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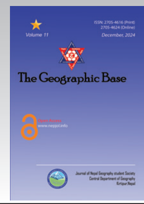

Nature of Lightning Hazard and Distribution during Post Monsoon Season in Makwanpur District

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Abstract

Nepal is one of the global hotspots for lightning events, with lightning strikes constituting a major natural disaster in the country. Among Nepal's districts, Makwanpur is particularly vulnerable to destructive thunderbolts. According to the DRR Portal, thunderbolts have caused 83 fatalities and 296 injuries in the district since 2011. This study focuses on analyzing the nature, distribution, and occurrence of Lightning in Makwanpur District during the late monsoon period, specifically from September to October 2024. The study observes lightning activity during this pre-winter season. A 32-day observation was conducted using satellite-enabled tools to monitor lightning occurrences, their proximity, and their characteristics, including power and polarity. For this purpose, Meteologix, an online Lightning and weather Monitoring tool was used. The finding shows that south-eastern part of Makwanpur district shows high concentration of lightning.

Introduction

Lightning is a discharge of electrostatic energy commonly through clouds. The cause of lightning is primarily clouds categorized as cumulonimbus. Thunderclouds are formed from cumulus clouds when hot moist air parcels rise through the atmosphere and cool down due to adiabatic expansion (Rakov and Uman, 2003). During this process, a large amount of charge accumulates in these clouds, dissipating to other parts of the cloud, different clouds, or the ground. According to the National Severe Storms Laboratory, U.S.A, (n.d.), there are several types of lightning. Intra Cloud lightning (IC), is a lightning bolt of lightning where charge dissipation takes place from one cloud to another within the same cloud. Cloud-to-cloud Lightning (CC), is a type of lightning where lightning flash travels from one cloud to another. Finally, CG or Cloud to Ground is a type of lightning where charge dissipation from the cloud makes contact with the ground. Almost all cases of fatalities can be attributed to CG lightning events.

When charge builds up on a cloud, both polarities (negative and positive) of charges are formed in the cloud, where the net positive charge accumulates at the top of the cloud, followed by the net negative charge at its bottom, and a positive charge at the bottom part (Rakov and Uman, 2003). Because of this reason, the dissipated charge on ground or clouds shows different polarities. As per the National Weather Service, U.S.A., (n.d.), a typical lightning flash can have 30,000 amperes of current at 300 million volts. This makes CG lightning very dangerous because electric discharge at this magnitude can easily injure or kill humans and animals alike, while also posing significant damage potential for physical structures or flora. According to the National Weather Service, the lightning channel temperature can reach up to 50,000 degrees Fahrenheit, an extreme temperature that also poses a risk for fire.

Total lightning density is the annual distribution of lightning frequency over a given area. For some parts of Makwanpur district, the lightning density per square kilometer is 16 per year (Vaisala, 2016-2023). This makes this region significantly vulnerable to risks associated with thunderbolts. Besides that, the presence of hills can provide a good target for Cloud-to-Ground strikes as per NSSL (n.d.). Lightning is most commonly observed during the pre-monsoon and monsoon seasons in Nepal (Saha, 2019). However, for 2024, it was predicted that above normal monsoon can be expected (The Kathmandu Post, 2024).

The primary objective of this study is to investigate the nature of lightning during the late monsoon season in the context of Makwanpur district's geographical conditions. Based on the data gathered through the study and the literature review, the study aims to identify risk zones based on the closest proximities of recorded lightning events.

Methods and Materials

Study area

The study area of this study is the Makwanpur district of Nepal. The spatial extension of Makwanpur district, Nepal, is 27.5546° N, 85.0233° E. It has an area of 2,426 km², with a rural population of 49.37% and an urban population of 50.63% as per the District Administration Office Website (n.d.). It has a total population of 466,073 as per the District Administration Office Website (n.d.). Ecologically, it lies in a subtropical to warm temperate region with elevation ranging from 142 to 2588 meters. The temperature regime varies from hot and wet in summer to warm and relatively dry in winter. Climate assessment conducted in Makwanpur district exhibited high variability in precipitation in the past (AEPC, 2011). Analysis of national–level data from 2015-16, covering human loss, casualties, financial loss, damages, and affected families, has shown that lightning is among the five most devastating disasters in Nepal (MOHA, 2017). Makwanpur is one of the districts with the most significant number of fatalities associated with lightning (DRR-Portal, 2024). The study area of Makwanpur district is expressed on the map in Figure 1. The map shows varied elevation details of the Makwanpur district alongside the administrative boundary.

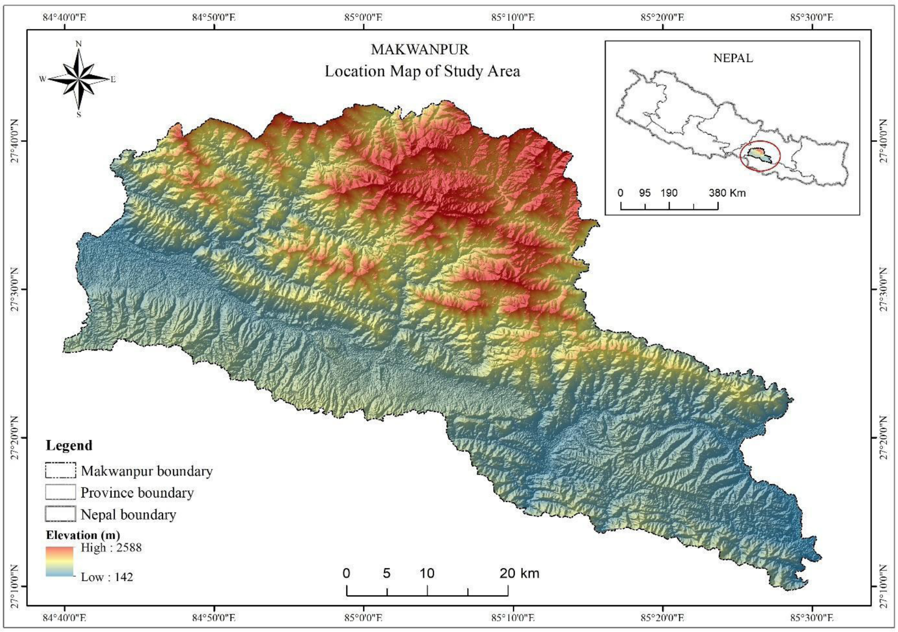

Figure 1. Location map of the study area.
Source: Department of Survey, Nepal (2024)

Data collection for lightning was conducted using Meteologix. Meteologix is a weather platform that provides weather data in visualized form online and enables scholars, businesses, and research institutions to study the phenomenon (Meteologix, 2024). The website provides users with a live lightning map, featuring an interface that displays data on date, time, polarity, and power of lightning in a given location. The data is refreshed every 5 minutes. Observations were carried out daily during the study period on the platform, and data were collected for this study. For discussion and analysis, we have resorted to various studies, research articles, and papers to deduce the reasoning that explains these phenomena. For this study, the map was set to Makwanpur, and observations were carried out from 19 September to October 20. The lightning location has been calculated based on the nearest place's proximity. The digital data extracted from the Department of Survey, Nepal. The reason for selecting this duration was the extended monsoon end phase (September – October window) in Nepal (DHM, 2024).

Vaisala's lightning density map has been used to study lightning density in Nepal. ArcGIS and Google Earth have been used to prepare and showcase maps and images, respectively. Maps for cloud-to-ground lightning and cloud-to-cloud lightning events were prepared. Maps for Negative and Positive Lightning have been prepared alongside for their proportional distribution.

There are some limitations to this study. The first one is the nature of data. The data used for analysis lacks latitude and longitude data to pinpoint lightning origins, so we used the nearest place as a proxy for both CG and CC events. While accuracy is maintained for regional proximity, we were unable to acquire precise geo data points. Another limitation is the available dataset, which does not include past observations. So observation has only been carried out during the September-October window. To mitigate this, we have compared the results with previous studies encompassing the study area.

Results and Discussion

Between September 19th and 20 October, there were 13 days with lightning events. A total of 1322 lightning were recorded during these 13 days, with six attributes giving a total of 7932 data points. Of 1322 lightning events, 59.2% of the total lightning that happened had negative polarity, and 40.8% of the total lightning that happened had a positive polarity. A total of 74.9% of the total lightning recorded was CG lightning, whereas 25.1% of the total lightning was CC lightning. The total number of CG lightning was 990, whereas the total number of CC lightning was 332. Figure 2 shows the total lightning density map for Nepal that has been live on the Vaisala platform.

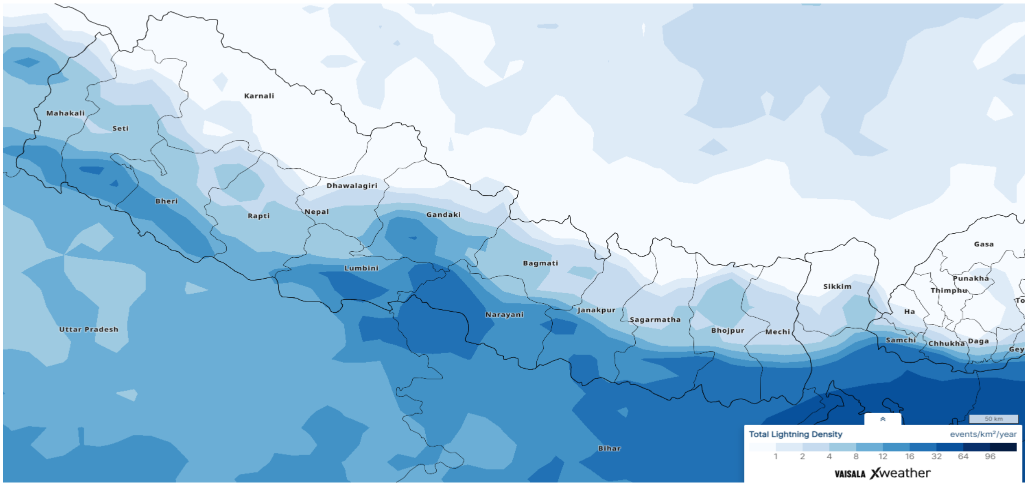

Figure 2. Total lightning density map

Source: Vaisala xweather platform, 2024

Polarity by lightning type

Lightning carries either positive or negative polarity. It was observed that for cloud-to-cloud lightning, only 16.86% were recorded to have negative polarity. 56 out of 332 lightning were negative, whereas the remaining 276 flashes were positive, representing 83.13%. Similarly, for cloud to ground lightning, however, 726 out of 990 flashes have negative polarity. This is 73.33% of total CG lightning. 26.66% of the total lightning that hit the ground had a positive polarity. Based on the above data, it can be stated that most of the lightning events associated with CC are positive in nature, whereas the majority of the lightning events associated with CG are negative. The result is also similar to the national average of 34% for cloud-to-ground Lightning (Nepali Times, 2019).

Power and polarity

The average current for all negative lightning was -53.12 kA. The minimum current recorded was -3kA, and the maximum recorded was -180kA. Each of these values were recorded only once. For CG lightning, the highest value recorded (considering polarity) was -180kA. For CC lightning, the highest value recorded was -27kA.

The average current for positive lightning was 51.87 kA. Here, the minimum recorded value stood at 3kA while the maximum value recorded was 220 kA, which was a CG event. For the CC lightning event, the highest recorded value was 29kA. From the distribution, we can observe a symmetrically skewed bell curve for CC and CG Lightning for positive polarity. Bimodal distribution is observed for CG lightning in negative polarity. The average for both polarities, compared to their frequency, also appears to be close to one another at 50±3 kA (figure.

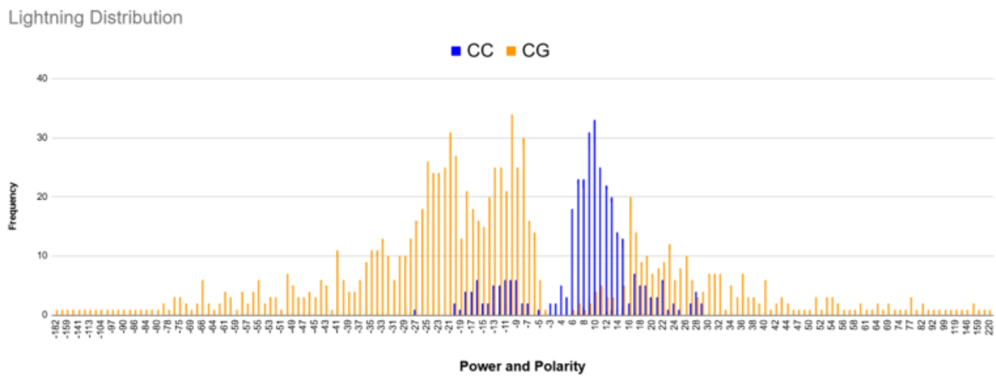

Figure 3. Power and polarity distribution of negative and positive lightning (CC & CG)

Source: Meteologix, 2024

Distribution by proximity to a place

Distribution of lightning across the district was recorded. The overall lightning density for Makwanpur district during the observation period was calculated to be 0.54 events/km^2, and the district average lightning was roughly 41 events per day. The majority of lightning has occurred during either early morning or nighttime during the observation period. The maximum number of lightning events occurred near Shripur Chaitwan, with 195 lightning events recorded. Out of this, 65 lightning were CC and 130 lightning were CG. A total of 131 lightning events were recorded near Raigaun, making it the second most prone vicinity to lightning. Of these 36 were cloud-to-ground lightning events and 95 were cloud-to-ground lightning events. Similarly, lightning activities near Dhiyal, Faparbari, and Harnamadi were also found to be significantly higher. The maximum number of CG events occurred near Shripur Chaitwan, with 130 CG events. However, in terms of the aggregated percentile, it is 66.6% of the total lightning. In terms of the distribution of lightning at events with values ≥10. Thingan is the location with the highest rate of CG events at 92%. Thingan has the highest rate for negative lightning for values ≥10 events at almost 82%. Shripur has the highest number of positive lightning strikes recorded at 62%. Shikharpur proximity has the highest average current at -58.5kA for negative lightning. For positive lightning, near Kulekhani, the average power was calculated to be 77kA. For CC lightning, the average current was calculated to be 24kA near Agara. The highest average value was calculated at 144kA near Kulekhani for a CG event in conditions where values for the number of events were ≥1.

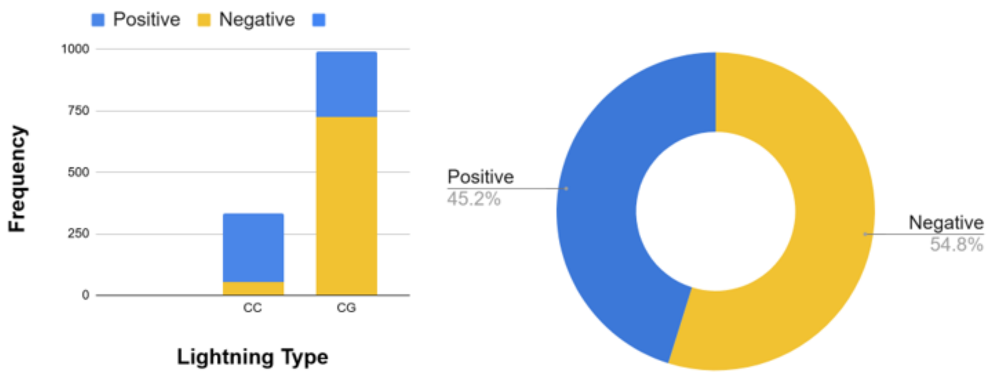

Figure 4a. Distribution of CC and CG lightning by polarity. **Figure 4b.** Polarity distribution of lightning.

Source: Meteologix, 2024

From the data, we found that the overall lightning density of Makwanpur during the research period was centered on the lower eastern Makwanpur district, with a significant presence in the eastern half of the district. In terms of administrative boundaries, the proximity of Raksirang, Kailash, and Indrasarowar shows minimum lightning frequency. Bakaiya, Bagmati, and Hetauda have relatively large amounts of lightning frequencies. These three local-level proximities constitute more than 67% or two-thirds of total lightning (both CC and CG) in Makwanpur district. The most observed Lightning in Makwanpur is negative lightning, which is predominantly CG in nature.

One reason for the large number of CG lightning is the dissipation of charge on the first hill contact points provided by two subsequent hills in the Chure range. These elevated regions can provide contact points for CG lightning. The lightning activity peaks around May in Nepal (Saha, 2019). However, during this observation period, we also observed significant lightning in September and October, which corresponds to the late monsoon. Lightning density in this region can be attributed to surface temperature and humidity (Saha, 2019). This is due to increased convective Available Potential Energy, CAPE. CAPE or Convective Available Potential Energy is the potential energy carried by an air parcel due to lift created by positive buoyancy (AMS, 2024). Monsoon can be attributed to increased humid conditions in the region (DHM, 2024). Also, Makwanpur has one of the warmer average temperatures in Nepal (DHM, 2017). These conditions contribute to an increase in CAPE. In Nepal, the monsoon arrives from the Bay of Bengal (Navaya, 1980). Charged cumulonimbus clouds that are carried into Nepal may also contribute to lightning in this place and the adjoining part of the Tarai region.

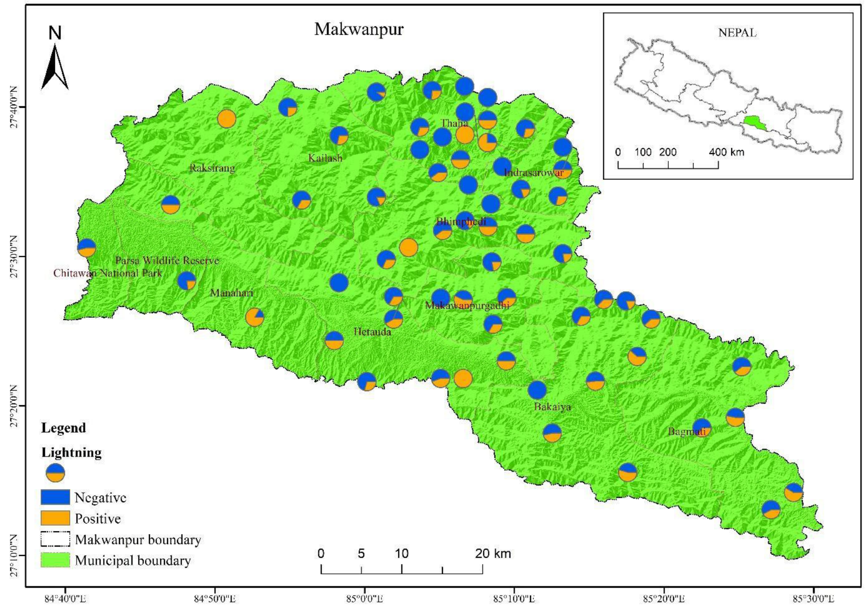

Figure 5a. Distribution of the proportion of CC and CG lightning in proximities

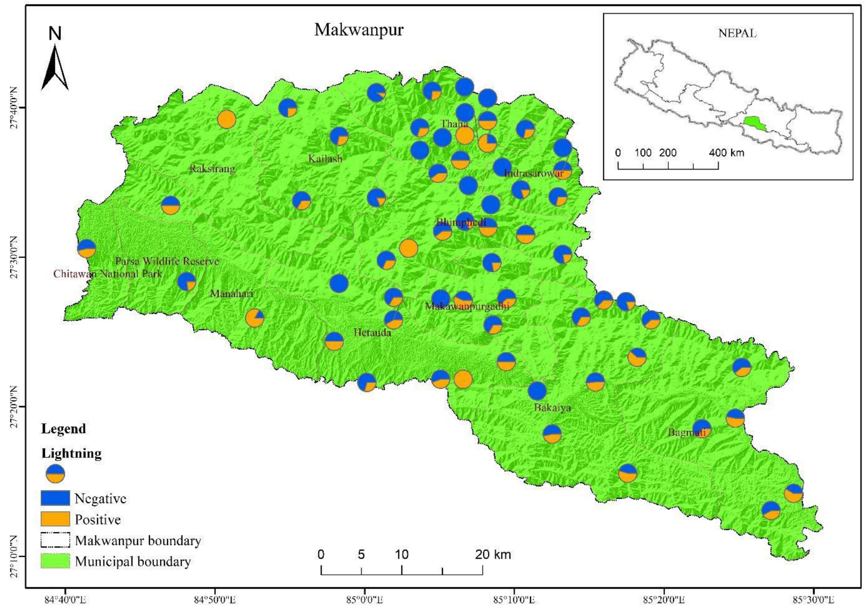

Figure 5b. Distribution of the proportion of negative and positive lightning in proximities across Makwanpur.

Source: Meteologix (2024), Department of Survey, Nepal (2024)

The distribution of CC lightning and CG lightning in Makwanpur is represented in Figures 5a and 5b. Here, we can observe that the proximities of both CC and CG lightning is distributed across the district. However, we can observe that the proportion of CG lightning increases as we move towards the hilly part of Makwanpur, while the proportion of CG and CC lightning is present frequently on observations made at lower proximities. This can be because the mountainous region is responsible for providing a feasible environment for CG lightning (Adhikari, 2024).

Another way to look at this can be to understand the vertical tripole structure (Rakov and Uman, 2003). Here, clouds arriving from the southeastern part with lower elevation come into contact with hills, where they have the opportunity to dissipate their charge into the ground. This may contribute to low-ampere CG lightning in the southern part of Makwanpur. This, however, means that the negative charge and top-level positive charge are required to dissipate. Since the built-up here is maximum, the power at which the top layer's positive charge dissipates is higher. So inevitably, when the positive lightning does hit later during the storm, the thunderbolts that are positive may be even more dangerous (NOAA, 2023). An example of this is observed in Chitlang, which saw positive CG lightning flashes with 147 kA, Kulekhani with 146 kA, and Betini with 220 kA. However, it is not possible to draw a conclusion as an even more discrete dataset is required in this regard. From the general observation, we can claim that the proportion of CG lightning increases as we move towards the more hilly terrains of Makwanpur.

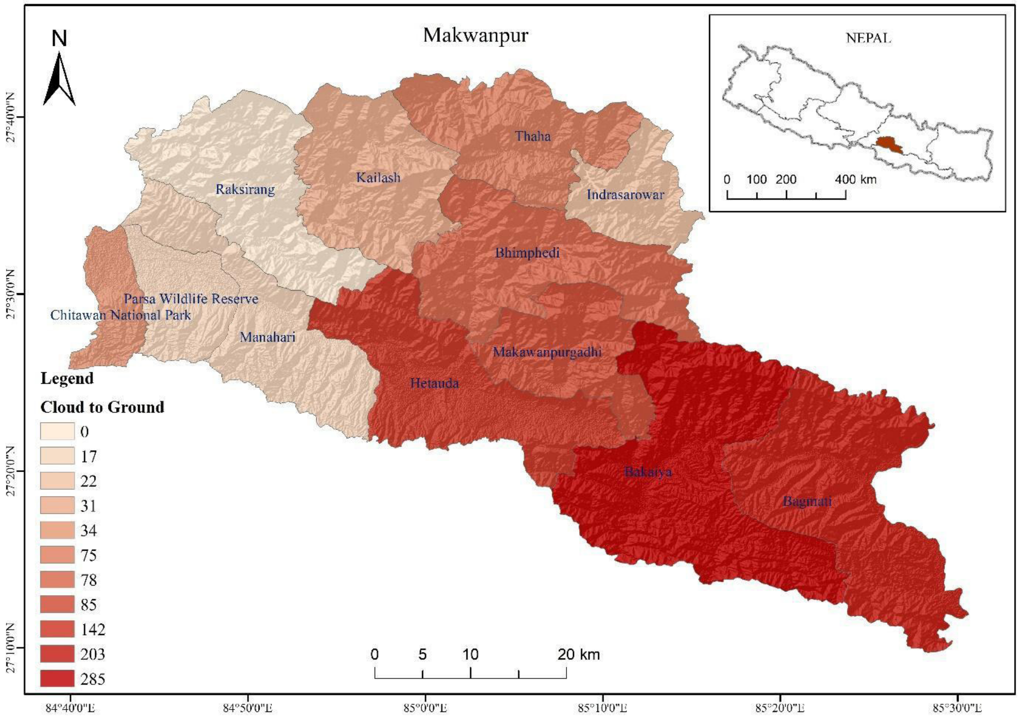

Figure 6. Cloud-to-ground lightning distribution during the observation period by local levels in Makwanpur district.

Source: Meteologix (2024), Department of Survey, Nepal (2024)

From the observation, it was found out that the maximum number of CG lightning occurred around the local levels of Bakaiya, Bagmati, and Hetauda. These local levels account for 50% of total CG lightning in Makwanpur district. Moreover, these places also resemble unique Chure hill features, such as sudden hills and the presence of low-lying areas. Chitwan National Park, Makwanpurgadhi, Bhimphedi, and Thaha also show a reasonable amount of CG lightning proportion. However, due to the increased number of CG lightning frequency, we can identify Bagmati, Bakaiya, and Hetauda as hazard zones for lightning, followed by Makwanpurgadhi and Bhimphedi. The distribution pattern of Lightning for Negative and positive Lightning also appears to be similar to the aggregated lightning distribution, as shown in Figure 7. Here, we can observe a similar distribution pattern for negative and positive lightning, with lower eastern Makwanpur exhibiting the most significant proportion of the both (CC and CG) lightning events.

Besides this, the presence of vegetation is significant in these regions. This increases the amount of moisture trapped by vegetation and, in turn, creates favorable conditions for lightning buildup (Vassiliki, 2008). Besides this, the vegetation that primarily consists here is occupied by a forest that covers 59.14% of the total area (Tamang, R., & Chapagain, 2021). This may increase CG probability by contributing to moisture release during hot weather. This can increase humidity and contribute to thunderstorm cloud formation (Rakov and Uman, 2003), and also provide a ground point for CG lightning under their height and conductivity. The presence of such vegetation poses a significant risk for cloud-to-ground lightning events.

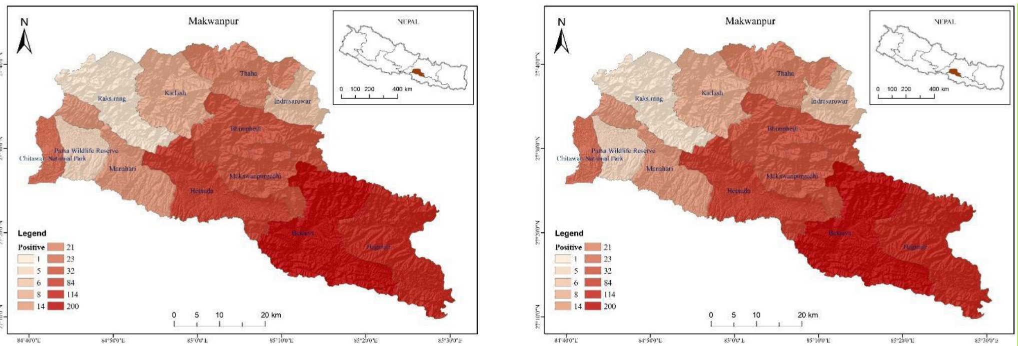

Figure 7a. Distribution of positive lightning in Makwanpur

Figure 7b. Distribution of negative lightning in Makwanpur

Source: Meteologix (2024), Department of Survey, Nepal (2024)

Similarly, it has also been observed that the majority of Cloud-to-Cloud lightning has concentrated in lower Makwanpur. The distribution of cloud-to-ground lightning spans across the northern part of the Makwanpur district. This may be because the tall mountains provide a favorable environment for CG lightning to occur due to the shorter distance between the ground and the cloud. Distribution of CG lightning by proximity has been represented in a heatmap in Figure 8. In Figure 9, we can see a stark difference in the distribution pattern for CC lightning. However, this can also be attributed to the frequency of CC lightning being lower than CG during the study period.

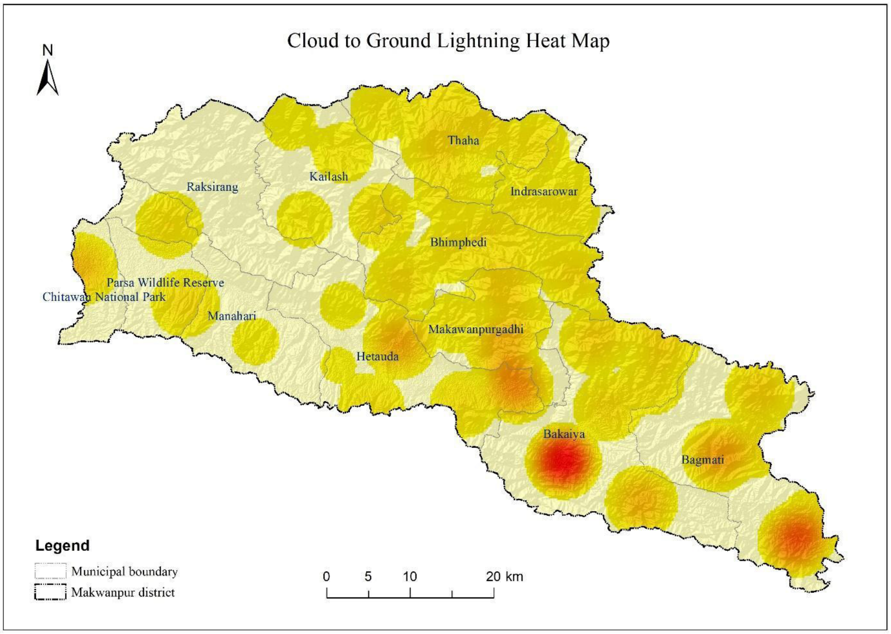

Figure 8. Cloud-to-ground lightning heatmap in Makwanpur district during the study period

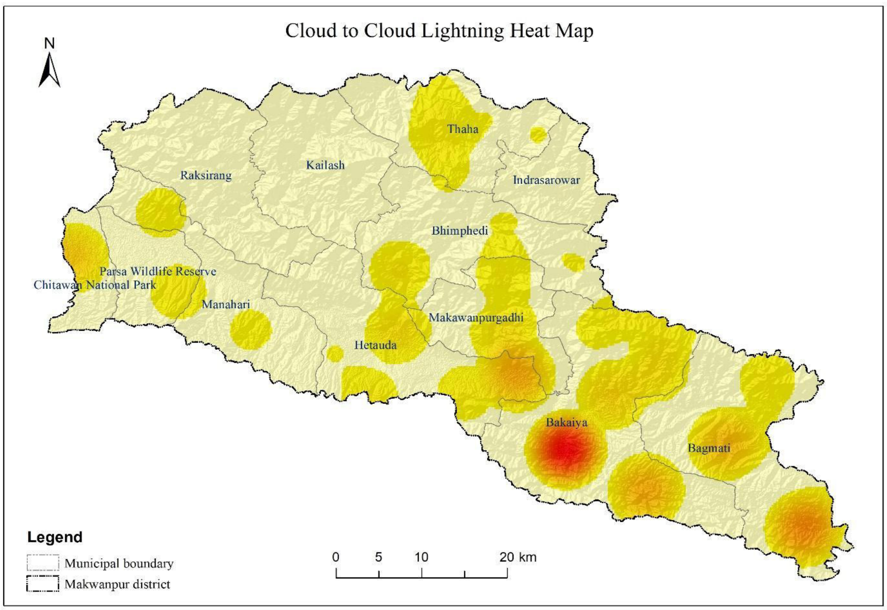

Figure 9. Cloud-to-cloud lightning heatmap in Makwanpur district during the study period
Source: Meteologix (2024), Department of Survey, Nepal (2024)

Conclusion

Makwanpur district has several factors that contribute to a higher chance of CG lightning, as reflected in both our observation and literature review. The low eastern region of Makwanpur is susceptible to both CG and CC lightning events, characterized by higher frequencies of lightning of both polarities. Lightning variation can be observed as we move north towards the more hilly regions of Makwanpur, in terms of proportional distribution between CG and CC events. However, more data is required in this regard to elaborate on the lightning phenomenon over Makwanpur district. Our study reveals that Low Eastern Makwanpur has the highest concentration of lightning events, rendering it a high-risk zone for lightning-related disasters. The risk zones include local levels like Bagmati, Makwanpurgadhi, Bakaiya, Hetauda, and Chitwan National Park. However, records of high-power (current) lightning in upper Makwanpur suggest that lightning risk cannot be related solely to frequency. The presence of significant vegetation cover may increase the probability of CG lightning in the Makwanpur district. The findings provide the basis for disaster preparedness in proximity areas with the largest lightning frequency (CG). The findings can be used to reduce the chances of wildfire during winter.

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