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Assessment of Air Pollutant Levels Before and After Diwali in Jaipur, India

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ABSTRACT

Background: Air pollution is a major environmental health concern, and festival-related activities such as firecracker bursting during Diwali significantly contribute to short-term deterioration in air quality. **Objective:** To assess the variation in air pollutant levels before and after Diwali in Jaipur and evaluates the impact of firecracker emissions on ambient air quality. **Methodology:** An observational cross-sectional study was conducted using secondary data obtained from the Central Pollution Control Board (CPCB). Data on AQI and major air pollutants (PM2.5, PM10, NO_2, NH_3, SO_2, CO, and Ozone) were collected from six monitoring stations in Jaipur for 15 days before and 15 days after Diwali (excluding peak days). Statistical analysis was performed using paired t-test, with $p<0.05$ considered significant. **Results:** A significant increase in PM2.5 levels was observed post-Diwali (179.1±55.82 µg/m³ to 256.9 ± 55.23 µg/m³; $p<0.001$). Ozone levels also increased significantly (82.3±18.8µg/m³ to 100.4±12.4 µg/m³; p=0.003). Other pollutants such as PM10, NO_2, NH_3, SO_2 and CO showed no statistically significant change. **Conclusion:** Diwali celebrations significantly worsen air quality, particularly increasing PM2.5 and ozone levels. Regulatory measures and public awareness are essential to mitigate these effects.

Keywords: Air Pollution, Diwali, PM2.5, AQI, Firecrackers, Jaipur

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Introduction

Air quality is intricately connected to the global climate and ecosystems. The primary contributors to air pollution, such as the combustion of fossil fuels, are also significant sources of greenhouse gas emissions. Therefore, implementing policies aimed at reducing air pollution presents a dual benefit: improving public health by lowering diseases linked to poor air quality and simultaneously aiding both short- and long-term climate change mitigation efforts.[1]

Exposure to high levels of air pollution can lead to various health problems. It is crucial to thoroughly assess both the short- and long-term public health consequences of air pollution, particularly the effects of fine particles that can penetrate deep into the lungs and pose significant health risks. Increased exposure to air pollution heightens the risk of respiratory infections, heart disease, stroke, and lung cancer, particularly among vulnerable populations such as children, the elderly, and those living in poverty. Additionally, poor air quality can increase the risk of stillbirth, miscarriage, and neurological conditions like cognitive impairment and dementia.

In 2019, air pollution was responsible for approximately 6.7 million deaths, with nearly 85% of these deaths attributed to non-communicable diseases (NCDs) such as ischemic heart disease, stroke, lung cancer, asthma, chronic obstructive pulmonary disease (COPD), and diabetes. This makes air pollution the second leading cause of NCDs worldwide, following tobacco**.**

Particulate matter (PM) refers to tiny particles suspended in the air, such as dust, dirt, soot, smoke, and liquid droplets. High concentrations of particulate matter are commonly emitted by diesel vehicles and coal-fired power plants. Particles smaller than 10 micrometers in diameter (PM10) are particularly concerning for health, as they can be inhaled and accumulate in the respiratory system. Of these, particles less than 2.5 micrometers in diameter (PM2.5), known as "fine" particles,[2] pose the most significant health risks. Due to their minute size, about 1/30th the width of a human hair, PM2.5 particles can penetrate deep into the lungs and even enter the bloodstream.[3]

Despite ongoing efforts to promote eco-friendly alternatives aimed at reducing air quality issues, the ambient air quality during the Diwali festival has seen a significant increase compared to regular days. This spike highlights the detrimental impact of fireworks combustion on the atmospheric environment. Additionally, Diwali coincides with the onset of winter, characterized by lower atmospheric mixing heights, colder temperatures and high humidity levels along with calm wind conditions (wind speeds below 0.5 m/s). As a result, emissions from Diwali fireworks and other human activities do not disperse effectively leading to a buildup of pollutants near ground level, where they can adversely affect respiratory health. As a result, emissions from Diwali fireworks and other human activities do not disperse effectively leading to a buildup of pollutants near ground level, where they can adversely affect respiratory health.[6,7,8]

Methodology: This observational cross-sectional study was conducted to assess the impact of Diwali celebrations, specifically the bursting of fireworks, on air quality in Jaipur, Rajasthan. The study focused on analyzing the Air Quality Index (AQI) and key air pollutants PM2.5, PM10, NO2, NH3, SO2, CO and Ozone over a period spanning 15 days before and 15 days after Diwali from 14th October 2024 to 17th November 2024, excluding peak period around Diwali (i.e., 29th October to 2nd November 2024) to avoid confounding peak festival effects.

Aim of the Study: To evaluate the variation in air pollutant levels before and after Diwali in Jaipur, India and to assess the impact of firecracker emissions on the ambient air quality.

Objectives of the Study:

1. To compare the levels of major air pollutants (PM 2.5, PM10, NO_2, NH_3, SO_2, CO and Ozone) before and after Diwali in Jaipur.
2. To identify the change in Air Quality Index (AQI) before and after Diwali across different monitoring stations in Jaipur

Study Design: This observational cross-sectional study was conducted to assess the impact of Diwali celebrations, specifically the bursting of fireworks, on air quality in Jaipur, Rajasthan. The study focused on analyzing the Air Quality Index (AQI) and key air pollutants PM2.5, PM10, NO2, NH3, SO2, CO and Ozone over a period spanning 15 days before and 15 days after Diwali, from 14th October 2024 to 17th November 2024 ,excluding peak days of Diwali festival.

Study Duration: Three months, with a data collection period from 14th October 2024 to 17th November 2024

Study Area: The study area includes six major monitoring stations in Jaipur:

[1] Aadarsh Nagar, [2] Police Commissionerate, [3] Shastri Nagar, [4] RIICO Sitapura, [5] Murlipura, [6] Mansarover

Inclusion Criteria: (a) Data collected 15 days before and 15 days after Diwali. (b) Daily monitoring of key pollutants at the six stations.

Exclusion Criteria: Data corresponding to the peak Diwali period (29th October to 2nd November 2024) were excluded from the analysis to minimize the influence of extreme pollution levels associated with intensive firecracker activity.

Data Collection: Air quality data was collected from the Central Pollution Control Board (CPCB) website,[5] which provides real-time air quality monitoring data across various stations in Jaipur. The data was sourced from six specific monitoring stations, selected for their comprehensive coverage of different areas within the city:

- Aadarsh Nagar
- Police Commissionerate
- Shastri Nagar
- RIICO Sitapura

- Murlipura
- Mansarover

The study focused on the daily concentrations of the following pollutants:

- PM2.5 (Particulate Matter <2.5 micrometers)
- PM10 (Particulate Matter <10 micrometers)
- NO2 (Nitrogen Dioxide)
- NH3 (Ammonia)
- SO2 (Sulfur Dioxide)
- CO (Carbon Monoxide)
- Ozone

Air Quality Index (AQI) Calculation: AQI values were computed using the following formula:

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}.$$

Where:

Where I_p = the index for pollutant p

C_p = the truncated concentration of pollutant p

BP_{Hi} = the concentration breakpoint that is greater than or equal to C_p

BP_{Lo} = the concentration breakpoint that is less than or equal to C_p

I_{Hi} = the AQI value corresponding to BP_{Hi}

I_{Lo} = the AQI value corresponding to BP_{Lo}

This describes the relationship between pollutant concentration and AQI levels, specifying how breakpoints are used to calculate AQI based on concentration values for each pollutant. This formula allows the calculation of the AQI based on pollutant concentration ranges, which helps standardize the values for each pollutant. **Data Analysis:** The collected data was organized and analyzed to compare the air quality levels excluding peak Diwali days. The following steps were undertaken using MS EXCEL and SPSS Version 25***Calculation of Average Pollutant Levels:*** The daily average concentrations of each pollutant were calculated for the pre-Diwali period (14thOctober to 28th October 2024) and the post-Diwali period (3rd November to 17th November 2024).

1. ***Comparison of Pre- and Post-Diwali Data:*** The mean values of each pollutant for the pre-Diwali period were compared with the corresponding mean values for the post-Diwali period to determine any significant changes in air quality.
2. ***Statistical Analysis:*** A paired *t*-test was employed to assess the statistical significance of differences in pollutant levels before and after Diwali. This test was considered appropriate as the analysis was based on paired observations with pollutant measurements from the same monitoring stations matched across corresponding days in the pre- and post-Diwali periods, enabling within station comparison and controlling for location-specific variability. The level of statistical significance was set at $p < 0.05$. Additionally, the percentage change in pollutant levels was calculated to quantify the impact of Diwali festivities on air quality. The findings were consistent with the Wilcoxon signed-rank test, which also demonstrated a statistically significant increase in PM2.5 and ozone levels ($p < 0.05$).
3. **Graphical Representation:** Pollutant levels were visualized using line graphs and bar charts to illustrate the variations across the monitoring stations over the study period.

Ethical Considerations: As the study utilized publicly available data from the CPCB website. However, the research was conducted in accordance with ethical standards for data analysis and reporting.

Result

Table-1: PM2.5 Levels and AQI Categories Before and After Diwali

PM2.5 (µg/m³)					
AQI Monitoring stations	**CUT off**	**Before Diwali**		**After Diwali**	
		Mean ± SD	**AQI category**	**Mean ± SD**	**AQI category**
Aadarsh Nagar	**Good (0-30)**	173.93±55.82	Very Poor	254.81 ±61.65	Severe
Police Commissionerate	**Satisfactory (31-60)**	167.08±50.94	Very Poor	249.77±51.48	Very Poor
Shastri Nagar	**Moderate (61-90)**	173.00±57.15	Very Poor	283.19±45.07	Severe
RIICO Sitapura	**Poor (91-120)**	203.73±65.11	Very Poor	263.38±41.53	Severe
Murlipura	**Very Poor (121-250)**	187.36±63.40	Very Poor	243.19±68.56	Very Poor
Mansarover	**Severe 250+**	169.53±53.34	Very Poor	247.07±51.57	Very Poor

PM2.5 levels increased across all monitoring stations after Diwali, with AQI categories worsening from "Very Poor" to "Severe" in most areas, indicating a substantial deterioration in air quality.

Table-2: PM10 Levels and AQI Categories Before and After Diwali

PM 10 (µg/m³)					
AQI Monitoring stations	**CUT off**	**Before Diwali**		**After Diwali**	
		Mean ± SD	**AQI category**	**Mean ± SD**	**AQI category**
Aadarsh Nagar	**Good** (0-50)	133.73±19.01	Moderate	139.625± 24.57	Moderate
Police Commissionerate	**Satisfactory** (51-100)	160.60±95.19	Moderate	171.56 ± 94.46	Moderate
Shastri Nagar	**Moderate** (101-250)	123.73±17.62	Moderate	182.25 ± 28.05	Moderate
RIICO Sitapura	**Poor** (251-350)	198.53±37.67	Moderate	179.43 ± 44.70	Moderate
Murlipura	**Very poor** (351-430)	168.20±53.65	Moderate	184.00 ± 42.98	Moderate
Mansarover	**Severe** 430+	209.73±44.73	Moderate	201.00 ± 67.08	Moderate

Table 2 demonstrates that PM10 levels showed only a marginal increase after Diwali, with AQI remaining in the "Moderate" category across all stations.

Table-3: NH3 Levels and AQI Categories Before and After Diwali **NH3 (µg/m³)**

AQI Monitoring stations	**CUT off**	**Before Diwali**		**After Diwali**	
		Mean ± SD	**AQI category**	**Mean ± SD**	**AQI category**
Aadarsh Nagar	**Good** (0-200)	17.47± 13.13	Good	10.93 ± 3.97	Good
Police Commissionerate	**Satisfactory** (201-400)	17.00± 6.16	Good	13.62 ± 7.55	Good
Shastri Nagar	**Moderate** (401-800)	24.2 ± 21.04	Good	20.25 ± 10.73	Good
RIICO Sitapura	**Poor** (801-1200)	9.33 ± 2.61	Good	12.5 ± 3.18	Good
Murlipura	**Very Poor** (1200-1800)	2.93 ± 0.27	Good	3.43 ± 1.59	Good
Mansarover	**Severe** (1800+)	22.25± 28.57	Good	9.00 ± 1.5	Good

Table 3 reveals that NH_3 levels remained within the "Good" category both before and after Diwali, showing no significant variation.

Table- 4: CO levels and AQI Categories before and after Diwali					
CO					
AQI Monitoring stations	**CUT off**	**Before Diwali**		**After Diwali**	
		Mean ± SD	**AQI category**	**Mean ± SD**	**AQI category**
Aadarsh Nagar	**Good** (0-1.0)	54.06 ±11.06	**Severe**	55.18±10.76	Severe
Police Commissionerate	**Satisfactory** (1.1-2.0)	61.5 ±14.27	**Severe**	49.06±27.16	Severe
Shastri Nagar	**Moderate** (2.1-10)	66.33±45.74	**Severe**	67.25±43.90	Severe
RIICO Sitapura	**Poor** (10-17)	86.4 ±31.16	**Severe**	76.43±24.26	Severe
Murlipura	**Very Poor** (17-34)	71.64±12.51	**Severe**	58.75±17.23	Severe
Mansarover	**Severe** (34+)	78.26±40.93	**Severe**	77.53±37.25	Severe

Table 4 indicates that CO levels were consistently high and remained in the “Severe” category both before and after Diwali, with no significant change.

Table-5: OZONE Levels and AQI Categories Before and After Diwali

OZONE					
AQI Monitoring stations	**CUT off**	**Before Diwali**		**After Diwali**	
		Mean ± SD	**AQI category**	**Mean ± SD**	**AQI category**
Aadarsh Nagar	**Good** (0-50)	76.2 ±18.80	Satisfactory	97.5 ±13.51	Satisfactory
Police Commissionerate	**Satisfactory** (51-100)	52.0 ±15.21	Satisfactory	54.68±28.43	Satisfactory
Shastri Nagar	**Moderate** (101-168)	121.3 ±21.17	Moderate	130.87±28.20	Moderate
RIICO Sitapura	**Poor** (169-208)	119.13±16.96	Moderate	93.18±14.01	Satisfactory
Murlipura	**Very Poor** (209-748)	83.42±37.38	Satisfactory	152.5±33.79	Moderate
Mansarover	**Severe** 748+	41.60±10.33	Good	73.73±11.51	Satisfactory

Table 5 shows that ozone levels increased after Diwali, with some monitoring stations shifting from “Satisfactory” to “Moderate” category.

Table-6: Pre-Diwali and Post-Diwali Pollutant Levels with Statistical Significance

Pollutant	**Pre-Diwali**	**Post-Diwali**	
	Mean ± SD	**Mean ± SD**	**P-value**
PM2.5	179.1 ± 55.82	256.9 ± 55.23	**<0.001 (s)**
PM10	133.7 ± 19.01	142.2 ± 23.1	0.287
NO_2	76.73 ± 37.08	64.3 ± 15.6	0.276
NH_3	17.47 ± 13.13	11.2 ± 3.97	0.721
SO_2	15.93 ± 2.58	15.13 ± 2.1	0.857
CO	54.07 ± 11.06	56.6 ± 9.49	0.51
Ozone	82.3 ± 18.8	100.4 ± 12.4	**0.003 (s)**

Table 6 presents the statistical comparison of pollutant levels before and after Diwali. A statistically significant increase was observed in PM2.5 ($p<0.001$) and ozone levels ($p=0.003$). However, PM10, NO_2, NH_3, SO_2 and CO did not show statistically significant changes**.**

Table-7: Percentage change of different types of Air pollutants before and after Diwali.

	Before Diwali Average	After Diwali Average	Percentage Difference
PM2.5	179.1	256.9	+43.4
PM10	133.7	142.2	+6.4
NO_2	76.73	64.3	−16.2
NH_3	17.47	11.2	−35.9
SO_2	15.93	15.13	−5.0
CO	54.07	56.6	+4.7
Ozone	82.3	100.4	+22.0

Table 7 shows the percentage change in pollutant levels. PM2.5 exhibited the highest increase (43.4%), followed by ozone (22%), whereas NH_3 and CO showed a decline. Other pollutants showed minimal variation.

Conclusion

The present study demonstrates a significant increase in PM2.5 and ozone levels following the Diwali festival, indicating a deterioration in ambient air quality due to festive activities. PM2.5 concentrations increased markedly from 179.1 µg/m³ before Diwali to 256.9 µg/m³ after Diwali, reflecting a 43.4% rise. Similarly, ozone levels increased from 82.3 µg/m³ to 100.4 µg/m³, showing a 22.0% increase. In contrast, other pollutants such as PM10, NO_2, NH_3, SO_2 and CO did not show statistically significant changes suggesting relatively stable levels during the study period.

The study underscores the necessity for ongoing monitoring and potential regulatory measures to address air quality deterioration during festive periods. Given that high levels of PM2.5 are linked to serious health risks including respiratory infections and cardiovascular diseases these findings highlight the urgent need for public health interventions and policies to mitigate pollution during celebrations.

Discussion

The present study demonstrated a significant increase in PM2.5 and ozone levels following Diwali, indicating deterioration in ambient air quality during the post-festival period.

These findings are consistent with previous studies. Thakur et al. reported a significant rise in particulate matter levels during Diwali due to firecracker emissions.[6] Similarly, Seaton et al. emphasized the adverse health effects of fine particulate matter, particularly its role in causing respiratory and cardiovascular morbidity.[7] Nongkynrih et al also highlighted that air pollution is a major environmental health concern and is associated with multiple adverse health outcomes.[8]

These findings are further supported by studies conducted in Indian metropolitan cities. Guttikunda and Gurjar reported sharp increases in particulate matter levels in Delhi during Diwali, attributing it to firecracker emissions and unfavourable meteorological conditions.[9] Tiwari et al. also observed significant spikes in PM2.5 concentrations during Diwali, emphasizing the contribution of fireworks and vehicular emissions.[1]

Ozone levels also showed a statistically significant increase after Diwali. This may be attributed to the formation of secondary pollutants through photochemical reactions involving precursor gases released during fireworks. Similar findings were reported by Jain S et al. who observed increased ozone formation during post-Diwali periods due to enhanced photochemical activity.[11] Additionally; Jean C et al. highlighted the role of atmospheric chemistry and meteorological conditions in secondary pollutant formation, including ozone.[12]

Ozone levels also showed a statistically significant increase after Diwali. This may be attributed to the formation of secondary pollutants through photochemical reactions involving precursor gases released during fireworks, leading to further deterioration in air quality. In contrast, pollutants such as PM10, NO_2, NH_3, SO_2, and CO did not show statistically significant changes in the present study. This observation is in agreement with Nongkynrih et al, who noted that variations in certain gaseous pollutants may not always be significant and are influenced by environmental and meteorological factors.

Overall, PM2.5 showed the highest increase (43.4%) after Diwali, followed by ozone (22%), indicating that fine particulate matter is the most sensitive indicator of pollution changes during festival periods.

Limitation: This study utilized secondary data and did not account for individual exposure levels or detailed meteorological parameters such as wind speed and temperature. Additionally, exclusion of peak Diwali days may have led to underestimation of the highest pollution levels.

Recommendations

1. **Public Awareness**: Educate the community on the health impacts of air pollution and promote eco-friendly celebration alternatives.
2. **Regulatory Measures**: Implement restrictions on fireworks usage during festivals to mitigate pollution.
3. **Enhanced Monitoring**: Increase air quality monitoring during festive periods to provide real-time data and health advisories.

These findings underscore the need for ongoing monitoring and regulatory actions to protect public health during celebrations.

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