COVID 19 Lockdown - Air Quality Reflections in Indian Cities

Sunil Gulia1*, Nitin Goyal2, Saurabh Mendiratta1, Tridipa Biswas1, S.K. Goyal1, Rakesh Kumar3

1 CSIR-National Environmental Engineering Research Institute, Delhi Zonal Centre, Naraina, New Delhi -110028, India
2 CSIR-National Environmental Engineering Research Institute, Mumbai Zonal Centre, Worli, Mumbai – 400018, India
3 CSIR-National Environmental Engineering Research Institute, Nehru Marg, Nagpur, 440020gpur 440020, India

ABSTRACT

The emergence of COVID-19 put pressure on the Governments of most of the countries in the world to enforce nationwide lockdown (restriction of all non-essential activities) to curtail the spread of infection. The nationwide lockdown created an adverse impact on the economies around the world and altered the day-to-day life of people. The restrictions on pollution generating activities during the lockdown period resulted in an overall improvement of the air quality throughout the world including India. This study evaluated the impact on air quality in 46 cities throughout India and the findings indicate that on average, PM2.5 and NOx concentrations reduced by about 34% and 60%, respectively at different locations in India. PM2.5 concentrations reduced by about 23%, 16%, 32%, and 28% in small, medium, large and megacities, respectively. However, the reduction in NOx concentrations was dissimilar to PM2.5 in these cities. The findings further suggested that the impact of lockdown on air quality was not homogenous across the country and was probably due to varying background contributions. The average concentrations of PM2.5 and NOx at background stations were found higher in large and mega cities than the smaller cities. The PM2.5 concentrations at background stations were higher in North India in comparison to other parts of India.

Keywords: Restricted emission activities, Populated cities, Background concentrations, India, Lockdown

1 INTRODUCTION

The emergence of COVID-19 has placed the whole world on the brink of grave health risks. As of June 1, 2020, the total reported confirmed cases were 6,057,853 including 371,166 deaths globally as per World Health Organization (WHO, 2020). COVID-19 has infected more than 200 countries worldwide including India and WHO had already declared COVID-19 as a pandemic on March 11, 2020. Most of the countries had implemented several strategies to prevent the disease from spreading. Social distancing and restricted movement were the major actions adopted by many countries including China, Italy, France, Spain, Philippines, Brazil, Singapore, India amongst others (Chen et al., 2020; Nakada and Urban, 2020, Venter et al., 2020).

The COVID-19 pandemic created unprecedented situations throughout the world and forced lockdown conditions in several countries. In India, efforts were made at local, regional, and national levels to restrict non-essential movement and contact amongst the human population to impede the spread of COVID-19. The government of India had declared nationwide lockdown from March 25, 2020, in a phased manner viz. Phase I from March 25 to April 14, Phase II from April 15 to May 3, Phase III from May 4 to 17, and Phase IV from May 18 to 31, 2020. The lockdown was...
enforced very effectively throughout the country wherein only essential services were kept operational and all other commercial, political, religious, educational, and entertainment activities amongst others were restricted. In Phase II, certain relaxations were extended to offices and agriculture activities (from April 20, 2020, onwards) and relaxations for several other services were extended strategically in Phase III and IV.

This countrywide lockdown situation restricted the Industrial production activities, all forms of transport (air, water, and land), hotels and restaurants, shopping malls, street eateries, tourism, construction and mining amongst others.

Though COVID-19 had severe adverse impacts on the economy throughout the world including India (Dev and Sengupta, 2020), it also brought a positive impact on air quality across the globe wherever lockdowns were implemented (Han et al., 2020; Isaifan et al., 2020; Nakada and Urban, 2020; Tobias et al., 2020; Xu et al., 2020). IEA (2020) has reported that the world experienced a sharp decline in carbon emissions between January and April 2020 compared to average levels in 2019, and could decline anywhere between 4.4% to 8% by the end of this year. The coronavirus-triggered lockdown has led to a steep fall in global carbon emissions by about 17% in early April as compared to 2019 levels with India’s emissions dropping by about 26% (Le Quéré et al., 2020).

Several Indian cities have been reporting poor levels of air quality in the past especially during post-monsoon and winter seasons (Gurjar and Nagpure, 2019; Guttikunda et al., 2019). The nationwide lockdown in India had reduced the air pollution load significantly in many cities and the atmospheric visibility had improved due to reduced levels of particulate matter. In the month of April, Dhauladhar mountain ranges of Himalayas were visible from Jalandhar (Punjab), and the Gangotri mountain ranges were visible from Saharanpur (Uttar Pradesh) which are about 200 km away (CNN, 2020; TOI, 2020). Researchers had reported reduced air pollution levels in selected Indian cities due to the nationwide lockdown (Jain and Sharma, 2020; Mahato et al., 2020; Mitra et al., 2020; Sharma et al., 2020). These studies were based on limited monitoring data and were restricted to megacities, however, there was a need to analyze the overall effect of lockdown throughout the Indian subcontinent.

The present study was undertaken to evaluate the impact of restricted activities due to lockdown on air quality in India. The present study analyses: i) change in pollutant (PM$_{2.5}$ and NO$_x$) concentrations at 58 continuous ambient air quality station (CAAQMS) spread over 46 cities throughout India; ii) Zone-wise impact estimates i.e., for cities located in Northern, Eastern, Central, Western and Southern India and further differentiated based on the population of the city; iii) Categorization of all 58 stations into the background, residential/commercial and kerbside/industrial stations based on their site features; iv) Calculation of representative background values for selected pollutant concentrations in different regions of India.

2 METHODOLOGY

2.1 Selection of CAAQMS and Study Period

To evaluate the impact of restricted emission activities on air quality during the lockdown period in India, hourly average pollutant concentrations were collected from several continuous ambient air quality monitoring stations (CAAQMS) operated by Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs). The selection of CAAQMS was an important step in the present analysis and the criteria adopted were: i) availability of active CAAQMS (operating condition); ii) population of the city (Small $\leq$ 0.5 million, Medium = 0.5–1.0 million, Large = 1.0–5.0 million and Mega $\geq$ 5.0 million) and iii) Location of the city in India viz. North, East, Central, West, and South of India. Data were collected from 58 stations spread over 46 cities across India as listed in Table S1 of supplementary information (SI). The information of cities based on population and locations have been presented in Table 1. Out of the total 46 cities, 21 falls in North zone, 5 in East zone, 7 in Central zone, 6 in West zone, and 7 in the South zone. Number of CAAQMS stations are being operated higher in north zone compared to other zones of the country. Cities are more closer in northern zone which increase the possibility of intercity transboundary pollution contribution compared to other parts. The categorization of CAAQMS based on population was delineated as 15 in small, 9 in medium, 18 in large, and 5 in a mega-city. Out of 15 small cities, 9 are presented in North zone and 4 in central zone, similarly, out of
Table 1. Classification of cities based on location and population.

| Size of City/Locations | Nos. of City (Nos. of Stations) | Total |
|------------------------|---------------------------------|-------|
|                        | Small (Nos. of Stations)        |       |
|                        | > 0.5 million                   | 15 (15) |
|                        | 0.5–1.0 million                 | 9 (9)  |
|                        | 1.0–5.0 million                 | 17 (18) |
|                        | > 5.0 million                   | 5 (16) |
|                        | Total                           | 46 (58) |

17 large cities, 9 are in north zone and 2 in each other zone of country. Out of 5 megacities, 2 are located in west and south zone each and 1 in North zone.

The selection of the study period was another key parameter to accurately estimate the impact of restricted emission activities. The study period was selected in a way that both pre-lockdown (with source activities) and lockdown period (limited source activities) could be covered. The period from March 1 to 21, 2020, and March 25 to April 19, 2020, were selected to represent the pre-lockdown and lockdown period, respectively. The period of March 22 to 24, 2020 was disregarded as only a few states had declared the lockdown, and these days were not a true representative of either pre-lockdown or lockdown period. The nationwide lockdown started from March 25, 2020, and continued until April 19, 2020, with full restrictions except for essential services. Conditional relaxations to operate offices and agricultural activities were extended from April 20, 2020, onwards.

Since the fate of air pollutants in the atmosphere is governed by the meteorological conditions, it was necessary to establish uniformity in meteorological parameters at all selected stations to compare the pre-lockdown and lockdown period. The average wind speed, relative humidity, and ambient temperature during pre-lockdown and lockdown periods and their differences were compiled, as shown in Fig. 1 and summarized in Table 2. It was observed that average wind speeds at all the selected stations were practically similar during both the periods, except at Panipat (Haryana) and Patiala (Punjab), where wind speed during lockdown was higher than pre-lockdown. The relative humidity in the Northern zone was slightly less during the lockdown period as compared to the pre-lockdown period at almost all the stations while ambient temperatures were found to be slightly higher during the lockdown period. Overall insignificant differences were observed in other parts of the country except for two stations in the Eastern and Central zone. The average wind speed increased by about 9.6% in the Northern zone; however, it decreased in the Western and Southern zone by about 3 to 5%. The relative humidity decreased by about 28% in the Northern zone while it increased slightly in the Western zone from pre-lockdown to lockdown period. The ambient temperatures increased by about 16 to 22% in the Northern and Eastern zones. The differences in relative humidity and ambient temperatures during the two study periods in the Northern zone might influence the assessment of restricted activity on air quality due to lockdown, but there were insignificant changes in meteorology in other zones of India.

As lockdown was enforced throughout India, source activities in all directions from the stations were restricted homogenously, thus the impact of wind direction was considered to be negligible during these days. Thus, it was thus inferred that the difference between pollutant concentrations during pre-lockdown and lockdown period at the selected stations would be independent of the meteorological factors except for few stations in the north zone and would be impacted primarily by the reduction in emission load in the atmosphere due to restricted activities.

2.2 Data Collection

Real-time air quality monitoring across several cities in India by the deployment of CAAQMS has been underway for several years (CPCB, 2011). These stations were deployed for air quality assessment and management rather than for any statutory purpose. PM$_{2.5}$ was monitored through Beta Attenuation Method (BAM)/Tapered Element Oscillating Microbalance (TEOM) while NO$_x$ was monitored through Gas-phase Chemi-luminescence method. The calibration,
Fig. 1. Change in meteorological parameters from pre-lockdown to lockdown period at selected Stations in India.

Table 2. Region-wise summary of differences in meteorological parameters during pre-lockdown and lockdown periods.

| Regions/zones | Wind Speed (m s\(^{-1}\)) | Relative Humidity (%) | Ambient Temperature (°C) |
|---------------|----------------------------|-----------------------|--------------------------|
|               | Pre-lockdown | Lockdown | Difference (%) | Pre-lockdown | Lockdown | Difference (%) | Pre-lockdown | Lockdown | Difference (%) |
| Northern      | 1.56         | 1.71     | 9.64          | 65.61          | 47.11     | −28.20         | 22.57        | 27.63     | 22.40          |
| Eastern       | 1.39         | 1.50     | 7.66          | 69.87          | 62.45     | −7.42          | 23.28        | 27.16     | 16.66          |
| Central       | 0.89         | 0.94     | 5.34          | 44.69          | 36.06     | −19.32         | 28.97        | 30.42     | 5.01           |
| Western       | 1.86         | 1.77     | −5.25         | 51.45          | 53.14     | 3.28           | 29.96        | 32.40     | 2.44           |
| Southern      | 1.59         | 1.54     | −2.99         | 58.26          | 55.83     | −2.43          | 28.86        | 29.41     | 1.92           |

Operation, and maintenance of all stations were being carried out through the common guidelines issued by CPCB. Data were available in public domain on the website of CPCB (URL: https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing). These data on the portal...
get sourced directly from the continuous analyzers without scrutiny. The hourly average data of PM$_{2.5}$ and NO$_x$ were collected from the common portal and converted into the daily average for further analysis. The outliers from each data set were removed for both extreme lower and upper percentile values, which were seen to be out of the trend. The monitoring stations exhibited missing data for respective pollutant for few hours during the study period which might be due to long power cuts and maintenance (CPCB, 2020). The data for these missing hours were excluded from the statistical analysis.

2.3 Data Analysis

2.3.1 Impact on air quality due to lockdown

The city-wise and zone-wise impacts were calculated by comparing the pollutant concentration data of the pre-lockdown and lockdown period. The percentage difference was calculated by using Eq. (1).

$$\Delta c = \frac{(C_L - C_{PL}) \times 100}{C_{PL}}$$

where $\Delta c$ is the percentage change in concentration from Pre-lockdown to lockdown period, $C_L$ is the average pollutant concentrations during lockdown; $C_{PL}$ is the pollutant Concentration during Pre-lockdown period.

2.3.2 Estimation of background concentration

The study further attempts to estimate the background concentration by selecting the representativeness of each monitoring station. The background/baseline concentration has been defined as the pollution generating from the i) natural sources, ii) nearby sources other than the one currently considered and iii) unidentified sources. Generally, the background/baseline concentrations are required to predict incremental contributions from a source at a particular location. In the absence of source activities, average pollutant concentrations represent the contribution from natural sources, which can be treated as background/baseline concentration. In the Indian cities, another source to consider is the emission from cooking activities in residential areas, which is an essential activity for survival. Any such emissions would be a part of an urban background, which would vary as per the city’s size (basically in terms of the population). It would further depend on the location of the CAAQMS in the city as the impact of emission from cooking will be reflected more when it is located in a residential area.

3 RESULTS AND DISCUSSION

3.1 Impact on Air Quality during Lockdown Period in India

3.1.1 Zone-Wise

The restriction on all non-essential activities during the lockdown period in India had resulted in significant impacts on air quality. The difference between average pollutant concentrations during pre-lockdown and lockdown period at all 58 monitoring stations were calculated, as presented in Fig. 2.

On an average, the difference in PM$_{2.5}$ and NO$_x$ concentrations were found to be about –34% (52–34 $\mu$g m$^{-3}$) and –49% (69–35 $\mu$g m$^{-3}$), respectively, in North zone, during lockdown period when compared to pre-lockdown period. The negative sign indicates a reduction due to the lockdown impact. The impact on both selected pollutants correlated well for most of the cities. In some of the cities, NO$_x$ data were not available for the study period, so excluded from the analysis and only PM$_{2.5}$ data were analyzed for these cities such as Rohtak, Narnual, and Faridabad in Haryana.

In the East Zone, the average difference in PM$_{2.5}$ and NO$_x$ concentrations were found to be about –17% (66–54 $\mu$g m$^{-3}$) and –57% (70–30 $\mu$g m$^{-3}$), respectively. The impact on PM$_{2.5}$ and NO$_x$ were correlated well for most of the cities except Varanasi (UP) and Gaya (Bihar). The impact on PM$_{2.5}$ was slightly less than NO$_x$ concentration, which might be due to variations in sources for both pollutants.
The average difference in PM$_{2.5}$ and NO$_x$ concentrations were found to be 1.7% (36.5–37.2 µg m$^{-3}$) and −46% (35–19 µg m$^{-3}$), respectively, in the Central zone. The average PM$_{2.5}$ concentrations in this region exhibited an increase of 1.7% instead of a decrease except for Nagpur (Maharashtra), which shows a 26% decrease. However, a significant reduction in NO$_x$ concentrations indicates the impact of restricted activities, which were not reflected in PM$_{2.5}$ indicating the dominance of different background sources of PM$_{2.5}$ in this zone compared to other zones.

The impact in the West zone was found to be significant with −31% (41 to 28 µg m$^{-3}$) and −60% (54–22 µg m$^{-3}$) for PM$_{2.5}$ and NO$_x$ respectively. However, in the South Zone, the impacts were −26% (31–23 µg m$^{-3}$), and −32% (39–27 µg m$^{-3}$), for PM$_{2.5}$ and NO$_x$, respectively.

On an average, the PM$_{2.5}$ reduced by −34%, −17%, −31%, and −26% in North, East, West, and South zone, respectively, and increase of 1.7% in Central zone. Similarly, the NO$_x$ reduced by −49%, −57%, −46%, −60%, and −32% in North, East, Central, West, and South zone in selected Indian cities as presented in Table 3. It could be inferred that the percentage reduction in NO$_x$ concentrations was higher than PM$_{2.5}$ during lockdown periods throughout the country. The impact of lockdown was not homogenous throughout the country as natural contribution varies zone wise. In addition, some cities have industries related to essential services, which operated during this lockdown period and would have contributed to the pollution load of the city for a specific pollutant. The regional meteorology in different parts of the country plays an important role in the dispersion of pollutants resulting in variable impacts in different zones.

In order to visualize the results effectively, the percentage difference of PM$_{2.5}$ and NO$_x$ at several monitoring stations in various zones were plotted using GIS application on the map of India as presented in Figs. 3 and 4, respectively.
Table 3. Summary of the impact of lockdown on Air Quality in India.

| Pollutant | Parameters | % Change in lockdown period in the Zone |
|-----------|------------|----------------------------------------|
|           |            | North | East | Centre | West | South |
| PM\(_{2.5}\) | Mean       | –34   | –17  | 1.7    | –31  | –26   |
|           | Maximum    | –52   | –48  | –26    | –38  | –43   |
|           | Minimum    | –16   | –6   | 19     | –10  | –2    |
| NO\(_x\)  | Mean       | –49   | –57  | –46    | –60  | –32   |
|           | Maximum    | –71   | –76  | –60    | –84  | –61   |
|           | Minimum    | 3     | 9    | –6     | –5   | 13    |

Note: (–) negative sign indicates a reduction in concentrations.

Fig. 3. Map showing CAAQMS locations and percentage difference in PM\(_{2.5}\) concentration from pre-lockdown to lockdown period at selected stations (Red colour values indicate stations serial number and black colour value shows percentage difference).

3.1.2 Based on city population

During the lockdown period, emissions from cooking activities in low-income residential sectors were a continuous source of pollution, which positively correlated with the population of the city. However, a reflection of these emissions only shows on CAAQMS, which were located in the residential area. Given the above, the cities were categorized based on population size as described in Table 1.
The average differences in PM$_{2.5}$ and NO$_x$ concentrations were found as $-23\%$ and $-41\%$, respectively, in small cities having a population $< 0.5$ million as presented in Table 4. In medium-size cities, the impact was $-16\%$ and $-56\%$ for PM$_{2.5}$ and NO$_x$, respectively. These differences in large cities were $-32\%$ and $-42\%$, respectively. The impact in mega-cities were significant with $-28\%$ and $-46\%$ for PM$_{2.5}$ and NO$_x$, respectively. The PM$_{2.5}$ concentrations reduced by $-23\%$, $-16\%$, $-32\%$, and $-28\%$ in small, medium, large, and mega-cities, respectively, indicating that large and mega-cities experienced higher impacts as compared to smaller cities. However, a similar pattern was not observed for NO$_x$. The major PM$_{2.5}$ generating activities in large & mega cities include Industrial emissions, vehicles movement, solid waste burning in open, operations of diesel generator (DG) sets in commercial areas, restaurants/hotels and street tandoors and their intensity of emission is higher in highly populated cities. All these sources were shutdown during lockdown as there was no demand except essential/emergency services and this reduction in activities/emission was reflected in higher reduction of PM$_{2.5}$ concentration in large and mega cities. This is further supported through zone wise comparision of results of PM$_{2.5}$ reduction as higher in North zone (maximum nine large cities). North Indian cities generally have higher particulate matter concentration compare to other region (AirVisual, 2018; Jain and Sharma, 2020). However, NO$_x$ reduction was found a maximum of 56% in medium scaled cities. The reductions in large & mega cities are comparatively less (42–46%) which might be due to higher per capita LPG consumption by domestic sector during the lockdown period which may
**Table 4. Impact of lockdown on air quality in small, medium, large and mega-cities in India.**

| Pollutant Parameter | Parameter | Small | Medium | Large | Mega |
|--------------------|-----------|-------|--------|-------|------|
| PM<sub>2.5</sub>   | Mean      | –23   | –16    | –32   | –28  |
|                    | Maximum   | –46   | –40    | –52   | –41  |
|                    | Minimum   | 19    | 15     | 5     | –2   |
| NO<sub>x</sub>     | Mean      | –41   | –56    | –42   | –46  |
|                    | Maximum   | –66   | –84    | –81   | –67  |
|                    | Minimum   | –6    | –33    | 13    | –10  |

limit higher emission from domestic sector and influence the overall NO<sub>x</sub> emission reduction at city levels.

### 3.2 Estimation of Background Concentrations

During the lockdown period, all the activities were restricted which generally contributes to the emissions in a city. Only activities related to essential services were allowed, however, their impact would be negligible in comparison to the overall emission load of the city. Though, certain stations recorded higher concentration during the lockdown period as compared to the pre-lockdown period, indicating the presence of sources in close vicinity. Hence, the location of a station is an important factor in order to estimate the background concentration of a city. Given the above, the location of each station was surveyed and studied using Google Earth and a comparative table was prepared. Based on the studied site features, these stations were categorized into three representative types viz. background, residential/commercial, and kerbside/industrial stations as presented in Table 5. The land-use features of all selected stations have been presented in SI Table S2. The background stations were those, which were located in open areas, where no sources were visible in the vicinity and the sites; generally surrounded by green areas and located towards the outskirts of the city. The residential/commercial stations were selected based on their vicinity to residential and commercial activities and located in the city center or populated areas. The kerbside/industrial stations were marked along the edge of a major road i.e., National highway, State highway, and major city road and/or in an industrial area.

Out of 58 stations, 13 were marked as background, 22 as residential/commercial, and 26 as kerbside/industrial stations. The average concentrations of PM<sub>2.5</sub> and NO<sub>x</sub> at background stations, were 29 (23–48) µg m<sup>–3</sup> and 22 (7–62) µg m<sup>–3</sup>, respectively. The average concentrations at residential stations for PM<sub>2.5</sub> was ~36 (23–78) µg m<sup>–3</sup> and NO<sub>x</sub> ~34 (16–66) µg m<sup>–3</sup>, respectively. At kerbside/industrial stations, the values were PM<sub>2.5</sub> ~37 (20–66) µg m<sup>–3</sup> and NO<sub>x</sub> ~31 (9–128) µg m<sup>–3</sup>, respectively. The higher concentrations at residential/commercial areas clearly indicate the presence of urban sources during the lockdown period, which does not reflect at the background stations.

Further, Pearson correlations were estimated between pollutants to evaluate the impact of any common sources for each of the 13 background station category. The high positive correlation between pollutants indicates the presence of a source, which influences both the pollutants. No significant correlations were found between PM<sub>2.5</sub> and NO<sub>x</sub> at all stations as described in Table 5, except DL-Najafgarh i.e., 0.61. This station was not considered as representative background station.

The average concentration at selected 12 representative background stations during the lockdown period are presented in Table 6. These may be well adopted as background concentration for these regions/cities for the summer season, which starts from the beginning of March month in India. The average concentrations of PM<sub>2.5</sub> and NO<sub>x</sub> were ~40 µg m<sup>–3</sup> and ~35 µg m<sup>–3</sup> respectively, which were slightly higher than the background concentration of stations located in small cities surrounded by agriculture fields in North India viz. Narnaul, Hisar and Rohtak, all in Haryana. Similarly, in Central India, the CAAQMS in Nagpur represents background station and average concentrations were ~23 µg m<sup>–3</sup> and ~27 µg m<sup>–3</sup>, for PM<sub>2.5</sub> and NO<sub>x</sub>, respectively. In Mumbai, two stations were selected as background stations, viz. Powai and Colaba. The average concentrations at these stations were found in the range of 24 to 27 and 9 to 16 for PM<sub>2.5</sub> and NO<sub>x</sub> respectively. The
Table 5. Classification of stations and average pollutant concentrations.

| Classification of CAAQMS | Site Feature                                                                 | Number of Stations | Kerbside/Traffic Site/Industrial zone/Residentia/Open Area | Average & Range Concentration during lockdown period (Units: µg m⁻³) |
|-------------------------|-------------------------------------------------------------------------------|--------------------|------------------------------------------------------------|-----------------------------------------------------------------|
| Background Station      | CAAQMS located in an open area, no direct vicinity of any sources, Site surrounded by green area e.g., building located in the outskirt of the city | 13                 | No sources in the current vicinity of the stations. Very less possibility of transport from distant sources. Emission from the scattered residential unit can impact these CAAQMS, but not significantly | PM₂.₅: 29 (23–48) NOₓ: 22 (9–48) |
| Residential/Commercial  | Surrounded by residential and commercial activities                           | 20                 | Emission from populated residential cooking.              | PM₂.₅: 36 (23–78) NOₓ: 34 (12–66) |
| Kerbside/Industrial     | Close to the major road i.e., National Highway, State Highway or major city road. Located near to Industrial area or within industrial area | 25                 | Emission from vehicles used for transport of essential goods supply, emission from industrial activities related to essential services | PM₂.₅: 37 (20–66) NOₓ: 26 (7–62) |

Total: 58

Table 6. Average pollutant concentration at selected representative background stations and their contribution to NAAQS values.

| Sr. No. | Cities/CAAQMS       | Correlation Coefficient between PM₂.₅ & NOₓ | Average Concentration during lockdown (µg m⁻³) | Percentage of NAAQS PM₂.₅ NOₓ |
|---------|---------------------|---------------------------------------------|------------------------------------------------|-----------------------------|
| 1       | HR – Narnaul        | -                                           | 25                                             | -                           |
| 2       | HR – Hisar          | 0.48                                        | 35                                             | 19                          |
| 3       | HR – Rohtak         | -                                           | 37                                             | -                           |
| 4       | HR – Karnal         | 0.43                                        | 36                                             | 10                          |
| 5       | PB – Ludhiana       | -0.35                                       | 17                                             | 48                          |
| 6       | DL – Alipur         | 0.52                                        | 40                                             | 35                          |
| 7       | MH – Nagpur         | 0.42                                        | 23                                             | 27                          |
| 8       | MH-Mumbai-PO        | 0.44                                        | 27                                             | 9                           |
| 9       | MH-Mumbai-Colaba    | 0.52                                        | 24                                             | 12                          |
| 10      | AP – Amravati       | 0.27                                        | 21                                             | 7                           |
| 11      | KER – Trivendram    | 0.04                                        | 15                                             | 16                          |
| 12      | TL-Hyderabad        | -0.06                                       | 27                                             | 47                          |

The nationwide lockdown due to COVID-19 restricted most of the pollution generating average concentration at background stations located in south India exhibits lower concentrations as compared to other selected stations. The average concentrations at Trivandrum in Kerala were ~21 µg m⁻³ and ~7 µg m⁻³, respectively for PM₂.₅ and NOₓ.

The background concentrations were also analyzed to represent them as a percentage of 24-hour NAAQS standard in India, as presented in Table 6. The 24-hour NAAQS value for PM₂.₅, and NOₓ in India, were 60 µg m⁻³ and 80 µg m⁻³, respectively. The average background concentrations were found to be in the range of 25% to 67% of NAAQS for PM₂.₅, and 8% to 60% of NAAQS for NOₓ.

4 SUMMARY AND CONCLUSIONS

The nationwide lockdown due to COVID-19 restricted most of the pollution generating
activities throughout India. This study attempted to evaluate the impact of the lockdown on air quality in 46 cities spread across India. This study presents the analysis of air quality data for different zones in India viz. Northern, Eastern, Central, Western and Southern. In addition, city-wise data were analyzed on the basis of small, medium, large, and mega-cities (the classification of cities was based on population). The salient findings of the studies are:

- In the Northern Zone, the difference in PM$_{2.5}$ and NO$_x$ concentrations during the lockdown period as compared to the pre-lockdown period were found to be about $-34\%$ $(52–34 \, \mu g \, m^{-3})$ and $-49\%$ $(69–35 \, \mu g \, m^{-3})$, respectively. In the Eastern zone, these differences for PM$_{2.5}$ and NO$_x$ concentrations were about $-17\%$ $(66–54 \, \mu g \, m^{-3})$ and $-57\%$ $(70–30 \, \mu g \, m^{-3})$, respectively. In the Central Zone, these were about $1.7\%$ $(36.5–37.2 \, \mu g \, m^{-3})$ and $-46\%$ $(35 \, \mu g \, m^{-3})$, respectively. The differences for PM$_{2.5}$ and NO$_x$ concentrations were about $-31\%$ $(41–28 \, \mu g \, m^{-3})$ and $-60\%$ $(54–22 \, \mu g \, m^{-3})$, respectively in the western zone and $-26\%$ $(31–23 \, \mu g \, m^{-3})$ and $-26\%$ $(39–27 \, \mu g \, m^{-3})$, respectively in Southern zone.

- Based on population of cities, the average differences in PM$_{2.5}$ and NO$_x$ concentrations were found as $-23\%$ and $-41\%$, respectively, in small cities, $-16\%$ and $-56\%$ for PM$_{2.5}$ in medium cities, $-32\%$ and $-42\%$, in large cities and $-28\%$ and $-46\%$ in mega cities.

- The average PM$_{2.5}$ concentrations during lockdown period at remote (representative of background) stations were higher in North India $(17–40 \, \mu g \, m^{-3})$ compared to the other parts $(15–27 \, \mu g \, m^{-3})$ of India. Similarly, for NO$_x$, the ranges were $10–48 \, \mu g \, m^{-3}$ at CAAQMS located in Northern India and $9–27 \, \mu g \, m^{-3}$ at other parts of India except Hyderabad $(47 \, \mu g \, m^{-3})$. Higher level of pollutant concentration in northern region might be due to presence of many high density populated cities in the regions and located in the same wind sector. Along with this, unfavourable meteorological condition and geographical features may also be responsible for the higher concentration in northern area.

- The study also provides representative background concentrations for selected stations (representing area) in India that were not available so far and would find a use for air pollution-related studies in future in that particular city.

- The findings of the study indicate that proportion of average PM$_{2.5}$ concentrations was in the range of $25–60\%$ of specified standard $(60 \, \mu g \, m^{-3})$ at representative background stations where these values for NO$_x$ were $8–60\%$ of specified standard $(80 \, \mu g \, m^{-3})$. These findings provide a database for the policymaker to think about the need of revision of existing national ambient air quality standards, 2009.

- The findings further indicate that there may be an array of sources in each city and undertaking source apportionment studies for a better understanding of sources and their relative contributions to the air quality would be required to help the policymakers to decide on formulating the control strategies in future.

### ADDITIONAL INFORMATION

#### Declaration of Competing for Interest

The authors declare that there are no financial and personal interests to influence the results and work presented in the manuscript.

#### Author Statement

Sunil Gulia: Concept, Methodology, Data Analyses, and writing the original manuscript. Nitin Goyal: Review and re-writing, Saurabh Mendiratta: Data Collation and Data preparation, Tridipa Bishwas: Bar chart plotting on India Map using GIS; S.K. Goyal: Review and Re-writing, Rakesh Kumar: Conceptualization.

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SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at https://doi.org/10.4209/aaqr.200308

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