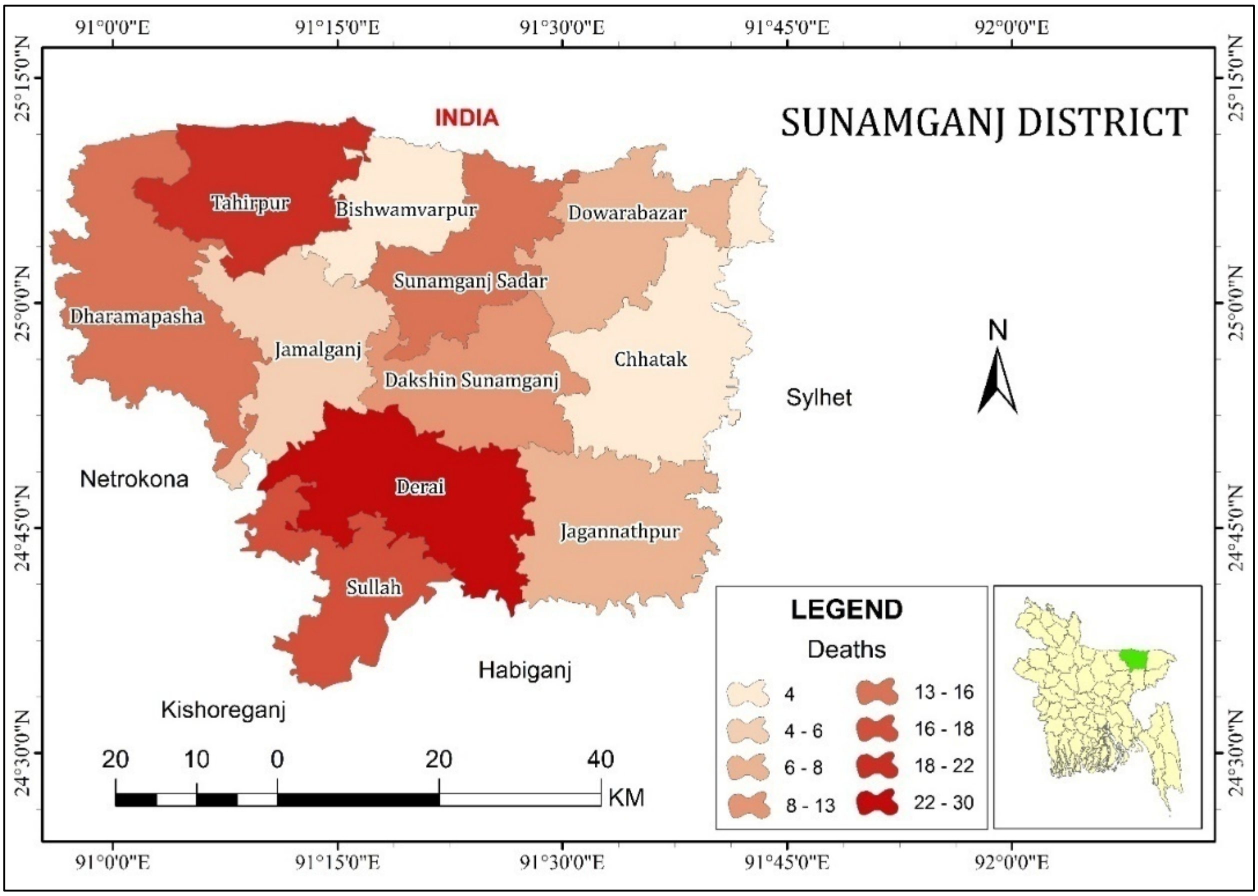

Figure 3: Distribution of lightning fatality by Upazila

Table 4: Options for adaptation to reduce the adverse consequences of lightning.

No.	Options for Adaptation	% of Respondents (multiple answers)
1.	Dissemination of proper knowledge about lightning, safety measures, and first aid	46
2.	Public awareness building regarding outside movement during a thunderstorm	45
3.	House safety and facilitating emergency shelter	91
4.	Using covered vehicles for travelling during a thunderstorm	57
5.	Aiding victim families for recovery and rehabilitation	62

Almost half of the respondents opined that proper knowledge about self-protection techniques during lightning and primary emergency treatment of victims should be disseminated through an extensive campaign in lightning prone areas. To ensure the proper dissemination and fruitful receipt of knowledge and information, all classes of the society based on age, sex, occupation, i.e., students, youths, local leaders, teachers, farmers, housewives, NGO workers, etc. should be involved in these activities. Annual or biannual emergency drill at every school with the participation of students, village or *mohalla* facilitated by schoolteachers, volunteers, and social workers in assisting with local leaders, local government, fire service, and civil defence department, hospitals would be hugely beneficial for residents of lightning prone areas. The almost same portion of respondents also emphasized awareness building about movement and maintaining lightning safety measures/instructions among mass people. Since this study found that most of the victims who died from lightning went or remained outside for technical purposes despite knowing that they might be affected by lightning, therefore, it is difficult to restrict them since earning money is very important for surviving. But repeated and continuous publicity will make them understand that saving their life is more important for taking care of their families. Most vehicles are not lightning protected in rural areas as they are mostly open and have no safety measures. However, developing and adopting a new design of vehicles with the highest lightning safety at an affordable cost might attract rural people to use lightning-protected vehicles. Besides pre-disaster and during-disaster adaptation measures, some post-disaster measures are also needed to recover and rehabilitate victim families. Since, in most cases, adult men with earning potentiality die in

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lightning events (Biswas et al. 2016), necessary assistance is required for immediate recovery and livelihood rehabilitation of victims' families. Therefore, a comprehensive lightning disaster management action plan is required with the participation of all government and non-government stakeholders and funding agencies for fruitful adaptation implementation.

4. CONCLUSIONS

This study initiated to find the association of thunderstorm with climatic variables, their consequences and driving factors, and the spatial distribution of fatalities in the Sunamganj district, the northeastern part of Bangladesh. After analyzing the time series data of climatic variables, lightning frequency as well as the household survey data with proper methods and techniques, it can be concluded that the occurrence of lightning are significantly and positively associated with the variation of local climatic variables that makes the occurrence of lightning more likely in future as the climatic variables implied with an upward trend. Besides, the condition was more vulnerable for farmers who work in agricultural fields during the storm in the monsoon season due to the unavailability of adequate shelter adjacent to the agricultural field for protection from lightning strikes. Since farmers and other dwellers who died by lightning strikes were mainly engaged with agricultural activities and could not stop themselves from going to the field, these activities are their main source of income. Therefore, some protective measures, i.e., plantation of long palm trees, trees with large canopy (banyan trees), and the building of temporary shelters nearby their workplaces, have to be arranged. However, currently, BMD is counting the lightning event through visual observation and manual recording systems, which is an inferior and inadequate procedure to collect accurate data. Thus its capacity to sense and forecast lightning through detecting the gathering of thunderstorms should be enhanced by installing Doppler Radar System in the northeast part of the country. Implementing adaptation strategies to reduce lightning-induced fatalities should be undergone within an integrated, comprehensive approach by involving vulnerable communities, local governments, stakeholders, national government, etc. A mass and continuing awareness-building campaign on initial techniques should be recommended amongst rural households to prevent injuries and fatalities. This study can significantly advance the scientific knowledge on thunderstorm hazard management and also be a good referral approach as many underdeveloped and developing countries have been facing casualties in recent times. Finally, to achieve this goal in a holistic approach, indigenous knowledge and techniques of rural residents should be considered for getting highly constructive outcomes.

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