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SARS-CoV-2 pandemic lockdown: Effects on air quality in the industrialized Gujarat state of India

S. Selvam,⁎ P. Muthukumar, S. Venkatramanan, P.D. Roy, K. Manikanda Bharath, K. Jesuraja

Department of Geology, V.O. Chidambaram College, Tuticorin, Tamil Nadu, India
Registration No: 1921223221045, Affiliated to Manonmaniam Sundaranar University, Tirunelveli, Tamil Nadu, India
Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City, Viet Nam
Instituto de Geología, Universidad Nacional Autónoma de México (UNAM), Ciudad Universitaria, Ciudad de México, CP 04510, Mexico
Institute for Ocean Management, Anna University, Chennai, Tamil Nadu, India

HIGHLIGHTS
• Reduction of 30–84% in NO2 during COVID-19 lockdown in western India.
• Increasing O3 (16–58%) was mainly due to less NO emission.
• Overall improvement of Air Quality Index (AQI) by 58% compared to 2019.
• Populated cities with more industrial activities showed higher improvement in air quality (AQI: +60–75%).

GRAPHICAL ABSTRACT

ABSTRACT

Two weeks after the world health organization described the novel coronavirus (SARS-CoV-2) outbreak as pandemic, the Indian government implemented lockdown of industrial activities and traffic flows across the entire nation between March 24 and May 31, 2020. In this paper, we estimated the improvements achieved in air quality during the lockdown period (March 24, 2020 and April 20, 2020) compared to the pre-lockdown (January 1, 2020 and March 23, 2020) by analyzing PM2.5, PM10, SO2, CO, NO2, and O3 data from nine different air quality monitoring stations distributed across four different zones of the industrialized Gujarat state of western India. The Central Pollution Control Board (CPCB)-Air Quality Index (AQI) illustrated better air qualities during the lockdown with higher improvements in the zones 2 (Ahmedabad and Gandhinagar) and 3 (Jamnagar and Rajkot), and moderate improvements in the zones 1 (Surat, Ankleshwar and Vadodara) and 4 (Bhuj and Palanpur). The concentrations of PM2.5, PM10, and NO2 were reduced by 38–78%, 32–80% and 30–84%, respectively. Functioning of the power plants possibly led to less reduction in CO (3–55%) and the declined emission of NO helped to improve O3 (16–48%) contents. We observed an overall improvement of 58% in AQI for the first four months of 2020 compared to the same interval of previous year. This positive outcome resulted from the lockdown restrictions might help to modify the existing environmental policies of the region. © 2020 Elsevier B.V. All rights reserved.

⁎ Corresponding author.
E-mail address: geoselvam10@gmail.com (S. Selvam).
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1. Introduction

The recently discovered infectious SARS-CoV-2 virus, first identified in China (Wuhan), has already infected 427,000 deaths all over the world (source: Johns Hopkins University). There are 2 million confirmed cases and about 427,000 deaths only in the USA. The other worst-affected countries like Brazil (828,810 cases with 41,828 deaths), Russia (528,964 cases with 6948 deaths), UK (294,379 cases with 41,662 deaths), Spain (243,605 cases with 27,136 deaths), and Italy (236,651 cases with 34,301 deaths) have also reported high casualties (Our World in Data, 2020; Gayathri, 2020). The very first case in India was reported on January 30, 2020 and the Indian government ordered national level lockdown on March 24, 2020 in order to maintain social and physical distancing and subsequently, extended the restrictions on industrial activities until May 31, 2020 due to growing number of infections in urban centers of several industrial and highly populated states. Along with the restricted industrial activities, the closure of shopping malls, hotels, gym, universities, schools and colleges have caused reduction in the activities of transportation. The total number of positive cases, however, has increased to 320,922 and the death toll to 9195 on June 14, 2020 (Kachroo, 2020; Sinha, 2020). The state of Maharashtra continues to remain the worst affected (104,568 cases) and it is followed by Tamil Nadu with the number of confirmed cases increased to 42,687. The states of Delhi (38,958), Gujarat (23,038), Uttar Pradesh (13,118) and Rajasthan (12,401) are the other affected federal states.

In some of the recent research, the improvement in air quality during the lockdown period was related to the closure of industries and reduction in vehicle transit. For example, Mahato et al. (2020) used the National Air Quality Index (NAQI) data from 34 monitoring stations of Delhi (India), and observed 40–52% reduction in PM2.5, PM10, NO2, SO2, CO and NH3 concentrations compared to a month before the lockdown. Nakada and Urban (2020) and Zambrano-Monserrate et al. (2020) used the Copernicus Atmospheric Monitoring Service to analyze air quality data in São Paulo state of Brazil and in Hubei province of China, respectively. They observed that the concentrations of air pollutants decreased by 50–60% in Brazil during April 2020 and 20–30% in China during February 2020. Tobias et al. (2020) analyzed air quality data from Barcelona in Spain and observed an average reduction of 51% in nitrogen dioxide (NO2) and 31% in particulate matter (PM10) compared to the same period over the last four years.

The Gujarat state of western India has several cities with poor air quality (e.g. Ahmedabad, Rajkot, Vadodara and Surat) due to the presence of power plants, street dust, transportation, outdoor waste incineration, construction and brick kilns. There are also several industrial zones of multinational groups on the city outskirts (Upadhyay, 2019). In terms of air pollution, Ahmedabad has been ranked as the fourth most contaminated in India (CPCB, 2019). This research assessed the changes occurred in air qualities by comparing the concentrations of PM2.5, PM10, SO2, CO, NO2 and O3 over the lockdown period with the pre-lockdown period from nine air quality monitoring stations within four different zones of Gujarat (Fig. 1).

2. Materials and methods

Fig. 1 shows locations of air quality monitoring stations of the CPCB (Central Pollution Control Board, 2020) at 9 different cities of Gujarat state grouped into four different zones: zone 1 (Surat, Ankleshwar, and Vadodara), zone 2 (Ahmedabad and Gandhinagar), zone 3 (Jamnagar and Rajkot), and zone 4 (Bhuj and Palanpur). We used contents of the particles with diameter $\leq 2.5 \mu m$ (PM2.5) and $\leq 10 \mu m$ (PM10), concentrations of nitrogen dioxide (NO2), carbon monoxide (CO), sulfur dioxide (SO2) and Air Quality Index (AQI). Daily data (24 h) between January 1, 2020 and April 20, 2020 were used for this evaluation and we separated the data in terms of pre-lockdown period (January 1, 2020 to March 23, 2020) and lockdown period (March 24, 2020 to April 20, 2020). The average concentrations of air pollutants of the lockdown period were compared with pre-lockdown values in order to estimate the changes in %. We also compared the average data of January–April 2020 with the same interval of the previous year. The tropospheric monitoring instrument of the precursor Copernicus Sentinel-5 (S5p/TROPOMI) established by the European Space Agency (ESA) provided nitrogen dioxide (NO2) data ($\mu mol/m^2$) for both the pre-lockdown and lockdown periods for the Gujarat state covering an area of ca.196,024 km² (e.g. Tobias et al., 2020).
3. Results and discussion

3.1. Concentration of air pollutants

3.1.1. Zone 1

Concentrations of air pollutants reduced in this zone of dominant fabric and transportation sectors during the lockdown period (Table 1). Compared to the pre-lockdown, the mean concentrations of PM$_{2.5}$ and PM$_{10}$ decreased by 51% and 48%, respectively. Contents of SO$_2$ (-54%) and NO$_2$ (-30%) also decreased. Concentration of CO (-55%) showed the highest reduction in this zone compared to the other zones (Fig. 2a). The maximum daily average of O$_3$ (total variation of +10 μg/m$^3$) increased by 25%. Reduction in traffic in the industrial sectors led to less NO emission and less O$_3$ consumption.

3.1.2. Zone 2

Contents of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO and NO$_2$ decreased by 38–82% (Table 1 and Fig. 2b). Compared to the pre-lockdown period, the mean concentrations of PM$_{2.5}$ and PM$_{10}$ decreased by 34% and 47%, respectively. Declined PM$_{10}$ could be due to shutdown of pharmaceutical, petroleum and petrochemical, steel recycling, auto parts manufacturing, beverage manufacturing and textile industries that contributed to air pollution of Ahmedabad. Similarly, the reduction in automobile transport within Gandhinagar contributed to less air pollutants. Concentrations of other pollutants such as SO$_2$ (-58%), NO$_2$ (-82%) and CO (-38%) also reduced during the lockdown period. The reduction in CO (-38%) was much less compared to SO$_2$ and NO$_2$ and this is due to functioning of the power plants. The maximum daily average of O$_3$ increased by 38% (15 μg/m$^3$) during the lockdown period. Reduction in transport and industrial activities along with more insolation and temperature of March–April might have contributed this increase.

Zone 3: Compared to the pre-lockdown, the mean PM$_{2.5}$ and PM$_{10}$ levels decreased by 78% and 80%, respectively (Table 1 and Fig. 2c). Both of them showed the highest rates of reduction compared to other zones. The rate of decrease for SO$_2$ (-58%) was also highest among all the zones. It must be due to restrictions imposed on navigation activities of large cargo ships, ferries and cruises. Other pollutants such as NO$_2$ (-50%) and CO (-49%) decreased compared to the pre-lockdown (Fig. 2c). The total variation of +61 μg/m$^3$ in O$_3$ was negligible, but it showed an upward trend (increased by 48%).

Zone 4: It lacks dominant industrial and transportation activity, and it hosts cities with the lowest air pollution levels among all the four zones. However, the trends of PM$_{2.5}$, PM$_{10}$, SO$_2$, CO and NO$_2$ decreased by 3–84% compared to the pre-lockdown values (Table 1). Concentrations of PM$_{2.5}$ decreased by 38%, PM$_{10}$ decreased by 32%, SO$_2$ reduced by 22%, NO$_2$ reduced by 84% and CO decreased by a negligible 3%. Similarly, the maximum daily average of O$_3$ (total variation of +2 μg/m$^3$) also showed minimal increase, but it had an upward trend with an increase of 34% (Fig. 2d). Minimal changes in CO and O$_3$ reflected that lockdown had less effect on this zone with smaller number of industries as well as less population.

3.2. S5p/TROPOMI NO$_2$ trends

The mean concentration of tropospheric NO$_2$ estimated (μmol/m$^3$) from S5p/TROPOMIESA satellite data showed lower values for the lockdown period (i.e. March 24, 2020 to April 20, 2020) compared to the pre-lockdown period (Fig. 3; e.g. Tobias et al., 2020; Gorelick et al., 2017). The overall NO$_2$ content in the state decreased by 62% during the lockdown compared to pre-lockdown values (Fig. 3). It almost mimics the changes estimated in data obtained from the air quality monitoring stations (Table 1). NO$_2$ decreased by 82% in zone 2 (58 μg/m$^3$) and 84% in zone 4 (10 μg/m$^3$) during the lockdown period compared to the pre-lockdown. Changes observed in the zones 1 and zone 3 with reductions of 30% (12 μg/m$^3$) and 50% (10 μg/m$^3$) were comparatively less.

3.3. Comparison between 2019 and 2020

We compared the data of January–April 2020 and January–April 2019 to evaluate the effect of lockdown on the long-term changes in air quality (Table 1). The network of air quality monitoring stations maintained by CPCB provided PM$_{2.5}$ and PM$_{10}$ concentrations for the same interval for two years. Compared to the 2019 values, the average concentration of PM$_{2.5}$ decreased by 39% (92 μg/m$^3$) and the average content of PM$_{10}$ reduced by 44% (84 μg/m$^3$) in 2020. NO$_2$ also exhibited a decreasing trend in 2020 and its concentration was reduced by 59% (15 μg/m$^3$) (Fig. 4). The concentrations of CO decreased by 25% (33 μg/m$^3$). Both NO$_2$ and CO are released through road traffic, especially from diesel combustion, and to a lesser extent from gasoline transport vehicles, manufacturing industry and power plants in the urban part of the study area. Closure of traffic flow during the lockdown period led to reduction in the concentrations of NO$_2$ and CO. Minimal shipping and fishing activity caused reduction in the emission of SO$_2$ by 40%

Table 1

| Pollutants | January–April (2019) | Pre-lockdown (January 1, 2020 to March 23, 2020) | Lockdown (March 24, 2020 to April 20, 2020) | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 1 | Zone 2 | Zone 3 | Zone 4 | 2019–2020 |
|------------|----------------------|-----------------------------------------------|---------------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|-----------|
|            |                      | Zone 1                                        | Zone 2                                      | Zone 3 | Zone 4 | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Variation and % change | Change in (% of lockdown) | Variation and % of change between 2019 and 2020 |
| PM$_{2.5}$ | 114                  | 127                                            | 139                                          | 156    | 64     | 90     | 75     | 89     | 44     | -37 (51%) | -34 (48%) | -67 (78%) | -20 (38%) | -92 (30%) |
| PM$_{10}$  | 111                  | 117                                            | 126                                          | 126    | 81     | 91     | 79     | 54     | 65     | -26 (48%) | -47 (78%) | -67 (80%) | -72 (80%) | -84 (44%) |
| CO         | 43                   | 46                                             | 37                                           | 10     | 35     | 27     | 27     | 6      | 36     | -19 (55%) | -10 (38%) | -10 (50%) | -4 (8%)  | -33 (25%) |
| NO$_2$     | 27                   | 28                                             | 91                                           | 20     | 16     | 16     | 33     | 10     | 6      | -12 (30%) | -58 (82%) | -10 (58%) | -10 (84%) | -15 (50%) |
| SO$_2$     | 34                   | 48                                             | 62                                           | 15     | 10     | 28     | 40     | 3      | 7      | -20 (54%) | -22 (58%) | -12 (58%) | -3 (22%)  | -22 (40%) |
| O$_3$      | 18                   | 33                                             | 61                                           | 8      | 44     | 43     | 76     | 14     | 46     | +10 (25%) | +15 (38%) | +6 (48%)  | +2 (16%)  | +30 (58%) |
| AOI        | 128                  | 135                                            | 142                                          | 171    | 81     | 103    | 86     | 89     | 65     | -32 (39%) | -56 (60%) | -82 (75%) | -16 (64%) | -106 (58%) |
Fig. 2. Daily average concentrations of air pollutants (PM$_{2.5}$ in $\mu$g/m$^3$, PM$_{10}$ in $\mu$g/m$^3$, CO in $\mu$g/m$^3$, NO$_2$ in $\mu$g/m$^3$, SO$_2$ in $\mu$g/m$^3$ and O$_3$ in $\mu$g/m$^3$) during pre-lockdown and lockdown periods in four different zones of Gujarat State, India. (zone 1 (a): Surat, Ankleshwar and Vadodara; zone 2 (b): Ahmedabad and Gandhinagar; zone 3 (c): Jamnagar and Rajkot; zone 4 (d): Bhuj and Palanpur).
(22 μg/m³). Finally, the O₃ levels increased by 58% (+30 μg/m³) as the lockdown led to reduction of NO emission and less consumption of O₃ during the titration (i.e., NO + O₃ = NO₂ + O₂). The higher insolation and warmer temperatures of March–April might have also helped to increase the levels of O₃. Our results suggest that the lockdown led to an important improvement in long-term air quality and it should be considered as an alternative measure to reduce air pollution. The effect of lockdown, observed through the data of less than a month (i.e. March 24, 2020 to April 20, 2020) caused reduction in air pollutants by more than half for the four-month long study interval.

3.4. Changes in air quality index

The Air Quality Index (AQI) is based on aggregation method of Ott (1978) and it was calculated using the five different pollutants (i.e. PM₁₀ and PM₂.₅, SO₂, NO₂ and CO) (CPCB, 2014; USEPA, 2006). The CPCB describes the AQI in six different categories, i.e. good, satisfactory, moderately polluted, poor, very poor and severe (Table 2). Fig. 5 depicts the AQI patterns during the pre-lockdown (January 1, 2020–March 23, 2020) and lockdown (March 24, 2020–April 20, 2020) periods over the Gujarat state. The improvement in air quality of zone 1 is evident from AQI value showing a change of 32% (−32) compared to pre-lockdown period (Table 1). This zone comprises of industrial centers at Surat, Ankleshwar and Vadodara and the effect of lockdown should be considered by the state government to modify the industrial and transport policies for a better long-term air quality. AQI values changed by 60% and 75% in zones 2 and 3 showing net reductions in counting by −56 and −82, respectively (Table 1 and Fig. 5). Both the zones have highly populated cities of Gandhinagar, Ahmedabad, Jamnagar, and Rajkot, and they host several power plants and industrial complexes.

Fig. 3. Mean levels of tropospheric NO₂ measured by the S5p/TROPOMI-ESA in Gujarat state of western India during the pre-lockdown and lockdown periods.

Fig. 4. Comparison of mean levels of tropospheric NO₂ measured by the S5p/TROPOMI-ESA between January–April 2019 and January–April 2020 in the Gujarat state of western India.
Significant improvement in AQI values during the lockdown period suggest that decrease in the industrial activities and traffic flow in both the zones led to significant reduction in air pollutants. Zone 4 showed a change of 34% in AQI (net counting reduction of 16) and it was related to decrease in air pollution in the less populated cities of Bhuj and Palanpur. This zone also has a smaller number of industries compared to other zones. The AQI of the entire interval including the pre-lockdown and lockdown periods (i.e. January–April 2020) improved by 58% (net counting reduction of 106) in comparison with the same interval of previous year (i.e. January–April 2019). The average CPCB-AQI of January–April 2020 improved by 106 net counting or 58%. This is also reflected by increase in 8 h daily maxima O₃ levels (16–48%), probably due to the combination of less NO emission and usual increase of insolation and temperature during March–April.

Declared of competing interest

We declared of interest statement.

CRediT authorship contribution statement

S. Selvam:Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Software, Investigation, Writing - original draft.P. Muthukumar:Data curation, Formal analysis.S. Venkatramanan:Investigation, Resources, Software.P.D. Roy:Conceptualization, Investigation, Project administration, Writing - review & editing.K. Manikanda Bharath:Validation, Visualization.K. Jesuraja: Data curation, Formal analysis.

Table 2
Six different categories of CPCB air quality indices calculated using five pollutants (i.e. PM₂.₅, PM₁₀, CO, NO₂, and SO₂) and their comparison with USEPA.

| AQI (USEPA, 2006) | Category | AQI (CPCB, 2014) | Category |
|--------------------|----------|------------------|----------|
| >50                | Good     | 0–50             | Good     |
| 51–100             | Moderate | 51–100            | Satisfactory |
| 101–150            | Unhealthy for sensitive groups | 101–200 | Moderately polluted |
| 151–200            | Unhealthy | 201–300 | Poor |
| 201–300            | Very unhealthy | 301–400 | Very poor |
| 301–500            | Hazardous | 401–500 | Severe |

Fig. 5. Changes in AQI in four different zones of Gujarat state in western India during the pre-lockdown and lockdown periods of 2020. Comparison with AQI of the same interval of previous year (January–April 2019) indicates an overall change of 58% with reduction in net counting of 106.
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