



## Research Article



# Short-term variability on particulate and gaseous emissions induced by fireworks during Diwali celebrations for two successive years in outdoor air of an urban area in Delhi, India

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Received: 23 September 2020 / Accepted: 18 November 2020 / Published online: 27 November 2020  
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## Abstract

This study was conducted at a traffic-congested residential area of Delhi, India, to assess the effect of firecrackers burning on air pollutants concentrations for two successive years 2017 and 2018. The temporal variation of air pollutants (PM<sub>10</sub>, PM<sub>2.5</sub>, PM<sub>1</sub>, NO<sub>2</sub>, SO<sub>2</sub>, inhalable, thoracic and alveolic particles) was assessed by doing diurnal monitoring of air pollutants five days before, after and on the day of Diwali. The increased level of PM was observed as 1.6–2.8 times high on Diwali as measured on pre and post-Diwali. The gaseous pollutants have also exhibited significant increase in pollution during late night hours of Diwali day. The higher level of pollutants has been observed during late night hours than evening hours.  $R^2 > 0.81$  has been observed between PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub> with inhalable, thoracic and alveoli particles, respectively. Although AQI was observed very high for both the sampling years, a significant reduction of 35%, 22% and 43% was observed in AQI during 2018 in comparison with 2017 during pre-Diwali, Diwali and post-Diwali, respectively. Such high significant variations were attributed to more stubble burning practices during 2017 and adverse meteorological conditions during 2018. The other factors like variation in the month of Diwali celebration, rules and regulations regarding burning of firecrackers during different years also play a significant contribution toward lowering the pollution level during 2018. Such high levels of particulate matter during Diwali episode have serious threats to human health.

**Keywords** Particulate matter · Gaseous pollutant · Diwali episode · Stubble burning · Meteorological conditions · Ambient air · Delhi

## 1 Introduction

The air quality of Delhi has been deteriorating day by day and the recent data suggests that it is the worst ranked city with fine particulate (PM<sub>2.5</sub>) air pollution throughout the world [63]; [49]. Various studies have found that in Delhi and its National Capital Region (NCR), vehicular exhaust, emission from industries, waste and biomass burning practices, and constructional activities account for the large amount of particulate, gaseous and toxic air pollutants [10, 41, 51]. This pollution load when gets accompanied by any episodic events such as the Diwali (Deepawali)

and stubble burning creates a disaster in the atmosphere [29, 61]. Diwali is one of the main religious festivals of the Hindus, celebrated every year in the month of October or November by lighting of lamps, diyas and candles, shopping practices, distribution of sweets, worship of goddess Laxmi and burning of fire crackers. During this festival, the burning of firecrackers has been gaining the criticism since a long time, as this practice is adding to the air and noise pollution on the Earth [19, 46]. The smoke produced by burning of fire crackers supplements the level of particulate matter, oxides of sulfur and nitrogen, carbon dioxide, heavy metals, volatile organic compounds and many other

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harmful chemical compounds [9, 61], [3], 5, 54, 15, 7]. It has been found that the smoke emitted by the bursting of certain crackers is said to be more harmful than that produced by factories and vehicles. The level of emission of these pollutants depends on the chemical composition of different fireworks and sparklers [30, 62, 65]. Since this festival has been celebrated just before the beginning of the winter season, the atmosphere during this time is misty with low wind speed and mixing height [21]. The smoke released by fire crackers gets trapped in the mist due to adverse meteorological conditions and causes the high rise in pollution level by impacting the environment severely. It has been also noticed that during this time the burning of stubble was carried out by nearest states of Delhi like Haryana and Punjab [27, 60]. Overall, the pollution from burning of firecrackers, stubble burning along with the simultaneous effects of adverse meteorological parameters results in worsening the air quality of Delhi and making Diwali as a major episodic event for creating air pollution in India.

It is evident that the higher levels of these pollutants and elevated air quality index (AQI) values are responsible for hazardous impacts (both short-term and long-term) on human health. The short-term effects include burning of eyes, problem in breathing, sneezing, cough, heaviness in upper respiratory system, fever, headache, insomnia, etc, while the long-term effects include respiratory diseases including asthma, bronchitis, bronchiolitis, cardiovascular effects, reduce in visibility, strokes, lung cancer, neurological problems, leukemia, reproductive disorders, etc. [1, 2, 55, 66], 43, 42, 34. Therefore, such short-term exposure to these pollutants especially particulate matter having aerodynamic diameter less than  $2.5 \mu\text{m}$  during Diwali episode is a serious matter of concern due to its negative health impacts [50]. A much higher exposure to these atmospheric pollutants has been observed by Delhi's during such episodic days. Such increased exposure has been directly linked with increased health problems. The health of human is affected negatively by such exposure and results in the increment in hospital admissions [16, 23, 25, 26]. Majority of the people during this time faces the problem of skin allergy, burning sensation in eyes, shortness of breath, choking of lungs, and discomfort in respiration, sneezing, headache, etc. The people who were already suffered from the adverse health problems like asthma, lung infection, asthmatic bronchiolitis, lung cancer, cardiopulmonary diseases are worst affected due to these episodic events [11, 24, 39, 44]. Along with the human being, the animals, birds and other living organisms have been also affected as badly due to air and noise pollution produced during the festival [32, 37].

Worldwide, different researchers have identified the effects of burning of fire crackers on ambient air pollution

levels during different festivals such as Independence day celebration in USA [52], Chinese Spring Lantern festival in China [7, 64], Taiwan's Lantern Festival [59], New Year's celebrations [18] and Diwali celebrations in India [30, 46]. In India also, various studies have been conducted for identifying the effect of firework activities during Diwali festival on ambient air quality. Very high level of particulate matter and gaseous pollutants have been reported during Diwali episode in different Indian cities including Lucknow [6], Delhi [53, 58], Kolkata [9, 56], Hyderabad [65], Agra [40] and Udaipur [62].

The present study has been designed to evaluate the levels of particulates ( $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ ,  $\text{PM}_1$ , inhalable (INH), thoracic (THO) and alveolic particles (ALV)) and gaseous pollutants ( $\text{SO}_2$  and  $\text{NO}_2$ ) during the Diwali episode and identify the effect of short-term degradation of air quality. This study is important as it identified the elevated levels of alveoli particles and  $\text{PM}_1$  which are very harmful for human respiratory and cardiopulmonary health and the data for which is very limited. Although various studies have been conducted on air quality status during Diwali, this study is important as it compares the levels of pollution during two consecutive years 2017–2018, along with the predominated effects of stubble burning and meteorological parameters collectively on these levels.

## 2 Materials and methods

### 2.1 Study site description

East Delhi, known as Trans Yamuna region, is one of the most populated districts of city Delhi. The city has been encircled by the Yamuna river from West, Ghaziabad and Gautam Buddha Nagar District of Uttar Pradesh from the east and south, respectively. According to 2001 census, the population of East Delhi was recorded as 1,448,770 with population density of 22,639 persons per  $\text{km}^2$  within  $64 \text{ km}^2$  area. In 2011 census, East Delhi has a population of 1,707,725 with population density of 26,683 inhabitants per  $\text{km}^2$  with population growth rate of 16.68% over 2001–2011 [8]. In this research work, the sampling was carried out in one of the major and oldest locality named as Durgapuri Chowk ( $28.6988^\circ \text{N}$  and  $77.2926^\circ \text{E}$ ) of Shahdara, East Delhi. The sampling site is traffic-congested cum residential in spatial distribution and surrounded by the old Shree Durga temple near the 100 feet road. The sampling location was selected in a manner to study the effect of traffic as well as the effect of burning of firecrackers on the air quality. The major sources of pollution at the study site were mainly the vehicles, constructional and some of the commercial activities including sweets shops, bakery, furniture, garment showrooms, etc. For the sampling of

selected air pollutants, the sampling instruments were placed at the rooftop of a two-story building, situated near roadside area of Durgapuri Chowk. The sampling location is shown in Fig. 1.

### 3 Sampling method

In order to study the temporal variation in the distribution of particulate and gaseous pollutants, the sampling of these pollutants was carried out five days before Diwali, on the day of Diwali and five days after Diwali celebration for two consecutive years 2017 and 2018. During 2017, the festival was celebrated on 19 October, while in 2018, the festival was celebrated on 7 November. The sampling of gaseous pollutants has been carried out twice in a day, where 18:00–22:00 h and 24:00–04:00 h were considered as evening and late night hours, respectively. The concentration of SO<sub>2</sub> and NO<sub>2</sub> was measured using modified West and Gaeke, and modified Jacob and Hochheiser methods, respectively [13]. The monitoring of particles (PM<sub>10</sub>, PM<sub>2.5</sub>, PM<sub>1</sub>, inhalable, thoracic and alveolic) have been also done twice in a day done, where 18:00–24:00 h and 24:00–06:00 h were considered as evening and late night hours, respectively. The sampling of particulate was carried out using aerosol spectrometer (Grimm technology Model 1.108, Germany). The instrument makes use of scattering of light phenomenon for counts of particle, in which a semiconductor laser provides the source of light. The signal scattered by the particle passes through the beam of laser and gets collected at about 90° through a mirror and is conveyed to a recipient diode. Aerosol spectrometer gives real-time data for classifications of particle size and single particle counts. The instrument operates efficiently for given time resolution and is easy to handle. The results at a regular interval of five minutes were analyzed using GRIMM software program, and by this way, mass concentration of the particles was detected [30]. The data of meteorological parameters including relative humidity (RH), wind speed (WS), vertical wind speed (VWS) and ambient temperature (AT) have been procured from nearest monitoring station of Central Pollution Control Board (CPCB).

### 4 Calculation of air quality index (AQI)

In this study, AQI has been used as a tool to measure the quality of ambient air. It focuses on the effects of air pollution on human health after exposure to unhealthy air within a few hours or days [35]. The high level of air pollution and AQI results in more adverse effects on human health [31]. There are six different classified AQI categories

for which color codes were defined for good (0–50, minimal health impacts), satisfactory (51–100, minor breathing discomfort to vulnerable people), moderately polluted (101–200, breathing discomfort to the people with lungs, asthma and heart diseases), poor (201–300, breathing discomfort to most people on prolonged exposure), very poor (301–400, respiratory illness on prolonged exposure) and severe (401–500, affects healthy people and seriously impacts those with existing diseases) air quality as dark green, light green, yellow, dark yellow, red and dark red, respectively. In this work, AQI was determined using the concentration of three criteria pollutants PM<sub>10</sub>, PM<sub>2.5</sub> and NO<sub>2</sub> in order to identify the overall AQI value [14].

### 5 Results and discussion

Particulates (PM<sub>10</sub>, PM<sub>2.5</sub>, PM<sub>1</sub>, INH, THO and ALV) and gaseous pollutants (SO<sub>2</sub> and NO<sub>2</sub>) were monitored five days before, five days after Diwali and during the Diwali festival to study the influence of fireworks in the ambient air. The concentration and short-term variations of these pollutants during pre-Diwali, Diwali and post-Diwali celebrations are represented in Table 1 and Fig. 2, respectively.

### 6 Levels and diurnal pattern of air pollutants

The average level of particulates (PM<sub>10</sub>, PM<sub>2.5</sub>, PM<sub>1</sub>) during Diwali celebrations 2017 and 2018 was observed as 2.94–3.41, 4.90–4.94, 5.28–5.78 times higher, respectively, than pre-Diwali days during two consecutive years. Similarly, these average levels during Diwali celebrations were 2.48–2.54, 2.85–3.24, 3.45–4.30 times higher than pre-Diwali for INH, THO and ALV particles, respectively, during 2017 and 2018. Also, the levels for PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub> were 1.77–1.99, 2.18–2.81 and 2.02–2.28 times higher, respectively, during post-Diwali as compared with pre-Diwali. Similarly for INH, THO and ALV particles, the levels were 1.33–1.74, 1.63–1.77, 1.57–1.98 times higher, respectively, during post-Diwali as compared with pre-Diwali. Interestingly, it has been clear from Fig. 2a, b, c, d, e, f that the levels of particulate pollution during post-Diwali days were found to be greater than those recorded during the pre-Diwali days for both of the years. These short-term degraded variations in air quality were attributed to bursting of fireworks which results in increasing and accumulating the high number of particles. The higher concentration during post-Diwali was attributed to more accumulation of particles in the urban atmosphere after the celebrations of Diwali as these particulates have tendency to remain

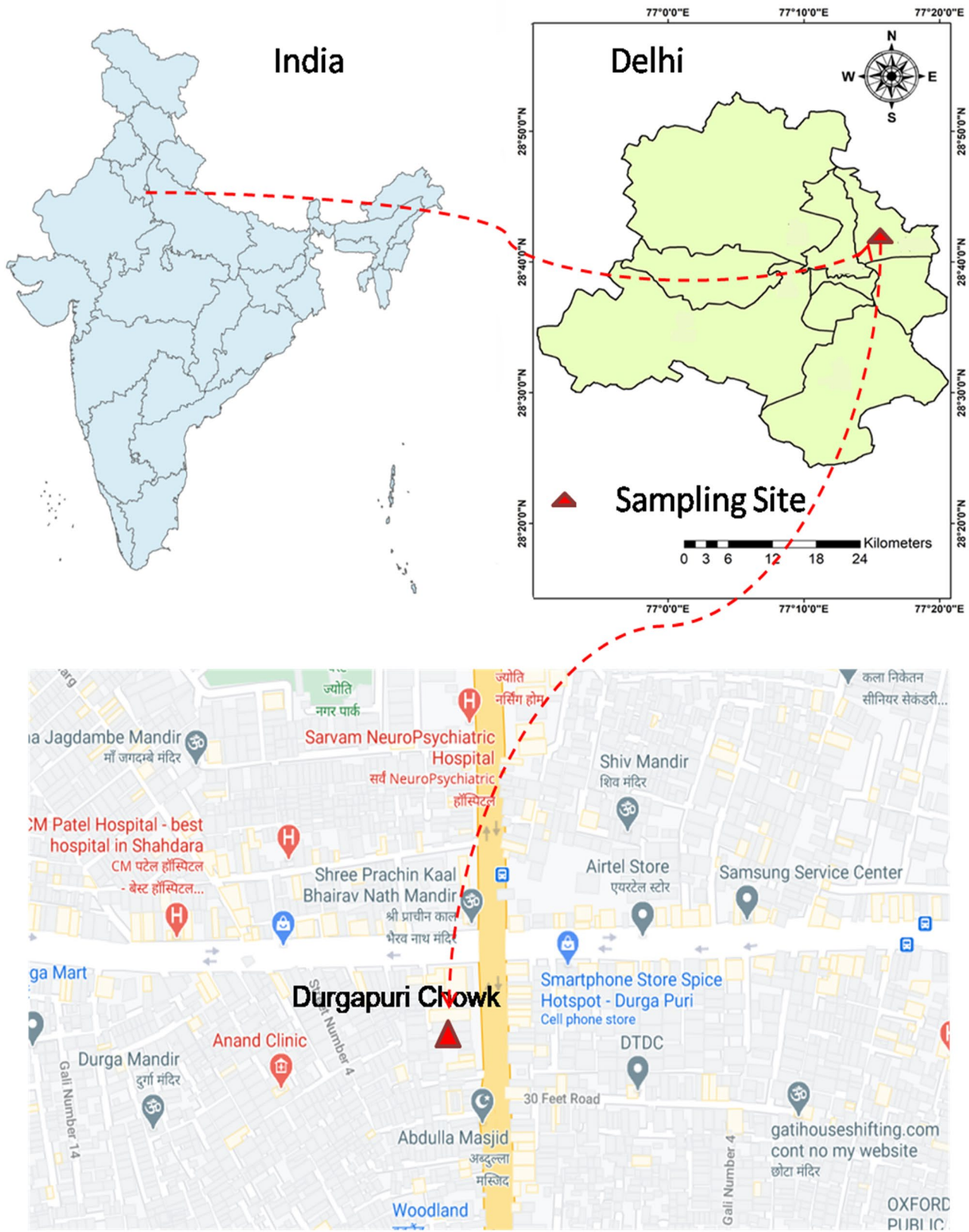


Fig. 1 Delhi map representing sampling site for pollutants measurement during Diwali

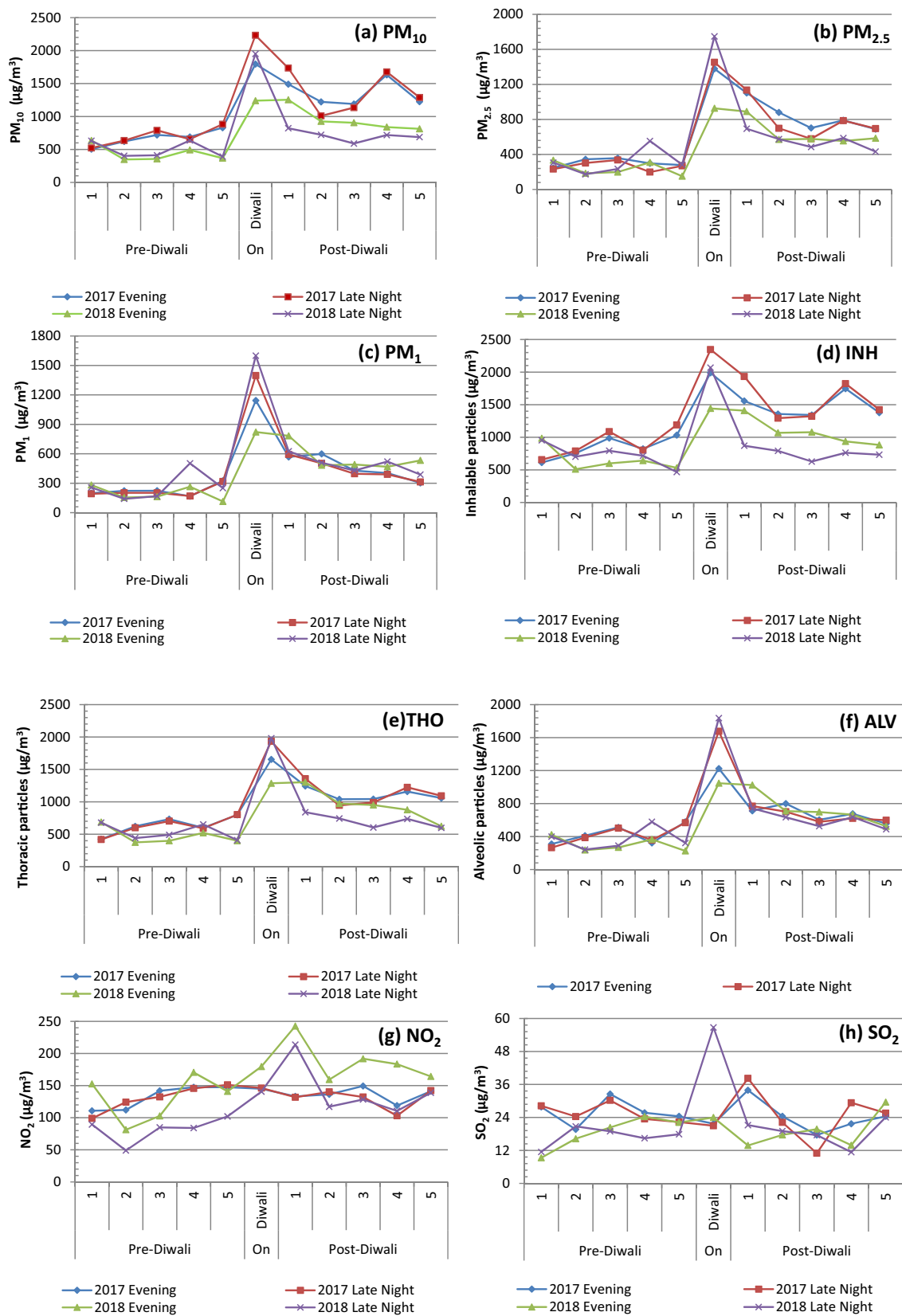
**Table 1** Concentrations of Particulate and gaseous pollutants during pre-Diwali, Diwali and post-Diwali episodes

Concentration ( $\mu\text{g}/\text{m}^3$ )	Pre-Diwali		Diwali		Post-Diwali	
	2017	2018	2017	2018	2017	2018
<i>PM<sub>10</sub></i>						
Mean	685.23	467.73	2013.93	1595.02	1360.33	828.01
SD	124.26	122.09	309.01	501.57	253.15	181.52
Min	504.32	348.22	1795.43	1240.35	1009.82	589.98
Max	883.23	637.57	2232.43	1949.68	1734.56	1253.92
<i>PM<sub>2.5</sub></i>						
Mean	286.58	272.84	1415.50	1337.59	805.89	595.22
SD	51.52	117.58	52.11	580.76	183.18	123.80
Min	198.99	151.40	1378.65	926.93	578.67	432.67
Max	357.89	553.62	1452.34	1748.25	1135.43	889.69
<i>PM<sub>1</sub></i>						
Mean	222.11	229.49	1270.45	1210.56	449.60	522.83
SD	55.41	113.00	179.89	549.95	109.98	111.06
Min	167.64	113.82	1143.25	821.69	302.43	387.65
Max	324.56	502.52	1397.65	1599.44	598.76	782.71
<i>Inhalable particles</i>						
Mean	873.42	689.96	2167.21	1755.10	1517.18	915.91
SD	190.95	178.41	252.18	443.03	233.81	223.95
Min	612.26	466.74	1988.89	1441.82	1293.45	627.67
Max	1189.82	984.95	2345.53	2068.37	1932.22	1408.57
<i>Thoracic particles</i>						
Mean	628.96	504.73	1794.44	1632.88	1114.79	824.84
SD	135.17	124.00	198.16	490.74	128.11	217.14
Min	418.98	373.98	1654.32	1285.88	945.67	598.77
Max	802.34	687.15	1934.56	1979.88	1356.78	1302.91
<i>Alveolic particles</i>						
Mean	420.98	334.93	1450.45	1441.33	661.41	664.64
SD	112.12	110.27	319.75	558.15	83.13	152.76
Min	265.21	225.61	1224.35	1046.66	555.99	488.63
Max	578.94	578.47	1676.54	1836.00	799.99	1024.41
<i>SO<sub>2</sub></i>						
Mean	25.86	17.79	21.34	40.36	24.83	18.78
SD	3.86	4.65	0.51	23.17	7.77	5.35
Min	19.64	9.32	20.98	23.98	10.98	11.38
Max	32.50	24.31	21.70	56.74	38.21	29.57
<i>NO<sub>2</sub></i>						
Mean	131.24	105.77	145.67	160.14	132.87	165.03
SD	18.64	37.52	0.80	27.58	13.28	43.18
Min	98.92	48.92	145.10	140.64	102.99	110.58
Max	151.23	170.60	146.23	179.64	149.40	242.71

suspended in the urban atmosphere for several hours to days. [19, 30].

The average levels of  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$  and  $\text{PM}_1$  in 2017, on the day of Diwali, were found to be  $2013.93 \pm 309.01$ ,  $1415.50 \pm 52.11$  and  $1270.45 \pm 179.89 \mu\text{g}/\text{m}^3$ , respectively. The average levels of  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ ,  $\text{PM}_1$  during the day of Diwali in 2018 were  $1592.02 \pm 501.57$ ,  $1337.59 \pm 580.76$  and  $1210.56 \pm 549.95 \mu\text{g}/\text{m}^3$ , respectively. The levels of

$\text{PM}_{10}$ ,  $\text{PM}_{2.5}$  and  $\text{PM}_1$  were 1.26, 1.10 and 1.05 times lower in 2018 than 2017. The decrease in particulate levels observed during 2018 has shown the better management practices and difference in the month for celebration of Diwali festival. During 2017, the Diwali was celebrated on October, and surprisingly, it was coincided with stubble burning practices by the nearby states of Delhi including Punjab and Haryana. The combined effect of stubble



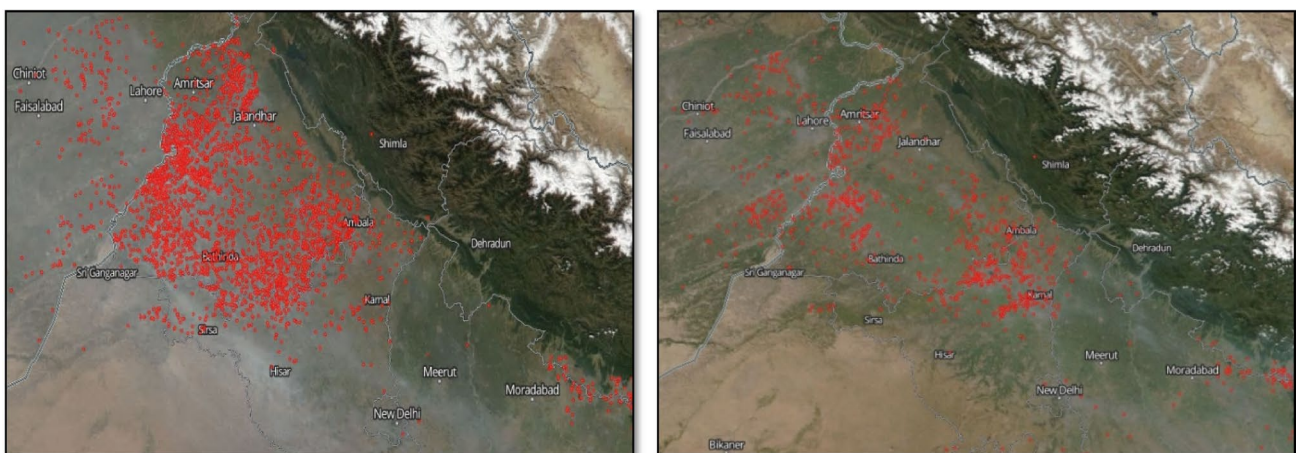
**Fig. 2** Short-term variations in the level of air pollutants during Diwali episode- **a** PM<sub>10</sub>, **b** PM<sub>2.5</sub>, **c** PM<sub>1</sub>, **d** inhalable particles, **e** thoracic particles, **f** alveolic particles, **g** NO<sub>2</sub> and **h** SO<sub>2</sub>

burning practices and Diwali celebration results in accumulation of these finer particles for a long period in ambient air. However, during 2018 Diwali was celebrated in month of November and the stubble burning was carried out much before the festival resulting in escaping a proportion of finer particles which were accumulated in the air of Delhi. The variation in stubble burning practices has been identified by satellite imagery released by NASA and shown in Fig. 3. It has been found that burning of paddy crop residue, which is one of the major causes of air pollution, declined by 15% and 41% in 2018 over 2017 and 2016 levels, respectively, in Punjab, Haryana, Uttar Pradesh and Delhi NCR. It has been possible due to promotion of agricultural mechanization for in situ management of crop residue [57]. A study [17] has also shown that cracker burn injury cases during Diwali of 2017 reduced by 63% compared to the previous year.

During 2017 and 2018, the  $PM_{10}$  level has crossed the National ambient air quality standards (NAAQS) of  $PM_{10}$  by 20 and 16 times, respectively, and  $PM_{2.5}$  by 24 and 22 times, respectively [12]. A similar study [36] has reported that in 2016 the highly increment pollution level during Diwali celebration realized the adverse respiratory and cardiopulmonary health effects of these pollutants on Delhi's inhabitants. Due to these adverse health impacts of firecrackers burning, the supreme court of India has decided to ban the sale of fireworks in Delhi during Diwali festivals in 2017, and during 2018, the use of green crackers was emphasized. Therefore, the stringent policy leads in reduction of  $PM_{10}$  and  $PM_{2.5}$  levels by 20.8% and 5.5%, respectively, during 2018 as compared with 2017. But the results have clearly shown that only the policy formulation will not work alone properly and for solving this problem, the proper implementation of rules and policies is highly needed.

The concentration of gaseous pollutants was observed to be higher during 2018 Diwali celebrations in compare with 2017. These yearly alterations may be characterized to the adverse meteorological conditions in 2018. Overall, gaseous pollutants show nonsignificant variations if we compare pre-/post-Diwali events with Diwali. The study carried out in urban air of Delhi [32] also found that during Diwali days, the use of fireworks results in increasing the level of  $PM_{10}$  by 1.3–4.0 times if we compare with pre- and post-Diwali days. While, the gaseous pollutants  $SO_2$  and  $NO_2$  show very less significant variation during Diwali and non-Diwali days. Similarly, a study [20] conducted in rural area of Haryana also identified the level of  $PM_{2.5}$  as 5 times higher than NAAQS standard of  $PM_{2.5}$  proposed by CPCB. However, till now there is no standard for  $PM_1$  particles, but such high levels of  $PM_1$  observed in this study particularly during Diwali and post-Diwali are the great concern for cardiopulmonary health. As, such high levels of finer particles resulted in dysfunctioning of alveolar cells. The overall results procured from our study clearly identified that particulate matter is the major pollutant in order to deteriorate the urban air quality.

The diurnal pattern for the levels of pollutants reveals significant changes during evening and late night hours. The concentrations of pollutants during Diwali late nights were higher than their respective evening times levels during both of the monitoring years (Fig. 2). During 2017, all particulate particles show almost similar pattern in concentrations during evening and late night hours except for  $PM_{10}$  and inhalable particles where a much higher concentration has been recorded during late night as compare with evening hours. Other studies also reported the similar kind of results as obtained in present study [6, 9]. For both of the years, the concentration of pollutants during Diwali day was observed to be higher in late night hours except



**Fig. 3** Satellite Imagery showing stubble burning practices in nearby states of Delhi by NASA on 14 October **a** 2017 and **b** 2018

for NO<sub>2</sub>. The higher value of NO<sub>2</sub> during evening hours was attributed to the vehicular practices and the higher values of other pollutants during late night hours particularly due to accumulation of particulate due to fireworks. The finer particles remain suspended for a long time period in ambient air than coarser particles [46]. The percentage contribution of fine particles during pre-Diwali, Diwali and post-Diwali days clearly suggests that particulates in the size less than 2.5 μm contributed more air pollution. During 2017, PM<sub>10</sub>/PM<sub>2.5</sub> ratio was varied as 1.42–2.39 with maximum value during pre-Diwali and minimum during Diwali. Also, this ratio was less for post-Diwali than pre-Diwali celebrations clearly suggesting the contribution of fireworks in increasing and accumulating the particles and affecting the human health [33].

### 7 Variation in AQI

The data attained from ambient air quality measurement for Diwali and non-Diwali days at the study site were converted into AQI and shown in Fig. 4. It is observed that

the study location has been recorded as severely polluted during Diwali. The AQI was observed as 719 ± 155, 2380 ± 387 and 1563 ± 316 μg/m<sup>3</sup> for pre-Diwali, Diwali and post-Diwali, respectively, during 2017. The category of AQI was severe for all the monitoring days except during pre-Diwali days 2 and 3 for 2018. Also, comparatively lower AQI was observed for 2018 as 466 ± 138, 1857 ± 627 and 898 ± 227 μg/m<sup>3</sup>, respectively, for pre-Diwali, Diwali and post-Diwali. A significant reduction in AQI has been observed from 2017 to 2018 as 35%, 22% and 43% during pre-Diwali, Diwali and post-Diwali, respectively. This reduction can be clearly understand by satellite imagery showing the decrease in the crop residue burning practices during 2018 through Fig. 3. A similar kind of study carried out by Kumar and Gupta [30] in East Delhi has also found an increase in AQI by 36–47% during 2012 and 2013 Diwali festival as compared with pre-Diwali events. Similarly, Nasir and Brahmaiah [38] have also identified 18–68% increase in AQI during Diwali days with non-Diwali days for period 2009–2010 at Vadodara city of Gujarat, India. In this study, it has been found that PM<sub>10</sub> and PM<sub>2.5</sub> are the major contributors for high level

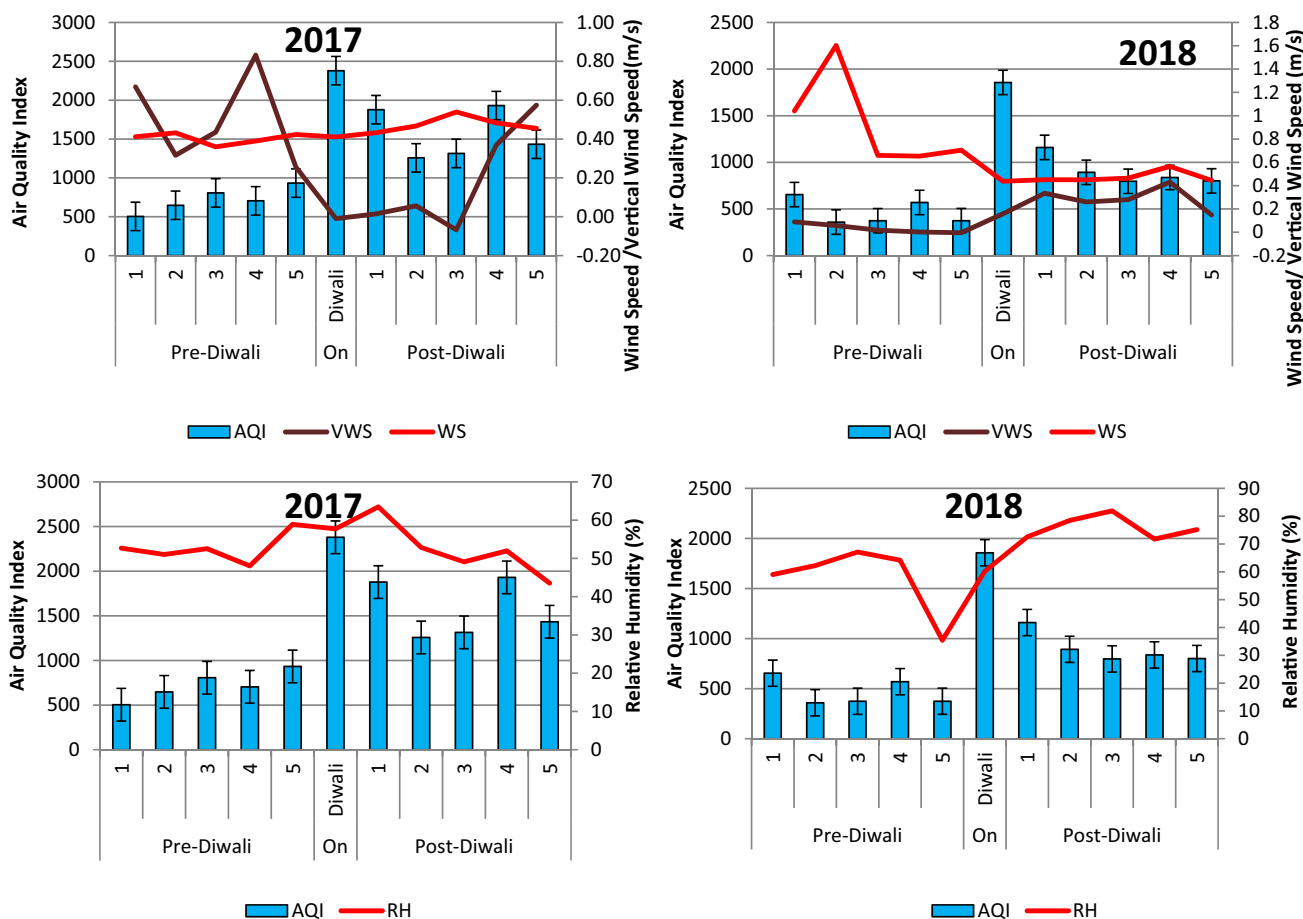


Fig. 4 AQI and variation with meteorological parameters during 2017 and 2018



of AQI indicating the serious threats of these pollutants on human health.

### 8 Effect of meteorology on air quality

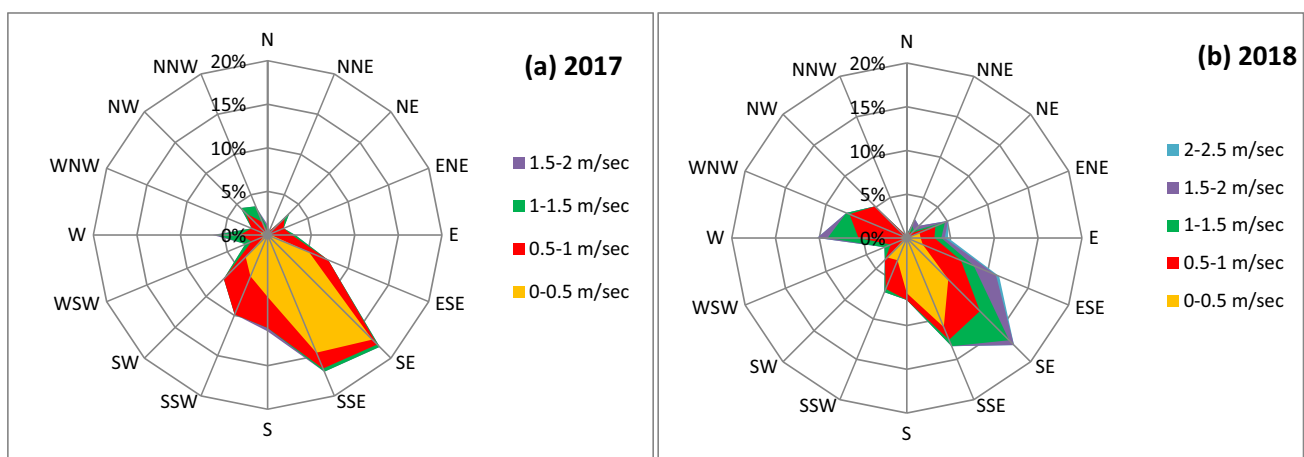
The descriptive statistics of various meteorological parameters and the concentration of air pollutants monitored during Diwali episodes for years 2017 and 2018 are given in Table 2. The VWS (m/s), RH (%), WS (m/s) and AT (°C) indicate only slight changes for particular year, suggesting the minimal interference of the meteorology for pre, post-Diwali and Diwali days. However, it has been reported that average WS and RH were recorded higher in 2018 as compared to 2017 during Diwali episode. It has been depicted from wind rose diagrams (Fig. 5) that during the sampling

days, approximately 90% times WS remained very low, i.e., less than 1 m/sec (56% and 34% times in the range of 0–0.5 m/sec and 0.5–1.0 m/sec, respectively) for year 2017. This low WS resulted in accumulation of particles in ambient air. For year 2018, the WS was 39%, 37% and 15% times fall in the range of 0.5–1.0 m/sec, 0–0.5 m/sec and 1–1.5 m/sec, respectively. The average value of WS was observed as 0.44 ± 0.08 m/s and 0.68 ± 0.36 m/s during 2017 and 2018, respectively. Also, average RH was obtained as 52.90 ± 10.32% and 66.19 ± 14.34% during 2017 and 2018, respectively. The study also found that average VWS and AT were recorded to be lower during 2018 as compared to 2017. The average value of VWS was observed as 0.31 ± 0.30 m/s and 0.16 ± 0.15 m/s during 2017 and 2018, respectively. Also, average AT was obtained as 26.42 ± 4.36 and 21.96 ± 2.33 °C during 2017 and 2018, respectively. It

**Table 2** Descriptive statistics of air pollutants and meteorological parameters

	Minimum	Maximum	Mean	SD	Skewness	Kurtosis	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
2017							2018					
VWS	− 0.10	0.89	0.31	0.30	0.29	− 1.03	− 0.01	0.45	0.16	0.15	0.49	− 0.96
RH	37.87	72.21	52.90	10.32	0.24	− 1.28	32.42	89.84	66.19	14.34	− 0.58	0.49
WS	0.34	0.71	0.44	0.08	2.26	7.94	0.43	1.65	0.68	0.36	1.71	2.28
AT	20.82	34.93	26.42	4.36	0.14	− 1.31	18.37	26.93	21.96	2.33	0.40	− 0.24
NO <sub>2</sub>	98.92	151.23	133.29	15.53	− 0.97	− 0.12	9.32	56.74	20.29	9.46	2.84	10.80
SO <sub>2</sub>	10.98	38.21	24.98	5.82	0.07	1.17	48.92	242.71	137.65	48.25	0.28	− 0.31
INH	612.26	2345.53	1283.65	471.74	0.51	− 0.36	466.74	2068.37	889.50	367.60	1.80	4.11
THO	418.98	1934.56	955.74	382.91	0.82	0.74	373.98	1979.88	752.79	379.22	1.85	4.27
ALV	265.21	1676.54	623.86	313.94	2.10	5.69	225.61	1836.00	585.38	364.26	2.08	5.89
PM <sub>10</sub>	504.32	2232.43	1112.88	481.87	0.65	− 0.40	348.22	1949.68	733.97	375.58	1.77	4.25
PM <sub>2.5</sub>	198.99	1452.34	625.26	381.16	0.80	− 0.29	151.40	1748.25	516.17	352.12	2.14	6.51
PM <sub>1</sub>	167.64	1397.65	420.81	309.82	2.16	4.82	113.82	1599.44	452.02	325.47	2.18	6.77

(N = sample size = 22, concentration of NO<sub>2</sub>, SO<sub>2</sub>, INH, THO, ALV, PM<sub>10</sub>, PM<sub>2.5</sub>, and PM<sub>1</sub> is in µg/m<sup>3</sup>, VWS and WS (m/s)



**Fig. 5** Wind rose diagram during Diwali sampling: **a** 2017, **b** 2018

has been reported that local meteorological conditions can significantly influence the concentration of pollutants via dispersion, resulting in a further dilution of emissions from fireworks [4]. A large fluctuation in VWS has been observed during 2017 than 2018, and the VWS remains less than 0.2 m/s for maximum monitoring time with range of -0.01 to 0.45 m/s during 2018. For 2017, along with the burning of firecrackers, the low WS (0.41 m/s) and minimum VWS (0.00 m/sec) on Diwali day also play a major role in accumulation of these particles in ambient air for a long time [48]. It can be identified from Fig. 4a that VWS was decreased after Diwali celebrations which lead to increase in the concentration of these particles after post-Diwali. In 2017, the high wind speed, more stubble burning during Diwali period, was resulted in more accumulation of particles, whereas in 2018, the low ambient temperature and low VWS resulted in adverse increment in pollution level along with Diwali celebrations.

Here, principal component analysis (PCA) has been also applied on air quality data sets and meteorological parameters for Diwali and pre, post-Diwali days collectively during 2017 and 2018 to classify the possible principal meteorological parameters added to emission of pollutants. The component plots for the same have been shown in Fig. 6. For this purpose, the factors which contributed by having eigenvalue greater than one have been selected in this analysis. A total of 83.06% and 86.44% of the total variation have been explained by first four factors in 2017 and 2018, respectively. During 2017, Factor 1 explained 42.73% of the total variance and had very strong positive loadings (>0.92) for all particulate matter of different aerodynamic diameters showing that the emission source of all these

pollutants is same particularly burning of fire crackers and biomass. Hence, the emission from fireworks and biomass burning are the first main sources of high particulate during this episode. Also, strong negative loadings of VWS indicate the negative effects of VWS on increased particulate level. Factor 2 explained 22.49% of total variations and had strong positive loading (>0.93) between AT and SR and strong negative loadings with RH. Hence, meteorological parameters like AT, SR and RH are the second main contributing factors in dispersion of pollutants. Factor 3 explained 12.82% variation and showing negative loadings with WS showing that during these episodes low wind speed is the third most contributing factor [48]. Factor 4 explained 5.12% of total variations and has strong loading with VWS showing it as the fourth contributing factor in pollutants dispersion. The loadings of these factors for both years 2017 and 2018 are clearly shown in Table 3. From these results, it can be clearly estimated that VWS, AT and WS are the most affecting meteorological parameters for degrading the ambient air quality.

### 9 Interspecies correlation and linear regression analysis

$R^2$  also known as the coefficient of determination for the linear regression analysis has been considered as a major statistical tool to find out the proximity and best fitted correlation in the air quality data sets [67]. The higher value of  $R^2$  is the indication of better model responsible to explain the sum total of all variation in the values with the mean value. In this work, the scatter plots showing

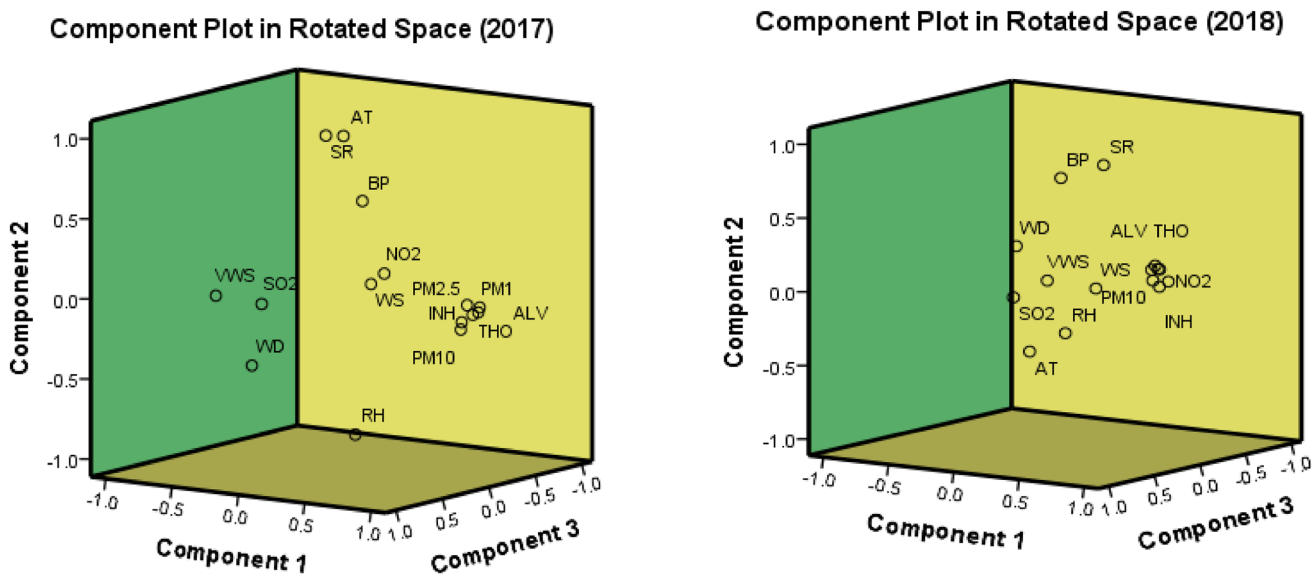


Fig. 6 Component plots between air pollutants and meteorological parameters during 11 days of monitoring in 2017 and 2018

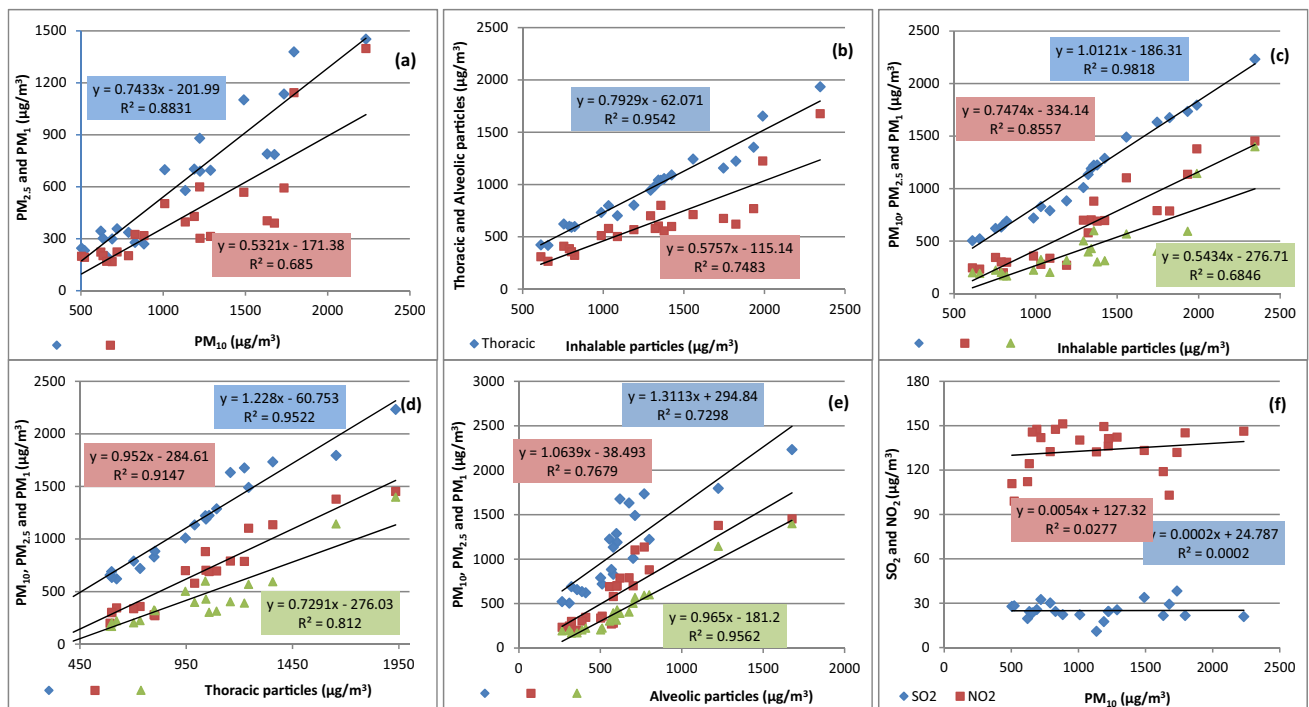
**Table 3** PCA of air pollutants and meteorological parameters

	2017					2018				
	Components				Communi- ties extrac- tion	Components				Communi- ties extrac- tion
	1	2	3	4		1	2	3	4	
VWS	-0.65	-0.03	0.39	0.25	0.64	0.22	0.11	0.41	0.74	0.95
RH	0.26	-0.83	0.17	0.24	0.83	0.11	-0.31	0.05	0.30	0.95
WS	0.13	0.06	-0.21	-0.87	0.81	-0.26	-0.17	-0.81	0.22	0.92
SR	-0.19	0.93	-0.08	0.06	0.91	0.35	0.84	-0.03	-0.03	0.83
AT	-0.04	0.95	-0.04	0.04	0.91	-0.28	0.50	-0.12	0.13	0.92
NO <sub>2</sub>	0.27	0.22	-0.56	0.41	0.60	0.78	0.08	-0.12	-0.42	0.83
SO <sub>2</sub>	0.05	0.10	0.84	0.12	0.73	0.30	0.07	0.88	0.20	0.92
INH	0.97	-0.10	0.02	-0.08	0.95	0.93	0.11	0.19	0.14	0.93
THO	0.99	-0.02	-0.08	-0.02	0.98	0.91	0.23	0.24	0.19	0.98
ALV	0.93	-0.04	-0.18	0.18	0.93	0.91	0.25	0.21	0.13	0.99
PM <sub>10</sub>	0.96	-0.06	0.04	-0.12	0.95	0.93	0.16	0.26	0.17	0.99
PM <sub>2.5</sub>	0.97	0.03	0.03	-0.10	0.95	0.92	0.23	0.19	0.10	0.98
PM <sub>1</sub>	0.92	-0.02	-0.17	0.13	0.89	0.92	0.22	0.17	0.09	0.98

Extraction method: principal component analysis  
 Rotation method: Varimax with Kaiser normalization

the regression equation and  $R^2$  value between particles of different aerodynamic diameters are plotted in Fig. 7. It has been found that very strong positive value ( $R^2 > 0.95$ )

has been observed between thoracic and PM<sub>10</sub> with inhalable particles, and PM<sub>10</sub> with thoracic particles and PM<sub>1</sub> with alveolic particles. Also, strong positive ( $R^2 > 0.81$ )



**Fig. 7** Scatter plots showing interspecies relationship between different pollutants: **a** PM<sub>10</sub> with PM<sub>2.5</sub> and PM<sub>1</sub>, **b** inhalable particles with thoracic and alveoli particles, **c** inhalable particles with

PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub>, **d** thoracic particles with PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub>, **e** alveolic particles with PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub>, and **f** PM<sub>10</sub> with SO<sub>2</sub> and NO<sub>2</sub>

coefficient value has been determined between  $PM_{2.5}$  with  $PM_{10}$  and inhalable particles, and  $PM_1$  with thoracic particles. A strong moderate value ( $R^2 > 0.72$ ) has been observed between alveolic particles with  $PM_{10}$ ,  $PM_{2.5}$  and  $PM_1$ . A moderate value ( $R^2 = 0.685$ ) has been obtained between  $PM_{10}$  and  $PM_1$ . Other studies [22, 28, 45] carried out in different cities of world have also obtained the similar kind of trend between the different sizes of particles. These size-segregated results clearly signify that there is a very strong correlation between finer  $PM_1$  with alveolar particles, finer  $PM_{2.5}$  with thoracic particles and coarser  $PM_{10}$  with inhalable particles. Hence, it is easy and accurate to predict the level of  $PM_{10}$ ,  $PM_{2.5}$  and  $PM_1$ , if we know the value of INH, THO and ALV particles, respectively, and vice versa, using the linear regression equation obtained in this study. An insignificant value of  $R^2$  (Fig. 7f) has been obtained between  $PM_{10}$  with  $SO_2$  and  $NO_2$ , which clearly indicates that during Diwali episode the level of gaseous pollutants is not directly dependent upon the particulate levels, and the festival emits mainly the high level of particulate pollution in ambient air.

## 10 Conclusions

The study illustrated that the use of fireworks during Diwali festival creates an additional major source of pollution during Diwali month than other sources. It has been found that during 2017, more stubble burning practices, use of fireworks played a major role in high emission of these pollutants. Whereas, in 2018 although the stubble burning practices were reduced, the adverse meteorological conditions (lower vertical wind speed and ambient air temperature) during Diwali in 2018 resulted in more suspension of these particles for a longer period in ambient air. The study found that the concentration of air pollutants was reduced during 2018 as compared to 2017, may be due to comparatively low sale of fireworks, difference in the month of Diwali celebration and less crop residue burning practices. Also, a substantial reduction in AQI was observed from 2017 to 2018 as 35%, 22% and 43% during pre-Diwali, Diwali and post-Diwali, respectively. This study clearly shows that how even after knowing the adverse effects of burning crackers people still indulge in this act. The study suggests that it is time we all must stop taking pleasure in such trivial things and think about the bigger picture. Diwali is a beautiful festival and we must retain its beauty and sanctity by saying no to crackers. We must not ruin the fun by polluting the environment and incurring health problems. We must remember that this trivial act of ours is becoming a cause of global concern. It is contributing to global warming which is one of the biggest threats to our environment. There is a need for adopting

the rules and policies formulated by government bodies as a responsible citizen. It is time to understand that this is not adding to the celebration, this is only adding to the pollution and causing serious harm to our planet.

**Acknowledgements** One of the authors Ms. Anchal Garg gratefully acknowledges the scholarship provided by GGSIP University, New Delhi, vide letter no: GGSIPU/DRC/Ph.D./Adm./IPRF/2017/178 dated 08/03/17. The authors would also like to thank Director (Research & Consultancy) for providing financial assistance in the form of Faculty Research Grant Scheme to carry out the research study.

## Compliance with ethical standards

**Conflict of interest** The authors are not having any conflict of interest.

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