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Lightning activity over Nepal and its association with meteorological parameters

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Abstract

This study delves into Nepal's climatology, focusing on the correlation between lightning occurrences and key parameters: temperature, Aerosol Optical Depth (AOD), Convective Available Potential Energy (CAPE), and Specific Humidity. By dividing Nepal into three regions-eastern (Region 1), middle (Region 2), and western (Region 3) to account for parameter variations, the research aims to uncover patterns in lightning behavior. The study reveals that lightning frequency is closely linked to specific meteorological conditions. Notably, during the pre-monsoon months of April, May, and June, lightning activity and average Cape values peak. Similarly, average temperature reaches its maximum in April, May, June, and July, while AOD exhibits its highest levels in the pre–monsoon period, with higher values in Region 1, moderate in Region 2, and lower in Region 3. These findings emphasize the role of thermodynamic factors in driving lightning occurrences. By shedding light on the interconnections of lightning with temperature, AOD, CAPE, and specific humidity, the study contributes to a better understanding of Nepal's climatic dynamics and lays the groundwork for informed disaster preparedness and policy decisions.

Keywords
Atmosphere, AOD, CAPE, himalayas, lightning flash density, specific humidity.

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1 Introduction

Lightning is a natural atmospheric phenomenon. The world's most lightning-prone locations are tropical continental areas including Africa, South America, and the Maritime Continent [1]. Local topography and a number of meteorological variables, including surface temperature, relative humidity (RH), wind shear, ozone and other trace gas distribution, and aerosol loading, influence lightning features on a regional level [2–8]. The significant volume of water vapor that arrives from the Indian Ocean has a major impact on the Himalayan region [9]. Weather forecasting, the distribution of weather alerts, regional effect mitigation, increased public awareness, and industrial safety all depend on knowledge of the geographical and temporal properties of lightning in the tropics. One estimate of global fatalities is several thousand [10], another is 6000 fatalities per year [11], and the third is 24,000 fatalities per year [12]. It is estimated that 240,000 people are injured each year based on lightning stroke density and populations in the tropical and subtropical areas of the world. Based on the density and population of lightning strikes in tropical and subtropical regions of the world, an estimated 240,000 persons are hurt annually [12]. Also, Nepal experiences a relatively high lightning-related fatality rate, with an estimated 4 deaths per million people per year and about 103 fatalities annually based on national population of approximately 30 million [13].

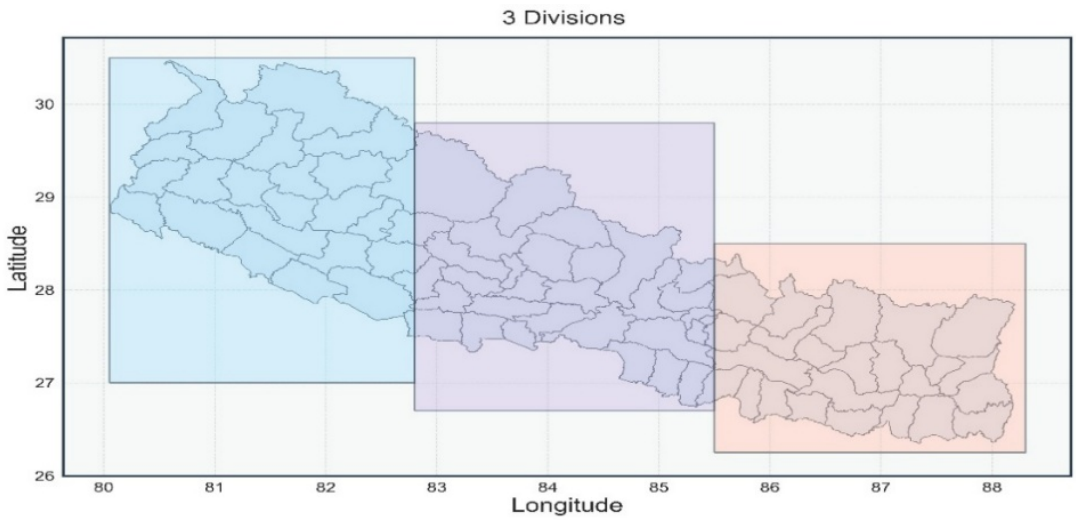


Figure 1: The study area in the Himalayan region is classified into three longitudinal regions.

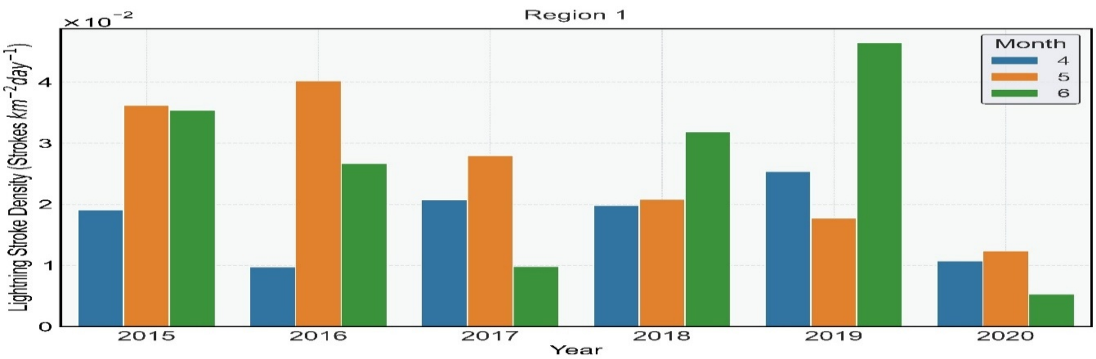
Nepal's topography comprises three distinct physiographic regions: mountains, hills, and plains. In the northern section of Nepal, the terrain is characterized by mountainous landscapes, bordered by the imposing Himalayan Mountain range. Nepal's terrain is characterized by an extreme elevation gradient, increasing from about 69 m in the south to 8,848.86 m [14] in the north. This dramatic variation in altitude also corresponds to changes in climate. The lower regions of Nepal typically feature a humid and warm climate, whereas the mountainous areas exhibit notably colder and less humid conditions. In addition, due to the increasing influence of moisture transport from the Bay of Bengal, the spatial variations condition also exist longitudinally. These combined altitudinal and longitudinal climatic variations play an important role in shaping the spatial distribution of lightning activity across Nepal.

This study focuses on three geographical regions in the Himalayan country, Nepal. In order to gain a better understanding of conditions of thermodynamic parameters and its impact on lightning activity, we separated the study region into three areas, as illustrated in Figure 1. A portion of the eastern region is covered by the first region (Region 1), which is situated within (26.25–28.5° N, 85.5–88.3° E). The second region, known as Region 2, is situated within (26.7-29.8° N, 82.8–85.5° E). The third region, known as Region 3, is situated in the western portion and is situated within (27-30.5° N, 80.05–82.8° E. Fig.1 displays several regions. The country's boundaries lie between latitudes 26–30° N and longitudes 80–88° E.

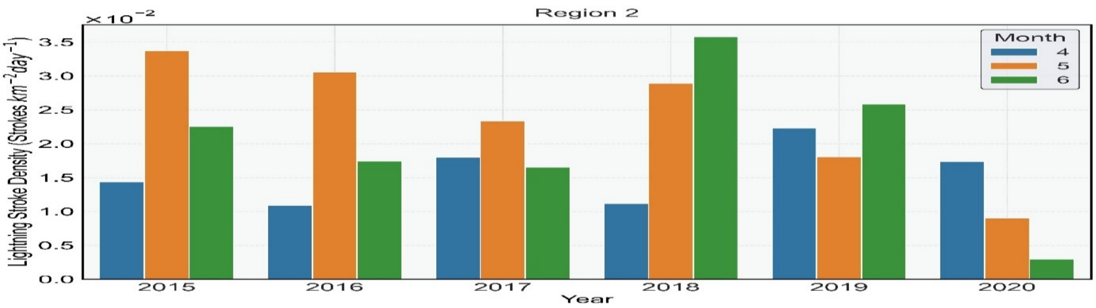
2 Materials and methods

This experiment was conducted using lightning data (GLD360 set) that was acquired from Vaisala Inc. The GLD360 sensors operate in the very low frequency (VLF) range (500 to 50 kHz), which represents their inherent detection bandwidth, and the sensors are ground-based. The GLD360 provides information on lightning strike timing, position, peak current, and polarity. It is believed that cloud–to–ground (CG) flashes account for the majority of the reported strokes. The network employs both magnetic direction-finding and time–of–arrival techniques. The aerosol optical depth (AOD) data were derived from observations collected by the moderate resolution imaging Spectro radiometer (MODIS), located on the sun-synchronous Aqua satellite that passes at ∼13:30 local time (LT). The AOD, a dimensionless metric that displays aerosol concentrations in the vertical column of the atmosphere above the observation location, is used to represent aerosol data. It measures the amount of solar energy that is lost due to dust, smoke, haze, and other floating particles in the atmosphere and shows aerosol loading.

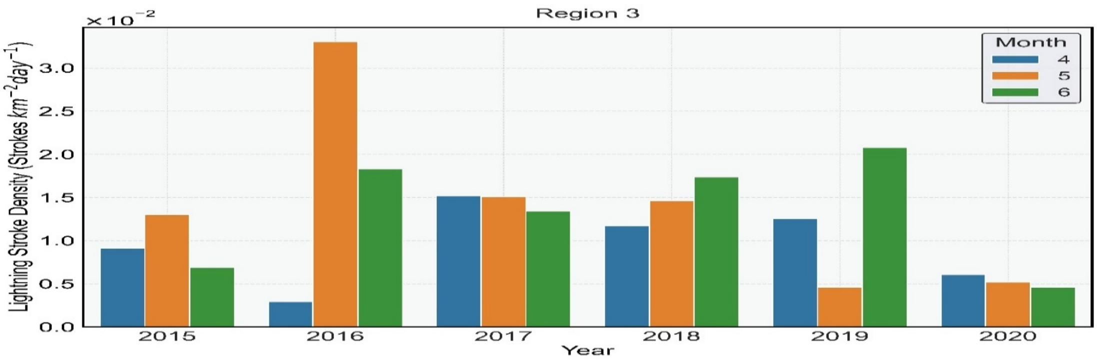
The meteorological data utilized in this study were obtained from the ERA5 reanalysis dataset, provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). ERA5 offers a comprehensive set of meteorological variables that were replicated by combining observational data with advanced modeling techniques [15]. We extracted key meteorological parameters, including CAPE, Surface temperature at 2m (T2m), and Specific Humidity from the ERA5 dataset in 0.250 × 0.250 resolution (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-singlelevels?tab=overview). The extracted parameters were then analyzed in association with lightning occurrence to find potential correlations.



(a) Region 1



(b) Region 2



(c) Region 3

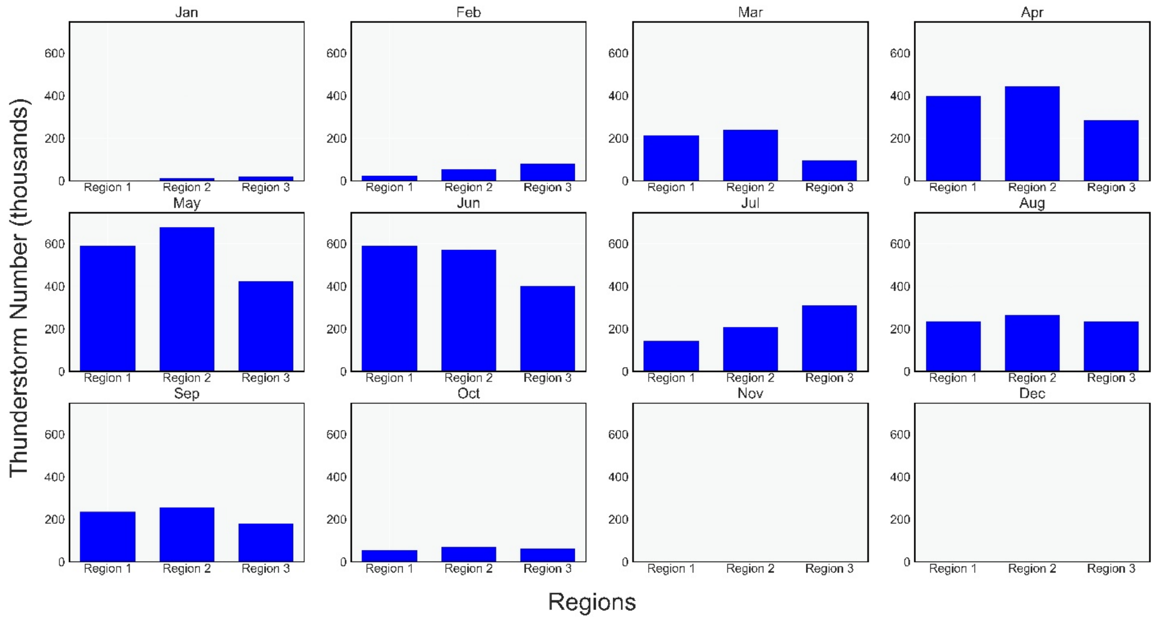
Figure 2: Lightning Stroke Density (flash $km^{-2}day^{-1}$) during April, May, and June for the year from 2015 to 2020 A.D.

3 Results and discussion

3.1 Results

In this study, we have studied lightning climatology over different regions of Nepal. Besides this, we studied the effects of different thermodynamic factors on lightning activities. Various atmospheric parameters influence cloud electrification and, consequently, lightning occurrence. Due to the topographical variations of Nepal, we divided it into 3 different regions which is shown in Figure 1.

Figure 2(a-c) displays the annual total lightning flash density (total flashes per area per day) for three distinct locations from 2015 to 2020 A.D. It has been noted that the year 2019 has the highest frequency of lightning strikes across all regions, whereas 2020 has fewer lightning strikes than the previous five years. Because of the worldwide lockdown caused by the COVID-19 pandemic, most anthropogenic aerosol-producing activities were suspended this year.



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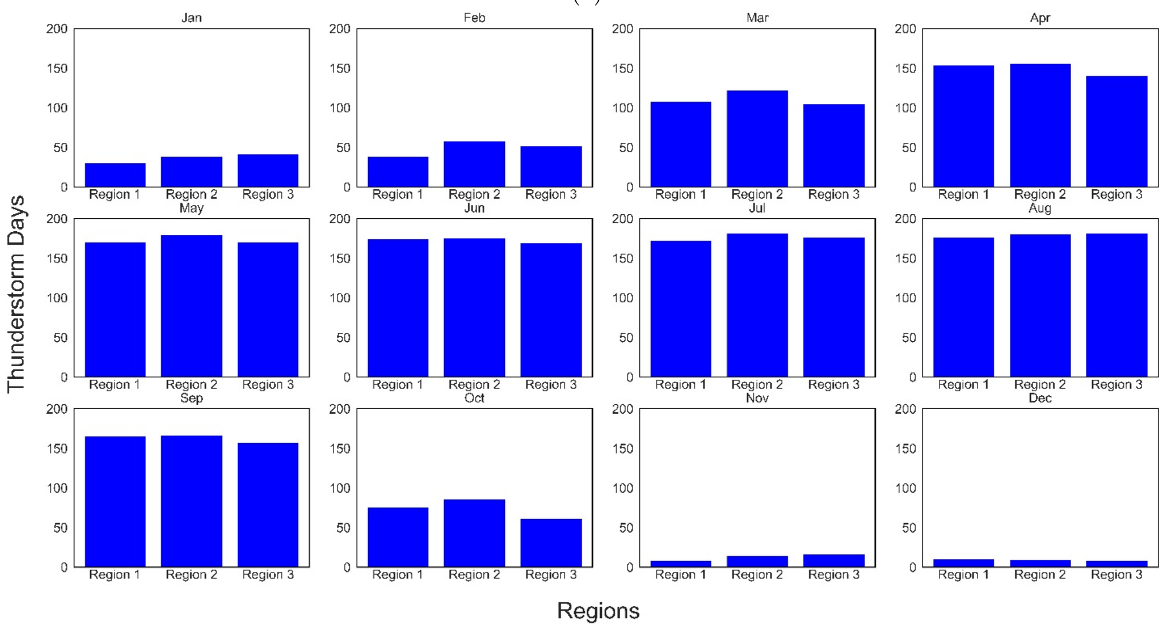
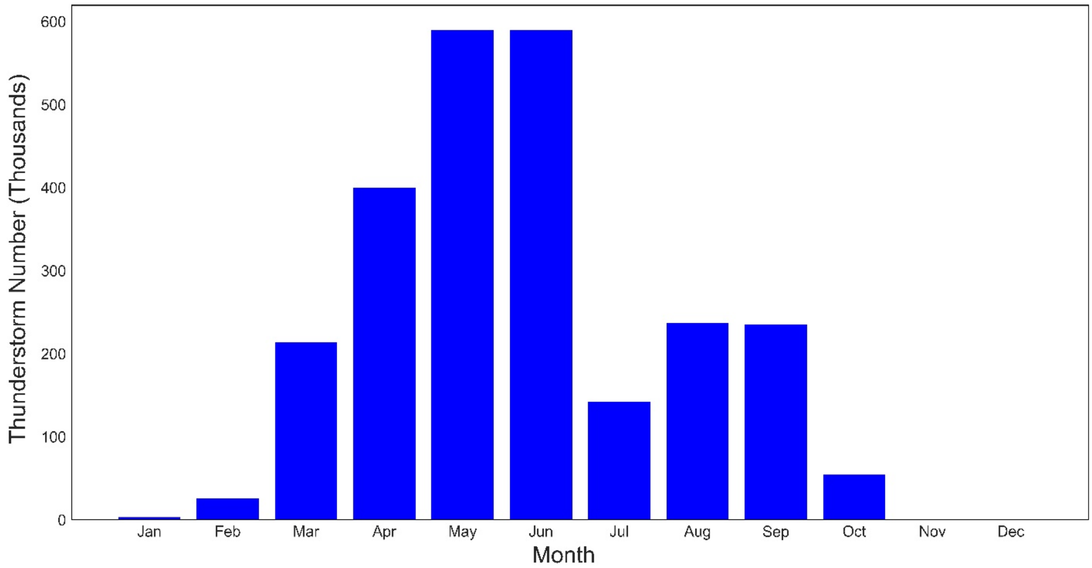


(b)

Figure 3: (a) Lightning flashes, and (b) the total number of thunderstorm days recorded in Nepal's three regions between 2015 and 2020 A.D.

We plotted Figure 3 (a,b), which shows the monthly change of thunderstorm occurrence frequency in three locations of Nepal over a six-year period, to learn more about thunderstorms and the lightning that goes along with them. The overall pattern indicates that from April to June, thunderstorm activity progressively increases from the east to the west. Our observations indicate that Nepal's Regions 2 and 1 have the highest rates of thunderstorms. The results confirmed that the measured mean lightning flash rate density increased steadily starting in January, peaked in May, and then gradually declined until December. But for years 2018 and 2019, the value of lightning activities is maximum in the month of June. Additionally, we noticed that the flash rate density decreased as altitude increased, and that lightning is generally less common in Nepal's northern regions than in its southern ones.



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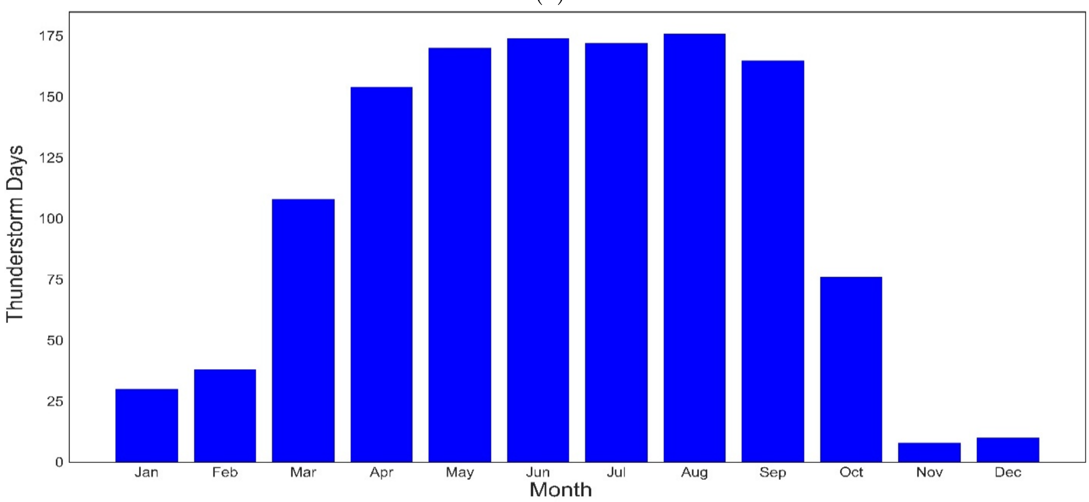


(b)

Figure 4: Monthly variations of (a) total thunderstorm occurrence, and (b) thunderstorm occurrence days in Nepal during 6 years from 2015 to 2020 A.D.

The monthly variation in thunderstorm frequency over Nepal from 2015 to 2020 A.D. is depicted in Figure 4(a). However, thunderstorm days peak in May and June, as illustrated in Figure 4(b), with a strong tendency in the monthly variation of peak activity throughout the pre-monsoon season. We also found that lightning activities are maximum in pre-monsoon season and less in monsoon and then increase in post-monsoon.

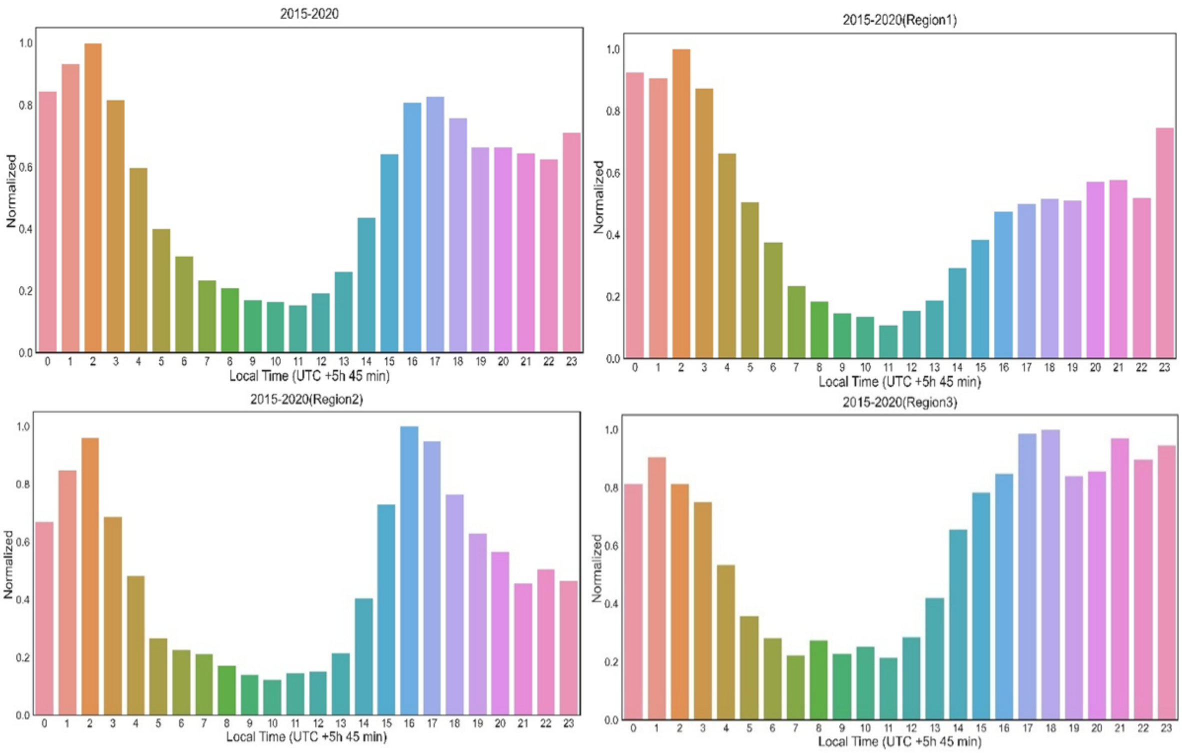


Figure 5: The normalized hourly variation of the total number of lightning flashes in Nepal from April to June. For normalization, the maximum flash count data is divided by the hourly lightning flash count data. Nepal is represented by the first figure, Region 1 by the second, Region 2 by the third, and Region 3 by the fourth.

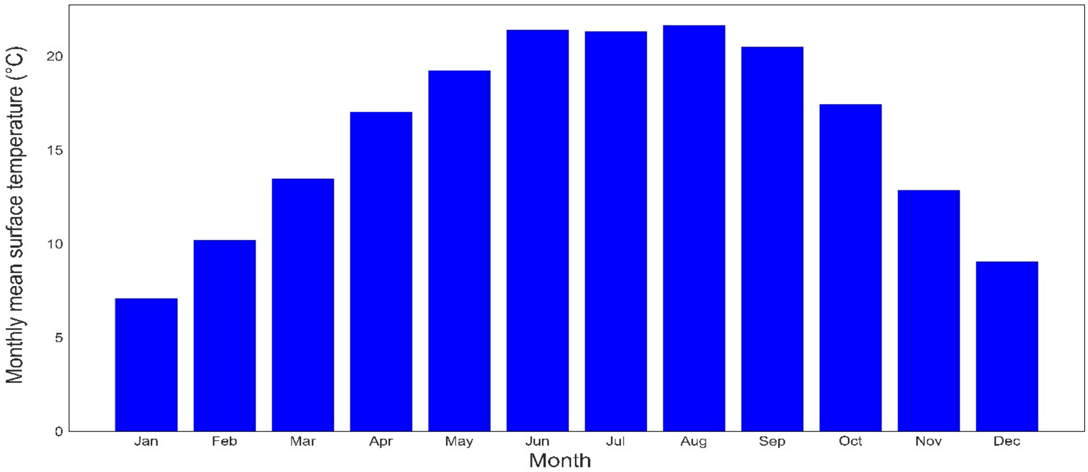
The diurnal variation of lightning activity all over Nepal and for 3 different regions are depicted in Figure 5. We found that the maximum lightning activities occur after 2 p.m. local time and early morning time. For Region 1, the maximum lightning occurrence is in the early morning but for Region 3, the lightning occurrence is evening time. The results highlight the dual role of surface heating and nocturnal convection [16]. The Himalayan region's south-facing slopes are home to Nepal's complicated orography, nighttime complex mesoscale convective activity, low-level monsoon, and transient convection southwester, which are the main causes of lightning activity during local midnight and morning. The highest frequency of lightning activity occurred during local afternoon and early evening, exhibiting characteristics that are common throughout the world [17, 18]. This observation is consistent with the previous observations [19–21].

As shown in Figure 6(a), the monthly mean surface temperature over Nepal for a period of six years climbed monotonically from January to August and then fell monotonically from August to December. The graph illustrates how surface warming of the Earth strongly modifies the vertical temperature structure of the atmosphere. During May, warming exceeding 17°C contributes to enhance atmospheric instability, creating favourable conditions for thunderstorm development [22]. The finding of Figure 3(a and b) is also supported by the fact that the mean surface temperature is at its highest in Region 1 during the months of June, July, and August, as shown in Figure 6(b). The lightning strike is most frequent in premonsoon season, which may be because Region 1 has the highest average surface temperature among the other regions.

Figure 7 depicts the Convective Available Potential Energy (CAPE) values observed over six-year periods in three distinct regions. Notably, CAPE reaches its peak during the pre-monsoon season, coinciding with heightened lightning activity. CAPE consistently rises from the western to the eastern regions during the pre-monsoon season, while the trend reverses during the monsoon and post-monsoon seasons. Consequently, lightning activity is most pronounced in the eastern region during the pre-monsoon season and in the western region during the post-monsoon season. This demonstrates that lightning activity and CAPE are positively correlated.

Figure 8 presents the aerosol optical depth (AOD) values for six-year periods spanning from 2015 to

2020 A.D. across three distinct regions. Notably, the graph reveals that the maximum AOD value is consistently observed in the month of June. Furthermore, the trend in AOD values exhibits a gradual increase from January through June, followed by a subsequent decrease from July to December. This intriguing observation suggests a potential connection between AOD levels and lightning activity. As AOD reflects the concentration of aerosols and particulate matter in the atmosphere, its variations could influence atmospheric conditions relevant to lightning formation. The peak AOD in June, concurrent with the highest lightning activity, prompts us to explore the possibility of a causal link.



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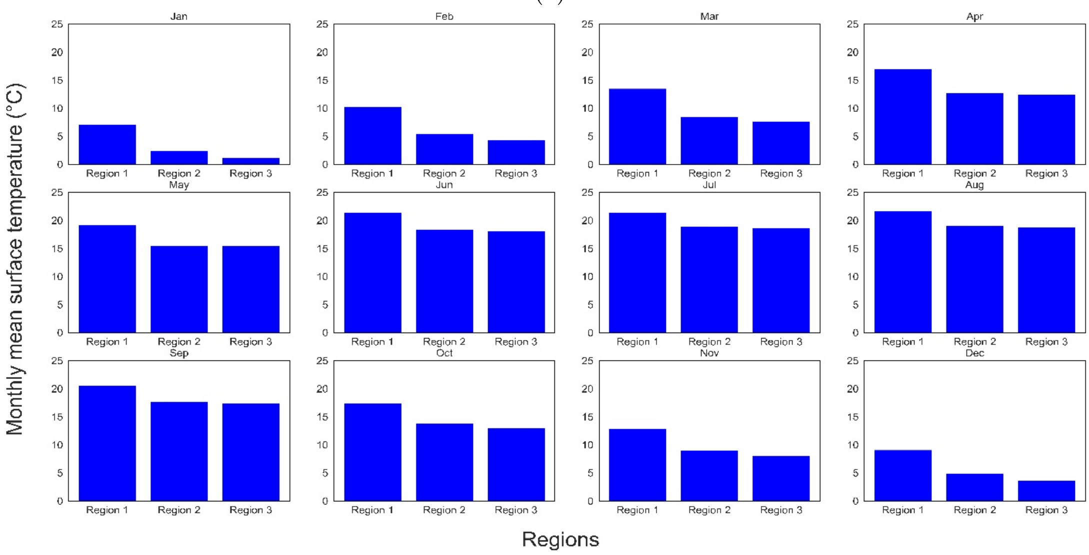
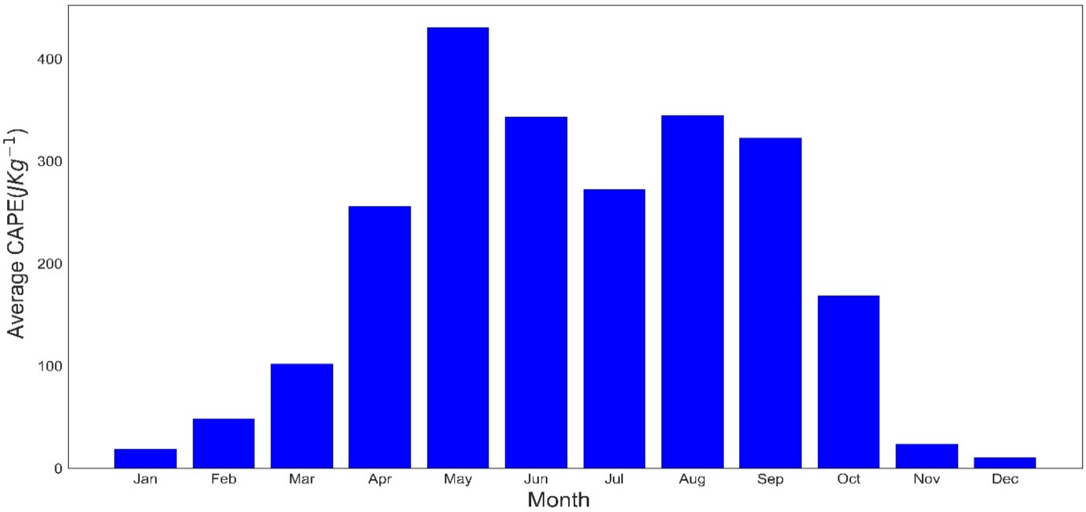


(b)

Figure 6: (a) Monthly averaged surface temperature across Nepal from 2015 to 2020 A.D. (b) Monthly averaged surface temperature for the three regional divisions of Nepal over the same time-frame.

Figure 9 illustrates the monthly variation of lightning flash density over different regions and its correlation with various thermodynamic parameters. The flash density is higher in eastern part that is region1 and slightly decreases from the eastern to western part. Lightning activity is maximum from March to July, and during this period the values of thermodynamic parameters also increase, indicating a significant correlation between lightning activity and thermodynamic conditions.

Figure 10 shows the correlation between lightning flash density (FD) and thermodynamic parameters namely AOD, CAPE and Specific Humidity. The first figure displays a heatmap of the correlation matrix, revealing a strong positive correlation of FD with AOD, CAPE and SH. The upper right panel shows the scatterplot of FD versus AOD, with a correlation coefficient of 0.828. The lower left panel represents FD versus CAPE, with a correlation coefficient of 0.82. The lower right panel shows FD versus SH with a correlation coefficient of 0.74. The results indicate that FD is strongly and positively associated with aerosol loading, convective instability, and lower atmospheric moisture in the study region. This study has some limitations. The ERA5 reanalysis data has relatively coarse spatial resolution (∼25 km), which may not fully capture local convective processes over complex terrain. Radar observations and validation with other lightning detection networks or satellite datasets were not included due to data limitations, which could improve future studies.



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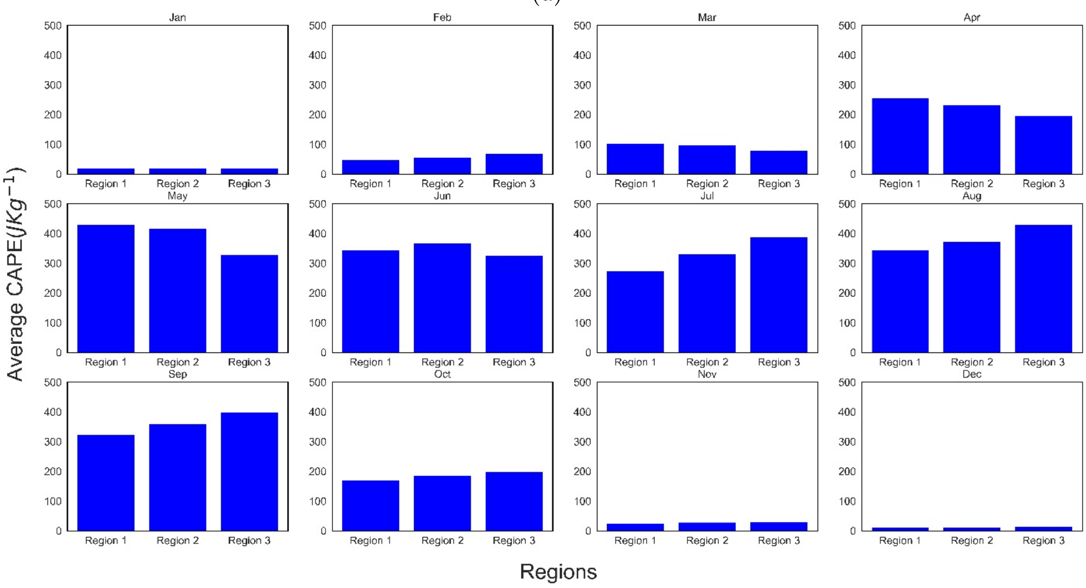
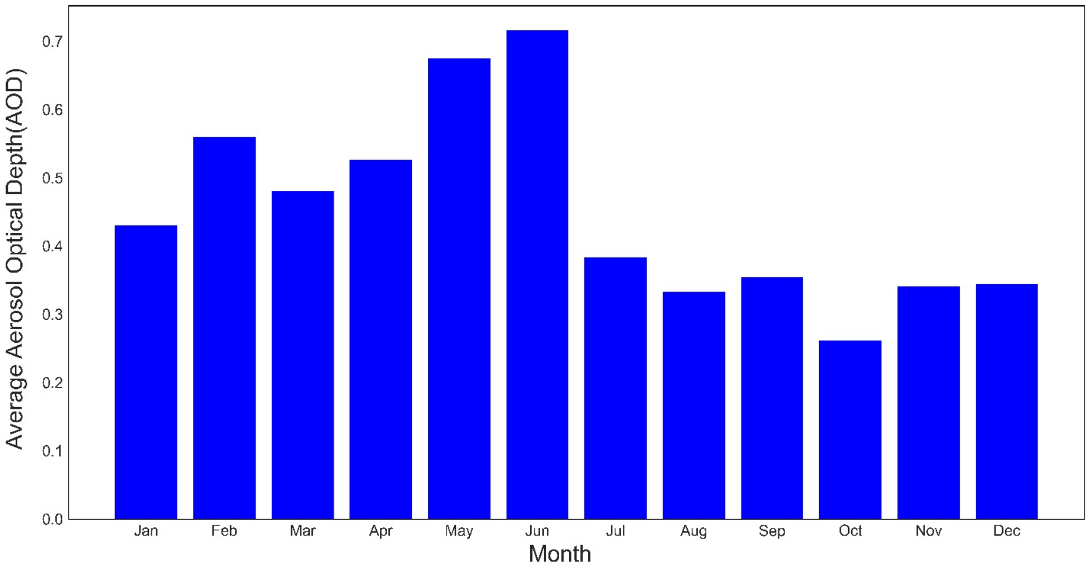


(b)

Figure 7: (a) Monthly averaged CAPE distribution over Nepal from 2015 to 2020 A.D., and (b) Monthly averaged CAPE variation within the three regional divisions of Nepal over the same period.

3.2 Discussion

In this study, we conducted an examination of lightning climatology in Nepal spanning from 2015 to 2020 and its association with thermodynamic parameters. Our analysis of GLD360 data over these six years revealed that the lightning flash rate density consistently peaked in May. However, it is noteworthy that in the years 2018 and 2019, the highest lightning activity occurred in June. If we take into account a long-term tendency in lightning that originates from the country's central and eastern regions, April and May may be the months that produce the most lightning overall in Nepal. Additionally, our results align with the independent analysis of thunderstorm frequency. The central or middle region typically shows comparatively less lightning activity in comparison to the eastern and western regions of the Himalayas. This is probably because of lower temperatures and mid-level humidity [23, 24]. Furthermore, the most intense and tall pre-monsoon cumulonimbus storms, which originate from deep convection over the Ganges delta region and are similar to the severe storm outbreaks in the Terai region, have significantly higher temperatures than the hilly and mountainous regions.



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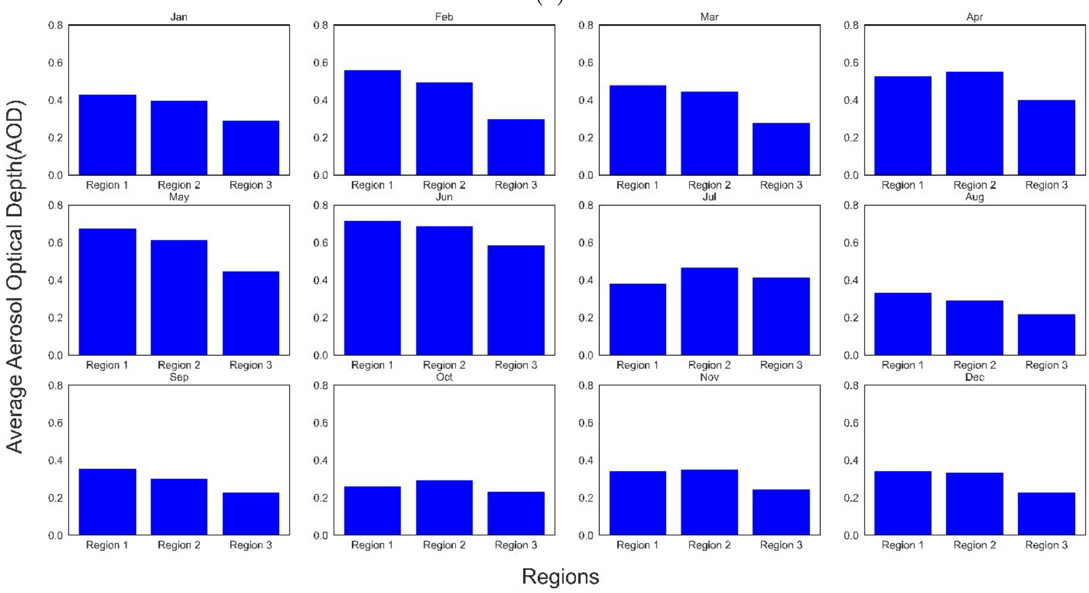

(b)

Figure 8: (a) Monthly averaged aerosol optical depth (AOD) over Nepal from 2015 to 2020 A.D., and (b) Monthly averaged AOD variation within the three regional divisions of Nepal over the same time-frame.

The lightning flash density is observed higher in eastern part and gradual decrease towards the western part. The Bay of Bengal's moist air inflow, which encounters the rugged terrain of steep hills and mountains, leads to increased turbulence. This turbulent environment is the factor contributing to the prevalence of lightning activity across the western to eastern regions. The eastern region (Region 1) receives some additional moisture, and the strong orographic lifting establishes deep convection causing more strikes. The moisture content and therefore, convective intensity diminishes as their air mass rolls westward towards the country's heartland leading to diminished lightning activity. Similar spatial patterns have been reported in previous studies over South Asia [25, 26].

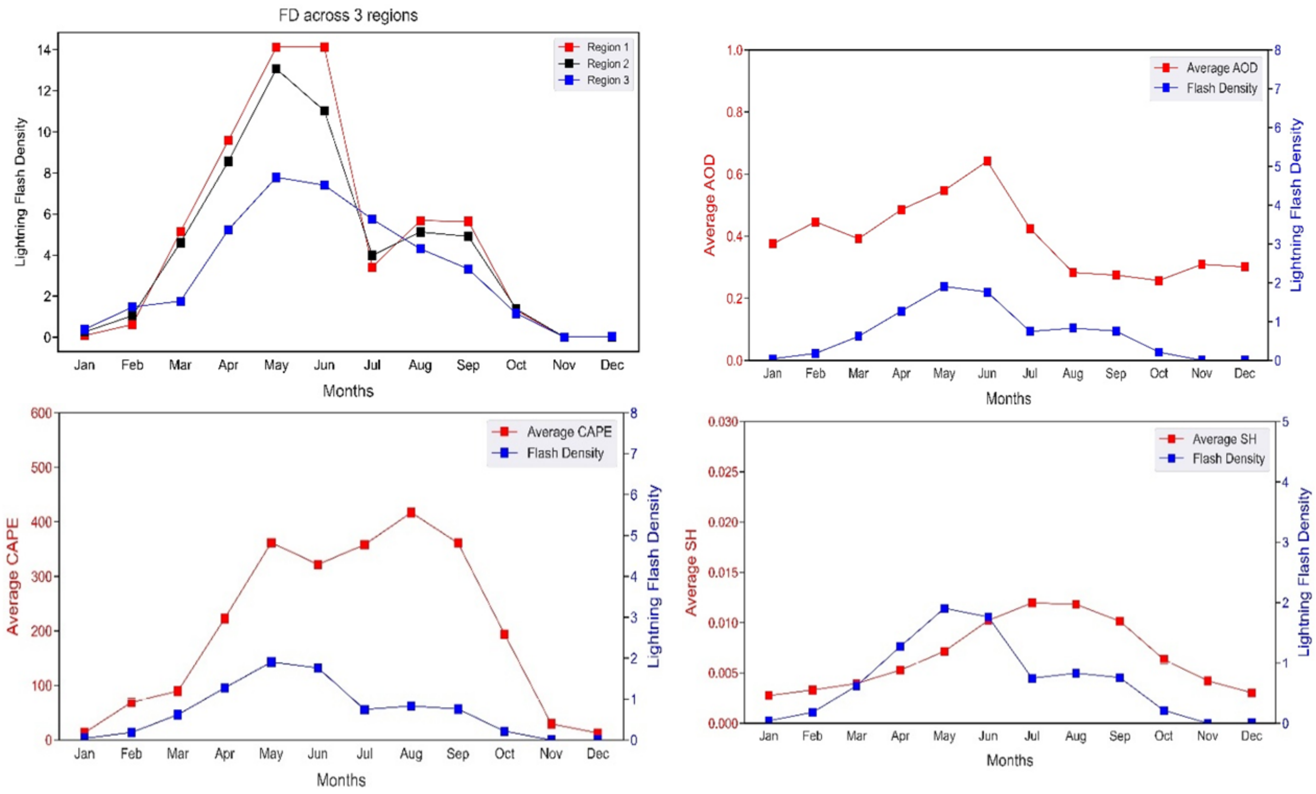

Figure 9: Monthly variation of lightning flash density over different regions and its correlation with thermodynamic parameters.

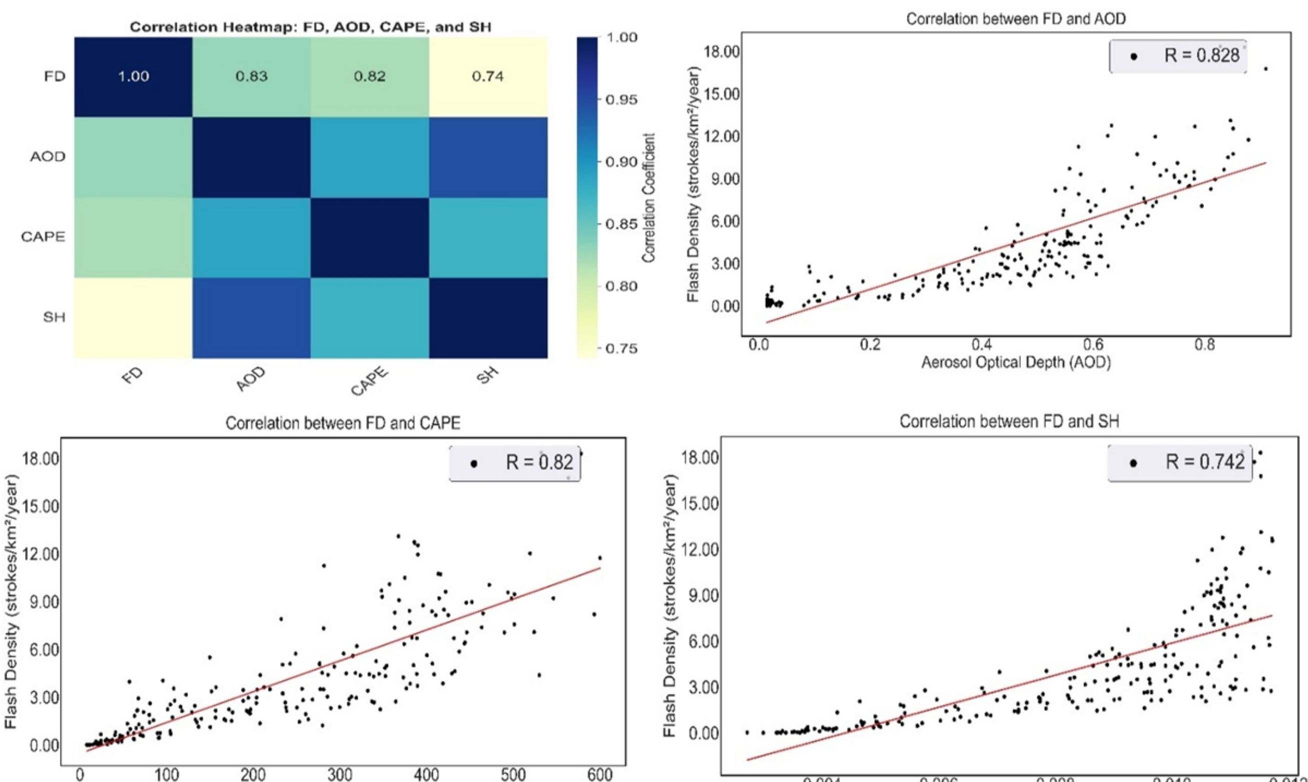

Figure 10: Correlation of Flash Density with AOD, CAPE and Specific Humidity.

The significant correlations between flash density and thermodynamic parameters such as AOD, CAPE, and specific humidity indicate that lightning activity is closely linked with atmospheric instability, moisture availability, and aerosol loading. The atmospheric instability brought on by temperature disparity, air parcels rise as a result of orographic lifting [27]. Higher CAPE supports stronger updrafts, while increased specific humidity enhances cloud development, both favouring electrification processes. Additionally, elevated aerosol concentrations may modify cloud microphysics and intensify charge separation, leading to increased lightning frequency. These finding are consistent with previous studies [20, 28–30], which highlights the combined influence of thermodynamic and microphysical factors on lightning activity.

4 Conclusion

This study investigated lightning activity over Nepal during a six-year period (2015–2020) using data from the GLD-360 network along with meteorological parameters. The results indicated that lightning activity is strongly seasonal, with the highest occurrence during the premonsoon months specially May and June. Furthermore, the results showed that regional variations in lightning distribution are influenced by atmospheric conditions.

The result indicates that thermodynamic parameters such as surface temperature, Convective Available Potential Energy (CAPE), specific humidity, and aerosol optical depth (AOD) play vital roles in influencing lightning activities in Nepal. The higher value of CAPE and temperature help create instability, enhance convective development, and increase lightning occurrence, while specific humidity supports cloud formation and electrification processes. The observed linkage between lightning activities and these atmospheric variables indicate that lightning activity in Nepal is closely linked with atmospheric instability and regional climatic conditions.

In conclusion, this study sheds light on Nepal's lightning patterns over a substantial period, affirming previous pre-monsoon activity findings. The interconnected roles of climate-related variables in lightning behavior suggest the importance of considering these factors in predictive models and disaster preparedness efforts. The established correlations provide a foundation for enhancing meteorological forecasting, advancing risk assessment, and informing measures to mitigate lightning-related impacts in the region.

Conflict of interest

The authors of the work declare that they have no known conflict of interest.

Data availability statement

The data used in the work will be made available by the corresponding author on reasonable request.

Acknowledgments

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Authors' contributions

PK: Writing-original draft, Software, Investigation, Formal analysis, Data curation, Conceptualization. SS: Writing-review & editing, Supervision, Resources, Funding acquisition, Conceptualization. MG: Writing–review & editing, Supervision. KNP: Writing-review & editing, Supervision.

References

[1] Christian HJ, Blakeslee RJ, Boccippio DJ, Boeck WL, Buechler DE, Driscoll KT, et al. Global frequency and distribution of lightning as observed from space by the Optical Transient Detector. Journal of Geophysical Research: Atmospheres. 2003;108(D1):ACL-4.

[2] Goswami BB, Mukhopadhyay P, Mahanta R, Goswami BN. Multiscale interaction with topography and extreme rainfall events in the northeast Indian region. Journal of Geophysical Research: Atmospheres. 2010;115(D12).

[3] Williams ER. Lightning and climate: A review. Atmospheric research. 2005;76(1-4):272-87.

[4] Jayaratne ER, Kuleshov Y. The relationship between lightning activity and surface wet bulb temperature and its variation with latitude in Australia. Meteorology and Atmospheric Physics. 2006;91(1):17-24.

[5] Khain AP. Notes on state-of-the-art investigations of aerosol effects on precipitation: a critical review. Environmental Research Letters. 2009;4(1):015004.

[6] Lee SS, Donner LJ, Phillips VTJ, Ming Y. The dependence of aerosol effects on clouds and precipitation on cloud-system organization, shear and stability. Journal of Geophysical Research: Atmospheres. 2008;113(D16).

[7] Lee SS, Donner LJ, Penner JE. Thunderstorm and stratocumulus: how does their contrasting morphology affect their interactions with aerosols? Atmospheric Chemistry and Physics. 2010;10(14):6819-37.

[8] Pawar V, Pawar SD, Beig G, Sahu SK. Effect of lightning activity on surface NOx and O3 over a tropical station during premonsoon and monsoon seasons. Journal of Geophysical Research: Atmospheres. 2012;117(D5).

[9] Malla G. Climate change and its impact on Nepalese agriculture. Journal of Agriculture and Environment. 2008;9:62-71.

[10] Gomes C, Ab Kadir MZA. A theoretical approach to estimate the annual lightning hazards on human beings. Atmospheric Research. 2011;101(3):719-25.

[11] Cardoso I, Pinto J O, Pinto IRCA, Holle R. Lightning casualty demographics in Brazil and their implications for safety rules. Atmospheric Research. 2014;135:374-9.

[12] Holle RL, Lopez RE. A comparison of current lightning death rates in the US with other locations and times. In: International Conference on Lightning and Static Electricity; 2003. p. 16-8.

[13] Sharma S, Neupane B, Kc HB, Koirala MP, Damase NP, Dhakal S, et al. Lightning threats in Nepal: occurrence and human impacts. Geomatics, Natural Hazards and Risk. 2022;13(1):1-18.

[14] Majupuria TC. Nepal nature's paradise: insight into diverse facets of topography, flora and ecology. 1985.

[15] Hersbach H, Bell B, Berrisford P, Hirahara S, Horányi A, Muñoz-Sabater J, et al. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society. 2020;146(730):1999-2049.

[16] Karki P, Sharma S, Biswasharma R, Pawar SD, Gopalkrishnan V, Gyawali M, et al. Spatio-Temporal variation of Lightning Activity over Nepal's Complex Terrain: Links to Altitude and Meteorological Factors. Journal of Atmospheric and Solar-Terrestrial Physics. 2025:106615.

[17] Barros AP, Lang TJ. Exploring spatial modes of variability of terrain–atmosphere interactions in the Himalayas during monsoon onset. Hydrosciences Rep Series. 2003;3(001).

[18] Barros AP, Kim G, Williams E, Nesbitt SW. Probing orographic controls in the Himalayas during the monsoon using satellite imagery. Natural Hazards and Earth System Sciences. 2004;4(1):29-51.

[19] Boeck WL, Mach DM, Goodman SJ, Christian J HJ. Optical Observations of Lightning in Northern India Himalayan Mountain Countries and Tibet. In: Atmospheric Electricity; 1999. .

[20] Kumar P, Kapur S, Choudhary A, Singh AK. Spatiotemporal variability of optical properties of aerosols over the Indo-Gangetic Plain during 2011–2015: P Kumar et al. Indian Journal of Physics. 2022;96(2):329-41.

[21] Pawar SD, Gopalakrishnan V, Murugavel P. Role of orography in inducing high lightning flash rate at the foothills of Himalaya. Earth, Planets and Space. 2015;67(1):51.

[22] Price C, Asfur M. Can lightning observations be used as an indicator of upper-tropospheric water vapor variability? Bulletin of the American Meteorological Society. 2006;87(3):291-8.

[23] Damase NP, Banik T, Paul B, Saha K, Sharma S, De BK, et al. Comparative study of lightning climatology and the role of meteorological parameters over the Himalayan region. Journal of Atmospheric and Solar-Terrestrial Physics. 2021;219:105527.

[24] Saha K, Damase NP, Banik T, Paul B, Sharma S, De BK, et al. Satellite-based observation of lightning climatology over Nepal. Journal of Earth System Science. 2019;128(8):221.

[25] Chakraborty R, Chakraborty A, Basha G, Ratnam MV. Lightning occurrences and intensity over the Indian region: long-term trends and future projections. Atmospheric Chemistry and Physics. 2021;21(14):11161-77.

[26] Singh P, Ahrens B. Modeling Lightning Activity in the Third Pole Region: Performance of a km-Scale ICON-CLM Simulation. Atmosphere. 2023;14(11):1655.

[27] Weston KJ. The dry-line of Northern India and its role in cumulonimbus convection. Quarterly Journal of the Royal Meteorological Society. 1972;98(417):519-31.

[28] Qie K, Qie X, Tian W. Increasing trend of lightning activity in the South Asia region. Science Bulletin. 2021;66(1):78-84.

[29] Jnanesh SP, Lal DM, Gopalakrishnan V, Ghude SD, Pawar SD, Tiwari S, et al. Lightning characteristics over humid regions and arid regions and their association with aerosols over Northern India. Pure and Applied Geophysics. 2022;179(4):1403-19.

[30] Lal DM, Umakanth N. Lightning association with aerosol and relative humidity over Andhra Pradesh and adjacent area in southeast India: a general prospection. Pure and Applied Geophysics. 2024;181(6):1987-2003.