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Research Article

VARIOUS TYPES OF LIGHTNING OBSERVED IN MOUNTAINOUS REGION RECORDED FROM KATHMANDU, NEPAL

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ABSTRACT

Vertical electric fields of lightning, generated by thunderstorms manifest on the rugged terrain in the mountainous vicinity of Kathmandu, Nepal. Diverse forms of lightning occurrences have been meticulously documented from a hill station in Kathmandu spanning a three-year interval, commencing from 2015 through 2017. Throughout this duration, cloud-to-cloud lightning discharges constituted 62.8% of the occurrences, while cloud-to-ground lightning discharges accounted for 20.4%. Additionally, 9.5% of the observed events were characterized as unusual lightning phenomena, and 2.9% were attributed to breakdown events. The elevated hills and tall structures inherent to the mountainous landscape significantly influence lightning activity, contributing to a heightened frequency of ground flashes in contrast to other areas.

Keywords: Density of CG lightning, different types of lightning, lightning in mountainous region, vertical electric fields

INTRODUCTION

In our solar system, the primary source of energy is the sun. Earth receives both heat and light energy from the sun, which sustains life on our planet. The Earth's revolution around the sun gives rise to distinct seasons. During the pre-monsoon period, the intense summer sunlight warms the Earth and its surface, leading to expansion of air from atmosphere and the evaporation occurs from water surface. The rising of this evaporated water vapor, followed by condensation at higher altitudes where it's colder, leads to the formation of cumulonimbus clouds (Malan, 1963). Within these clouds, various phases of water crystals, including tiny ice crystals, snow crystals, and graupel particles, form as a result of freezing and condensation. The molecules of water are moving randomly within the cloud, due to factors like mutual contact, collision, and friction, leading to electrification phenomena. This results in the accumulation of significant charges within the cloud (Rakov & Uman, 2003). The charge distribution within thunderstorms follows a tri-pole model, in which the negative charge remains at the center part, same number of positive charges just above it, and pockets of positive charge at the lower part inside cloud (Rakov & Uman, 2003).

When a particular region within a cloud accumulates a substantial electrical charge, it reaches a point where it can no longer hold the charge. This triggers an electrical discharge known as lightning. Lightning emits a range of electromagnetic radiation with varying wavelengths, making it an intricate electrical phenomenon (Rakov & Uman, 2003). The hydro-meteorological processes over mountainous terrains in the Himalayan region, along with the formation of thunderclouds, the charge structure of clouds, and lightning flash signatures, have been subjects of interest for scientists (Barros & Lang, 2003). Rakov and Uman (2003) have noted that thundercloud lightning patterns are influenced by factors such as latitude, topography, season, and storm type. Lightning phenomena are mainly two types of discharges: cloud discharges and ground discharges. Cloud discharges are about three times more frequent than ground discharges. The discharge of lightning initiation occurs from negative charge center of the cloud and terminates within a thundercloud (Bazelyan & Raizer, 2000; Rakov & Uman, 2003). Ground discharges are classified into four types: upward negative and positive, downward negative and positive (Berger, 1977; Nanevicz *et al*., 1987; Uman, 1987).

Williams (1989) also described the tri-pole charge structure of a thundercloud, where the main negative charge is centered within the cloud, and same number of positive charges is above the main negative charge center, and pocket positive charges remain at the cloud's bottom part. During a cloud's developmental phase, intra-cloud lightning (IC) typically occurs initially, followed by cloud-to-ground (CG) lightning. Both types of lightning occur during the mature stage of the cloud, while decay stage thunderstorms see their occurrence diminish (Williams, 1989). Nag and Rakov, in their work published in 2012, provided an explanation for the structure of thunderclouds and the potential occurrence of positive lightning. They highlighted the role of an excess of pocket positive charges within the tri-pole charge structure of thunderclouds as a contributing factor to the occurrence of positive lightning (Nag & Rakov, 2012).

Positive lightning is relatively rare, accounting for only about 10% of CG lightning. However, Baral *et al.* (1993) found a higher percentage of CG lightning in Nepal, reaching up to 38%, which they attributed to the rugged terrain and diverse topography. The unique geographical structure of Nepal, spanning from lowlands to the highest peaks like Mount Everest, contributes to significant climate variations within short distances (Adhikari, 2019; Wu *et al.*, 2019). These variations in temperature and geography also contribute to the increased occurrence of positive CG lightning in this region (Uman, 2001). Positive CG lightning, with average currents of 30kA and potential temperatures reaching up to 30,000 K, is particularly hazardous due to its higher current strength and temperature compared to negative CG lightning (Uman, 2001; Cooray, 2015). The multiplicity of positive CG lightning strokes up to four in a single flash has been documented in the Himalayan region (Adhikari *et al.*, 2016).

Positive flashes are prevalent during the dissipating stage of thunderstorms and are more destructive than their negative counterparts (Schumann *et al.*, 2013; Nag & Rakov, 2014). Unusual waveforms have also been observed in mountainous regions, in which the opposite polarity leader pulses before the return strokes in positive ground flashes (Adhikari *et al.*, 2017; Johari *et al.*, 2017). Lightning-related fatalities are higher in developing countries, with an estimated range of 6,000 to 24,000 deaths annually in the world (Holle, 2016). Cooper and Holle (2019) reported that over 24,000 people lose their lives annually due to lightning, and more than 240,000 sustain injuries worldwide.

Given the global impact of lightning incidents on human lives, livestock, equipment, and infrastructure, lightning protection measures are essential. Lightning protection systems typically consist of arrestors, down conductors, and ground terminals, which are installed on buildings to safeguard against lightning strikes and their associated hazards (Adhikari, 2021).

MATERIALS AND METHODS

In this research, the focus was on recording lightning electric field signatures at the station. This station in Kathmandu, Nepal is located at a latitude of 27°44'N, a longitude of 85°19'E, and an altitude of approximately 1300 meters above sea level. Lightning discharge phenomena encompass electrical discharges that emit electromagnetic radiation with varying wavelengths and frequencies. The electromagnetic radiation emanating from this phenomenon radiates in possible directions. The vertical electric field of radiations being detected by a horizontal plate as shown in figure 1. Figure 1 illustrates that model which is used for ground-based electric field measurements. The installed instrument in Kathmandu had the capacity to record various types of lightning flashes across a radius of about 500 kilometers, as affirmed by different authors (Adhikari *et al.*, 2016). Given that thousands of lightning events occur within a minute, it's not feasible to capture all these flashes simultaneously using the instruments (Holle, 2016). Thus, only the captured waveforms by this instrument, were subject to analysis in this study. These captured waveforms encompassed Cloud discharges, Ground discharges, isolated breakdown pulses, preliminary breakdown pulses, positive and negative lightning return strokes, and other categories.

As already mentioned, lightning is primarily categorized into two types: Cloud Discharges, accounting for about two-thirds, and Ground Discharges, constituting about one-third (Rakov & Uman, 2003). Within the realm of Ground Discharges, the classification extends to negative and positive lightning, based on the transfer of charges (-ve and +ve) from the cloud to the ground. Cooray (2015), Nag and Rakov (2009), Sharma *et al.* (2005), and various other researchers have corroborated this idea, emphasizing that approximately 10% of lightning return strokes are positive, while the remainder are negative (Sharma *et al.*, 2005; Nag and Rakov, 2009; Cooray, 2015).

Baral *et al.* (1993) conducted research in Kathmandu and found that positive lightning return strokes ranged from 26% to 38% (averaging at 34%). This proportion of positive lightning strokes is influenced by diverse factors including geographical structure, latitudes, humidity, temperature, and seasons (Rakov & Uman, 2003). Similar experiments were also carried out by Galvan and Fernando (2000), Sharma *et al.*, (2008), Nag and Rakov (2009), Ahmad *et al.* (2010), Baharudin *et al.* (2012), and Johari *et al.* (2017) to observe lightning phenomena.

In the scope of this study, over seven thousand waveforms were observed, measured, and recorded from the measuring station in Kathmandu over a span of three years (2015 to 2017), forming the basis of analysis. The diverse categories of lightning waveforms were explored to gain insights into the intricate nature of lightning discharges and their variations.

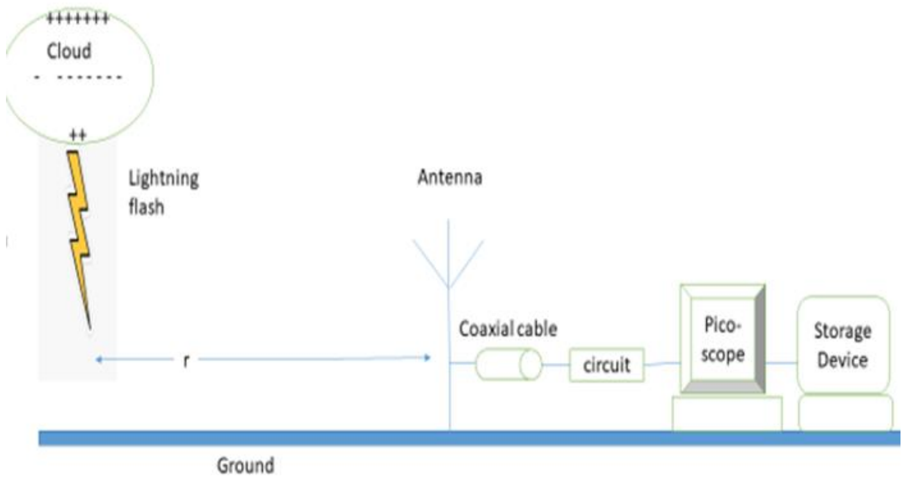

Figure 1. Illustration model of electric field measurement.

In this study, the electromagnetic field process was employed to capture vertical electric field waveforms generated by lightning. This involved placing a parallel plate antenna above the building whose height is more than twelve meters. Figure 2 illustrates the installation of the parallel plate antenna used which had a capacitance value of sixty pico-Farad. The electronic circuit produces output waveform to the oscilloscope (Pico-scope 6404D) as depicted in Figure 3. The signals waveform received from this setup through the circuit in the oscilloscope. The time interval of the recording waveform is 500 milliseconds, with a sampling rate of 312 million samples per second. This allowed for the precise capturing of lightning-related electric field waveforms.

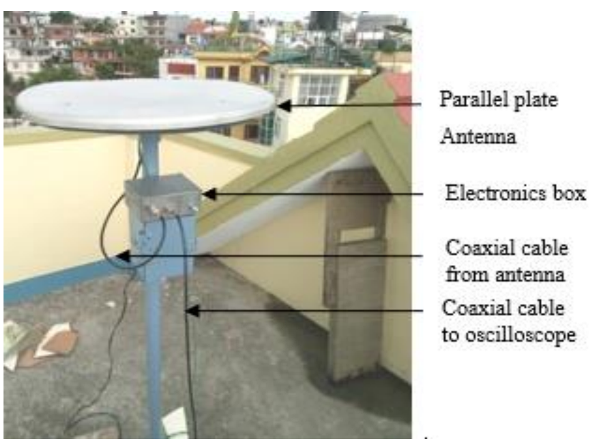

Figure 1. The parallel-plate antenna installed in Kathmandu.

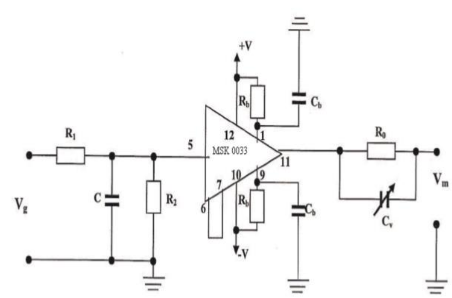

Figure 3. The buffer circuit inside the electronic box used in this research.

RESULTS

Lightning discharge is categorized into two types: Cloud Discharges, accounting for about two-thirds, and Ground Discharges, constituting about one-third (2). Within the realm of Ground Discharges, the classification extends to negative and positive lightning, based on the transfer of charges (positive and negative) from the cloud to the ground. The electric fields generated by lightning discharges were captured and recorded over a span of three years from 2015 to 2017. During this timeframe, the measuring station in Kathmandu, Nepal, observed and recorded more than seven thousand lightning flashes. However, certain types of flashes were excluded from analysis. This included flashes with saturated values, those with very low amplitudes close to the noise level, and events that couldn't be reliably detected. After excluding these cases, a total of five thousand eight hundred ninety lightning flashes were retained for analysis. These flashes exhibited various waveform patterns, ranging from typical to unusual. Additionally, the recorded data included isolated breakdown pulses, preliminary breakdown pulses, and more, which are detailed in Table 1.

Table 1. Various types of lightning waveforms were recorded over the three years.

Main Activity/ Descriptions	Lightning waveforms in different years			
	2015	2016	2017	Total
Cloud Activity	2119	954	625	3698
Return Stroke	725	408	70	1203
Total unusual events	422	102	38	562
Total of IBP/ PBP	141	22	7	170
Other Events	242	15	-	257
Grand Data Total	3649	1501	740	5890

Table 2 provides the distribution of different types of lightning flashes as percentages, and a visual representation of this distribution is presented in Figure 4. These tables and figures offer insights into the occurrence and composition of different lightning phenomena captured and analyzed during the research period.

Table 2. Various types of lightning waveforms expressed in percentage.

Various types of lightning flashes	Lightning waveforms in different years			Average in percentage
	2015	2016	2017	
Cloud Activity	58%	63.5%	84.5%	62.8%
Return Stroke	19.9%	27.2%	9.5%	20.4%
Unusual events	11.6%	6.8%	5.1%	9.5%
IB/ PBPulses	3.9%	1.5%	0.9%	2.9%
Other Events	6.6%	1.0%	---	4.4%

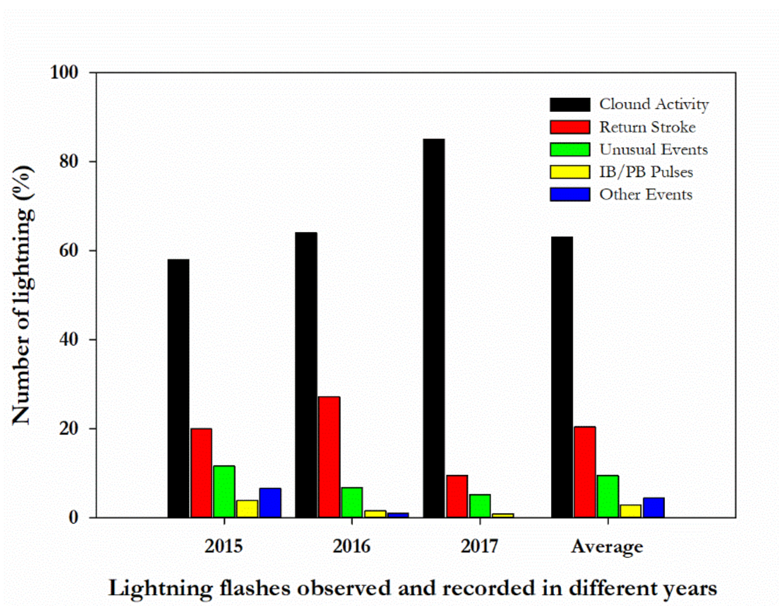

Figure 4. The various types of Lightning flashes presented in bar diagram.

The analysis of the observed data revealed varying proportions of various types of lightning waveforms over the years. In 2015, cloud-to-cloud lightning constituted 58% of the lightning flashes, which increased to 63.5% in 2016, and further to 84.5% in 2017. On average, cloud-to-cloud lightning accounted for 62.8% of all lightning flashes. An illustration of a cloud-to-cloud lightning flash is depicted in Figure 5. For cloud-to-ground lightning discharges, the proportions were 19.9%, 27.2%, and 9.5% respectively in 2015, 2016 and 2017. On average, cloud-to-ground lightning flashes made up 20.4% of all lightning flashes in which this lightning waveform is presented in Figure 6. Unusual lightning events were observed at rates of 11.6% in 2015, 6.8% in 2016, and 5.1% in 2017. On average, unusual lightning events constituted 2.9% of the total lightning phenomena which is presented as an example in Figure 7. Preliminary breakdown (PB) and isolated breakdown (IB) pulses were recorded at rates of 3.9% in 2015, 1.5% in 2016, and 0.9% in 2017. On average, these breakdown pulses contributed to 2.9% of the total lightning events. These breakdown events are illustrated in Figure 8.

Comparing the lightning data observed and measured in Kathmandu, Nepal, with other published records by Rakov & Uman, (2003), Cooray (2015), Nag and Rakov (2009), and more, supports the consistency of findings. The observed data corroborates that cloud discharge constitutes about two-thirds of lightning activity (62.8% here), while ground discharge constitutes about one-third (21% here). Despite variations in distributions, the presence of unusual lightning activities remained in our region, reinforcing the similarity of main lightning phenomena across years. These variations in distribution can be attributed to factors such as geographical structure, latitudes, humidity, temperature, and seasons.

DISCUSSION

Lightning is an electrical discharge phenomenon that occurs when a specific region of the atmosphere accumulates a significant amount of electrical charge. This discharge process emits the radiation of lightning of various wavelengths, with complex and intriguing subject of study for the scientific community. To capture the comprehensive activity of lightning flashes, a longer window size of 500 ms was selected. This choice enabled the capturing of the entire flash activity, including its multiplicity and intricate structures. When recording and measuring, it is crucial for the time window to be slightly longer than the waveform's duration. Adjusting the trigger level and pre-trigger time manually is necessary. Typically, setting the pre-trigger time and main event time to a ratio of 20:80 of the total window size allows for studying waveforms before the trigger as well as during the main events. Even a flash activity of 250 ms can be fully captured using this window size. However, selecting a shorter window size, like 100 ms, would result in only 80 ms for the main events, possibly missing some subsequent lightning stroke activities.

During the process of lightning, various cloud activities occur. Lightning flashes consist of several stages, including the breakdown stage, intermediate stage, leader stage, return stroke, continuing current stage, dart leader stage, and subsequent return stroke stage. When a specific region within a cloud accumulates enough charge and its potential surpasses a certain threshold, a breakdown occurs within the cloud. This is followed by the intermediate stage, during which the charge progresses towards the ground incrementally, known as the stages of stepped leader. As it gets close to an object on the ground, an answering leader from the ground connects, resulting in the return stroke. This phase is termed "Return stroke," as a substantial current rapidly neutralizes the previously ionized channel. Positive and negative ground flashes transport respective charges from the cloud to the ground, with negative ground flashes being more prevalent.

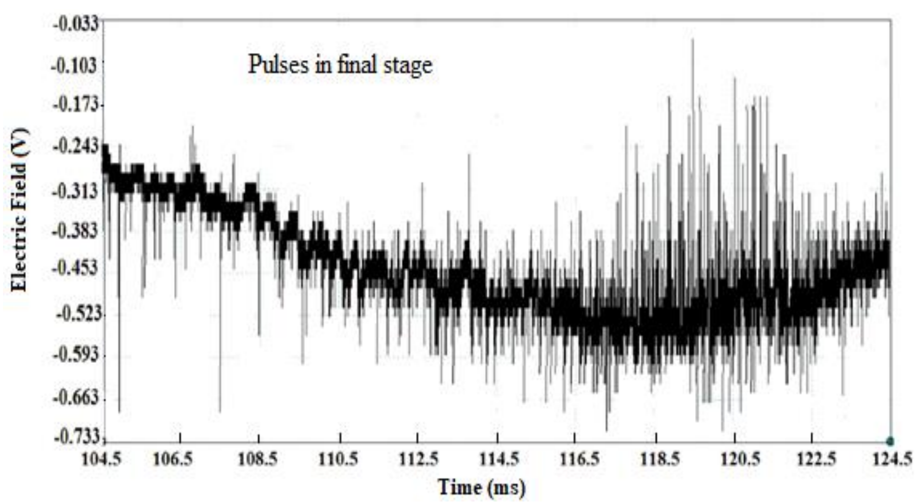

Figure 5. Example of cloud-to-cloud lightning flash.

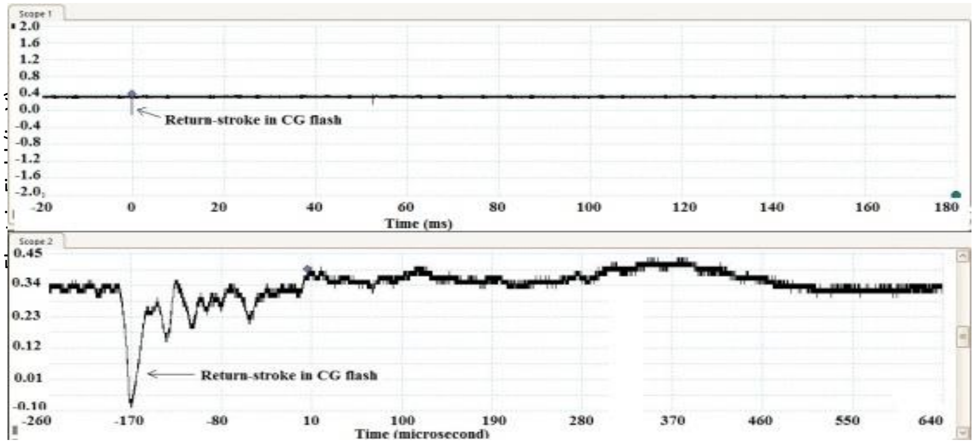

Figure 6. Recorded waveform of a CG flash in 2015 (1) Scope1 presents the full waveform. (2) Scope 2 is the zoomed part of the return stroke.

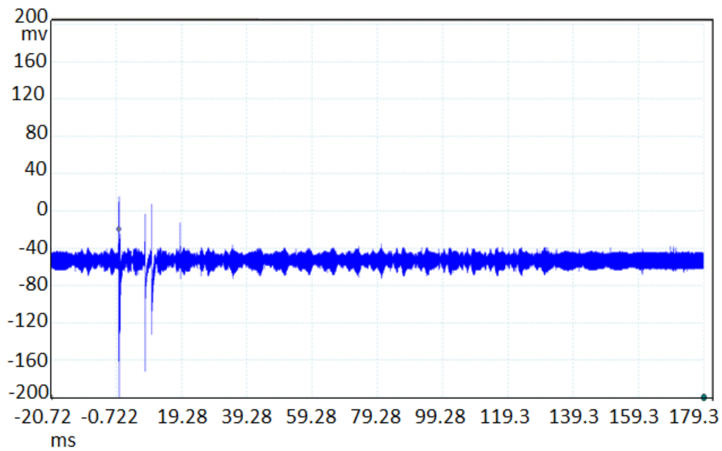

Figure 7. Unusual lightning waveforms, Time in ms along X-axis and Electric field in mV along Y-axis

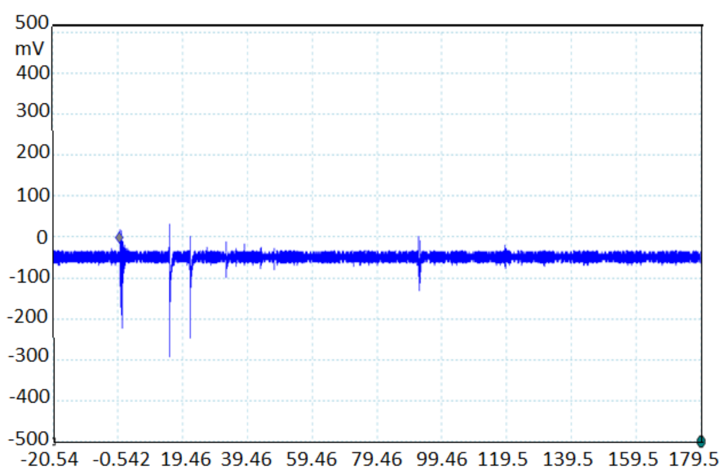

Figure 8. Unusual lightning waveforms with the Breakdown Pulses, Time in ms along X-axis and Electric field in mV along Y-axis

Initially, in 2015, low threshold and trigger values were set, capturing smaller values to gather more data. Later, the threshold value was raised by adjusting the trigger level, resulting in fewer observations. However, even with these adjustments, the distribution of lightning types, including intra-Cloud, inter-Cloud, CG lightning, remained consistent as reported by other researchers.

Positive lightning is more intense than negative lightning due to its higher current and temperature. Its occurrence is influenced by factors such as latitude, topography, season, and storm type. In the mountainous region, cloud-to-ground lightning is more frequent, likely due to the unique geography. The cloud structure follows a tri-pole charge model, where the negative charge is centered of thundercloud, positive charges are both above and below as shown in figure 9 (Adhikari *et al*., 2021). Excessive +ve charge at lower part of the cloud can affect lightning behavior, potentially converting ground (CG) lightning to cloud lightning.

In this region, cloud lightning is more common due to the presence of positive pocket charges. Positive CG flashes originate from upper positive regions, while negative CG flashes stem from -ve charge areas within thunderclouds. During the observed period, 1203 out of 5890 flashes were cloud-to-ground, 3698 were cloud-to-cloud, 562 were unusual, and 170 were breakdown pulses. This reflects the various lightning phenomena recorded in the Himalayan region.

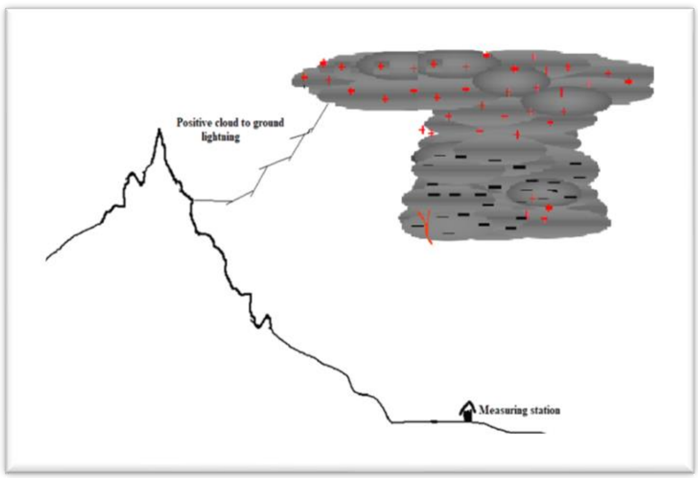

Figure 9. The tri-pole charge structure of the thundercloud.

CONCLUSIONS

A horizontal flat plate antenna was strategically placed to measure the vertical electric field over this region in Kathmandu, Nepal. This antenna was designed to capture the vertical electric fields generated by lightning phenomena. Over a span of three years, specifically from 2015 to 2017, the vertical electric fields associated with various types of lightning were detected and recorded. During this three-year duration, a variety of lightning activities were observed and subsequently analyzed. Among these various types of lightning, cloud lightning accounted for 62.8% of the occurrences, cloud-to-ground (CG) lightning constituted 20.4%, unusual lightning events were 9.5%, and breakdown events represented 2.9% of the recorded instances. The specific geographical features of the mountainous region, including hills, tall structures, and mountains, played an important role in shaping the distribution and occurrence of CG lightning.

Spatial relationships between the positive and negative charges within a thundercloud, as well as the distance between the top of the mountains and the positive charges within the cloud, had substantial effects on the various events observed within the lightning phenomena. This interaction is particularly noteworthy in understanding why the density of CG flashes in mountainous regions tends to be higher compared to other areas. The distinctive topography of the region, with its elevated landscape and varied structures, contributes to the prevalence of CG lightning in this specific mountainous environment.

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CONFLICT OF INTEREST

The author declares no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

REFERENCES

Adhikari, B. (2021). *Lightning Fatalities and Injuries in Nepal.* American Meteorological Society: Weather, Climate and Society; Vol.13.

Adhikari, P.B. (2019),Variation of atmospheric temperature with height in the phenomena of lightning waveforms, *World Journal of Applied Physics, 4*(4), 46-50, doi: 10.11648/j.wjap.20190404.11.

Adhikari, P.B., Adhikari, A., & Tiwari, A.K. (2021). Effects of lightning as a disaster in Himalayan region. *Bibechana*, 18(2),117-129. doi: 10.3126/Bibechana.v18i2.29168

Adhikari, P.B., Sharma, S.R., & Baral, K.N. (2016). Features of positive ground flashes observed in Kathmandu Nepal. *Journal of Atmospheric and Solar-Terrestrial Physics, 145*, 106-113.

Adhikari, P.B., Sharma, S.R., Baral, K.N., & Rakov, V.A. (2017). Unusual lightning electric field waveforms observed in Kathmandu, Nepal, and Uppsala, Sweden; *Journal of Atmospheric and Solar Terrestrial Physics,* 164, 172-184.

Ahmad, N.A., Fernando, M., Baharudin, Z.A., Cooray, V., Ahmad, H., & Malek, Z.A. (2010). The characteristics of narrow bipolar pulses in Malaysia. *Journal of Atmospheric and Solar Terrestrial Physics*, *72*, 530-540.

Baharudin, Z.A., Fernando, M., Ahmad N.A., Mäkelä, J.S., Rahman, M., & Cooray, V. (2012). Electric field changes generated by the preliminary breakdown for the negative cloud-to-ground lightning flashes in Malaysia and Sweden. *Journal of Atmospheric and Solar Terrestrial Physics*, *84*, 15-24.

Baral, K., & Mackerras, D. (1993). Positive cloud-to-ground lightning discharges in Kathmandu thunderstorms. *Journal of Geophysical Research*, *98*, 10331-10340.

Barros, A., & Lang, T. (2003). Monitoring the monsoon in the Himalayas: Observation in Central Nepal, June 2001. *Monthly Weather Review, 131*, 1408-1427.

Bazelyan, E., & Raizer, Y. (2000). *Lightning Physics and Lightning Protection.* Institute of Physics Publishing Dirac House UK.

Berger, K. (1977). *The earth flash. In Lightning, Physics of lightning* (Vol. 1). New York: Academic Press.

Cooper, M.A., & Holle, R.L. (2019) *Reducing lightning injuries worldwide*. Springer Natural Hazards Series (p.p.3-4) ISBN 978-3-319-77561-6. doi: 10.1007/978-3-319-77563-0.

Cooray, V. (2015). *An Introduction to Lightning*. Springer Netherlands.

Galvan, A., & Fernando, M. (2000). Operative characteristics of a parallel-plate antenna to measure vertical electric fields from lightning flashes, Uppsala University, Sweden.

Holle, R.L. (2016) *Lightning-caused deaths and injuries related to agriculture*. In: Preprints of the 33rd international conference on lightning protection, Estoril, Portugal, 25–30 Sept 2016.

Johari, D., Cooray, V., Rahman, M., Hettiarachchi, P., & Ismail, M.M. (2017). Characteristics of leader pulses in positive ground flashes in Sweden. *Electric Power Systems Research*, 153, 3-9.

Malan, D.J. (1963). *Physics of Lightning.* English Universities Press Ltd.

Nag, A., & Rakov, V. (2009). Some inferences on the role of lower positive charge region in facilitating different types of lightning. *Geophysical Research Letters,* 36, L05815. doi: 10.1029/2008GL036783.

Nag, A., & Rakov, V.A. (2012). Positive lighting: An overview, new observations, and inferences. *Journal of Geophysical Research: Atmospheres*, 117, D08109, 1-20.

Nag, A., & Rakov, V. A. (2014). Parameters of electric field waveforms produced by positive lightning return strokes. *IEEE -TEMC*, 56, 932-939.

Nanevicz, J.E., Vance, E.F., & Hamm, J.M. (1987). Observation of lightning in the frequency and time domains. In R. Gardner (Ed.) *Lightning Electromagnetics, 7,* 267-286.

Rakov, V., & Uman, M.A. (2003). *Lightning: physics and effects*. New York: Cambridge University Press.

Schumann, C., Saba, M.M., Da Silva, R.B., & Schulz, W. (2013). Electric fields changes produced by positive cloud- to-ground lightning flashes. *Journal of Atmosphere and Solar-Terrestrial Physics*, *92*, 37-42.

Sharma, S.R., Fernando, M., & Gomes, C. (2005). Signatures of electric field pulses generated by cloud flashes. *Journal of Atmospheric and Solar-Terrestrial Physics*, *67*, 413-422.

Sharma, S.R., Fernando, M., & Cooray, V. (2008). Narrow positive bipolar radiation from lightning observed in Sri Lanka. *Journal of Atmospheric and Solar- Terrestrial Physics*, *70*, 1251-1260.

Uman, M.A. (1987). *The lightning discharge.* New York: Dover Edition.

Uman, M.A. (2001). *The Lightning Discharge.* Dover Edition, New York.

Williams, E. (1989). The tri-pole structure of thunderstorms. *Journal of Geophysical Research, 94,* 13151-13167.

Wu, T., Wang, D., & Takagi, N. (2019). Intracloud lightning flashes initiated at high altitudes and dominated by downward positive leaders. *Journal of Geophysical Research: Atmospheres, 124*(13), 6982-6998.