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Air Quality in Six Northern Indian Cities During Diwali 2020: The Real Tragedy in Disguise

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North Indian cities have been highly polluted, especially in winters, which coincide with the Diwali festival. This year, the government imposed ban on the burning of firecrackers. This study was undertaken from 4th-21st November, 2020 to monitor the air quality variation with respect to PM_{10} and $PM_{2.5}$ for Delhi, Lucknow, Ghaziabad, Muzaffarnagar, Greater Noida and Bulandshahar cities during and post Diwali period, to know whether there was any impact of the warnings. The hourly variations in the AQI were very poor between 8:00 p.m.-10:00 p.m. on Diwali day. Significant short term variation in the AQI was observed during the night. A weak positive correlation was obtained between the temperature and AQI, whereas a negative relationship was established with humidity. As compared to last year's AQI, higher values were obtained this year. The short-term variation in air quality may prove crucial in future in the wake of COVID-19 pandemic.

Keywords: COVID-19, Firecrackers, Correlation, Pollution.

INTRODUCTION

The winter season in Northern India onsets from October and extends till February. It has been observed that air pollution is usually worse in winter season due to greater suspension time of pollutants in the air, owing to lower temperature, wind speed and high moisture content [1]. Proper mixing and dispersion do not take place at low wind speed, leading to frequent smog and longer retention time of pollutants at a particular place. The winter months coincide with Diwali (festival of lights), one of the largest festivals in India, celebrated with great fervour especially in northern India. The traditional firecrackers burning during the festival leads to a huge variation in air quality as the perilous aftermath. A distinct association between air pollution and firecracker burning has been established in the previous studies [1]. The research has been mainly concentrated on measuring pollutants' concentration before, during and after the festival [2]. The havoc caused during the festival led to a ban on the selling of firecrackers by the Supreme Court of India in 2017. The air quality variation during Diwali, which is of short-term in nature is gaining considerable interest as the short-term variation causes long term adverse health effects [3]. In 2019, after Diwali, metropolitan cities like Delhi, Patna and Lucknow were worst hit in terms of air quality.

According to the Central Pollution Control Board's (CPCB) network of monitoring centres, the Air Quality Index (AQI) of these cities reached around 400 which was far more worse than the previous year's data. The deterioration in Delhi's air was also due to the stubble burning in neighbouring states , which was exacerbated by the burning of firecrackers [4]. Elaborating on the last year's variation in the air quality of the national capital during the Diwali episode, about a week before the festival the AQI crossed 300, which was categorized as very poor. On Diwali day, the AQI reached to 340 and the morning after, it went further higher reaching upto 368. What makes firecrackers so hazardous is the pollutants which are released in the environment, including sulphur dioxide and nitrogen oxides, particulate matter (PM_{10} and $PM_{2.5}$), water soluble ions and heavy metals [5]. Out of these pollutants, $PM_{2.5}$, is extremely harmful, owing to its small size and deeper penetration in the respiratory tract and to lungs. Firecracker burning led to a high hourly average of the $PM_{2.5}$ concentration during

Diwali in the previous years. On November 9, 2020, National Green Tribunal imposed a ban on the selling and burning of firecrackers till 30 November in the capital city and neighbouring areas considering the escalating air pollution levels. This year, the Diwali season was particularly very crucial for Indian population due to the current pandemic situation. After a drop in the number of active COVID-19 cases, many countries from Europe are reporting a resurgence of new cases, which has already created much havoc since its origin in December, 2019 from Wuhan, China [6]. As countries are already gearing up to combat the resurgence of the deatly virus, where does it leave India?

India and U.S.A. emerged as the epicentres of the pandemic at later stages. As of November 2, 2020 India reported a count of 82,308,88 cases with 12,3229 casualties. The leading Indian states with higher number of cases are Delhi, Maharashtra, Andhra Pradesh, Karnataka, Madhya Pradesh, Uttar Pradesh, Tamil Nadu and Haryana. Maharashtra with a death count of 44,464 leads the tally. North Indian states like Delhi, Uttar Preadesh and Punjab have also contributed significantly in the total mortality caused by COVID-19 [7]. West Bengal and Tamil Nadu are the other states with a high death rate. After attaining the peak or the highest daily average reported on September 17, India has seen a decline in the active cases. India crossed 80 lakh confirmed COVID-19 cases on 28 October, while the number of deaths crossed the grim figure of 1 lakh 20 thousands a day later. The country, however, has witnessed a drop in daily cases since past few days, with the Health Ministry on October 31, 2020 reporting 48,648 fresh infections. Post-Diwali, there is a greater possibility of the particles to remain suspended in the air and the virus may also tag along leading to higher transmission probability. People who are already suffering from respiratory diseases like chronic obstructive pulmonary diseases (COPD) and asthma are more at risk to catch the COVID-19 infection through the inhalation of suspended particulate matter [8]. The inflammation in lungs caused by elevated particulate contamination, clubbed with the current spread of COVID-19 infection can be many times more deadlier [9]. The particulate matter level in the ambient air is affected by the variation in source strength and meteorological conditions such as relative humidity, precipitation, wind speed and its direction. In developing countries like India, the spread of the virus may be influenced by ambient air pollution, because pollution has been proven to accelerate respiratory illnesses and COVID-19 is a respiratory disease. The impact of COVID-19 may be more severe in cities with high air pollution. The immunity of those living in such cities is compromised by toxic air [10].

In the past few years, smog related issues have commonly occurred in North India as an after effect of Diwali, hence the present study was focused on six major north Indian cities including the capital New Delhi, the industrial hub Greater Noida and Lucknow, the capital of Uttar Pradesh state. The other three selected cities were Ghaziabad, Muzaffarnagar and Bulandshshar. According to the recent bulletin issued by the Central Pollution Control Board (CPCB), Government of India, covering 115 cities across India, the AQI in these six North Indian cities has been categorized as "very poor" at the onset of winter season in 2020. The pilot study was conducted to see the variation in the air quality of these cities during Diwali time and how it is being affected by the meteorological parameters including temperature, relative humidity and wind speed and whether the daily variation in the AQI has any association with the number of COVID-19 cases as reported during the study period, as the number of cases are already surging again in Central and North Indian states.

EXPERIMENTAL

To assess the impact of firecracker burning on air pollution, six of the most polluted cities in northern region *viz.* Delhi, Lucknow, Ghaziabad, Greater Noida, Muzaffarnagar and Bulandshahar were selected for the present study. In order to see the overall impact of firecracker burning, the variation in AQI with respect to PM_{10} and $PM_{2.5}$were recorded at the interval of every 3 h *viz.* at 8:00 a.m., 11:00 a.m., 2:00 p.m., 5:00 p.m., 10:00 p.m. and 12:00 a.m. from 4th November-21st November, 2020. Full day variation is important to assess short-term variations and subsequent health impact, therefore from 12th 16th November 2020, including pre-Diwali, Diwali and post-Diwali day, the hourly variations in the values were recorded from 6:00 a.m.-12:00 a.m. from www.airnow.gov.

The recorded data was freely available on the internet and did not require any special permission. Meteorological data including temperature, wind speed and humidity were also recorded for the study period from www.aqicn. The selection of the monitoring stations was done according to the consistency of the available data and the most polluted site was selected for recording the AQI data. Any missing observation was excluded from the analysis. The air quality indexes were further converted into concentrations by using an online AQI calculator (www.airnow.gov), to know the average concentrations of the pollutants. The geographical details of the selected cities are given in Table-1. The number of COVID-19 cases reported during the study period was also recorded on daily basis for the selected cities, to know whether the air

TABLE-1
DETAILS OF THE SELECTED CITIES

City	Monitoring station	Population	Area (Km^2)	Coordinates
Lucknow	Lalbagh	3,677,000	631	26.84°N, 80.94°E
Muzaffarnagar	New Mandi	717,000	204.8	29.47°N, 77.70°E
Greater Noida	Knowledge Park-V	107,675	380	28.47°N, 77.51°E
Bulandshahar	Yamunapuram	235,310	64	28.40°N, 77.85°E
Ghaziabad	Vasundhara	1,729,000	210	28.67°N 77.42°E
Delhi	Punjabi Bagh	16,787,941	1484	28.70°N, 77.10°E

quality variation during the Diwali time had any associ-ation with the number of cases reported [7].

RESULTS AND DISCUSSION

Average concentrations: The average concentrations of PM_{10} and $PM_{2.5}$ were obtained with the help of an online AQI to concentration convertor. The AQI values which were above 500 could not be converted to the corresponding concentration. The average concentrations of $PM_{2.5}$ and PM_{10} from 4th-21st November, 2020 are presented in Table-2. The highest and lowest $PM_{2.5}$ concentrations (μg/m^3) for Lucknow, Delhi, Ghaziabad, Greater Noida, Muzaffarnagar and Bulandshahar were 391, 340, 482, 456, 292, 494 and 54.5, 74.0, 70.9, 67.1, 24.4 and 55.0, respectively, whereas PM_{10} concentrations (μg/m^3) were 594, 565, 532, 586, 587, 548 and 103, 154, 183, 181, 105 and 155, respectively. The lowest concentrations were obtained between 16th-17th November when, the North Indian cities received the average rainfall between 3.1-4.4 mm, which may be responsible for the scrubbing and wash out effect.

Short term/hourly variation in AQI during Diwali: Short term elevation (hourly variation) in the concentration of pollutants has been associated with immediate increase in mortality [11]. The short term effects are accounted for the long-term health impacts and used to indicate the variation in the daily burden from acute responses [12]. Sudden rise in the concentration of pollutants has been known to induce inflammatory response, including alveolar cytokine release which is responsible for bronchospasm and impaired pulmonary function [13]. It has been associated with increased blood clotting factors such as increased fibrinogen, C-reactive protein or by inducing cardiotoxicity. Short term effects have also known to induce plaque formation, temporary coronary occlusion [14], ischaemia [15] and increased production of reactive oxygen species, *etc.* Short term variations have also been linked to all-cause respiratory and cardiac mortality. Epidemiological studies have

TABLE-2
AVERAGE CONCENTRATION OF $PM_{2.5}$ AND PM_{10} IN DELHI, LUCKNOW, BULANDSHAHAR, GHAZIABAD, GREATER NOIDA AND MUZAFFARNAGAR FROM 4th-21st NOVEMBER, 2020

Date	$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	Temp.	Humidity	$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	Temp.	Humidity	$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	Temp.	Humidity
	Delhi				Lucknow				Bulandshahar			
04-11-2020	163.6	513	20.6	60.80	223	412	22.83	31.83	190.80	528	33.4	42.4
05-11-2020	319.1	486	22.0	58.20	184	572	21.00	51.33	326.10	NA	32.8	39.4
06-11-2020	248.3	497	19.6	61.60	265	NA	21.50	55.67	343.30	464	33.2	37.0
07-11-2020	320.1	519	19.0	61.60	314	461	21.50	51.32	267.60	489	32.8	40.0
08-11-2020	338.2	521	19.6	64.30	225	439	21.50	56.33	286.80	NA	33.0	45.4
09-11-2020	340.3	NA	18.0	72.70	255	456	22.50	52.67	494.30	548	32.4	45.2
10-11-2020	NA	NA	23.0	64.00	248	394	22.00	55.00	356.50	492	32.0	53.4
11-11-2020	NA	565	18.5	77.00	198	382	23.00	54.50	308.00	354	32.6	49.0
12-11-2020	187.8	384	19.8	72.14	256	472	22.71	62.00	195.14	140.7	33.4	46.2
13-11-2020	235.2	399	20.4	64.40	196	347	24.31	51.89	237.32	186.8	33.3	43.0
14-11-2020	412.5	NA	19.5	68.00	337	543	22.85	56.61	520.00	NA	31.4	47.3
15-11-2020	237.2	366	20.8	65.30	335	504	24.78	52.63	275.00	225.1	32.2	51.8
16-11-2020	74.8	131	21.0	74.15	32	50	20.15	85.61	131.38	47.6	31.8	58.7
17-11-2020	105.8	154	22.3	66.16	55	151	22.17	79.50	55.00	155	31.8	57.8
18-11-2020	74.8	179	10.5	62.00	67	137	22.17	72.83	72.90	213	31.8	52.8
19-11-2020	129.0	247	18.0	66.60	86	169	22.00	64.83	146.50	223	32.6	46.4
20-11-2020	153.5	181	17.8	68.60	125	169	19.83	50.50	158.50	285	32.0	45.6
21-11-2020	167.6	197	14.6	69.80	121	193	18.33	41.50	184.80	233	31.6	39.8
	Ghaziabad				Greater Noida				Muzaffarnagar			
04-11-2020	156.5	532	29.0	57.00	321.1	NA	31.8	33.4	231.2	488	29.50	47.83
05-11-2020	307.0	476	29.0	50.00	353.0	571	33.0	31.0	235.2	587	30.30	46.17
06-11-2020	275.7	485	29.2	55.60	290.8	539	32.4	27.2	292.8	392	31.00	45.00
07-11-2020	263.6	514	29.3	57.60	265.6	586	32.4	35.2	179.7	417	30.33	48.33
08-11-2020	299.9	NA	29.0	67.00	316.0	NA	32.6	47.2	186.8	468	30.50	52.67
09-11-2020	392.8	NA	30.0	73.20	447.4	NA	33.6	42.4	216.0	407	30.50	54.67
10-11-2020	NA	NA	29.0	63.50	456.4	NA	33.2	59.6	184.8	295	31.00	53.33
11-11-2020	482.2	482	29.2	68.20	349.3	476	33.0	50.0	142.6	331	31.17	53.00
12-11-2020	206.0	526	29.0	69.70	140.7	271	33.1	47.8	152.5	389	30.57	51.71
13-11-2020	260.5	497	28.9	60.60	226.1	508	33.2	45.2	166.6	308	30.63	49.10
14-11-2020	NA	NA	29.5	65.00	322.1	517	33.3	47.4	277.7	445	30.14	50.85
15-11-2020	267.6	387	29.2	67.30	201.9	354	33.1	62.6	117.4	245	29.68	53.63
16-11-2020	82.6	165	29.2	77.07	50.5	90	33.2	74.0	20.6	51	32.69	54.92
17-11-2020	70.9	183	29.0	69.16	67.1	181	33.2	59.2	24.4	105	31.50	52.00
18-11-2020	72.9	265	29.0	74.50	72.9	259	33.4	53.8	43.2	145	31.83	53.17
19-11-2020	132.9	297	28.2	60.16	117.4	416	33.0	48.2	109.7	239	32.00	51.17
20-11-2020	158.5	343	28.2	56.30	164.6	365	33.4	40.8	107.7	227	27.00	50.67
21-11-2020	185.8	254	28.3	55.00	160.5	243	32.4	32.0	100.0	173	31.50	4.83

established a substantial significant association between the concentration of particulate matter in the air and adverse health impacts. Although, the health impact from pollution results due to complex transformation in air, $PM_{2.5}$ is the most harmful as these small particles may penetrate deep inside the lungs through the respiratory tract, causing short term effect on nose, eyes and throat. Table-3 summarizes the short term effects of $PM_{2.5}$ and PM_{10} and their threshold limits.

Hourly change in the AQI was observed from 13th-16th November to assess the short term variation (Table-4). The data was recorded between 8:00 a.m.-12:00 a.m. It was seen that the AQI deteriorated drastically in evening hours between 6:00 p.m.-2:00 a.m. and was mostly in hazardous category. The maximum AQI with respect to $PM_{2.5}$ as reported from Lucknow, Delhi, Ghaziabad, Greater Noida, Muzaffarnagar and Bulandshahar were 709, 530, 552, 520, 824, 999 and 999, 999, 729, 618, 999, 999 for PM_{10}, respectively on Diwali day. Highest values were obtained around midnight and remained so till the next morning. The data showed that the AQI elevated after 6:00 p.m. and kept rising for the next seven hours. An

TABLE-3
SHORT TERM EFFECTS AND AMBIENT 24 h THRESHOLD LIMITS OF $PM_{2.5}$ AND PM_{10} (μg/m^3) [Ref. 18]

Pollutant	WHO	CPCB	Short term effect
$PM_{2.5}$	25	60	Lung irritation, coughing, sneezing, runny nose and shortness of breath
PM_{10}	50	100	Cardiac and respiratory related hospitalizations

TABLE-4
HOURLY VARIATIONS IN $PM_{2.5}$ AND PM_{10} AQI IN DELHI, LUCKNOW, GHAZIABAD, BULANDSHAHAR, GREATER NOIDA AND MUZAFFARNAGAR DURING DIWALI

Time	13-11-2020		14-11-2020		15-11-2020		13-11-2020		14-11-2020		15-11-2020	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
	Delhi						Lucknow (Lalbagh)					
6:00 a.m.	327	232	434	372	476	544	219	178	188	117	394	282
7:00 a.m.	328	279	434	372	408	317	204	171	191	130	181	84
8:00 a.m.	327	232	496	469	408	317	196	163	195	134	338	253
9:00 a.m.	377	300	492	495	408	317	209	301	195	139	434	415
10:00 a.m.	377	300	492	495	356	246	218	189	217	157	377	192
11:00 a.m.	420	429	535	646	359	279	228	178	202	145	308	146
12:00 a.m.	422	477	514	593	302	209	211	155	191	143	246	143
1:00 a.m.	368	409	464	531	302	209	211	155	184	129	207	127
2:00 a.m.	293	337	464	531	302	209	151	157	175	138	192	118
3:00 a.m.	163	110	340	296	246	195	151	157	175	138	188	108
4:00 a.m.	163	110	217	139	202	143	159	106	171	108	188	108
5:00 a.m.	163	110	223	138	199	143	169	104	187	114	197	156
6:00 a.m.	165	103	244	168	199	142	182	121	206	135	219	160
7:00 a.m.	163	104	307	225	199	143	200	149	223	151	219	160
8:00 a.m.	170	136	442	537	199	140	307	595	317	422	396	526
9:00 a.m.	210	272	530	697	199	104	319	574	379	454	408	451
10:00 a.m.	210	272	530	824	187	154	373	518	490	764	419	384
11:00 a.m.	365	405	530	824	234	160	351	531	690	999	403	311
12:00 a.m.	398	429	530	854	267	163	309	147	731	999	350	362
	Ghaziabad						Bulandshahar					
6:00 a.m.	330	178	502	530	999	308	353	561	432	403	344	225
7:00 a.m.	316	173	502	550	424	399	367	543	427	402	387	315
8:00 a.m.	316	173	539	662	424	399	429	751	418	394	390	330
9:00 a.m.	493	779	539	662	424	399	468	752	430	432	391	359
10:00 a.m.	467	702	513	684	389	379	347	406	516	585	354	322
11:00 a.m.	341	415	513	684	389	379	241	235	395	387	342	330
12:00 a.m.	309	364	534	732	389	325	218	194	377	392	275	242
1:00 a.m.	309	364	534	732	389	325	152	89	329	266	236	192
2:00 a.m.	191	162	534	732	202	195	151	92	310	230	213	173
3:00 a.m.	191	162	534	732	202	170	154	103	213	156	194	157
4:00 a.m.	182	160	267	209	202	170	155	104	248	178	200	175
5:00 a.m.	175	153	302	338	202	170	170	164	273	354	228	225
6:00 a.m.	178	182	428	654	202	164	199	482	317	417	256	270
7:00 a.m.	178	282	500	841	202	160	208	487	541	973	235	134
8:00 a.m.	255	521	500	841	202	152	265	561	775	999	294	170
9:00 a.m.	342	657	544	765	202	137	299	561	999	999	258	157
10:00 a.m.	431	674	706	970	202	152	320	550	999	999	218	123
11:00 a.m.	431	674	706	999	202	152	362	539	999	999	217	114
12:00 a.m.	479	691	706	999	202	153	377	520	829	975	193	96

	Greater Noida						Muzaffarnagar					
6:00 a.m.	353	561	402	357	340	250	186	157	317	177	184	141
7:00 a.m.	367	543	430	451	344	305	178	139	317	178	174	110
8:00 a.m.	429	751	460	506	370	366	167	147	317	181	183	150
9:00 a.m.	468	752	462	552	391	382	218	218	317	218	184	151
10:00 a.m.	347	406	420	490	337	300	210	255	317	273	172	116
11:00 a.m.	241	235	417	461	296	246	189	159	276	192	174	114
12:00 a.m.	218	194	406	448	246	195	184	164	263	178	174	131
1:00 a.m.	152	89	315	293	220	176	184	164	206	121	172	129
2:00 a.m.	151	92	258	180	191	159	182	161	163	81	172	129
3:00 a.m.	154	103	213	152	180	138	184	133	163	74	168	125
4:00 a.m.	155	104	195	138	185	147	170	117	154	64	168	126
5:00 a.m.	170	164	218	237	202	222	170	109	176	120	171	131
6:00 a.m.	199	482	246	499	186	123	167	128	188	153	180	163
7:00 a.m.	208	487	323	456	177	98	199	184	221	200	229	263
8:00 a.m.	265	561	412	472	212	132	265	195	298	470	238	263
9:00 a.m.	299	561	414	471	241	153	312	225	376	563	246	209
10:00 a.m.	320	550	456	493	238	154	317	269	744	999	246	209
11:00 a.m.	362	539	493	578	227	143	317	269	824	999	159	85
12:00 a.m.	377	520	520	618	200	122	317	183	650	999	78	29

approximate increase of 30-40% in wheezing, respiratory troubles, exacerbation of the bronchial asthma have been reported during Diwali festival [16]. Inhalation of smoke from fireworks may cause cough, fever and dyspnoea leading to acute eosinophilic pneumonia. Findings of a study conducted in Bejaia, Algeria, showed that the short term variation in the ambient PM_{10} concentration was linked to cardiac and respiratory hospitalization [17]. Short term variation in particulate matter has been associated with an increase in mortality events [18]. The National Morbidity and Mortality Study (NMMAPS) confirmed the association between daily deaths and particulate matter of aero-diameter equal or less than 10 µm and a reduction of 5 µg/m^3 in the PM_{10} level could reduce respiratory hospitalizations. Short-term elevation in the concentrations of trace elements from firecrackers may also cause neurological and hematological effects on the exposed population. Fig. 1 represents the hourly variation in AQI as observed on pre-Diwali, Diwali and post-Diwali day with respect to variation in $PM_{2.5}$.

Air quality index variation: AQI signifies the health of the ambient air and shows how polluted it is or may become in the near future. Health concerns for different target groups can also be predicted by the AQI for a particular region or city. It is primarily focused on the health effects one is likely to experience within a few hours or days after breathing unhealthy air. For the study period (4th-21st November, 2020), the recorded AQI values for all the six cities were mainly hazardous with

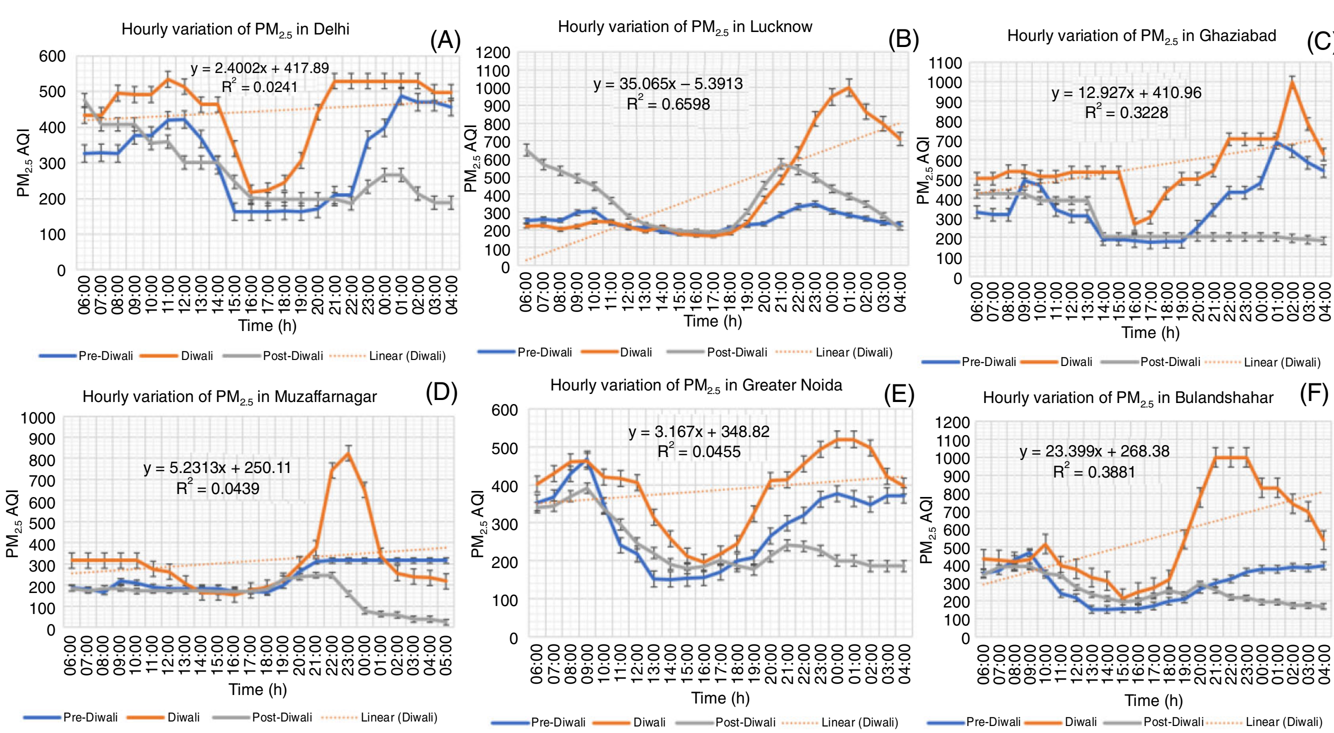

Fig. 1. Hourly variation in AQI with respect to $PM_{2.5}$

respect to both $PM_{2.5}$ and PM_{10}. As compared to previous year's values, a significant increase was observed in the AQI values, which is very alarming amidst the current pandemic situation. Fig. 2 represents the average AQI values. High variation in the AQI was observed for $PM_{2.5}$ earlier also, which may result in hazardous short-term effects [19]. Rise in daily premature mortality has also been associated with short-term health impacts resulting from ambient $PM_{2.5}$ concentrations, emphasizing on the importance of reducing emissions during Diwali festival to improve public health. In past also, high variations have been obtained at night time (10:00 p.m.-2:00 a.m.) on Diwali day and after. As compared to previous year (2019), higher average AQIs were obtained this year during the festival which is quite serious in the wake of the present pandemic situation. Only in Muzaffarnagar, as compared to last year, low AQI values were obtained on pre and Diwali day, still, the AQI was higher than last year on the post-Diwali day. It was seen that the AQI remained hazardous post Diwali, establishing that the particulate concentration did not dilute and disperse easily owing to the low wind speed showing an anti-correlation between the wind speed and $PM_{2.5}$ loading. Another probable reason of high AQI in the night hours is the shallow planetary boundary layer (PBL), which along with low wind speed does not easily dilute the surface $PM_{2.5}$ [20].

Meteorological factors and variation in concentration: Meteorological parameters are of high importance because transportation of air pollutants is governed by meteorological parameters such as temperature, wind speed and relative humidity [21]. The concentration of pollutants is more or less a function of mixing depth and also regulated by wind speed and physical size of the city. Wind speed may fluctuate from place to place and also varies throughout the day [22]. Seasonal changes also influence the concentration of pollutants. In order to see the daily changes in the average temperature, wind speed and relative humidity, they were recorded for all the selected cities. The average temperature, relative humidity and wind speed is given in Table-5. A positive but weak correlation was obtained between the temperature and AQI when it was plotted for $PM_{2.5}$ (Fig. 3) whereas a negative correlation was obtained with respect to humidity (Fig. 4). Similar observations were made in the rest of the cities as well. Previously, it has been shown that temperature has a positive correlation to the particulate concentration, whereas a negative correlation was obtained with respect to humidity [23]. The negative correlation with humidity may be due to the increase in the rate of absorption of particulate matter with the increase of humidity. Table-6 represents the average AQI values from 4th-21st November 2020.

TABLE-5
AVERAGE METEOROLOGICAL DATA COLLECTED DURING THE STUDY

City	Average temp. (°C)	Average humidity	Average wind speed (km/h)
Lucknow	21.96 ± 1.48	57.30 ± 12.88	2.47 ± 2.25
Muzaffarnagar	30.65 ± 1.22	48.50 ± 11.25	1.38 ± 1.02
Greater Noida	32.96 ± 0.46	46.51 ± 12.36	2.13 ± 0.73
Bulandshahar	32.45 ± 0.65	46.75 ± 6.23	2.50 ± 1.58
Ghaziabad	29.01 ± 0.43	63.71	4.51 ± 1.83
New Delhi	19.16 ± 2.91	66.51 ± 0.35	0.97 ± 1.26

COVID-19 with respect to air pollution: COVID-19 is linked to respiratory trouble, which may be influenced adversely by ambient air pollution, especially in developing countries like India. A study conducted in the USA associated $PM_{2.5}$ level with the death rate concluding that the countries with annual

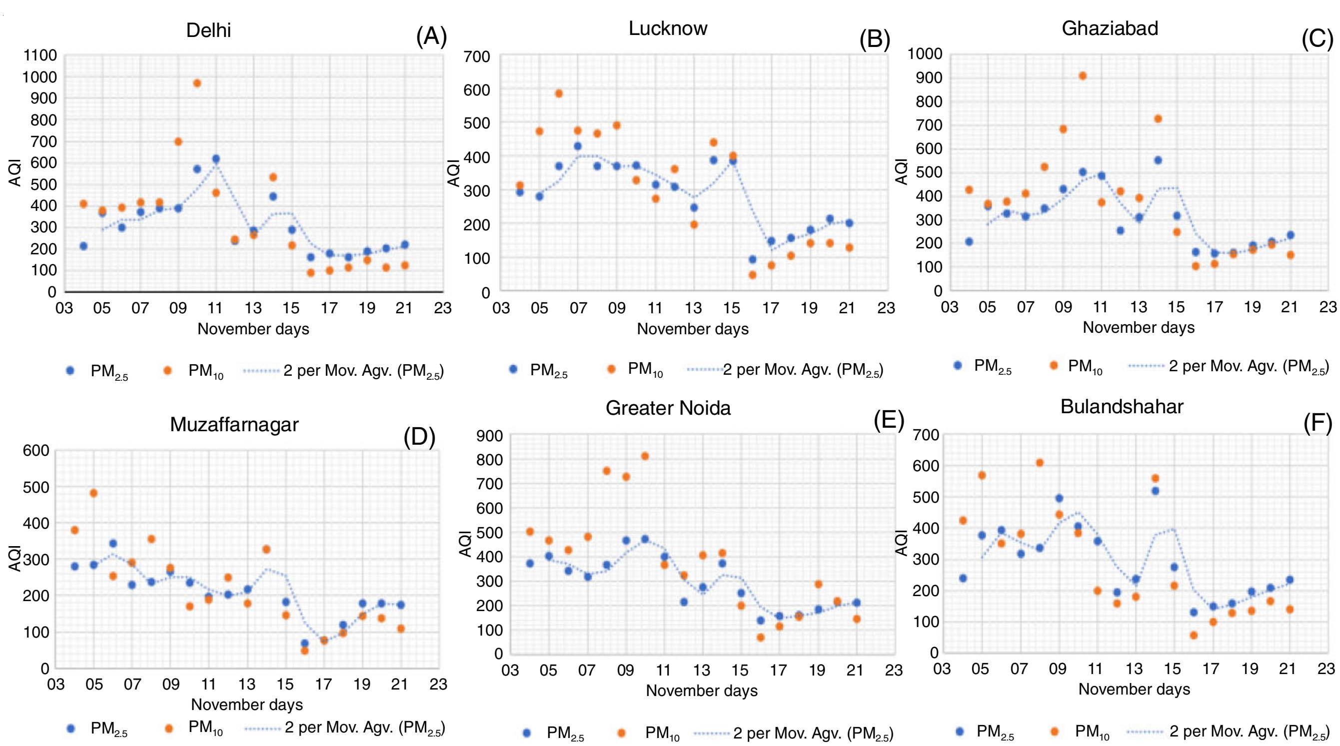

Fig. 2. AQI representation with respect to $PM_{2.5}$ and PM_{10}

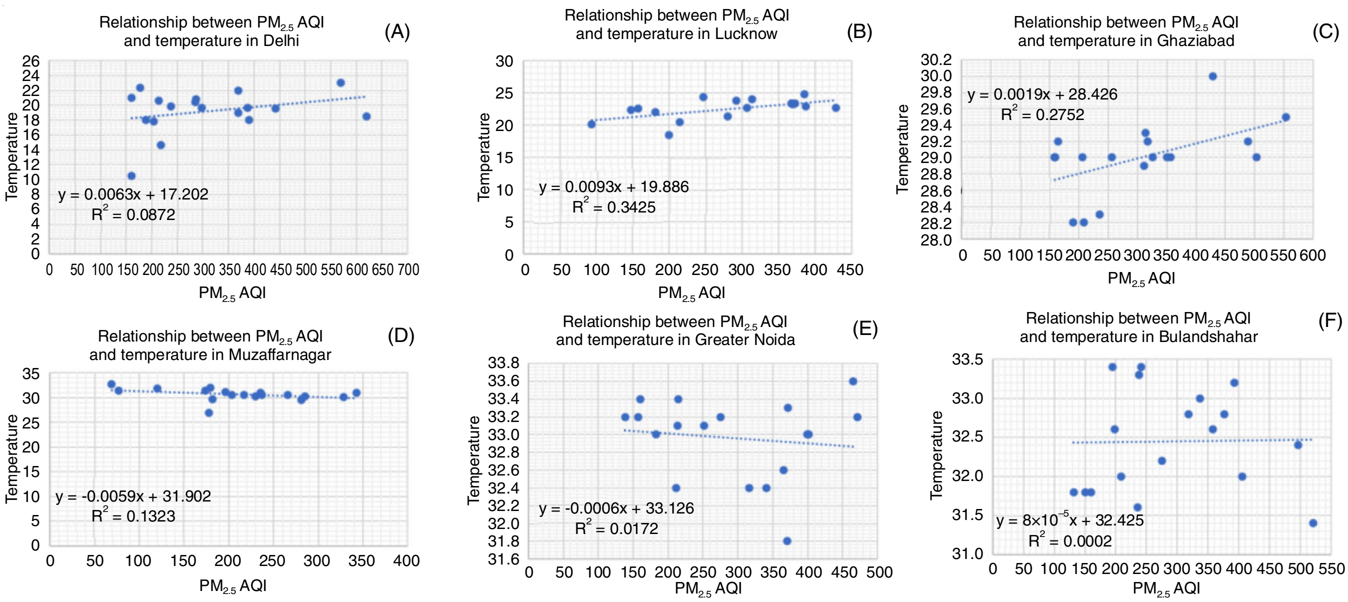

Fig. 3. Correlation between temperature and AQI with respect to $PM_{2.5}$

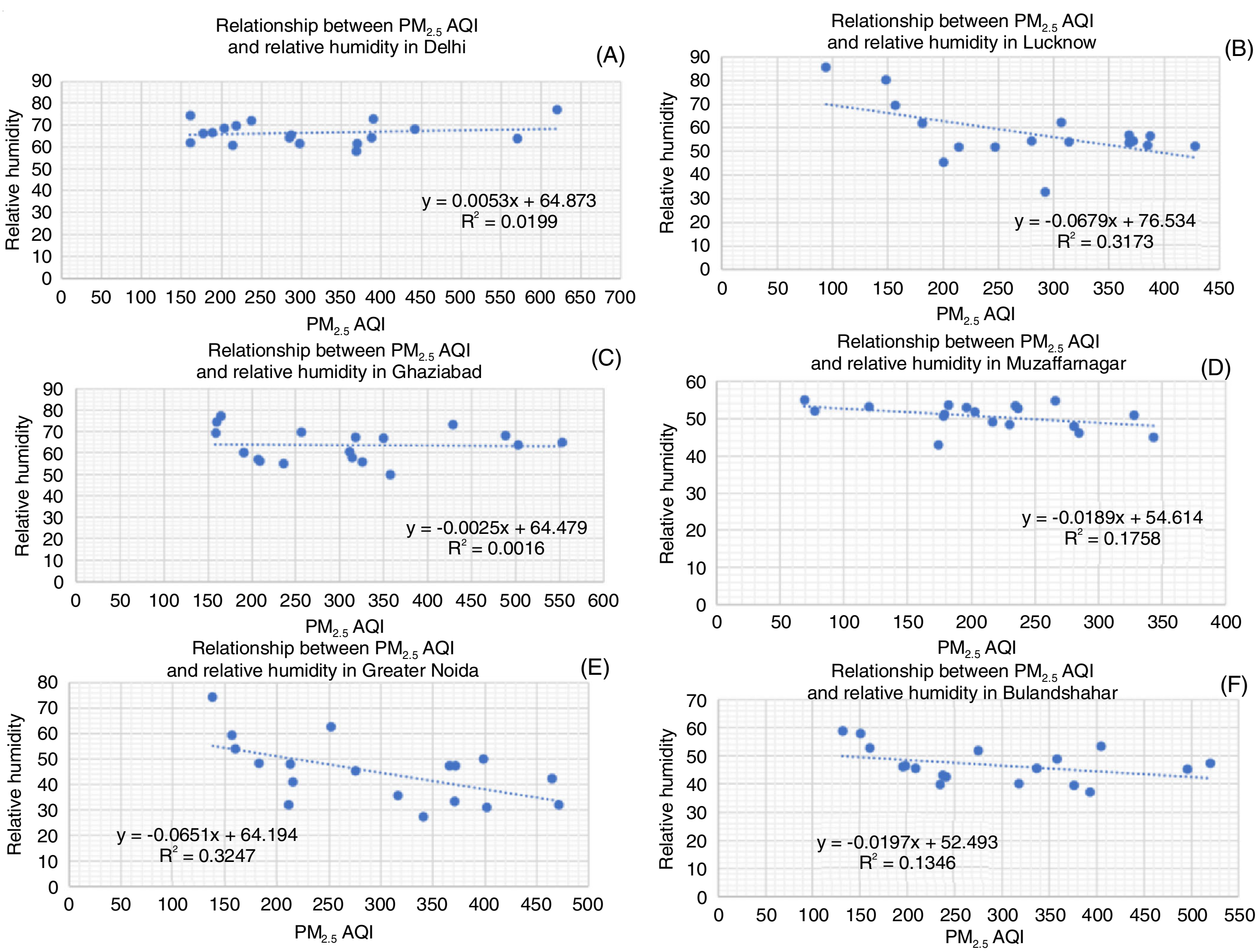

Fig. 4. Correlation between relative humidity and AQI with respect to $PM_{2.5}$

high particulate contamination like India are more at risk [24]. Oxidizing pollutants may cause despaired immune functions and hamper the efficiency of lungs to clear off the virus. Findings from Italy have highlighted that the virus became more lethal in the regions with high pollution like Lombardy and Emilia Romagna, making it an important co-factor [25]. Adsorption

TABLE-6
AVERAGE AQI VALUES IN DELHI, GHAZIABAD, BULANDSHAHAR, GREATER NOIDA, MUZAFFARNAGAR AND LUCKNOW

Date	Delhi		Ghaziabad		Bulandshahar		Greater Noida		Muzaffarnagar		Lucknow	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
04-11-2020	214	409	207	428	241	424	371	503	281	381	273	284
05-11-2020	369	378	357	366	376	569	402	467	285	483	235	468
06-11-2020	298	392	326	377	393	350	341	435	343	255	316	524
07-11-2020	370	415	314	410	318	382	316	482	230	291	364	347
08-11-2020	388	417	350	524	337	610	366	751	237	355	275	319
09-11-2020	390	697	429	685	496	444	465	726	266	276	306	340
10-11-2020	570	969	503	909	405	385	471	812	235	171	298	258
11-11-2020	620	461	488	373	358	200	399	365	196	189	249	240
12-11-2020	238	243	256	422	195	159	195	159	203	250	212	280
13-11-2020	285	265	311	392	237	180	275	404	217	178	226	240
14-11-2020	442	533	553	729	520	559	371	413	328	327	325	349
15-11-2020	287	217	318	247	275	216	251	200	182	146	298	228
16-11-2020	161	88	165	106	131	57	138	68	69	48	96	58
17-11-2020	177	100	159	115	151	101	157	114	77	76	151	99
18-11-2020	161	113	160	156	160	153	160	153	120	96	157	103
19-11-2020	189	147	191	172	198	286	183	286	179	143	167	108
20-11-2020	204	114	209	195	209	216	215	216	178	137	187	108
21-11-2020	218	122	236	150	235	145	211	145	174	110	185	120

of COVID-19 can occur on particulate matter causing long range transportation. A latest study has suggested that the virus can travel through the air and stay suspended for about a half-hour [26]. A study conducted in 120 cities of China between 23rd January- 29th February, 2020 focusing on meteorological variations and concentration of $PM_{2.5}$, PM_{10}, SO_2, CO, NO_2 and O_3 on the spread of the virus found a positive correlation between $PM_{2.5}$, PM_{10}, NO_2 and O_3 with COVID-19 confirmed cases. A 10 μg/m^3 increase in the concentration was associated with 2.24, 1.76, 6.94 and 4.76% hike in the confirmed cases associated with $PM_{2.5}$, PM_{10}, NO_2 and O_3 indicating a significant influence of air pollution with COVID-19 cases and thereby emphasizing on the importance of countrywide lockdown as a preventive measure. However, the present study did not support a correlation between poor AQI with the daily COVID-19 cases reported. There was no positive relationship established between the AQI with respect to $PM_{2.5}$ and the COVID-19 cases (Fig. 5). A correlation coefficient of 0.39, 0.26, 0.38, 0.18, 0.06 and 0.07 were obtained between the number of COVID-19 cases reported and the $PM_{2.5}$ AQI for the study period. Table-7 summarizes the number of cases reported during the study period. Although, the short term effect did not show any positive association between the COVID-19 related cases and adverse rise in the air quality, in future, long-term exposure to air pollution and COVID-19 infection may have an additive adverse effect on health, particularly related to heart and blood

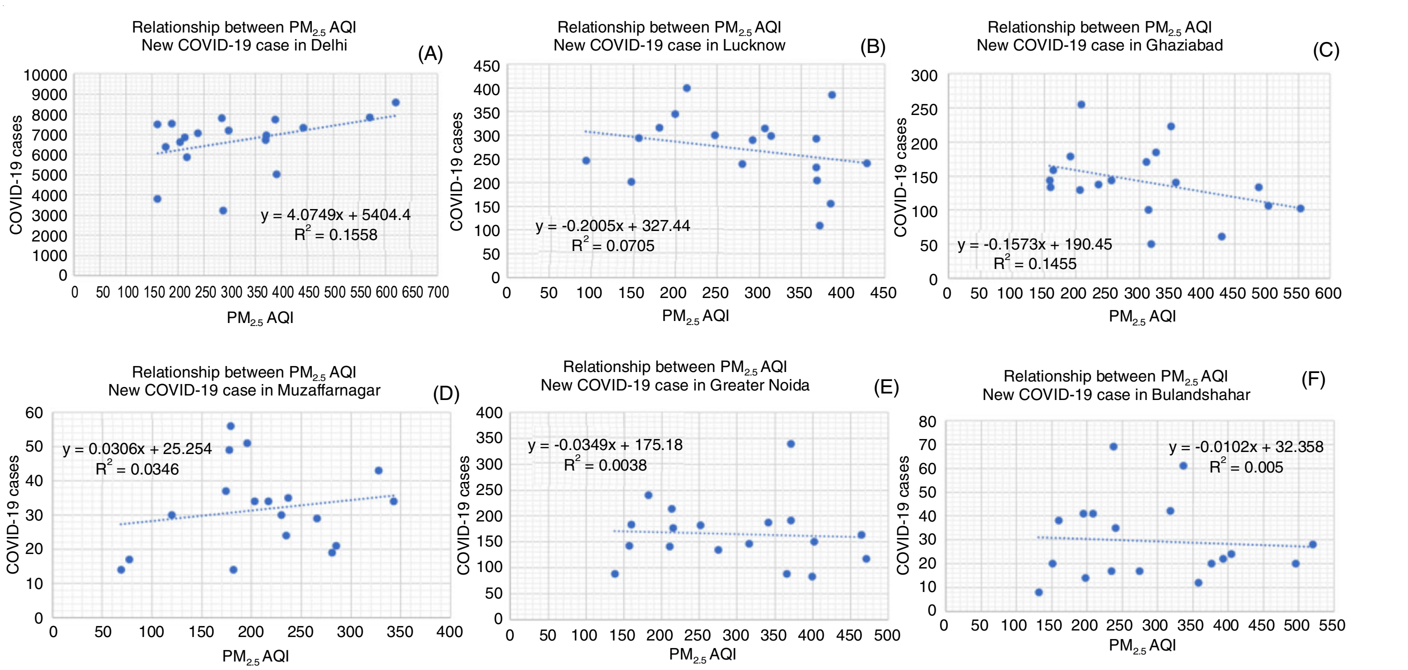

Fig. 5. Relationship between AQI with respect to $PM_{2.5}$ and COVID-19 cases reported from 4th-21st November, 2020

TABLE-7
COVID-19 REPORTED CASES FROM DELHI, GHAZIABAD, BULANDSHAHAR, GREATER NOIDA, MUZAFFARNAGAR AND LUCKNOW

Date	Delhi		Ghaziabad		Bulandshahar		Greater Noida		Muzaffarnagar		Lucknow	
	Cases	Deceased	Cases	Deceased	Cases	Deceased	Cases	Deceased	Cases	Deceased	Cases	Deceased
04-11-2020	6842	51	130	0	35	1	340	0	19	0	290	1
05-11-2020	6715	66	141	1	20	1	150	0	21	0	240	11
06-11-2020	7178	64	185	0	22	0	187	0	34	1	293	5
07-11-2020	6953	79	100	0	42	0	146	0	30	0	241	5
08-11-2020	7745	77	223	0	61	1	88	1	35	0	232	1
09-11-2020	5023	71	61	0	20	0	164	0	29	0	205	2
10-11-2020	7830	83	107	0	24	0	117	1	24	0	109	4
11-11-2020	8593	85	134	0	12	0	83	1	51	1	298	0
12-11-2020	7053	104	144	0	41	0	214	1	34	1	315	4
13-11-2020	7802	91	171	1	69	0	134	0	34	1	300	4
14-11-2020	7340	96	103	1	28	0	192	1	43	0	386	2
15-11-2020	3235	95	50	0	17	0	182	0	14	0	155	5
16-11-2020	3797	99	159	1	8	1	88	0	14	0	247	1
17-11-2020	6396	99	144	0	20	0	142	0	17	0	202	3
18-11-2020	7486	131	134	1	38	0	183	0	30	1	295	6
19-11-2020	7546	98	179	2	14	1	240	0	56	0	316	3
20-11-2020	6608	118	255	0	41	1	177	1	49	1	400	4
21-11-2020	5879	111	138	1	17	1	141	1	37	2	345	3

vessels, leading to greater vulnerability and less resistance to COVID-19.

Conclusion

The current time has become very crucial for India as the rest of the world is experiencing a re-surge in COVID-19 cases. The festival of Diwali coinciding with the onset of winter season has augmented the gruesome health effects related to poor air quality countrywide, which is of particular concern during the pandemic times. Despite the ban imposed on the burning of firecrackers, hazardous AQI values were recorded on the day of Diwali and after, for six of the most polluted cities in northern region *viz.* Delhi, Lucknow, Ghaziabad, Greater Noida, Muzaffarnagar and Bulandshahar selected for the study. As depicted by the hourly variation data, the AQI values further deteriorated in the evening hours having the peak around midnight. Short term variations in air quality may lead to long-term health effects related to pulmonary and cardiovascular systems and these are the systems which are greatly affected in COVID-19 infection. Present findings have minutely studied the variation in air quality during the festive season in some of the prominent/North Indian cities including the national capital, New Delhi. Although, the present study suggested no positive relation between COVID-19 related cases and deterioration of the air quality due to short term exposure, however, long term exposure to air pollution along with COVID-19 infection may lead to unfavourable effects on health. In order to curb air pollution, several policies and strategies have been devised by the Government of India [27]. The findings suggest what lies ahead of us in future and calls for stringent policies that are utmost necessary to be implemented to reduce air pollution and for the protection of health of an individual and community. Furthermore, modelling and emission flux studies are needed to better understand the variation in particulate matter during Diwali festival and thereafter, and how it is going to affect human health in the long run.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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