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Effect of nation-wide lock-down due to Covid-19 over industrial pollution in Delhi, India

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Abstract

In India, very first infection due to Covid-19 was reported by end of January 2020 and, the same has been increased with the span of time. In order to fight the increasing risk among the citizens of nation, the complete lock-down was declared on March 25, 2020 for initially 21 days and thereafter it has been subsequently increased up to its present 4th phase, which would be remain continue until May 31, 2020. First two phases of lock-down were imposed without any relaxation, however, there were gradual relaxation implemented in third and fourth lock-down phases. Air pollution depends on emission of the pollutants from vehicles and industries, as well as dust from construction activities. Due to lock-down, operations concerning these activities were completely shut down. The effect of lock-down on PM2.5, PM10, NO2, SO2, CO and AQI level was studied and comparison of PM2.5, PM10, NO2, SO2, CO and AQI during lock-down with same dates of previous year was also considered.

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1. Introduction

In the last week of year 2019, after reporting of the suspected pneumonia infection cases in China, World health Organization (WHO) started an investigation on this unknown disease. On January 10, 2020 based on information provided by China’s authorities, the WHO recommended public health measure and the surveillance of influenza and severe acute respiratory infections. WHO does not endorse any specific steps for travelers. On January 30, 2020 WHO declared the 2019-nCoV outbreak a Public Health Emergency of International concern [1–2]. On January 13, 2020 officials confirmed a case of the 30 (Covid-19) in Thailand. It was the first case outside china. India reported its first case of Covid-19 on January 30, 2020. With the advances of days, the number of cases of Covid-19 infection kept on increased. India has suspended all tourist visas, as a majority of the confirmed cases were linked to other countries in March 2020. The transmission of Covid-19 accelerated with much pace during March. On March 25, 2020, the Government of India (GoI) implemented a nationwide lock-down for 21 days [Phase-I] in-line with other countries to check the spread of infections due to Covid-19 [3]. Fig. 1 shows the major countries, implemented lock-down along with their population under the lock-down. On 14 April, lock-down again extended the nation-wide until 3 May [Phase-II] [4]. On 1 May, the Government of India extended the nation-wide lock-down further by two weeks until 17 May [Phase-III]. As on date, India has reported more than 112,000 infections due to Covid-19 across the country, with about 13,000 infections due to Covid-19 in Delhi itself. In Phase I and II lock-down, all commercial activities were not allowed all over the country, including Delhi. But in Phase-III of lock-down, Public transport was remained shut, private vehicles were allowed to some extent. India has declared Phase IV of lock-down from 18 May to 31 May 2020. In lock-down IV all construction works were allowed. Industries were also allowed. The personal and commercial vehicles were also granted with some conditions. Pollution refers to the contamination of the environment with unwanted materials that may deteriorate the human

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In Delhi pollution due to vehicular emissions, dust and industries are 41%, 21.5% and 18%, respectively [5–6].

The National Capital Territory (N. C. T.) of Delhi (GNCT) covers an area of 1,484 square kilometers and the population of Delhi are about 20 million [7]. The primary source of pollution in N.C.T. is emission pollution. The other sources include dust from construction sites and other industrial activities [8]. Pollution has been a very bigger threat in the city for more than two decades and GoI and Government of National Capital Territory (GNCT), Delhi have been working to check the different pollution sources including air pollution. Fig. 2 shows the level of air pollution in the city for past couple of years. Fig. 2 shows the quality of air of Delhi with level of particulate matters (PM2.5 and PM10) in the air. Regulatory bodies have several times implemented Odd-Even scheme to limit vehicular emissions, restrictions over the constructions etc., but favorable outcome of such efforts is yet to come [9–11].

2. Materials and Methodology:

Delhi Pollution Control Committee (an organization under GNCT, Delhi) has mandated to record the daily pollution level data. In order to accomplish this work, there are 26 stations allocated in Delhi for continuous monitoring of real time data from these stations (Fig. 3) [12]. At these stations, measurements are taken regarding the gas concentration (of Ammonia, Benzene, Carbon Mono-oxide, Nitrogen dioxide, Nitrogen oxide, Oxides of Nitrogen, Ozone, p-Xylene, Sulphur Dioxide and Toluene), particulate concentration (PM2.5, PM10) and meteorological conditions (ambient temperature, barometric pressure, relative humidity, solar radiation, vertical wind speed, horizontal wind speed and wind direction. The air quality of the industrial stations / clusters is generally poor and even during the days of lock-down; their air quality is a serious concern to be examined (Fig. 4) [13]. One can see that air quality is still unhealthy in the four industrial stations Bawana, Jhilmil Colony and Wazirpur of Delhi to be considered for this study. In what follows, we have collected data of PM2.5, PM10, NO2, SO2, CO and AQI for the lock-down periods corresponding to Phases –1st, to 3rd and also for previous year 2019 during the same time of slot. The real time data of different pollutants during lock-down period of different phases 1st to 3rd were collected [14].

Table 1 discusses the particulate matters and gases concentration being considered for assessment of AQI of the four industrial stations with its safe limits for each of the factor contributing to the AQI. These information’s have been collected from World Air Quality Index platform for the year 2019 and 2020 and critically examined. The salient outcome of the investigations is present in the upcoming section of the manuscript. Moreover, geological information of the chosen stations is as follows: Bawana (Latitude 28.7757959 and Longitude 77.0462514), Jhilmil Industrial Area (Latitude 28.672114 and Longitude 77.313832) and Wazirpur (Latitude 28.700505 and Longitude 77.165603). The same has been shown in the map below (highlighted in red circle in Fig. 3). In the analysis below, Area-1 has been used for Wazirpur, and Area-2 for Jhilmil Industrial Area, while Area-3 for Bawana [16–18].

3. Results and discussion

PM2.5, PM10, O3, NO2, SO2, CO and AQI data has been collected from monitoring stations as mentioned above. The values are based on daily average and are converted to the US EPA AQI standard. The data for 2020 has been divided into 4 broad buckets, on the basis of lock-down imposed by the government due to COVID-19.

- Pre-Lock-down: 1st March 2020 to 24th March 2020 (24 days)
- Lock-down 1.0: 25th March 2020 to 14th April 2020 (21 days)
- Lock-down 2.0: 15th April 2020 to 3rd May 2020 (19 days)
- Lock-down 3.0: 4th May 2020 to 17th May 2020 (14 days)

3.1. Analysis of change in pattern recognition for the concentration of the pollutants by considering current lock-down period together with period of the previous year 2019

In order to study the impact of lock-down on the concentrations of the PM2.5, PM10, O3, NO2, SO2, CO and AQI in the period 25th March to 17th May for year 2019 and during lock-down of the current year, 2020. An in-depth analysis has also been carried out regarding to all the three stations. Most of the pollutants were found to be in declining trend comparing to its status of the previous year except a little increasing trend in SO2 in the Area –2 (Jhilmil Colony) and Area-3 (Bawana), and CO in Area-1 (Wazirpur) and Area-2. The same has been depicted in the Figs. 5a-5g below.
comparison of the above mentioned parameters pronounced that there is significant variation in these parameters with an increasing in O₃ contrary decline patterns of other parameters.

3.2. Statistical assessment of variations of parameters in different phases of lock-down

Further, we have analyzed the average, minimum and maximum of PM₂.₅, PM₁₀, O₃, NO₂, SO₂, CO and AQI for 3 phases of the lock-down. The comparison has been done by taking average over the three periods. The analysis has been presented in the table 2 below. The table shows the variations of the parameters phase-wise and one may be able to see that a significant variation has been attained in the inter-phases w.r.t. the same period during 2019.

The details findings of table 2 may be summarized as below:

- PM₂.₅ has shown the decrement in average, minimum and maximum values. Thus, it can be seen that lock-down has a positive impact in reducing PM₂.₅. The average value has decreased by 33.44% in Area-1, 29.66% in Area-2 and 26.55% in Area-3.
- PM₁₀ has shown the reduction in the values of average, minimum and its maximum. Thus, it can be seen that lock-down has a positive impact in reducing PM₁₀. The average value has decreased by 65.50% in Area-1, 58.80% in Area-2 and 53.14% in Area-3.
- O₃ has declined by a significant 66.20% in Area-1 during Lock-down 1.0 and an average of 14.04% in Area-1 during Lock-down 2.0 and Lock-down 3.0. But, on the other hand, minimum value of O₃ has increased by 46.91% in Lock-down 1.0, 147.84% in Lock-down 2.0 and 184.50% in Lock-down 3.0. Though, maximum value has decreased by 51.80%.
- NO₂ has shown decline in average, minimum and maximum values. Thus, it can be seen that lock-down has a positive impact in reducing NO₂. The average value has decreased by 62.42% in Area-1, 37.42% in Area-2 and 49.90% in Area-3. The minimum value has increased by 3.58% in Area-2 during Lock-down 3.0 and has increased by 23.36% in Area-3 during Lock-down 3.0.
- SO₂ has shown a decrease in Area-1 and increase in Area-2 and Area-3. SO₂ has decreased by 43.14% in Area-1 and has increased by 8.82% in Area-2 and increased by 4.72% in Area-3.
- CO has shown increase in average, minimum and maximum values in Area-1 and Area-2 but a decrease in Area-3. CO has increased by 13.39% in Area-1, 2.71% in Area-2 and decreased by 58.45% in Area-3.
- AQI has shown decline in average, minimum and maximum values. Thus, it can be seen that lock-down has a positive impact in reducing AQI. The average value has decreased by 48.88% in Area-1, 41.83% in Area-2 and 42.43% in Area-3.
3.3. Analysis of concentration change of major pollutants for the pre and during lock-down period:

The data has been analyzed to find the change in the values of percentage of PM$_{2.5}$, PM$_{10}$, O$_3$, NO$_2$, SO$_2$, CO and AQI from pre-Lock-down to Lock-down 1.0, Lock-down 1.0 to Lock-down 2.0 and Lock-down 2.0 to Lock-down 3.0. The values of the concentration have been analyzed and are presented in the table 3 below.

### Table 1

| Sl. No. | Parameter | Limits (Good / Satisfactory / Unhealthy / Poor / Very poor / Severe) |
|---------|-----------|---------------------------------------------------------------|
| 1       | PM$_{2.5}$(24 – hr) µg/m$^3$ | 30 / 60 / 90 / 120 / 250 / 380 |
| 2       | PM$_{10}$(24 – hr) µg/m$^3$  | 50 / 100 / 250 / 350 / 430 / 700 |
| 3       | O$_3$(8 – hr) ppb             | 25 / 51 / 86 / 106 / 381 / 450 |
| 4       | NO$_2$(24 – hr) ppb           | 21 / 43 / 96 / 149 / 213 / 750 |
| 5       | SO$_2$(24 – hr) µg/m$^3$      | 0.1 / 0.3 / 0.6 / 0.9 / 1.2 / 1.5 |
| 6       | CO(24 – hr) ppm              | 0.9 / 1.7 / 8.7 / 14.8 / 29.7 / 40.0 |
| 7       | AQI Range                    | 50 / 100 / 200 / 300 / 400 / 5000 |

3.3.1. Pre-Lock-down to Lock-down 1.0

The pictorial representation of these parameters have been depicted in the figure below (where Pre-Lock-down has been written as PLDN and N depicts the day remaining to Lock-down 1.0, i.e., 1st March has been depicted as PLD24 and 24th March as PLD1. Also, Lock-down 1.0 has been depicted as LDY, where Y indicates the day of Lock-down 1.0, i.e., 25th March as LD1 and 14th April as LD121). The same is graphically represented in Figs 6a-6g. In Y = αX + β, value of α is coming negative in PM$_{2.5}$, PM$_{10}$, NO$_2$, CO and AQI. Thus, showing the positive impact of lock-down on environment. But, O$_3$ and SO$_2$ have positive value of α, except for Area-2, where SO$_2$ has negative value. Equations of each parameter in the different areas for the given phase are shown in Table 4.

- PM$_{2.5}$, PM$_{10}$, NO$_2$, CO and AQI have shown a decrease in value due to Lock-down 1.0 if compared with Pre-Lock-down period. This decrease is primarily due to closure of construction, industries, and traffic during Lock-down 1.0.
- O$_3$ and SO$_2$ have shown an increase in value due to Lock-down 1.0. It has increased by an average of 79.85%. Whereas, SO$_2$ has increased by 14.86% in Area-1, 30.82% in Area-3 and decreased by 20.07% in Area-2.

3.3.2. Pre-lock down to Lock-down 2.0

PM$_{2.5}$, PM$_{10}$, O$_3$, NO$_2$, SO$_2$, CO and AQI concentration has been analyzed from Pre-Lock-down to Lock-down 2.0. The same has been depicted in the figure below (where Lock-down 2.0 has been depicted as LD2X, where X indicates the day of Lock-down 2.0, i.e., 15th April as LD21 and 3rd May as LD219). In Y = αX + β, value of α is coming negative in PM$_{2.5}$, PM$_{10}$, NO$_2$, CO and AQI. Thus, showing the impact of lock-down has a positive impact on environment. But, some have positive value of α as depicted below (Table 5 and Figs. 7a–7d).

Further, comparisons have been done between Lock-down 1.0 and Lock-down 2.0. PM$_{2.5}$, PM$_{10}$, O$_3$, and AQI have shown an increase in value from Lock-down1.0 across all 3 stations. The increase is primarily due to relaxations provided in subsequent phases of Lock-down.

NO$_2$ has decreased by 26.64% in Area-1 and increased by an average of 14.30% in Area-2 and Area-3. SO$_2$ has decreased by 13.41% and 15.79% in Area-1 and Area-3, respectively. But has shown an increase of 29.90% in Area-2. CO has decreased by 22.31% in Area-1 and increased by an average of 14.5% in Area-2 and Area-3.

3.3.3. Pre-lock down to Lock-down 3.0

PM$_{2.5}$, PM$_{10}$, O$_3$, NO$_2$, SO$_2$, CO and AQI concentration has been analyzed from Pre-Lock-down to Lock-down 2.0. The same has been depicted in the figure below (where Lock-down 3.0 has been depicted as LDZ, where Z indicates the day of Lock-down 3.0, i.e.4th May as LD31 and 17th May as LD314.). In Y = αX + β, value of α is coming negative in PM$_{2.5}$, PM$_{10}$, NO$_2$, CO and AQI. Thus,
Fig. 5a. Variation of PM$_{2.5}$ during 2019 and 2020 (during March 25 – May 17).

Fig. 5b. Variation of PM$_{10}$ during 2019 and 2020 (during March 25 – May 17).

Fig. 5c. Variation of O$_3$ during 2019 and 2020 (during March 25 – May 17).

Fig. 5d. Variation of NO$_2$ during 2019 and 2020 (during March 25 – May 17).
showing that the impact of lock-down has a positive impact on environment. But some have positive value of $\alpha$ as depicted in Table 6.

PM$_{2.5}$, PM$_{10}$, O$_3$, NO$_2$, SO$_2$, CO and AQI concentration have all increased from Lock-down 2.0 to Lock-down 3.0. The primary reason has been the relaxations given by the government from Lock-down 2.0 onwards. During lock-down 1.0 and 2.0 all commercial activities and movement of vehicle including personal vehicle were not allowed. From April 20, private vehicle movement started because of relaxation in lock-down. Nitrogen dioxide (NO$_2$) levels in capital Delhi increased as lock-down 3.0 kicked in on May 4 to control the novel Corona virus disease (COVID-19) spread. As offices were allowed to reopen with 33 per cent staff, personal vehicles came out on roads in increased numbers as compared to the second phase of lock-down. Centre for Science and Environment (CSE) carried out a quick assessment of Delhi's air quality to see how the spurt in personal vehicular movement impacted NO$_2$ levels. This is because vehicles are among the key contributors of NO$_2$. The main source of nitrogen dioxide resulting from human activities is the combustion of fossil fuels (coal, gas and oil) espe-

![Variation of SO$_2$ during 2019 and 2020 (during March 25 – May 17).](image)

![Variation of CO during 2019 and 2020 (during March 25 – May 17).](image)

![Variation of AQI during 2019 and 2020 (during March 25 – May 17).](image)
Table 2
Variation of PM$_{2.5}$, PM$_{10}$, O$_3$, NO$_2$, SO$_2$, CO and AQI during 1st to 3rd phases of the lock-down.

|                      | PM$_{2.5}$       | Minimum | Maximum |
|----------------------|------------------|---------|---------|
|                      | Average          |         |         |
| Area-1               | Lock-down 1.0    | -35.48% | -45.07% |
|                      | Lock-down 2.0    | -30.59% | -46.62% |
|                      | Lock-down 3.0    | -34.26% | -43.90% |
| Area-2               | Lock-down 1.0    | -40.54% | -45.78% |
|                      | Lock-down 2.0    | -20.24% | -29.61% |
|                      | Lock-down 3.0    | -28.19% | -26.26% |
| Area-3               | Lock-down 1.0    | -30.47% | -26.28% |
|                      | Lock-down 2.0    | -17.76% | -22.00% |
|                      | Lock-down 3.0    | -31.41% | -13.97% |
| PM$_{10}$            | Average          |         |         |
|                      | Minimum          |         |         |
| Area-1               | Lock-down 1.0    | -65.19% | -55.92% |
|                      | Lock-down 2.0    | -60.78% | -57.35% |
|                      | Lock-down 3.0    | -71.03% | -51.02% |
| Area-2               | Lock-down 1.0    | -62.01% | -56.14% |
|                      | Lock-down 2.0    | -50.48% | -51.07% |
|                      | Lock-down 3.0    | -63.91% | -46.52% |
| Area-3               | Lock-down 1.0    | -56.53% | -43.82% |
|                      | Lock-down 2.0    | -42.97% | -35.90% |
|                      | Lock-down 3.0    | -59.92% | -24.38% |
| O$_3$                | Average          |         |         |
|                      | Minimum          |         |         |
| Area-1               | Lock-down 1.0    | -66.20% | 46.91%  |
|                      | Lock-down 2.0    | -17.00% | 147.84% |
|                      | Lock-down 3.0    | -11.07% | 184.50% |
| Area-2               | Lock-down 1.0    | -32.49% | 220.19% |
|                      | Lock-down 2.0    | -63.91% | 103.75% |
|                      | Lock-down 3.0    | -11.46% | 305.65% |
| Area-3               | Lock-down 1.0    | -22.86% | 77.81%  |
|                      | Lock-down 2.0    | -5.26%  | 130.55% |
|                      | Lock-down 3.0    | 12.95%  | 280.37% |
| NO$_2$               | Average          |         |         |
|                      | Minimum          |         |         |
| Area-1               | Lock-down 1.0    | -52.52% | -21.10% |
|                      | Lock-down 2.0    | -66.10% | -47.92% |
|                      | Lock-down 3.0    | -68.62% | -49.68% |
| Area-2               | Lock-down 1.0    | -40.52% | -36.77% |
|                      | Lock-down 2.0    | -38.27% | -31.03% |
|                      | Lock-down 3.0    | -33.48% | 3.58%   |
| Area-3               | Lock-down 1.0    | -55.07% | -3.68%  |
|                      | Lock-down 2.0    | -48.93% | -14.63% |
|                      | Lock-down 3.0    | -45.68% | 23.36%  |
| SO$_2$               | Average          |         |         |
|                      | Minimum          |         |         |
| Area-1               | Lock-down 1.0    | -36.54% | -7.57%  |
|                      | Lock-down 2.0    | -43.94% | -17.26% |
|                      | Lock-down 3.0    | -48.93% | -73.62% |
| Area-2               | Lock-down 1.0    | -25.09% | 3.54%   |
|                      | Lock-down 2.0    | 12.57%  | 42.63%  |
|                      | Lock-down 3.0    | 38.97%  | 95.73%  |
| Area-3               | Lock-down 1.0    | 7.70%   | -2.03%  |
|                      | Lock-down 2.0    | -12.75% | -1.38%  |
|                      | Lock-down 3.0    | 19.21%  | 148.74% |
| CO                   | Average          |         |         |
|                      | Minimum          |         |         |
| Area-1               | Lock-down 1.0    | 36.30%  | 150.16% |
|                      | Lock-down 2.0    | 1.34%   | -4.34%  |
|                      | Lock-down 3.0    | 2.52%   | 15.07%  |
| Area-2               | Lock-down 1.0    | -6.17%  | 35.26%  |
|                      | Lock-down 2.0    | 7.56%   | 69.02%  |
|                      | Lock-down 3.0    | 6.72%   | 173.82% |
| Area-3               | Lock-down 1.0    | -62.11% | -64.60% |
|                      | Lock-down 2.0    | -59.90% | -56.01% |
|                      | Lock-down 3.0    | -53.34% | -35.73% |
| AQI                  | Average          |         |         |
|                      | Minimum          |         |         |
| Area-1               | Lock-down 1.0    | -46.99% | -49.71% |
|                      | Lock-down 2.0    | -43.98% | -47.97% |
|                      | Lock-down 3.0    | -55.67% | -35.45% |
| Area-2               | Lock-down 1.0    | -45.07% | -48.31% |
|                      | Lock-down 2.0    | -32.28% | -38.05% |
|                      | Lock-down 3.0    | -48.13% | -30.53% |
| Area-3               | Lock-down 1.0    | -45.96% | -34.58% |
|                      | Lock-down 2.0    | -34.09% | -29.69% |
|                      | Lock-down 3.0    | -47.24% | -18.87% |
cially fuel used in cars. It is also produced from making nitric acid, welding and using explosives, refining of petrol and metals, commercial manufacturing, and food manufacturing [19].

### 4. Conclusions

This paper presents a comprehensive study of environmental status of Delhi, the capital of India over a period of two consecutive years with the aims to investigate the implications of 3 phases of lock-down imposed for a period from March 25, 2020 to May 17, 2020. The following conclusions are drawn from the present investigation:

- 3 major industrial cum residential areas of Delhi (Narela, Bawana and Jhilmil Colony) are investigated. The each area is having about thousands of industries and population of about 100, 000 or more.

### Table 3

|                | PM$_{2.5}$ Lock-down 1.0 | PM$_{2.5}$ Lock-down 2.0 | PM$_{2.5}$ Lock-down 3.0 |
|----------------|---------------------------|---------------------------|---------------------------|
| Area-1         | -28.15%                   | 4.97%                     | 12.60%                    |
| Area-2         | -32.63%                   | 13.18%                    | 11.58%                    |
| Area-3         | -20.37%                   | 4.99%                     | 16.44%                    |

|                | PM$_{10}$ Lock-down 1.0   | PM$_{10}$ Lock-down 2.0   | PM$_{10}$ Lock-down 3.0   |
|----------------|---------------------------|---------------------------|---------------------------|
| Area-1         | -45.12%                   | 13.56%                    | 7.85%                     |
| Area-2         | -40.15%                   | 28.75%                    | 8.83%                     |
| Area-3         | -22.34%                   | 27.41%                    | 2.82%                     |

|                | O$_3$ Lock-down 1.0       | O$_3$ Lock-down 2.0       | O$_3$ Lock-down 3.0       |
|----------------|---------------------------|---------------------------|---------------------------|
| Area-1         | 199.60%                   | 168.09%                   | 3.19%                     |
| Area-2         | 33.83%                    | 17.81%                    | 24.43%                    |
| Area-3         | 6.11%                     | 27.41%                    | 2.82%                     |

|                | NO$_2$ Lock-down 1.0      | NO$_2$ Lock-down 2.0      | NO$_2$ Lock-down 3.0      |
|----------------|---------------------------|---------------------------|---------------------------|
| Area-1         | -15.14%                   | -26.64%                   | 3.64%                     |
| Area-2         | -47.94%                   | 4.13%                     | 20.12%                    |
| Area-3         | -49.32%                   | 24.47%                    | 18.96%                    |

|                | SO$_2$ Lock-down 1.0      | SO$_2$ Lock-down 2.0      | SO$_2$ Lock-down 3.0      |
|----------------|---------------------------|---------------------------|---------------------------|
| Area-1         | 14.86%                    | -13.41%                   | 5.29%                     |
| Area-2         | -20.07%                   | 29.90%                    | 4.28%                     |
| Area-3         | 30.82%                    | -15.79%                   | 11.36%                    |

|                | CO Lock-down 1.0          | CO Lock-down 2.0          | CO Lock-down 3.0          |
|----------------|---------------------------|---------------------------|---------------------------|
| Area-1         | -16.42%                   | -22.31%                   | 9.08%                     |
| Area-2         | -16.50%                   | 7.39%                     | 6.59%                     |
| Area-3         | -52.91%                   | 21.61%                    | 3.29%                     |

|                | AQI Lock-down 1.0         | AQI Lock-down 2.0         | AQI Lock-down 3.0         |
|----------------|---------------------------|---------------------------|---------------------------|
| Area-1         | -30.18%                   | 5.59%                     | 11.77%                    |
| Area-2         | -32.53%                   | 15.04%                    | 11.80%                    |
| Area-3         | -26.67%                   | 16.30%                    | 14.55%                    |

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**Fig. 6a.** Variation of PM$_{2.5}$ during 2019 and 2020 (during March 25 - April 14).
Fig. 6b. Variation of PM<sub>10</sub> during 2019 and 2020 (during March 25 - April 14).

Fig. 6c. Variation of O<sub>3</sub> during 2019 and 2020 (during March 25 - April 14).

Fig. 6d. Variation of NO<sub>2</sub> during 2019 and 2020 (during March 25 - April 14).

Fig. 6e. Variation of SO<sub>2</sub> during 2019 and 2020 (during March 25 - April 14).
Fig. 6f. Variation of CO during 2019 and 2020 (during March 25 - April 14).

Fig. 6g. Variation of AQI during 2019 and 2020 (during March 25 - April 14).

Table 4
Model equation for each parameter in phase I.

| Sl. No. | Parameter | Model equation (Y = aX + b) and R² | Area-1            | Area-2            | Area-3            |
|---------|-----------|-------------------------------------|-------------------|-------------------|-------------------|
| 1       | PM<sub>2.5</sub> | -1.3116x + 165.63; 0.284                    | -1.6258x + 160.66; 0.2754 | -1.0669x + 165.64; 0.1806 |
| 2       | PM<sub>10</sub>  | -1.888x + 141.67; 0.3009                  | -1.4019x + 112.2901 | -0.6997x + 111.08; 0.0676 |
| 3       | O₃         | 0.221x - 8.797; 0.2546                   | -1.4019x + 112.2901 | -0.6997x + 111.08; 0.0676 |
| 4       | NO<sub>2</sub> | -0.129x + 22.01; 0.2218                  | -0.2827x + 23.72; 0.2719 | -0.2445x + 16.864; 0.5249 |
| 5       | SO<sub>2</sub> | 0.0228x + 6.543; 0.0206                  | -0.0368x + 14.233; 0.0183 | 0.1147x + 8.088; 0.2888 |
| 6       | CO         | -0.0978x + 20.374; 0.0624                 | -0.0832x + 16.037; 0.0633 | -0.18x + 10.296; 0.5914 |
| 7       | AQI        | -1.4974x + 172.6; 0.3038                 | -1.4268x + 158.09; 0.2449 | -1.0327x + 163.58; 0.142 |

Table 5
Model equation for each parameter in phase I.

| Sl. No. | Parameter | Model equation (Y = aX + b) and R² | Area-1            | Area-2            | Area-3            |
|---------|-----------|-------------------------------------|-------------------|-------------------|-------------------|
| 1       | PM<sub>2.5</sub> | -0.8477x + 157.62; 0.2603                    | -0.7343x + 145.35; 0.1435 | -0.5002x + 156.98; 0.1093 |
| 2       | PM<sub>10</sub>  | -1.1368x + 129.16; 0.32                  | -0.5536x + 98.103; 0.1234 | 0.0555x + 99.181; 0.0011 |
| 3       | O₃         | 0.03416x - 2.6852; 0.0608                | 0.1976x + 11.833; 0.4114 | 0.2706x + 15.832; 0.4916 |
| 4       | NO<sub>2</sub> | -0.1888x + 23.085; 0.6102                | -0.2152x + 22.644; 0.3549 | 0.1309x + 14.868; 0.3653 |
| 5       | SO<sub>2</sub> | -0.005x + 6.998; 0.0027                  | 0.0284x + 13.072; 0.0217 | 0.0378x + 9.2584; 0.0833 |
| 6       | CO         | -0.1403x + 21.092; 0.2983                 | -0.0309x + 15.129; 0.0249 | -0.091x + 8.6802; 0.3304 |
| 7       | AQI        | -0.9483x + 163.1; 0.2774                 | -0.7128x + 145.41; 0.1477 | -0.4259x + 152.62; 0.0566 |
Fig. 7a. Variation of PM$_{2.5}$ and PM$_{10}$ during 2019 and 2020 (during March 25 – May 17).

Fig. 7b. Variation of O$_3$ and NO$_2$ during 2019 and 2020 (during March 25 – May 17).
These areas have been investigated for their air pollution and particulate matter content, contributing to air quality index (AQI). The factors considered are PM$_{2.5}$, PM$_{10}$, O$_3$, NO$_2$, SO$_2$, CO and AQI. The data on daily average basis has been taken from the World Air Quality Index (WAQI).

The lock-down has been imposed in three phases; 1st to 3rd, which had very limited accessibility, while the phase 4th of lock-down brought a lot of liberations. There is significant change in all parameters except O$_3$, particularly phase 1st for corresponding days of 2019/2020, then the deviation kept on decreasing for comparable days of 2019/2020. The data is plotted suitably to discuss the same. This comprehensive investigation presents an in-depth comparison among all these factors.

Each phase of lock-down has been plotted for the AQI and its contributing factors, in order to investigate an in-depth comparison of the factors under consideration.

Fig. 7c. Variation of SO$_2$ and CO during 2019 and 2020 (during March 25 – May 17).

Fig. 7d. Variation of AQI during 2019 and 2020 (during March 25 – May 17).
**Fig. 8a.** Variation of PM$_{2.5}$ during 2019 and 2020 (during March 25 – May 17).

**Fig. 8b.** Variation of PM$_{10}$ during 2019 and 2020 (during March 25 – May 17).
Table 6
Model equation for each parameter in phase I.

| Sl. No. | Parameter | Model equation \((Y = a + bX)\) and \(R^2\) | Area-1 | Area-2 | Area-3 |
|---------|-----------|------------------------------------------|-------|-------|-------|
| 1       | PM\(_{2.5}\) | \(-0.4071X + 147.07; 0.0906\) | \(-0.1754X + 149.42; 0.0225\) |       |       |       |
| 2       | PM\(_{10}\)  | \(-0.7095X + 119.07; 0.2081\) | \(0.0713X + 98.586; 0.0028\) | \(0.0713X + 98.586; 0.0028\) |       |       |
| 3       | \(O_3\)    | \(0.296X - 1.5806; 0.6022\) | \(0.3275X + 14.566; 0.6206\) | \(0.3275X + 14.566; 0.6206\) |       |       |
| 4       | \(NO_2\)   | \(-0.7159X + 22.039; 0.5189\)  | \(-0.0735X + 13.491; 0.2028\) | \(-0.0735X + 13.491; 0.2028\) |       |       |
| 5       | \(SO_2\)  | \(-0.0023X + 0.9206; 0.001\) | \(0.0268X + 9.4755; 0.0646\) | \(0.0268X + 9.4755; 0.0646\) |       |       |
| 6       | CO         | \(-0.1102X + 20.25; 0.2943\) | \(-0.0677X + 8.1158; 0.3083\) | \(-0.0677X + 8.1158; 0.3083\) |       |       |
| 7       | AQI        | \(-0.4848X + 151.97; 0.1124\) | \(-0.3024X + 135.43; 0.0427\) | \(-0.1083X + 144.87; 0.006\) |       |       |
The lock-down has brought favorable changes to the environment through improved AQI and pollutants level, leading to clean air specially in phase 1st, though later the air has not been so clean.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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