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# Ground Flash Density Mapping in Nepal: Enhancing Lightning Performance and Resilience of Distribution Lines

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**Abstract- This paper presents the first comprehensive Ground Flash Density (GFD) map of Nepal, an essential tool for addressing the high incidence of lightning strikes that significantly threaten the country's power infrastructure. Analyzing data from the GLD360 network over 2015-2019, the study maps lightning activity across Nepal, highlighting its year-round occurrence with a peak during the pre-monsoon season. The findings show the highest frequency of lightning strikes in the Terai region, decreasing with elevation. The GFD map specifically identifies a critical 30 km segment of a 33 kV distribution line, which recorded an extraordinary 10,751 flashes, peaking at a density of 25.31 strokes/km². Additionally, the study advocates for ongoing monitoring to assess the efficacy of implemented mitigation strategies. This includes tracking arrester currents and deploying high-speed cameras for detailed lightning strike analysis, which will contribute to a deeper understanding of lightning behavior and further improve protective measures for Nepal's power systems.**

**Keywords- Ground flash density, lightning, Nepal, distribution system, line arresters, ArcGIS**

## 1. INTRODUCTION

Lightning is a significant natural hazard that poses considerable risks to power systems worldwide. In Nepal, lightning is the second deadliest natural disaster after the earthquake, causing numerous fatalities and tremendous property damage worth billions of Rupees each year [1,15]. Lightning causes severe disruptions to the power grid yearly leading not only to power outages but also to damage critical infrastructure, impacting economic activities and the daily lives of citizens [2]. Elevated hills and mountains of Nepal further aggravate the threat not only to the people and livestock but also to the transmission and communication system. Lightning overvoltages are caused in three different ways: a) Lightning strikes directly onto a transmission line b) Lightning strikes in the tower or the ground wire of an overhead line c) Lightning strikes in the vicinity of a line or a substation. To implement protective measures against the lightning overvoltage on the transmission system risk assessment is inevitable. One of the main components of lightning risk assessment is lightning ground flash density. Furthermore, the extent of damage depends upon the magnitude of current associated with lightning stroke which in turn relies on the nature of lightning ground flash. Positive ground flashes generally possess a high magnitude current compared to their negative counterparts. This study considers lightning ground flash density for both positive and negative strokes to understand the nature and extent of damage it can cause of the transmission system. Therefore, understanding and mitigating lightning-related hazards is crucial for ensuring the reliability and resilience of Nepal's power distribution network.

Ground Flash Density (GFD) is a key parameter in assessing the lightning risk to power systems. GFD represents the number of lightning flashes per unit area per year and is typically measured in flashes per square kilometer per year. Accurate GFD mapping helps identify high-risk areas, enabling targeted measures to protect power lines and reduce lightning-induced outages. GFD is estimated from the keraunic level (regional lightning activity-thunderstorm days per year ($T_d$)) as follows [3]:

$$GFD(N_g) = 0.04\, T_d^{1.25} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Research on GFD and its impact on power systems is extensive. A comprehensive overview of lightning physics, emphasizing the critical role of precise GFD data, is provided in [4]. Studies have shown that understanding and mapping GFD can identify vulnerable areas and suggest improvements in power systems to mitigate lightning strike damage [5, 6]. For instance, detailed seasonal GFD maps have guided strategies to improve distribution line performance in Peninsular Malaysia [7, 8]. Similar findings from Pakistan emphasize the importance of GFD mapping in enhancing power system resilience [5]. GFD serves as a parameter to gauge the intensity of lightning activity. While it does not directly improve line performance, it provides critical information that allows for targeted mitigation strategies to enhance the resilience and reliability of power distribution networks. In Nepal, while satellite-based observations provide valuable insights into lightning patterns [9], case studies emphasize the urgent need for localized GFD data to protect rural mini-grids and improve power reliability [2, 10]. Although research from regions like Pakistan and Malaysia demonstrates the benefits of detailed GFD mapping for power systems [5, 7, 8], Nepal lacks comprehensive GFD studies that consider local weather and topographical features. Recent studies have also highlighted the effects of urbanization on lightning activity and the importance of advanced lightning protection methods [11, 12, 13]. This study aims to fill this gap by providing a detailed analysis of GFD in Nepal, identifying lightning hotspots along 33 kV distribution lines, and evaluating the impact of lightning on the power distribution network. By leveraging GIS software and recent lightning data, this research aims to contribute to the development of effective lightning protection strategies tailored to Nepal's unique climatic and geographical conditions.

The remaining part of the article is arranged as follows: Section II provides background information on the study area, including details on the GIS software used, and the study area map of Nepal. Section III delves into the methodology employed, outlining the calculation of GFD for different weather scenarios and the software process involved. Section IV presents and analyzes the resulting ground flash density map, followed by observations and potential applications. Section V concludes with a summary of key findings and outlines future research directions.

## 2. STUDY AREA AND TECHNICAL FRAMEWORK

The country of Mount Everest, Nepal, lies in the northern hemisphere of latitude 26.37°N to 30.45°N and longitude 80.066°E to 88.2°E in a Himalayan region [1]. The altitude of the country ranges heterogeneously from 59 m to 8848.86 m. The land of the lowest altitude lies in the Terai while that of the highest altitude (i.e., Mount Everest) lies in the Himalayan region. It has normally been observed that lightning ground flash density decreases away from the equator [14]. However, the decrease in the lightning density trend is not uniform and the Hindu Kush Himalayan region receives higher flash density and appears to be the lightning hotspot. The elevated hills and mountains are likely to receive more lightning ground flashes than the other places at similar altitudes. Owing to its mountainous topography Nepal is highly prone to lightning-related human injuries and fatalities ranking 1st in South Asia in the perspective of human casualties per year per million population [1, 15], damage to houses and buildings, and disturbances in power supply system. Unlike other regions across the globe, Nepal receives relatively high positive ground flashes as compared to their negative counterpart [16,17], Although a lightning flash density map has been obtained covering entire regions of Nepal a particular emphasis is given over the Lahorpati 33 kV distribution line located in the Mahottari district of the Tarai region, which is known for its high average GFD. This distribution line, spanning a length of 30 km from point A to point B, as illustrated in Figure 1, was selected for detailed study. The primary objective of this investigation was to use the preliminary findings from GFD analysis to develop strategies aimed at improving the protection and performance of the distribution line.

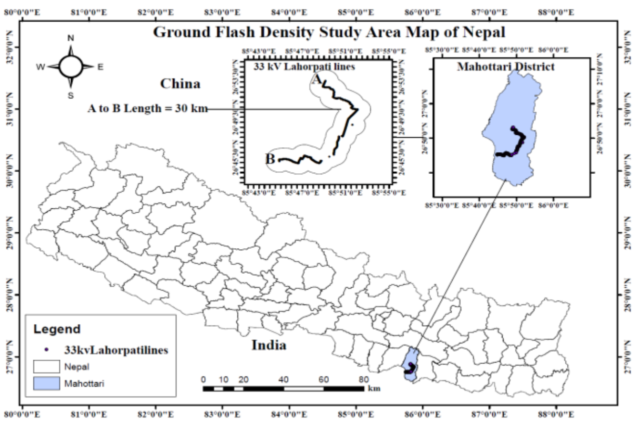

Fig. 1 Study area map of Nepal

## 3. ASSESSMENT PROCEDURE

Data on lightning activities over Nepal, spanning from 2015 to 2019, was sourced from the Global Lightning Dataset (GLD-360). The GLD-360 is a global, real-time lightning detection network that, as of 2022, operates nearly 100 stations worldwide. The distribution line data was provided by the Nepal Electricity Authority (NEA) [18]. The methodology used to analyze lightning data and develop GFD maps for Nepal and 33kV distribution lines involves several detailed steps. Initially, the lightning data is segregated by season and categorized into positive and negative strikes. A comprehensive base map of Nepal is prepared, and lightning data from 2015 to 2019 is gathered and stored in a geodatabase using ArcGIS 10.8 server software [19]. The Nepal projection for the northern hemisphere at 45 degrees North is applied to ensure accuracy. A 0.1°x0.1° (100 km$^2$) grid is created on the Nepal base map, clipped to fit the country's geographical boundaries. The lightning data is separated into winter, pre-monsoon, monsoon, and post-monsoon seasonal datasets to reflect seasonal variations. These datasets are spatially joined with the clipped base map to integrate the data accurately. To calculate the GFD, the number of lightning occurrences in each grid is counted and divided by the area (100 km$^2$) per year. Seasonal GFD maps are then generated to visualize the distribution and intensity of lightning activity [8,19]. Each season's lightning data is categorized into positive and negative strikes. These datasets are then plotted separately to highlight the seasonal variations in positive and negative lightning activity. Finally, graphs representing these datasets are plotted using Python to represent the findings. This comprehensive approach ensures a detailed and accurate analysis of lightning activity in Nepal. Figure 2 illustrates the flow chart of current work.

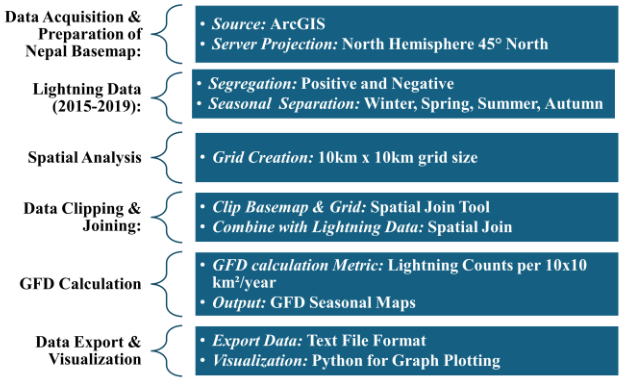

Fig. 2 Flow chart of current work

## 4. RESULTS AND DISCUSSION

The plots are represented seasonally, with separate analyses for positive and negative lightning strikes. The values, provided in strokes per square kilometer (strokes/km²) for various areas, are visualized on an ArcGIS 10.8. Figures 3 and 4 illustrate the average lightning activity for the winter season (December to February), showing positive and negative strikes, respectively. The highest GFD values are 0.54 strokes/km² for positive strikes and 1.077 strokes/km² for negative strikes, which are relatively low [20]. During the pre-monsoon season (March to May), the intensity of lightning activities increases significantly, as shown in Figures 5 and 6. The highest GFD values recorded are 8.48 strokes/km² for positive strikes and 10.40 strokes/km² for negative strikes, marking this period as the most intense on a seasonal basis.

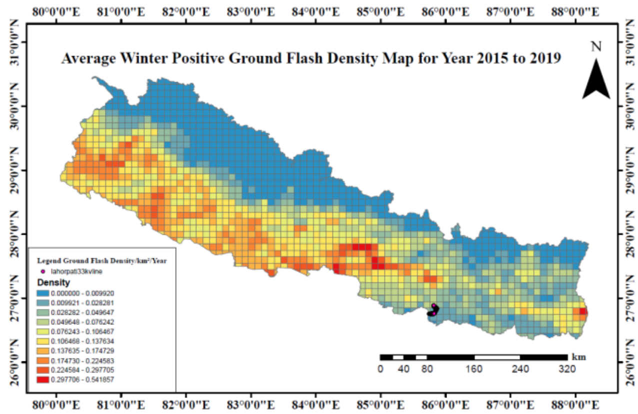

Fig. 3 Average winter positive (strokes/km$^2$)

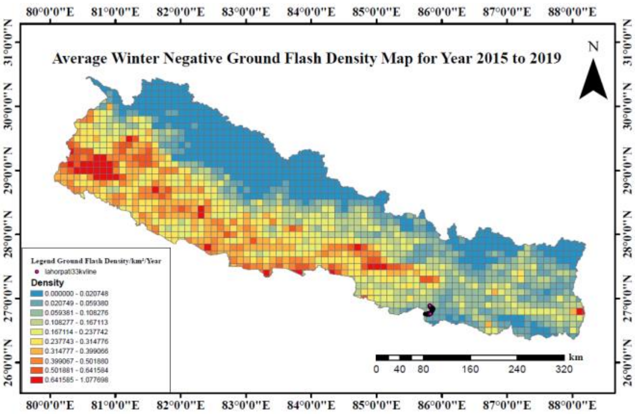

Fig. 4 Average winter negative (strokes/km$^2$)

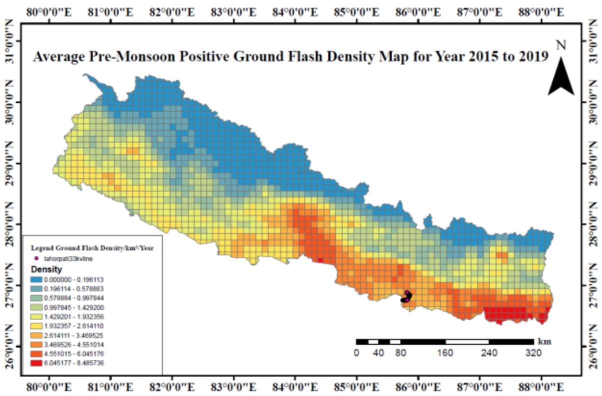

Fig. 5 Average pre-monsoon positive (strokes/km$^2$)

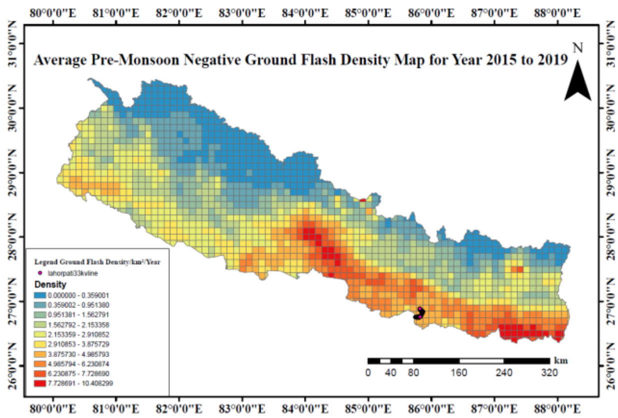

Fig. 6 Average pre-monsoon negative (strokes/km$^2$)

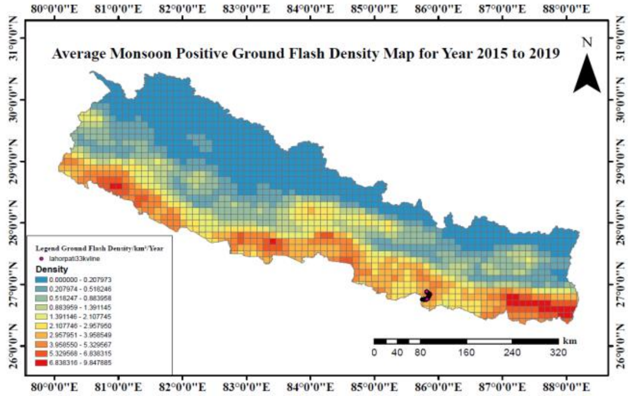


Fig. 7 Average monsoon positive(strokes/km$^2$)

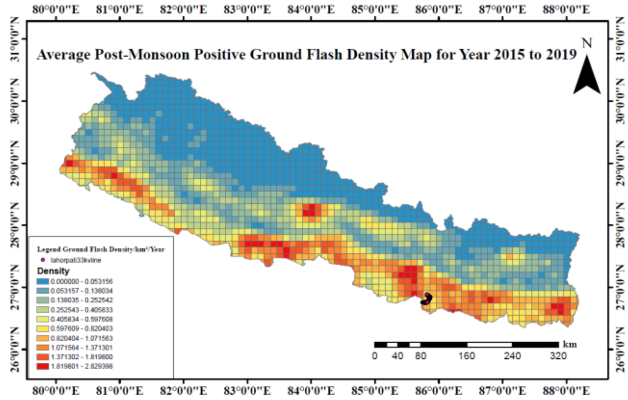


Fig. 9 Average post-monsoon Positive (strokes/km$^2$)

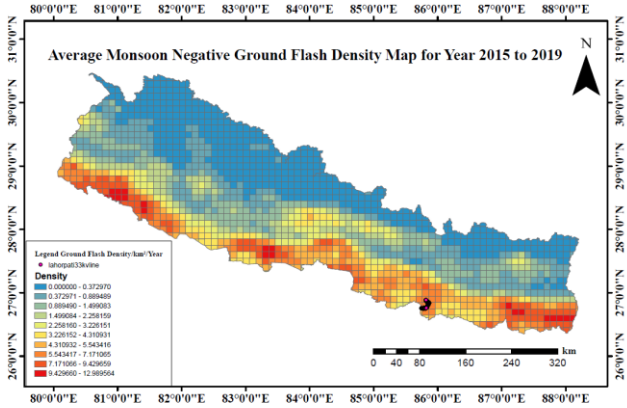


Fig. 8 Average monsoon negative (strokes/km$^2$)

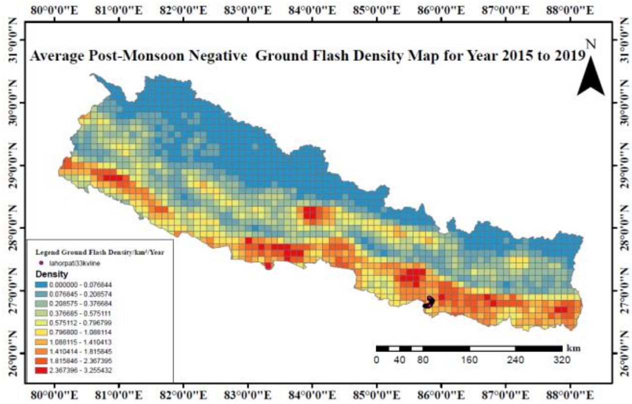


Fig. 10 Average post-monsoon Negative (strokes/km$^2$)

In the monsoon season (June to August), the intensity reaches its peak, with negative strikes at 12.98 strokes/km² and positive strikes at 9.84 strokes/km², as depicted in Figures 7 and 8. This highlights the high susceptibility of the Nepal to lightning strikes during the monsoon season [7].In the post-monsoon season (September to November), the intensity of lightning activity decreases compared to the pre-monsoon and monsoon seasons. Figures 9 and 10 show GFD values of 2.82 strokes/km² for positive strikes and 3.23 strokes/km² for negative strikes. Notably, lightning activities are minimal from November to January. When aggregated annually, the ground flash density map of Nepal, shown in Figures 11 and 12, indicates that lightning GFD ranges from 0 to 18.28 strokes/km²/year for negative strikes and 0 to 16.50 strokes/km²/year for positive strikes. This comprehensive analysis underscores the varying seasonal intensity of lightning activities and the particular vulnerability of the region during the monsoon season.

### A. KEY OBSERVATIONS IN THE TERAI REGIONS

It is observed that the Terai region, which lies close to the southern part of Nepal and is connected to India, experiences the highest values for lightning strikes. This pattern is evident in the eastern, central, and western parts of the Terai. However, as the elevation increases from sea level into the mountain region, the frequency of lightning activities decreases significantly, and there are almost no lightning

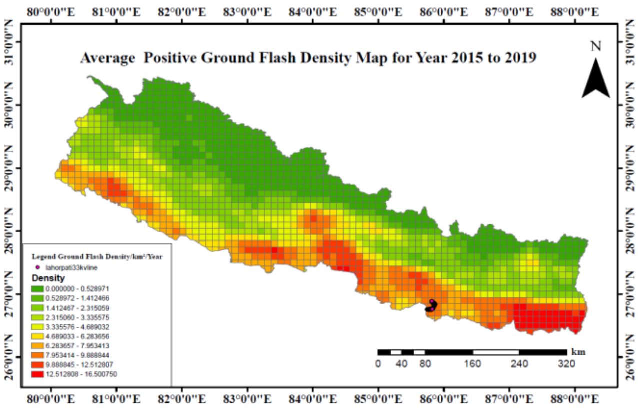


Fig. 11 Average five-year positive (strokes/km$^2$)

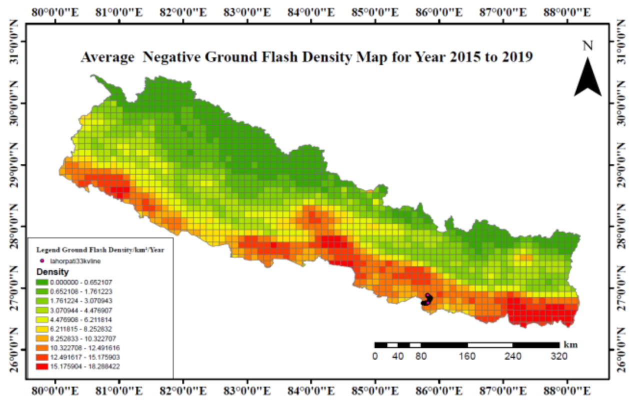


Fig. 12 Average five-year negative (strokes/km$^2$)

activities observed in higher altitudes. These were relatively shallow activities confined to the lower elevations. The seasonal analysis of lightning flashes reveals distinct patterns for both positive and negative lightning types. During the Winter season, there were 54,232 positive lightning flashes and 130,135 negative flashes during the period of this study. The pre-monsoon season saw a substantial increase, with 1,222,031 positive flashes and 1,832,954 negative flashes recorded across Nepal. In the monsoon season, the counts slightly decreased for positive flashes to 110,000, while negative flashes remained high at 1,642,038. The post-monsoon season recorded 289,416 positive flashes and 431,023 negative flashes. This data highlights that the pre-monsoon and monsoon seasons experience the highest lightning activity [19], with negative lightning consistently outnumbering positive lightning in all seasons. The findings underscore the need for targeted lightning protection measures, especially in the Terai region, to mitigate the impact of these frequent and intense lightning events on the power infrastructure.

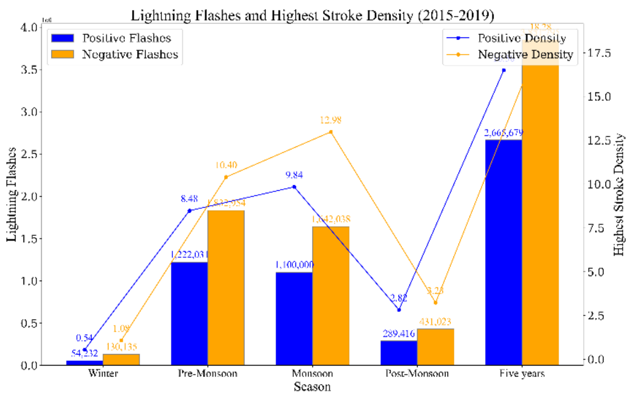


Fig. 13 Seasonal occurrence of lightning strokes

## B. LINE CONFIGURATION AND MODEL

Table1: Details of the 33kVdistribution lines

| Date | Time | Latitude | Longitude | Intensity | Strokes density | Joint Count |
|---|---|---|---|---|---|---|
| 2015-3-27 | 03:04:19 | 26.772 | 85.742 | 78.1(High) | 11.69 | 9 |
| 2015-03-30 | 08:37:51 | 26.797 | 85.862 | -44.5 | 17.6 | 94 |
| 2016-05-31 | 02:29:21 | 26.839 | 85.888 | -8.9 | 25.31(High) | 9 |
| 2017-07-23 | 00:42:57 | 26.841 | 85.889 | 7.1 | 17.60 | 10 |
| 2015-03-27 | 06:48:36 | 26.807 | 85.841 | -36.2 | 23.79 | 131(High) |

The 33 kV distribution line, spanning 30 km as depicted in Figures 14 and 15 (with the location of the study area given in Fig. 1), has been a focal point for lightning activity analysis. A 2 km buffer zone was established around the perimeter of the line, extending 1 km on each side, to facilitate the geographical and spatial analysis of lightning activity from 2015 to 2019. Within this buffer zone, 10,751 lightning events were recorded, indicating significant electrical activity along this line. The lightning events varied in intensity and stroke density, reflecting substantial variability in electrical activity. The mean stroke density across these events is 16.79 strokes/km², with a standard deviation of 19.39. This suggests that, while the average lightning activity is relatively high, there is considerable variability in the number of strokes. Notably, extremely high stroke densities were observed on May 31, 2016, with 25.31 strokes/km² shown in Table 1. The distribution line experienced both high and low-intensity lightning strikes. A high-intensity strike of 78.1 kA was recorded on March 27, 2015, while a low-intensity strike of -44.5 kA occurred on March 30, 2015. The number of flashes impacting the distribution line also varied significantly, affecting anywhere from as few as 9 joints to as many as 131 joints. This variation indicates the potential for differing degrees of impact on the distribution infrastructure. Given the substantial number of lightning events and the associated variability in stroke density and intensity, it is crucial to implement robust lightning mitigation measures for this 33 kV distribution line. These measures could include installing lightning arresters, enhancing grounding systems, and conducting regular maintenance and inspections to ensure the resilience of the electrical infrastructure against future lightning activity [21]. When the transmission and distribution power grid is superimposed on the ground flash density map of Nepal, the study specifically plotted the 33 kV distribution line from Lahotpati to Aurahi, which spans 30 km [22]. The analysis identified lightning-prone zones within a 2-kilometer buffer around the line, using a grid resolution of 0.01°x0.01° (approximately 1 km$^2$). Figures 14 and 15 illustrate the maps of lightning flashes and ground flash density over five years within the 2 km buffer area along the 30 km stretch of the 33 kV distribution line.

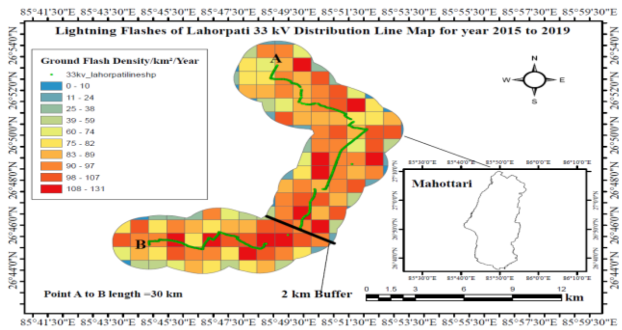


Fig. 14 Lightning flashes of 33kV distribution lines with 1km$^2$ grid.

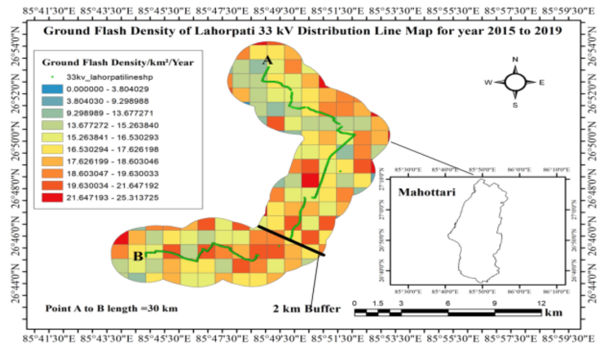


Fig. 15 GFD of 33 kV distribution lines with 1km$^2$ grid.

## 5. CONCLUSION

This paper presents data collected from lightning activities in Nepal from 2015 to 2019, culminating in the creation of the first ground flash density map of this mountainous country. The analysis covers both spatial and temporal dimensions. It was found that lightning strikes occur in Nepal through all seasons, with a peak frequency during the pre-monsoon season (March to May). The Terai region, encompassing the eastern, central, and western parts of Nepal, experiences the highest lightning strike values. In contrast, as the elevation increases, the incidence of lightning strokes decreases. The distribution line was analyzed within a 2 km buffer zone for the practical application, revealing 10,751 lightning flashes, the highest density being 25.31 strokes/km², and a maximum of 131 flashes in a single event. The study uses the ground flash density map to identify lightning-prone zones, aiming to enhance the lightning resilience of Nepal's transmission and distribution lines by framing a GFD-based protection strategy. Moreover, the comparatively higher percentage of positive ground across Nepal throughout all seasons manifests the higher level of protective measures against lightning on the power system. The outcome of this study lays a foundation for adopting appropriate protective measures in compliance with the standards set by the International Electrotechnical Commission (IEC). This GFD map is valuable for power system operators and meteorologists, architects, mega-structural engineers, and communication service providers. Monitoring the improvement of line lightning performance after implementing mitigation measures is essential for validating investments. Efforts should include tracking the actual current through arresters and, where possible, using high-speed cameras on poles for detailed lightning analysis. This approach allows for validating the lightning location system network with real-world data, enhancing our understanding of mitigation effectiveness and expanding knowledge of lightning phenomena.

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