RESEARCH ARTICLE

Insights into the Air Quality Indices and its Linkage with Diwali Festival Celebrations in Delhi, India in November 2023: A Case Study

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Abstract

Air pollution, especially during the winter months, is a cause of concern in the capital city of Delhi and adjacent areas. Particulate matter (PM_{10}, $PM_{5.0}$, and $PM_{2.5}$) generated from various sources has been implicated in poor air quality and adverse impacts on human health. In the present study, the status of air pollution in Delhi in November 2023 was assessed. Diwali was celebrated on 12th November 2023. The air quality indices (particulate matter) data was retrieved from the Central Pollution Control Board (CPCB) website pre-Diwali and post-Diwali to comprehend the trends. During Diwali, an increase in PM_{10} in 2023 compared to the year 2022 was noted. A 42% reduction of PM_{10} was noticed in 2023 compared to the average concentration in 2021. However, a 45% overall increase of $PM_{2.5}$ was observed compared to 2022. The air quality two days prior to Diwali was poor. Though the Government has taken many steps and various awareness campaigns have been launched, people have not stopped bursting crackers in Delhi. However, to mitigate the pollution levels, certain other initiatives such as community festivities and traditional celebration methods, should be incentivized and propagated.

Keywords: AQI, Cracker bursting, Delhi, Diwali, Pollution.

Highlights

- Air quality in Delhi worsened during Diwali in 2023, 45% increase observed in $PM_{2.5}$ levels compared to 2022.
- A 42% reduction in PM 10 levels observed compared to 2021.
- Firecrackers bursting despite the ban spiked the pollution levels two days post-Diwali.
- Sustainable behavior, community participation and adoption of traditional celebration practices are promising options to curb the menace.

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Introduction

The issue of air pollution in Indian cities, particularly Delhi, has gained significant attention on both national and international platforms, especially from 2000-2020 and onwards (Cropper *et al*., 2011; Rizwan *et al*., 2013; Khan, 2023). Delhi consistently grapples with pervasive ambient air pollution, which intricately influences diverse facets of development (Chaudhary, 2023). The deteriorating air quality in the capital city has been a cause for concern, with various factors, such as stubble burning, contributing to the problem (Kulkarni *et al*., 2020; Khan *et al*., 2023). Understanding the factors behind the poor air quality index (AQI) is crucial for safeguarding public health, shaping effective policies, optimizing resource allocation, and fostering community engagement (Liu *et al*., 2016). Curbing air pollution is imperative for advancing environmental sustainability and enhancing emergency preparedness (Kotze, 2015; Nayak and Chaudhary, 2018).

Diwali is celebrated throughout the subcontinent, marked by lavish celebrations featuring an elaborate presentation of fireworks and pyrotechnic displays on a nationwide scale (Wise, 2019; Yadav *et al*., 2022). The national capital, New Delhi, adheres to this tradition with equal fervor and over the last three decades, fireworks and crackers have integrated with the festival. Cracker bursting probably is also seen as a display of wealth and an increase in the purchasing power of the residents. Diwali is observed annually in either October or November (Kumar, 2020; Yadav, 2022). The CPCB data and a plethora of research papers published in the last few years have implicated cracker burning as a foremost reason for poor air quality in the national capital (CPCB, 2019; Saha *et al*., 2021; Saxena *et al*., 2020). Numerous research teams have examined the impact of firecrackers, an intrinsic element of the festival, on ambient air quality during Diwali, focusing on pollutant concentrations, chemical speciation, and associated health effects (Daga *et al*., 2019; Singh *et al*., 2019; Khurana *et al*., 2023). These fireworks are composed of paper tubes filled with a combination of various

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harmful metal salts, soot-charcoal, sulfur dust, and a few binding agents. Upon ignition, they release dense plumes of smoke and vibrant illuminations (Yadav *et al*., 2022).

Fireworks consist of various chemicals, including arsenic, sulfur, and manganese, besides oxalates and salts that are bound in many metal complexes (Wang *et al*., 2007; Ajith *et al*., 2019). Upon ignition, these fireworks emit a plethora of pollutants, including some greenhouse gases and suspended particles with a size below 10 micrometers in diameter. Metals such as Al, Cd, Pb, Si and As, which pose significant health risks also show a spike (Nasir and Brahmaiah, 2015).

According to a study conducted in Thiruvananthapuram, India, there was a significant increase in atmospheric black carbon during the fireworks display on Diwali compared to normal days (Nasir and Brahmaiah, 2015). Similarly, studies conducted in Nagpur and Kolkata have also revealed the adverse effects of firecracker burning during Diwali on air quality (Verma and Deshmukh, 2014; Deka and Haque, 2014**;** Khaparde *et al*., 2011).

Additionally, data shows that the concentration of air pollutants such as PM10 and SO2 significantly increased during Diwali, attributed to adverse changes in the meteorological parameters such as a decrease in the 24-hour average mixing height, temperature, and wind speed conditions and the burning of firecrackers (Nasir and Brahmaiah, 2015). Furthermore, the issue of stubble burning in neighboring states of Punjab and Haryana is seen as a potential contributor to the deteriorating air quality in Delhi during the post-Diwali period (Tripathi, 2019). Stubble burning is a common agricultural practice where farmers burn leftover crop residue after harvesting their crops (Jethva *et al*., 2018). Crop residue incineration releases a substantial number of pollutants into the air, including fine particulate matter and gases like carbon monoxide and volatile organic compounds (Oanh *et al*., 2018; Deshpande *et al*., 2023). These pollutants can travel long distances and contribute to the already high levels of air pollution in Delhi. Several studies have been conducted throughout India to evaluate the impact of Diwali emissions on air quality (Ravindra *et al*., 2022; Mandal *et al*., 2022). These studies have consistently reported higher concentrations of pollutants during the days of Diwali, including increased levels of respirable particulate matter, sulfur dioxide, nitrogen dioxide, and volatile organic compounds. These pollutants have been linked to various health issues, including respiratory tract infections, worsening of asthma and chronic obstructive pulmonary disease, cardiovascular complications, and other serious health hazards (Rizwan *et al*., 2013; Kumar *et al*., 2023). In Delhi, the primary healthcare facilities are overwhelmed with infants, children, and the elderly suffering from chronic respiratory ailments. Exposure to lead (Pb) gives rise to significant disorders, encompassing neurological and hematological problems. Cadmium (Cd), nickel (Ni), and hexavalent chromium (Cr VI) exposure pose toxic and carcinogenic risks to the bronchial tree. Elevated concentrations of copper (Cu) and cadmium (Cd) contribute to the onset of chronic lung diseases, resulting in respiratory irritations (Lin, 2016). Additionally, the inhalation of smoke emanating from fireworks induces symptoms that cause chronic respiratory, nasal and cardio-vascular problems (Hirai *et al*., 2000). The combustion of firecrackers was further linked to markedly elevated levels of personal exposure to PM 2.5, indicating a potential for significant health issues and disease burden, particularly in children (Saxena *et al*., 2020). Perchlorate, a fundamental constituent of firecrackers, is also exerting adverse effects on our ecosystem by contaminating the groundwater and surface water (Acevedo-Barrios, 2018). This contamination poses a potential ecological threat, and it hinders the uptake of iodide by the thyroid gland due to particulate matter deposition through precipitation (Kulshreshtha *et al.,* 2021).

Delhi also witnesses a phenomenon of haze-fog pollution that causes low visibility, formation of dust clouds, reduced plant, and crop growth, compromised human and animal health and global climate dynamics (Jenamani, 2007; Mohan and Payra, 2009). Haze is characterized as a meteorological occurrence resulting in less than 10 km of atmospheric visibility, attributable to suspended solid or liquid particulates, smoke, and vapor (Kumar, 2018; Kumari *et al*., 2021). Its occurrence is frequently associated with elevated aerosol concentrations originating from anthropogenic sources and the development of secondary aerosols through gas-to-particle conversion facilitated by specific meteorological conditions (Singh and Dey, 2012). The confluence of heightened air pollutant levels and stagnant atmospheric conditions, characterized by low wind speeds (below 2 m/s) and a shallow boundary layer height (approximately 500–800 m), promotes the formation of haze. This process induces alterations in aerosol composition through aqueous phase reactions on aerosol particles. (Pachauri *et al*., 2013). The deteriorating AQI (air quality index) severely impacts human health and well-being, especially young children and adults, resulting in chronic respiratory problems. Over the last few years, various awareness drives have been carried out through print, electronic, and social media on stopping the crackers from bursting, banning the crackers from bursting after a particular time, and other political initiatives (Yadav *et al*., 2022; Jain *et al*., 2022).

Therefore, it is important to understand the reasons and factors that adversely affect the air quality in the National Capital. The present study's central objective was to comprehensively compare Delhi's air quality index (AQI) levels, specifically focusing on the days leading up to and succeeding the Diwali celebration. This investigation aims to discern the primary causative factors behind the deterioration of AQI, exploring the potential contributions from pollutants emitted by firecrackers and agricultural stubble burning. In addition to this comparative analysis, the study endeavors to identify and analyze the specific atmospheric conditions that may have played a role in influencing the observed fluctuations in AQI levels during this critical period. Through this multifaceted examination, we aspire to contribute valuable insights into the complex dynamics of associated air quality variations.

Methodology

The study site for this study is the National Capital of Delhi, spread on both the banks of Yamuna in northern India between the latitudes of 28°-24'-17" and 28°-53'-00" North and longitudes of 76°-50'-24" and 77°-20'-37". Data was retrieved from various primary sources, including CPCB reports and research papers. The potential impact of average temperature and relative

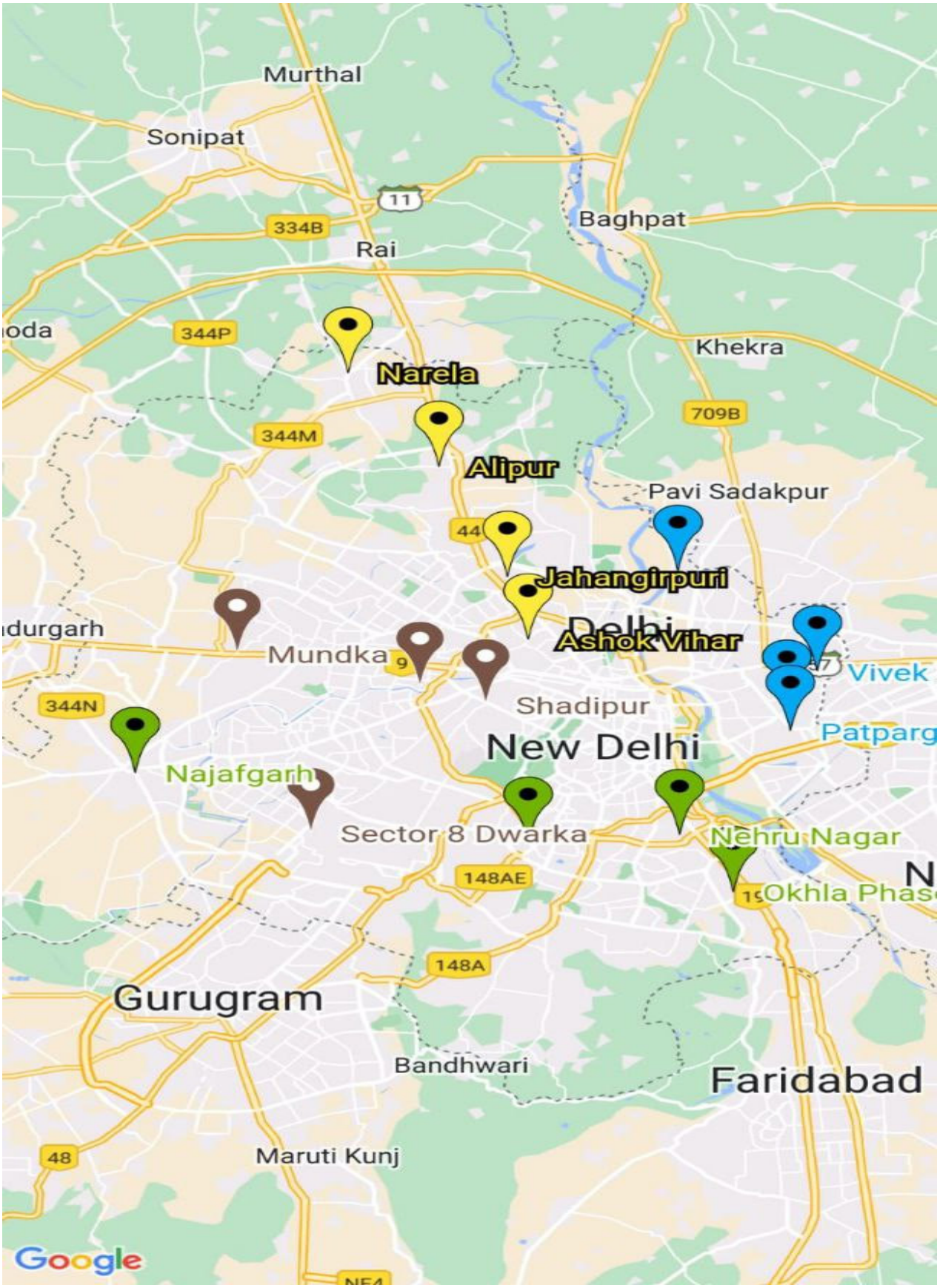

Fig. 1: Map showing location of sampling sites in the city

humidity on PM2.5 and PM10 concentrations throughout the Diwali month was also looked at by collating the data. Data was gathered from 16 Delhi stations, four located in North, South, East, and West Delhi. Data was tabulated and analyzed using standard methods in MS Excel. The wind velocity and temperature data was taken from the India Meteorological Department (IMD) India. A map showing the location of sampling sites in the city is attached below in Fig. 1.

Results And Discussion

The mean Air Quality Index (AQI) over a 24-hour period was compiled by utilizing data from the Central Pollution Control Board, Government of India website, spanning four days before and four days after Diwali. Despite observing a 42% rise in AQI after Diwali compared to Diwali day this year, it is noteworthy that two days preceding Diwali recorded even more alarming AQI levels in Delhi. This raises the question of whether the real culprit could be the burning of firecrackers during Diwali.

The AQI levels are tabulated and graphed below in Table 1 and Fig. 2.

Furthermore, five-year data of Delhi AQI one day post-Diwali was analyzed, and it was observed that there was a 30% decrease in AQI levels on Diwali day compared to 2022 and a marginal 0.3% reduction the day after Diwali compared to the same period in 2022. Both instances suggest an improvement to some extent. The question arises: are we making progress in the right direction concerning government restrictions on construction activities, stubble burning, and firecracker use during this period? This requires further contemplation. The data is tabulated in Table 2, and the trendline is depicted in Fig. 3.

Table 1: Mean AQI comparison- Pre and Post Diwali 2023

8.11.2023	426
9.11.2023	437
10.11.2023	279
11.11.2023	220
12.11.2023 **(DIWALI)**	218
13.11.2023	301
14.11.2023	397
15.11.2023	398
16.11.2023	419

Table 2: Five-year data of Delhi AQI one day post Diwali

Year	Mean AQI one day post Diwali
2019	368
2020	435
2021	462
2022	302
2023	301

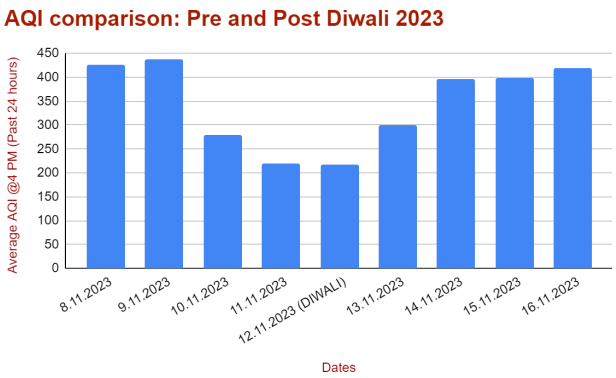

Fig. 2: Mean AQI comparison- Pre and Post Diwali 2023

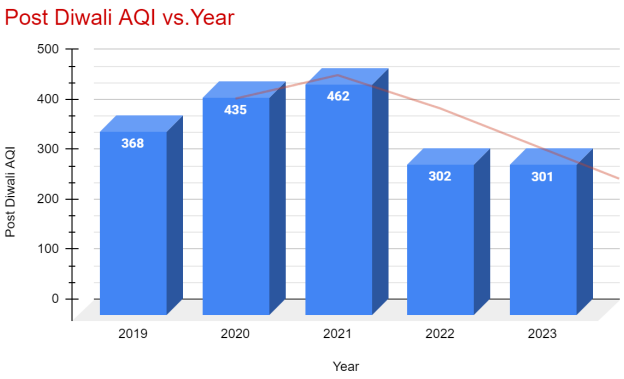

Fig. 3: Five-year data of Delhi AQI one day post Diwali

Meteorological conditions are known to significantly impact pollution levels (Chanchpara *et al*., 2023). Pollutants accumulate during calm conditions, characterized by wind speeds not exceeding 10 km/h. Wind speeds of 15 km/h or higher facilitate the dispersion of pollutants, essentially purifying the air. The direction of the wind is just as crucial as its speed. Pratap *et al.* (2021) carried out a five yearlong study (2011-16) in Varanasi and other urban areas and observed PM 10 and 2.5 surge, but a moderate increase in ozone and carbon monoxide. Precipitation patterns, the topography of the Indo-Gangetic plain and temperature patterns clearly have a bearing on the aerosol dispersal and persistence. During the stubble-burning season, moderate northwesterly winds transport smoke from agricultural fires in Punjab and Haryana to the National Capital Region (NCR) and beyond.

As per, Chanchpara *et al.* (2023), the peak Air Quality Index (AQI) was recorded on the third day of Diwali 2021 in Bhavnagar (a coastal city in Gujarat), primarily attributed to elevated levels of PM 2.5. Remarkably, a subsequent decline in AQI was noted by the fifth day, underscoring the inherent

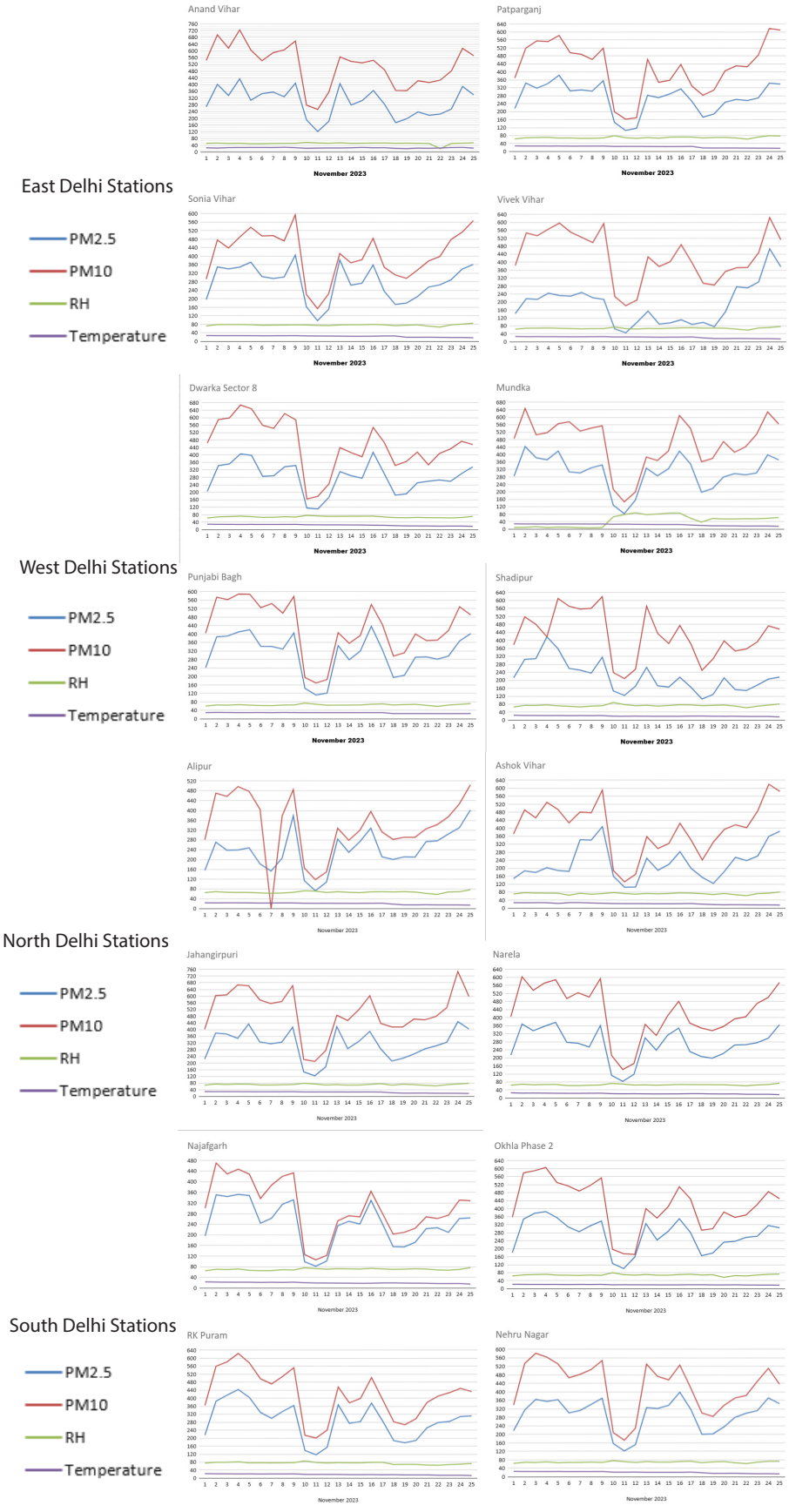

Fig. 4: Day wise record of parameters in November 2023

Table 3: Min-Max level of parameters in November 2023

East-Delhi Stations

	Anand Vihar Delhi - DPCC		Patparganj Delhi - DPCC	
	Max	Min	Max	Min
PM2.5	434.16	121.74	383.49	105.75
PM10	724.24	252.47	617.79	162.21
Temperature	28.55	20.17	28.25	16.08
Humidity	57.25	20.17	79.54	62.34
	Sonia Vihar Delhi - DPCC		Vivek Vihar Delhi - DPCC	
	Max	Min	Max	Min
PM2.5	405.39	97.16	466.73	45.4
PM10	594.51	153.54	624.27	181.44
Temperature	27.72	17.31	26.68	14.95
Humidity	85.18	67.23	77.45	58.93

West-Delhi Stations

	Dwarka-Sector 8 Delhi - DPCC		Mundka Delhi	
	Max	Min	Max	Min
PM2.5	414.68	110.85	443.4	83
PM10	667.5	164.02	647.32	146.33
Temperature	29.35	18.01	28.83	15.92
Humidity	76.29	62.6	87.66	7.45
	Punjabi Bagh Delhi - DPCC		Shadipur Delhi - CPCB	
	Max	Min	Max	Min
PM2.5	436.93	112.68	417.81	105.75
PM10	589.27	169.38	619.03	208.38
Temperature	30.56	24.95	24.45	16.52
Humidity	74.36	59.08	88.29	62.13

North-Delhi Stations

	Alipur		Ashok Vihar	
	Max	Min	Max	Min
PM2.5	402.1	72.55	407.58	104.8
PM10	504.14	117.6	619.65	131.32
Temperature	23.81	14.36	27.95	15.82
Humidity	76.41	57.8	80.87	62.79
	Jahangirpuri		Narela	
	Max	Min	Max	Min
PM2.5	447.42	123.47	376.43	83.1
PM10	747.58	209.84	603.05	142.18
Temperature	29.2	17.86	26.34	17.31
Humidity	78.96	63.82	74.19	61.16

South-Delhi Stations

	Najafgarh		Okhla Phase 2	
	Max	Min	Max	Min
PM2.5	352.56	81.98	385.35	100.82
PM10	470.79	106.29	606.15	171.19
Temperature	23.53	15.01	22.3	17.82
Humidity	76.74	65.27	79.73	56.76
	RK Puram		Nehru Nagar	
	Max	Min	Max	Min
PM2.5	443.53	116.68	399.05	122.24
PM10	623.92	200.67	581.94	172.65
Temperature	22.63	13.3	26.38	14.35
Humidity	86.01	64.68	76.36	62.66

self-purification mechanisms within the natural environment (Chanchpara *et al.,* 2023). The observed decline in AQI was not evident in the context of Delhi in 2023, possibly attributable to its non-coastal geographical location, resulting in comparatively limited wind dynamics that impede the efficient dispersion of suspended pollutants in the atmosphere. In a nationwide study conducted by Ganguly *et al.* (2019), the researchers observed that the cracker ban showed a positive impact and pollution level increase in northern India was mostly due to the burning of agricultural waste and stubble.

On Diwali day 2023, northwesterly winds were recorded with a speed up to 10 K/h with a clear sky which was favorable for the dispersal of pollutants. This suggests that the combined influence of wind direction and speed, particularly during Diwali and stubble burning, significantly exacerbated air quality index (AQI) levels around Diwali. As reported by the Delhi Pollution Control Board, overall, 33% increase was observed in the city average of PM10 in 2023 concerning the previous year, 2022. 42% reduction was observed in city average PM 10 concentration in 2023 concerning the year 2021. An overall increase was observed in city average concentration of PM 2.5 in 2023. The reduction was seen in the city's average concentration of PM 2.5 in 2023 compared to 2021. All the gaseous pollutants, harmful-toxic gases and volatile organic chemicals were below the standards set by the National Ambient Air Quality Standard (NAAQS), a nodal agency that monitors the data on air pollution.

The findings do not show a correlation between particulate matter concentrations and temperature or humidity during November 2023. The max-min levels of the concerned parameters have been tabulated and day-wise records have been graphed below in Table 3 and Fig. 4, respectively.

The analysis does not demonstrate any significant relationship between the levels of particulate matter and the atmospheric conditions, suggesting that changes in humidity or temperature were not strongly associated with variations in particulate matter concentrations during the Diwali month this year. In other words, the observed data and plotted trends do not provide evidence of a noteworthy relationship between the atmospheric conditions (humidity and temperature) and the levels of particulate matter. Furthermore, the decreasing patterns observed in the Mean Air Quality Index (AQI) over the preceding years, along with the analyses conducted before and after Diwali for the current year, as summarized in Tables 1 and 2, suggest a potential amelioration in terms of air quality. The trends reflected in the data figures indicate a positive trajectory, implying that efforts of the Government and individual awareness to address air quality concerns may soon be yielding favorable outcomes. The cumulative evidence, rooted in scientific rigor and empirical data, not only accentuates the lack of a substantial relationship between atmospheric conditions and particulate matter levels but also provides optimism for the efficacy of ongoing initiatives to mitigate air pollution and foster a healthier environmental landscape.

Conclusion

The research clearly shows that the pollution in Delhi is not solely because of burning crackers and using inflammable sound bursting stuff during Diwali. Air quality and air quality

indices vary because the prevalent environmental factors before and after the festival show significant changes. When the temperature drops during Diwali, the concentration of PM increases, causing smoggy and hazy conditions. The visibility is better when the temperature stays between 10 to 18 degrees during the day, and pollutants disperse. However, this year the winds helped to disperse the pollutants, resulting in poor air quality but better than previous years. The improved air quality in 2023 can be attributed to proactive measures taken by the Government and increased awareness among citizens who chose not to burst crackers. Despite this, the air quality in Delhi is a cause of concern as it affects the health of the young and the elderly. While environmental factors affecting air quality are beyond our control, we can regulate human actions that negatively impact it. Behavioral changes in individuals, adoption of sustainable practices and respect for legislation can help bring changes in society and reduce pollution levels as crackers are still the culprits.

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Author's Contributions

Authors Monika Koul (MK) and Jyoti Bhola (JB) conceptualized, supervised, and selected the methodology for carrying out the work; **Anudeepti Bajpai (AB)** organized the content and wrote the first draft; **Saiyam Jain (SJ)** and **Daksh Jain (DJ)** carried out data visualization, analysis, and validation; **MK** and **JB** refined and revised the manuscript. All the authors contributed equally to finalizing the manuscript.

Conflict Of Interest

None

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