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Geospatial Analysis of Lightning Incident Zoning in Bangladesh

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Abstract: *Lightning is one of the deadliest natural hazards in Bangladesh, claiming hundreds of lives annually and causing significant damage to infrastructure, especially in rural areas. This study presents a comprehensive analysis of lightning incidents across Bangladesh from 2017 to 2020, utilizing Geographic Information Systems (GIS) for spatial and temporal analysis. The primary objective of the study is to identify high-risk zones and temporal patterns to aid in the prediction and mitigation of lightning-related hazards. The study incorporates data from meteorological agencies, newspaper reports, and government databases, analyzing the frequency, intensity, and distribution of lightning incidents. Using advanced GIS tools such as Moran's I for spatial autocorrelation and kriging interpolation for spatial distribution, the study identifies regions where lightning strikes are most prevalent and investigates the seasonal patterns of these incidents. The findings reveal that lightning incidents are highly clustered in specific regions, particularly during the pre-monsoon and monsoon seasons, with divisions like Sylhet, Khulna, and Rajshahi being disproportionately affected. Moreover, the results indicate a rise in lightning incidents over the study period, likely influenced by changing climatic conditions. The analysis provides valuable insights for policymakers and disaster management authorities, highlighting the need for region-specific interventions and public awareness campaigns. By mapping lightning-prone areas and identifying temporal trends, the report contributes to the development of targeted strategies to reduce lightning-related deaths and injuries, enhancing overall public safety in Bangladesh.*

Keywords: Lightning, spatial autocorrelation, kriging interpolation, spatial distribution, temporal trends

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Introduction

Lightning is a serious natural hazard that significantly threatens human life, infrastructure, and the environment. In Bangladesh, where thunderstorms are common, lightning frequently causes fatalities and substantial property damage. The monsoon-driven climate in the region further exacerbates the frequency of these dangerous events. Studies have shown that the incidence of lightning fatalities in Bangladesh is approximately 0.9 per 1,000,000 populations per year. [1] As a result, lightning has emerged as a critical issue that demands attention from researchers, policymakers, and disaster management authorities.

Recognizing the severity of this issue, the Government of Bangladesh officially included lightning in the country's disaster list in 2016. [2], [3] This move marked a pivotal step toward addressing the dangers associated with lightning, acknowledging it as a serious threat alongside other natural disasters such as floods and cyclones.

This study employs advanced spatial analysis techniques, including Moran's I and kriging interpolation, to analyze the distribution of lightning events and identify high-risk regions. By investigating the factors contributing to lightning frequency and its geographic clustering, this research aims to provide critical insights for disaster management and policy development. The findings emphasize the importance of localized early warning systems, public awareness campaigns, and targeted safety measures to enhance resilience and reduce the impact of lightning hazards in Bangladesh.

Bangladesh, due to its geographical position and tropical monsoon climate, experiences frequent thunderstorms during pre-monsoon (March-May) and monsoon (June-September) seasons. The Bangladesh Meteorological Department (BMD) has recorded a sharp rise in fatalities linked to lightning in recent years, prompting the government to declare it a national disaster in 2016 (Bangladesh Meteorological Department, 2018). **[8]**

According to the Bangladesh Meteorological Department (BMD), lightning incidences in Bangladesh have been progressively increasing over time. For instance, the agency documented nearly 300 lightning-related fatalities in 2018, one of the highest numbers in recent memory. Studies have indicated that because of their geographic and climatic

characteristics, Bangladesh's northern and central regions especially the divisions of Rajshahi and Mymensingh are the most affected.
Climate change is intensifying lightning strikes due to increased heat and atmospheric moisture, posing a serious threat to densely populated and agriculture-dependent Bangladesh. The World Meteorological Organization (WMO) warns that shifting weather patterns could lead to more frequent and powerful thunderstorms across South Asia, including Bangladesh.

Lightning strikes cause casualties, infrastructure damage, and livestock losses, particularly in rural areas. Despite these risks, preventive measures like lightning protection systems remain limited. Efforts are underway, including government initiatives to install lightning rods, early warning systems, and public awareness campaigns during the rainy season. However, more research and policy actions are needed to address this growing threat and better protect communities.

However, despite this extensive research, there are gaps in understanding how lightning incidents manifest in underdeveloped regions, particularly in South Asia. While Holle (2016) mapped lightning-related fatalities globally, showing high concentrations in Africa and South Asia, comprehensive data on Bangladesh remains limited. [6] This gap highlights the need for region-specific studies, especially in tropical, monsoon-driven climates like Bangladesh, which experience seasonal spikes in lightning incidents. Murugavel et al. (2014) further emphasized the variability of lightning activity across South Asia, stressing the need for high-resolution, localized analysis. [12]

Despite advancements in lightning research, particularly through remote sensing and GIS technologies, South Asia, and specifically Bangladesh, remain under-researched. While Rakov & Uman (2003) provided foundational knowledge on lightning mechanics, they did not address the socio-economic impacts of lightning in developing countries like Bangladesh. [5] Furthermore, although Romps et al. (2014) predicted an increase in lightning activity due to climate change, the impact of these changes on lightning patterns in monsoon-driven regions remains unclear. [7]

Finally, while meteorological data is relatively well-studied, the integration of socio-economic vulnerabilities into lightning risk models remains limited. Murugavel et al. (2014) pointed out that rural agricultural populations, particularly in Bangladesh, face increased exposure to lightning, but there is a lack of comprehensive models that consider both environmental and social factors in risk assessment. [12] This study aims to integrate these factors into a GIS-based model to provide a more accurate assessment of lightning risk in Bangladesh.

Study Area

The study focuses on Bangladesh, a tropical country located between latitudes 20°34' and 26°38'N and longitudes 88°01' and 92°41'E. The country's geography includes a combination of low-lying floodplains, river deltas, coastal regions, and hilly areas. These geographical features, combined with the tropical monsoon climate, make Bangladesh highly susceptible to thunderstorms and lightning incidents, particularly during the pre-monsoon (March–May) and monsoon (June–September) seasons. The study was conducted across all administrative divisions of Bangladesh, focusing on the thana (sub-district) level, which provides a finer spatial resolution for analyzing lightning incidents.

Methodology

Research on global lightning patterns has evolved significantly with the advancement of satellite-based detection systems. For instance, Rakov & Uman (2003) provided a comprehensive understanding of lightning's physical properties, establishing that tropical region, especially near the equator, are most affected due to intense convective storms.[4] Similarly, studies utilizing the Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD) found that the highest lightning flash rates occur in Africa's Congo Basin, parts of Southeast Asia, and South America, areas characterized by warm, moist air conducive to thunderstorm formation.[5]

Data Collection and Processing

To ensure the robustness of the analysis, the study relied on multiple data sources, each contributing unique and valuable information about lightning incidents in Bangladesh. National and regional newspapers provided timely reports with detailed information on lightning incidents, including date, time, and location, essential for capturing real-time temporal patterns. Academic articles and government publications offered contextual analyses, statistical summaries, and insights into broader lightning trends, framing the study within existing research. Scientifically validated data from lightning detection systems, cross-referenced with government disaster databases, provided systematic records of incidents, including fatalities and property damage, enhancing the study's validity.

The raw data from multiple sources were processed as follows: Lightning incidents lacking geographic coordinates were geocoded based on the closest reported locations. This was done using ArcGIS 10.8 and Google Earth Pro for accurate mapping. All datasets were cleaned to remove duplicates and inconsistencies. Cross-referencing between BMD data and media reports helped verify the accuracy of incident records. The cleaned data were imported into ArcMap, where they were compiled into an attribute table for subsequent spatial analysis. The table included fields such as location (latitude and longitude), date, time, and the impact (fatalities, injuries, infrastructure damage) of each lightning incident.

Several advanced Geographic Information Systems (GIS) techniques were employed to analyze the spatial and temporal patterns of lightning incidents: *Geographic Information System (GIS) Tools*. ArcMap and QGIS were used to create maps that integrated the lightning incident data. This enabled the identification of high-risk areas and the detection of potential patterns in the geographic distribution of lightning strikes.

Spatial Autocorrelation (Moran's I): To measure the degree of clustering, Moran's I statistic was applied to the lightning incident data. A positive Moran's I value indicated clustering of lightning incidents in specific regions, while a negative value suggested spatial dispersion. The results were statistically validated using z-scores and p-values, ensuring that observed patterns were not due to random chance.

Inverse Distance Weighting (IDW) Interpolation: This method was employed to estimate lightning strike density, chosen for its suitability in addressing the clustered spatial distribution identified by Moran's I analysis. Using the Geostatistical Wizard, IDW generated a continuous surface map, highlighting areas with sparse direct observations and providing critical insights into lightning risk zones across Bangladesh.

Temporal Analysis: The temporal analysis was performed by grouping lightning incidents by month and season, allowing for the identification of peak periods for lightning activity. A time-series analysis was conducted to determine trends in lightning occurrences over the four-year period, revealing increased lightning frequency during the pre-monsoon and monsoon seasons. Temporal variations were visualized using line graphs to highlight fluctuations in lightning activity.

Results

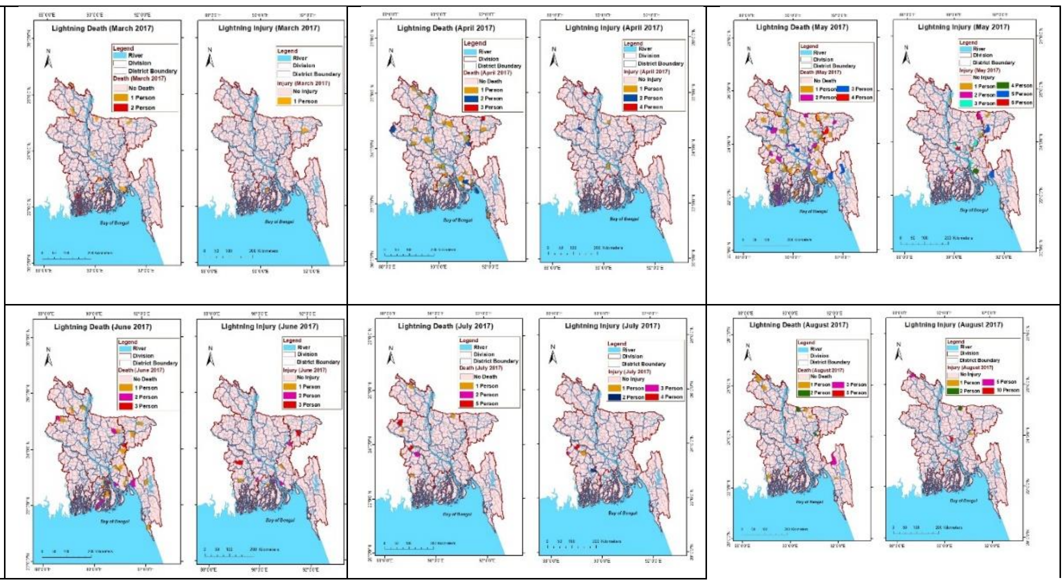
Spatial Patterns of Lightning Incidents Across Bangladesh

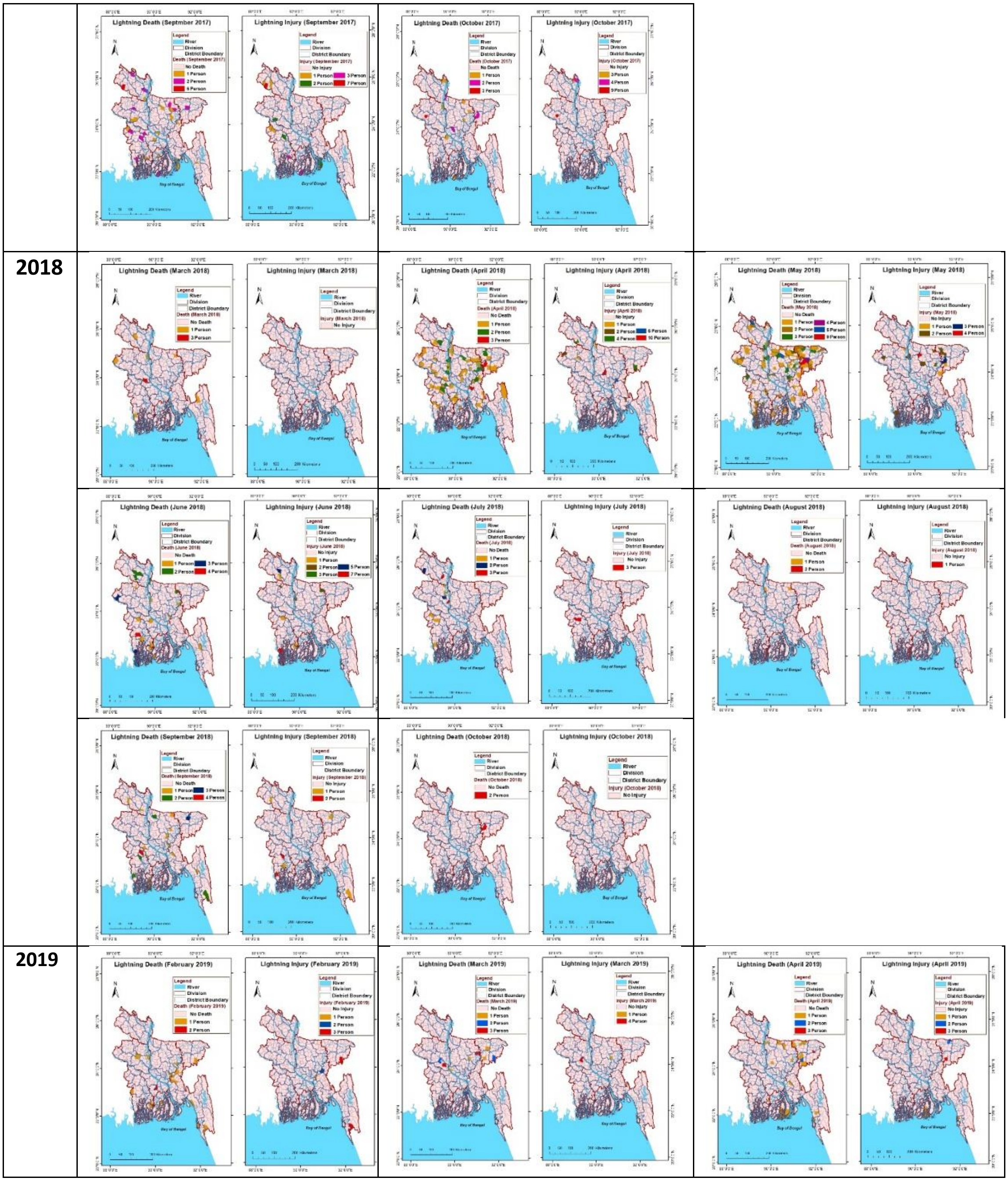
The spatial analysis conducted in this study highlights the distribution of lightning incidents across Bangladesh, revealing patterns and identifying vulnerable areas. Using data from 2017 to 2020, the analysis provides a detailed view of the geographical spread of these events.

Distribution of Incidents Across Bangladesh:

Lightning incidents in Bangladesh vary monthly, influenced by seasons and geography. This section focuses on active months for targeted analysis. The maps visually represent high-frequency regions, highlighting spatial trends throughout the year and offering insights into areas most affected by lightning.

2017




Lightning Death (Septmber 2017)
Lightning Injury (September 2017)
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2018
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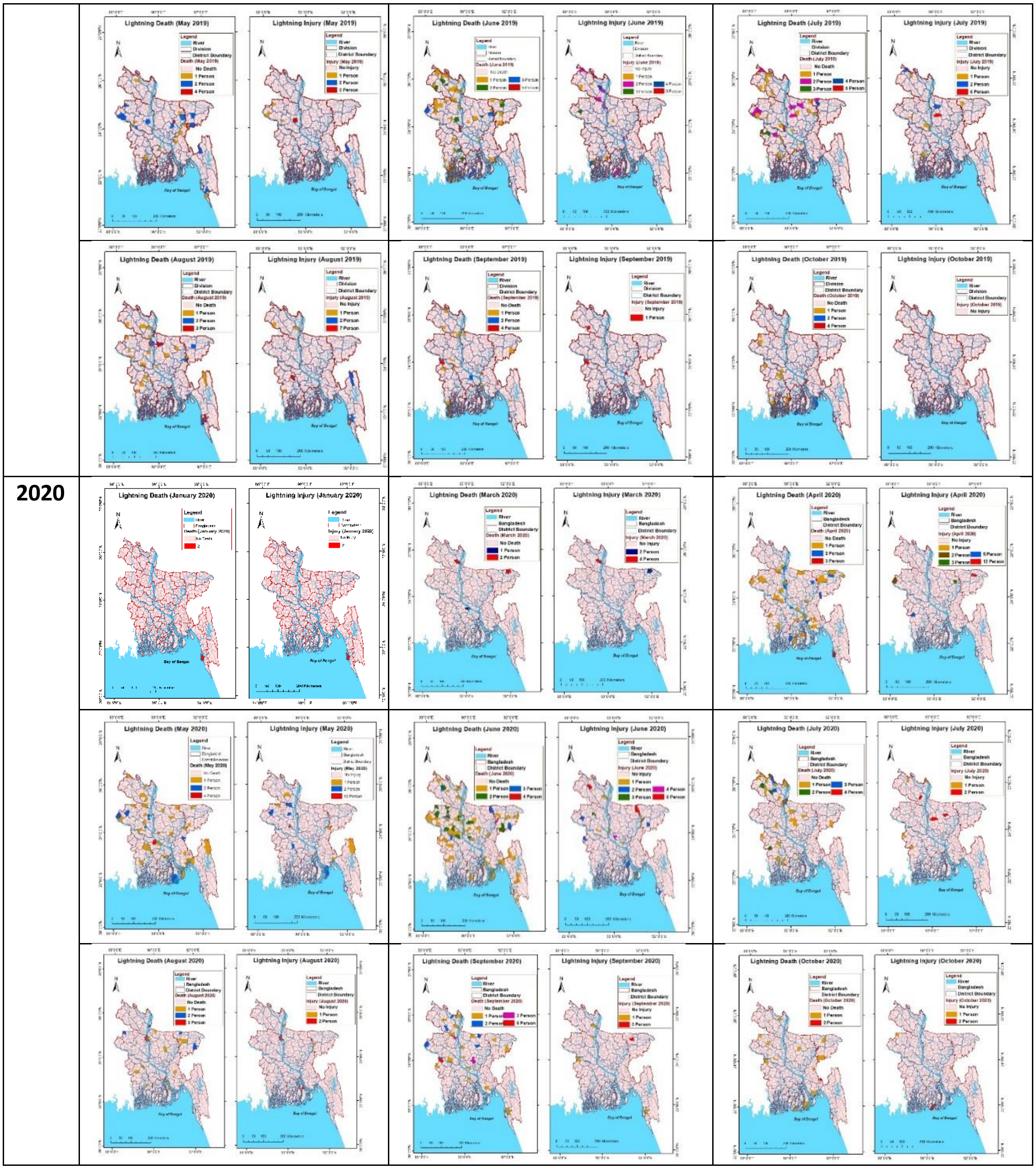
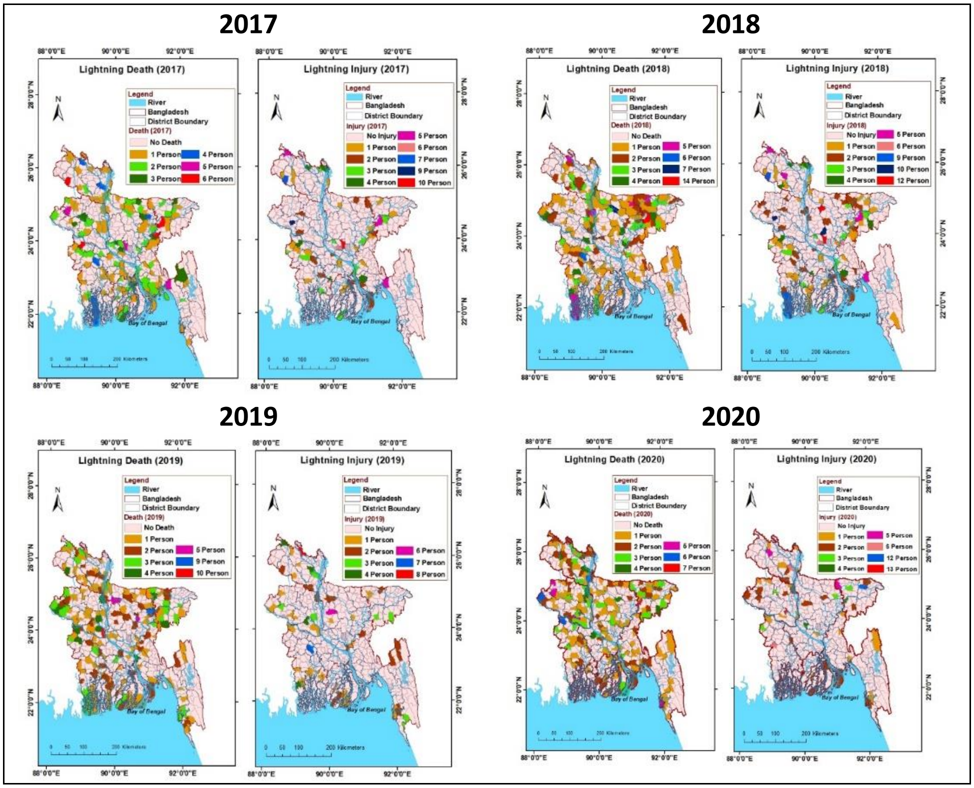


Map 1: Spatial Patterns of Monthly Lightning (2017 to 2020)



Map 2: Spatial Patterns of Annual Lightning (2017 to 2020)

Identification of High-Risk Zones

High-risk zones are regions with consistently high lightning activity, resulting in significant fatalities and injuries. Using data from 2017 to 2020, these zones were identified based on two key criteria:

- Frequency of Lightning Incidents: Areas with recurring high lightning activity over multiple months or years.
- Deaths and Injuries: Regions with a high toll of fatalities and injuries, highlighting zones where lightning poses severe risks to human life.

Figure 1: Regional Analysis of Lightning Incidents (2017-2020)

Findings

- Rajshahi experienced the highest number of lightning incidents over the four years, with a significant peak of 130 incidents in 2020. Rangpur and Sylhet also recorded consistently high incidents, notably increasing to 93 and 88 respectively in 2020.
- Dhaka shows moderate to high incidents, but shows a decreasing trend from 81 in 2017 to 48 in 2020.
- Chattogram is highly affected in 2017 (95 incidents) but decreased over time, indicating a decreasing risk.
- Barisal remained the least affected region, maintaining the lowest incident numbers throughout the period.

Spatial Clustering of Incidents

Moran's I is a powerful statistical tool used to evaluate whether nearby locations have similar or dissimilar values. In the context of this study, Moran's I was applied to the lightning incident data to determine if there is spatial autocorrelation, in other words, whether lightning incidents are more likely to occur near each other or if they are randomly spread across Bangladesh.

The charts show lightning strike patterns over months and years, highlighting areas of concentration and geographic distribution.

Monthly Spatial Autocorrelation Patterns of Lightning Incidents (2017-2020)
(Using Moran's I)

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
2017	N/A	N/A	Clust-ered	Clust-ered	Clust-ered	Clustered	Random	Clustered	Random	Clustered	N/A	N/A
2018	N/A	N/A	Clustered	Clustered	Clustered	Clustered	Random	Random	Clustered	Random	N/A	N/A
2019	N/A	Clustered	Random	Random	Clustered	Clustered	Clustered	Clustered	Clustered	Random	N/A	N/A
2020	Random	N/A	Random	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	N/A	N/A

Figure 2: Monthly Spatial Autocorreletaion Patterns of Lightning (2017-2020)

Interpretation of Cluster Patterns

- Pre-Monsoon and Monsoon Clustering: Lightning incidents from March to June consistently show clustering, aligning with pre-monsoon and monsoon seasons when thunderstorms are frequent.
- Consistent Clustering in Early Monsoon: April, May, and June across 2017–2020 exhibit recurring high-risk zones for lightning incidents.

- Annual Cluster Patterns: Each year (2017–2020) shows a spatially clustered distribution of lightning incidents, indicating a consistent trend.
- Overall Trend: Lightning incidents predominantly cluster rather than distribute randomly.

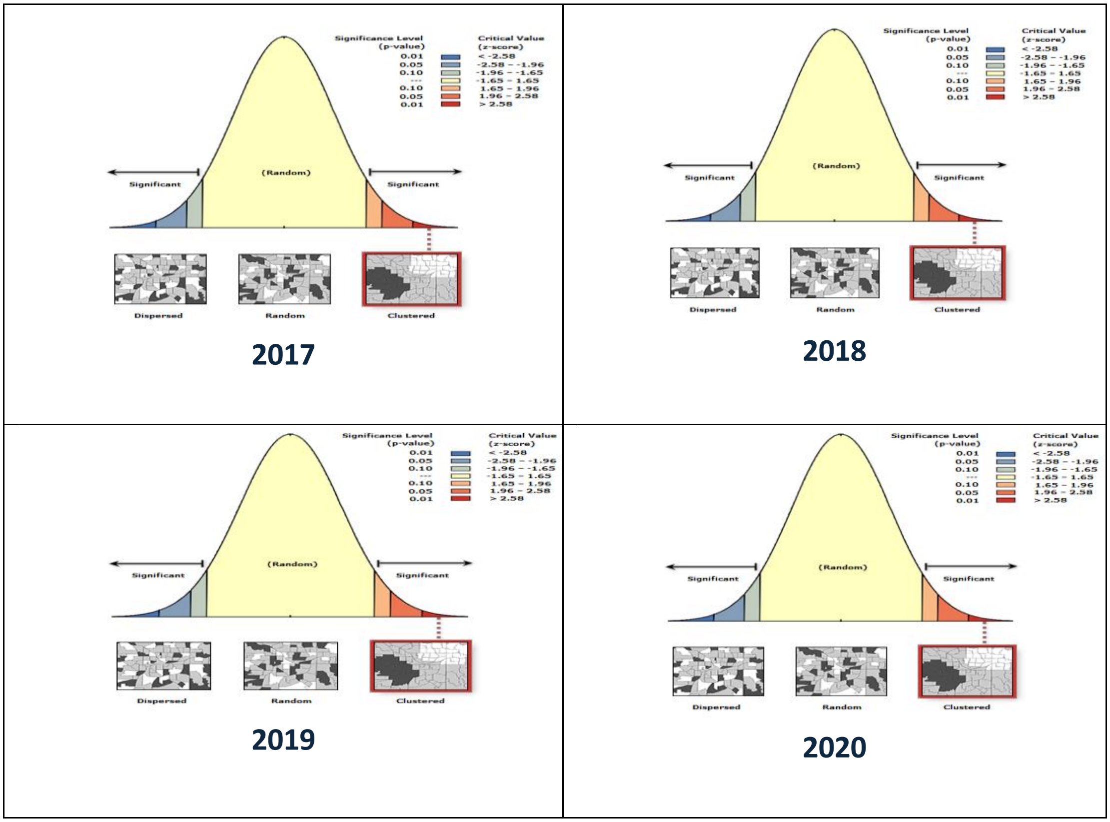


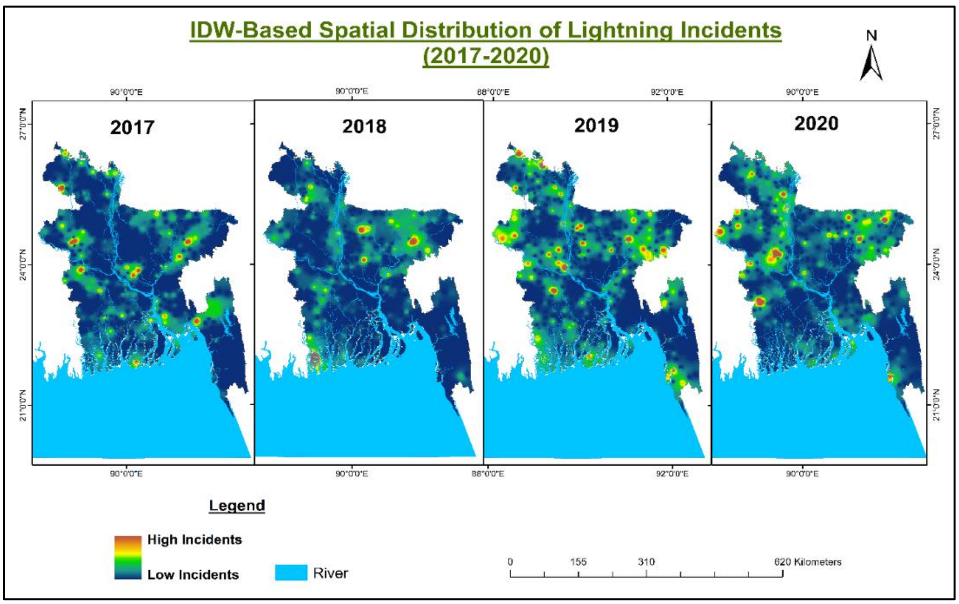
Figure 3: Spatial Autocorreletaion Patterns of Lightning (2017-2020)

The significance of clustering was evaluated based on z-scores and p-values. As shown in the bell curves for each year, areas with z-scores greater than 1.65 and corresponding p-values less than 0.10 indicate statistically significant clustering of lightning events, mostly occurring in April, May, and June. These clusters fall on the right side of the normal distribution curve and are marked in orange and red zones, representing higher levels of statistical confidence ($p < 0.05$ or $p < 0.01$). Random distributions lie within the central yellow area where the z-scores range between -1.65 and 1.65, and the p-values are higher, indicating no significant spatial autocorrelation. Dispersed patterns fall on the left side of the curve with negative z-scores less than -1.65, although such patterns were not dominant in the observed period. The maps underneath each year's curve visually represent these patterns, where black-highlighted areas framed in red boxes show significant clusters based on the calculated statistics.

Cluster patterns in April, May, and June highlight high-risk areas, guiding disaster management efforts like lightning rod installation and public awareness campaigns. Random patterns in other months help optimize resource allocation and risk mitigation strategies.

Spatial Distribution Using Inverse Distance Weighting (IDW):

IDW (Inverse Distance Weighting) is a deterministic interpolation method that estimates values at unknown locations based on nearby measured values, giving more weight to closer points. IDW interpolation was used because of Moran's I results for lightning incidents (2017–2020) indicate a clustered pattern. Deterministic methods like IDW are suitable for clustered or dispersed data as they rely on spatial proximity without assuming statistical distribution.



Map 3: IDW- based Spatial Distribution of Lightning (2017-2020)

Interpretation

The maps generated using IDW interpolation demonstrate the spatial distribution of lightning incidents across Bangladesh from 2017 to 2020. The color gradient indicates the intensity of lightning strikes in different regions, where warmer colors represent higher frequencies of incidents and cooler colors indicate lower frequencies

Color Code:

- Red areas represent regions with high lightning incidents, indicating zones with frequent lightning activity.
- Green areas represent low lightning incidents, indicating regions with fewer or no lightning strikes.
- The blue lines represent the major rivers of Bangladesh.

Year-wise Interpretation

2017: Northern Bangladesh, particularly in Rajshahi, Mymensingh, and Chattogram, shows high frequencies of lightning incidents, with strong clustering in the northern part (red areas). Dhaka and Khulna also report a significant number of incidents.

2018: Northern and central Bangladesh (Rajshahi, Rangpur, Dhaka, and Sylhet) experience intense lightning activity. Khulna also reports high activity, but the southern regions show moderate occurrences.

2019: A shift in activity is noted, with some areas in northern Bangladesh (Rajshahi and Rangpur) showing reduced intensity, while Chattogram and Sylhet report an increase in incidents. Khulna remains moderately affected.

2020: Northern and central regions experience a decrease in intensity, though Rajshahi and Sylhet still show significant incidents. Khulna and Chattogram experience fewer incidents compared to previous years, while Barisal continues to show the least lightning activity.

Key Findings

1. Northern Bangladesh (Rajshahi, Rangpur, Mymensingh) consistently experiences high lightning incidents across all years.
2. Southern regions, particularly Khulna, have moderate lightning activity, but a reduction is noted in 2020.
3. Central regions, including Dhaka, remain at a steady risk for lightning incidents.
4. The year 2018 saw the most widespread lightning incidents, with intense activity across many regions.

Temporal Analysis of Lightning Incidents

Temporal analysis helps to understand the temporal change over time in Bangladesh, particularly over the years 2017 to 2020. It also helps to analyze, when lightning happens most frequently, and whether there are noticeable trends over different time periods. By analyzing annual, seasonal, and monthly patterns, we can gain insights into the timing of lightning incidents and identify periods of increased risk.

Annual Trends (2017-2020):

Annual trends are analyzed to see if there are any significant changes in the frequency of lightning incidents over the study period. By examining the annual data, it can be determined whether certain years saw a higher concentration of incidents compared to others.

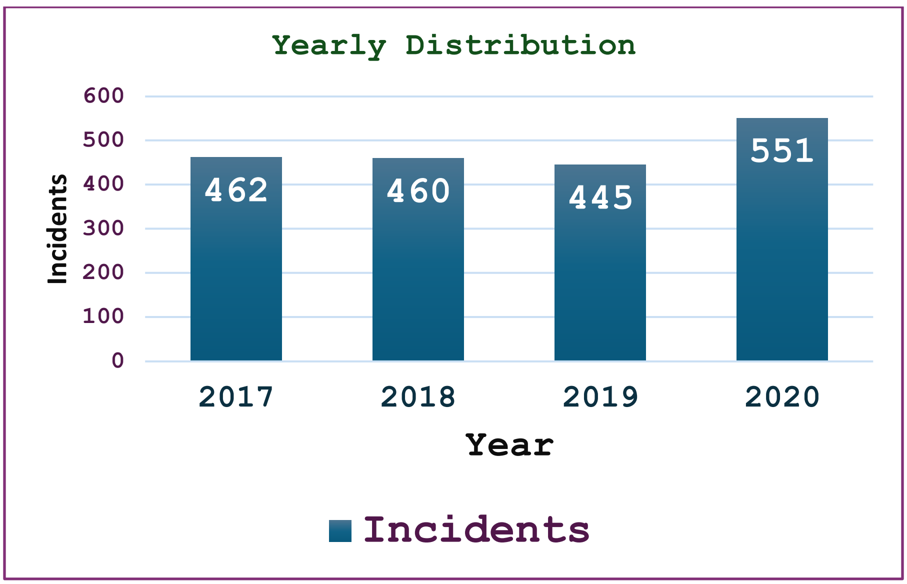


Figure 4: Yearly Distribution of Lightning Incidents (2017-2020)

Key Findings

The graph illustrates the yearly distribution of lightning incidents in Bangladesh from 2017 to 2020. Key findings from the data are as follows:

1. **General Trend**: The number of lightning incidents fluctuates slightly over the four-year period, but an upward trend is evident by 2020.
2. **2017-2019**: The lightning incidents show a relatively stable pattern between 2017 and 2019, with incidents ranging between 445 and 462 per year. Specifically:
    - In 2017, the total number of incidents was 462.
    - A slight decrease is observed in 2018, with 460 incidents.
    - The lowest point occurs in 2019, where the incidents drop to 445.
3. **2020 Increase**: There is a notable increase in incidents in 2020, with the total rising sharply to 551. This suggests that environmental or climatic conditions during 2020 may have contributed to a significant rise in lightning activity, making it the year with the highest number of incidents during this period.
4. **Overall Insight**: While the incidents remained relatively consistent from 2017 to 2019, the surge in 2020 suggests that certain factors, such as atmospheric instability or climatic changes, could have led to increased thunderstorm activity. Further analysis would be needed to understand the specific causes of this spike in 2020.

This upward trend in 2020 is a concerning development and may suggest the need for heightened lightning risk awareness and preparedness in the future.

Monthly Incident Patterns

Monthly analysis of lightning incidents reveals how the frequency of these events fluctuates throughout the year, providing deeper insights into the exact months when the risk is highest. By understanding the monthly trends, the periods with the most concentrated lightning activity can be identified, which helps in planning safety measures and raising public awareness.

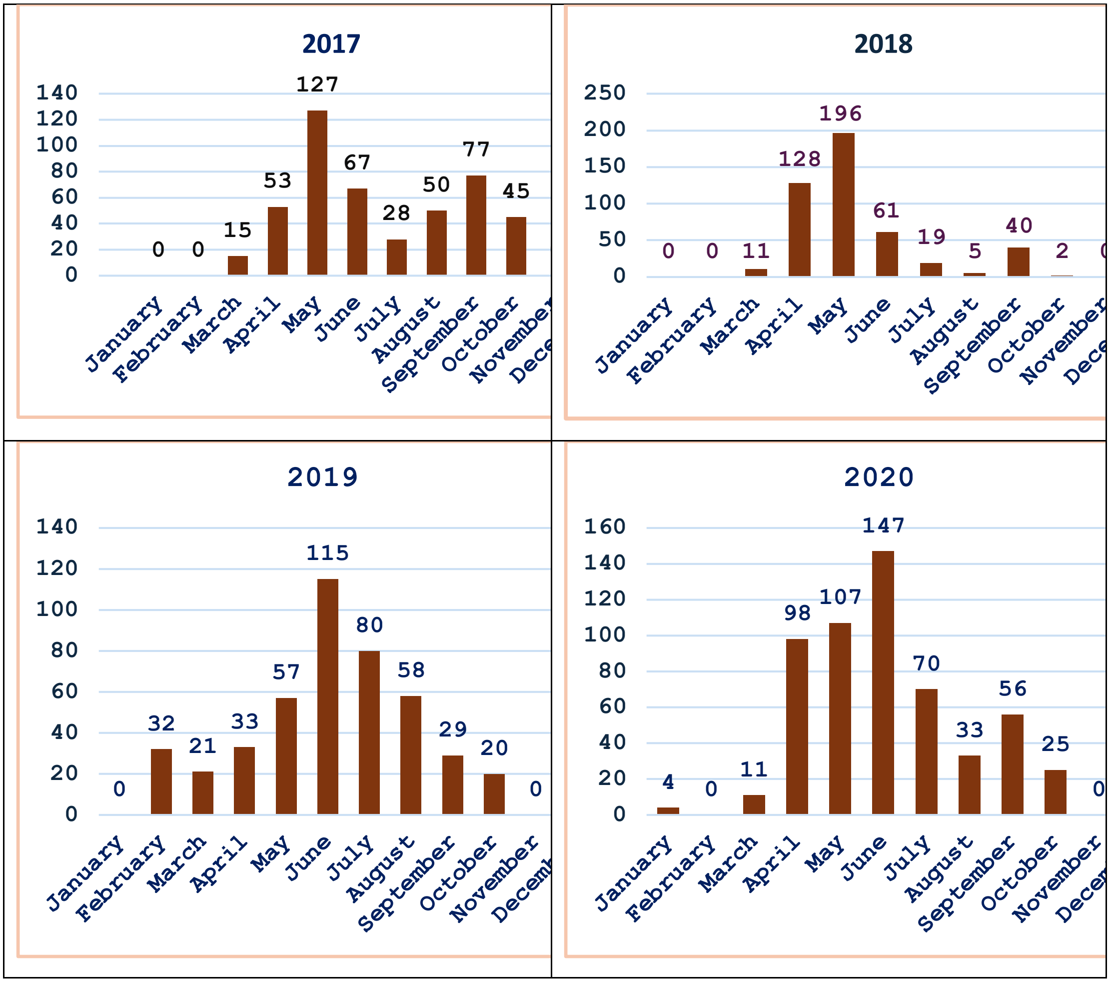


Figure 5: Temporal Analysis of Lightning Incidents (2017-2020)

Findings

The graphs illustrate the monthly distribution of lightning incidents in Bangladesh from 2017 to 2020, revealing some important patterns in how lightning activity is distributed throughout the year:

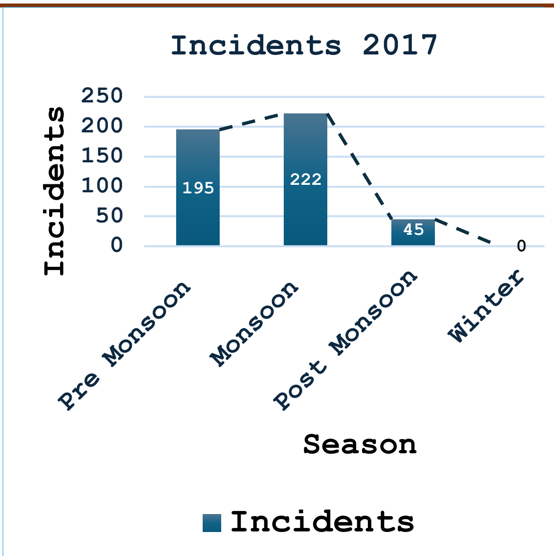
1. Peak Lightning Months:
    - May and June consistently emerge as the months with the highest number of lightning incidents across all four years.
        - In 2017, May recorded the highest incidents with 127, followed by June with 97 incidents.
        - In 2018, May again saw the highest incidents, spiking to 196, followed by June with 61 incidents.
        - In 2019, June marked the highest number of incidents with 115, followed by July with 80 incidents.
        - Similarly, in 2020, June recorded the highest incidents at 147, followed by May with 107.
2. Pre-Monsoon and Monsoon Dominance:
    - April, May, June, and July, falling within the Pre-Monsoon and Monsoon seasons, consistently show high activity.
        - April experiences a noticeable increase in incidents, especially in 2020 with 98 incidents, showing the gradual onset of the lightning season.
        - May and June are consistently the most active months, especially during the peak of the Monsoon season.
3. Minimal Activity in Post-Monsoon and Winter Months:
    - October to February exhibit almost no lightning activity, as shown by the near-zero or zero values across all four years.
        - For example, December and January recorded zero incidents in all years, while November occasionally shows a very low number of incidents.
4. Yearly Variations:
    - 2018 witnessed a particularly high spike in May compared to other years, with 196 incidents. This could indicate unusually active storm conditions during the Pre-Monsoon season.
    - 2019 displayed a more even distribution across June and July, with no single month seeing a dramatic spike in incidents.
    - After August, the number of lightning incidents begins to taper off significantly, with September and October showing a sharp decline. This pattern indicates the end of the Monsoon season and a transition into calmer weather.
    - September still showed some activity in 2017 and 2018, with incidents ranging from 19 to 77, but this drops off in subsequent months.

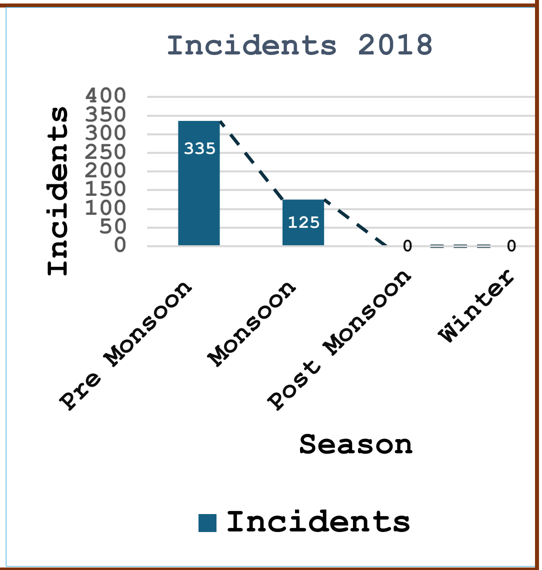
Seasonal Variations

Lightning incidents vary by season, which is a crucial aspect of temporal analysis. Bangladesh experiences distinct seasons—pre-monsoon, monsoon, and post-monsoon—each of which can have a significant impact on the occurrence of thunderstorms and lightning. Seasonal variation is analyzed how lightning pattern changes with seasons.

Bangladesh climate is divided into the following seasons. Winter: December, January and February. Pre monsoon: March, April and May. Monsoon: June, July, August and September. Post Monsoon: October and November. [9]

Pre Monsson - (March, April, May)	**Monsoon – (June, July, August, September)**
Post Monsoon – (October, November)	**Winter – (December, January, February)**





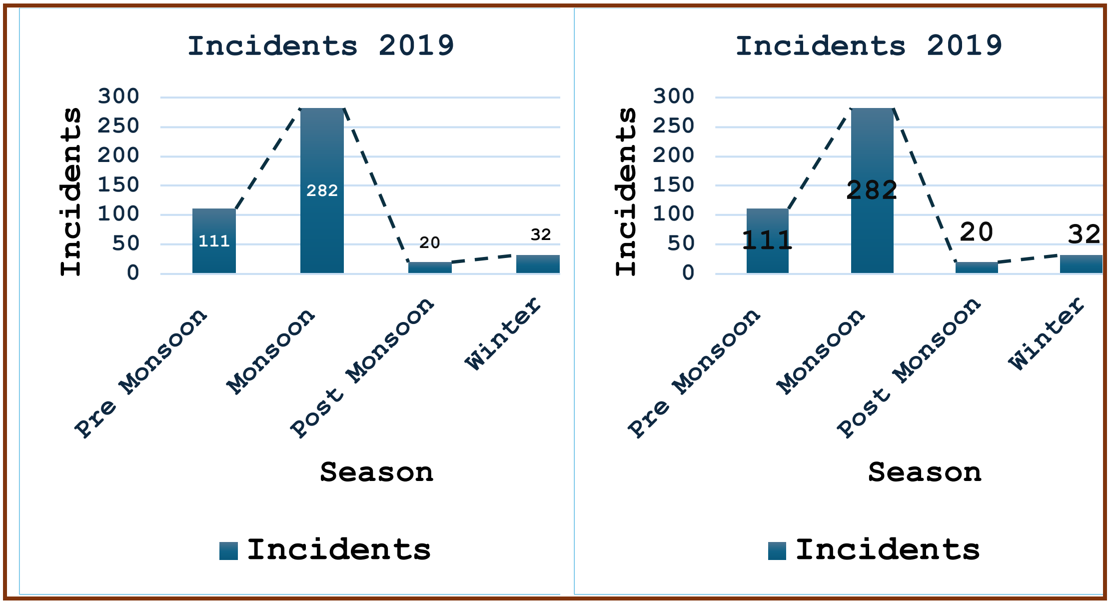


Figure 6: Seasonal Variation Analysis (2017-2020)

Findings

These graphs illustrate the seasonal distribution of lightning incidents in Bangladesh across four years, from 2017 to 2020. Key insights from the data are as follows:

1. Pre-Monsoon vs. Monsoon Dominance:
   - Pre-Monsoon (March, April, May) and Monsoon (June, July, August, September) seasons are consistently the most active periods for lightning incidents across all four years.
   - The highest number of lightning incidents tends to occur during the Monsoon season, particularly in 2017 (222 incidents), 2019 (282 incidents), and 2020 (306 incidents).
   - The Pre-Monsoon season also records significant activity, especially in 2018 (335 incidents), which shows a peak of lightning incidents during this season.
2. Post-Monsoon and Winter Activity:
   - The post-monsoon season (October, November) and Winter season (December, January, February) exhibit very few or no lightning incidents in all years.
     - For example, in 2017, the post-monsoon season saw only 45 incidents, and Winter had no recorded incidents. Similarly, in other years, the Post-Monsoon and Winter seasons show minimal activity, suggesting that these periods are much safer in terms of lightning risks.

3. Yearly Variation:
   - There is some variability in which season records the highest number of incidents:
     - In 2017, lightning incidents peak during the Monsoon season.
     - In 2018, however, the Pre-Monsoon season records the highest number of incidents, with a significant count of 335 compared to 125 in the Monsoon.
     - In 2019 and 2020, Monsoon dominates again, with 282 and 306 incidents, respectively.
4. Consistent Low Activity in Winter:
   - Winter months show almost no lightning activity across all four years. This is consistent with the stable, dry weather conditions in Bangladesh during this period.

Discussion

The spatial analysis revealed significant clustering of lightning incidents across northern Bangladesh, with Rajshahi, Rangpur, and Sylhet divisions showing consistently high activity during pre-monsoon and monsoon seasons. These patterns highlight the influence of unique atmospheric and topographical conditions that make these regions more vulnerable to convective thunderstorms. Temporal trends revealed that April to June are the peak months, with a notable rise in incidents in 2020. This increase may indicate shifts in atmospheric conditions, potentially linked to climate change. The use of IDW interpolation was guided by the clustered patterns identified through Moran's I analysis. IDW, being a deterministic method, effectively captures localized variations, aligning well with the spatial characteristics of the data.

Comparison with Previous Studies

The findings align with earlier research on lightning activity in Bangladesh and tropical regions. Studies by Dewan et al. (2017) and Khan et al. (2018) identified similar seasonal and spatial patterns, with pre-monsoon months showing the highest lightning incidents. Northern regions, including Rajshahi and Sylhet, were highlighted as particularly vulnerable due to frequent convective activity. [10], [11] On a global scale, findings from Blakeslee et al. (2014) suggest that rising lightning incidents, like those observed in 2020, may be linked to climate-induced atmospheric instability, reinforcing the need for further investigation into these trends. [13]

Implications for Lightning Hazard Management

The results emphasize the importance of targeted disaster management interventions. High-risk areas during April to June should prioritize the installation of lightning rods, improved building infrastructure, and public education campaigns to mitigate fatalities. Rural areas, in particular, require focused interventions as inadequate infrastructure and awareness exacerbate vulnerability. The IDW-based spatial maps provide actionable insights, enabling authorities to allocate resources effectively and prioritize high-risk zones. Strengthening early warning systems and enhancing preparedness during peak months could further reduce lightning-related casualties.

Broader Context and Impact

This study contributes to understanding lightning hazards in tropical regions and their link to climate change. The findings highlight the socioeconomic vulnerability of rural, agriculture-dependent communities in northern Bangladesh. By addressing these risks through localized disaster management strategies, the study offers a model for mitigating lightning hazards in similar geographic contexts. Additionally, the rising frequency of lightning incidents underscores the need for integrating lightning risk reduction into broader climate adaptation frameworks.

Conclusion

The spatial and temporal patterns of lightning incidents in Bangladesh reveal significant insights into the dynamics of this natural hazard. Temporally, lightning activity is highest during the pre-monsoon (March-May) and monsoon (June-September) seasons, with May and June consistently recording the highest number of incidents. This heightened activity is primarily driven by high humidity and rising temperatures that favor thunderstorm formation. In contrast, lightning activity declines significantly in the post-monsoon (October-November) and winter (December-February) months, when cooler and drier weather conditions prevail, reducing the likelihood of thunderstorms. Spatially, high-risk zones such as Sylhet, Rajshahi, and Rangpur consistently report a greater number of lightning incidents and fatalities, largely due to their unique geographical and climatic conditions. On the other hand, regions like Barisal and parts of the southern divisions experience relatively lower lightning activity. Advanced GIS tools, including Moran’s I and kriging interpolation, confirm clustered spatial patterns and identify persistently high-risk zones across the country.

The human impact of lightning incidents is severe, with fatalities particularly concentrated in high-risk zones like Rajshahi and Sylhet, while injuries are more widespread but remain severe in these vulnerable areas. These findings highlight the urgent need for targeted interventions to protect vulnerable populations. Recommended applications include installing lightning protection systems, particularly in schools, hospitals, and residences in high-risk areas; enhancing real-time and seasonal early warning systems; and educating communities on lightning safety during the pre-monsoon and monsoon seasons. Additionally, integrating these findings into disaster management plans can aid in prioritizing resource allocation for high-risk zones.

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