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Amrit Research Journal April 2024, Vol. 4, Issue 2, 64-71
ISSN: 2738-9553
RESEARCH ARTICLE

Analysis of the Role of Lightning Activity in Triggering Forest Fires in Nepal

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(Received: August 1, 2023, Received in revised form: March 7, 2024, Accepted: March 7, 2024, Available Online)

DOI: https://doi.org/10.3126/arj.v4i2.65546

Highlights

- This study reveals a noteworthy correlation between lightning strikes and forest fires, particularly during the pre-monsoon season
- One crucial finding of this research is the analysis of the type of lightning strokes in hotspots, which showed that the number of positive strokes, rather than the overall number of lightning strikes, plays a crucial role in forest fire ignition.
- Although the importance of human-caused forest fires shouldn't be understated, comprehension of the function that lightning activity plays in forest fire ignition is essential for the creation of successful fire management and prevention plans.
- This study lays the foundation for region-specific fire management policies and practices, ultimately enhancing the resilience of Nepal's invaluable ecosystems and communities.

Abstract

Forest fires have emerged as a significant and pressing issue in Nepal, jeopardizing its natural ecosystems, biodiversity, and communities. While human activities have been traditionally linked to these fires, this study explores the potential impact of lightning strikes, a natural factor that could contribute significantly to the problem. Using data from Vaisala's Global Lightning Dataset (GLD 360) and the Moderate Resolution Imaging Spectroradiometer (MODIS) dataset, we investigate the relationship between lightning strikes and forest fires over the five years' period from 2015 to 2019. Advanced tools like ARC GIS and Python are employed for analysis. Preliminary findings indicate a noteworthy correlation, particularly during the pre-monsoon season. This investigation shows an interesting fact that positive lightning strokes are more likely to initiate forest fire as compared to their negative counter parts. This research offers a fresh perspective on lightning-induced forest fires in Nepal, paving the way for targeted fire management strategies and further investigation into lightning ignition mechanisms.

Keywords: *Lightning, forest fire, thunderstorms, Nepal, GIS, python*

Introduction

In Nepal, forest fires have become an increasingly pervasive and concerning issue, posing imminent threats to the nation's natural ecosystems, biodiversity, and the well-being of its communities. While the conventional belief attributes these fires primarily to anthropogenic activities, including agricultural practices and accidental ignitions, there exists a critical knowledge gap regarding other potential natural factors that might contribute significantly to this escalating problem. One such factor is lightning strikes, which can act as a potent ignition source for forest fires.

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Remarkably, despite the devastating impact of forest fires in Nepal, no comprehensive study has been conducted to investigate the role of lightning activity in igniting these fires. Recognizing the urgency of addressing this gap in knowledge, our research focuses on understanding the association between lightning strikes and forest fires in Nepal over a period of five years.

This study's significance lies in its novelty and the potential to offer valuable insights into the dynamics of forest fires in Nepal. We utilize data from Vaisala's Global Lightning Dataset (GLD 360), renowned for providing comprehensive and precise information on lightning activity worldwide. This dataset includes essential details such as the geographical location, time, and characteristics of lightning strikes, allowing us to explore their potential correlation with forest fire occurrences in Nepal.

In parallel, we collect forest fire data from the Moderate Resolution Imaging Spectroradiometer (MODIS) dataset, hosted by the Ministry of Forest and Environment in Nepal. The MODIS dataset is a reliable source of detailed and up-to-date information on active fire detections, offering crucial insights into the occurrence and distribution of forest fires across the country.

To conduct a rigorous analysis of data, we employ advanced tools such as ARC GIS and Python. These tools enable us to efficiently process and interpret the extensive dataset from both lightning and forest fires, with a particular focus on understanding patterns and trends in lightning activity and its association with forest fires. The emphasis is placed on the pre-monsoon season, when the risk of fire ignition is particularly heightened.

Preliminary findings from our study reveal some sort of relation between lightning activity and forest fires in Nepal, notably during the pre-monsoon season. These findings, while acknowledging the continued significance of human-caused fires, underscore the substantial role played by lightning-induced fires in the overall incidence of forest fires in the country.

This research serves as a valuable contribution to ongoing efforts to address forest fires in Nepal. It introduces a novel perspective on the ignition of fires by lightning, marking the first investigation of its kind in Nepal. Consequently, this study lays the foundation for future research on lightning-induced forest fires and opens avenues for the development of region-specific fire management policies and practices. Understanding the role of lightning activity in forest fire ignition is vital for authorities and policymakers to craft effective strategies for fire prevention and management, ultimately enhancing the resilience of Nepal's invaluable ecosystems and communities.

As our research progresses, we intend to delve deeper into the intricate mechanisms by which lightning ignites forest fires, further refining our comprehension of this complex relationship. The insights gained from this study will foster a more holistic approach to forest fire management and disaster preparedness, ensuring the sustainable protection of Nepal's invaluable natural resources and the creation of a safer environment for all.

Literature Review

Forest fires represent a significant global environmental challenge, and understanding their ignition sources is crucial for effective management. Lightning strikes have long been recognized as a natural ignition source for forest fires, and studies from various regions provide valuable insights into this phenomenon. For example, studies conducted in Ontario in 1991 discovered that the region's positive lightning discharges did not cause as many fires as the negative ones. [1]. Additionally, studies in the southern Great Plains in 2003 [2] highlighted the impact of anomalous lightning during abnormally dry and hot periods. These findings underscore the importance of considering lightning as a significant contributor to forest fires, even in regions not traditionally associated with high fire risk.

Furthermore, research from Finland in 2005 [3] emphasized the importance of thunderstorm characteristics in lightning-induced forest fires. Thunderstorms that were long-lasting and intense were found to be less likely to cause ignition compared to local, small-scale thunderstorms. This insight highlights the complexity of the relationship between lightning activity and fire ignition, suggesting that local weather conditions play a critical role. Similarly, research in Austria in 2012 [4] provided a comprehensive analysis of lightning-induced forest fires, including their seasonality, geographical distribution, and impact on different types of forests. These studies collectively contribute to our understanding of lightning's role in forest fires and underscore the need for region-specific investigations.

Moreover, lightning-induced forest fires are not only a matter of ignition but also have significant implications for fire dynamics. Research in North American boreal forests in 2017 [5] shown that the dynamics of burnt areas and interannual and long-term ignition are driven by lightning. This emphasizes the importance of considering lightning-induced fires in long-term

fire management strategies and highlights the need for a holistic understanding of the role of lightning activity in forest fire occurrence. As Nepal faces its own challenges with forest fires, it becomes essential to assess how lightning contributes to this issue in the unique context of the region. Although, there have been a few studies on lightning in Nepal pertaining its impact on human lives [6], its contribution on house fire [7], its impact of archeological buildings [8], its impact on telecom towers [9] etc. this is the first study to investigate the role of lightning on igniting the forest fire.

Methodology

The first step in this study involved acquiring two primary datasets: historical lightning strike data and historical forest fire incident data for Nepal for the years 2015, 2016, 2017, 2018 and 2019. These datasets were essential for analyzing the relationship between lightning activity and forest fires in the region. lightning strike data was obtained from Vaisala's Global Lightning Dataset (GLD 360) while ensuring that the lightning strike data covered a significant time frame, spanning multiple years, to capture long-term patterns.

The forest fire incident data was obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) dataset, hosted by the Ministry of Forest and Environment in Nepal while ensuring that the forest fire incident data included information on the location (latitude and longitude) and date of each incident.

Data preprocessing was a crucial step to ensure the accuracy and quality of the datasets.

Firstly, the lightning strike data was cleaned to remove any duplicate or erroneous entries and then was verified for the accuracy of location data and any outliers were removed. The date and time information were converted to a standardized format for consistency.

Secondly, the forest fire incident data was cleaned to eliminate duplicate or incomplete records and ensured that the location data was accurate and consistent. The date and time information were converted to a standardized format for uniformity across the dataset.

To look at the connection between lightning strikes and forest fires, the lightning strike data was sifted to find incidents that happened within ten kilometers of each forest fire incidence location. The distance between each lightning strike event and all forest fire incident points were calculated. Only those events that occurred within a 10-kilometer radius of any forest fire incident within a 24-hour period were retained for the purpose of this study.

Geographical Information System (GIS) software, in particular, ArcGIS was utilized to create detailed maps of Nepal that incorporated both lightning strike events and forest fire incident points.

The cleaned and filtered lightning strike and forest fire incident data was imported into ArcGIS, And the two datasets were overlayed on a map of Nepal to visualize their spatial distribution. Maps that clearly indicated the locations of lightning strikes and forest fire incidents were generated.

Major potential hotspots for forest fires were identified as areas where forest fire incidents occurred within a 5-kilometer radius of lightning strike events.

An assumption for the criteria for hotspot identification, specifying a 5-kilometer radius around each lightning strike event was made and calculated the frequency of lightning strikes and forest fires within each identified hotspot.

Results

In this study, lightning data obtained from VAISALA and the fire data acquired from MODIS were processed using ArcGIS and lightning heat maps were plotted for different years under study. Similarly, frequency of lightning occurrence was plotted against frequency of fire using python for each year.

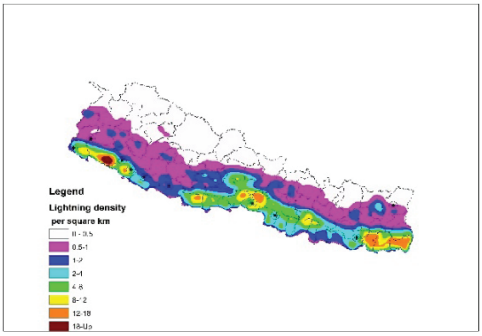

Fig. 1. Heatmap of lightning strokes for the year 2015

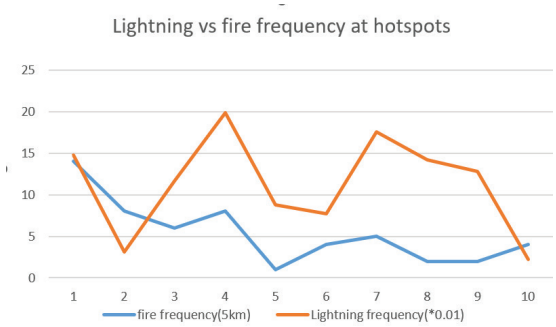

Fig. 2. 2015 hotspot frequency graph

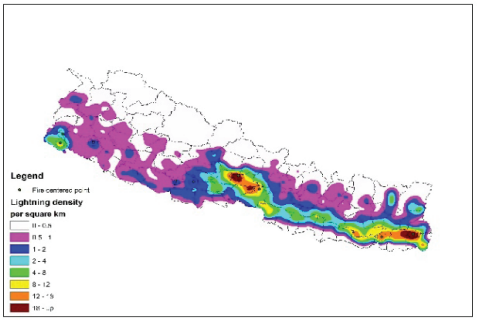

Fig. 3. *Heatmap of lightning strokes for the year 2016*

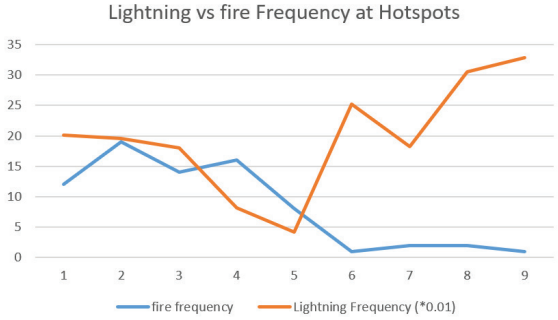

Fig. 4. *2016 hotspot frequency graph*

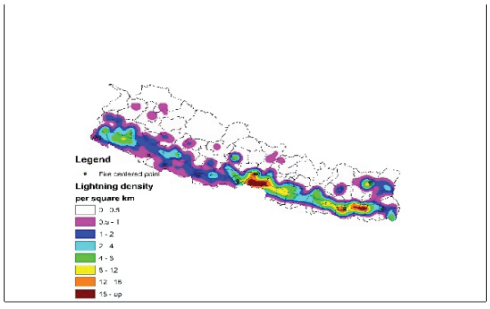

Fig. 5. Heatmap of lightning strokes for the year 2017

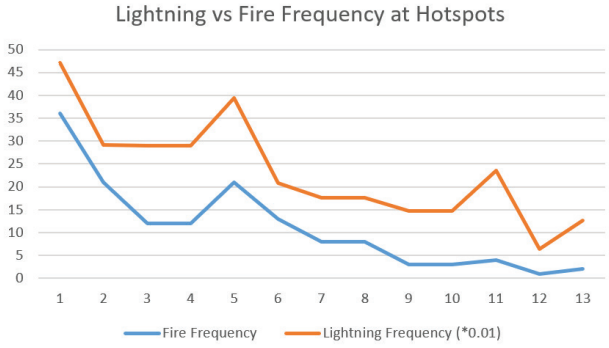

Fig. 6. 2017 hotspot frequency graph

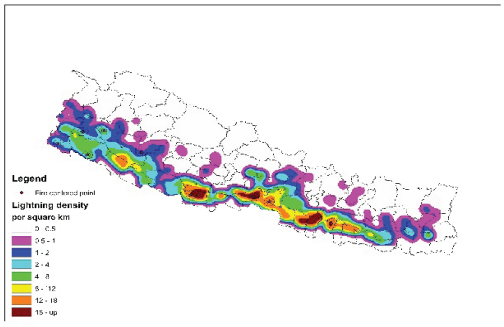

Fig. 7. Heatmap of lightning strokes for the year 2018

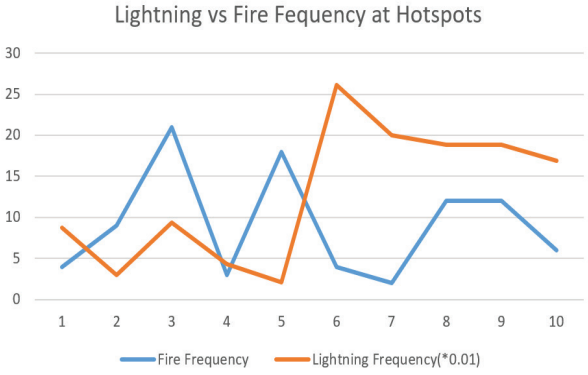

Fig. 8. 2018 hotspot frequency graph

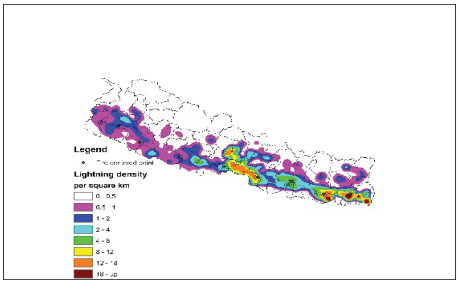

Fig. 9. Heatmap of lightning strokes for the year 2019

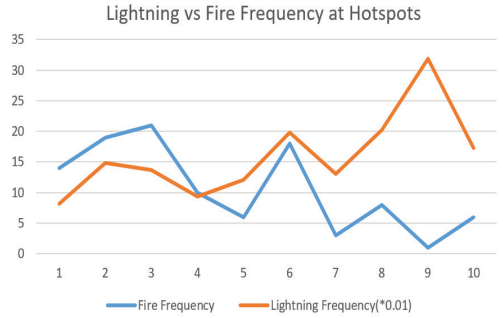

Fig. 10. 2019 hotspot frequency graph

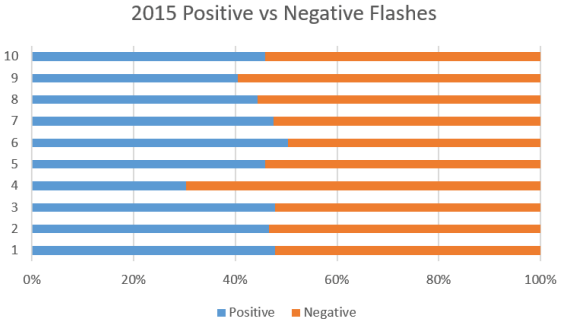

Fig. 11. *(a)*

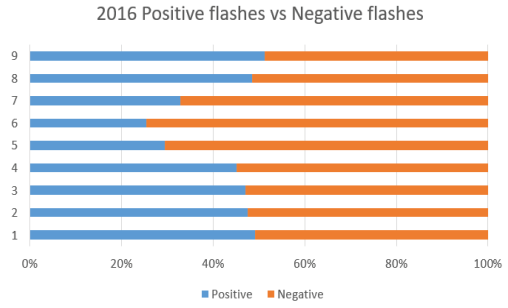

Fig. 11. *(b)*

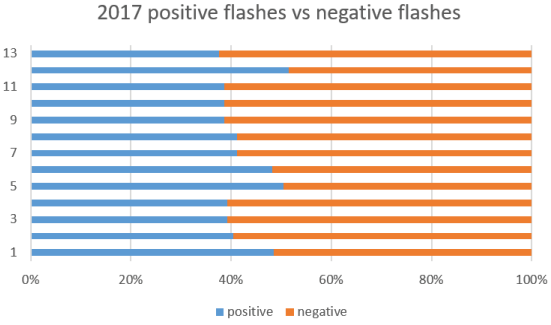

Fig. 11. *(c)*

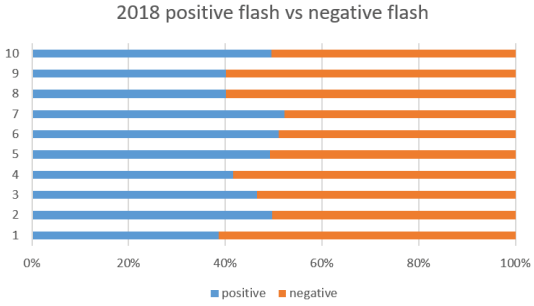

Fig. 11. *(d)*

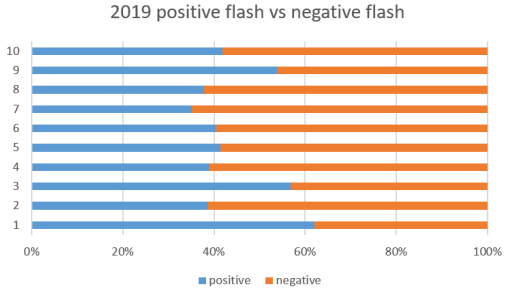

Fig: 11 (e)

Figures 11 (a-e): Plots of lightning ground flashes to exhibit the percentage of positive ground flashes against negative ground flashes for the years of study period.

Heat map and corresponding frequency plots for shown in figures 1 to 10 for the years 2015 to 2019. As depicted in the figures (1-10), the lightning density around the fire points is comparatively high and the corresponding plots also justify the same. However, it is not always the case. For example, in figure 4, for the year 2016, the fire occurrence is low while the lightning frequency is quite high. This means that occurrence of fire may not entirely depend on the frequency of lightning strikes. Which is well acceptable as one lightning strike is good enough to trigger the fire that may lead to engulf the forest around in a few weeks' time. Nevertheless, from the most of the plots it can be inferred that the higher the occurrence of lightning, the higher will be the probability of fire being ignited. Further, from the graphs shown in figures 11 (a-e), it is seen that a significant number of lightning strikes are positive type or positive ground flashes. The positive ground strikes are of much interest as they carry more current in the form of continuing current which a potential reason of igniting forest fire. As seen in the figures 11 (a-e), positive ground flashes can account up-to 64% of the ground flashes in some years e.g. 2019. In order to investigate on the role of positive ground flashes in igniting the forest fire, a detailed study on each such stroke occurring over the forest area should be taken into account.

Discussion

The data suggests a varying and relatively weak relationship between fire and lightning over the years. There is no consistent pattern of correlation, as the direction of the relationship fluctuates from negative to positive across different years.

However, it's important to note that the correlations are generally weak, with low R-squared values and high p-values in most cases, indicating that these variations may not be statistically significant. Therefore, it is challenging to definitively conclude whether there is a significant and consistent relationship between fire and lightning based on the frequency graph.

Therefore, the type of lightning for each of the hotspots was analyzed, to check for the positive and negative lightning strokes in each of the region for which the frequencies were analyzed. The results showed that an average of minimum 42% positive strokes and an average of 46% maximum positive strokes were observed for each year, for the 5 Km radius around each fire centric point at different lightning flash densities. The table 1 below is representative of the same.

Table 1: *Percentage occurrence of lightning ground flashes (positive and Negative strokes) over the study area in connection with forest fire*

Year	Positive Flashes and Negative Flashes at Hotspots	
	Positive(avg)	Negative(avg)
2015	45%	55%
2016	42%	58%
2017	43%	57%
2018	46%	54%
2019	45%	55%

This is a very significant result as the number of positive strokes follows a similar trend for all the different fire points at varying flash densities. We can infer from this that the number of Lightning strikes around a certain region is not a major cause of a forest fire, rather the type of lightning plays a crucial role in determining the occurrence of a forest fire ignition. Although only the occurrence of anomalous amounts of positive strokes is not the only cause, but they do point to the same, and suggest that the number of flashes is not a significant factor in igniting a forest fire in Nepal.

Conclusions

This research represents a pioneering effort to investigate the role of lightning activity in triggering forest fires in Nepal. Forest fires pose a significant threat to the nation's natural ecosystems, biodiversity, and communities. While human activities have been traditionally blamed for these fires, this study explored the potential impact of lightning strikes, a natural factor that had not been comprehensively studied in the Nepal's context.

As per the MODIS dataset 11681 forest fires were recorded over Nepal during the period of this study i.e., January 2015 to December 2019. Majority of the fire being recorded during the pre-monsoon period, a relatively dry period of the year coinciding

with the thunderstorm period over Nepal.

Anthropogenic activities are being considered to be major causes of forest fire [10], either on purpose or by mistake. Incorrect disposal of flaming matches or cigarette buts, youngsters starting fires unintentionally, coal manufacturers abandoning burned blazes, and fire remaining from a bonfire or picnic are the causes of unintended or accidental forest fires [11]. Whereas, the intention behind deliberate forest fire can be attributed for enhancing the new shoots of grass, enhancing fertility of the land, expanding the farm land etc. However, besides the anthropogenic activities, possible natural causes of forest fires in Nepal have not been explored.

To the greatest degree of our comprehension, this is an inaugural study done in Nepal that links lightning activity to forest fires. Using data from Vaisala's Global Lightning Dataset (GLD 360) and the MODIS dataset, the study revealed a noteworthy correlation between lightning strikes and forest fires, particularly during the pre-monsoon season. However, it's important to note that the correlation is variable across different years, and the strength of the relationship is generally weak, suggesting that other factors may also contribute to forest fire ignition.

One crucial finding of this research is the analysis of the type of lightning strokes in hotspots, which showed that the number of positive strokes, rather than the overall number of lightning strikes, plays a crucial role in forest fire ignition. This underscores the complexity of the relationship between lightning and forest fires, suggesting that local weather conditions and the type of lightning are significant determinants.

The control of forest fires in Nepal will be significantly impacted by the findings of this study. Although the importance of human-caused forest fires shouldn't be understated, comprehension of the function that lightning activity plays in forest fire ignition is essential for the creation of successful fire management and prevention plans. This study lays the foundation for region-specific fire management policies and practices, ultimately enhancing the resilience of Nepal's invaluable ecosystems and communities.

This study opens avenues for further research in several directions:

1. Future studies can delve deeper into the intricate mechanisms by which lightning ignites forest fires in Nepal. This will contribute to a more comprehensive understanding of this complex relationship.
2. Given the exhibited influence of lightning on fire dynamics, it is essential to consider lightning-induced fires in long-term fire management strategies. Research could explore the interannual and long-term trends in forest fire occurrence influenced by lightning activity.
3. Recognizing that the relationship between lightning and forest fires is context-dependent, further research can focus on specific regions within Nepal, taking into account the diverse geography and climate conditions of the country.
4. Understanding the role of lightning in forest fires can inform the development of effective mitigation strategies, including early warning systems, firebreak construction, and community education.

In conclusion, while this study provides valuable insights into the complex relationship between lightning activity and forest fires in Nepal, it also highlights the need for continued research and a holistic approach to forest fire management. The findings from this research have the potential to contribute significantly to safeguarding Nepal's natural resources and creating a safer environment for all its inhabitants.

Acknowledgement

The authors would like to thank ICIMOD for supplying the forest fire data and VAISALA for providing the lightning data. We acknowledge the assistance provided by the International Science Programme of Uppsala University Sweden (NEP01) to the Atmospheric and Material Science Research Center, Amrit campus.

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