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Effects of Diwali Celebration on Air Quality in India

Air Quality Overview




October 22, 2024

New Delhi

Introduction

The northern states of India, particularly the National Capital Territory of Delhi, experience significant air quality issues during the post-monsoon season. This seasonal air pollution begins in late September or October and persists for four to five months. During this time, New Delhi often ranks among the most polluted cities globally. Several factors contribute to this seasonal pollution, including Delhi's geographic location near the Himalayan mountains, intense construction activities, widespread use of fossil-fueled vehicles, and active crop burning in nearby agricultural regions [1,2,3].

The onset of the 'pollution season' frequently coincides with the Diwali festival, an annual celebration that has recently become the focus of environmental controversy. The smoke from firecrackers, traditionally ignited during Diwali, is commonly linked to severe air pollution in the northern states. Although there is broad consensus on the negative environmental impacts of firecracker burning during Diwali, the duration of these effects and their overall contribution to the deterioration of air quality in the subsequent months are not fully understood.

Numerous research studies have proved negative environmental effects of firecrackers [4,5]. It has also been shown that fireworks burning can have direct health effects, causing acute respiratory attacks [6]. In particular, multiple research papers describe air quality dynamics specifically during the Diwali celebration [7,8,9]. It has been shown that the celebration of Diwali is responsible for a significant increase in PM2.5 pollution in Delhi, worsening environmental conditions even further. However, the lasting impact of the celebration on the overall air pollution in northern regions has been found insignificant [7]. Various government measures, including a complete ban on firecracker distribution in the capital region during the festive season of 2017, have been implemented to mitigate these environmental impacts. Yet, this initiative has proven highly unpopular, and its effectiveness remains questionable.

Most of the studies concerning the environmental impact of the Diwali celebration are focused on the data collected from a specific region, most often located in the northern states. This study aims to assess the impact of firecracker emissions on air quality across the whole of India and identify the regions most affected. This involves analyzing air quality data during the festival season, isolating the components linked to firecracker emissions, and exploring the persistence of these effects. The conducted research provides the most complete and up-to-date insight into the environmental impact of the Diwali celebration, involving the analysis of data collected from 180 sites in 14 states across India. This comprehensive approach enables us to enhance our understanding of the issue and provide detailed quantitative assessments of how firecracker emissions affect air pollution nationwide.

Data

The research utilizes data provided by the Central Pollution Control Board (CPCB), encompassing information from a total of 523 sites over seven years, from 2017 to 2024. The data features a time resolution of one hour.

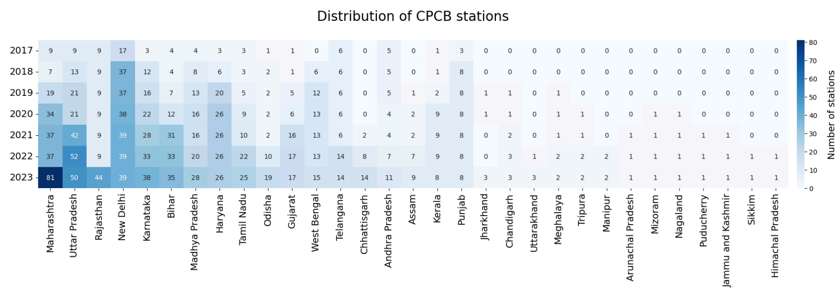

__Figure 1__: Number of CPCB stations per state (sorted by the number of stations in 2023).

To assess the impact of firecracker smoke, we selected stations that had been operational for at least five consecutive years (2019-2023) in states where at least four stations were consistently active, resulting in a total of 180 stations (Table 1). The CPCB stations offer a comprehensive range of air quality data, including concentrations of particulate matter (PM2.5 and PM10). We chose to focus on PM2.5 concentrations as they are the primary indicators of firecracker smoke.

State	# of stations	State	# of stations
New Delhi	36	Rajasthan	9
Haryana	20	Punjab	8
Uttar Pradesh	18	Bihar	7
Maharashtra	17	Telangana	6
Karnataka	14	Gujarat	5
Madhya Pradesh	13	Tamil Nadu	4
West Bengal	12	Andhra Pradesh	4

Table 1. Number of stations that were online at 2019-2023, used in this research

Air Quality Standards:

The recommended levels for PM2.5 are set according to the National Ambient Air Quality Standards (NAAQS). The standards require that the time-averaged concentration of PM2.5 should be 60 μg/m^3 for a 24-hour average, and 40 μg/m^3 for an annual average. Notably, NAAQS requires that the 24-hour average concentration of PM2.5 remain below 60 μg/m^3 for 98% of the year. However, it may exceed this threshold for 2% of the year, provided it does not occur on two consecutive days. Regrettably, recorded data show significant non-compliance with these standards, particularly in the northern regions.

In this study, concentrations below the recommended annual average level are indicated in green, while those falling between the recommended annual and 24-hour average levels are marked in yellow.

Results

Seasonal Trends

Our analysis begins by examining the seasonal trends in PM2.5 concentrations across different states, based on data collected from monitors operational from 2019 to 2023. This data is averaged annually and by state. In Figure 2, we present this data with states arranged from north to south. There is a distinct seasonal pattern, with a marked increase in PM2.5 concentrations from October to March, particularly in the northern states, especially those adjacent to the Capital Territory. The graph starts in July to more clearly illustrate these seasonal trends.

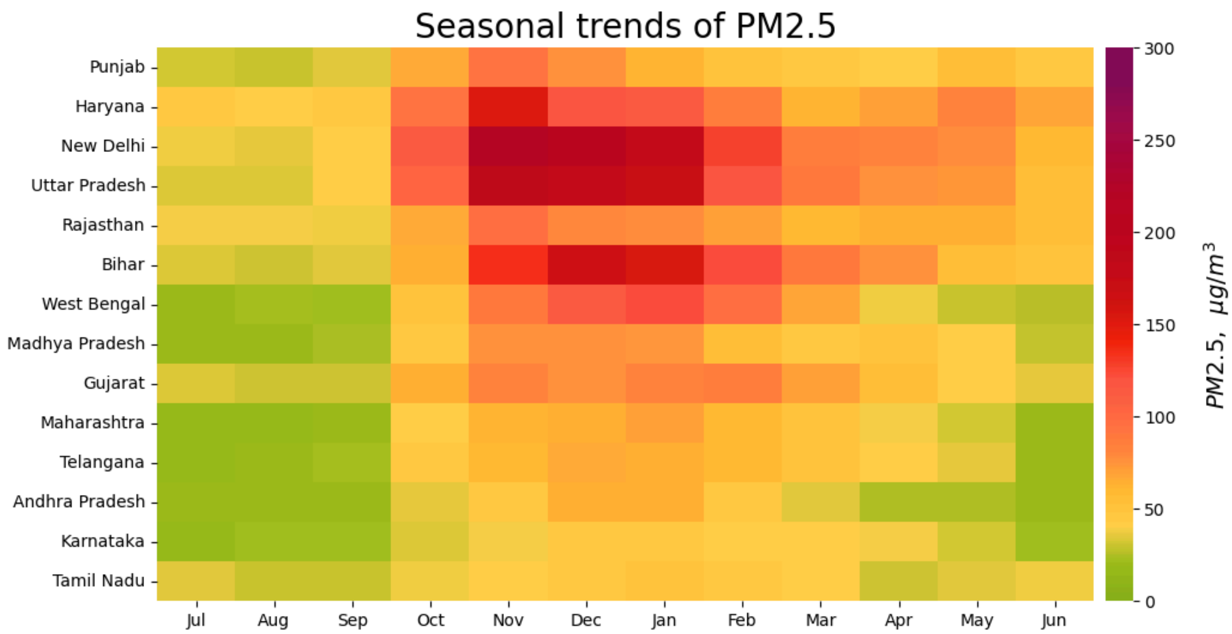

Figure 2. Monthly dynamics of PM2.5 levels, with states grouped from north to south.

Diwali Celebration

Each year, the date of Diwali is set by the lunar calendar, leading to varying dates in the Gregorian calendar. This variation enables us to assess the impact of firecracker smoke on overall air quality. To analyze this, we compared PM2.5 levels on Diwali with those on the same date over the previous four years. Given that seasonal air quality trends are influenced more by the calendar year than by the specific date of Diwali, we expect air quality on these dates across different years to be similar. This effect is exemplified in Figure 3.

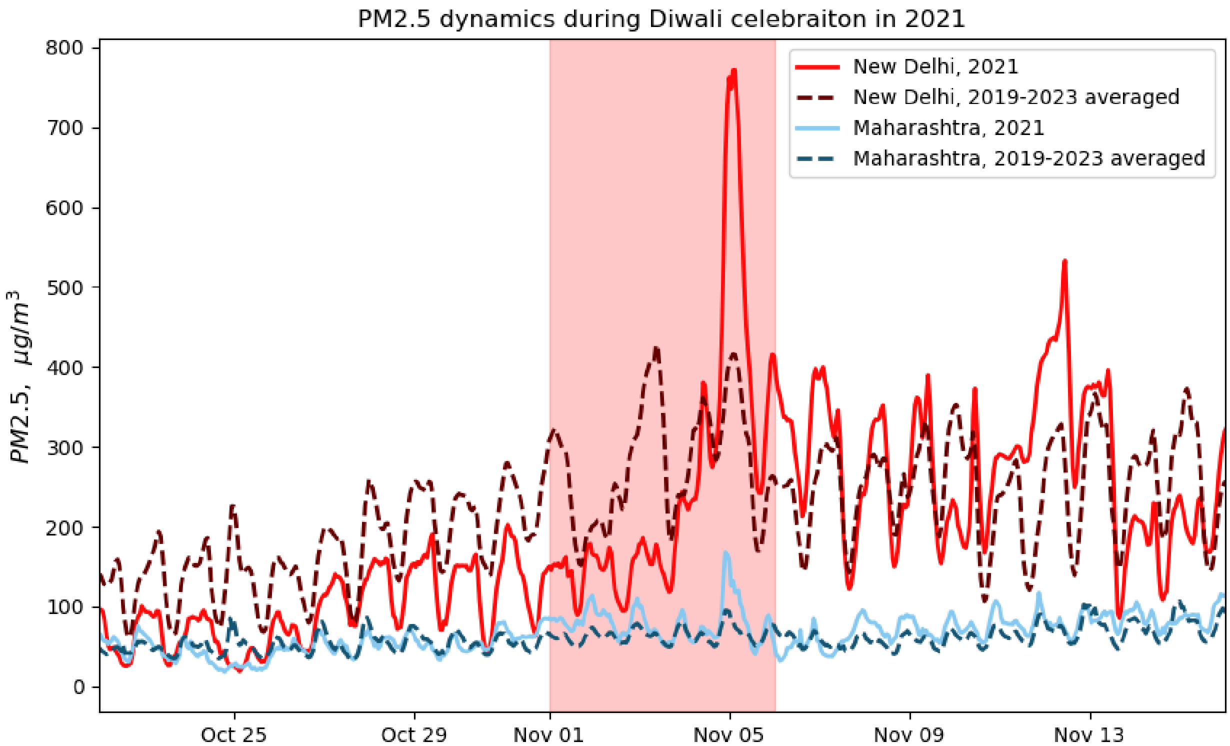

Figure 3. Example of PM2.5 dynamics during the festival season (colored with pink).

In Figure 3, data averaged from stations in New Delhi (34 stations) and Maharashtra (17 stations) is displayed. The data from the 2021 festival season is compared with an average over five years.

A significant peak in PM2.5 concentration is noted during the last night of the festival week, commonly referred to as "The Festival Night." This night marks the main celebration when the majority of firecrackers are ignited, constituting the primary focus of this research.

To analyze typical PM2.5 dynamics during the festival week, we centered the PM2.5 data around the last night of the Diwali celebration and averaged it over five years of observations (Figures 4-6). A 24-hour averaging method was applied to compare PM2.5 levels against NAAQS standards. As firecracker burning predominantly occurs overnight, the 24-hour averaging was conducted from midday to midday, rather than midnight to midnight, to prevent the dispersal of firecracker effects across two consecutive dates.

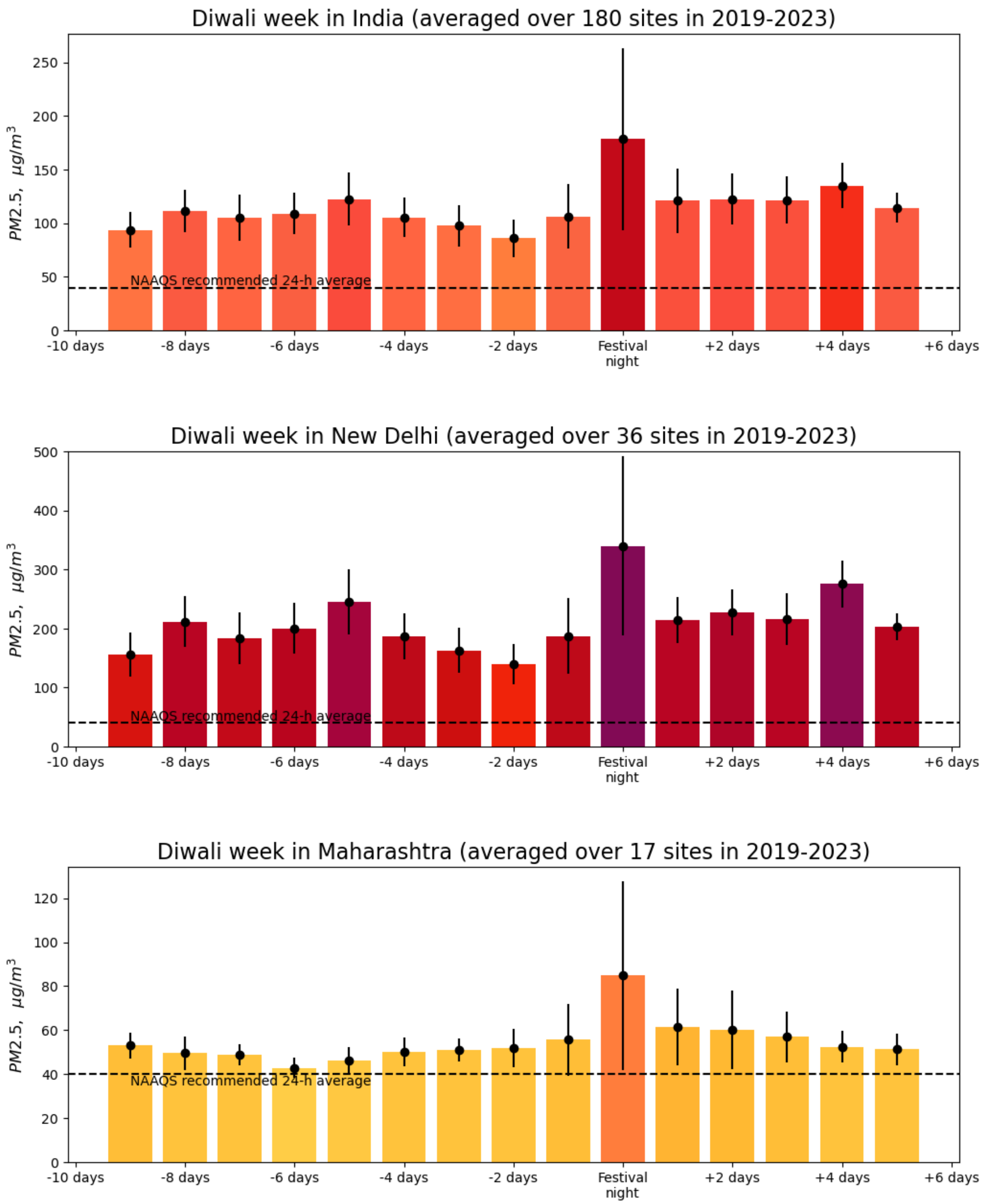

Figure 4. Ten days surrounding the last night of the Diwali celebration, averaged over five years of observations for all available sites in India (top), New Delhi (center), and Maharashtra (bottom).

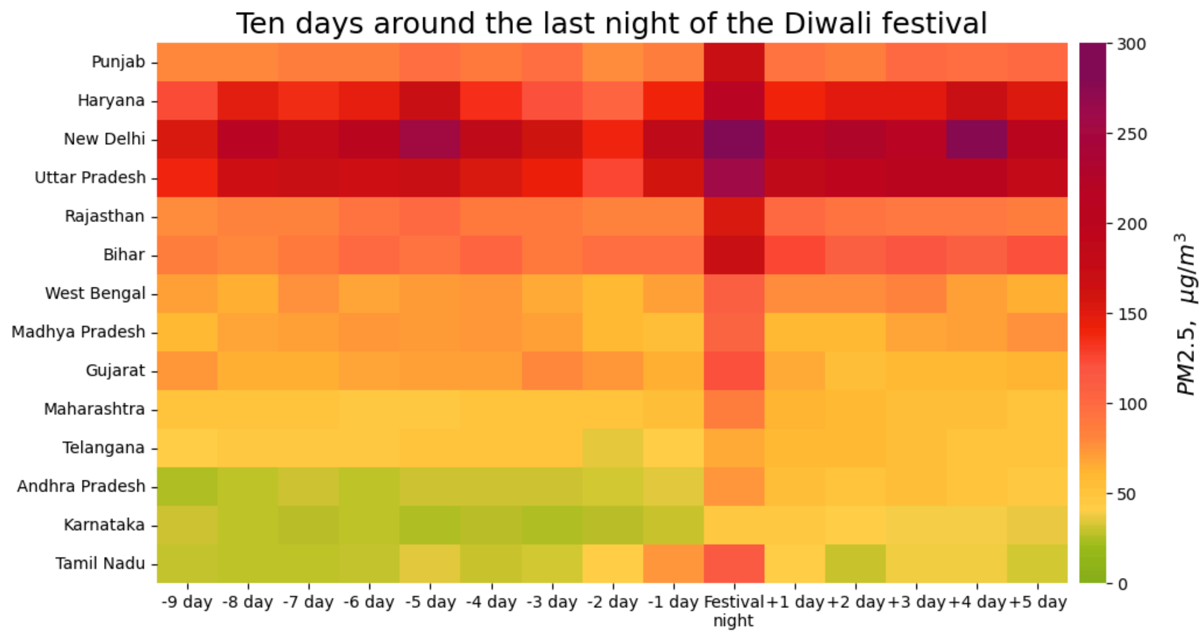

Figure 5. Ten days surrounding the last night of the Diwali celebration, averaged over the past five years.

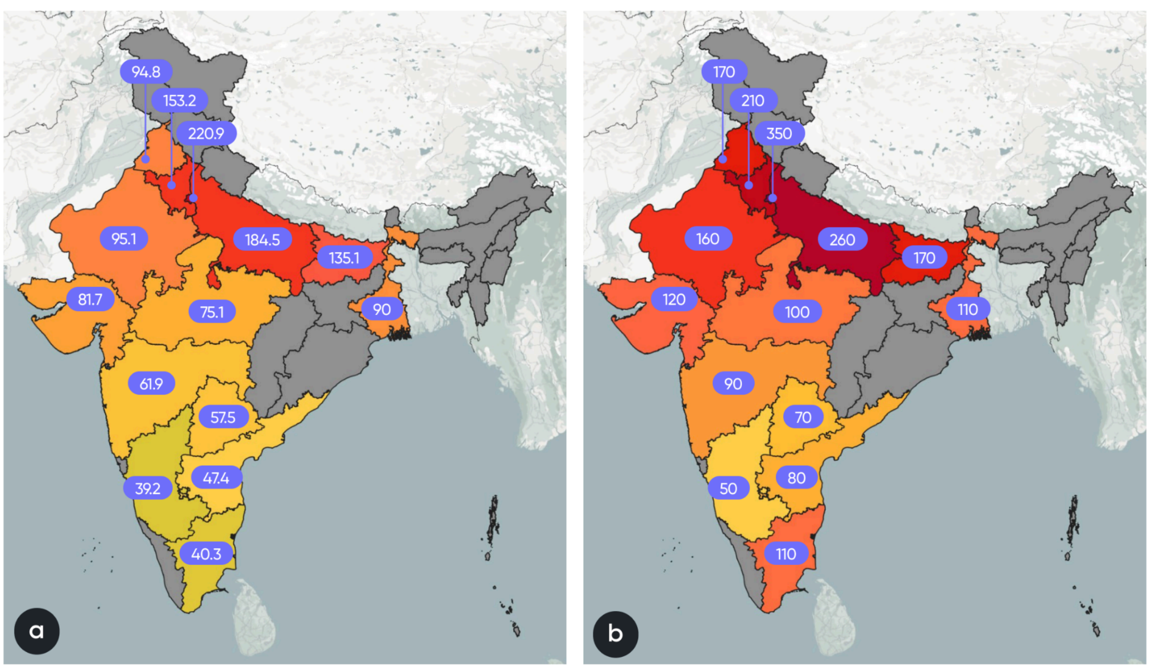

Figure 6. Average values of PM2.5 per state. (a) during November 2019-2023, (b) on Diwali Night 2019-2023.

It is clear that the impact of firecracker burning on overall PM2.5 levels is significant; however, it does not seem to extend significantly into the days following the Festival Night. While the average 24-hour PM2.5 concentrations on the nights after the Diwali celebration may appear elevated compared to those before, these differences are not statistically significant when considering the margin of error.

To quantitatively assess this effect, we analyzed the difference between the daily average PM2.5 levels during the Festival Night and the 24-hour average PM2.5 levels observed on the same date in the previous four years, normalized by the latter value. This measurement indicates the proportion of PM2.5 concentration on the Festival Night directly attributable to firecracker burning. As previously described, the 24-hour averaging was conducted from midday to midday to ensure that the impact of overnight firecracker burning is contained within a single 24-hour period.

We hypothesize that on regular, non-festival days, the distribution of this dimensionless parameter would follow a normal distribution. This assumption enables us to conduct a t-test to determine whether the PM2.5 levels on the Festival Night significantly differ from those on corresponding dates in other years when no celebration occurred. Table 2 presents p-values that illustrate the differences between the Festival Night, the Night before the Festival, and the Night after the Festival, compared to the 10-day period preceding the festival, aggregated over five years. A p-value less than 0.05 indicates a statistically significant difference from the baseline set, confirming that the PM2.5 levels on these dates are significantly higher than on regular days.

State	Night before the Festival	The Festival Night	Night after the Festival
New Delhi	0.5991	0.0337	0.718
Haryana	0.4607	0.0837	0.9526
Uttar Pradesh	0.2969	0.0232	0.4255
Maharashtra	0.4662	0.0838	0.2968
Karnataka	0.4766	0.0195	0.0505
Madhya Pradesh	0.0332	0.0009	0.0287
West Bengal	0.9314	0.4413	0.8664
Rajasthan	0.1464	0.0006	0.9474
Punjab	0.4534	0.0032	0.8005
Bihar	0.9471	0.0057	0.0861

Telangana	0.9861	0.0846	0.1796
Gujarat	0.0549	0.0284	0.2534
Tamil Nadu	0.0403	0.0036	0.1938
Andhra Pradesh	0.4414	0.0231	0.1075

Table 2. The *p*-values describing the statistical difference on Diwali. Statistically significant differences are highlighted in gray.

It is evident from the table that while the Festival Night is statistically distinct from the preceding 10 days, this statistical difference is seldom significant for the night before and the night after the Festival Night. An exception is observed in Madhya Pradesh, where the days before and after the Festival Night do not conform to the normal distribution of regular days within the state. The cause of this anomaly is not yet clear. However, we suspect that the data collected in this state may be influenced by the research limitations discussed below.

Discussion

Limitations of the Research

While we believe that this study provides a comprehensive overview of PM2.5 level dynamics during the Diwali celebration, several limitations should be considered.

Firstly, the study does not account for weather effects. It is well known that rainfall can significantly reduce PM2.5 concentrations. Averaging data across different years for the same region may increase the margin of error, as rainfall could occur during the festival season in some years. For example, in New Delhi in 2023, PM2.5 levels decreased dramatically two days prior to the festival night due to rainfall. This event notably accentuated the perceived impact of firecracker smoke on overall PM2.5 levels; however, we assume this was mitigated by averaging over five years of observations.

Weather analysis was not included in this study for several reasons. Firstly, the Diwali celebration occurs post-monsoon season when rainfall is relatively rare and considered a randomly distributed contributing factor. Secondly, while the effect of rainfall is well-understood and can be estimated, other factors of similar magnitude, such as crop burning in northern regions, are less well-documented. Including rainfall data without accounting for crop burning schedules would introduce an experimental bias into the statistical sample.

However, this approach is susceptible to errors—if rainfall occurred during the Diwali season in some states for five consecutive years, the impact of firecrackers would be underestimated and could be inaccurately reflected in the p-value table. To our knowledge, this effect did not occur in any of the studied states.

Secondly, this research focuses solely on PM2.5 pollution, the concentration of which is proven to have a strong correlation with per capita respiratory diseases [10], and does not consider multiple toxic gases and heavy metals also emitted during firecracker combustion [11]. These pollutants, including metals such as aluminum, manganese, and cadmium, can remain in the atmosphere for extended periods, posing long-term health risks. Prolonged exposure to these pollutants may lead to chronic obstructive pulmonary disease (COPD), respiratory illnesses, and other long-term health complications [12, 13]. Unfortunately, the CPCB air quality monitoring networks do not provide updates that we could include in this research.

Conclusion

Particulate matter pollution in India follows a seasonal trend that is consistent year after year. This pattern is clearly demonstrated using data from Central Pollution Control Board stations, highlighting a marked difference between the northern and southern states. While PM2.5 levels remain relatively low and stable in the southern states, the northern regions suffer from severe air pollution during the autumn and winter months.

The onset of the pollution season in the north often coincides with the Diwali celebration, leading to misconceptions about the causal relationship between the two. Despite various initiatives to reduce firecracker usage during Diwali, these efforts have yet to yield effective results.

It is evident that PM2.5 concentrations spike significantly on the last night of the Diwali festival, occasionally exceeding NAAQS thresholds by up to five times. However, studies have shown that the environmental impact of Diwali is transient, with air quality the night after Diwali typically resembling the nights preceding the festival.

The most significant effects of firecracker emissions are observed in states like Rajasthan and Madhya Pradesh, where baseline PM2.5 levels are relatively low during autumn, leading to the most pronounced peaks during the festival.

Acknowledgments

We extend our deepest gratitude to the Central Pollution Control Board (CPCB) for providing the air quality data critical for this study. We also appreciate the dedicated efforts of all individuals and organizations committed to improving air quality, which have significantly enriched our research.

Special thanks to our partners and collaborators whose insights and expertise have greatly enhanced this report. Their continuous support inspires us to further our work in air quality improvement and promote sustainable practices throughout India.

About Airvoice

Airvoice develops and manufactures innovative software and hardware solutions for air quality monitoring and management. Founded in 2021, the company has rapidly evolved to address global air quality challenges. Its commitment to advancing science-backed technologies is demonstrated through strategic partnerships with major universities and research institutions worldwide. These collaborations, including partnerships with the Indian Institute of Tropical Meteorology, the University of Arizona, Nanyang Technological University in Singapore, and many others, enhance Airvoice's robust research in atmospheric physics and AI technology, establishing it at the forefront of the emerging clean air industry.

Airvoice.India, launched in 2022 as a collaborative venture between Airvoice Global and Col. Bhawani Singh, is dedicated to revolutionizing air quality management across India. With its advanced technologies and extensive experience, the company is adept at providing solutions that cater to the unique air quality needs of various sectors, including urban environments, industries, and residential areas.

Focusing on sustainability and innovation, Airvoice.India has quickly become a leader in air quality solutions, contributing to national smart city initiatives and events like the B20 Sustainability Summit in Delhi. The company’s strategic initiatives aim to position India as a central hub for developing and deploying air quality improvements throughout Southeast Asia.

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