ASSESSMENT OF IMPACT OF COVID-19 LOCKDOWN ON AIR QUALITY IN NATIONAL CAPITAL REGION OF NEW DELHI, INDIA

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ABSTRACT

After the World Health Organization declared COVID-19 as pandemic on 11th March 2020, the Indian government adopted a complete phased lockdown strategy starting from 23rd March until 31st May 2020. During this period, road/rail/air traffic, industrial operations and offices were completely restricted except for the essential services. Here, an attempt was made to assess the effect of the lockdown period on five pollutants: PM_{10}, $PM_{2.5}$, SO_2, NO_x, and ozone at three sites, Jahangirpuri in North Delhi and Sonipat and Panipat townships located along the national highway leading to north India. These pollutants, except ozone, decreased at all sites during lockdown phase 1 compared to before lockdown. $PM_{2.5}$ load reduced by 28.1, 33.5, and 40.8 % at Jahangirpuri, Sonipat and Panipat, respectively. PM_{10} remained either close to or higher than National Ambient Air Quality Standards (NAAQS) due to prevailing high-speed winds. NO_2, a precursor for formation of O_3 decreased consistently at all sites, except an increase in phase 3 at Panipat whereas O_3 consistently increased. This was a paradoxical situation as O_3 is formed by photochemical reactions among NO_x and volatile organic compounds, which require further detailed studies. These observations indicate that air pollutants decreased specific to the site(s) and pollutant(s). Such restriction can be applied in the future to control air pollution in this region.

Keywords: *air pollution, lockdown, meteorology, criteria pollutants*

INTRODUCTION

The World Health Organization (WHO) [1] released the news on 5th January 2020 regarding the outbreak of a new virus, SARS-CoV-2 (corona virus) across the world. Since the reporting of first COVID-19 case on 30th January 2020 in the state of Kerala in India, the number of infected persons has crossed the 1.8 million mark with 40 thousand deaths until 3rd August 2020. The entire world order has changed with the outbreak of this pandemic. To restrict the spread, lockdown strategies were adopted by different countries at different times depending on their local conditions. All transport services (road/rail/air) were

restricted, industries operations were ceased, all academic institutes and offices were closed, all outdoor activities were restricted, shopping malls and markets were shut. Only essential services were in operation during lockdown periods. The unexpected and sudden lockdown proved to be a blessing in disguise for combating air pollution [2 - 5]. Wuhan city in China was the first place in the world to adopt the lockdown strategy on 23rd January 2020 which resulted in a 63 % and 35 % reduction in NO_2 and particulate matter, respectively. There was no significant effect on SO_2 and carbon monoxide [6]. Lockdown implemented on 23rd March in Southampton town in the UK resulted in a 92 % reduction in NO_2 emission as compared to previous years 2017 - 2019 [7]. In general, studies emerging from different countries reflect a reduction in air pollution during lockdown periods.

In India, Janta curfew (complete lockdown) was first imposed on 22nd March, 2020 to restrict the spread of corona virus followed by complete lockdown phase 1 (25th March - 14th April) when there was complete lockdown, lockdown phase 2 (15th April - 5th May) when selected agricultural and industrial activities were allowed, lockdown phase 3 (6th May - 26th May) when industrial and construction activities were allowed. It resulted in a measurable change in concentration of PM_{10} and NO_X. Approximately a 44 % reduction in $PM_{10,}$ 8 % reduction in $PM_{2.5}$, 44 % reduction in NO_X and 32 % reduction in CO was reported in New Delhi during Janta curfew [8]. The reasons for this sharp decline in pollution levels were restrictions on transport services, construction sites, and industrial activities. The Air Quality Index (AQI) values were reported as satisfactory to the moderate category during lockdown days in the National Capital Region (NCR) of New Delhi (CPCB, 2020). No city was reported to experience poor or very poor AQI category during lockdown. Overall, a decrease of 43, 31, 18, and 10 % in $PM_{2.5}$, PM_{10}, $NO_{2,}$ and CO levels, respectively, was noticed during lockdown in India, but O_3 showed a rise in concentration by 17 % and SO_2 showed pinpoint changes [3]. Due to limited industrial emissions and reduction in transport services, a decrease of 24 to 45 % in

emissions of carbon dioxide was observed in Kolkata in the eastern part of the country during lockdown [9]. Similarly, the AQI of Silicon Valley (Bengaluru) in southern India changed from hazardous to improved after imposing lockdown [10]. NASA also indicated a 40 - 50 % reduction in NO_2 levels in New Delhi and Mumbai during lockdown period and aerosol concentration was also lowest compared to the past 20 years of data [2, 11]. Thus, the lockdown period provided an opportunity for the impact of reduced emissions from different sources on air quality. The outcome of such studies can help us control air pollution in the future. New Delhi and its surrounding regions (NCR) are the most polluted parts of the country and therefore it was worth exploring the impact of lockdown on air quality. In the present study, the impact of lockdown period on ambient air quality parameters was studied for four different periods, i.e., before lockdown (4th March - 24th March), during lockdown phase 1 (25th March - 14th April) when there was complete lockdown, during lockdown phase 2 (15th April - 5th May) when selected agricultural and industrial activities were allowed, and during lockdown phase 3 (6th May - 26th May) when industrial and construction activities were allowed. A yearly comparison of air quality data was also done, in which March to April 2020 data was compared to air quality data of March to April 2019.

STUDY AREA AND DATA COLLECTION

Three locations, Jahangirpuri in north Delhi and Sonipat and Panipat in the state of Haryana (north to New Delhi) located along the national highway connecting New Delhi to North India were selected for this study. The study sites are both residential and industrial type with lots of agricultural activities [12]. All three locations remain inflicted with high air pollution due to vehicular and industrial emissions. The climate in the NCR region during the study period (March 2020 - June 2020) remained semi-arid with hot and dry

summer with a maximum temperature of 45 °C. Dust storms (Aandhi) originating in the Great Indian Thar desert in western India were an additional source of aerosols in this region during this period.

The 24 hour daily average ambient air quality data, i.e., particulate matter ≤ 2.5 µm ($PM_{2.5}$), particulate matter ≤ 10 µm (PM_{10}), nitrogen dioxide (NO_2), ozone (O_3) and sulphur dioxide (SO_2) used in this study was taken from State Pollution Control Stations in Sonipat and Panipat and from Central Pollution Control Board (CPCB), New Delhi. CPCB provides online data through the Central Control Room for Air Quality Management (app.cpcbccr.com). Meteorology affects the air quality both directly and indirectly and plays important role in the spread of pollutants [13, 14].

RESULTS AND DISCUSSION

The 24 hour average data on $PM_{2.5}$, PM_{10}, NO_2, O_3, and SO_2 for three Jahangirpuri, Sonipat, and Panipat sites before and during lockdown starting from 1st March, 2020 to 31st May, 2020 were recorded. The average values of all five pollutants at three locations for each period, i.e., BL - before lockdown and phases 1, 2, and 3 of lockdown with percentage changes in pollutant concentrations calculated with respect to the concentration in preceding phase (Table 1). In general, there has been a decrease in concentrations of all pollutants at all sites in the first phase of lockdown compared to the period before lockdown. In lockdown phase 2 and 3, the concentrations either remained same or increased depending on pollutant(s) and location(s). These variations in pollutant concentrations are discussed below.

Variations in particulate matter

The $PM_{2.5}$ concentrations were within the limits of National Ambient Air Quality Standards (NAAQS) at Sonipat and Panipat sites except for Jahangirpuri whereas PM_{10} was above the NAAQS limits at all sites. This was because the general public started taking precautions about unnecessary movements before lockdown. The higher levels of PM_{10} could be due to the windblown dust or local re-suspension of particles as has been reported previously for this region [13 - 15].

The $PM_{2.5}$ concentration at Jahangirpuri site varied from 21 to 119 µg/m^3 (avg. 73 µg/m^3) before the lockdown in March and reduced to the range of 25 - 78 µg/m^3 due to lockdown (phase 1), i.e., the reduction is about 28 % (Table 1 and Figure 1). PM_{10} concentration at Jahangirpuri varied from 49 - 321 µg/m^3 before lockdown, which was reduced by 35 % and was in the range of 52 - 168 µg/m^3 after 1st phase of lockdown. The concentration increased slightly after the 1st phase of lockdown because there was gradual lifting of restrictions from certain activities. At Sonipat, maximum concentration of PM_{10} was 212.7 µg/m^3 before lockdown in March, which was reduced by 37 % and the maximum value was 148.4 µg/m^3 after 1st phase lockdown (Table 1 and Figure 1), while $PM_{2.5}$ concentration decreased from 71.1 µg/m^3 to 39.1 µg/m^3, i.e., the reduction was 34 % during the 1st lockdown phase. At the Panipat site, PM_{10} level was reduced from 289.5 µg/m^3 before lockdown to 182.2 µg/m^3 during complete lockdown (phase 1) showing ~ 36 % reduction, but it was increased after relaxations on certain activities after phase 1. Similarly, $PM_{2.5}$ concentration reduced by 41 % from 102.4 µg/m^3 to 49.8 µg/m^3 during the 1st phase of lockdown. In average, both $PM_{2.5}$ and PM_{10} at Sonipat and Jahangirpuri site, New Delhi during the March to May 2020 were lower compared to the same period in the previous year (2019), except that they show a slight increase at Panipat site, which may be attributed to local factors (Figure 2).

Table 1. Average concentrations of pollutants at three different sites along national highway 44 in NCR region and percentage change (decrease or increase) in pollutant levels before lockdown and during lockdown phases

POLLUTANT	$PM_{2.5}$ (µg/m³)	PM_{10} µg/m³	SO_2 (µg/m³)	NO_2 (µg/m³)	O_3 (µg/m³)
NAAQS (National Ambient Air Quality Standards)	60	100	80	80	100
WHO	25	50	20	40	100
A) BL	JAHANGIRPURI				
Mean ± SD	73.1 ± 27.9	173 ± 69.5	2.4 ± 1	76.7 ± 29.5	6.5 ± 1.8
Range	21.45 - 119.67	49.25 - 321.46	1.16 - 4.31	26.61 - 128.91	5.29 - 9.45
PHASE 1	- 28.1 %	- 35.7 %	- 54 %	- 5.2 %	- 9 %
Mean ± SD	52.5 ± 14	111.2 ± 30.3	1.1 ± 0.2	72.7 ± 10.7	5.9 ± 0.4
Range	24.84 - 77.96	52.79 - 168.29	0.68 - 1.81	58.85 - 94.02	5.66 - 7.38
PHASE 2	- 5.9 %	+ 11.6 %	+ 9 %	- 20.9 %	+ 11.6 %
Mean ± SD	49.3 ± 18.1	124 ± 46.4	1.2 ± 0.5	57.4 ± 18.4	6.7 ± 1.4
Range	27.2 - 88.46	59.46 - 243.21	0.37 - 2.54	22.98 - 88.84	5.24 - 10.24
PHASE 3	+ 56.4 %	+ 48.6 %	+ 441 %	- 25 %	+ 262.6 %
Mean ± SD	77.2 ± 27.9	184.5 ± 56.3	6.5 ± 4.6	43.1 ± 7.5	24.2 ± 17.6
Range	42.17 - 136.54	95.88 - 287.89	0.7 - 13.06	31.74 - 55.69	5.77 - 59.71
B) BL	SONIPAT				
Mean ± SD	34 ± 13.6	135.6 ± 45.8	27.5 ± 1.6	47.2 ± 12.5	20 ± 9.9
Range	12.74 - 71.19	69.65 - 212.74	23.86 - 33.06	35.37 - 75.29	7.67 - 34.97
PHASE 1	- 33.5 %	- 37.3 %	+ 1.4 %	+ 17.9 %	- 27.3 %
Mean ± SD	22.6 ± 7.3	84.8 ± 27.2	27.9 ± 0.4	55.7 ± 10.8	14.5 ± 4.4
Range	10.83 - 39.13	34.02 - 148.49	27.05 - 28.79	38.85 - 74.31	10.44 - 24.59
PHASE 2	+ 50 %	+ 69 %	- 0.7 %	- 5.7 %	+ 10.9 %
Mean ± SD	33.8 ± 12.4	143.4 ± 48.4	27.8 ± 0.5	52.5 ± 20.3	16.2 ± 3.7
Range	15.56 - 63.8	51.01 - 237.34	26.23 - 28.71	27.08 - 96.54	11.3 - 24.56
PHASE 3	+ 30.3 %	+ 33.1 %	- 1.7 %	- 8.9 %	+ 30.8 %
Mean ± SD	44.2 ± 13.5	191.1 ± 49.5	27.3 ± 1.3	47.9 ± 12.3	21.2 ± 4.5
Range	20.63 - 69.17	84.85 - 289.21	22.25 - 28.45	27 - 68.14	14.35 - 30.46
C) BL	PANIPAT				
Mean ± SD	52.6 ± 19.7	149.5 ± 59.4	17.5 ± 6.2	72.2 ± 21.8	28.4 ± 8.6
Range	19.68 - 102.44	63.91 - 289.55	8.51 - 29.38	38.81 - 108.43	14.21 - 42.1
PHASE 1	- 40.8 %	- 36.1 %	- 35.7 %	- 31.4 %	+ 16.8 %
Mean ± SD	31 ± 8.8	95.4 ± 31.3	11.2 ± 4.1	49.5 ± 7.8	33.3 ± 4.5
Range	13.33 - 49.85	38.84 - 182.24	2.83 - 18.12	36.77 - 64.12	23.16 - 40.05
PHASE 2	+ 65.2 %	+ 101.7 %	+ 6.1 %	- 4.6 %	+ 21.6 %
Mean ± SD	51.3 ± 19.0	192.7 ± 71.8	11.9 ± 6.5	47.2 ± 19.9	40.4 ± 10.4
Range	22.43 - 90.3	77.24 - 321.36	4.5 - 30.26	15.4 - 73.57	28.24 - 69.4
PHASE 3	+ 12.8 %	+ 8.7 %	+ 235 %	+ 46.3 %	+ 45.9 %
Mean ± SD	57.9 ± 24.9	209.5 ± 76.6	40.1 ± 23.2	69.1 ± 45	59.1 ± 16.2
Range	26.26 - 111.21	134.06 - 345.19	8.46 - 74.16	7.09 - 151.16	43.24 - 80.15

(-) Decrease in conc.   < 10 %   10 - 30 %   30 – 50 %   > 50 %

(+) Increase in conc.   < 10 %   10 - 30 %   30 – 50 %   > 50 %

Percentage change is calculated relative to the values in preceding phase. BL - Before lockdown (4th March - 24th March); Phase 1 (25th March - 14th April) when there was complete lockdown; Phase 2 (15th April - 5th May) when selected agricultural and industrial activities were allowed; Phase 3 (6th May - 26th May) when industrial and construction activities were allowed.
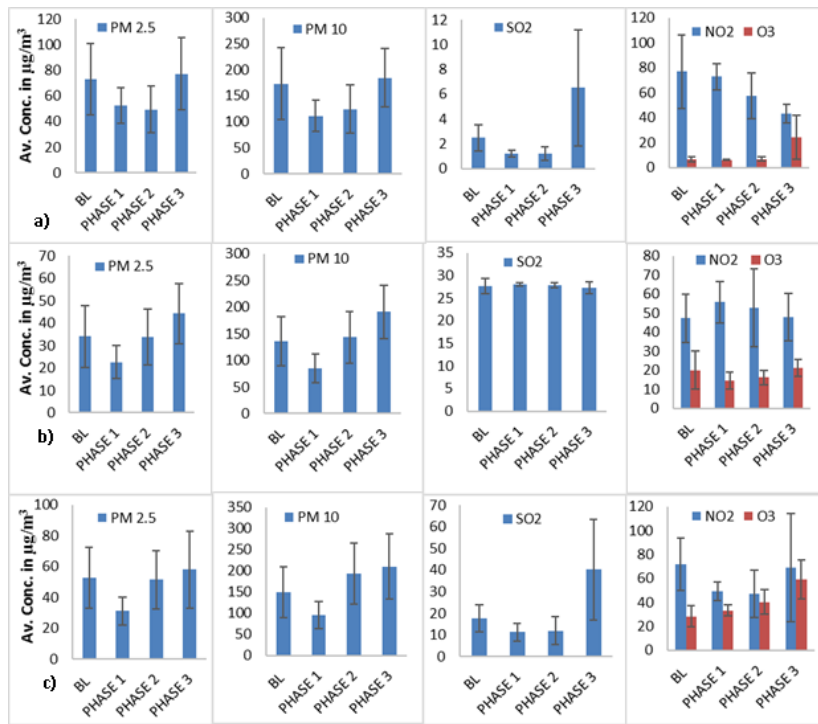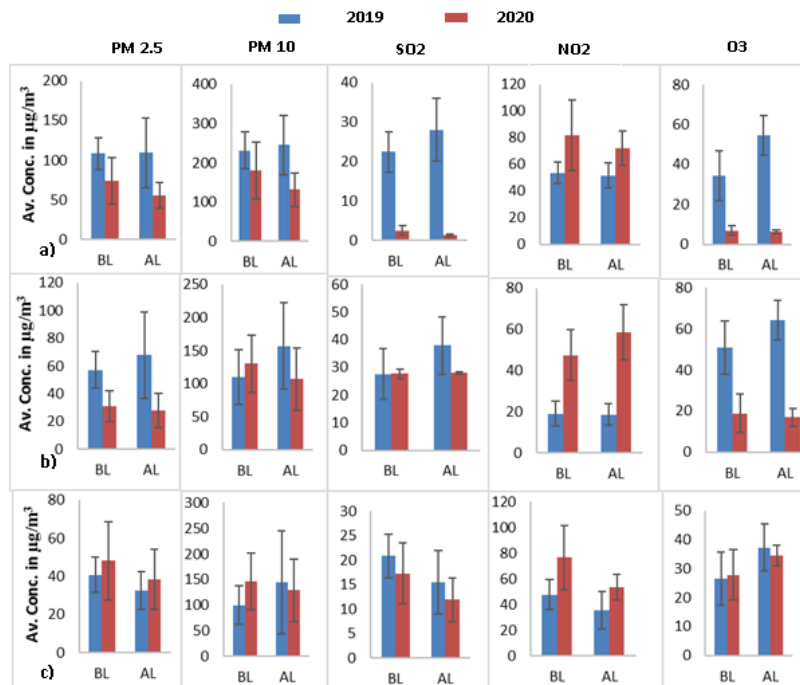
Figure 1. Concentration of PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$ and O$_3$ before lockdown and during different phases of lockdown in 2020 at: (a) Jahangirpuri (b) Sonipat and (c) Panipat (BL - before lockdown (4th March - 24th March); Phase 1 (25th March - 14th April) when there was complete lockdown; Phase 2 (15th April - 5th May) when selected agricultural and industrial activities were allowed; Phase 3 (6th May - 26th May) when industrial and construction activities were allowed)

Figure 2. Concentration of PM$_{2.5}$, PM$_{10}$, SO$_2$, NO$_2$ and O$_3$ before lockdown period (BL) and during lockdown period (AL) in 2020 compared to same period in previous year, i.e., in 2019 at (a) Jahangirpuri (b) Sonipat and (c) Panipat (BL - before lockdown (4th March - 24thMarch,2020); AL - during lockdown period (25th March - 26th May, 2020) - lockdown phases 1, 2 and 3)

Such high levels of both $PM_{2.5}$ and PM_{10} at Jahangirpuri could be attributed to vehicular emissions; vehicular movement induced re-suspension of surface dust and biomass burning at nearby dump yard site. Almost 89 % decline in the PM_{10} concentration has been observed at CRRI (Central Road Research Institute), New Delhi site due to lockdown by Kotnala [16]. At North Campus, Delhi University, New Delhi, $PM_{2.5}$ concentration decreased from 225.63 µg/m^3 before lockdown to 43.18 µg/m^3 after lockdown [17]. Jain and Sharma [18] have reported a significant decrease of 41 % and 52 % in the concentration of $PM_{2.5}$ and PM_{10}, respectively due to lockdown in Delhi. Similar to our observations, a decline of 45 % was observed in $PM_{2.5}$ concentration in Wuhan city, China due to the corona pandemic [18]. The increase in particulate matter at Sonipat and Panipat sites may be due to various industries, like fertilizers, thermal power stations and oil refineries situated in this region which became operational after 1st phase of lockdown. The decrease in the particulate matter at all three sites due to lockdown clearly indicated that the lockdown acted as a ventilator for the ambient atmosphere. Although PM_{10} and $PM_{2.5}$ were not within the NAAQS and WHO limits even after lockdown in NCR region, except $PM_{2.5}$ at Sonipat in the lockdown phase 1. Compared to same period in 2019, $PM_{2.5}$ and PM_{10} showed a decline, again due to restrictions (Figure 2). A slight increase in particulate matter concentration was noticed at the Panipat site, which can be attributed to local factors, like coal-based thermal power plants which were not shut down as an essential commodity during lockdown period and re-suspension.

Nitrogen dioxide and ozone

Vehicles are the major source of nitrogen dioxide along with power plants and industries, but during the lockdown period there was about 70 - 80 % reduction in road traffic in this region [18]. Ozone is formed via photochemical reactions among NO_x and volatile organic compounds. Meteorology also plays an important role in ozone formation because the photochemical reactions speed up during sunny days [19, 20]:

$$NO_2 + Sunlight \rightarrow NO + O$$
$$O + O_2 \rightarrow O_3$$
$$NO + O_3 \rightarrow NO_2 + O_2$$
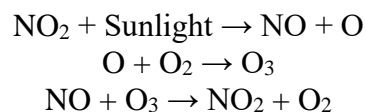
At the Jahangirpuri site, the average NO_2 before lockdown ranged from 26 - 128.9 µg/m^3, and the concentration was reduced to 58 - 94.0 µg/m^3 after the 1st phase of lockdown, denoting a significant decline (Figure 1 and Table 1). Similarly, a decrease in the concentration of NO_2 of about 50 % has been observed by Jain and Sharma [18] at Delhi due to lockdown. The NO_2 concentration continued to decrease in all subsequent phases of lockdown in the Jahangiripuri area because there were restrictions on vehicular movement, except for essential services. The O_3 was also decreased from 12.2 to 7.38 µg/m^3 during the 1st phase of lockdown at Jahangirpuri station, but began to increase continuously after relaxation in subsequent lockdown phases. This was a paradoxical observation because ozone forming precursor oxides (NO_x) decreased but ozone increased, which requires more detailed studies. The NO_2 concentration at the Sonipat site before lockdown varied from 35 - 75 µg/m^3 and the average NO_2 concentration first increased during lockdown phase 1 and then decreased (Table 1). This could be due to NO_x emissions from agriculture fields and wetlands because this period coincided with crop harvesting and residue burnings. Similar to the Jahangirpuri site, ozone showed an increase in phase 2 and 3. At Panipat site, NO_2 decreased in lockdown phase 1 and 2 by 31 % and 4.6 %, respectively, and then showed increase, but again ozone consistently increased (Table 1). An increase in NO_2 could be due to the starting of industrial operation in phase 3, but this could not directly explain the consistent increase in ozone at the Panipat. The sources of nitrogen dioxide in the Panipat region include vehicles, oil refinery, thermal power plant and fertilizer industries [21]. Similar to Panipat and Jahangirpuri, an increase of 7 % in O_3 concentration in New Delhi and 3 % in Chennai was observed [18]. Xu et.al. [22] have also reported an increase in the concentration

of O_3 in Wuhan city in China during the lockdown period. The concentration of NO_2 showed a significant increase compared to 2019 at all three sites, whereas ozone decreased significantly in 2020 compared to same period in 2019. The high concentration of NO_2 can be attributed to crop residue burning in the area and other agriculture field related emissions [23]. Increase in the concentration of O_3 may be associated with a decrease in concentration of particulate matter which resulted in more penetration of sunlight through atmosphere resulting in increase in photochemical activity and hence more O_3 formation [3]. These two observations require more detailed studies by incorporating more stations; regardless of lockdown, NO_2 showed a significant increase.

Sulphur dioxide

Sulphur dioxide concentration was higher at Sonipat and Panipat stations compared to Jahangirpuri, New Delhi station. Industries and coal-based thermal power plants are responsible for nearly 27 % higher SO_2 concentration in the NCR region compared to New Delhi [21]. The concentration of SO_2 shows a decrease at all three sampling stations during lockdown compared to the same time period last year (Figure 2). Sonipat station has recorded a very high concentration of SO_2 compared to the other two stations (Table 1 and Figure 1). The possible sources of SO_2 emission could be local industries, coal-based power plants, and domestic level burning activities. Stubble burning in this region could also have contributed SO_2 [23]. Singh and Sidhu [24] reported that about 25 - 30 % N and P, 35 - 40 % S, and 70 - 75 % of K uptake are retained in the wheat residue. Panipat site showed an increase in concentrations during lockdown phases 2 and 3, probably due to emissions from thermal power plant, National Fertilizer Limited and oil refinery operating around the city [25, 26]. The lowest concentration at Jahangirpuri site was due to phasing out of diesel vehicles and implications of Bharat Stage IV (BS-IV) norms in vehicles [8]. There was a significant decrease in concentration of SO_2 compared to last year,

i.e., 2019, and it was more prominent at the Jahangirpuri site compared to other two sites because of less vehicular movement in that particular area. The other two sites also showed a decrease in concentration, but to a limited extent due to local factors and thermal power stations located in that area.

Meteorology also played a significant role in the dispersion of air pollutants in almost all three sites. Generally, high wind speed and low relative humidity help the dispersion of air pollutants compared to stagnant days [3]. Before lockdown, the relative humidity varied from 54 to 96 % with a wind speed varying from 0.28 to 1.81 m/s in all three sites, which does not favour the dispersion of air pollutants. After lockdown, the relative humidity decreased to 33 %, although wind speed does not alter much. A negative correlation has also been observed between relative humidity and dispersion of particulate matter by Jayamurugan et.al. [27]. Thus, both lockdown and the prevailing meteorological conditions, like high wind speed and relative humidity, also played a role in reducing pollutants level. Thus, a decrease in pollution load due to lockdown has certainly helped in improving people's health and the exact benefit of this lockdown may not be good economically but would come in knowledge with due course of time.

CONCLUSION

The air quality has improved significantly after the implementation of lockdown compared to period before lock down. The concentrations of pollutants started to increase slowly during phase 2 due to relaxation in agricultural and industrial activities. The role of meteorological parameters was noticed during the study, particularly on PM_{10}. Maximum improvement in air quality was observed at Panipat site due to shut down of industries. The Jahangirpuri site in New Delhi also showed improvement in air quality during lockdown phases due to decrease in vehicular emissions, whereas at the Sonipat site, the air quality was better due to combined effect of shut down of the industry

and limited vehicular movements along the national highway. Although an epidemic, COVID-19 turned out to be a ventilator for the environment. The NO_2 and ozone maxima in concentration during the entire study period do not match each other at any site, although NO_2 is a strong precursor for ozone formation. This requires further investigations. The lockdown strategy could be implemented in the future to limit air pollutants, but with caution because it has a very negative effect on the economic and social environment of the country.

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