Air Quality and Its Relationship with COVID-19 Mortality in Hotspot Places of India: A Post-lockdown Analysis

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Abstract

The COVID-19 pandemic spread over the world like the wind with more than 400,000 documented cases as of March 24th, 2020. In this regard, strict lockdown measures were imposed in India on the same date to stop the virus spread. Thereafter, various lockdown impacts were observed and one of the immediate effects was a reduction in air pollution levels across the world. In this study, we have selected 14 major hotspot places where the COVID-19 cases were >1000 (as of 1st June 2020) that represents more than 70% mortalities of India. We assessed the impact of lockdown on different air quality indicators including ground (PM_{2.5}, PM₁₀, NO₂, SO₂, O₃, and AQI) and tropospheric nitric oxide (NO₂) concentrations through ground monitoring stations and Sentinel-5 satellite data respectively. We have found highest reduction in NO₂ (-48.68%), PM_{2.5} (-34.84%) and PM₁₀ (-33.89%) air pollutant (unit in µg/m³) levels post-lockdown. Moreover, tropospheric NO₂ (mol/m²) concentrations were also improved over Delhi, Mumbai, Kolkata, Thane, and Ahmedabad metro cities. Interestingly, air pollutant indicators have been correlated with different periods (as of 1st and 15th June 2020) of COVID-19 mortalities data to assess the bounding between these variables. Accordingly, we have found a strong positive correlation of mortalities data with ground PM₁₀ (R²=0.145; r =0.38) and AQI (R²=0.17; r =0.412) indicators and this relationship has been improved significantly on second time point. The correlation finding suggests that the long-term bad air quality may aggravate the clinical symptoms of the disease.

Introduction

The COVID-19 outbreak started from Wuhan city, capital of Hubei province (Raibhandari et al., 2020) when the first case of coronavirus was reported in December 2019 (Huang et al., 2020). The Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) gradually spread throughout the world and become a global health issue (Chen et al., 2020a; Gilbert et al., 2020) and later World Health Organization (WHO) has declared it a pandemic (Huang et al., 2020; Cucinatta & Venelli, 2020). In India, the first SARS-CoV-2 case was reported in the Kerala state in Jan 2020 (Gautam & Hens, 2020) and gradually spread in Maharashtra, Gujarat, Delhi, and rest of the states. Later, a countrywide lockdown was declared by the Prime Minister of India on the midnight of March 24th, 2020 that has been extended till April and further extended till June 2020 due to the fear of spreading the virus. By this countrywide lockdown, transportation and industrial activities were almost stopped and as a beneficial outcome, air pollution levels were drastically reduced in various cities of India (Sharma et al., 2020) reported by the Central Pollution Control Board (CPCB). The different pollution indexes were adopted throughout the world that includes various air pollutants and in India, Air Quality Index (AQI) often, also is termed as Air Pollution Index (API) is adopted to express the magnitude of air pollution (Shenfeld, 1970; Ott and Thorn, 1976; Murena, 2004). In the initial stage, some significant pollutants were not included which harms the respiratory system (Radojevic and Hassan, 1999; Qian et al., 2004). In this context, Indian National Air Quality Standards (INAQS) have included various air pollutants (PM_{2.5}, PM₁₀, O₃, SO₂, NO₂, NH₃, and

CO) to calculate the AQI through more than 200 monitoring stations across India (<http://www.cpcb.nic.in>).

India is one of the most polluted countries and 21 Indian cities are in the list of world's most 30 polluted cities (<https://www.iqair.com/us/world-most-polluted-cities>) that takes almost 12.4 million lives every year (Balakrishnan et al., 2018). In such conditions, the COVID-19 lockdown beneficially improved the air quality throughout the globe, and a decline in different air pollutants have been reported worldwide and in India employing ground monitoring stations and remote sensing datasets (Chauhan and Singh, 2020; Nakada and Urban, 2020). The drastic deduction (more than 50%) in different air pollutants were highlighted in megacity Delhi, India (Mahato et al., 2020).

Interestingly researches have established a relationship between air pollution and mortalities related to SARS-CoV-2 (Zhu et al., 2020; Conticini et al., 2020). In this regard ground and tropospheric pollutants (PM and NO₂) levels were correlated (Qin et al., 2020). Therefore, people living in polluted regions generally inhale toxic pollutants from the past couple of years are more prone to it that makes the immune system weaker (Viehmann et al., 2015; Schraufnagel et al., 2019). In this study, we have targeted only those 14 hotspots regions of India where the COVID-19 cases and mortalities (represents more than 70%) are reported high. Accordingly, this research aims to assess the reduction of AQI and different air pollutants (PM_{2.5}, PM₁₀, NO₂, O₃, and SO₂) at the ground monitoring station and extract the changes in Tropospheric NO₂ concentration employing remote sensing data. Moreover, the study also tried to establish the relationship between air pollutants and COVID-19 mortalities.

Material And Methods

To assure the post-lockdown changes in air pollution, we employed In-situ air quality monitoring data for more than 200 stations of India. Later, the Inverse Distance Weighted (IDW) interpolation technique was used to get the raster values for maximum area. These AQI were assessed on 25th February 2020 (a month before lockdown), 25th March 2020 (first day of lockdown) and 25th April 2020 (a month after lockdown) different dates to monitor the variations. Moreover the detailed investigation were performed using ground and tropospheric pollutant indicators for Ahmedabad, Aurangabad, Bhopal, Chennai, Delhi, Hyderabad, Indore, Jaipur, Jodhpur, Kolkata, Mumbai, Pune, Surat, Thane cities (Fig. 1). The criterion behind selecting these major places is that we have considered only those places where the number of cases was more than 1000 as of 1st June 2020 (Table 1). The statistical analysis was performed using Air Quality Index (AQI), and other pollutants *i.e.* PM_{2.5}, PM₁₀, NO₂, SO₂ and O₃ (units in µg/m³) monthly average data of mentioned places were procured for pre-lockdown (February 25th, 2020 and March 24th, 2020) and post-lockdown (March 25th, 2020 and April 24th, 2020) periods from Central Pollution Control Board (CPCB) portal (<https://cpcb.nic.in/>). At the same time, Remote sensing data was analyzed using Google Earth Engine that was collected from Copernicus Sentinel-5 Precursor Tropospheric Monitoring Instrument (S5p/TROPOMI) to know the spatial variations in tropospheric NO₂ (mol/m²) concentrations during the same average monthly time periods for the same study areas. Moreover, the linear regression

and correlation analysis were performed between different air pollutants with COVID-19 mortalities (as of 1st June 2020) obtained from different portals handling by the Ministry of Health & Family Welfare (<https://www.mohfw.gov.in> & <https://www.mygov.in/covid-19>). A similar investigation was performed after 2 weeks (as of 15th June 2020) of updated COVID-19 mortalities (Table 1) to assess the variations in the relationship between these variables.

Figure 1. Study area: The major COVID-19 vulnerable places marked with red color along with respective codes.

Table 1. COVID-19 mortality on two different time periods.

Results And Discussion

3.1. Air Pollution Levels and Reduction due to COVID-19 lockdown

In India, three weeks of lockdown was declared at midnight on the 24th of March 2020. Thereafter, the country has observed a remarkable reduction of about -36.10% in AQI on 25th March 2020 compared to a month before (25th Feb 2020) lockdown as per our statistical calculation using more than 200 air quality monitoring station data. The overall AQI of India has been reduced drastically as per the investigations. The maximum and minimum AQI values are visible and highlighting the improvements over the period of time (pre, during and post lockdown dates) in India (Fig. 2a-c). The average AQI before a month of lockdown was 128 that dropped down at 89 (on a very first day of lockdown) and further decreased after a month of lockdown that was 72. This continuous reduction in AQI clearly indicates that the atmospheric pollution of India has been improved a lot under the COVID-19 lockdown.

Figure 2. Air quality index levels in India: (a) a month before, (b) a next day and a month after (c) country lockdown.

In this research, we have analyzed one month average changes (between 25th Feb to 24th March 2020 and 25th March to 24th April 2020) as per the lockdown dates (pre and post) in different air pollutant indicators i.e PM_{2.5}, PM₁₀, NO₂, O₃, SO₂ (units in µg/m³) and AQI. We have found that all air pollutant concentrations have reduced drastically in the month of April 2020 (Post-lockdown period) compared to March 2020 (Pre-lockdown) (Fig. 3a-f). The PM_{2.5} was >100 µg/m³ at Jodhpur, Surat, and Thane cities, whereas Delhi, Jodhpur, Mumbai and Ahmadabad were the leading cities in PM₁₀ (most of them had >110 µg/m³) concentrations before lockdown period (Fig 3a, b). These regions have more traffic and industrial burden which was the main responsible reason for the high level of PM concentrations. A similar pattern has found in NO₂ levels where these pollutants were recorded higher at Indore, Thane, Jodhpur, and Ahmedabad stations (Fig. 3c) whereas SO₂ concentration was more at Aurangabad, Pune and Thane cities in a pre-lockdown phase that have been reduced considerably (Fig 3d). Interestingly, in 6 out of 14 cities, and increased has been observed in the O₃ level after lockdown (Fig. 3e). Aurangabad, Chennai, Delhi, Kolkata are few cities where the O₃ level has increased partially. The significant

improvement has been noticed in AQI levels of all cities among which Ahmedabad, Delhi, Jodhpur, and Kolkata cities were leading in poor air quality (Fig. 3f).

Figure 3. The pre- and post-lockdown variation in (a) $PM_{2.5}$, (b) PM_{10} , (c) NO_2 , (d) SO_2 , (e) O_3 and AQI (f) pollutant levels recorded at ground monitoring stations of different cities.

The changes (positive and negative percentage) in different air pollutants were calculated (Fig. 4 and Table 2) and accordingly it has been found that the average AQI is dropped almost -31.59% in studied cities. The highest average reduction has been found in NO_2 (-48.68) compare to other pollutants. The same trends of reductions were also observed in SO_2 (-37.76%), $PM_{2.5}$ (-34.84%), PM_{10} (-33.89%) and O_3 (-9.06%) air pollutant indicators. Results reveal that the NO_2 levels have reduced more in Thane, Mumbai, and Kolkata cities after imposed lockdown with 77%, 74%, and 68% respectively. These cities are known for heavy traffic loads with less density of roads that increase the burden of NO_2 levels. A similar trend of reduction is observed in both Particulate Matter ($PM_{2.5}$ and PM_{10}) with little variations. The remarkable improvement in $PM_{2.5}$ concentrations was observed at Pune, Thane, and Ahmedabad that was reduced -63%, -56%, and -43% respectively, however, it was high before the lockdown period at Jodhpur city. The prominent source of $PM_{2.5}$ is organic aerosols and motor vehicle traffic that are totally anthropogenic induced activities that stopped due to lockdown. The PM_{10} is highly controlled by construction sites, burning activities, industrial sources, and dusts factors that make Delhi, Jodhpur and Mumbai cities more prone in PM_{10} air pollutant. However, the higher reductions during lockdown were noticed in Pune (-59.7%), Thane (-58%), and Kolkata (-44.3%). The SO_2 pollutants that have shown considerable variation post-lockdown and the reduction have counted high in comparison to the other pollutants. The major reduction is observed in Aurangabad (-89%) and the rest of the cities and the chief reason behind the reduction in SO_2 level is an industrial activity that processes materials that contain sulfur. A concentration of O_3 shows negligible rising due to the high insolation between April to August period in the Indian subcontinent (Gorai et al., 2017). The concentration of O_3 increases in Aurangabad (19.2%), Hyderabad (12.29%), Kolkata (12.03%), Chennai (8.87%), and Delhi (6.3%) cities as they are known for industrial and transport dominated places.

Figure 4. The change reduction percentage of all air quality indicators.

Table 2. Post-lockdown percentage changes in air pollutant levels compare to pre-lockdown.

Moreover, tropospheric NO_2 (mol/m^2) pollutant concentrations were also mapped to observe the temporal variation through remote sensing data. Accordingly, we found a massive improvement in Delhi, Mumbai, Thane, Ahmedabad, Chennai and Hyderabad cities as the highest NO_2 concentrations (red color) scale showed $0.0001\ mol/m^2$ that is totally invisible post-lockdown compared to pre-lockdown (Fig. 5).

Figure 5. The average tropospheric NO_2 concentration variations in study area during a one-month pre- and post-lockdown period.

3.2. Relationship of Air Pollutants and COVID-19 Mortalities

The considered 14 places have covered almost >70% of COVID-19 mortalities and its growth rate is high in these hotspot regions compared to the rest of Indian places. The Mumbai and Delhi are main COVID-19 hotspot and polluted places in India and across the world. People are inhaling these toxic pollutants and dying from past decades, therefore, to find out the relationship between COVID-19 mortality and atmospheric pollution is an important task. In this regard, our linear regression results have shown satisfactory positive relationships with $PM_{2.5}$, PM_{10} , and AQI pollutant indicators (Fig. 6a, b and f). The analysis showed promising association between COVID-19 deaths and PM_{10} ($R^2=0.145$; $r=0.38$, $p=0.039$), AQI ($R^2=0.17$; $r=0.412$, $p=0.21$) and $PM_{2.5}$ ($R^2=0.107$; $r=0.32$, $p=0.081$) air pollutants. The weaker/negative correlation between these variables have found with SO_2 and O_3 air pollutants (Fig. 6d, e). The NO_2 pollutant at the ground insignificant relationship (Fig. 6c), whereas high concentrations of tropospheric NO_2 (mol/m^2) over Mumbai, Delhi, Thane and Ahmedabad places (Fig. 5) indicates it a contributing factor, as the COVID-19 deaths are more in these regions compared to rest of investigated places. However, we could make this relationship stronger when less vulnerable COVID-19 places would be correlated with good air quality regions.

Figure 6. Linear regression analysis of (a) $PM_{2.5}$, (b) PM_{10} , (c) NO_2 , (d) SO_2 , (e) O_3 and AQI (f) pollutant indicators with COVID-19 mortality data (as of 1st June 2020).

We have taken the COVID-19 mortalities data again after 2 weeks (as of 15th June 2020) to analyze the depth relationship between these two variables and our results again corroborate with significant improvements. As per the updated COVID-19 mortalities data, this relationship and correlation with PM_{10} ($R^2=0.207$; $r=0.455$, $p=0.036$) and AQI ($R^2=0.18$; $r=0.425$, $p=0.044$) have made stronger with significant improvements than before (Fig. 7a, b).

Figure 7. Relationship of updated COVID-19 mortality data (as of 15th June 2020) with (a) PM_{10} and AQI (b) indicators.

Interestingly, the associations with remaining air pollutants are still negligible. A similar attempt was also highlighted by Qin et al., (2020) where they have mentioned the fact that the people living under poor air quality regions are highly vulnerable to COVID-19 due to long-term inhalation of toxic pollutants. The bad air quality generally makes a weaker immune system of the human body (Schraufnagel et al., 2019) that may aggravate virus replication and diminish virus clearance by the host.

Conclusion

This study investigates the impact of lockdown on air quality that improved significantly and the detailed study was conducted on 14 major COVID-19 susceptible places of India. Our results reveal that the higher reductions were observed in NO_2 , PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) pollutants with a rate of -48.68%, -34.84% and

-33.89% respectively in 14 major COVID-19 vulnerable places. Moreover, tropospheric NO₂ (mol/m²) concentrations were also decreased especially over the Delhi, Mumbai, Thane, Pune, Kolkata and Ahmedabad places where the concentration was high before imposing lockdown. We tried to establish the relationship between COVID-19 mortalities (on two different time datasets) with different air pollutants and observed satisfactory positive correlations with PM₁₀ and AQI indicators. Interestingly, we found improvement in a relationship when correlated again with updated COVID-19 mortalities data. A similar attempt has been made in different regions of the world that strongly support our results (Wu et al., 2020; Chen et al., 2020). However, the SARS-CoV-2 is a communicable disease but at the same time people living under poor air quality with weakened immune systems are vulnerable or certain diseases also face higher risks and are experiencing the coronavirus pandemic with particular anxieties.

Declarations

Competing interests

The authors declare no competing interests.

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Tables

Table 1. COVID-19 mortality on two different time periods.

S.No.	Places	As of 1 st June 2020		As of 15 th June 2020	
		Cases	Deaths	Cases	Deaths
1	Ahmedabad	10590	722	16640	1187
2	Aurangabad	1289	48	2668	135
3	Bhopal	1271	59	2195	72
4	Chennai	11131	87	31896	344
5	Delhi	13677	287	41182	1327
6	Hyderabad	1178	23	3196	23
7	Indore	3064	116	4.63	170
8	Jaipur	1849	79	2532	133
9	Jodhpur	1275	17	2181	27
10	Kolkata	1693	184	3672	293
11	Mumbai	31972	1026	58226	2182
12	Pune	5996	274	12184	480
13	Surat	1351	62	2579	100
14	Thane	6958	93	18080	434

Table 2. Post-lockdown percentage changes in air pollutant levels compare to pre-lockdown.

S. No.	Places	PM _{2.5}	PM ₁₀	NO ₂	SO ₂	O ₃	AQI
1	Ahmedabad	-43.83	-36.42	-44.85	-51.71	-5.29	-27.87
2	Aurangabad	-32.79	-18.54	15.89	-89.40	19.30	-33.73
3	Bhopal	1.35	-22.42	-62.78	-5.34	-13.83	-15.83
4	Chennai	-39.53	210.67	-21.24	-39.41	8.87	-18.67
5	Delhi	-39.98	-35.55	-46.74	-2.17	6.33	-37.87
6	Hyderabad	-13.61	-29.94	-22.41	-0.32	12.30	-22.35
7	Indore	-33.51	-17.72	-60.35	-37.31	7.27	-18.29
8	Jaipur	-40.03	-34.40	-61.89	-6.81	-27.33	-27.03
9	Jodhpur	-32.73	-24.14	-61.85	-26.67	-2.00	-32.36
10	Kolkata	-32.50	-46.29	-67.98	-24.85	12.03	-38.64
11	Mumbai	-37.15	-44.33	-74.05	-39.15	-20.29	-36.74
12	Pune	-63.26	-59.70	-52.00	-50.55	-73.49	-53.02
13	Surat	-24.02	-12.95	-44.23	-67.84	-28.32	-23.67
14	Thane	-56.14	-58.12	-77.05	-87.06	-22.47	-56.14
Average change %		-34.84	-33.89	-48.68	-37.76	-9.07	-31.59

Figures

Figure 1

Study area: The major COVID-19 vulnerable places marked with red color along with respective codes and air quality monitoring stations.

Figure 2

Air quality index levels in India: (a) a month before, (b) the next day and a month after (c) country lockdown.

Figure 3

The pre- and post-lockdown variation in (a) PM_{2.5}, (b) PM₁₀, (c) NO₂, (d) SO₂, (e) O₃ and AQI (f) pollutant levels recorded at ground monitoring stations of different cities.

Figure 4

The change reduction percentage of all air quality indicators.

Figure 5

The average tropospheric NO₂ concentration variations in the study area during a one-month pre- and post-lockdown period.

Figure 6

Linear regression analysis of (a) PM2.5, (b) PM10, (c) NO2, (d) SO2, (e) O3 and AQI (f) pollutant indicators with COVID-19 mortality data (as of 1st June 2020).

Figure 7

Relationship of updated COVID-19 mortality data (as of 15th June 2020) with (a) PM10 and AQI (b) indicators.