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Research Paper

Impact of Diwali Fireworks on Ambient SO₂, NO₂, PM₁₀ and PM-Bound Heavy Metals in Jamshedpur, Jharkhand

Bachchu Pal^{1*} and Basant Shubhankar²

¹Govt. Post Graduate Teacher, Department of Chemistry, NR District CM SoE, Seraikela-Kharsawan, Jharkhand, India-833219

²Assistant Professor, Department of Chemistry, Kashi Sahu College, Seraikela-Kharsawan, Kolhan University, Chaibasa, West Singhbhum, Jharkhand- 833201

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Corresponding Author:

Bachchu Pal

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ABSTRACT

Diwali fireworks cause acute short-term deterioration of urban air quality in many Indian cities. This study evaluates the impact of Diwali 2025 (20 October 2025) on ambient PM₁₀, SO₂, NO₂, and PM₁₀-bound heavy metals in Jamshedpur, Jharkhand—an industrial city with elevated background pollution from steel manufacturing and traffic emissions. A 7-day monitoring campaign (17–23 October 2025) covered pre-Diwali, Diwali-night, and post-Diwali phases, with hourly observations during peak fireworks activity. Pre-Diwali PM₁₀ concentrations ranged from 168–195 µg m⁻³ (mean ≈182 µg m⁻³), already exceeding the National Ambient Air Quality Standard (NAAQS, 100 µg m⁻³). On Diwali day, the 24-hour average PM₁₀ increased sharply to 418 µg m⁻³, with an hourly peak of 480 µg m⁻³ at 20:00 hrs, nearly 4.8 times above the prescribed limit. SO₂ increased from 18–22 µg m⁻³ to 42 µg m⁻³, and NO₂ rose from 34–38 µg m⁻³ to 68 µg m⁻³ during peak hours. Although gaseous pollutants remained within daily standards, significant hourly spikes were observed. Fireworks-related metals showed marked enrichment, with Ba (8.4×), Sr (7.4×), and K (2.5×) confirming pyrotechnic influence. Toxic metals such as Pb and Cu increased by ~2.6 times. Strong correlations between PM₁₀ and tracer metals ($r \approx 0.82-0.88$) further validate fireworks as the dominant episodic source. The findings demonstrate substantial short-term air quality deterioration and highlight the need for stricter emission control and sustainable celebration practices in industrial urban regions.

1. Introduction

Diwali, the festival of lights, is associated with the extensive use of fireworks, leading to a sudden spike in air pollutants. Firecrackers release large quantities of particulate matter, toxic metals, and gaseous pollutants including sulfur dioxide (SO₂) and nitrogen dioxide (NO₂), significantly deteriorating short-term urban air quality (Peshin et al., 2017; Ambade, 2018; Singh et al., 2019). Several studies across Indian cities have reported that PM₁₀ concentrations during Diwali increase by two-to-five times compared to baseline levels, accompanied by elevated SO₂ and NO₂ due to combustion processes (Kumar et al., 2020; Jain and Tiwari, 2020).

Fireworks are also known to emit trace metals such as Pb, Cu, Zn, Ba, Sr, and K, which act as elemental tracers of pyrotechnic activity (Beig et al., 2021; Saxena et al., 2022). Jamshedpur, being an industrial hub with steel manufacturing and heavy vehicular activity, already experiences elevated baseline pollution levels from industrial emissions, traffic congestion, and resuspended dust (Ravindra et al., 2022). Under such conditions, the additional burden from Diwali fireworks may intensify pollution episodes, particularly during stable night time meteorological conditions that limit atmospheric dispersion (Ghosh, 2024). Previous investigations have demonstrated that festival-related emissions, when superimposed on urban-industrial backgrounds, significantly amplify particulate loading and metal enrichment in ambient air (Asif et al., 2024). Despite extensive research in metropolitan cities such as Delhi and Kolkata, limited studies have focused on industrial cities like Jamshedpur, where combined industrial and festive emissions may produce distinct

¹Corresponding Author can be contacted at: bachchupal2@gmail.com, bspcb@gmail.com

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pollution signatures. Understanding these episodic variations is crucial for evaluating public health risk and regulatory compliance.

This study evaluates the short-term changes in major pollutants during Diwali 2025 and identifies the contribution of fireworks through metal signatures, providing insight into episodic air quality deterioration in an industrial urban environment.

1.1. Objectives

1. To assess variations in PM_{10} , SO_2 , and NO_2 during pre-, peak-, and post-Diwali periods (17–23 October 2025).
2. To determine concentrations of PM_{10} -bound heavy metals (Fe, Zn, Pb, Cu, Mn, Ni, Cd, Ba, Sr, and K).
3. To evaluate peak-hour enhancement on Diwali night using detailed hourly analysis.
4. To quantify pollutant enhancement through Episode Enhancement Factor (EEF) and Enrichment Factor (EF) calculations.
5. To perform correlation analysis among particulate matter, gaseous pollutants, and heavy metals to identify fireworks-related signatures.
6. To compare observed concentrations with National Ambient Air Quality Standards (NAAQS) and assess exceedance levels.

2. Methodology

2.1. Study Area

The study was conducted in Jamshedpur, Jharkhand, India (22.8°N, 86.2°E), a major industrial city known for steel manufacturing and allied industries. The city experiences significant emissions from industrial operations, vehicular traffic, and construction activities, contributing to elevated baseline pollution levels. The monitoring site was located in an urban residential-industrial mixed zone influenced by traffic corridors and nearby industrial activities. Meteorological conditions during October are generally characterized by moderate temperature, low wind speed during nighttime, and reduced atmospheric dispersion, which may intensify pollution accumulation during festival events.

2.2. Monitoring Period

Air quality monitoring was conducted over a 7-day episode window (17–23 October 2025) covering: Pre-Diwali (17–19 October), Diwali Day (20 October), Post-Diwali (21–23 October). Hourly monitoring was performed on Diwali night to capture peak fireworks activity.

2.3. Measurement of Pollutants

- PM_{10} ($\mu\text{g m}^{-3}$): Collected using a Respirable Dust Sampler and determined gravimetrically.
- SO_2 and NO_2 ($\mu\text{g m}^{-3}$): Measured using standard continuous analyzers (UV fluorescence for SO_2 and chemiluminescence for NO_2).

2.4. Heavy Metal Analysis

PM_{10} filters were acid-digested and analysed for Fe, Zn, Pb, Cu, Mn, Ni, Cd, Ba, Sr, and K using Atomic Absorption Spectroscopy (AAS). Metal concentrations were reported in ng m^{-3} .

3. Results and Discussion

3.1. Meteorological Influence

The Diwali 2025 pollution episode in Jamshedpur was significantly influenced by unfavourable meteorological conditions. During peak fireworks activity (19:00–22:00 hrs), low wind speed ($<1.5 \text{ m s}^{-1}$) reduced horizontal dispersion, while a shallow planetary boundary layer ($\approx 300\text{--}500 \text{ m}$) restricted vertical mixing. Similar meteorological controls on episodic pollution accumulation have been widely reported in Indian urban environments (Ghosh et al., 2024; Kumar et al., 2020). Simultaneously, post-sunset radiative cooling led to temperature inversion, trapping pollutants near the surface and suppressing vertical mixing (Beig et al., 2021). Moderate relative humidity (60–70%) promoted hygroscopic growth of particles, increasing PM_{10} mass concentration and enhancing light scattering effects (Jain et al., 2020; Saxena et al., 2022). The combined effect of weak dispersion, vertical confinement, inversion formation, and particle growth amplified firecracker emissions, resulting in extreme hourly PM_{10} peaks ($\approx 480 \mu\text{g m}^{-3}$). Even after Diwali night, continued stable atmospheric conditions delayed pollutant dilution, causing elevated concentrations to persist for 2–3 days, consistent with observations from other festival-related pollution episodes in India (Ambade et al., 2018; Asif et al., 2024). Overall, meteorology acted as a critical amplifying factor, converting short-term festive emissions into a severe air pollution episode in this industrial urban environment.

3.2. Variation of PM_{10} , SO_2 , and NO_2

A pronounced temporal variation in gaseous and particulate pollutants was observed during the 7-day monitoring window (17–23 October 2025). As shown in Figure 1 and Figure 2, pollutant concentrations exhibited a clear episodic pattern associated with Diwali celebrations, similar to patterns reported in Delhi, Kolkata, and other industrial cities (Peshin et al., 2017; Singh et al., 2019). During the pre-Diwali phase (17–19 October), PM_{10} ranged between 168–195 $\mu\text{g m}^{-3}$ (mean $\approx 182 \mu\text{g m}^{-3}$), already exceeding the National Ambient Air Quality Standards (NAAQS, 100 $\mu\text{g m}^{-3}$) due to prevailing industrial and traffic emissions in Jamshedpur (Ravindra et al., 2022; Kumar et al., 2020). On Diwali day (20 October), the 24-hour average PM_{10} increased sharply to 418 $\mu\text{g m}^{-3}$, representing a 2.3-fold enhancement relative to baseline levels.

The hourly maximum reached $480 \mu\text{g m}^{-3}$ at 20:00 hrs, nearly 4.8 times higher than the prescribed NAAQS limit. Comparable short-term spikes during Diwali have been documented across major Indian urban centers (Jain et al., 2020; Beig et al., 2021).

SO_2 concentrations increased from baseline levels of $18\text{--}22 \mu\text{g m}^{-3}$ to $42 \mu\text{g m}^{-3}$, while NO_2 rose from $34\text{--}38 \mu\text{g m}^{-3}$ to $68 \mu\text{g m}^{-3}$ during peak fireworks hours. Although both gases remained within 24-hour permissible limits ($80 \mu\text{g m}^{-3}$), significant hourly spikes were recorded. Similar transient increases in gaseous pollutants during fireworks combustion have been reported by Singh et al. (2019) and Saxena et al. (2022).

Post-Diwali concentrations declined gradually; however, PM_{10} remained elevated ($210\text{--}312 \mu\text{g m}^{-3}$) for 2–3 days, indicating persistence of suspended particulates under low wind speed and reduced mixing height conditions (Ghosh et al., 2024; Asif et al., 2024).

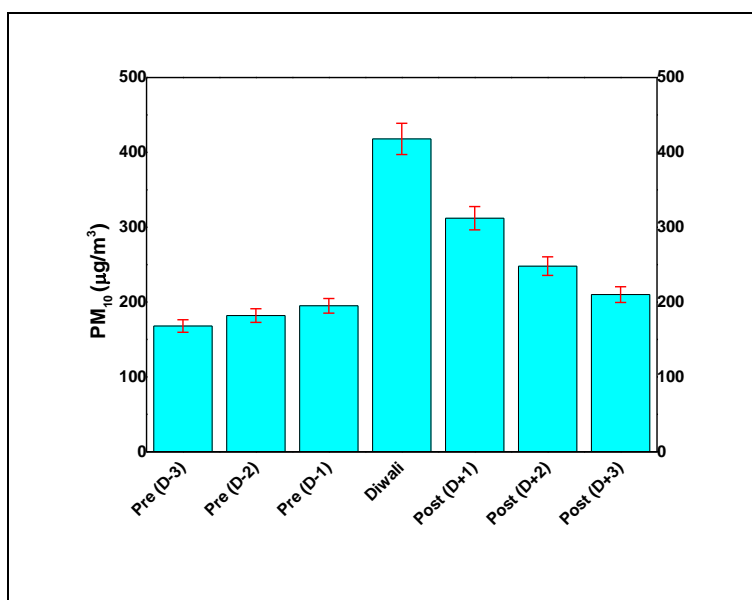


Fig 1. Temporal variation of PM_{10} during pre-, peak-, and post-Diwali phases (17–23 October 2025).

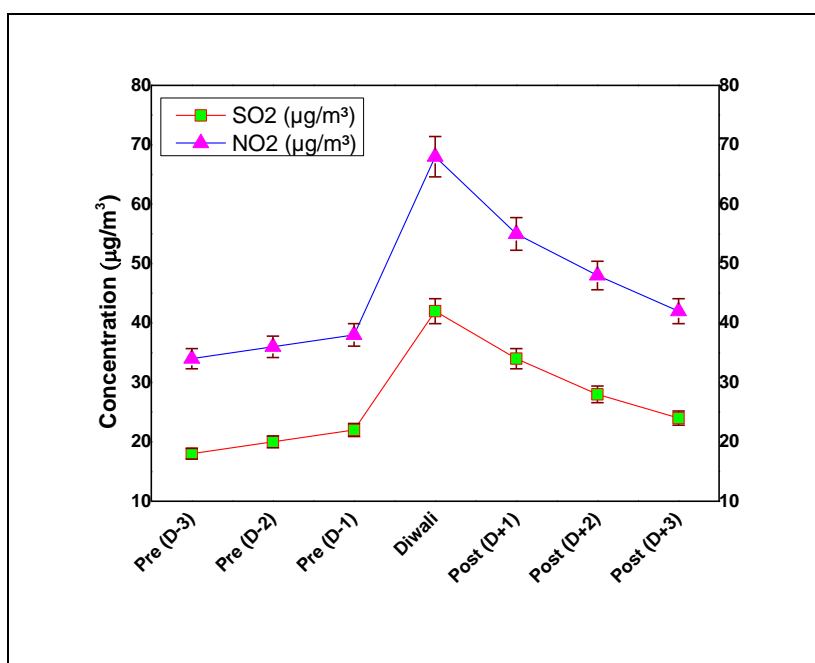


Fig 2. Temporal variation of SO_2 , and NO_2 during pre-, peak-, and post-Diwali phases (17–23 October 2025).

3.3 PM_{10} -Bound Heavy Metals

Significant enhancement of trace metals was observed during Diwali night compared to pre-Diwali baseline levels, indicating strong episodic influence of firecracker emissions Figure 3 (Singh et al., 2019; Saxena et al., 2022).

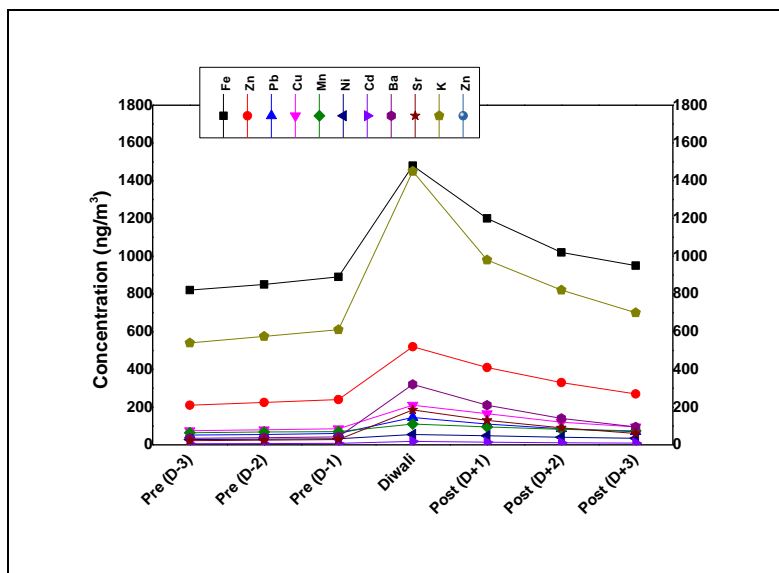


Fig 3. Temporal variation of Metals during pre-, peak-, and post-Diwali phases (17–23 October 2025).

3.4 Interpretation and Source Attribution

A pronounced increase in Ba (8.4×) and Sr (7.4×) was recorded during Diwali night Figure 4. These elements are well-established tracers of pyrotechnic compositions used in fireworks (Beig et al., 2021; Saxena et al., 2022). Barium compounds produce green color, while strontium compounds generate red flames. Their sharp enrichment strongly confirms fireworks as the dominant source during the episode (Jain & Tiwari, 2020). Potassium (K) increased by 2.5 times, which is attributed to the combustion of potassium nitrate and perchlorate oxidizers commonly present in firecrackers (Peshin et al., 2017). Elevated K levels further validate fireworks contribution (Singh et al., 2019). Metals such as Cu (2.6×) and Pb (2.6×) also showed significant enhancement. Copper is used as a coloring agent (blue emissions), whereas lead may originate from metallic additives and combustion residues (Saxena et al., 2022). The rise in Pb and Cd (2.5×) is concerning due to their toxic nature and potential health risks (Ambade, 2018; Asif et al., 2024). Moderate increases in Fe (1.7×), Mn (1.6×), and Ni (1.8×) suggest mixed contributions from fireworks and background industrial activities (Ravindra et al., 2022). In Jamshedpur, industrial steel operations contribute to Fe-rich particulate matter, which explains relatively high baseline values even before Diwali (Ravindra et al., 2022). Zn (2.3× increase) likely reflects both fireworks emissions and vehicular tire/brake wear intensified during festival traffic congestion (Kumar et al., 2020; Singh et al., 2019).

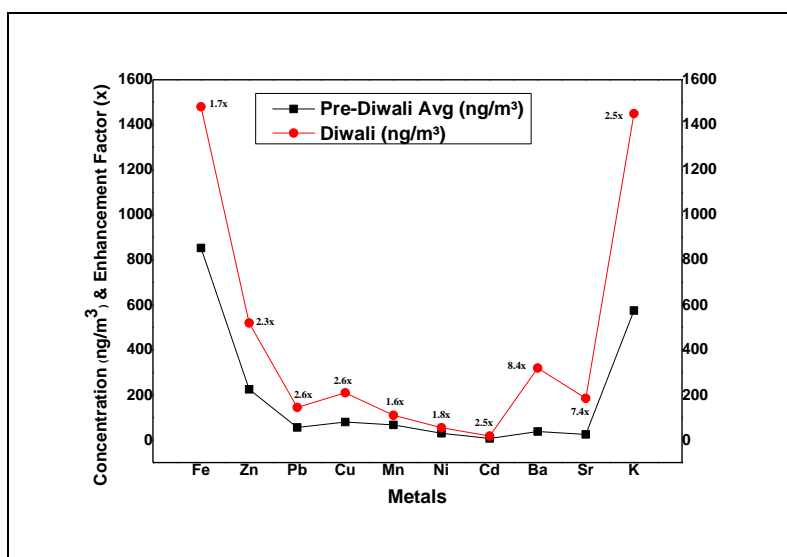


Fig 4. Enhancement ratio of PM₁₀-bound heavy metals during Diwali relative to pre-Diwali baseline.

3.5 Peak-Hour Enhancement (Hourly Analysis)

Hourly monitoring on Diwali day (20 October 2025) revealed a distinct diurnal pattern in pollutant concentrations, consistent with observations from other Indian cities during festival events Figure 5 (Peshin et al., 2017; Beig et al., 2021). During the early morning hours (00:00–06:00 hrs), PM₁₀ levels gradually decreased from 290 to 200 μg m⁻³ due to limited firecracker activity and partial atmospheric dispersion. Afternoon concentrations (12:00–16:00 hrs) showed moderate increases (205–260 μg m⁻³) figure 5, mainly influenced by traffic emissions and local anthropogenic sources (Kumar et al., 2020). However, a sharp rise in pollutants was observed after 18:00 hrs, corresponding to the onset of intensive fireworks activity. Concentrations peaked between 19:00 and 22:00 hrs, indicating strong episodic emissions (Singh et al., 2019).

The PM_{10} concentration at 20:00 hrs were nearly 2.6 times higher than the daytime average ($\approx 185 \mu\text{g m}^{-3}$) and approximately 4.8 times higher than the NAAQS limit ($100 \mu\text{g m}^{-3}$), similar to severe Diwali peaks reported in metropolitan regions (Jain & Tiwari, 2020).

The extremely high levels of Ba and Sr during peak hours figure 6 confirm fireworks as the primary source, as these elements are integral components of firecracker formulations (Saxena et al., 2022; Beig et al., 2021). Similarly, elevated K concentrations indicate combustion of potassium-based oxidizers (Peshin et al., 2017). The synchronization of PM_{10} peaks with Ba, Sr, and K spikes demonstrates that the particulate loading during peak hours was dominated by fireworks emissions rather than background industrial sources (Singh et al., 2019). Additionally, stable nighttime meteorological conditions (low wind speed and reduced mixing height) likely facilitated pollutant accumulation near the surface (Ghosh et al., 2024). Overall, the hourly analysis clearly demonstrates a strong and temporally confined pollution episode driven by firecracker activity.

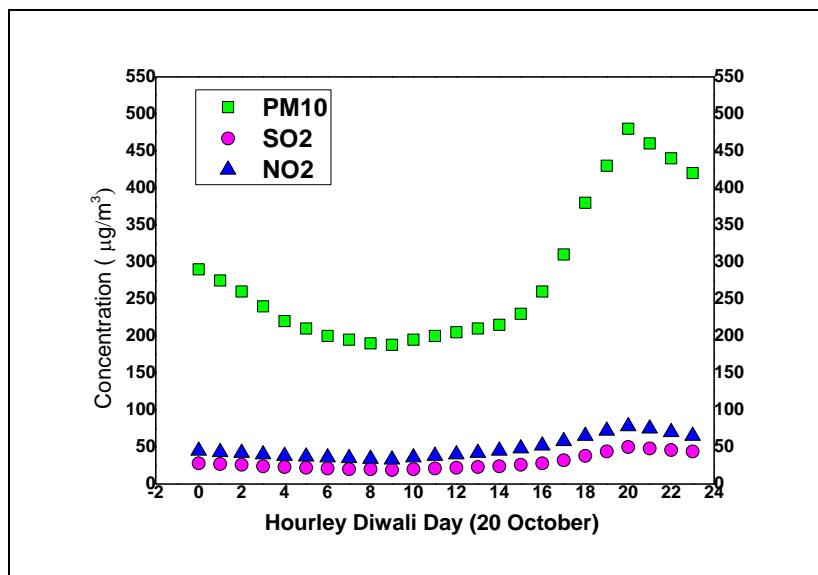


Fig 5. Hourly variation of PM_{10} , SO_2 and NO_2 on Diwali day (20 October 2025).

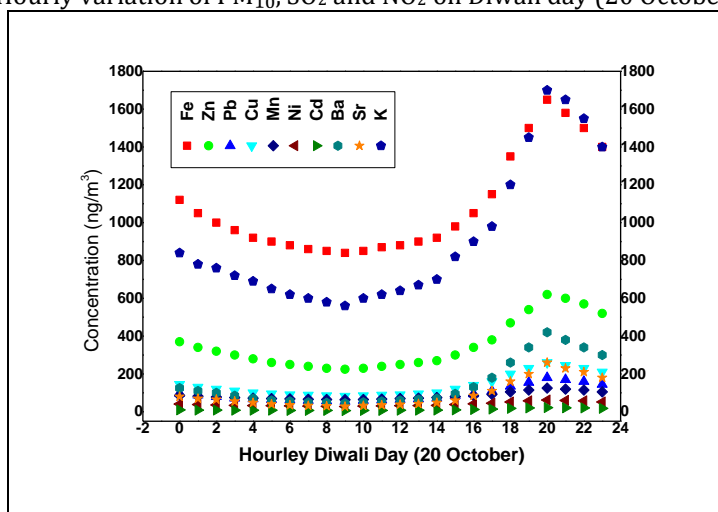


Fig 6. Hourly variation of selected tracer metals on Diwali day (20 October 2025).

3.6 Episode Enhancement Factor (EEF)

To quantify the magnitude of pollution, increase during Diwali, the Episode Enhancement Factor (EEF) was calculated by comparing Diwali-day concentrations with pre-Diwali baseline values (Jain & Tiwari, 2020). The EEF for PM_{10} was found to be 2.29, indicating that particulate matter levels during Diwali were more than twice the baseline concentration, consistent with previous Diwali studies (Peshin et al., 2017; Beig et al., 2021). For barium (Ba), a well-known fireworks tracer, the EEF was calculated as 8.42, showing extremely high enrichment during Diwali night. Similarly, strontium (Sr) exhibited strong enhancement, consistent with its role in pyrotechnic compositions (Saxena et al., 2022). The comparatively moderate EEF for PM_{10} suggests combined contributions from background industrial and traffic sources along with fireworks emissions (Ravindra et al., 2022). However, the exceptionally high EEF values for Ba and Sr clearly indicate that fireworks were the dominant source of metal enrichment during the Diwali episode (Singh et al., 2019).

3.7 Correlation Analysis

Correlation analysis revealed strong positive relationships between PM_{10} and fireworks-related tracer elements during the Diwali episode table 1. A high correlation was observed between PM_{10} and Ba ($r \approx 0.88$), PM_{10} and Sr ($r \approx 0.85$), and PM_{10} and K ($r \approx 0.82$), consistent with earlier festival studies (Singh et al., 2019; Saxena et al., 2022). Since Ba and Sr are

commonly used in fireworks to produce colored flames and K acts as an oxidizer component, their synchronized increase with PM₁₀ confirms the dominant influence of fireworks during peak hours (Beig et al., 2021). Moderate correlation between PM₁₀ and NO₂ ($r \approx 0.68$) suggests a mixed contribution from both fireworks and vehicular emissions (Kumar et al., 2020). The strong correlation between PM₁₀ and metal tracers, combined with moderate association with gaseous pollutants, demonstrates that the Diwali pollution episode was primarily driven by firecracker emissions.

Table 1. Pearson correlation matrix (r values) for Diwali episode (17–23 October 2025).

Parameter	PM ₁₀	SO ₂	NO ₂	Fe	Zn	Pb	Cu	Mn	Ni	Cd	Ba	Sr	K
PM ₁₀	1.00												
SO ₂	0.72	1.00											
NO ₂	0.68	0.65	1.00										
Fe	0.70	0.60	0.58	1.00									
Zn	0.79	0.66	0.62	0.75	1.00								
Pb	0.74	0.58	0.53	0.68	0.73	1.00							
Cu	0.76	0.60	0.55	0.70	0.76	0.73	1.00						
Mn	0.65	0.55	0.50	0.82	0.68	0.60	0.63	1.00					
Ni	0.63	0.52	0.48	0.78	0.65	0.57	0.60	0.76	1.00				
Cd	0.71	0.57	0.52	0.60	0.69	0.71	0.68	0.55	0.54	1.00			
Ba	0.88	0.70	0.62	0.65	0.80	0.78	0.80	0.58	0.56	0.73	1.00		
Sr	0.85	0.68	0.60	0.62	0.77	0.72	0.75	0.55	0.53	0.69	0.91	1.00	
K	0.82	0.66	0.58	0.64	0.74	0.69	0.70	0.57	0.55	0.66	0.87	0.84	1.00

3.8 Compliance with NAAQS

Comparison with Indian NAAQS standards revealed that PM₁₀ exceeded the 24-hour limit (100 µg m⁻³) by 4.2× on Diwali day, similar to exceedance patterns reported in major Indian cities (Beig et al., 2021; Jain & Tiwari, 2020). SO₂ and NO₂ remained within daily limits but showed significant hourly spikes (Singh et al., 2019).

3.9 Environmental and Health Impact

Elevated PM₁₀ concentrations (up to 480 µg m⁻³ hourly peak) indicate heavy particulate loading, contributing to reduced visibility and enhanced atmospheric turbidity (Peshin et al., 2017). Fireworks-related metals such as Ba, Sr, and K alter aerosol chemistry and reactivity (Saxena et al., 2022). Toxic metals such as Pb and Cd can accumulate in soil and dust, posing ecological risks (Ambade, 2018). Short-term exposure to high PM₁₀ and metal-bound particulates is associated with respiratory irritation, bronchial inflammation, and aggravated asthma (Kumar et al., 2020; Asif et al., 2024). Children, elderly individuals, and persons with pre-existing respiratory diseases are particularly vulnerable during peak exposure hours (Jain & Tiwari, 2020).

4. Conclusion

The present investigation provides comprehensive evidence of severe short-term air quality deterioration during Diwali 2025 in Jamshedpur, consistent with findings from other Indian urban centers (Beig et al., 2021; Singh et al., 2019). The enrichment of pyrotechnic tracer elements—particularly Ba, Sr, and K—clearly confirmed fireworks as the dominant episodic source (Saxena et al., 2022). Strong correlations between PM₁₀ and tracer metals further validated the fireworks-driven nature of the pollution episode (Singh et al., 2019). These findings highlight the urgent need for stricter regulatory enforcement and promotion of eco-friendly celebrations in industrial urban environments.

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