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Research Article

Air Pollution Trend and Variation during a Mega Festival of Firecrackers (Diwali) in Context to COVID-19 Pandemic

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ABSTRACT The present study was conducted in Lucknow city to assess the impact of firecracker burning during Diwali, from 2 November 2021–6 November 2021 including the pre and post-Diwali days. The concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3, benzene and toluene, were monitored from the Central Pollution Control Board site on an hourly basis. The Air Quality Index was also recorded for PM_{10}, $PM_{2.5}$, SO_2 and NO_2. A questionnaire survey was done with 51 doctors to know the reported complaints post-Diwali. On Diwali night the $PM_{2.5}$ value reached 262 μg m^{-3} around 22:00 hours and the maximum value (900 μg m^{-3}) was obtained on 5 November, reported from the Central School monitoring station. From Gomti Nagar highest $PM_{2.5}$ value obtained on Diwali day was 538 μg m^{-3} at 23:00 hours reaching 519 μg m^{-3} post-Diwali. Areas belonging to the old part of the city witnessed higher variations as $PM_{2.5}$ crossed 900 μg m^{-3}, in Lalbagh and Talkatora areas. The multivariate analysis showed that on Diwali night there was an increase of 204, 386, 344 and 341 in the $PM_{2.5}$ concentration reported from Gomtinagar, Central School, Talkatora and Lalbagh stations, showing that firecracker burning resulted in a significant increase in air pollution. The Toluene/Benzene ratio was mostly more than 1 indicating that toluene and benzene may be emitted from other sources as well including the mobile sources. Around 50–75% rise was seen in the number of patients post-Diwali. 57.1% of the reported cases had respiratory issues, followed by allergic reactions. The data obtained from Lalbagh, Talkatora and Central School showed that although the values remained high, a decreasing trend was seen in the AQI compared to previous years which is a good sign and may be attributed to public awareness and the ongoing pandemic making people conscious.

KEY WORDS Questionnaire, Multi-variate, $PM_{2.5}$, Health, Benzene, Toluene, Dispersion

1. INTRODUCTION

Diwali is celebrated every year with great fervour during October or November in India. It is one of the most important festivals in India, and during the festival, firecrackers are busted as they are associated with festivities. Air quality degradation around Diwali is a major issue. Chemicals such as KNO_3, $KClO_3$, As, S, Mn, $Na_2C_2O_4$, Al, $Fe_2O_3 \cdot H_2O$, $KClO_4$, $Sr(NO_3)_2$, $Ba(NO_3)$ and charcoal are released in firecrackers (Barman *et al.*, 2008). During the display of pyrotechnics such as "blue lightning rockets" and "fountains" hazardous air pollutants such as polychlorinated dioxins and furans are also released along with SO_2, KNO_3, charcoal, CO_2, CO, suspended particles (PM_{10}, $PM_{2.5}$) and numerous metals all of which cause health hazards as found in previous studies (Tao *et al.*, 2014; Croteau *et al.*, 2010). A few important reactions of fireworks are given as Equations 1–8. It has been reported by Balram (2018) that the levels of atmospheric black carbon become many times higher during Diwali as compared to normal days. Similarly, levels of PM_{10} and Total Suspended Particulate Matter (TSPM) also increase many times beyond the permissible levels during the festival leading to short-term variations in air quality. Yasutake *et al.* (1997) reported that the particulate contamination generated during Diwali has drawn concern due to its short and long-term effects exerting toxic effects on animal and plant tissues upon accumulation. O_3 can also be formed in the environment without reacting with NOx due to the burning of sparkles (Attri *et al.*, 2001). Ganguly *et al.* (2009) reported the effects of fireworks during Diwali on surface ozone from Delhi. Firework emission during the Diwali festival has led to short-term variation in the air quality and a two to three times increase in the PM_{10} concentrations and total suspended particles as reported from Hisar city by Ravindra *et al.* (2003). The 24-h average concentration of PM_{10} was 5.7 times higher than the control day, whereas SO_2, and NOx were 6.6 and 2.7 times more than the normal days, as reported from Lucknow by Barman *et al.* (2008). Compounds like dioxin and furan have also been found to be in increased concentrations during the bonfire, suggesting fireworks could also be a significant source of organic pollutants (Bates, 1995). Kulshrestha *et al.* (2004) reported a high level of different trace elements in the ambient air of Hyderabad, owing to fireworks during the Diwali festival. The exposure to short-term pollution during the festival has witnessed an increase of 30 to 40% in the cases reporting wheezing, attacks of bronchial asthma and bronchitis as reported by Clark (1997). These symptoms may also arise due to inhalation of smoke released from firecrackers causing acute eosinophilic pneumonia, cardiovascular diseases, respiratory health impacts, and reproductive and developmental effects such as the elevated risk of preterm birth (Cheng, 2014; Liu *et al.*, 2003). There is a strong relationship between a higher concentration of SO_2 and several health effects like cardiovascular diseases (Chen *et al.*, 2005), asthma, and bronchitis (Barnett *et al.*, 2005), reproductive and developmental effects such as the increased risk of preterm birth (Liu *et al.*, 2003). Short-term elevation in the concentration of trace elements from fireworks can induce neurological and haematological effects on the exposed. The meteorological conditions along with emissions from fireworks lead to reduced visibility and the production of dense smoke clouds which persist in the environment for longer durations. The research around Diwali has been mainly focused on measuring the concentrations of pollutants (Chatterjee *et al.*, 2013). Since the festival is celebrated with great fervour in North India, the cities belonging to the region are more susceptible to bear the aftermath and consequences of the mayhem caused by the pollution during the festival. Toxic smog has been witnessed across North India, including the national capital Delhi post-Diwali over the years. Anthropogenic activities, stubble burning and weather conditions make the air pollution levels in 'very poor' and 'hazardous' categories. Considering Lucknow-the capital city of Uttar Pradesh, an alarming rise in air pollution has been witnessed in the city with the $PM_{2.5}$ levels reaching 4–14 times higher than the National Ambient Air Quality Standards (NAAQS) limits during Diwali [https://timesofindia.indiatimes.com/city/lucknow/diwali-crackers-choke-lucknow-pollution-reaches-3-year-high/articleshow/87577307.cms]. The 24-hour particulate concentrations during Diwali, in the city are 2.49 and 5.67 times higher than pre-Diwali day as reported by Barman *et al.* (2007), whereas the concentration of SO_2 was 1.95 and 6.59 times higher compared to the concentration of pre-Diwali and normal days. According to a study conducted by the Central Pollution Control Board (CPCB), Govt. of India, across 115 Indian cities, the Air Quality Index (AQI) of Lucknow city has been categorized as very poor, especially during the winter season reported by Lawrence *et al.* (2020) in their research. With the ongoing COVID-19 pandemic, the Diwali season has become quite crucial for the Indian population, among the states witnessing the highest number of cases and mortality caused by COVID-19 Delhi, Uttar Pradesh and Haryana find a prominent place. Barman *et al.* (2007) reported that the impact of the deadly viral disease may be more severe in cities with high air pollution as the immunity of the people is already compromised by the exposure to toxic air. Lawrence *et al.* (2020) suggested that the accumulation of particulate matter in the air may assist the transmission of the virus. People suffering from the chronic obstructive pulmonary disease (COPD) and asthma are more susceptible to COVID-19 infection (Liu *et al.*, 2003). Sharma *et al.* (2020) reported that the inflammation in the lungs caused by particulate matter can worsen the health of a COVID-19 infected patient. In developing countries like India, the spread may be influenced by ambient air pollution. The disturbance in air quality caused by the air pollution during Diwali and associated health hazards has also created awareness in the public about the negative aspects of burning firecrackers. Several campaigns have been initiated against fireworks burning with the main agenda of creating awareness among the public on the hazardous effects of fireworks on flora and fauna as reported by Yerramsetti *et al.* (2013). The pollution disaster caused during the festival led to a ban on firecrackers imposed by the Supreme Court of India in 2017. The present study was conducted in Lucknow city to know the variation in pollutants' concentrations during the Diwali period. It is well known that the short term variation in air quality occurs after fireworks burning, but this is the first time not only concentrations and AQI of main pollutants like PM_{10}, $PM_{2.5}$, NO_2, SO_2, O_3 and CO were monitored but the changes in the concentrations of benzene, toluene, ethylbenzene and xylene were also measured. Correlations between the meteorological parameters like temperature, wind speed and humidity and the concentrations of PM_{10} and $PM_{2.5}$ were also studied. The data was collected not only from one but all four monitoring stations located in the city to identify the other contributing factors in different areas. Another important aspect of the study was a questionnaire survey which was done with 51 medical doctors to know the common symptoms and problems reported by the patients during the Diwali period which may be an outcome of the drastic short-term variation in the air quality. A comparison was also studied between the AQI values during Diwali-2021 with the previous years to know whether there is some awareness among the public regarding the hazards of fireworks burning. The findings of the study may be suggestive of the fact whether the general public has taken the warnings and bans issued by the government seriously or not.

$$Sr(s)+C(s)+O_2 \rightarrow SrCO_3 \quad (1)$$

$$SO_2 + O_2 \rightarrow SO_3 + heat \quad (2)$$

$$2NO + O_2 + 2NO_2 \quad (3)$$

$$NO_2 + hv \rightarrow NO + O \quad (4)$$

$$6KNO_3 + C_7H_4O+2S \rightarrow K_2CO_3 + K_2S + 4CO_2 + 2CO + 2H_2O + 3N_2 \quad (5)$$

$$KNO_3 + C + S \rightarrow CO_2 + SO_2 + N_2 + K_2O \quad (6)$$

$$O_2 + Al \rightarrow Al_2O_3 + heat\ and\ light \quad (7)$$

$$3KClO_4 + 8Al \rightarrow 4Al_2O_3 + 3KCl \quad (8)$$

2. MATERIALS AND METHODS

The study was conducted from 2nd November 2021 to 6th November 2021 covering the Pre-Diwali, Diwali and Post-Diwali days. The Air quality index (AQI) values were recorded concerning PM_{10}, $PM_{2.5}$, SO_2, and NO_2 for Lucknow city. The concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3, benzene and toluene were also recorded for the study period from Gomtinagar, Talkatora, Central School, and Lalbagh monitoring stations to know the variation in pollutants [https://app.cpcbccr.com/ccr]. The AQI values were recorded from https://aqicn.org/city and concentrations were recorded from https://app.cpcbccr.com/ccr. Relative humidity, temperature, wind speed, wind direction and solar radiation were recorded from https://app.cpcbccr.com/ccr. The data were recorded on an hourly basis. 24 hours' data was recorded on all the selected days. All the data were tabulated in MS Excel 2016. The location of the monitoring stations is marked in Fig. 1. A questionnaire survey was done with 51 medical doctors in the city to know the commonly reported issues from patients post-Diwali. A questionnaire survey may be used to collect data from a large target group which be easily interpreted. Medical doctors were selected from all over the city, especially from the locations in which the monitoring stations were located. Doctors with specializations in pulmonary, cardiology, neurology and paediatrics were selected for the survey. The questionnaire was conducted according to the recommendations of the Helsinki Declaration and compiled under the guidance of medical doctors. Voluntary answering was sought and clear instructions were given to the respondents it was also declared that the personal information would be kept confidential and used for research purposes only. The questionnaire was developed as a Google form containing ten questions with multiple choices. Questions about the area of specialization, age

Fig. 1. Map showing the details of monitoring stations.

and sex of the patient, rise in the number of patients post-Diwali, children visiting the clinic and affected age groups were added to the questionnaire. These questions were included to know the effect of short-term air quality variation in the air quality on the health of the exposed people.

2.1 Site Description

Lucknow is situated on the northern Gangetic plains of India. It is the capital city of Uttar Pradesh. The geographical location of Lucknow is between 26.50° North and 80.50° East. The city is located at an elevation of 123 meters above sea level. The total area covered by Lucknow is around 3,204 sq. km. According to the 2011 census, the population of Lucknow was 2,817,105 (https://worldpopulationreview.com/world-cities/lucknow-population). The present population of Lucknow is around 3.7 million. Lucknow covers 2,528 area sq. km with 1,816 density km^{-2}. According to the Road transport yearbook for the years 2017–2018 and 2018–2019, there was a rise of 167,945 in the number of the total registered vehicles. For the year 2018–2019, there were 2,340,901 total registered vehicles including non-transport (2,260,585) and transport (80,316) (https://www.upsrtc.com/). In the study, the air quality data were recorded from four monitoring stations viz. Lalbagh west and Talkatora, are located in the old part of the city, whereas Central School and Gomtinagar monitoring stations are located in the newly developed trans-Gomti area.

Lalbagh: is one of the central, historic and prominent business centres of Lucknow city. Lalbagh is located with the GPS coordinates of 26°50′45.6432″N and 80°56′28.7592″E. The latitude of Lalbagh, Lucknow, Uttar Pradesh, 26.846012 and the longitude is 80.941322. Lalbagh is a congested residential area with heavy traffic density in spatial distribution.

Talkatora: is one of the most important industrial areas in Lucknow. The latitude of Talkatora is 26°50′2.4″N and the longitude is 80°53′44.6244″E. The area is densely populated with heavy traffic flow and is one of the largest and oldest residential colonies. There are several small and medium industries situated in the area with high emissions.

Gomtinagar: is a prominent area located about 2 miles east of Lucknow city. The latitude of Gomtinagar is 26.862410, and the longitude is 81.050348. It is located with the GPS coordinates of 26°51′44.6760″N and 81°1′13.2528″E. It is one of the most recently developed and well-planned residential areas, with houses having proper ventilation and greenery around.

Aliganj, Central school: The latitude of Central School is 26°51′9.6312″N and the longitude is 80°59′46.0464″E. It is the second-largest residential area located in the North-Eastern part of the city and situated in the trans-Gomti region. The area is recently developed, well-planned with moderate to high traffic density.

It has also been noticed that industrial emissions may also impact the environment severely. The smoke released from firecrackers gets trapped in the mist which is facilitated by meteorological conditions. The bad air quality at the onset of winters may be attributed to the long-range transportation facilitated by meteorological parameters including wind speed and direction and must be explored further for a conclusive relationship. At higher altitudes, the effect of the pollutants released from the fireworks may be diluted, thereby reducing the health impact as reported by Betha *et al.* (2013), whereas ground-level exposure results in a short-term impact on human health. Table 1 summarizes the major industries around the four monitoring stations which may also lead to hazardous emissions, thereby exacerbating the pollu-

Table 1. Industrial data.

Gomtinagar	Lalbagh	Talkatora	Central School
1. Nucon industries private limited.	1. Visaka industries limited	1. Prag Industries	1. Bravia Techno Solutions Pvt. Ltd.
2. Grihasti industries	2. Spectrochem private limited.	2. Eveready Industries India Limited	2. Indianmicrosystems
3. Jyoti steel Industries	3. Traders India	3. Greenply Industries Limited	3. Bravia Techno Solutions Pvt. Ltd.
4. Leotronic Scales private limited	4. Anup and Company	4. Needle Industries Pvt. Ltd.	4. EPABX Dealer Lucknow smart school softwares
5. Sarda plywood Industries	5. Cold Form Engineering Private Limited.	5. Industries Accesitor	
6. Shine Star Industries		6. Super Industries	
7. Sun Fields Industries		7. Anukampa Poly packaging industries	
8. Evergreen earthcare industries		8. Super star Industries	
9. Vinmax Agro Industries Pvt. Ltd.		9. Mayur ply Industries Pvt. Ltd.	
10. Shree Vaishnavi Agro Industries.		10. Soni Industries	
11. Armstrong World Industries		11. Mercury Components Co. Pvt. Ltd.	
12. Kanak trading co.		12. Swastik Scientific Industries	
13. Gloria Engineering Company		13. Suncosmo Industries Pvt. Ltd.	
14. Delhi electronic Co.		14. Nishan industries	
		15. Alvi Packaging Industries	
		16. Jain Microsystems India	
		17. Guru Enterprises	
		18. Saksham Enterprises.	

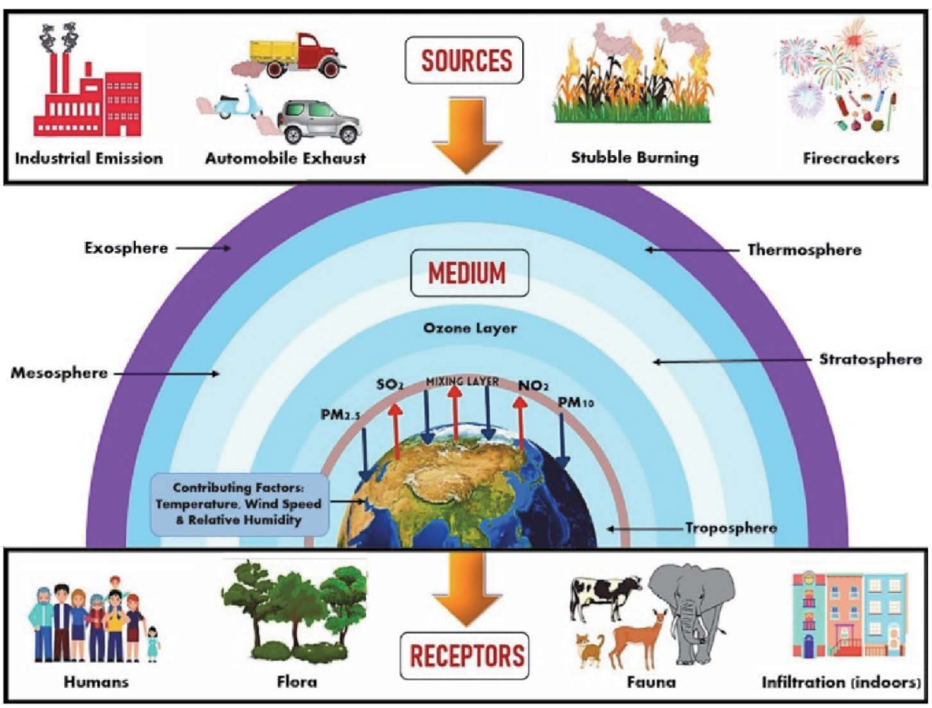

Fig. 2. Air Pollution Disperison and associated factors.

tion. Fig. 2 represents that the major sources of air pollutants are not only pyrotechnics but also factors like-industrial emission, stubble burning and vehicular exhaust which are some of the anthropogenic sources of air pollution. These factors contribute to a drastic rise in the concentrations of pollutants.

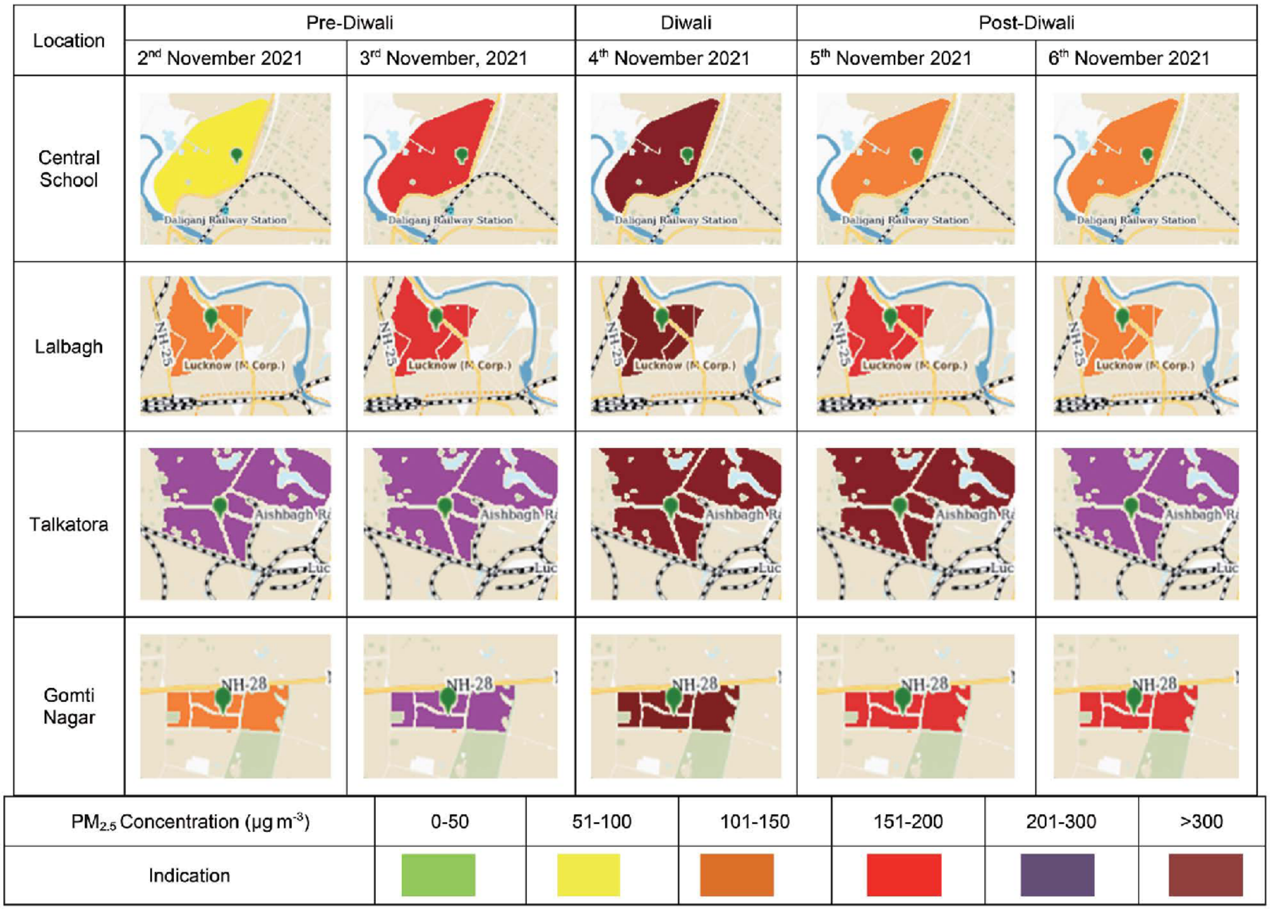

Fig. 3. Map indicating $PM_{2.5}$ concentrations.

3. RESULTS AND DISCUSSION

3. 1 Variation in Particulate Concentration

The hourly variation in the concentration showed that on Diwali day, i.e., 4 November 2021 the $PM_{2.5}$ value was as high as 262 μg m^{-3} around 22:00 hours and continued to rise till the next day with the maximum value obtained on 5 November being 900 μg m^{-3}, as reported from Central School monitoring station. Similarly from Gomti Nagar highest $PM_{2.5}$ value obtained on Diwali day was 538 μg m^{-3} around 23:00 hours. Post-Diwali day the highest concentration of $PM_{2.5}$ was 519 μg m^{-3}. Areas belonging to the old part of the city witnessed higher variations in concentrations as $PM_{2.5}$ crossed the 900 μg m^{-3} mark, as reported in Lalbagh and Talkatora areas. The higher particulate concentrations in these areas may also be attributed to vehicular exhaust, garbage burning and industrial emissions. $PM_{2.5}$, or fine particles, can remain airborne for longer periods, travel hundreds of miles and tend to deposit on the ground. Fig. 3 presents the variation in concentrations of $PM_{2.5}$. The colour-coded area signifies the relative $PM_{2.5}$ concentrations around the monitoring sites mentioned. The PM_{10} concentrations also remained very high on Diwali and post-Diwali days. The PM_{10} concentration on 5th November reached up to 911 μg m^{-3} and 955 μg m^{-3} respectively in Lalbagh and Talkatora areas. Due to the turbulent mixing of particles through direct contacts, particulates react with gaseous and non-gaseous molecules, creating aerosols in the ABL, and dispersion is extremely fast in vertical and horizontal directions. As a result, during Diwali, the concentration of particulates increased significantly, resulting in smog clouds and reduced visibility. Acute respiratory sickness and inflammatory reactions following Diwali confirm the variance in boundary level dynamics caused by higher concentrations of particulates in lower as well as boundary level atmospheres.

3.2 Variation in Gaseous Concentration

The smoke produced by firecracker burning also elevates the level of gaseous pollutants including SO_2, NO_2, CO, CO_2, O_3 etc. as shown by Chatterjee *et al.* (2013). The concentration of emitted pollutants is dependent on the chemical composition. The atmospheric boundary layer (ABL), which accounts for 10% of the troposphere, is heavily influenced by terrestrial activities. During the day, unstable stratifications rise as a result of temperature and radiation processes. During the night, due to surface cooling, stable stratifications emerge primarily as a result of turbulence, wind speed, and depth. Ravindra *et al.* (2003) observed that the concentration of SO_2 during Diwali increased 10 times, whereas PM_{10} and NO_2 increased more than twice, in comparison to control days. The concentration of SO_2 reached 98.16 µg m^{-3} post-Diwali day as compared to 46.8 µg m^{-3} observed on the Diwali day as reported from Talkatora station. The highest concentration for NO_2 was found to be 202.68 µg m^{-3} on Diwali day as reported from the Central school monitoring station and post-Diwali concentration reached up to 175.3 µg m^{-3}. The highest average concentrations of CO were reported from Lalbagh and Talkatora stations on Diwali day being 2.82 mg m^{-3} and 2.43 mg m^{-3} and the highest hourly concentrations of the pollutant reported from the same stations were 5.59 and 6.22 mg m^{-3}. Trace gases such as CO, NOx, SO_2 and O_3 may lead to dense clouds of smoke as reported by Man-

Table 2. 24 hr. Average concentrations of $PM_{2.5}$ and PM_{10}.

Date	$PM_{2.5}$ (µg m^{-3})	PM_{10} (µg m^{-3})
	Talkatora	
2/11/2021	143.45	421.26
3/11/2021	218.75	504.78
4/11/2021	228.22	315.65
5/11/2021	244.89	410.03
6/11/2021	211.05	358.22
	Central School	
2/11/2021	69.95	154.81
3/11/2021	77.15	160.54
4/11/2021	103.61	216.26
5/11/2021	190.34	200.01
6/11/2021	84.72	182.72
	Lalbagh	
2/11/2021	113.13	229.12
3/11/2021	116.42	236.87
4/11/2021	221.47	217.91
5/11/2021	213.00	306.85
6/11/2021	72.52	295.82
	Gomtinagar	
2/11/2021	81.05	113.84
3/11/2021	90.5	121.08
4/11/2021	145.84	189.45
5/11/2021	157.66	357.77
6/11/2021	118.63	174.25

Table 3. 24 hr. Average concentrations of SO_2, NO_2, CO, O_3, C_6H_6 and $C_6H_5CH_3$.

Date	Central School						Lalbagh					
	SO_2 (µg m^{-3})	NO_2 (µg m^{-3})	CO (mg m^{-3})	Ozone (µg m^{-3})	Benzene (µg m^{-3})	Toluene (µg m^{-3})	SO_2 (µg m^{-3})	NO_2 (µg m^{-3})	CO (mg m^{-3})	O_3 (µg m^{-3})	Benzene (µg m^{-3})	Toluene (µg m^{-3})
02/11/21	3.71	109.66	0.99	44.32	4.02	8.49	6.20	61.96	2.99	20.57	19.91	11.43
03/11/21	3.44	106.60	1.12	50.71	4.68	11.27	5.71	65.17	3.19	31.73	4.50	9.24
04/11/21	9.40	100.32	1.20	45.22	6.55	14.83	15.64	56.98	2.82	38.71	5.61	11.46
05/11/21	10.42	91.24	1.60	42.83	6.31	12.66	12.50	51.98	2.50	37.30	2.25	3.96
06/11/21	6.75	57.14	1.70	66.22	6.34	12.72	12.46	45.54	2.32	50.05	1.35	4.00
Date	Gomtinagar						Talkatora					
	SO_2 (µg m^{-3})	NO_2 (µg m^{-3})	CO (mg m^{-3})	Ozone (µg m^{-3})	Benzene (µg m^{-3})	Toluene (µg m^{-3})	SO_2 (µg m^{-3})	NO_2 (µg m^{-3})	CO (mg m^{-3})	O_3 (µg m^{-3})	Benzene (µg m^{-3})	
02/11/21	25.22	44.27	1.10	43.41	30.95	99.35	14.83	94.46	1.00	47.44	14.50	
03/11/21	25.48	54.33	1.11	41.67	38.89	117.65	14.07	100.33	1.36	47.17	11.00	
04/11/21	25.75	52.19	1.12	33.78	34.33	105.20	17.51	72.27	2.43	51.15	6.00	
05/11/21	25.09	51.62	1.09	31.34	32.09	84.23	45.16	59.50	2.13	53.46	4.73	
06/11/21	25.51	28.03	1.11	45.43	20.00	52.73	16.81	46.93	1.35	80.91	2.31	

dal *et al.* (2011). The highest average concentration of O_3 was reported from Talkatora station where it reached up to 51.15 μg m^{-3} on Diwali day and the post-Diwali concentration reached up to 80.91 μg m^{-3}. The highest hourly concentrations of O_3 obtained from Talkatora, Central School, Lalbagh and Gomtinagar monitoring stations on Diwali day were 138.09, 120.19, 98.11 and 76.67 μg m^{-3} respectively. The surface ozone is controlled by solar radiation during the daytime, which during the night is chemically removed by nitrogen monoxides. The formation of surface ozone during Diwali has been attributed to firecracker burning. Average concentrations of the measured pollutants are given in Tables 2, 3. Hourly concentrations of the pollutants are given in Tables S1–S8.

3.3 Variation in BTEX's Concentration

Although prohibited by the government, the presence of organic compounds like benzene and toluene was marked around the Diwali period. Bretón *et al.* (2020) revealed that respiratory problems including acute bronchitis, heart ailments, and lung diseases have increased drastically due to high benzene concentrations which is been classified as a carcinogen. Average concentrations of toluene were low, however, as compared to pre-Diwali, higher values were obtained on Diwali day. From Lalbagh, the average reported concentration of toluene was 11.46 μg m^{-3} and from Central School station the reported average concentration was 14.83 μg m^{-3}. However, the highest average concentration of toluene reported from the Gomtinagar monitoring station was 105.2 μg m^{-3}. The high emissions may be associated not only with firecrackers but the vehicular load mainly buses and trucks throughout the day in the Gomtinagar area as it is situated on the outskirts of the city. The vehicular exhaust may involve the emission of unburned hydrocarbons due to incomplete combustion along with SO_2, NO_2 and CO. These primary pollutants react with atmospheric O_3 and form damaging secondary pollutants like benzene and toluene. They are toxic and genotoxic in photochemical reactions as reported previously (Adamović, 2013).

3.4 Variation in AQI

According to USEPA (2014), the Air Quality Index (AQI) is a tool to disseminate qualitative information on air quality (good, satisfactory moderately polluted, poor, very poor and severe). Air Quality Index denotes the health and quality of ambient air and how polluted it may get in the coming future. AQI prediction may help in the forecast of health concerns to be experienced within a few hours or days of exposure for different target groups for a particular city. In the present study, AQI was recorded during the Diwali period for PM_{10}, $PM_{2.5}$, SO_2 and NO_2. The hourly AQI values of $PM_{2.5}$ and PM_{10} reached up to 999 on Diwali night and remained the same till the early hours post-Diwali. The highest AQI value for O_3 (76) was observed on 6^{th} November 2021 around 14:00 hours, reported from Talkatora station. The highest AQI value for NO_2 (101) was observed on Diwali night from the Central School station whereas the highest AQI value (50) for SO_2 was reported post-Diwali from Talkatora station. The average AQI values were the poorest and most hazardous for the Talkatora area (Table 4). The sudden fluctuation in the pollutants' level causes an inflammatory response and alveolar cytokine release associated with bronchospasm and impaired pulmonary function

Table 4. Average AQI values.

Date	$PM_{2.5}$	PM_{10}	NO_2	SO_2
Talkatora				
2/11/2021	201.4	276.91	43.12	7.00
3/11/2021	267.60	381.5	48.25	7.70
4/11/2021	253.25	244.04	33.41	6.80
5/11/2021	399.91	510.83	29.25	23.25
6/11/2021	262.33	280.16	27.33	8.54
Central School				
2/11/2021	147.75	100.29	54.12	1.80
3/11/2021	155.25	101.16	52.33	1.95
4/11/2021	189.08	136.66	47.71	6.30
5/11/2021	380.80	399.45	45.29	4.54
6/11/2021	160.95	109.66	37.87	3.17
Lalbagh				
2/11/2021	182.67	135.41	28.75	3.67
3/11/2021	182.08	142.25	29.25	3.17
4/11/2021	223.45	184.20	27.25	5.95
5/11/2021	359.04	496.83	24.46	6.25
6/11/2021	187.62	352.91	24.46	6.87
Gomtinagar				
2/11/2021	162.25	80.166	27.541	13.08
3/11/2021	210.37	86.08	25.08	13.20
4/11/2021	233.08	118.70	23.45	13.50
5/11/2021	258.70	311.58	25.20	13.54
6/11/2021	185.91	258.25	27.20	14.25

Fig. 4. Comparison in AQI values on Diwali night.

Ghio *et al.* (2000). Hourly variations in AQIs are given in Tables S9–S12. The AQI variation was also compared with Muzaffarnagar, Ghaziabad, Greater Noida, Bulandshahar and Delhi on Diwali night at 22:00 hours. These cities were selected because according to the Central Pollution Control Board (CPCB), the AQI in these cities has been very poor (Lawrence *et al.*, 2021) (Fig. 4).

3.4.1 Comparison of AQI with Previous Years during the Diwali Period

Owing to the hazardous effects associated with fireworks, the Supreme Court banned firecrackers in areas with good or moderate air quality. The increase in airborne pollution up to 29 times higher than the World Health Organisation (WHO) standards led the Supreme Court to ban the sale of fireworks in the national capital Delhi. This year the Uttar Pradesh government also banned the use of firecrackers in the National Capital Region (NCR) and in areas where the air quality is poor and allowed only the burning of green crackers for two hours in cities with moderate AQI, except Lucknow, Kanpur, Agra, Bulanshahr, Muzaffarnagar etc. [https://zeenews.india.com/india/up-govt-bans-sale-and-use-of-firecrackers-in-ncr-cities-where-air-quality-is-poor-2406633.html]. The current pandemic scenario has only added to the concern and it becomes utmost necessary to know whether the administrative warnings and bans have any impact on the population. The pre-Diwali, Diwali and post-Diwali AQI values of $PM_{2.5}$ obtained from the three monitoring stations were compared for the years 2016–2021 (Fig. 5). The range of AQI concerning $PM_{2.5}$ is given in Fig. 6. The data obtained from the Lalbagh, Talkatora and

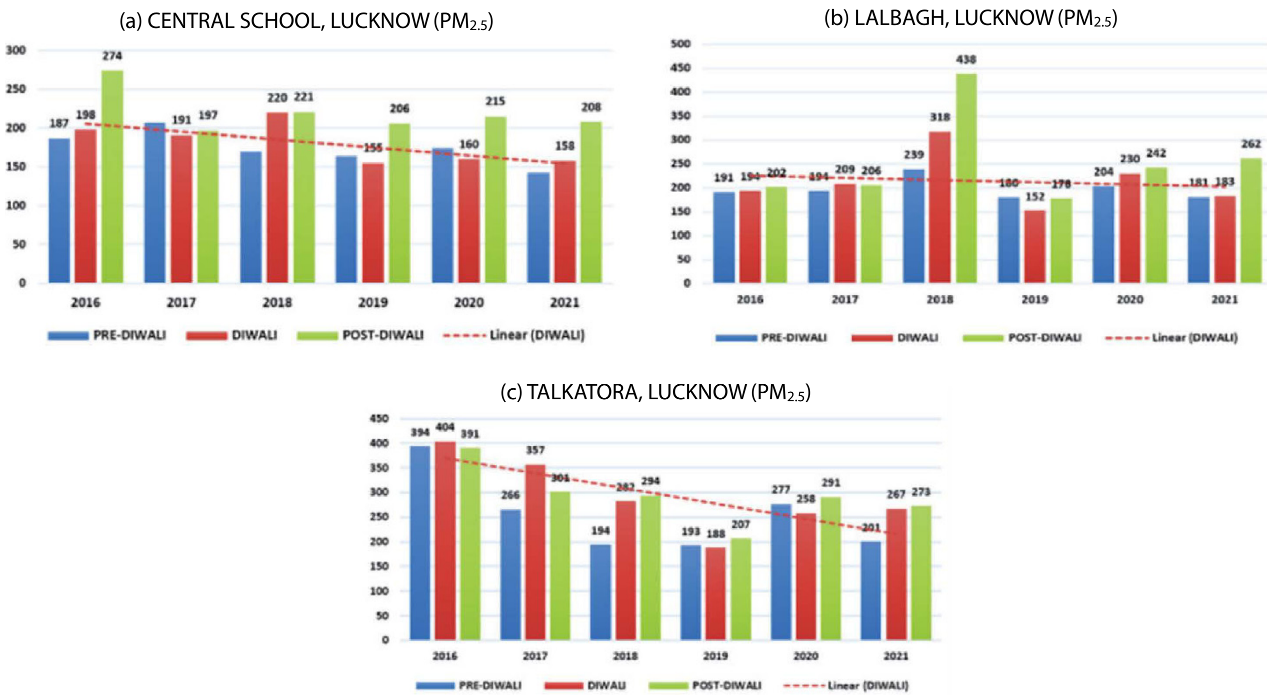

Fig. 5. Comparison between AQI values of $PM_{2.5}$ with last previous years (2016–2021).

Central School stations showed that although the values remained high this year as well, a slightly decreasing trend was seen in the AQI which is a good sign. It was found that the AQI values remained quite high post-Diwali every year, which may be assisted by several other factors. The decreasing trend may be due to the spreading of awareness among the masses through social media, television and radio etc. A recent survey-based study has also revealed that 2 in every three households in India have acknowledged not burning firecrackers during Diwali and 42% of the households welcomed the ban imposed by the government. However, 53% of households said no restrictions should be imposed on cracker burning as they don't associate it with air quality worsening. In many north Indian cities, the AQI has already crossed the 300 mark at the onset of winters [https://theprint.in/environment/2-in-3-families-wont-burn-crackers-this-diwali-but-53-dont-support-ban-says-survey/760848/]. In the wake of the COVID-19 pandemic, the sale of the firecrackers also dipped this year. The pandemic has caused the closure of many firecracker manufacturing units. Raw material costs have increased by 40 per cent. The fear of the third COVID-19 wave and cracker ban last year has left many traders hesitating to buy the product [Indiatoday.in/India/story/sivakasi-

Fig. 6. Range of AQI with respect to $PM_{2.5}$.

tamil-nadu-firecrackers-industries-diwali-pollution-1870265-2021-10-28]. Fig. 5a-c represent the variation in AQI during the Diwali period over six years. Although the AQI improved this year on Diwali day, post-Diwali higher

Table 5. Average meteorological data.

Date	Central School						Lalbagh					
	Temp (°C)	RH (%)	WS ($m\ s^{-1}$)	WD (deg)	SR ($W\ m^{-2}$)	BP (mm Hg)	Temp (°C)	RH (%)	WS ($m\ s^{-1}$)	WD (deg)	SR ($W\ m^{-2}$)	BP (mm Hg)
2/11/21	20.7	62.15	0.33	198.87	54.46	758.42	23.5	58.93	0.39	178.68	66.15	757.39
3/11/21	20.4	70.60	0.39	171.98	53.11	758.13	22.7	66.94	0.34	203.96	62.93	757.01
4/11/21	20.8	77.29	0.42	92.709	52.39	757.25	22.9	69.98	0.35	243.69	60.01	756.23
5/11/21	20.9	73.22	0.21	150.68	51.21	756.52	22.1	64.74	0.20	210.64	54.24	755.48
6/11/21	20.1	65.06	0.22	124.90	50.16	755.41	20.4	56.89	0.55	239.96	60.83	754.19
Date	Gomtinagar						Talkatora					
	Temp (°C)	RH (%)	WS ($m\ s^{-1}$)	WD (deg)	SR ($W\ m^{-2}$)	BP (mm Hg)	Temp (°C)	RH (%)	WS ($m\ s^{-1}$)	WD (deg)	SR ($W\ m^{-2}$)	BP (mm Hg)
2/11/21	23.6	51.51	1.24	215.19	94.55	751.09	23.37	57.61	0.75	122.72	87.17	757.31
3/11/21	23.5	55.82	0.93	222.83	95.48	751.02	23.37	62.71	0.78	143.97	87.94	756.79
4/11/21	23.5	60.72	0.78	176.82	95.80	751.24	22.85	68.64	0.82	245.52	88.08	756.12
5/11/21	23.5	58.60	0.72	164.95	93.61	751.34	22.97	63.97	0.79	199.68	79.45	755.33
6/11/21	22.8	55.68	0.79	156.17	90.26	751.37	22.06	57.37	0.86	251.43	83.07	754.33

Temp = Temperature
RH = Relative humidity
WS = Wind speed
WD = Wind direction
SR = Solar radiation

AQI values were obtained for both PM_{10} and $PM_{2.5}$ as compared to last year. The AQI for SO_2 and NO_2 were higher as compared to last year, however not in the hazardous category (Table 5). The lower AQI values post-Diwali in 2020 may be due to the post-Diwali rainfall (3.1–4.4 mm) in Northern Indian cities which may be responsible for the scrubbing and washout effect as suggested by Lawrence *et al.* (2020). The average AQI of $PM_{2.5}$ gradually decreased as compared to last year.

3.5 Variation in Particulate Concentration during Diwali Period in 2020 and 2021

A comparison was done for the concentration of PM_{10} and $PM_{2.5}$ obtained from three monitoring stations viz. Talkatora, Central School and Lalbagh for the years 2020 and 2021 to study the variation (Figs. 7, 8). High post-Diwali concentrations were obtained for the previous and the current year. The average concentration of $PM_{2.5}$ was higher in 2020 on Diwali day as the reported concentration for Talkatora (257.62 $\mu g\ m^{-3}$) and Central School (151.46 $\mu g\ m^{-3}$) whereas on Diwali day in 2021 the average values were 197.34 and 100.43 $\mu g\ m^{-3}$ respectively. The average concentration reported from Lalbagh increased marginally as compared to 2020 with the reported value of 205.3 $\mu g\ m^{-3}$. It has been found that the burning of firecrackers may lead to undesirable mass loading of $PM_{2.5}$, and associated chemicals like elemental carbon, organic carbon, water-soluble carbon and trace gases etc. which worsens the ambient air quality for a long time as reported by Kotnala *et al.* (2021). The comparison in AQI values is given in Table S13.

3.6 Association with Meteorological Parameters

Venkatachalappa *et al.* (2003) suggested that pollutants while getting diffused are moved downwind. Hence the people living adjacent to such polluted areas may also be affected by the area source pollution. Thereby it becomes important to determine the distribution of pollution in urban areas the wind flow and wind direction may play a crucial role in the dispersion of pollution. The wind flow may vary differently in different regions generating mesoscale wind which influences the urban pollution pattern as reported earlier (Dilley *et al.*, 1971). To assess the impact of meteorological parameters on pollution mixing and dispersion including the wind profile, temperature, relative humidity, solar radiation and atmospheric pressure were recorded from all four monitoring stations on the CPCB website. The wind speed was

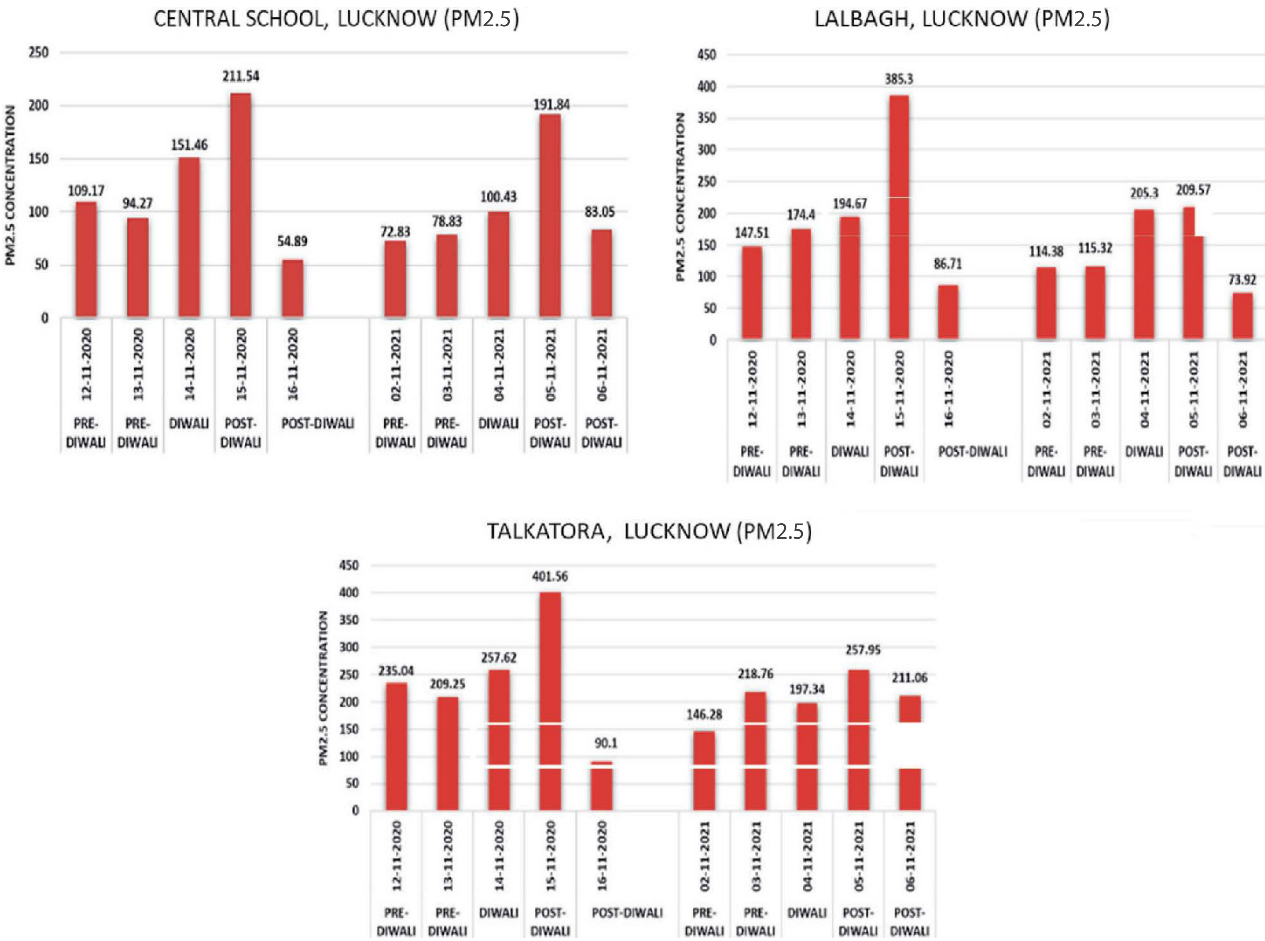

Fig. 7. Comparison between average concentrations of $PM_{2.5}$.

between 1 and 0.2 m s^{-1}. Mostly the wind flowed in the southeast direction. The highest variation in wind speed was obtained from Gomtinagar station where the speed varied between 0.7–1.2 m s^{-1}. Low wind speed results in a decrease in boundary layer height, making the atmospheric conditions unfavourable for the dispersion and dilution of pollutants. It was observed that during the night time wind speed decreased as compared to daytime. The decrease between the day and night wind speed was most prominent in the Lalbagh area where the wind speed was between 0.3–1.0 m s^{-1} (day) and 0.08–0.1 m s^{-1} (night). It is assumed that the pollutants are emitted at a constant rate from the area source and spread within the mixing layer adjacent to the earth's surface where mixing takes place as a result of turbulence and convection motion. The relative humidity might also have contributed to the slow dispersion of pollutants. During the daytime, the relative humidity was found to be between 45–50% and during the night time reached between 60–90%. A previous study reported low relative humidity of 42% in the daytime which increased up to 63% at night-time during the Diwali period and the meteorological factors favoured the pollutant concentration in the environment as reported by Ganguly *et al.* (2019). The average day temperature at all four monitoring stations ranged between 26–29°C, whereas the temperature during the night dipped and was between 18–20°C. The hazy atmospheric conditions at the onset of winters have become a major public concern as it leads to low visibility. Zhang *et al.* (2014) suggested that the weakening of the monsoon leads to calmer winds and rather stagnant weather conditions leading to haze days. Similarly, the festival of Diwali is celebrated at the onset of the winter season, when the monsoon withdraws its activity and similar meteorological conditions persist. The low visibility is generally due to the high concentration of fine

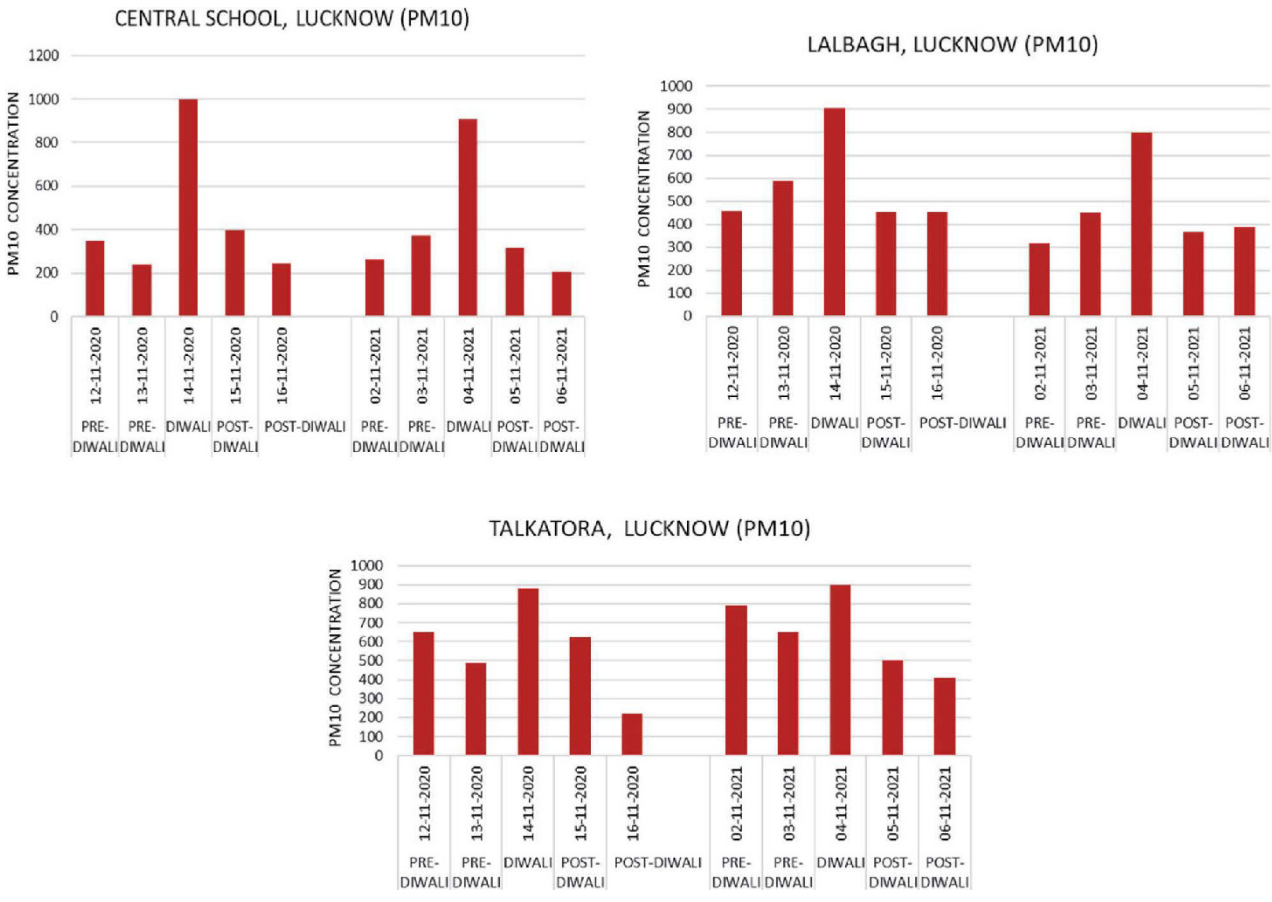

Fig. 8. Comparison between average concentrations of PM_{10}.

particulate matter. Extensive studies have been carried out in China to establish a correlation between climate conditions and haze in China. Zhang *et al.* (2014) studied the meteorological parameters including ground-level temperature, wind speed, wind direction, relative humidity and solar constant (W m^{-2}). The highest solar constant was observed at Gomtinagar station, with average values of 438.25, 450 and 460 W m^{-2} for pre-Diwali, Diwali and post-Diwali days. The meteorological conditions (low wind speed, declining temperature, lowered night-time boundary layer height, etc.) during the Diwali period might have led to the unfavourable build-up of atmospheric pollutants close to the surface layer. Table 5 represents the average meteorological data and Fig. 9 represents the wind profile of Lucknow city.

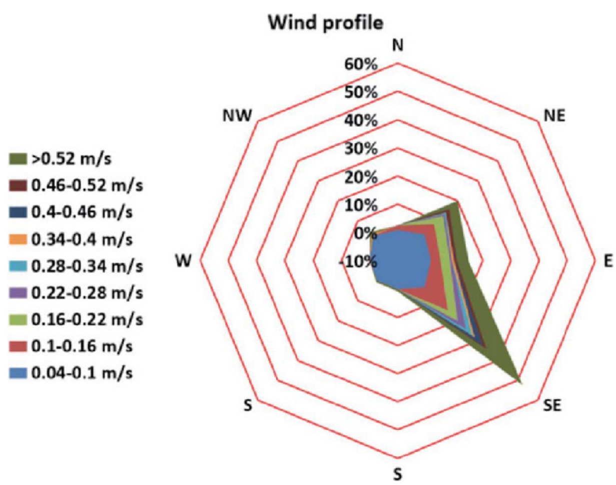

Fig. 9. Wind profile of Lucknow city during the study period.

3.7 Multivariate Analysis

To examine the effect of firecracker burning and lightning on air pollution, we established specifications that link these variables together. We estimated the parameters of the specifications using the ordinary least squared

(OLS) regression model where the variable of interest is the Diwali Dummy (DD) which takes a value of one for Diwali night (23:00 hours on 4 November 2021 to 8:00 am on 5 November 2021) and zero otherwise. We kept track of the temperature and humidity of the surrounding areas where the pollution was measured. With these control variables, we estimated the following OLS regression model, represented by Equation 9:

$$PM_{2.5} = \beta_0 + \beta_1 \times \text{Temp} + \beta_2 \times \text{Humidity} + \beta_3 \times \text{DD} + \varepsilon \quad (9)$$

where the dependent variable, $PM_{2.5}$, is the concentration of particulate material in the air and is a measure of pollution. where the dependent variable, $PM_{2.5}$, is the concentration of particulate material in the air and is a measure of pollution. In the above equation, β_0, β_1, β_2, and β_3 are the regression parameters and ε is the stochastic error term. A *P*-value of less than 0.01 for the regression parameter indicates that the related variable is statistically at less than one per cent level. In Table 6 we have reported the results for specification (1) for four locations in the city of Lucknow namely Gomtinagar, Central School, Talkatora and Lalbagh. The coefficient of the DD is positive and statistically significant at less than 1% level for all four locations. These results suggested that on Diwali night there was an increase of 204, 386, 344 and 341 in the $PM_{2.5}$ concentration in the Gomtinagar, Central School, Talkatora and Lalbagh areas respectively, thereby concluding that the use of firecrackers on Diwali night resulted in a significant increase in air pollution.

3.8 Meteorological Parameters and Their Correlation with Particulate Matter

Meteorological parameters are one of the important factors to influence urban air quality. Among them, temperature, relative humidity and wind speed and direction are considered major factors because they may affect the dispersion process, removal mechanisms and formation of atmospheric particles thus, playing a significant role in controlling the concentrations of air pollutants. To establish the relationship between the different metrological parameters and the pollutants released during the burning of firecrackers during Diwali, the Correlation Coefficient method was used via Microsoft Excel. The place of data recording was chosen as Gomti Nagar since large variations especially in the case of particulate matter or the chief pollutants were seen in that particular area.

The correlation coefficient (ρ) is a measure that determines the degree to which the movement of two different variables is associated. The possible range of values for the correlation coefficient is −1.0 to 1.0. A value of zero indicates that there is no relationship between the two variables. The formula used for the calculation of the correlation coefficient via excel is done using the function = CORREL (array 1, array 2), where the particulate matter either $PM_{2.5}$ or PM_{10} consists of array 1 while supposedly the meteorological parameters temperate, humidity and wind speed are taken as array 2 respectively.

There is a negative correlation seen in the case of temperature and particulate matter. Therefore it is evident from the given data that as the temperature lowers the concentration of particulate matter increases (Fig. 10). During the measurement periods, $PM_{2.5}$ and PM_{10} concentration values for nighttime and daytime quite similar although slightly higher during the night. This is because the particulate matter remains suspended at low temperatures i.e. night time and its concentration increases during the day due to the action of solar radiations acting on the particulate matter and decomposing it. Since the festival of Diwali coincided with November during which the weather is relatively cool, the burning of firecrackers especially during the night contributed significantly to increasing the concentration of pollutants and making its decomposition difficult at low temperatures.

A positive correlation was obtained between humidity and the concentration of particulate matter (Fig. 11). The value of positive correlation for $PM_{2.5}$ and PM_{10} increases

Table 6. Multivariate analysis.

Parameter	Gomtinagar			Lucknow Central			Talkatora			Lalbagh		
	Coefficient	*P*-value	T stat	Coefficient	*P*-value	T stat	Coefficient	*P*-value	T stat	Coefficient	*P*-value	T stat
Intercept	−17.6205	0.910189	−0.11305	−48.3818	0.739133	−0.3338	19.79825	0.939152	0.076501	260.9925	0.228169	1.211493
Temp	1.109091	0.793457	0.262428	1.533279	0.668269	0.42962	2.423383	0.728763	0.34761	−3.46111	0.578187	−0.55761
Humidity	3.078822	0.020196	2.355123	2.590271	0.017973	2.400279	2.626492	0.117834	1.575633	0.085872	0.949586	0.063364
DD	204.221	1.92E-06	5.015656	386.5316	1.31E-18	10.53258	343.8498	6.03E-14	8.541184	340.9215	3.7E-14	8.632923

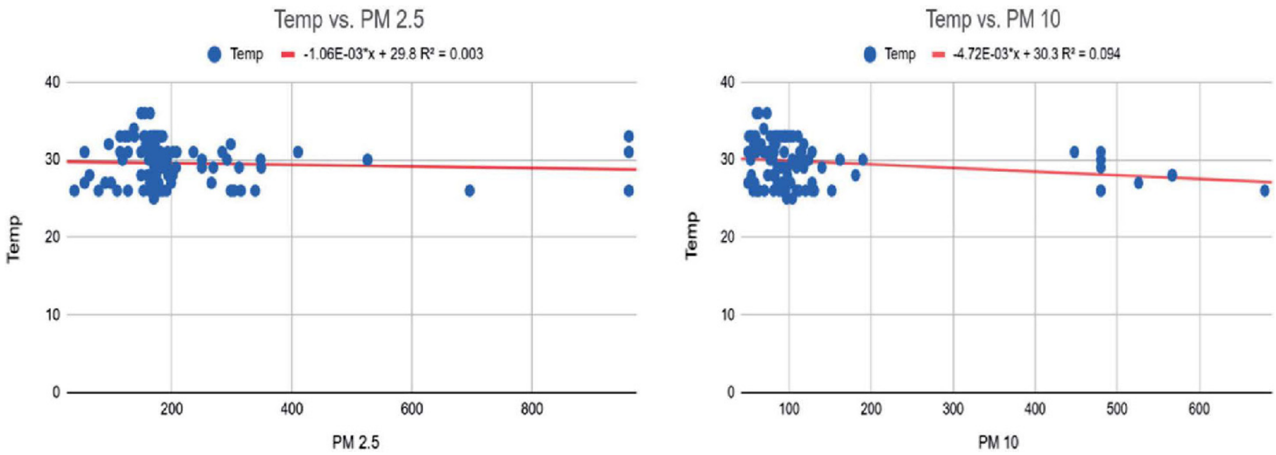

Fig. 10. Correlation graphs between Temperature vs $PM_{2.5}$ and PM_{10} showing the correlation value of −0.0572557008 and −0.3058730183 respectively.

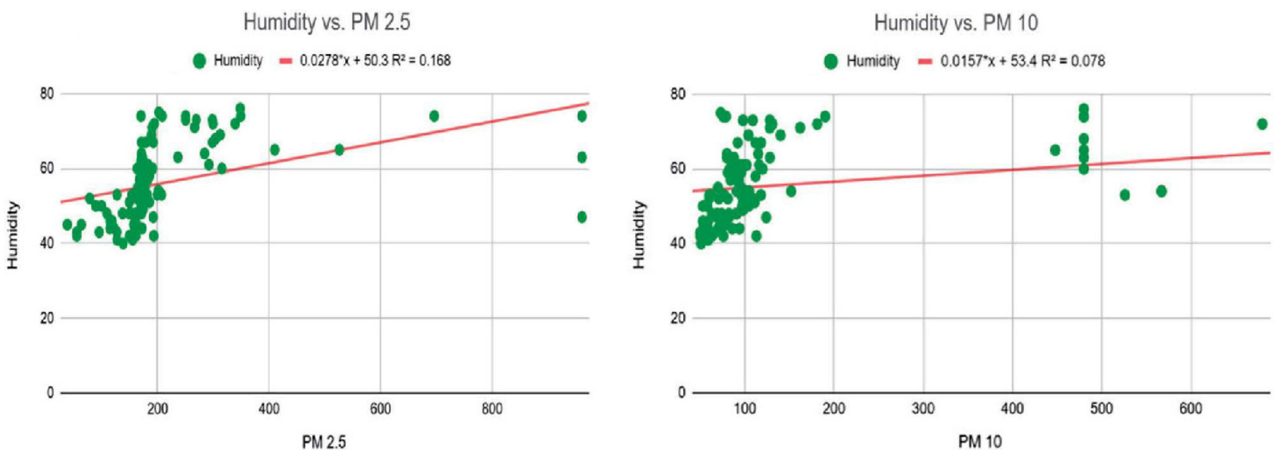

Fig. 11. Correlation graph between Humidity vs $PM_{2.5}$ and PM_{10} showing the correlation value of 0.4102661892 and 0.2791932001 respectively.

up to a certain threshold value, beyond which the correlation ceased. Humidity affects the natural deposition process of PM, because moisture particles adhere themselves to PM, increasing the atmospheric PM concentration. But as the humidity increases, as also seen in the graph, moisture particles eventually grow in size to a point where 'dry deposition' occurs, reducing $PM_{2.5}$ and PM_{10} concentrations in the atmosphere.

A negative correlation is seen in the case of wind speed and particulate matter (Fig. 12). There was significantly low speed seen during November and because Diwali falls in November, there was an increase in pollutants and low wind speed contributed greatly to the increase in the concentration of the pollutants.

3.9 Health Risk Assessment Associated with Benzene and Toluene

The emission of benzene and toluene is largely due to human activities including vehicular exhaust and stubble burning. The source of pollution may be ascertained by the ratio of aromatic compounds. In the present study, the toluene and benzene T/B ratio was calculated for Lalbagh, Central School and Gomtinagar stations from where significant concentrations of benzene and toluene were reported. The T/B ratio was found to be more than 1 on most of the monitoring days, indicating that toluene and benzene may be emitted from other sources as well including the mobile sources as suggested by Khoder (2007). The ratio less than 1 indicates that the emission

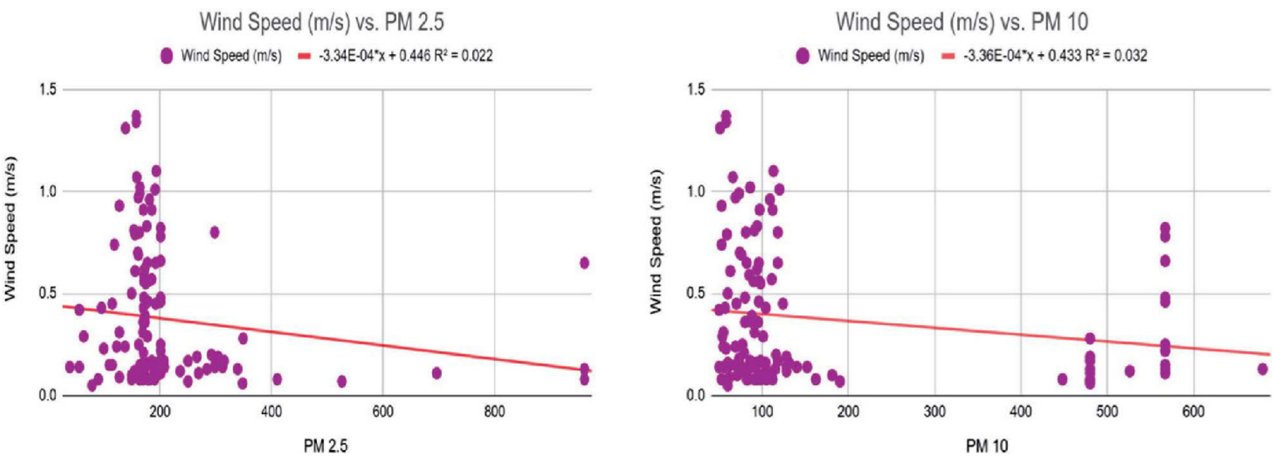

Fig. 12. Corelation between Wind speed vs $PM_{2.5}$ and PM_{10} showing the correlation value of −0.1482398226 and 0.1799183163 respectively.

Table 7. T/B ratios.

Date	Lalbagh			Central School			Gomtinagar		
	Benzene ($\mu g\ m^{-3}$)	Toluene ($\mu g\ m^{-3}$)	T/B ratio	Benzene ($\mu g\ m^{-3}$)	Toluene ($\mu g\ m^{-3}$)	T/B ratio	Benzene ($\mu g\ m^{-3}$)	Toluene ($\mu g\ m^{-3}$)	T/B ratio
02/11/2021	19.92	11.43	0.57	4.02	8.49	2.11	30.96	99.36	3.20
03/11/2021	4.5	9.24	2.05	4.68	11.27	2.41	38.89	117.65	3.02
04/11/2021	5.62	11.47	2.04	6.55	14.84	2.26	34.33	105.2	3.06
05/11/2021	2.25	3.96	1.76	6.32	12.67	2.00	32.09	84.23	2.62
06/11/2021	1.35	4.00	2.96	6.34	12.73	2.00	20.00	52.73	2.64

of benzene is from vehicular sources and toluene is released from both mobile and point sources, however, the value greater than 1 indicates that some other sources may be responsible for the release of benzene and toluene including the industrial emissions. On Diwali day, the highest T/B value (3.06) was obtained from the Gomtinagar station. A low T/B ratio indicates that the primary emission source is traffic Miller *et al.* (2011). The reaction of benzene and toluene with hydroxyl (OH) radicals decreases the toluene and benzene concentrations as deduced by Miller *et al.* (2011), showing that low ambient T/B ratios are due to emission from distant sources and may have degraded over time, whereas higher T/B ratios are obtained from fresh vehicular emissions. Table 7 represents the T/B ratios at the three monitoring stations.

3. 10 Questionnaire Survey Results

A questionnaire survey was done with 51 medical doctors post-Diwali to know the issues reported by patients related to the exposure to Diwali pollution. Of the total doctors surveyed, 33% (n = 35) practised general medicine and 21% (n = 11) were pulmonologists, whereas five (9.8%) of them were cardiologists and five (9.8%) were paediatricians. A wider range of specialists was selected from across the city to know different symptoms and problems reported by the patients during the Diwali period. Approximately 50–75% rise was seen in the number of patients post-Diwali as reported by 37.3% (n = 19) doctors. 58.8% of the cases were related to respiratory issues as reported by as thirty doctors, followed by allergic reactions (41.2%), as reported by 21 doctors. Cases of asthma were also reported by 25.5% (n = 13) of doctors. The symptoms were found prevalent in adults (84.3%) as reported by 43 doctors, followed by children between 5–13 years (23.5%) and infants (11.8%). There is a greater possibility of the PM_{10} going deep into the lungs. During fireworks burning there is a greater possibility of their carrying a complex mixture of toxic pollutants released fireworks. The effect of PM_{10} on pediatric and respiratory diseases following fireworks burning has been explored showing a decrement in peak expiratory flow rates in children (Hoek *et al.*, 1998).

The common symptoms observed were shortness of breath (39.2%), stubborn cough (39.2%), uneasiness (37.3%), congestion (37.3%) and blocked or runny nose (35.3%). Itching in the eyes and skin (33.3%) was also reported. Particulate matter and SO_2 are primarily responsible for aggravating respiratory conditions like asthma and bronchitis as studied by Hatamabadi *et al.* (2013). Short-term pollution exposure also leads to exacerbation of bronchitis, asthma and other symptoms which cause-related an increase in emergency visits to hospitals as reported by Sharma *et al.* (2015). The National Morbidity and Mortality Study (NMMAPS) has confirmed a relationship between daily mortality and particulate matter and the reduction in the concentration of PM_{10} also reduces hospitalization related to respiratory issues. An increase of 10 µg m^{-3} in the concentration of PM_{10} may lead to premature death, aggravated asthma, emergency hospital admissions and aggravated respiratory issues COEHA (1996). Susceptible individuals like elderly people and those having any pre-existing heart and lung disease are more at risk upon PM_{10} exposure. A high concentration of SO_2 absorbed in the particulate matter can be transported deep down in the lungs having a higher retention time. SO_2 being acidic can cause severe damage to lung tissues. Sulphates have a gruesome health impact and stay in the air for a long time (Dockery *et al.*, 1993). An exposure of ten minutes of SO_2 present in a concentration above 1.32 mg m^{-3} can lead to short-term asthma manifestation. Like SO_2, NO_2 is also a lung irritant capable of generating biochemical changes and lung damage upon acute and chronic exposure Hoek *et al.* (1998). A significant association has been found between an emergency hospital visit and high levels of SO_2 and NO_2 and exacerbation of chronic bronchitis (Ponka and Virtanen, 1994). Even healthy people can have health impacts from polluted air including respiratory or breathing issues and may have difficulty during exercise or outdoor activities. Cardiovascular problems were also diagnosed by 18.4% (n = 9) doctors. High air pollution levels can cause immediate health problems including aggravated cardiovascular and respiratory illness and added stress to the heart and lungs as reported by Daga *et al.* (2019). Table 8 summarizes the survey results.

Table 8. Questionnaire survey results.

Area of medicine expertise		
Expertise	Percentage	Number of respondents
Pediatrics	9.8	5
Cardiology	9.8	5
Gynecology	5.9	3
Pulmonology	21.6	11
Neurology	4	2
General medicine	33.4	35
Orthopaedic	4	2
Dentistry	4	2
Dermatologist	2	1
Raprosopic surgeon	2	1
Surgery	4	2
Approximate rise in number of patients post-Diwali		
Rise	Percentage	Number of respondents
Less than 25%	25.5	13
25–50%	31.4	16
50–75%	37.3	19
More than 75%	5.9	3
No rise	0	0
Patients visiting post Diwali were usually diagnosed with		
Disease	Percentage	Number of respondents
Asthma	25.5	13
Tuberculosis	9.8	5
Respiratory problems	58.8	30
Allergies	41.2	21
Sinusitis	17.6	9
Cardiovascular problems	19.6	10
Hormones imbalance	2	1
The symptoms were more prevalent in		
Age group	Percentage	Number of respondents
Infants	11.8	6
Children aged between 5–13	23.5	12
Adults	84.3	43
The symptoms were more common in		
Gender	Percentage	Number of respondents
Males	49	25
Females	51	26
What are the symptom(s) reported by patients post Diwali		
Symptom	Percentage	Number of respondents
Shortness of breath	39.2	20
Stubborn cough	39.2	20
Blocked/runny nose	35.3	18
Congestion	37.3	19
Fever and chills	27.5	14
Wheezing	29.4	15
Uneasiness	37.3	19
Nausea	25.5	13
Itching in eyes and skin	33.3	17
Sinus infection	27.5	14
Migraine	15.7	8
Muscle pain	17.6	9
Dry skin/scalp or dermatitis	23.5	12
Hoarse voice	13.7	7
Dry/sore throat	19.6	10

3.11 COVID-19 Mortality and Association with Fine Particulate Concentration

Ray *et al.* (2020) reported that COVID-19 spread may be spread adversely by ambient air pollution, particularly in developing countries like India. The $PM_{2.5}$ level may be associated with the death rate, and countries like India with high particulate concentrations are at greater risk. Oxidising pollutants usually hamper the lung efficiency and adsorption of the virus can occur on particulate matter causing long-range transportation and the virus can travel through the air and remain suspended for a long time as reported by Fiorillo *et al.* (2020). A 10-μg m^{-3} rise in the concentration of $PM_{2.5}$ is associated with a 2.24% rise in COVID-19 cases. During the preceding decade, particulate matter pollution in cities across the Indian subcontinent, including Lucknow, increased alarmingly. Particulate matter deposited on the skin and in the nasal tube may be the source of allergies, skin diseases, and respiratory issues. The most severe health risks come from fine particles, which can enter the lungs and accumulate. Lung tissue fibrosis can occur as a result of PM build-up as reported by Shubhankar *et al.* (2016). Individuals with impaired lung function are more likely to experience severe breathing and blood O_2 saturation-related difficulties, which frequently need hospitalisation and ventilator treatment, and so air pollution has had an indirect role in COVID-19 mortality as reported by Kumar *et al.* (2021). To assess a probable relationship between the $PM_{2.5}$ concentration with COVID-19 related mortality in the Lucknow region, a scatter plot was plotted between the mortality and $PM_{2.5}$ concentration during the second wave of the pandemic for 1 April 2021 to 31 May 2021. For the plot, the equation y = mx+c was used where m represents the slope and c represents the y-intercept (Fig. 13). The positive and negative values of m represent the positive and negative trends, whereas a zero value represents no trend at all. A positive R-squared value corresponding to a 5.49% mortality rate was obtained with the respect to the concentration of $PM_{2.5}$. Although the correlation was weak, it must be kept in mind that during the considered period complete lockdown was imposed due to which air quality improved substantially. However, in long run, the impact of the $PM_{2.5}$ concentration on COVID-19 related susceptibility must be studied for a clear elucidation.

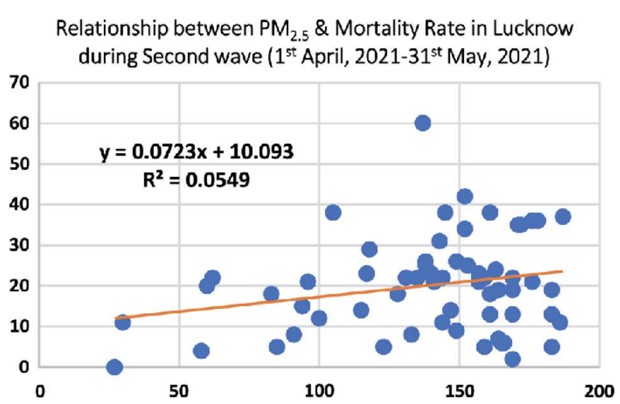

Fig. 13. Regression plot between $PM_{2.5}$ concentration and COVID-19 mortality.

4. CONCLUSION

The present study conducted in Lucknow city reveals that the use of firecrackers during Diwali is a significant source of particulate matter ($PM_{2.5}$, PM_{10}) and other gaseous pollutants in ambient air, affecting urban air quality. The data collected from four different CPCB monitoring stations also indicated that along with firecracker emission, secondary emission sources like industrial emissions, and vehicular exhaust facilitated by favourable meteorological conditions like wind speed, humidity and temperature assist the short-term variation in pollutants' concentration and AQI. Other pollutants which made their presence felt were benzene and ethylbenzene which need further exploration to ascertain their exact sources. The questionnaire survey results also indicated that the short-term variation in concentrations led to hospital visits as the number of cases related to respiratory issues increased post-Diwali. However, a positive finding that was unfolded is that a declining trend was observed in the rise of concentrations as compared to the previous five year's data. This could be due to public awareness regarding the hazardous effects of firecracker burning and the current pandemic making people more conscious about their well-being and health.

CONFLICT OF INTEREST

None declared.

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REFERENCES

Adamović, D., Dorić, J., Vojinović-Miloradov, M. (2013) BTEX in the Exhaust Emissions of Motor Vehicles. In Causes, Impacts and Solutions to Global Warming (Dincer, I., Colpan, C., Kadioglu, F. Eds), Springer, New York, NY, pp. 333–342. https://doi.org/10.1007/978-1-4614-7588-0_21

Ambade, B. (2018) The air pollution during Diwali festival by the burning of fireworks in Jamshedpur city, India. Urban Climate, 26, 149–160. https://doi.org/10.1016/j.uclim.2018.08.009

Attri, A.K., Kumar, U., Jain, V.K. (2001) Microclimate: Formation of ozone by fireworks. Nature, 411(6841), 1015.

Barman, S.C., Singh, R., Negi, M.P.S., Bhargava, S.K. (2008) Ambient air quality of Lucknow City (India) during use of fireworks on Diwali festival. Environmental Monitoring and Assessment, 137, 495–504. https://doi.org/10.1007/s10661-007-9784-1

Barnett, A.G., Williams, G.M., Schwartz, J., Nekker, A.H., Best, T.L., Petriescgevsjt, A.L., Simpson, R.W. (2005) Air Pollution and Child Respiratory Health: A CaseCrossover Study in Australia and New Zealand. American Journal of Respiratory and Critical Care Medicine, 171, 1272–1278.

Bates, D.V. (1995) Adverse health impacts of air pollution-Continuing problems. Scandinavian Journal of Work, Environment & Health, 21, 405–411.

Betha, R., Balasubramanian, R. (2013) Particulate emissions from commercial handheld sparklers: evaluation of physical characteristics and emission rates. Aerosol and Air Quality Research, 13, 301–307. https://doi.org/10.4209/aaqr.2012.08.0208

Bretón, J.G.C., Bretón, R.M.C., Morales, S.M., Kahl, J.D.W., Guarnaccia, C., Severino, R.D.C.L., Marrón, M.R., Lara, E.R., Fuentes, M.D.L.L.E., Chi, M.P.U., Sanchez, G.L. (2020) Health Risk Assessment of the Levels of BTEX in Ambient Air of One Urban Site Located in Leon, Guanajuato, Mexico during Two Climatic Seasons. Atmosphere, 11, 165. https://doi.org/10.3390/atmos11020165

Chatterjee, A., Sarkar, C., Adak, A., Mukherjee, U., Ghosh, S., Raha, S. (2013) Ambient air quality during Diwali festival over Kolkata mega-city in India. Aerosol and Air Quality Research, 13, 1133–1144. https://doi.org/10.4209/aaqr.2012.03.0062

Chen, L.H., Knutsen, S.F., Shavlik, D., Beeson, W.L., Peterson, F., Ghamsary, M., Abbey, D. (2005) The Association between Fatal Coronary Heart Disease and Ambient Particulate Air Pollution: Are Females at Greater Risk? Environmental Health Perspectives, 113, 1723–1729.

Cheng, Y., Engling, G., He, K., Duan, F., Du, Z., Ma, Y., Liang, L., Lu, Z., Liu, J., Zheng, M., Weber, R.J. (2014) The characteristics of Beijing aerosol during two distinct episodes: impacts of biomass burning and fireworks. Environmental Pollution, 185, 149–157. https://doi.org/10.1016/j.envpol.2013.10.037

Clark, H. (1997) Air pollution from fireworks. Atmospheric Environment, 31, 2893–2894.

Croteau, G., Dills, R., Beaudreau, M., Davis, M. (2010) Emission factors and exposures from ground-level pyrotechnics. Atmospheric Environment, 44(27), 3295–3303. https://doi.org/10.1016/j.atmosenv.2010.05.048

Daga, M.K., Mawari, G., Bharali, D., Banker, H., Mehar, P., Saluja, P., Kumar, D., Kumar, D., Jha, M.K., Gargava, P. (2019) Assessment of the air quality and its impact on health and environment in India. Indian Journal of Medical Specialities, 10, 117–125. https://doi.org/10.4103/INJMS.INJMS_15_19

Dilley, J.F., Yen, K.T. (1971) Effect of a mesoscale type wind on the pollutant distribution from a line source. Atmospheric Environment, 6, 843–851.

Dockery, D., Pope, C.I., Xiping, X. (1993) An association between air pollution and morality in six US cities. New England Journal of Medicine, 329(24), 1753–1759.

Fiorillo, L., Cervino, G., Matarese, M., D'Amico, C., Giovanni, S., Paduano, V., Fiorillo, M.T., Moschella, A., La Bruna, A., Romano, G.L., Laudicella, R., Baldari, S., Cicciù, M. (2020) COVID-19 Surface Persistence: A Recent Data Summary and Its Importance for Medical and Dental Settings. International Journal of Environmental Research and Public Health, 17, 3132. https://doi.org/10.3390/ijerph17093132

Ganguly, N.D. (2009) Surface Ozone Pollution during the Festival of Diwali, New Delhi, India. Earth Science India, 2, 224–229.

Ganguly, N.D., Tzanis, C.G., Philippopoulos, K., Deligiorgi, D. (2019) Analysis of a severe air pollution episode in India during Diwali festival - A nationwide approach. Atmosfera, 32, 225–236. https://doi.org/10.20937/ATM.2019.32.03.05

Ghio, A.J., Kim, C., Devlin, R.B. (2000) Concentrated Ambient Air Particles Induce Mild Pulmonary Inflammation in Healthy Human Volunteers. American Journal of Respiratory Critical Care and Medicine, 162, 981–988. https://doi.org/10.1164/ajrccm.162.3.9911115

Hatamabadi, H.R., Tabatabaey, A., Heidari, K., Khoramian, M.K. (2013) Firecracker injuries during Chaharshanbeh Soori festival in Iran: A case series study. Archives of Trauma Research, 2, 46–49. https://doi.org/10.5812/atr.9250

Hoek, G., Dockery, D.W., Pope, A., Neas, L., Roemer, W., Brunkreef, B. (1998) Association between PM_{10} and decrements in peak expiratory flow rates in children: reanalysis of data from five panel studies. European Respiration Journal, 11, 1307–1311.

Holopainen, J., Kivimäenpää, M., Nizkorodov, S. (2017) Plant-derived Secondary Organic Material in the Air and Ecosystems. Trends in Plant Science, 22, 744–753. https://doi.org/10.1016/j.tplants.2017.07.004

Khoder, M. (2007) Ambient levels of volatile organic compounds in the atmosphere of Greater Cairo. Atmospheric Environment, 41, 554–566. https://doi.org/10.1016/j.atmosenv.2006.08.051

Kotnala, G., Kumar, M., Sharma, A.K., Dhaka, S.K., Gadi, R., Ghosh, S.C., Saxena, M., Sharma, S.K., Saha, A.R., Nautiyal, A., Sharma, A., Sharma, C., Kotnala, R.K., Mandal, T.K. (2021) Variations in chemical composition of aerosol during Diwali over mega city Delhi, India. Urban Climate, 40, 2021, 100991. https://doi.org/10.1016/j.uclim.2021.100991

Kulshrestha, U.C., Nageswara Rao, T., Azhaguvel, S., Kulshrestha, M.J. (2004) Emissions and Accumulation of Metals in the Atmosphere due to Crackers and Sparkles during Diwali Festival in India. Atmospheric Environment, 38, 4421–4425.

Kumar, D., Singh, A.K., Kumar, V., Poyoja, R., Ghosh, A., Singh, B. (2021) COVID-19 Driven Changes in the Air Quality: a Study of Major Cities in the Indian State of Uttar Pradesh. Environmental Pollution, 274, 116512. https://doi.org/10.1016/j.envpol.2021.116512

Lawrence, A., Abraham, A., Ali, F., Arif, S., Fatima, U., Fatima, S., Khan, T. (2021) Air Quality in Six Northern Indian Cities during Diwali 2020: The Real Tragedy in disguise. Asian Journal of Chemistry, 33, 909–918. https://doi.org/10.14233/ajchem.2021.23102

Liu, S., Knewski, D., Shi, Y., Chen, Y., Burnett, R.T. (2003) Association between gaseous ambient air pollutants and adverse pregnancy outcomes in vancouver. Environmental Health Perspective, 111, 1773–1778. https://doi.org/10.1289/ehp.6251

Mandal, P., Prakash, M., Bassin, J.K. (2012) Impact of Diwali celebrations on urban air and noise quality in Delhi City, India. Environmental Monitoring and Assessment, 184, 209–215. https://doi.org/10.1007/s10661-011-1960-7

Miller, L., Xu, X., Wheeler, A., Atari, D.O., Grgicak-Mannion, A., Luginaah, I. (2011) Spatial Variability and Application of Ratios between BTEX in Two Canadian Cities. Scientic World Journal, 11, 2536–2549. https://doi.org/10.1100/2F2011/2F167973

Ravindra, K., Mor, S., Kaushik, C.P. (2003) Short-term variation in air quality associated with firework events: A case study. Journal of Environment Monitoring, 5, 260–264.

Ponka, A., Virtanen, M. (1994) Chronic bronchitis, emphysema and low-level air pollution in Helsinki, 1987–1989. Environmental Research, 65, 207–217.

Ray, D., Salvatore, M., Bhattacharya, R., Wang, L., Du, J., Mohammad, S., Purkayastha, S., Haldar, A., Rix, A., Barker, D., Kleinsasser, M., Zhou, Y., Bose, D., Song, P., Banerjee, M., Baladandayuthapani, V., Ghosh, P., Mukherjee, B. (2020) Predictions, role of interventions and effects of a historic national lockdown in India's response to the COVID-19 pandemic: data science call to arms. Harvard Data Science Review, 2020. https://doi.org/10.1162/99608f92.60e08ed5

Sharma, S., Nayak, H., Lal, P. (2015) Post-Diwali morbidity survey in a resettlement colony of Delhi. Indian Journal of Burns, 23, 76–80. https://doi.org/10.4103/0971-653X.171662

Sharma, S., Zhang, M., Anshika, Gao, J., Zhang, H., Kota, S.H. (2020) Effect of restricted emissions during COVID-19 on air quality in India. Science of Total Environment, 728, 138878. https://doi.org/10.1016/j.scitotenv.2020.138878

Shubhankar, B., Ambade, B. (2016) Review on Composition: Emission Sources of RSPM, TSPM, Heavy Metals and Ions with Effect on Environment and Health. Research Journal of Chemistry and Environment, 20, 31–43.

Tao, Y., Mi, S., Zhou, S., Wang, S., Xie, X. (2014) Air pollution and hospital admissions for respiratory diseases in Lanzhou, China. Environmental Pollution, 185, 196–201. https://doi.org/10.1016/j.envpol.2013.10.035

Venkatachalappa, M., Khan, S.K., Kakamari, K.A.G. (2003) Time dependent mathematical model of air pollution due to area source with variable wind velocity and Eddy diffusivity and chemical reaction. Proceedings of Indian National Science Acadamy, 69, 745–758.

Verma, C., Deshmukh, D.K. (2013) The ambient air and noise quality in India during diwali festival: a review. Recent Research in Science and Technology, 6, 203–210.

Yasutake, A., Hirayama, K. (1997) Animal models. In Handbook of Human Toxicology (Massaro, E.J. Ed), CRC Press, Boca Raton, New York.

Yerramsetti, V.S., Sharma, A.R., Navlur, N.V., Rapolu, V., Dhulipala, N.S.K., Sinha, P.R. (2013) The impact assessment of Diwali fireworks emissions on the air quality of a tropical urban site, Hyderabad, India, during three consecutive years. Environmental Monitoring Assessment, 185, 7309–7325. https://doi.org/10.1007/s10661-013-3102-x

Zhang, R., Li, Q., Zhang, R. (2014) Meteorological conditions for the persistent severe fog and haze event over eastern China in January 2013. Science China Earth Sciences, 57, 26–35. https://doi.org/10.1007/s11430-013-4774-3