Impact of thunderstorm activities on tropospheric NOx adversely affecting the climate change over Bagmati province of Nepal

Shriram Sharma*, *, Naba Raj Regmi**and Sujan Neupane*****

*Department of Physics, Amrit Campus, Tribhuvan University, Kathmandu Nepal.

**Department of Physics Golden Gate College, Tribhuvan University Kathmandu Nepal.

***South Asian Lightning Network, Kathmandu Nepal.

Abstract: Lightning is a complex electrical discharge that occurs in the atmosphere. Huge currents associated with the lightning discharge raises the ambient temperature resulting in the change in atmospheric chemistry. The extreme temperatures within lightning channels break apart molecular nitrogen (N_2) and oxygen (O_2) to produce nitrogen oxides (NO_x). NOx act as indirect greenhouse gases by producing the tropospheric Ozone. Likewise, NOx gases also affect the global greenhouse gas budget through the change in concentration of hydroxyl radical (OH) and Methane. This study analyzes the association of lightning stroke density with the tropospheric NOx over the Bagmati province (central region) of Nepal, during pre-monsoon and post-monsoon for 3 years (2018 to 2020). The tropospheric NOx was examined by utilizing the data from Ozone Monitoring Instrument (OMI), whereas the lightning stroke data was obtained from VAISALA's Global Lightning Detection (GLD-360) Network. The lightning stroke density for each season were plotted against the corresponding average value of NOx to obtain the correlation coefficient over the period of study. Strong positive correlations between lightning and NOx production during per-monsoon periods were obtained for all the three years of study period, whereas, comparatively weak correlations are obtained for the post-monsoon seasons. Nevertheless, the NOx production due to lightning is found to be strong, during the pre-monsoon period, a relatively dry season over the Bagmati province. This clearly indicates that lightning is a big source of tropospheric NOx,that in turn produces greenhouse gases and hence contributes to the climatic changes over the central region on Nepal.

Keywords: Lightning; Tropospheric NOx; Thunderstorms; Climate change.

1. Introduction

Lightning is a complex atmospheric electrical discharge that occurs due to the electrical imbalance in the atmosphere. Lightning discharge is accompanied by a huge amount of electrical current ranging from a few thousands of amperes to a few hundred thousand of amperes. The large current flowing through the atmosphere produces extremely hot channel (~30,000 K) of ionized gases changing the chemistry of the atmosphere. The study of lightning and related phenomena involves the synthesis of many branches of physics, from atmospheric physics to plasma physics to quantum electrodynamics, and provides a plethora of challenging unsolved problems[1]. Lightning converts the atmospheric nitrogen molecule into its oxides namely nitrogen dioxide (NO_2) and nitric oxide (NO) as the extreme temperatures within lightning channels break apart molecular nitrogen (N_2) and oxygen (O_2). Nitrogen oxides produced by lightning (LNO_x) play an important role in determining mid- and upper-tropospheric concentrations of the hydroxyl radical (OH), methane (CH_4), and ozone (O_3) [2, 3]. Bond et al[4], observed that production of NO_x by tropical lightning is significant throughout the year. Lightning accounts for almost all of the NO_x emitted over the oceans and 50–90% of NO_x emitted over some continental areas on a seasonal basis[4]. Using the NOx data obtained from Ozone Monitoring Instrument Allen et al[2] found that lightning flash counts from World Wide Lightning Location Network (WWLLN) were distinctly correlated with LNOx estimates. They reported that a mean midlatitude production efficiency (PE) of the lighting flash as 180 ± 100 moles of NOx per flash. Whereas, in the tropics, they found a mean LNO_x production of 170 ± 100 mol per flash with the mean PE at tropical marine locations with low flash rates approximately twice as large as at tropical continental locations with high flash rates[3] commonly experienced atmospheric phenomenon and carrying huge amount of electric current and light and the loudest sound commonly occurring on Earth. Most of the lightning is generated in

Author for correspondence: Shriram Sharma, Department of Physics, Amrit Campus, Tribhuvan University, Kathmandu, Nepal.

Email: ramhome2@hotmail.com

Received: 20 June 2023; Received in revised form: 01 July 2023; Accepted: 04 July 2023.

Doi: https://doi.org/10.3126/sw.v16i16.56866

thunderstorms and is characterized by a length of 5-10 km at the extreme over 100 km^2 .

The lightning discharges can vaguely be divided into two categories namely cloud discharges and cloud-to-ground discharges. The cloud discharges do not involve the earth for the electrical discharge whereas the cloud-to-ground flashes do. Over two third of the lightning discharges are cloud flashes and the rest are cloud-to-ground flashes. There have been numerous studies on lightning discharges across the globe to understand the physics of atmospheric discharges, their impacts, their association with other atmospheric factors etc. A very few studies have been conducted in Nepal on various facets of lightning[5-20]. However, to the best of our knowledge, study of the lightning discharges in association with the NOx has not been carried out as of now. Since, nitrogen oxides are the greenhouse gases that adversely impact the climate ecosystem, it is of great interest to understand their production by atmospheric electrical discharge i.e., lightning and their role in generating the thunderstorm

activities focusing at mountainous topography of Bagmati province, Nepal.

In this study we analyze the association of NOx with lightning activity over the central region of Nepal in order to investigate the possible impact of lightning in the production of greenhouse gases and hence its contribution in future climate. We observe the change in concentration of NOx in the atmosphere I

association with lightning activities and hence find the contribution of lightning in the formation of NOx in atmosphere.

For the purpose, we investigate the effect of lightning activity on surface NOx during the pre-monsoon and post-monsoon seasons over Baghmati Province, Nepal.

2. Methodology

In this study we have utilized the NOx data acquired by Ozone Monitoring Instrument (OMI) which is an instrument used to distinguish the smokes, dusts, sulfates and so on. Studying the effect of lightning activity on surface NOx in the Bagmati Province during the pre-monsoon and post-monsoon seasons using satellite data requires a specific research design that incorporates satellite imagery and data analysis techniques. In this study, the main task is to find the relation between the lightning stroke density and concentration of nitrogen oxides.

Lightning data for the pre-monsoon and post-monsoon periods have been acquired from VAISAL's lightning detection systems namely Global Lightning Dataset (GLD) 360. The data obtained from the two systems have been plotted over the Bagmati Province in Python software and analyzed for their possible association using statistical tools.

The geographical map of Bagmati province was obtained in Python using the shape files and the lightning stroke data and average NOx data were overlaid. The whole province was divided into 10x10 grids and the data for each grid were plotted against each other. Figure 1 shows the geographical map gridded map of Bagmati Province as obtained in the Python.

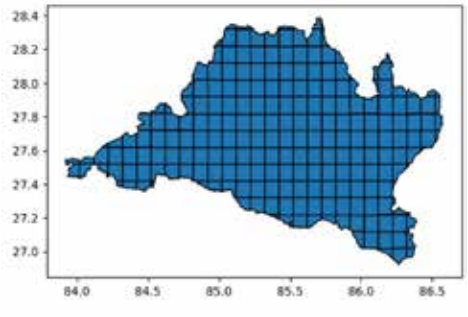

Figure 1 Geographical map of Bagmati province in 10 km x10 km grid plotted in Python.

3. Analysis and Results

The relation between the lightning stroke density and average NO_x over Bagmati Province was studied. The main objective of the study was to analyze the possible correlation between the lightning stroke density and nitrogen oxides. We analyze the data for pre- and post-monsoon seasons for the period of three years i.e., from 2018 to 2020.

3.1. Lightning Stroke Density and NOX, Pre-monsoon and Post Monsoon

The lightning stroke density and the average value of NOx concentration over Bagmati Province have been plotted for the pre-monsoon and post-monsoon period for the year 2018. The graphs in figure 2 (a) and 2 (B) depict the correlation coefficient between the stroke density and average NOx.

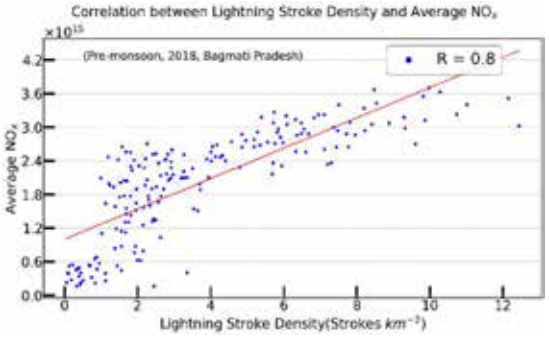

Figure: 2 (a) A plot for correlation coefficient between the lightning stroke density and average NOx for Pre-monsoon (2018)

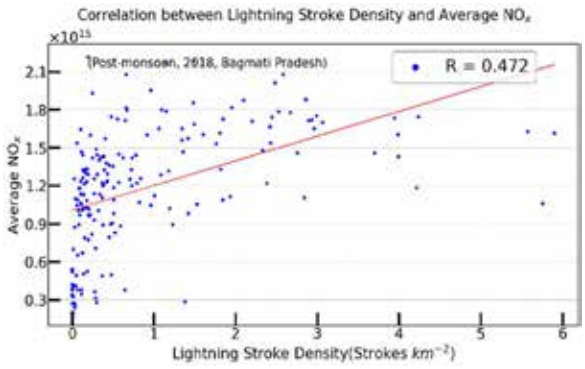

Figure: 2 (b) A plot for correlation coefficient between the lightning stroke density and average NOx for Post-monsoon (2018)

As seen from the graphs in figure 2 (a), there is an excellent correlation between the stroke density and NOx for the pre-monsoon of 2018 with Pearson's correlation coefficient of 0.8 whereas, that for the post-monsoon is relatively poor with a correlation coefficient of 0.47.

Similarly, the correlation coefficient for the pre-monsoon period for the year 2019 was found to be 0.74 (figure 3, a); whereas the correlation coefficient for the post-monsoon period for the year 2019 is found to be 0.62 (figure 3, b)

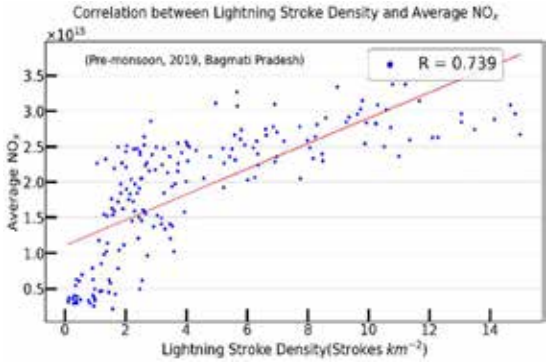

Figure: 3 (a) A plot for correlation coefficient between the lightning stroke density and average NOx for Pre-monsoon (2019)

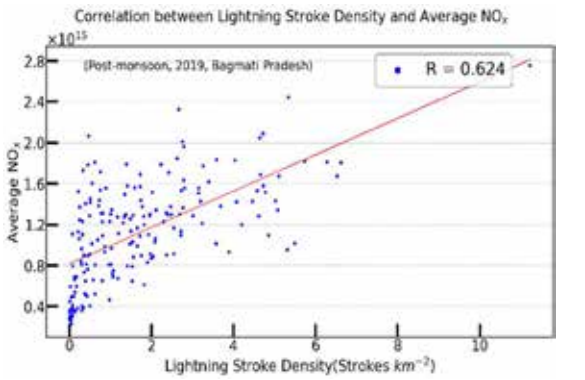

Figure: 3 (b) A plot for correlation coefficient between the lightning stroke density and average NOx for Post-monsoon (2019).

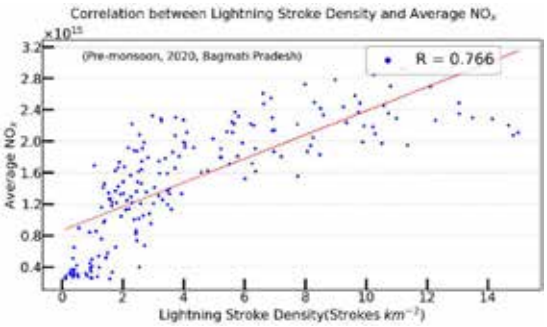

Figure: 4 (a) A plot for correlation coefficient between the lightning stroke density and average NOx for Pre-monsoon (2020)

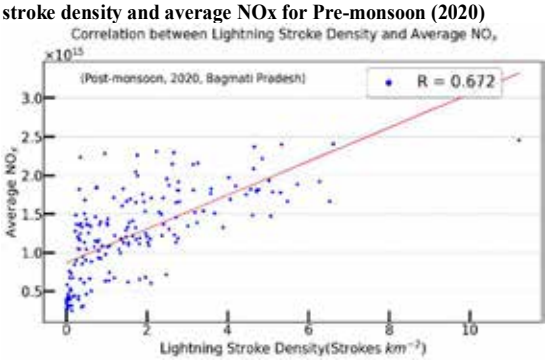

Figure: 4 (b) A plot for correlation coefficient between the lightning stroke density and average NOx for Post-monsoon (2020).

The correlation coefficient over the pre-monsoon period for the year 2020 was found to be 0.77 (figure 4, a); whereas the correlation coefficient over the post-monsoon period for the year 2020 is found to be 0.67 (figure 4, b).

4. Discussion and conclusion

In this study, we have selected Bagmati province to analyze the association between the lightning stroke density and the tropospheric NOx. Since, Bagmati province is densely populated and excessive anthropogenic activities take place in the province, it is not known as of today if NOx play role in lightning activity or vice versa, we chose this province to observe the possible association between the two. It is to be noted that two seasons namely pre- and post-monsoon have been considered for the study because the lightning activities are predominant during these seasons and the relevance can be justified.

Based on the analysis and the subsequent results, it is seen that average NOx concentration is positively correlated with lightning stroke density over Bagmati province for both the seasons and over the period of three years (2018-2020). The positive and strong correlation between the lightning stroke density and NOx is in agreement with the report that lightning contributes over 23% of NOx production in the tropics[21].

Furthermore, the correlation is very strong during the pre-monsoon period as compared to that in the post-monsoon season. This suggests us that lightning activity produces more NOx while the atmosphere is relatively dry. This is an

indication that drier pre-monsoons create larger amount of NOx the green house gas, adversely affecting our climate system. This also indicates that drier pre-monsoons can be warmer and may result in the extreme weather events.

Acknowledgement

Authors wish to acknowledge the financial support from the International Science Programme (ISP) of Uppsala university, Sweden to Atmospheric and Material Science Research Center (AMSRC) at the Department of physics, Amrit Campus through NEP01, project to carry out research activities.

References

1. Dwyer, J. R. and Uman, M. A. 2014. The Physics of Lightning. *Physics Reports*. **534**: 147–241. http://dx.doi.org/10.1016/j.physrep.2013.09.004
2. Allen, D. J., Pickering, K. E., Bucsela, E., Krotkov, N., & Holzworth, R. 2019. Lightning NOx production in the tropics as determined using OMI NO_2 retrievals and WWLLN stroke data. *Journal of Geophysical Research. Atmospheres*. **124**(23): 13498– 13518. https://doi.org/10.1029/2018JD029824
3. Allen, D. J., Pickering, K. E., Bucsela, E., Bucsela, E., Geffen, J.V., Lapierre, J., Koshak, W., Eskes, H. 2021. Observations of lightning NO_x production from tropospheric monitoring instrument case studies over the united states. *JGR Atmospheres*. **126 (10).** https://doi.org/10.1029/2020JD034174
4. Bond, D., Steiger, S., & Zhang, R. 2002. The importance of NOx production by lightning in the tropics. *Journal of Science And Technology.* **36**(9): 1509-1519.
5. Baral K. N., MacKerras, D. 1993. Positive cloud-to-ground lightning discharges in Kathmandu thunderstorms. *Journal of Geophysical Research: Atmospheres.* **98**(D6): 10,331-10,340
6. Adhikari. P. B., Sharma. S. and Baral. K. N. 2016. Features of positive ground flashes observed in Kathmandu Nepal. *Journal of Atmospheric and Solar Terrestrial Physics.* **145**: 106-113.
7. Adhikari. P. B., Sharma. S., Baral. K. N. and Rakov. V. 2017. Unusual lightning electric field waveforms observed in Kathmandu, Nepal and Uppsala, Sweden. *Journal of Atmospheric and Solar Terrestrial Physics.* **164**: (2017) 172–184
8. Saha, K., Damase, N. P., Banik, T., Paul, B., Sharma, S.R., De, B. K. and Guha, A. 2019. Satellite-based observation of lightning climatology over Nepal. *Journal Earth System Science.* **128**:221.
9. Saha, K., Damase, N. P., Banik, T., Paul, B., Sharma, S.R., De, B. K. and Guha, A. 2019. Satellite-based observation of lightning climatology over Nepal. *Journal Earth System Science.* **128**:221.
10. Damase, N. P., Banik, T., Paul. B., Shah, K., Sharma, S.R., De, B. K. and Guha, A. 2021. Comparative study of lightning climatology and the role of meteorological parameters over the Himalayan region. *Journal of Atmospheric and Solar Terrestrial Physics*. **219:**105527.
11. Sharma, S.R., Neupane, B., KC, H. B., Koirala, M. P., Damase, N. P., Dhakal, S., Gomes, C., Cooper, M. A., Holle, R. L., Bhusal, R. J., Cramer, J. and Said, R. Lightning threats in Nepal: occurrence and human impacts. *Geomatics, Natural Hazards and Risk.* **13**(1): 1-18. https://doi.org/10.1080/19475705.2021.2009922.
12. Adhikari, P. B. and Sharma. S. R. 2020. Characteristic Features of Electric Fields Radiated by Cloud Flashes in Himalayan Region*. International Journal of Antennas and Propagation.* Volume 2020 Article ID 6187635 https://doi.org/10.1155/2020/6187635
13. Sharma, S.R., Holle, R. L., Gassert, K., Said, R. and Cooper, M. A. 2021. Nepal: Human Threat and Occurrence of Lightning: AMS 101, 101st annual meeting.
14. Khadka, N., Bista, A., Bista, D., Sharma, S.R. and Adhikary, B. 2022. Direct Lightning Impact Assessment on a Rural Mini-Grid of Nepal. 35th International Conference on Lightning Protection (virtual platform).
15. Sharma, S.R., Holle, R. L. and Cooper, M. A. 2022. Life on Siwalik and Lesser Himalayas under the Extreme Threat of Lightning. 35th International Conference on Lightning Protection (virtual platform).
16. Sharma, S., Bhusal, R. J. and Holle, R. L. Lightning - A Potential Cause of House Fires during the Pre-monsoon Season. 36th International Conference on Lightning Protection (Cape Town, South Africa).
17. Sharma, S., Sharma, S. R. and Gomes, C. 2022. Archaeological sites in Nepal and India: Concerns of lightning risks. 36th International Conference on Lightning Protection (Cape Town, South Africa).
18. Sharma, S.R., KC, H. B., Gyawali, M., Lamsal, L., Neupane, S. and Karki, P. 2022. The possible impact of atmospheric aerosol and other factors on lightning over the rugged terrain of Nepal. 36th International Conference on Lightning Protection (Cape Town, South Africa).
19. Sharma, S.R., Gomes, C., Kumar, S. G. and Lubasi, F. C. 2022. Ubiquitous and Perplexing Proliferation of Nonstandard Lightning Protection System in Developing Countries. 36th International Conference on Lightning Protection (Cape Town, South Africa).
20. Khadka, N., Bista, D., Gomes, C., Sharma, S.R. and Adhikary, B. 2022. Distribution Network Impact Assessment with Geometrically Identified Strike Points. 36th International Conference on Lightning Protection (Cape Town, South Africa).
21. Bond, D. W., Steiger, S., Zhang, R., Tie, X., Orville, R. E. 2002. The importance of NOx production by lightning in the tropics. *Atmospheric Environment.* **36**(9): 1509-1519. https://doi.org/10.1016/S1352-2310(01)00553-2