Temporary reduction in air pollution due to anthropogenic activity switch-off during COVID-19 lockdown in northern parts of India

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Abstract
Due to fast and deadly spread of corona virus (COVID-19), the Government of India implemented lockdown in the entire country from 25 April 2020. So, we studied the differences in the air quality index (AQI) of Delhi (DTU, Okhla and Patparganj), Haryana (Jind, Palwal and Hisar) and Uttar Pradesh (Agra, Kanpur and Greater Noida) from 17 February 2020 to 4 May 2020. The AQI was calculated by combination of individual sub-indices of seven pollutants, namely PM$_\text{2.5}$, PM$_\text{10}$, NO$_\text{2}$, NH$_\text{3}$, SO$_\text{2}$, CO and O$_\text{3}$, collected from the Central Pollution Control Board website. The AQI has improved by up to 30–46.67% after lockdown. The AQI slope values $-1.87$, $-1.70$ and $-1.35$ were reported for Delhi, $-1.11$, $-1.31$ and $-1.04$ were observed for Haryana and $-1.48$, $-1.79$ and $-1.78$ were found for Uttar Pradesh (UP), which may be attributed to limited access of transportation and industrial facilities due to lockdown. The ozone (O$_3$) concentration was high at Delhi because of lesser greenery as compared to UP and Haryana, which provides higher atmospheric temperature favourable for O$_3$ formation. The air mass back trajectory (AMBT) analysis reveals the contribution of air mass from Europe, Africa and Gulf countries as well as local emissions from Indo-Gangetic Plain, Madhya Pradesh and Maharashtra states of India.

Keywords AQI · Lockdown · CPCB · Pollutants · Air mass back trajectory
1 Introduction

The influenza pandemic since the sixteenth century is known to occur twice or thrice every century (Potter 2001). In the twentieth century, the Spanish flu (1918), the Asian flu (1957) and the Hong Kong flu (1968) were reported, in which the Spanish flu originated by the H1N1 virus turned out to be the deadliest of all, killing 21–50 million people (Gottfredsson et al. 2008).

The COVID-19 pandemic (Driggin et al. 2020) originated in Wuhan, China, where the patient zero was in December 2019 (Culp 2020). COVID-19 is a single-stranded RNA virus, size ranging from 26 to 32 kilobases (Shereen et al. 2020). Its genome is highly identical to the bat’s genome, suggesting them to be its natural host. The transmission of the virus is through respiratory droplets which occur upon close contact to an infected person or via droplets fallen on the surface (Güner et al. 2020).

Since the disease occurred through human-to-human transmission (Huang et al. 2020), it soon spread to other parts of China. Considering this, the government implemented a lockdown in Wuhan on January 23, 2020. The countries, including India, evacuated their citizens from Wuhan, brought them back via special flights and quarantined them for 14 days (Singhal 2020).

The patient zero of COVID-19 was reported in Kerala (India) on January 30, 2020, (Sarkar et al. 2020). The number of cases reported as on 22 March 2020 6:30 pm IST was 360 including 319 Indians and 41 foreigners (WHO 2020). The Prime Minister of India declared a ‘Janata-Curfew (voluntary curfew or self-imposed lockdown by people without any penal action)’ on 22 March 2020 (7:00 a.m. to 9:00 p.m., IST) and lockdown from 25 March to 14 April 2020 to ‘break the chain’ to stop the spread. Lockdown was extended from 15 April to 3 May 2020 (Gautam and Hens 2020; Mitra et al. 2020).

Zoran et al. (2020) establish a link between the coronavirus and air pollution suggesting that the pollutants (PM$_{10}$ and PM$_{2.5}$) possibly attached with viruses and bacteria, which can be transported deep into the respiratory tract crossing the mechanical barriers attributing to a high risk of inflammation and hyper-responsiveness which may have a negative impact on the immune system. Zhu et al. (2020) also claimed that the higher concentration of PM$_{2.5}$, PM$_{10}$, CO, NO$_2$ and O$_3$ can increase the risk of COVID-19 infection.

After the lockdown, self-quarantine measures were enforced, resulting in less human mobility. Thus, the pollution caused as a result of anthropogenic activities was reduced significantly especially air pollution. The harmful pollutants emanated from industries, transportation, etc., were reduced to a remarkable level, thereby resulting in the cleansing of the environment (Sharma et al. 2020). Srivastava et al. (2020) also observed a significant decline in the concentration of atmospheric pollutants PM$_{2.5}$, NO$_2$, SO$_2$ and CO before lockdown (21 days) and after lockdown (21 days) over Delhi and Lucknow.

Based on literature review, we conclude that Haryana and Uttar Pradesh (UP) were not fully explored and compare with Delhi (one of the most polluted states of India). In this manuscript, three different locations from each state (Delhi, UP and Haryana) were consider along with two novel sites, Palwal and Hisar of Haryana. Further, air mass back trajectory (Sect. 3.5) analysis was performed to identify the origin of pollutants for the selected monitoring stations during 17 February 2020 to 4 May 2020. The details of site are also provided in Sect. 2.1.
2 Methodology and techniques

2.1 Site description

Delhi (most polluted region of India) was considered for this study along with its surrounding states Haryana (agricultural stubble burning is practiced at a large scale and also a well-developed industrial state) and UP (most populated state contributing greatly to air pollution due to anthropogenic activities). We picked three locations from each of these regions (total 9 monitoring stations), Jind, Palwal and Hisar from Haryana; Agra, Kanpur and Greater Noida from UP, and Delhi Technical University (DTU), Okhla and Patparganj (PJ) from Delhi (Fig. 1).

![Map of monitoring stations](image)
2.1.1 Delhi

It is known to have inhabited since sixth century BC. It is the national territory of India and was converted into union territory in the year 1956. The area of Delhi is 1483 km² (Micro, Small, Medium Enterprises Development Institute-Government of India (MSME-DI-GOI) 2012). Being the capital territory, the area is densely populated with a population of over 3 crores. The forest cover of Delhi is 20.20%; the industrial cover is 12% of the total area (MSME-DI-GOI 2012). The major sources of pollution are transportation, industries, power plants (Badarpur Thermal Power Station) and the burning of garbage. The pollution level reaches at its peak during November–December due to heavy metal-rich smoke of firecrackers (Sawlani et al. 2019).

2.1.2 Haryana

It is the leading contributor of Basmati rice (62%) in India (NCML 2019; Erenstein 2010). It surrounds Delhi on 3 sides. Its capital Chandigarh is shared with Punjab. The area of Haryana is 44,212 km², and its population is over 2.5 crores. The maximum area of the state is used for cultivation purposes, i.e. 84% of the total area. The forest cover of Haryana is 4% (MSME-DI-GOI 2015). The major sources of pollution include vehicular emission, garbage burning, agricultural stubble burning and construction dust.

2.1.3 Uttar Pradesh (UP)

It is the most populous state of India with a population of over 22.45 crores, i.e. approx. 17% of the total population of India (UIAI-GOI 2017) with area of 2,43,290 km². Forest cover is 16,582 km² (Anon 2017). The major sources of air pollution in UP are industrial emission, transportation, waste and garbage burning and road dust. Industrial emission is the biggest cause of pollution in Kanpur.

2.2 Description of the data set

Although the National Ambient Air Quality standards are usually taken for PM₁₀, PM₂.₅, NO₂, SO₂, CO, O₃, NH₃, Pb, Ni, As, benzo (a) pyrene and benzene (Akolkar 2016), the data are taken here only for the pollutants, PM₂.₅, PM₁₀, NO₂, NH₃, SO₂ and O₃ in μg/m³ and for CO in mg/m³ from Central Pollution Control Board (CPCB) website (https://app.cpcbccr.com/AQI_India/). The pollutants PM₂.₅, PM₁₀, NO₂, NH₃, SO₂ have a standard average of 24 h, whereas the pollutants O₃ and CO have a standard average of 8 h, i.e. data taken at 12:00 PM on 10 April 2020 of PM₂.₅ will be an average of hourly data taken for last 24 h. The Indian AQI system is defined as deliberation of each and every pollutants on human health, which can be calculated by using two steps involvements: (a) formation of individual sub-indices (SIs) of pollutants and (b) combination of sub-indices to obtain AQI (Akolkar 2016). The SIs (I₁, I₂,……., Iₙ) for N pollutant (X₁, X₂,……., Xₙ) are calculated by using sub-index functions as follows:

\[ I_i = f(X_i), \]
where \( i = 1, 2, \ldots, N \).

Now, aggregation of sub-indices \( (I_i) \) is calculated by using the following mathematical function (given below):

\[
I = F(I_1, I_2, \ldots, \ldots, I_N) \quad (2)
\]

The sub-index \( (I_p) \) for a known pollutant concentration \( (C_p) \) is given by

\[
I_p = \left\{ \left( \frac{I_H - I_L}{B_H - B_L} \right) \times \left( C_p - B_L \right) + I_L \right\} \quad (3)
\]

\( B_H \) = breakpoint concentration greater or equal to given concentration, \( B_L \) = breakpoint concentration smaller or equal to given concentration, \( I_H \) = AQI value corresponding to \( B_H \), \( I_L \) = AQI value corresponding to \( B_L \).

Furthermore, mathematically AQI is given by:

\[
AQI = \text{MAX}(I_p) \quad (4)
\]

where \( p = 1, 2 \ldots N \). (Mahato et al. 2020).

The standard value for each pollutant is given in Table 3 (Akolkar 2016). The Indian AQI system has been classified into six categories according to their sever range as mention in Table 4.

In UP, data of \( \text{PM}_{2.5}, \text{NO}_2, \text{SO}_2, \text{O}_3 \) and \( \text{CO} \) were available for Agra, whereas \( \text{PM}_{2.5}, \text{NO}_2, \text{SO}_2 \) and \( \text{O}_3 \) were available for Kanpur. The data for all the considered parameters were extracted and plotted from 17 February 2020 to 4 May 2020. However, data of some pollution parameters were missing on the CPCB website, and the reason could be some technical issues or rainfall. Furthermore, data were plotted to calculate the slope by linear fitting method using student version/trail of Origin Lab 2020b (Serial Number GL3S4-6089-7,609,063) software (Table 2). The air mass back trajectories were extracted from the National Oceanic and Atmospheric Administration (NOAA), Air Resources Laboratory (ARL) and Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Stein et al. 2015) to understand the transportation and origin of pollutants. This analysis was carried out by using Google Map Import application available in Origin Lab software.

3 Results and discussion

The AQI levels were high before lockdown period (17 February 2020 to 23 March 2020) which may be due to anthropogenic activities like transportation, industrial emission, burning of household, agricultural and electronic wastes. Figures 2, 3, 4, 5, 6 and 7 reveal a sudden decrease in the levels of pollutants in the before lockdown period on 3 dates 22 February 2020, 01 March 2020 and 09 March 2020 in all the 9 sites, which was due to rainfall/precipitation (Kim et al. 2014) as recorded by Indian Meteorological Department (IMD), Public Weather Bulletin (PWB) (IMD, 22 February 2020a; IMD, 01 March 2020b; IMD, 09 March 2020c).

3.1 Variation of atmospheric pollutants over Delhi

The daily average concentration of \( \text{PM}_{2.5} \) before (17/02/2020 to 24/03/2020) and after (25/03/2020 to 04/05/2020) lockdown fluctuated from 48 to 348 \( \mu g/m^3 \) and 43 to 137
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μg/m³ at DTU. It was observed to vary from 32 to 275 μg/m³ and 32 to 149 μg/m³ at Okhla, whereas it was reported in the range of 32 to 276 μg/m³ and 20 to 141 μg/m³ at PJ. Similarly, the variation of PM₁₀ was reported in the range of 49 to 372 μg/m³ and 57 to 150 μg/m³ over DTU and 41 to 269 μg/m³ and 32 to 136 μg/m³ over Okhla; however, it was 39 to 213 μg/m³ and 23 to 131 μg/m³ at PJ before and after lockdown, respectively. For NO₂, the values before and after lockdown were reported ranging from 6 to 75 μg/m³ and 11 to 36 μg/m³, 27 to 79 μg/m³ and 9 to 31 μg/m³ and 7 to 44 μg/m³ and 2 to 40 μg/m³ at the above monitoring locations. The level of NH₃ did not show a significant variation; the levels before and after the event ranged from 3 to 12 μg/m³ and

Fig. 2 The variations in levels of pollutants (PM₂.₅, PM₁₀, NO₂, NH₃) over Delhi during before (17 March 2020 to 24 March 2020) and after lockdown (25 March 2020 to 4 May 2020). Source: Based on CPCB dataset
2 to 4, 6 to 10 μg/m³ and 4 to 8 μg/m³ and 7 to 15 μg/m³ and 3 to 17 μg/m³, respectively. The AQI before and after lockdown was observed from 49 to 372 and 78 to 199, 41 to 275 and 48 to 149 and 23 to 179 for DTU, Okhla and PJ, respectively. SO₂ levels were almost constant varying with small perturbation under the standard (Table 3); however, it shows the before and after lockdown values from 6 to 17 μg/m³ and 7 to 21 μg/m³, 10 to 33 μg/m³ and 12 to 30 μg/m³ and 4 to 15 μg/m³ and 3 to 15 μg/m³ at the selected sites over Delhi before and after lockdown, respectively. The variation in the levels of CO before and after lockdown was recorded as 1.4 to 8 mg/m³ and 0.4 to 3.2 mg/m³, 2.6 to 9.9 mg/m³ and 4.8 to 8 mg/m³ and 1.8 to 6.3 mg/m³ and 1.1 to 3.9 mg/m³, respectively. O₃ variations were recorded as before and after lockdown from 33 to 209 μg/m³ and 44 to 172 μg/m³, 5 to 52 μg/m³ and 8 to 83 μg/m³ and 14 to 31 μg/m³ and 10 to 41 μg/m³, respectively. The average values before and after lockdown are given in Table 1.
The levels of PM$_{2.5}$ and PM$_{10}$ in DTU, Okhla and PJ can be seen in Fig. 2a, b fluctuating way above the National Air Quality Standard 60 µg/m$^3$ and 100 µg/m$^3$, respectively (Table 3). The sudden halt of transportation and industrial activities caused a remarkable decrease in PM$_{2.5}$ and PM$_{10}$. The PM$_{2.5}$ and PM$_{10}$ were reduced up to 64 µg/m$^3$, 45 µg/
m$^3$ and 40 μg/m$^3$ and 83 μg/m$^3$, 58 μg/m$^3$ and 56 μg/m$^3$, respectively, on 2 April 2020. But as soon as the relaxation was given, the curves again took a rise above the standard levels (Table 3) on 14 April 2020 to 130 μg/m$^3$, 149 μg/m$^3$ and 63 μg/m$^3$ and 114 μg/m$^3$, 136 μg/m$^3$ and 84 μg/m$^3$, but were lower in comparison with before lockdown. The overall reduction of PM$_{2.5}$ and PM$_{10}$ levels can be understood in terms of slope values (Table 2) −2.77, −2.49 and −2.13 and −1.91, −1.45 and −1.15 for DTU, Okhla and PJ station,

Fig. 5 The variations in levels of pollutants (SO$_2$, O$_3$, CO, AQI) over Haryana during before (17 March 2020 to 24 March 2020) and after lockdown (25 March 2020 to 4 May 2020). Source: Based on CPCB dataset
respectively. The negative slope indicates the decline in the pollution levels (Singh and Chauhan 2020). Similarly, NO$_2$ and NH$_3$ values were also showing the reduction in levels which can be seen in their slope values $-0.30$, $-0.63$ and $-0.27$ and $-0.02$, $-0.04$ and $-0.01$, respectively, given Table 2. The values of NO$_2$ and NH$_3$ just after lockdown were 18 $\mu g/m^3$, 13 $\mu g/m^3$ and 7 $\mu g/m^3$ and 3 $\mu g/m^3$, 5 $\mu g/m^3$ and 9 $\mu g/m^3$ on 2 April 2020 and
rise to values 30 μg/m³, 22 μg/m³ and 27 μg/m³ and 4 μg/m³, 7 μg/m³ and 17 μg/m³ on 16 April 2020 due to dust storm (NDTV, 15 April 2020). The NO₂ and CO concentrations depend upon the combustion practices carried out by industries, power plants and transportation (Mahato et al. 2020). Thus, the same can be seen for CO in Fig. 3c with slope values −0.04, −0.004 and −0.04, which suggests that there is not much change. The lowest values for CO just after lockdown were recorded as 0.7, 4.8 and 2.9 on 1 April 2020. Majorly, NH₃ is emitted as a result of agricultural activities (Tanvir et al. 2019). Emissions

Fig. 7 The variations in levels of pollutants (SO₂, CO, O₃, AQI) over UP during before (17 March 2020 to 24 March 2020) and after lockdown (25 March 2020 to 4 May 2020). Source: Based on CPCB dataset.
Table 1  Statistical summary of the studied parameters. Source: calculated based on CPCB dataset

| Sr. no. | Locations   | Lock down | PM$_{2.5}$ (mean ± SD) | PM$_{10}$ (mean ± SD) | NO$_2$ (mean ± SD) | NH$_3$ (mean ± SD) | SO$_2$ (mean ± SD) | CO (mean ± SD) | O$_3$ (mean ± SD) | AQI | % Change |
|---------|-------------|-----------|-------------------------|-----------------------|--------------------|--------------------|-------------------|----------------|-----------------|-----|-----------|
| 1       | Okhla       | Before    | 156 ± 71                | 150 ± 53              | 49 ± 15            | 8 ± 1              | 20 ± 5            | 6 ± 2          | 32 ± 12         | 165 ± 65 | 46.67     |
|         |             | After     | 70 ± 29                 | 84 ± 25               | 17 ± 6             | 6 ± 1              | 20 ± 4            | 6 ± 1          | 46 ± 14         | 88 ± 26  |           |
| 2       | DTU         | Before    | 203 ± 84                | 181 ± 25              | 42 ± 20            | 5 ± 2              | 9 ± 3             | 3 ± 1          | 73 ± 40         | 205 ± 82 | 40.00     |
|         |             | After     | 89 ± 29                 | 103 ± 19              | 23 ± 6             | 3 ± 1              | 15 ± 3            | 1 ± 1          | 93 ± 29         | 123 ± 31 |           |
| 3       | Patparganj  | Before    | 132 ± 67                | 122 ± 40              | 22 ± 8             | 11 ± 3             | 8 ± 2             | 4 ± 1          | 22 ± 4          | 139 ± 62 | 42.45     |
|         |             | After     | 63 ± 30                 | 75 ± 25               | 13 ± 9             | 11 ± 3             | 8 ± 2             | 2 ± 1          | 28 ± 7          | 80 ± 32  |           |
| 4       | Palwal      | Before    | 126 ± 64.1              | 123 ± 28.4            | 13 ± 6.3           | 24 ± 7.2           | 12 ± 7.2          | 6 ± 1.7        | 14 ± 2.9        | 143 ± 50.9 | 30.77     |
|         |             | After     | 72 ± 25.9               | 91 ± 18.2             | 7 ± 3.3            | 16 ± 4.8           | 20 ± 9.7          | 5 ± 0.8        | 13 ± 3.1        | 99 ± 24.3 |           |
| 5       | Jind        | Before    | 130 ± 54.6              | 96 ± 26.8             | 38 ± 17.2          | 14 ± 6.4           | 26 ± 11.2         | 3 ± 0.9        | 58 ± 13.4       | 130 ± 54.1 | 33.85     |
|         |             | After     | 67 ± 20.6               | 80 ± 25.9             | 17 ± 5             | 7 ± 1.3            | 29 ± 8.1          | 2 ± 1.3        | 60 ± 9.2        | 86 ± 26.7 |           |
| 6       | Hisar       | Before    | 125 ± 57.8              | 105 ± 303             | 43 ± 18.5          | 17 ± 7.3           | 19 ± 9.2          | 4 ± 3.2        | 20 ± 2.9        | 132 ± 54.2 | 33.34     |
|         |             | After     | 69 ± 24.3               | 85 ± 24.4             | 24 ± 4.9           | 14 ± 2.2           | 12 ± 5.3          | 3 ± 0.9        | 24 ± 8.1        | 88 ± 28.1 |           |
| 7       | Agra        | Before    | 123 ± 49.6              | N/A                   | 68 ± 9.3           | N/A                | 28 ± 10.5         | N/A           | 7 ± 3.5         | 174 ± 62.4 | 33.91     |
|         |             | After     | 81 ± 29.8               | N/A                   | 53 ± 8.5           | N/A                | 25 ± 5.4          | N/A           | 18 ± 10        | 115 ± 20.3 |           |
| 8       | Kanpur      | Before    | 131 ± 52                | N/A                   | 58 ± 21            | N/A                | 17 ± 8.1          | 5 ± 2.1        | 48 ± 8.5        | 131 ± 52  | 36.64     |
|         |             | After     | 77 ± 32.1               | N/A                   | 22 ± 11.3          | N/A                | 19 ± 3.5          | 4 ± 1.9        | 56 ± 8.8        | 83 ± 35.3 |           |
| 9       | Greater Noida| Before  | 164 ± 70.8              | 142 ± 45.7            | 59 ± 23.2          | 9 ± 2.6            | 21 ± 7.7          | 8 ± 3.6        | 62 ± 32.5       | 125 ± 47.2 | 31.20     |
|         |             | After     | 69 ± 34.5               | 89 ± 29.8             | 17 ± 3.3           | 7 ± 2              | 14 ± 3.3          | 10 ± 2         | 67 ± 17.1       | 86 ± 26.4 |           |
Table 2  Slope and $R^2$ values of the studied parameter Source: calculated based on CPCB dataset

| Location       | PM$_{2.5}$ | PM$_{10}$ | NO$_2$ | NH$_3$ | SO$_2$ | CO   | O$_3$ | AQI |
|----------------|------------|-----------|--------|--------|--------|------|-------|-----|
| 1 Greater Noida Slope | $Y = -2.25$ | $Y = -1.23$ | $Y = -0.98$ | $Y = -0.06$ | $Y = -0.1$ | $Y = 0.02$ | $Y = 0.23$ | $Y = -1.78$ |
|                | $X \pm 0.23$ | $X \pm 0.17$ | $X \pm 0.10$ | $X \pm 0.01$ | $X \pm 0.02$ | $X \pm 0.01$ | $X \pm 0.10$ | $X \pm 0.18$ |
| 2 Kanpur Slope | $Y = -1.50$ | N/A       | $Y = -0.84$ | N/A    | $Y = 0.02$ | N/A   | $Y = 0.11$ | $Y = -1.79$ |
|                | $X \pm 0.18$ | $X \pm 0.06$ | $X \pm 0.02$ | $X \pm 0.02$ | $X \pm 0.06$ | $X \pm 0.03$ | $X \pm 0.19$ | $X \pm 0.19$ |
| 3 Agra Slope  | $Y = -1.89$ | N/A       | $Y = 0.45$  | N/A    | $Y = 0.02$ | $Y = -0.04$ | $Y = 0.22$ | $Y = -1.48$ |
|                | $X \pm 0.17$ | $X \pm 0.03$ | $X \pm 0.02$ | $X \pm 0.03$ | $X \pm 0.06$ | $X \pm 0.03$ | $X \pm 0.16$ | $X \pm 0.16$ |
| 4 Palwal Slope | $Y = -1.56$ | $Y = -0.73$ | $Y = -0.10$ | $Y = -0.20$ | $Y = -0.02$ | $Y = -0.03$ | $Y = -0.03$ | $Y = 1.31$ |
|                | $X \pm 0.20$ | $X \pm 0.10$ | $X \pm 0.02$ | $X \pm 0.02$ | $X \pm 0.03$ | $X \pm 0.04$ | $X \pm 0.01$ | $X \pm 1.17$ |
| 5 Jind Slope  | $Y = -1.55$ | $Y = -0.33$ | $Y = -0.57$ | $Y = -0.08$ | $Y = 0.16$  | $Y = -0.003$ | $Y = 0.14$  | $Y = -1.11$ |
|                | $X \pm 0.17$ | $X \pm 0.10$ | $X \pm 0.05$ | $X \pm 0.02$ | $X \pm 0.03$ | $X \pm 0.04$ | $X \pm 0.04$ | $X \pm 0.18$ |
| 6 Hisar Slope | $Y = -1.32$ | $Y = -0.29$ | $Y = -0.27$ | $Y = -0.08$ | $Y = -0.08$ | $Y = -0.03$ | $Y = 0.05$  | $Y = -1.04$ |
|                | $X \pm 0.17$ | $X \pm 0.10$ | $X \pm 0.05$ | $X \pm 0.01$ | $X \pm 0.03$ | $X \pm 0.07$ | $X \pm 0.03$ | $X \pm 0.16$ |
| 7 Okhla Slope | $Y = -2.49$ | $Y = -1.45$ | $Y = -0.63$ | $Y = -0.04$ | $Y = -0.02$ | $Y = -0.004$ | $Y = 0.35$  | $Y = -1.70$ |
|                | $X \pm 0.20$ | $X \pm 0.17$ | $X \pm 0.05$ | $X \pm 0.004$ | $X \pm 0.02$ | $X \pm 0.01$ | $X \pm 0.05$ | $X \pm 0.25$ |
| 8 DTU Slope   | $Y = -2.77$ | $Y = -1.91$ | $Y = -0.30$ | $Y = -0.24$ | $Y = 0.12$  | $Y = -0.04$ | $Y = 0.73$  | $Y = -1.87$ |
|                | $X \pm 0.21$ | $X \pm 0.19$ | $X \pm 0.05$ | $X \pm 0.006$ | $X \pm 0.01$ | $X \pm 0.005$ | $X \pm 0.11$ | $X \pm 0.31$ |
| 9 Patparganj Slope | $Y = -2.13$ | $Y = -1.15$ | $Y = -0.27$ | $Y = -0.01$ | $Y = 0.03$  | $Y = -0.04$ | $Y = 0.16$  | $Y = -1.35$ |
|                | $X \pm 0.21$ | $X \pm 0.14$ | $X \pm 0.03$ | $X \pm 0.01$ | $X \pm 0.01$ | $X \pm 0.004$ | $X \pm 0.02$ | $X \pm 0.26$ |
|                | $R^2$ 0.55 | 0.44 | 0.51 | 0.02 | 0.11 | 0.54 | 0.42 | 0.29 |

Slope for a linear function is given by equation, $Y = mX + c$, where slope = $m$. The negative slope values explain the decline in the level and positive one explains the increment.
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from non-agricultural sources are negligible; therefore, not much difference in the concentration levels was seen as Delhi is mostly covered with non-agricultural area (Behera et al. 2013; Mahato et al. 2020; Sutton et al. 1995). The effect of pollutants (PM$_{2.5}$, PM$_{10}$, NO$_2$ and NH$_3$) on the AQI levels can be seen in Fig. 3d, and the highest to lowest value was 318 to 206 for DTU and PJ on 20 February 2020. After the implementation of lockdown on 2 April 2020, it declined to 83 (56) because of the concentrations of the pollutants (Table 4). The slope values $-1.87$, $-1.70$ and $-1.35$ are showing the overall reduction in the levels of AQI for before and after lockdown, due to less pollutant emission from anthropogenic sources. This increase in the PM$_{2.5}$, PM$_{10}$, NO$_2$, NH$_3$ and AQI is also reported by Sristava et al. (2020). In Delhi, Mahato and Ghosh (2020) based on their observation summarized the difference in the levels of PM$_{10}$, PM$_{2.5}$, SO$_2$, NO$_2$, CO, O$_3$ and NH$_3$ as 51.85%, 53.11%, 17.97%, 52.68%, 30.35%, 0.78% and 12.33%, respectively.

Table 3 Standard value of pollutants as set by CPCB (Akolkar 2016)

| Sr. no. | Pollutant                     | Standard value (μg/m$^3$) |
|--------|-------------------------------|---------------------------|
| 1      | Particulate matter 2.5 (microns) [24 h] | 60                        |
| 2      | Particulate matter 10 (microns) [24 h] | 100                       |
| 3      | Nitrogen dioxide (NO$_2$) [24 h] | 80                        |
| 4      | Ammonia (NH$_3$) [24 h] | 400                       |
| 5      | Sulphur dioxide (SO$_2$) [24 h] | 80                        |
| 6      | Carbon monoxide (CO) [8 h] | 4000                      |
| 7      | Ozone (O$_3$) [8 h] | 100                       |

The slope of SO$_2$ ($0.12$, $-0.02$, and 0.03) and O$_3$ ($0.73$, $0.35$, and 0.16) curves show a slight increase for DTU, Okhla and PJ, respectively. The concentrations of O$_3$ (Fig. 3b) increased primarily because of increase in atmospheric temperature in the northern region in between March to May (summers), which result in the photolysis/chemical production (Gaur et al. 2014). The ratio is especially increased after the lockdown because of lesser emission of NO which is converted into NO$_2$ while being in the atmosphere via a similar phenomenon (Gorai et al. 2017; Mahato et al. 2020).

### 3.2 Variation of atmospheric pollutants over Haryana

The levels of PM$_{2.5}$ in Haryana, before and after lockdown, ranged between 38 to 231 μg/m$^3$ and 26 to 130 μg/m$^3$, 39 to 240 μg/m$^3$ and 32 to 136 μg/m$^3$ and 51 to 247 μg/m$^3$ and 25 to 130 μg/m$^3$ for Jind, Palwal and Hisar, respectively. The variation in PM$_{10}$ before and after lockdown was seen 42 to 140 μg/m$^3$ and 21 to 127 μg/m$^3$, 56 to 171 μg/m$^3$ and 56 to 121 μg/m$^3$ and 44 to 183 μg/m$^3$ and 21 to 123 μg/m$^3$, respectively. The minima and maxima values of NO$_2$ before and after lockdown are given as 15 to 95 μg/m$^3$ and 26 μg/m$^3$ and 7 to 37 μg/m$^3$ and 1 to 19 μg/m$^3$, 18 to 132 μg/m$^3$ and 16 to 38 μg/m$^3$, respectively. Figure 4d shows variation in the levels of NH$_3$ fluctuating way below the standard level as given in Table 3, before and after lockdown from 7 to 28 μg/m$^3$ and 5 to 10 μg/m$^3$, 14 to 37 μg/m$^3$ and 6 to 22 μg/m$^3$, 7 to 28 μg/m$^3$ and 10 to 19 μg/m$^3$, respectively. CO levels in these areas are fluctuating around the standard levels (Table 3), before and after lockdown differing from 0.6 to 4.3 mg/m$^3$ and 0.3 to 5.3 mg/m$^3$, 0.6 to 9 mg/m$^3$ and 3.7 to 7 mg/m$^3$ and 1.2 to 15 mg/m$^3$ and 1 to 5.1 mg/m$^3$, respectively. All these pollutants were responsible for the decline in AQI of
Table 4 National AQI classes and concentration ranges of the pollutants (Mahato et al. 2020)

| AQI class (range)   | PM10 24-h (μg/m³) | PM2.5 24-h (μg/m³) | NO₂ 24-h (μg/m³) | NH₃ 24-h (μg/m³) | SO₂ 24-h (μg/m³) | CO 8-h (mg/m³) | O₃ 8-h (μg/m³) |
|---------------------|-------------------|--------------------|-------------------|------------------|-----------------|----------------|----------------|
| GOOD (0–50)         | 0–50              | 0–30               | 0–40              | 0–200            | 0–40            | 0–1           | 0–50           |
| SATISFACTORY (51–100)| 51–100            | 31–60              | 41–80             | 201–400          | 41–80           | 1.1–2         | 51–100         |
| MODERATE (101–200)  | 101–250           | 61–90              | 81–180            | 401–800          | 81–380          | 2.1–10        | 101–168        |
| POOR (201–300)      | 251–350           | 91–120             | 181–280           | 801–1200         | 381–800         | 10–17         | 169–208        |
| VERY POOR (301–400) | 351–430           | 121–250            | 281–400           | 1200–1800        | 801–1600        | 17–34         | 209–748        |
| SEVERE (401–500)    | > 430             | > 250              | > 400             | > 1800           | > 1600          | > 34          | > 748          |
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Haryana after implementation of lockdown. The AQI values before and after lockdown were recorded as 43 to 231 and 42 to 137, 56 to 240 and 56 to 146 and 51 to 247 and 25 to 144, respectively.

The levels of $\text{SO}_2$ before and after lockdown varied from 9 to 56 $\mu g/m^3$ and 11 to 44 $\mu g/m^3$, 1 to 25 $\mu g/m^3$ and 3 to 41 $\mu g/m^3$ and 5 to 50 $\mu g/m^3$ and 3 to 23 $\mu g/m^3$, respectively. $O_3$ was found increasing from before to after lockdown 27 to 100 $\mu g/m^3$ and 36 to 78 $\mu g/m^3$, 7 to 19 $\mu g/m^3$ and 4 to 22 $\mu g/m^3$ and 15 to 28 $\mu g/m^3$ and 14 to 47 $\mu g/m^3$, respectively, over monitoring stations. Haryana being the agricultural region is mostly affected by factors like agriculture waste burning, extracting wheat and husk. The levels of particulate matter in the air were mainly due to the husk removal from the wheat (Kaushik et al. 2006). The maximum levels of $\text{PM}_{2.5}$ and $\text{PM}_{10}$ were recorded as 231 $\mu g/m^3$, 240 $\mu g/m^3$ and 247 $\mu g/m^3$ and 140 $\mu g/m^3$, 171 $\mu g/m^3$ and 183 $\mu g/m^3$ for the stations. The lockdown affected the farmers by stopping their agricultural work for some duration, dropped the concentration levels of $\text{PM}_{2.5}$ and $\text{PM}_{10}$ up to 26 $\mu g/m^3$, 32 $\mu g/m^3$ and 25 $\mu g/m^3$ and 21 $\mu g/m^3$, 56 $\mu g/m^3$ and 21 $\mu g/m^3$, respectively. The arrival of a dust storm (mentioned earlier) and relaxation given to the farmers for harvesting the crops and other activities (Kharbikar et al. 2020) again increased the levels of $\text{PM}_{2.5}$ and $\text{PM}_{10}$ to 124 $\mu g/m^3$, 131 $\mu g/m^3$ and 80 $\mu g/m^3$ and 115 $\mu g/m^3$, 171 $\mu g/m^3$ and 102 $\mu g/m^3$, respectively, as on 16 April 2020. The overall decrease in particulate matter can be seen in the slopes of $\text{PM}_{2.5}$ ($-1.55$, $-1.56$ and $-1.32$) and $\text{PM}_{10}$ ($-0.33$, $-0.73$ and $-0.29$), respectively (Fig. 4a, b and Table 2).

$\text{NO}_2$ and $\text{NH}_3$ are mainly emitted by biomass burning, forest fires, vegetation, and agricultural crop emission, and fossil fuel combustion which is common in Haryana (Behera et al. 2013; Gadde et al. 2009; Srivastava et al. 2020). The highest values of $\text{NO}_2$ (95 $\mu g/m^3$, 14 $\mu g/m^3$, and 61 $\mu g/m^3$) and $\text{NH}_3$ (27 $\mu g/m^3$, 18 $\mu g/m^3$, and 21 $\mu g/m^3$) were found on 19 February 2020 and 5 Mar 2020, respectively. However, the lowest levels for $\text{NO}_2$ (13 $\mu g/m^3$, 7 $\mu g/m^3$, and 18 $\mu g/m^3$) and $\text{NH}_3$ (6 $\mu g/m^3$, 17 $\mu g/m^3$, and 11 $\mu g/m^3$) were recorded as on 2 April 2020 and 9 April 2020, respectively. The slope of $\text{NO}_2$ was reported as $-0.57$, $-0.10$, and $-0.27$; and of $\text{NH}_3$ $-0.08$, $-0.20$, and $-0.08$ (Fig. 4c, d and Table 2). The CO concentrations were fluctuating near the standard value as given in Table 3. The slope values for CO were $-0.003$, $-0.03$, and $-0.03$, which showed a decrease in the concentration of CO. The AQI slope values were $-1.11$, $-1.31$, and $-1.04$ of each station, respectively, showing the reduction in the level, and that may be due to decreased pollutant emission from anthropogenic activities. Before lockdown, the maximum AQI values were seen as 231, 240 and 247, and after the implementation of lockdown decreased to 42, 56, and 25, respectively. After lockdown, these values showed a sudden increase, i.e. 137, 140 and 138 on 16 April 2020 due to an increase in the levels of major pollutants, $\text{PM}_{10}$, $\text{PM}_{2.5}$, $\text{NH}_3$ and $\text{SO}_2$, because of dust storm (as mentioned earlier). $O_3$ concentrations in the environment majorly depend on the temperature because of which it was seen fluctuating in the observation period by the calculated slope values of 0.14, $-0.03$, and 0.05, respectively. A similar fluctuation was also found in $\text{SO}_2$ with slope values 0.16, 0.02, and $-0.08$, respectively. Mahato and Ghosh (2020) specifically mentioned the average percentage difference in the levels of pollutants during first phase of lockdown (24 March 2020 to 6 April 2020) as 34.4%, 34.6%, 44.7%, 41.1%, 2.2%, 20.1% and 6.7% change in the levels of $\text{PM}_{10}$, $\text{PM}_{2.5}$, $\text{NO}_2$, $\text{NH}_3$, $\text{SO}_2$, CO and $O_3$, respectively, over Jind.

3.3 Variation of atmospheric pollutants over Uttar Pradesh

The level of $\text{PM}_{2.5}$ in UP before and after the lockdown varied from 47 to 233 $\mu g/m^3$ and 41 to 150 $\mu g/m^3$, 53 to 253 $\mu g/m^3$ and 33 to 175 $\mu g/m^3$ and 43 to 285 $\mu g/m^3$ and 24 to 166
μg/m³ for Agra, Kanpur, and Greater Noida, respectively. Figure 6b shows the variation in the levels of PM₁₀ before and after lockdown from 56 to 250 μg/m³ and 26 to 160 μg/m³ for Greater Noida. The levels of NO₂ (Fig. 6c) fluctuated as before and after lockdown from 46 to 86 μg/m³ and 33 to 66 μg/m³; 28 to 134 μg/m³ and 9 to 51 μg/m³; and 9 to 110 μg/m³ and 12 to 24 μg/m³ for Agra, Kanpur and Greater Noida, respectively. Figure 6d shows the variation in levels of NH₃ before and after lockdown from 6 to 20 μg/m³ and 5 to 12 μg/m³ for Greater Noida. The CO levels before and after lockdown fluctuated from 1 to 9.5 mg/m³ and 1.5 to 8.8 mg/m³ and 3.1 to 13.8 mg/m³ and 5 to 14 mg/m³ for Agra and Greater Noida, respectively. The influence of the drop in the levels of pollutants (PM₂.₅, PM₁₀, NO₂, NH₃ and CO) can be seen in the form of AQI levels of UP, before lockdown and after lockdown which varied from 59 to 233 and 50 to 150; 53 to 253 to 46 and 175; and 56 to 285 and 70 to 170, respectively. SO₂ variations before and after lockdown were recorded as 22 to 70 μg/m³ and 13 to 40 μg/m³; 9 to 47 μg/m³ and 13 to 27 μg/m³; and 12 to 53 μg/m³ and 9 to 21 μg/m³, respectively. The O₃ varies from 4 to 174 μg/m³ in UP.

The PM₂.₅ and PM₁₀ being the major pollutants varied way above the standard values given in Table 3 as shown in Fig. 6a, b, respectively. The highest concentrations of PM₂.₅ were 228 μg/m³, 253 μg/m³ and 228 μg/m³ over Agra, Kanpur and Greater Noida, respectively, and of PM₁₀ was 212 μg/m³ over Greater Noida on 19 February 2020. The lockdown imposed in these regions reduced vehicular and industrial pollutions, showing a major decrease in concentration. On 3 April 2020, the values decreased to 43 mg/m³, 34 mg/m³ and 35 mg/m³ for PM₂.₅ and 54 mg/m³ for PM₁₀, respectively. In the third week of lockdown, the levels increased again to 111 mg/m³, 118 mg/m³, 120 mg/m³ and 120 mg/m³ as the government gave conditional relaxations. Overall, the slope is decreasing with the values −1.89, −1.50 and −2.25 and −1.20, respectively, as given in Table 2. NO₂ is not emitted directly into the environment but is formed from nitrogen atoms or NO upon reacting with oxygen. NO is found to occur as a result of anthropogenic activities like transportation (majorly), electricity generation, fossil fuel combustion, industrial emission (Popescu and Ionel 2010; Rai et al. 2011). Thus, after lockdown the values of the NO₂ decreased giving a negative slope, the value being −0.45, −0.84, and −0.98, respectively (Table 2). NH₃ is largely emitted from agricultural sources and in small amounts from vehicle’s motors and industries. Upon their halt, the level declined to give a slope value −0.06 in Greater Noida (Fig. 6d). NH₃ is largely emitted from agricultural sources and in small amounts from vehicle’s motors and industries. CO is mainly emitted by the incomplete combustion of biomass, fossil fuel, bio-fuel combustion, agricultural waste burning and industrial processes (Olivier et al. 1999). It is an unstable molecule and can easily react with oxygen to form CO₂. If inhaled, 80–90% of CO is absorbed and binds with haemoglobin (Hb) to form carboxyhaemoglobin (COHb), causing CO poisoning (Akolkar 2016). It combines with the oxygen in the blood and reduces the oxygen levels in the body, which can cause a slow death. The slope values of CO for Agra and Greater Noida were −0.04 and −0.05, respectively, showing the decrease in CO level overall (Table 2). The AQI values were decreasing, as the calculated slope values are −1.48, −1.79, and −1.78 of each station, respectively, showing the reduction in the level of AQI resulting due to less pollutant emission from anthropogenic sources. The maximum AQI levels were recorded as 233, 214 and 285 before lockdown. After the lockdown was announced, the AQI levels decreased to values 83, 64 and 90 on 7 April 2020 as can be seen in Fig. 7d. A sudden increase to 127, 160 and 170 on 16 April 2020 was observed due to the dust storm (mentioned earlier).

SO₂ and O₃ are fluctuating under the national standard levels as given in Table 4. Oxygen from NO₂ becomes free by the action of sunlight, and the free oxygen atom can react with O₂ to form O₃. The formation of O₃ by other processes depends on the atmospheric
temperature which has increased largely in northern India mainly due to chemical production/photochemical production during summers (Gaur et al. 2014) which is also our present range of observation (mentioned earlier). Thus, it resulted in a slope with values of 0.22, 0.11 and 0.23, respectively. The SO$_2$ slope value is 0.02 for Agra showing an increment and −0.02 and −0.1 for Kanpur and greater Noida, respectively, showing a gradual deduction (Fig. 7a, c). The air mass back trajectory is also plotted to identify the source of pollutants from long-range transportation and regional origin of pollutants (Sect. 3.5). In Greater Noida, the average percent difference was observed as 54.4%, 52%, 64.1% 17.9%, 3.3%, 43.9% and 32.4 in levels of PM$_{10}$, PM$_{2.5}$, NO$_2$, NH$_3$, SO$_2$, CO and O$_3$, respectively as reported by Mahato and Ghosh (2020) during the first phase of lockdown.

### 3.4 Impact on air quality index (AQI)

Figure 8 reveals that the significant decline in the AQI over all selected 9 stations with a dramatic impact attributed due to the implementation of nationwide stringent lockdown. Before lockdown, the average AQI was in poor range (AQI: 251 to 400) at DTU and Greater Noida and remaining others, i.e. Okhla, PJ, Jind, Hisar, Agra, Kanpur and Palwal, were moderately polluted (AQI: 101–250). However, after the implication of lockdown, the AQI in the moderately polluted zones was transformed into satisfactory air quality zones (AQI: 51 to 100) and poor air quality zones were changed into moderately polluted zones. The significant change in the AQI was observed for all the location, but in Okhla (46.67%), PJ (42.45%) and DTU (40.0%), AQI was remarkably improved as compared to other locations such as Kanpur (36.64%), Agra (33.91%) Jind (33.85%), Hisar (33.34%), Greater Noida (31.20) and Palwal (30.77%) during observation (Tables 1, 4). Mahato et al. (2020a) also reported a significant reduction of 59.4% and 52.92% during the lockdown period at industrial and transportation site over Delhi, whereas Srivastava et al. (2020) reported the AQI levels in the range of 137 to 210 before lockdown and AQI reduction up to 31.07

![Fig. 8 Data showing the average variations in levels of AQI before (17 March 2020 to 24 March 2020) and after lockdown (25 March 2020 to 4 May 2020) in Delhi, Haryana and Uttar Pradesh. Source: Based on CPCB dataset](image-url)
to 75.50 after lockdown over three selected locations in Delhi. Mahato and Ghosh (2020) observed a drastic decline in the AQI of up to 22.6% after lockdown over Jind (Haryana), whereas in Greater Noida, the AQI has improved by 53.9% and 43.6% after the first and second phase of lockdown.

### 3.5 Air mass back trajectory (AMBT) analysis

To understand the origin and transportation of pollutants, seven days’ air mass back trajectories (AMBTs) for Delhi (Okhla, DTU, and PJ), Haryana (Jind, Palwal, and Hisar) and UP (Agra, Kanpur, and Greater Noida) were plotted at the altitude of 1000 m (above mean sea levels) as suggested by Koracin et al. (2011). The AMBTs for three locations in Delhi (Fig. 9a), Haryana (Fig. 9b) and two locations Agra and Noida are confined in UP, so these monitoring stations are considered as a single unit (Unit 1) as well as one location in UP, i.e. Kanpur is sufficient distantly located, so it is considered as another unit (Unit 2) in UP (Fig. 9c). To distinguish between long-range (LR) and short-range (SR) transportation events, dash and solid line representations are adopted. Figures 2, 3, 4, 5, 6, 7 and 8 indicate significant variation in the concentration of PM$_{2.5}$, PM$_{10}$, NO$_2$, NH$_3$, SO$_2$, O$_3$, CO and AQI after and before the lockdown. In the case of Delhi, the air mass (AM) coming from European, Gulf and African region to Afghanistan via Rajasthan and Punjab to Delhi is also influenced by the regional/local emission from Indo-Gangetic Plain and adjacent regions in both cases. The variations of AMBTs were also well defined and explained by Tiwari et al. (2017) for Delhi. In Figs. 2 and 3, there are peaks in pollution parameters and AQI on 20 February 2020, 27 February 2020, 26 March 2020, 16 April 2020 and 23 April 2020 which indicates the long-range transportation of air mass from Gulf, European and African countries as well as the transportation from Indian Gangetic Plain (IGP) on 19 February 2020 and 30 April 2020.

Similarly, in the case of Haryana (Fig. 9b), the AM originated from European, Gulf and African countries as well as Indian western neighbouring countries such as Afghanistan, western Pakistan via Rajasthan, and Punjab to Haryana on 27 February 2020, 2 April 2020, 23 April 2020 and 30 April 2020 via LR transportation and responsible for the significant change in over Haryana (Fig. 4 and 5). It also indicates the significant contribution from local emission entities located in National Capital Region (NCR) and Madhya Pradesh (Gautam et al. 2018) on 20 February 2020, 19 March 2020 and 26 April 2020.

But in the case of UP, the air mass is transported from European, Gulf and African countries such as Afghanistan, Tajikistan and western Pakistan on 27 February 2020, 19 March 2020, 9 April 2020, 16 April 2020 and 23 April 2020 via LR transportation of pollutants. However, AM is also coming from some Indian states such as Rajasthan, Punjab to Haryana and Maharashtra to both the locations, i.e. unit 1 and unit 2 (Satsangi et al. 2013; Gautam et al. 2018).

### 4 Conclusion

The COVID-19 pandemic forced many countries to implement full or partial lockdown, causing a substantial reduction in the anthropogenic activities due to being prohibited from outdoor invasion which resulted in less transportation and shutting down of industries. On the one hand, it caused people to suffer, whereas on the other hand, the environment benefitted from reduced emission of atmospheric pollutants. Initially, the levels of the
Fig. 9  Air mass trajectory of data showing the variations in levels of AQI and pollutants in Delhi (a), Haryana (b) and Uttar-Pradesh (c). Source: Based on NOAA (HYSPLIT) dataset
considered pollutants PM$_{2.5}$, PM$_{10}$, NO$_2$, NH$_3$ and CO were well above the standard limits, which right after lockdown showed a sudden decline in the concentration level. Once the conditional relaxation was given, the levels again took a significant rise. The AQI is improved (reduced) up to 30–46.67% after implication of lockdown. The levels of the particulate matter showed the most reduction in Delhi, followed by UP and Haryana because of lesser vehicles on road and reduced industrial emissions. NO$_2$ levels have reduced mostly in UP, whereas a similar trend can be seen in Haryana and Delhi. The increase in the level of SO$_2$ followed a similar trend in all the three regions. The level of NH$_3$ reduced mostly in Haryana, followed by UP and Delhi as Haryana has most agricultural activity among the three regions which were halted. The level of O$_3$ was enhanced and found highest in Delhi because of lesser greenery when compared to UP and Haryana, which resulted in higher atmospheric temperature favourable for O$_3$ formation. The AMBT reveals that the air quality is potentially impacted by long-range and short-range/regional transportation of air masses, resulting in significant fluctuations in the major air pollutants. Considering the changes observed in air quality in such a short duration of inactivity, it can be conceived as an idea for future where the government can implement semi-lockdowns or even complete lockdowns. This will help maintain the improved quality of the air which will directly influence the health of environment and people.

5 Limitations

- The daily resolution of data was used for more precise detailing hourly data set which can be used to understand the diurnal variation.
- The missing data of some stations for some pollutants are due to the lack of instruments available there.
- Number of stations taken was only 3 for the whole state. Considering more stations might give better results.
- Only seven pollutants (PM$_{2.5}$, PM$_{10}$, NO$_2$, SO$_2$, NH$_3$, O$_3$ and CO) were considered. For more accurate detailing, more pollutants can be considered in the calculation of AQI.

6 Future research directions

- Proper instrumentation installation and regular calibration will allow more efficient studies.
- The spatial variation of pollutant with some location can performed over India.
- The further research must focus to calculate the timing of lockdown for different particular locations based on air moments, topography and background meteorological parameters.

Compliance with ethical standards

Conflict of 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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