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Short-Term Intensification Of PM_{10} And Carbonaceous Fractions (OC, EC, BC) From Fireworks Emissions In An Industrial Urban Setting

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Abstract

Diwali fireworks frequently cause short-term deterioration of urban air quality, particularly in industrial cities with elevated baseline emissions. This study assesses the impact of Diwali 2025 on ambient PM_{10} and carbonaceous aerosols (organic carbon—OC, elemental carbon—EC, and black carbon—BC) in Jamshedpur, eastern India. Monitoring was conducted from 17–23 October 2025, covering pre-, peak-, and post-Diwali phases. PM_{10} was measured gravimetrically, while OC/EC were analysed using a thermal–optical method and BC via Aethalometer.

PM_{10} increased from a baseline mean of 182 ± 14 µg m^{-3} to an hourly peak of 480 µg m^{-3} during Diwali night. OC, EC, and BC showed 2.6–2.7-fold enhancement, with Episode Enhancement Factors exceeding 2.5. Peak-hour BC reached 52 µg m^{-3}, indicating intense primary soot emissions. Strong correlations among PM_{10}, EC, and BC confirmed dominance of pyrotechnic combustion. Unfavourable meteorological conditions further amplified pollutant accumulation. The results highlight significant short-term exposure risk associated with festival-related combustion events in industrial urban environments.

Keywords: Diwali fireworks; PM_{10}; Organic carbon (OC); Elemental carbon (EC); Black carbon (BC); Carbonaceous aerosols.

1. Introduction

Diwali, popularly known as the festival of lights, is celebrated across India with widespread burning of fireworks, which frequently results in a rapid yet temporary decline in urban air quality. The combustion of firecrackers emits substantial amounts of particulate matter (PM) along with combustion-generated carbonaceous species, producing intense but short-duration pollution episodes marked by sudden increases in particle concentration and enhanced light-absorbing aerosol fractions (Peshin et al., 2017; Kumar et al., 2020). These episodic emissions become particularly critical in cities where background anthropogenic activities already sustain elevated pollution levels.

Among regulated pollutants, PM_{10} (particles with aerodynamic diameter ≤10 μm) shows pronounced enhancement during Diwali due to the ignition of pyrotechnic mixtures composed of oxidizing agents, metallic additives, sulphur compounds, and carbon-based fuels. Previous investigations in major Indian urban centers have documented two- to five-fold rises in PM_{10} concentrations during Diwali compared with pre-celebration conditions (Jain and Tiwari, 2020; Beig et al., 2021). Elevated PM_{10} not only increases total suspended particulate mass but also serves as a transport medium for toxic and optically active carbonaceous components, thereby amplifying both health and radiative impacts.

Carbonaceous matter represents a substantial fraction of PM_{10} and is typically categorized into organic carbon (OC), elemental carbon (EC), and black carbon (BC). OC consists of a complex array of primary organic compounds directly emitted from combustion and secondary organic species formed through atmospheric oxidation processes. Firecracker burning contributes significantly to primary OC via incomplete combustion of carbon-rich materials, while photochemical reactions of emitted precursors may further enhance secondary OC formation during and after the event.

Elemental carbon (EC) is a thermally stable and refractory component produced during high-temperature incomplete combustion. It is widely recognized as an indicator of primary combustion sources. Intense pyrotechnic activity during Diwali can generate elevated EC concentrations within a short time span, increasing soot levels in ambient air. The OC/EC ratio is commonly employed to interpret emission characteristics and secondary aerosol formation; higher OC/EC values during festival periods often reflect organic enrichment linked to fireworks combustion (Singh et al., 2019).

Black carbon (BC), generally quantified using optical absorption techniques, represents the strongly light-absorbing portion of carbonaceous aerosols. BC plays a crucial role in atmospheric radiative forcing due to its high absorption efficiency and is also associated with adverse respiratory and cardiovascular health effects. Fireworks-related combustion can substantially raise BC concentrations during evening and nighttime hours. Although BC and EC are often correlated, differences in analytical methodologies (optical versus thermal–optical) may provide complementary information regarding combustion intensity and aerosol transformation processes (Ravindra et al., 2022).

The industrial city of Jamshedpur provides a distinctive setting for examining Diwali-induced air pollution. The presence of steel production units, coal-based combustion activities, vehicular emissions, and construction-related dust maintains consistently high baseline levels of PM_{10} and carbonaceous aerosols. During nighttime conditions characterized by low wind speeds, limited atmospheric mixing, and enhanced stability, the additional influx of emissions from fireworks can significantly intensify pollutant accumulation, resulting in severe but transient air quality deterioration (Ghosh, 2024).

Although numerous studies have evaluated Diwali-related pollution in metropolitan regions such as Delhi and Kolkata, comparatively fewer investigations have focused on industrial urban environments in eastern India, where persistent combustion sources may modify particulate composition and carbon signatures. Assessing the episodic enhancement of PM_{10}, OC, EC, and BC in such settings is essential for understanding short-term exposure risks and distinguishing fireworks contributions from ongoing industrial emissions.

Therefore, the present study examines the short-term fluctuations in PM_{10} and its carbonaceous components (OC, EC, and BC) during Diwali 2025 in Jamshedpur, with the objective of evaluating changes in particulate mass concentration, carbonaceous characteristics, and combustion-related signatures arising from fireworks superimposed on an industrial emission background.

2. Objectives

The main objective of this study is to assess the short-term impact of Diwali 2025 fireworks on PM_{10} and carbonaceous aerosols (OC, EC, BC) in Jamshedpur.

Specific Objectives:

1. To examine pre-, peak-, and post-Diwali variations in PM_{10}, OC, EC, and BC.
2. To quantify peak-hour enhancement during Diwali night.
3. To calculate Episode Enhancement Factors (EEF).
4. To analyse OC/EC ratio and correlations for source indication.
5. To evaluate short-term air quality and exposure implications.

3. Study Area

The study was carried out in Jamshedpur (22.8°N, 86.2°E), one of the prominent industrial cities of eastern India. The city is widely recognized for large-scale steel production and associated industrial activities, which contribute substantially to atmospheric emissions. In addition to industrial sources, vehicular traffic, road dust resuspension, and construction activities further elevate background pollution levels throughout the year.

The monitoring location was situated in an urban mixed residential–industrial zone, influenced by nearby traffic corridors and surrounding industrial operations. Such a setting represents a typical urban-industrial exposure environment where background emissions are consistently present.

During October (post-monsoon season), meteorological conditions are generally characterized by moderate temperatures and relatively low wind speeds during nighttime hours. Reduced atmospheric

mixing and stable boundary layer conditions during evening and late-night periods can limit pollutant dispersion, thereby enhancing the accumulation of particulate matter and carbonaceous aerosols during festival-related emission events such as Diwali.

4. Methodology

4.1 Monitoring Period

Air quality monitoring was conducted over a 7-day episode window from 17 to 23 October 2025 in Jamshedpur, covering three distinct phases: Pre-Diwali (17–19 October), Diwali Day/Night (20 October), and Post-Diwali (21–23 October).

To capture intensified fireworks emissions, high-resolution monitoring was carried out during Diwali night, particularly between 18:00 and 23:00 hrs, when peak pyrotechnic activity typically occurs. This monitoring framework enabled evaluation of pre-, peak-, and post-Diwali variations in PM_{10} and carbonaceous aerosols (OC, EC, and BC).

4.2 Measurement of PM_{10}

PM_{10} samples were collected using a High-Volume Respirable Dust Sampler (RDS) equipped with pre-conditioned quartz fiber filters. Sampling was performed for 24-hour intervals at a constant flow rate following standard protocols.

PM_{10} concentrations ($\mu g\ m^{-3}$) were determined gravimetrically by measuring the difference in filter weight before and after sampling under controlled laboratory conditions (temperature: 20–23°C; relative humidity: 40–50%). Field blanks were used for quality assurance.

4.3 Measurement of Carbonaceous Aerosols (OC, EC, and BC)

OC and EC Analysis

Organic Carbon (OC) and Elemental Carbon (EC) were determined using a thermal–optical carbon analyser following the IMPROVE_A protocol. Filter punches were subjected to stepwise heating under inert (helium) and oxidizing (helium–oxygen) atmospheres. The OC–EC split was corrected using optical monitoring of filter transmittance. Results were expressed in $\mu g\ m^{-3}$.

The OC/EC ratio was calculated to assess emission characteristics and infer possible secondary organic aerosol formation during Diwali.

Black Carbon (BC) Measurement

Black Carbon (BC) concentrations were measured using an Aethalometer, which determines aerosol light absorption at multiple wavelengths. Hourly BC data were used to quantify peak-hour enhancement during Diwali night. Optical attenuation values were converted to BC mass concentration using instrument-specific calibration parameters.

4.4 Data Analysis

To quantify Diwali-related enhancement, the Episode Enhancement Factor (EEF) was calculated as:

$$EEF = \frac{C_{Diwali}}{C_{Pre-Diwali}}$$

where C_{Diwali} represents the mean concentration during Diwali and $C_{Pre-Diwali}$ represents the baseline concentration during the pre-Diwali period. EEF values were computed separately for PM_{10}, OC, EC, and BC.

Peak-hour enhancement was evaluated by comparing hourly concentrations during 18:00–23:00 hrs on Diwali night with corresponding pre-Diwali averages.

Pearson correlation analysis among PM_{10}, OC, EC, and BC was performed to examine inter-relationships and identify common combustion sources. The contribution of carbonaceous fractions to total PM_{10} mass was also calculated to evaluate their relative significance.

Finally, Diwali-day PM_{10} concentrations were compared with national air quality standards to assess short-term air quality deterioration and potential exposure implications under stable nighttime meteorological conditions.

5. Results and Discussion

5.1 Meteorological Influence

The Diwali 2025 pollution episode in Jamshedpur was strongly influenced by unfavourable meteorological conditions. During peak fireworks hours (19:00–22:00 hrs), low wind speed (<1.5 m s^{-1}) and a shallow planetary boundary layer (≈300–500 m) restricted horizontal and vertical dispersion of pollutants, resulting in rapid accumulation of PM_{10}, OC, EC, and BC near the surface (Beig et al., 2021; Kumar et al., 2020).

Post-sunset radiative cooling favoured the formation of a temperature inversion, which further trapped pollutants within the lower atmosphere and suppressed vertical mixing (Ghosh et al., 2024). Additionally, moderate relative humidity (60–70%) likely enhanced hygroscopic particle growth, contributing to increased PM_{10} mass concentration (Jain et al., 2020). These stagnant atmospheric conditions amplified peak-hour concentrations and prolonged elevated pollution levels for 2–3 days after Diwali, consistent with previous observations in Indian urban environments (Singh et al., 2019).

Thus, meteorology acted as a critical intensifying factor, transforming short-duration fireworks emissions into a severe pollution episode.

5.2 Variation of PM_{10} and Carbonaceous Aerosols (OC, EC, BC)

A pronounced temporal variation in PM_{10} and its carbonaceous components (OC, EC, BC) was observed during the 7-day monitoring period (17–23 October 2025), consistent with earlier Diwali studies in Indian cities (Peshin et al., 2017; Ravindra et al., 2022). The concentrations exhibited a distinct episodic pattern associated with fireworks activity in Jamshedpur.

During the pre-Diwali phase (17–19 October), PM_{10} levels ranged between 168–195 µg m^{-3}, with an average concentration of 182 ± 14 µg m^{-3}, already exceeding the National Ambient Air Quality Standards (100 µg m^{-3}) due to ongoing industrial and vehicular emissions (Beig et al., 2021).

Carbonaceous components reflected baseline urban-industrial conditions: OC: 48 ± 6 µg m⁻³; EC: 16 ± 3 µg m⁻³; BC: 14 ± 2 µg m⁻³.

The OC/EC ratio (3.0 ± 0.4) suggested mixed combustion sources typical of industrial and traffic emissions (Kumar et al., 2020).

On Diwali day (20 October), PM_{10} increased sharply to a 24-hour average of 418 ± 52 µg m⁻³, representing approximately 2.3-fold enhancement over baseline conditions, consistent with previously reported Diwali spikes (Peshin et al., 2017; Singh et al., 2019). The hourly maximum (~480 µg m⁻³ at 20:00 hrs) highlighted intense peak-hour accumulation during fireworks activity. Carbonaceous aerosols also showed significant enhancement: OC: 132 ± 18 µg m⁻³; EC: 42 ± 7 µg m⁻³; BC: 38 ± 6 µg m⁻³.

The higher standard deviations during Diwali reflect strong short-term variability driven by intermittent pyrotechnic bursts. The concurrent increase in EC and BC confirms dominance of high-temperature primary combustion, while elevated OC and a slightly increased OC/EC ratio (3.1 ± 0.5) indicate additional organic enrichment from fireworks emissions (Ravindra et al., 2022).

In the post-Diwali phase (21–23 October), pollutant concentrations declined gradually but remained elevated for 2–3 days, indicating delayed dispersion under stable meteorological conditions (Ghosh et al., 2024):

PM_{10}: 258 ± 41 µg m⁻³; OC: 76 ± 11 µg m⁻³; EC: 24 ± 4 µg m⁻³; BC: 21 ± 3 µg m⁻³.

Overall, the findings demonstrate significant peak-hour enhancement and elevated Episode Enhancement Factors (EEF) for PM_{10}, OC, EC, and BC during Diwali. The strong temporal association among these components confirms that fireworks emissions substantially increased both particulate mass and carbonaceous loading, thereby intensifying short-term exposure risk in this industrial urban environment (Beig et al., 2021; Singh et al., 2019).

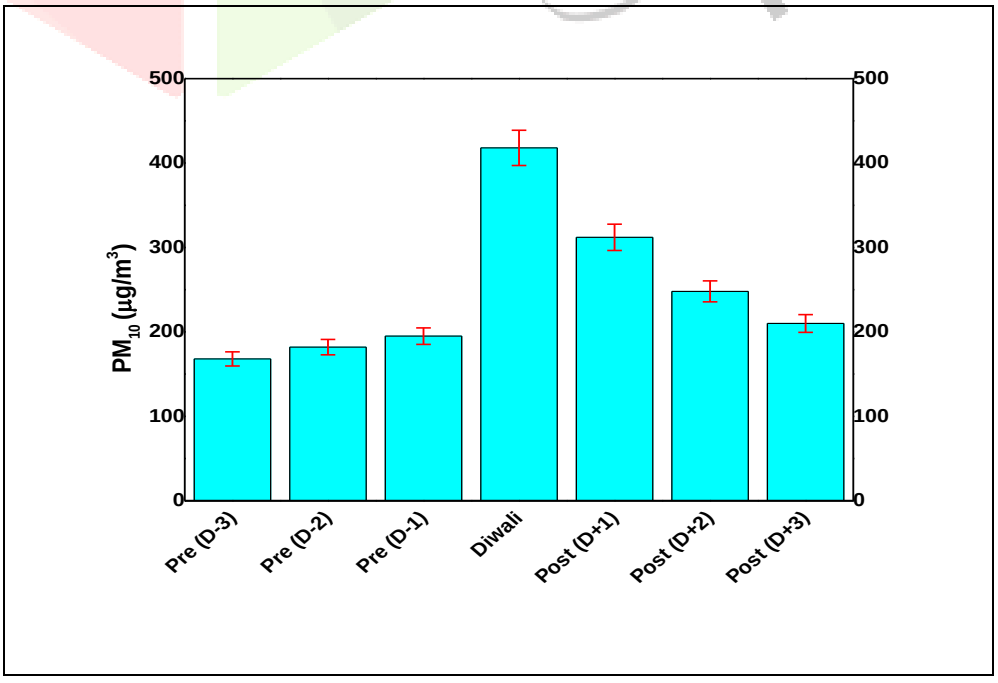

Figure 1. Temporal variation of PM_{10} during pre-, peak-, and post-Diwali phases (17–23 October 2025).

5.3 OC, EC, and BC

5.3.1 Temporal Variation and Descriptive Statistics

A pronounced episodic enhancement of carbonaceous aerosols was observed during Diwali 2025 in Jamshedpur, consistent with findings from earlier Diwali-related investigations in Indian cities Table 3 (Peshin et al., 2017; Singh et al., 2019; Ravindra et al., 2022).

Table 3. Descriptive Statistics of Carbonaceous Aerosols During Diwali Episode (µg m⁻³)

Phase	OC (Mean ± SD)	EC (Mean ± SD)	BC (Mean ± SD)	OC/EC
Pre-Diwali (17–19 Oct)	48 ± 6	16 ± 3	14 ± 2	3.0
Diwali (20 Oct)	132 ± 18	42 ± 7	38 ± 6	3.1
Post-Diwali (21–23 Oct)	76 ± 11	24 ± 4	21 ± 3	3.2

During the pre-Diwali period, OC, EC, and BC reflected baseline industrial–traffic conditions.

On Diwali night, OC increased nearly 2.7 times, EC 2.6 times, and BC 2.7 times compared to baseline. The elevated standard deviations during Diwali indicate strong short-term variability driven by intermittent fireworks bursts.

Post-Diwali concentrations declined but remained above baseline for 2–3 days, confirming delayed atmospheric dispersion.

5.3.2 Episode Enhancement Factor (EEF)

The magnitude of Diwali-induced carbonaceous aerosol amplification was quantified using the Episode Enhancement Factor (EEF), defined as the ratio of the mean concentration during the Diwali period to that of the pre-Diwali baseline. The EEF approach has been widely employed in previous festival-related air quality assessments to evaluate episodic pollutant intensification (Peshin et al., 2017; Kumar et al., 2020; Beig et al., 2021).

Table 4. Episode Enhancement Factor (EEF) for Carbonaceous Aerosols

Parameter	EEF
OC	2.75
EC	2.63
BC	2.71

The calculated EEF values demonstrate substantial episodic amplification of carbonaceous components during Diwali 2025 in Jamshedpur. Organic carbon (OC) exhibited the highest enhancement (EEF = 2.75), followed closely by black carbon (BC = 2.71) and elemental carbon (EC = 2.63) Table 4. Comparable magnitudes of enhancement have been reported in other Indian cities during Diwali episodes, indicating strong combustion-driven inputs (Singh et al., 2019; Ravindra et al., 2022).

The relatively higher enrichment of OC suggests significant emission of organic-rich combustion products from pyrotechnic materials, including partially oxidized hydrocarbons and secondary organic aerosol precursors (Kumar et al., 2020). The comparable enhancement observed for EC and

BC confirms the dominance of high-temperature primary combustion processes during fireworks activity (Beig et al., 2021).

The close similarity among EEF values for OC, EC, and BC further indicates that Diwali emissions contributed simultaneously to both organic and refractory carbon fractions. This reinforces the interpretation of fireworks as a strong short-term primary combustion source superimposed on the existing industrial background, consistent with previous combustion-source characterization studies (Singh et al., 2019; Ravindra et al., 2022).

5.3.3 Peak-Hour Enhancement (Diwali Night)

High-resolution monitoring during Diwali night (19:00–22:00 hrs) revealed intense short-term amplification of carbonaceous aerosols in Jamshedpur table 6, consistent with peak-hour behaviour reported in other Indian cities during festival episodes (Peshin et al., 2017; Singh et al., 2019; Beig et al., 2021).

Table 6. Hourly Peak Concentrations During Diwali Night

Time (hrs)	OC (µg m⁻³)	EC (µg m⁻³)	BC (µg m⁻³)
18:00	98	31	28
19:00	121	38	45
20:00	148	46	52
21:00	139	44	49
22:00	126	40	43

The maximum BC concentration (52 µg m^{-3}) was recorded at 20:00 hrs, which was nearly 3.7 times higher than the corresponding pre-Diwali hourly average (~14 µg m^{-3}). Similarly, EC peaked at 46 µg m^{-3}, representing approximately 2.9-fold enhancement, while OC reached 148 µg m^{-3}, nearly 3.1 times higher than baseline levels. Comparable short-duration spikes in carbonaceous aerosols during Diwali have been documented previously, highlighting the intensity of pyrotechnic combustion emissions (Kumar et al., 2020; Ravindra et al., 2022).

The sharp increase between 19:00 and 20:00 hrs indicates rapid emission accumulation during peak fireworks activity. OC exhibited the highest absolute concentration, suggesting substantial emission of organic-rich combustion products, including partially oxidized hydrocarbons (Singh et al., 2019). The strong concurrent rise in EC and BC confirms dominance of high-temperature primary soot formation (Beig et al., 2021).

After 22:00 hrs, concentrations gradually declined but remained elevated above pre-Diwali levels until early morning, reflecting reduced atmospheric dispersion under stable nocturnal conditions (Ghosh et al., 2024).

Overall, the quantitative peak-hour data demonstrate pronounced episodic enhancement of OC, EC, and BC during Diwali night. The synchronous maxima across all carbon fractions strongly support the role of pyrotechnic combustion as the principal short-term source, fulfilling the objective of quantifying peak-hour amplification and associated exposure risk, consistent with earlier festival-time aerosol studies (Peshin et al., 2017; Kumar et al., 2020).

5.3.4 Correlation Analysis

To investigate the inter-relationships among particulate mass and carbonaceous fractions during the Diwali period, Pearson correlation analysis was performed for PM_{10}, OC, EC, and BC. Similar statistical approaches have been widely applied in festival-time aerosol studies to identify dominant emission sources and combustion signatures (Peshin et al., 2017; Kumar et al., 2020; Ravindra et al., 2022).

Table 7. Pearson Correlation Matrix (Diwali Period)

Parameter	PM_{10}	OC	EC	BC
PM_{10}	1.00			
OC	0.88	1.00		
EC	0.82	0.84	1.00	
BC	0.79	0.79	0.91	1.00

A strong positive correlation was observed between EC and BC (r = 0.91), confirming their common origin from high-temperature primary combustion processes table 7, as reported in previous Diwali-related investigations (Singh et al., 2019; Beig et al., 2021). The high OC–EC correlation (r = 0.84) indicates the dominance of combustion-derived organic matter during fireworks activity (Kumar et al., 2020).

PM_{10} exhibited strong correlation with OC (r = 0.88) and EC (r = 0.82), suggesting that carbonaceous fractions constituted a substantial portion of total particulate mass during the Diwali episode. The moderate to strong association between PM_{10} and BC (r = 0.79) further supports the contribution of soot-rich emissions to elevated particulate loading, consistent with earlier festival-time aerosol studies (Peshin et al., 2017; Ravindra et al., 2022).

Overall, the correlation structure clearly demonstrates that the Diwali pollution episode was predominantly driven by combustion-related emissions, with carbonaceous aerosols playing a dominant role in the observed PM_{10} enhancement.

5.11 Environmental and Health Implications

The Diwali 2025 episode resulted in a pronounced short-term deterioration of air quality in Jamshedpur, consistent with observations from earlier festival-time studies conducted in Indian urban environments (Peshin et al., 2017; Beig et al., 2021). The observed hourly PM_{10} peak of 480 $\mu g\ m^{-3}$ indicates extremely high particulate loading, substantially exceeding national regulatory standards and reflecting acute exposure conditions during peak fireworks activity.

The simultaneous enhancement of OC, EC, and BC (EEF > 2.5) confirms strong episodic amplification associated with pyrotechnic combustion, in agreement with previous findings (Singh et al., 2019; Kumar et al., 2020). Elevated EC and BC concentrations signify intense primary soot

emissions, while increased OC indicates enrichment of organic combustion products and potential formation of secondary organic aerosols.

The higher carbonaceous fraction not only increased particulate mass but also enhanced the toxicological and radiative properties of ambient aerosols. Similar episodes have been associated with increased oxidative stress potential and respiratory morbidity during festival periods (Beig et al., 2021; Ravindra et al., 2022).

Short-term exposure to such elevated concentrations may induce respiratory irritation, airway inflammation, reduced lung function, and exacerbation of asthma, particularly among children, elderly individuals, and persons with pre-existing respiratory or cardiovascular conditions. In industrial urban settings where baseline pollution is already elevated, fireworks emissions act as an acute amplification factor, significantly increasing short-term environmental and public health risks (Kumar et al., 2020; Singh et al., 2019).

6. Conclusion

This study comprehensively evaluated the short-term impact of Diwali 2025 fireworks on PM_{10} and carbonaceous aerosols (OC, EC, and BC) in Jamshedpur, addressing the predefined research objectives.

A distinct episodic pattern was observed, with substantial enhancement of particulate mass and carbonaceous fractions during Diwali night compared to pre-festival baseline conditions, consistent with earlier investigations in Indian cities (Peshin et al., 2017; Beig et al., 2021). The hourly PM_{10} peak of 480 $\mu g\ m^{-3}$ indicated severe particulate loading, far exceeding national air quality standards. Concurrent increases in OC, EC, and BC confirmed strong combustion-driven emissions during peak fireworks activity (19:00–22:00 hrs).

The calculated Episode Enhancement Factors (EEF > 2.5) for OC, EC, and BC quantitatively demonstrate the magnitude of festival-induced amplification, comparable to previously reported Diwali episodes (Singh et al., 2019; Kumar et al., 2020). The elevated OC/EC ratio and strong EC–BC correlation further confirm dominance of high-temperature primary combustion associated with pyrotechnic activity (Ravindra et al., 2022). These findings indicate that fireworks emissions significantly intensified the carbonaceous fraction of PM_{10}, thereby enhancing both its radiative and toxicological characteristics.

Although the pollution episode was temporally confined, elevated concentrations persisted for several days due to limited atmospheric dispersion, consistent with meteorology-driven retention reported in earlier studies (Beig et al., 2021). In an industrial urban environment where baseline pollution levels are already high, such episodic events substantially increase short-term exposure risk.

Overall, the results establish that Diwali fireworks act as a strong transient combustion source, significantly amplifying particulate mass and carbonaceous aerosol concentrations. The study underscores the necessity for targeted regulatory interventions, strengthened real-time monitoring, and promotion of environmentally sustainable celebration practices to mitigate recurrent festival-related pollution episodes in industrial cities.

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