URSI-RCRS 2024, ARIES/GEHU, Bhimtal, India, 22 - 25 October, 2024

Impact of Climate Change and Socioeconomy on Lightning Fatalities across India

R. Chakraborty*(1) and S. Chaudhuri (2)
(1) Department of Physics and Nanotechnology, SRMIST, Chennai 603203, rohitc744@gmail.com
(2) Department of Economics, University of Calcutta, Kolkata 700050, sravaitri@gmail.com

Abstract

The present study examines the spatiotemporal distribution of lightning fatality during the last 25 years in a state wise manner. Initial investigations revealed a doubling in countrywide lightning fatality between 1998-2022. Subsequently, the use of the lightning fatality density and its climatic trend enabled the identification of 13 key lightning risk states. Finally, most of selected states show no influence of lightning frequencies on fatality thereby pointing at probable influence of other socioeconomic drivers.

1. Introduction

Lightning fatality in the Indian subcontinent has become a major contributor to deaths from natural disasters compared to other weather extremes such as earthquakes, floods, cyclones and heatwaves [1-2]. This is because convective occurrences and thunderstorms are a predominant climatic feature over the Indian tropics which are frequently accompanied by lightning episodes [3-7]. Lightning is a rapid and massive discharge of electricity in the atmosphere, which can be classified as cloud to ground and cloud to cloud. These extremes tend to be highly erratic in its position and timing. According to most of the past research, a gradually warming climate is expected to experience more frequent and intense lightning occurrences at the rate of 10 percent per 1 degree centigrade. Thus, research related to attribution, understanding and prediction of lightning and related weather extremes have become a major concern at present among researchers and policymakers alike [8-12].

Compared to the global average, the burden of lightning casualty falls dis-proportionately on developing countries. The key reasons for this discrepancy mainly arise from occupational hazards, which imply that a major percentage of population are engaged in agriculture and allied activities, requiring them to work outdoors therefore increasing their exposure to thunderstorms. Secondly, housing structures are less robust in developing economies as they lack features like proper grounding that offer protection from lightning strikes. Furthermore, literacy rates are very low in these countries making lightning safety education less accessible, and this leaves people without crucial knowledge on how to evade or minimize risks during thunderstorms. Finally, challenges in rural settings such as almost non-existent healthcare infrastructure to treat lightning injuries promptly also affect the survival rates of such victims.

Though lightning is considered as one of the most significant atmospheric hazards, systematic documentation ad research in this topic is far too scarce. One of the studies [13] showed that the estimates between ranges of 6000 to 24000 fatalities yearly while injuries reported are far higher. Some other studies such as [14-17] investigated lightning deaths across India between 1979-2011. Diurnal variation of lightning across India as observed by a study [18] found the diurnal maximum at 1530 IST with a minimum during morning times. Another study [19] used satellite data of LIS from 1998 to 2013 and find that lightning events are most prevalent along mountain foothills of different states, but fatalities are low owing to scant population in these regions. A worldwide overview of lightning fatalities is done by some past research [20-21] which revealed that lightning fatalities has dropped in developed economies as the majority of population shifted to urban areas which in turn happened due to their decreasing dependence on agriculture. Similarly, the decrease in death can also be associated to increase in awareness, improvement in weather forecasts, housing, vehicles and health care. In a further study [22] showed that more than half of the reported incidents of death and injuries due lightning come from India, followed by Bangladesh and Philippines. Further, such events mainly occurred in agricultural fields during the rainy season and with more men dying, the common crop under cultivation was found to be rice and paddy.

2. Methodology

The pervious section enumerated a list of past works on lightning fatality both over India and globally. Nevertheless, most of the above-mentioned research fails to elaborate on the spatiotemporal distribution of lightning fatality and its association with anthropogenic factors. Hence this study attempts to utilize data on various properties of lightning such as its frequency, intensity and its associated fatality in a state wise manner between 1998-2022. Lightning fatality information for the said time period is sourced in state wise format along with all other natural causes yearly from the National Crime Records Bureau (NCRB) under Ministry of Home Affairs (MHA), Government of India since 1986. On the other hand, lightning frequency and radiance is utilized from Lightning Imaging Sensor observations onboard the TRMM and the International Space Station (ISS) satellite during the periods 1998-2014 and 2017-2022 [23-24]. This gridded data has also been categorized state wise by matching these with the state boundary coordinates.

3. Results and Discussion

3.1 Distribution of lightning fatalities over Indian region

The climatic trends of total lightning fatalities is first analyzed across India for the study period (1998-2022). As expected, a statistically significant strengthening is observed from ~ 1500 in 2000 to 3000 after 2020 with high goodness of fit (R^2 0.7137) and low p (4.97 e-7) values as already expected from past research. These results indicate a doubling of the lightning toll in between these years. However, the rate of increase weakened post 2019 which might be to an extent related to the decrease in outdoor labor activities because of COVID-19 restrictions. Next, the state wise annual average lightning mortality is presented in Figure 1.

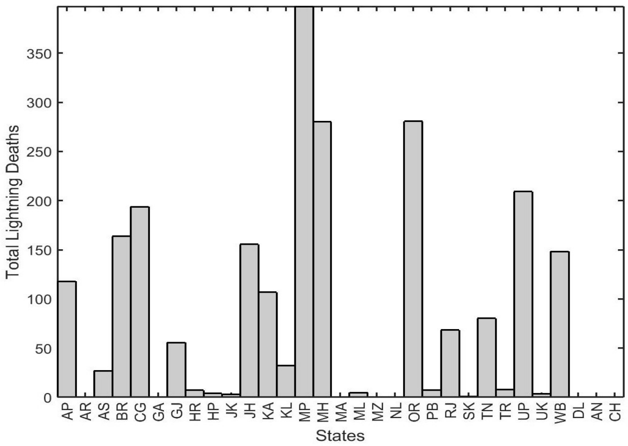

Figure 1. Distribution of total lightning deaths.

It can be observed that among 35 states and union territories only 31 are taken for further analysis as for the rest of the states there is insufficiency of data. Furthermore, out of the 31 regions, most areas show less than 50 deaths annually due to lightning while 14 states can be identified wherein the lightning mortality is substantial.

In fact, states namely Madhya Pradesh (MP), Maharashtra (MH) and Orissa (OR) exhibit over 250 lightning deaths annually and this hints towards the importance of detailed future research on these states. They are followed by some moderately affected states such as Bihar (BR), Chhattisgarh (CG), Uttar Pradesh (UP) and West Bengal (WB) (~ 150 deaths). Finally, there are 7 less effected states namely: Andhra Pradesh (AP), Gujarat (GJ), Jharkhand (JH), Jammu and Kashmir (JK), Karnataka (KA), Rajasthan (RJ), Tamil Nadu (TN). Here it may be noted that most of the high and moderately affected states are all situated along the core monsoon zone. As a result, these states often get more impacted by thunderstorms during the pre and post monsoon season followed by depressions and low-pressure systems during monsoon. On the other hand, the rest of the states are either located away from the above-mentioned regions such as the Peninsular states or some in separate distinct areas such as Rajasthan and Jammu and Kashmir, the reasons for which will be investigated in the forthcoming sections.

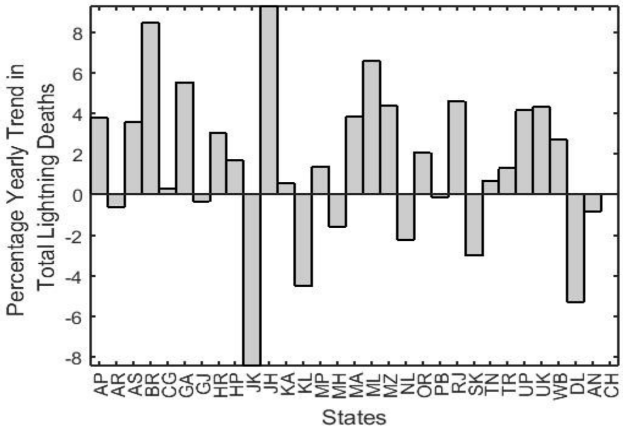

Figure 2. Percentage yearly trends in lightning fatalities.

Next, an attempt is undertaken to observe the climatic trends of lightning fatalities across India in Figure 2. About half of the states show an increase in lightning deaths. However, the magnitude of such is found to be prominent in only 10 states where a 4% increase per year or a net doubling in 25 years is observed. Out of these states the majority falls along the east coastline (AP, OR, WB) and the Core Monsoon Zone (CG, MP, UP, JH, BR) which face isolated thunderstorms as well as low pressure systems throughout the year. Notably some states like BR and JH show very strong growth in lightning fatality which underlines the need to study these states in detail. Also, some states which do not fall under these regions (Assam (AS), RJ, Meghalaya (ML), Tripura (TR)) but still exhibit an increase in deaths, indicates that socioeconomic drivers such as informality, housing, awareness, deforestation and others might also play a decisive role behind this reported increase. While most states exhibit increased lightning deaths, some have shown weak to prominent decline in fatalities such as Kerala (KL), Maharashtra (MH), Sikkim (SK), Delhi (DL). While this result goes against the current mindset of climate change where lightning and its associated hazards are projected to increase in a warming climate, there may still be some other inhibiting factors like increased awareness and economic development in these states which may have played a pivotal role which therefore needs to be understood in future.

3.2 Relationship between lightning frequency and fatality for lightning risk states

From the previous section, it has become evident that lightning fatalities and their climatic trends are quite prominent only in certain states of the country. Hence to proceed forward in a focused way, attempt is now made to identify and analyze only those states where all necessary factors such as lightning death average and its trends are stronger. Furthermore, the population of all states are different and the fitted trends on lightning fatalities can also arise due to spurious outliers in the time series. Hence, the state wise lightning fatality count has been divided by the population of the state and the goodness of fit of the trends have also been calculated. Next, a product of the lightning fatality density, the climatic yearly percentage trend and its goodness of fit are multiplied to identify states where both the lightning density as well as climatic trends in lightning deaths are alarming based on the magnitudes of the product.

The above-mentioned analysis resulted in the selection of 13 states: JH, BR, OR, CG, MP, ML, WB, AP, UP, RJ, MH, KL and JK. Out of these states JH and BR emerge as high lightning fatality risk states where lightning fatality density as well as its intensification trends are statistically significant. Secondly, OR, CG and MP are the medium risk states as they commonly serve as the eastern side of the Indian Core Monsoon Zone and hence it is expected to be vastly impacted by the climate patterns followed by the socioeconomic causes. Next comes WB, UP, RJ, AP and ML where lightning risks are much lower. These states come from diverse topography and hence it needs to be checked that under what conditions the expected increase in lightning deaths can be minimized.

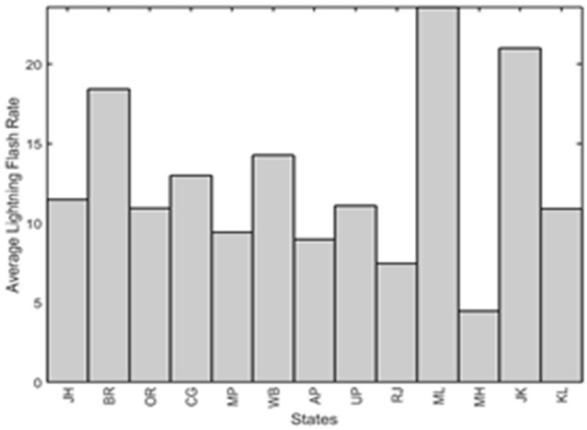

Figure 3. Lightning flash rates over 13 selected states

Finally, lightning risk is found to be decreasing or negative over JK, MH and KL. While the recent decline in lightning over MH and KL may be attributed to increasing awareness and improving standards of living, though the same cannot be warranted for JK and so it needs to be examined whether other factors have ~~also~~ played any role here. In accordance with the previous section, it is next attempted to decipher whether the observed acceleration in lightning risk over the Indian states is mainly attributed to climate change or not.

To understand this, frequency of lightning flashes is averaged state wise and depicted for 13 states in Figure 3. It is seen that lightning flashes are most frequent over the Himalayan foothills in JK and ML, this explains that the impact of climatic drivers should be much stronger on fatality in these states. Next, the lightning frequency assumes medium values over BR, JK, WB, UP, OR, CG and KL as these states experience frequent thunderstorms and low- pressure systems in majority of the year. Thus, these states are expected to show strong lightning fatalities if climate change serves to be a primary controlling factor. Finally, average lightning flash rate is least over MH explaining observed decline in lightning fatalities in presence of urbanization and awareness scenarios.

Finally, it is attempted to investigate the presence of any intercorrelation between lightning fatality and climate change in the form of lightning frequency trends. The goodness of fit for all 13 states shown in Figure 4 depicts an interesting picture where the variance in lightning fatality is well explained by climatic drivers in very few states.

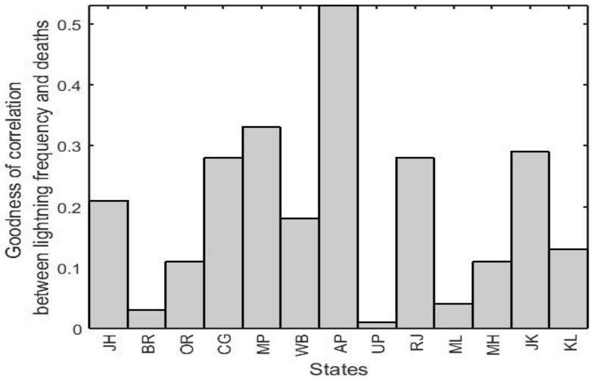

Figure 4. Goodness of fit between LFR and fatality

For instance, the goodness of fit values is greater than 0.25 (correlation greater than 0.5) only for CG, MP, AP, RJ and JK thus climate change should play some role behind fatality increase in these states. However, it cannot be clearly established in most of these states except AP. Hence there may be other socioeconomic factors too which may be equally important over CG, MP and JK. Next, correlations are lesser over WB and JH meaning that climate change can only play a secondary role on fatality here. Finally, for states BR, OR, UP, ML, MH and KL the values are close to zero indicating that the observed increase in fatalities is solely due to anthropogenic influences and not climate change.

4. Conclusions

Lightning in the past couple of decades has emerged as the major contributor to natural cause deaths over the Indian region. However, studies on lightning deaths are scattered, scarce and lack scientific reasoning. Hence the present study attempts to investigate the spatiotemporal distribution in lightning deaths over the last 25 years (1998-2022) and then explores its relationship with the lightning properties (frequency and radiance) in a state wise manner. Initial investigations revealed a doubling in countrywide lightning fatality between 1998-2022. States along the eastern coasts and the core monsoon zones are found to be the most lightning fatality risk prone zones. Furthermore, the long-term trends in lightning fatality is found to be increasing in the majority of the states barring a few where the socioeconomic reasons seem to inhibit the expected accelerating rise in a warming climate. Subsequently, the use of the lightning fatality density and its climatic trend enabled the identification of 13 key lightning risk states which were further categorized as high, moderate, low and negative. The distribution of lightning revealed maximal values along the Himalayan foothills followed by the coastal regions and the monsoon zones. However, apart from a few, most of the selected states show little to no influence of climate change induced lightning frequencies on fatality. This in turn can open a possibility that a range of socioeconomic factors also need to be considered to impact the observed fatality trends in future research.

5. Acknowledgements

RC is grateful to the Ministry of Science and Technology, Government of India, for providing support in the form of the INSPIRE faculty research grant (IFA19-EAS79).

6. References

1. R. Chakraborty, A. Chakraborty, G. Basha, M. Venkat Ratnam, "Lightning occurrences and intensity over Indian region: long term trends future projections", *Atmospheric Chemistry and Physics*, **21**, 2021, pp. 11161-11177, https://doi.org/10.5194/acp-21-11161-2021

2. S. Jana, R., Chakraborty, and A. Maitra, "A. Lightning Prediction Using Electric Field Measurements Associated with Convective Events at a Tropical Location". *Pure Applied Geophysics*, **180**, 2023, pp. 1173–1184, https://doi.org/10.1007/s00024-023-03229-7.

3. R. Chakraborty, S. Das, S. Jana, A. Maitra, "Nowcasting rain events using multi-frequency radiometric observations", *Journal of Hydrology*, **513**, 2014, pp. 467 – 474. https://doi.org/10.1016/j.jhydrol.2014.03.066

4. A. Maitra, R. Chakraborty, "Prediction of Rain Occurrence and Accumulation using Multifrequency Radiometric Observations", *IEEE Transactions in Geoscience and Remote Sensing*, **56(5)**, 2018, DOI: https://doi.org/10.1109/TGRS.2017.2783848

5. R. Chakraborty, G. Basha and M. Venkat Ratnam, "Long-term trends of instability associated parameters over Indian region obtained using a radiosonde network", *Atmospheric Chemistry and Physics,* **19(6)**, 2019, pp 3687–3705. https://doi.org/10.5194/acp-19-3687-2019

6. G. Rakshit, R. Chakraborty and A. Maitra, "Micro rain radar and radiometric measurements to unravel contrasting features of rain microstructure below and above the boundary layer," *Radio Science*., **59(2),** 2024 pp. 1-13, https://doi.org/10.1029/2023RS007875

7. A. Maitra, G. Rakshit, S. Jana and R. Chakraborty, "Effect of Boundary Layer Dynamics on the Profiles of Rain Drop Size Distribution During Convective Rain," *IEEE Geoscience Remote Sensing Letters*, **16(7)**, 2019, pp. 1007-101, https://doi.org/10.1109/LGRS.2019.2891906

8. R. Chakraborty, B.K. Guha, S. Talukdar, M. Venkat Ratnam, A. Maitra, "Growth in mid-monsoon phases over Indian region: prevailing influence of anthropogenic aerosols", *Atmospheric Chemistry Physics*, **19(19)**, 2019, pp. 12325-12341, https://doi.org/10.5194/acp-19-12325-2019

9. D. Aggarwal, R. Chakraborty, and R. Attada, "Investigating bi-decadal precipitation changes over the Northwest Himalayas during the pre-monsoon: role of Pacific decadal oscillations", *Climate Dynamics*., **62**, 2024, pp. 1203–1218, https://doi.org/10.1007/s00382-023-06969-3

10. R. Chakraborty and A. Chakraborty, "Sensitivity of Surface Temperatures towards Lightning over the Indian Subcontinent," *URSI GASS*, Sapporo, Japan, 2023, pp. 1-4, https://doi.org/10.23919/URSIGASS57860.2023.10265597

11. S. Chaudhuri, R.., Bhattacharyya, and S. Bhattacharya, "Rural urban migration with heterogeneous firms, heterogonous laborer and the effect of wage subsidy", *Theoretical and Applied Economics*, **28(3),** 2021**,** pp. 143-156

12.S. Chaudhuri, "Welfare enhancing uncertainty." *Theoretical and Applied Economics* **27(4)**, 2020, pp. 73-88.

13.C. Gomes and M.Z.A.A. Kadir, "A Theoretical Approach to Estimate the Annual Lightning Hazards on Human Beings", *Atmospheric Research*., **101**, 2011, pp. 719–725.

14. M. Das, S. Sampath and G. Mohankumar, "Lightning Hazard in Kerela", *Journal of Marine Atmospheric Research*, **3**, 2007, pp. 111–117.

15. M. Das. G. Mohankumar and S. Sampath, "Investigations Mechanisms Involvement Objects and Personnel in Lightning Disaster", *Journal of Lightning Research*, **1**, 2009, pp. 36–51.

16. S.J. Gadge and M.B. Shrigiriwar, "Lightning: A 15 Year Study of Fatal Cases at SVNGMC Yavatmal", *Journal of Forensic Medical Science and Law,* **22**, 2013, pp. 1–5.

17. O. Singh "Lightning Fatalities India: 1979–2011", *Meteorological Applications*, **22(4)**, 2015, pp. 770–778.

18. S.S. Kandalgaonkar, M.I.R. Tinmaker, J.R. Kulkarni and A. Nath, "Diurnal Variation Lightning Activity over Indian Region", *Geophysical Research Letters*., **30**, 2003, pp. 20–22.

19. P.K. Yadava, M. Soni, S. Verma, H. Kumar, A. Sharma and S Payra, "Major Lightning Regions Associated Casualties over India", *Natural. Hazards*., **101**, 2020, pp. 217-229.

20. M.Z.A.A. Kadir, M.A. Cooper and C. Gomes, "An Overview of the Global Statistics on Lightning Fatalities", *30th International Conference on Lightning Protection*, Cagliari, Italy, 13-17 September, 2010.

21. R.L. Holle, "Annual Rates of Lightning Fatalities by Country", *20th International Lightning Detection Conference* 21–23 June, 2008, Tucson, AZ, USA.

22. R.L. Holle, "Lightning- Caused Deaths and Injuries Related to Agriculture", *6th International Lightning Meteorology Conference*, 2016, San Diego, California, USA.

23. H.J., Christian, R.J., Blakeslee, and S.J., Goodman, "Lightning imaging sensor (LIS) for the international space station". In *AIP Conference Proceedings* **504(1)**, pp. 423-428.

24. D.J., Cecil, D.E., Buechler, and R.J. Blakeslee, "Gridded lightning climatology from TRMM-LIS and OTD: Dataset description" *Atmospheric Research*, **135**, 2014, pp. 404-414.