Assessment of Air Pollution status during COVID-19 Lockdown (Mar-May 2020) over Bangalore City in India

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Abstract

The Coronavirus disease 2019 (COVID-19), which became a global pandemic by March 2020 (WHO, 2020), forced almost all countries over the world to impose the lockdown as a measure of social distancing to control the spread of infection. India also strictly implemented a countrywide lockdown, starting from 24th March onwards. This measure resulted in the reduction of the sources of air pollution in general; industrial, commercial, and vehicular pollution in particular, with visible improvement in Ambient Air Quality. In this study, the impact of COVID-19 lockdown on the ambient concentration of air pollutants over the city of Bengaluru (India) is assessed using Continuous Ambient Air Quality Measurement (CAAQM) data from 10 monitoring stations spread across the city. The data was obtained from Central Pollution Control Board (CPCB) and Karnataka State Pollution Control Board (KSPCB). The analysis of the relative changes in the ambient concentration of six major air pollutants (NO, NO\(_2\), NO\(_X\), PM\(_{2.5}\), O\(_3\), and SO\(_2\)) been carried out for two periods; March-May 2020 (COVID-19 lockdown) and the corresponding period of 2019 which was Non-COVID. The analysis revealed significant reduction in the concentration of ambient air pollutants at both daily and monthly intervals. This can be attributed to the reduction in sources of emission; vehicular traffic, industrial, and other activities. The average reduction in the concentration of NO, NO\(_2\), NO\(_X\), PM\(_{2.5}\), and O\(_3\) between 1st March to 12th May 2020 was found to be 63%, 48%, 48%, 18%, and 23% respectively when compared to the same period in 2019. Similarly, the comparative analysis of pollutant concentrations between pre-lockdown (March 01- March 23) and lockdown (Mar 24-May 12) period, shown a huge reduction in the ambient concentration of air pollutants; 47.3% (NO), 49% (NO\(_2\)), 49% (NO\(_X\)), 10% (SO\(_2\)), 37.7% (PM\(_{2.5}\)), and 15.6% (O\(_3\)), resulting in improved air quality over Bangalore during the COVID-19 lockdown period. It is shown that the strict lockdown resulted in a significant reduction in the pollution levels. Such lockdowns may be useful as emergency intervention strategies to control air pollution in megacities when ambient air quality deteriorates dangerously.

1. Introduction

The outbreak of Coronavirus disease 2019 (COVID-19) reported to be originated in Wuhan, China, in late December 2019 (Li et al 2020; Lewis 2020; Morawska and Cao 2020) became a global pandemic by March 2020 as declared by the World Health Organization on 11th March 2020. The global health emergency led to the call for strict shutdown with many measures like; curfews, lockdown, and air travel restrictions, which resulted in disruption of social and economic activities with huge economic loss (Leggett 2020). The reduction of anthropogenic activities during the Covid-19 outbreak played a key role in significantly reducing air pollution and improving ambient air quality (He et al 2020; Isaifan 2020). He et al (2020) also found that highly industrialized and colder cities experienced a larger reduction in air pollution levels.
Nitrogen dioxide (NO₂), Nitric Oxide (NO), Sulphur dioxide (SO₂), particulate matter (PM₂.₅ and PM₁₀) are some of the major ambient air pollutants in urban and industrial environments contributing to air pollution and deteriorating air quality. The NO₂ is responsible for catalyzing the ozone (O₃) and acts as a precursor to inorganic aerosols, with consequences for human health (Atkinson et al. 2018; Faustini et al. 2014; Lelieveld et al. 2015; Myhre et al. 2013). Various studies have also demonstrated the role of these pollutants in severe health-related problems like respiratory and cardiovascular disorders, hypertension, and lung cancer in human beings (Humbal et al 2019; Le Tertre et al 2002; Koken et al 2003; Persinger et al 2004; Pope et al 2004; Saeha et al 2020). The sulphur dioxide is the major precursor for the nucleation formation of particles in the atmosphere, which in turn leads to increased human exposure to ultra-fine particles in high-density population zones (Kulmala et al 2004).

Meteorological factors such as wind speed, precipitation, and the height of the atmospheric boundary layer do play an important role in determining the ambient concentration of air pollutants for a given rate of emissions at source (Tayanc 2000; Singal and Prasad 2005). The wind speed also leads to greater dispersion of atmospheric pollutants (Holzworth 1967; Shair 1974); similarly, temperature also has a direct impact on the ambient air quality (Bashir et al 2020). Generally, the excess concentration of greenhouse gasses controls the temperature variation in the lower atmosphere. The accumulation of CO, NO₂, SO₂, PM₁₀, and PM₂.₅ in lower atmosphere modify the intensity of surface air temperature (Global Carbon Project 2020). The two particulate pollutants PM10 and suspended particulate matter (SPM) show a negative correlation with rainfall, humidity, and wind speed during the study period (March-May 2020) which is known to be related to atmospheric washout. Higher concentrations are normally recorded in the winter seasons for both particulate pollutants (Vijay Bhaskar et al. 2010).

During March-May 2020, India faced the COVID-19 crisis with the number of cases increasing exponentially (Gouda et al 2020; Venkata S Ram et al 2020). As exposure to air pollution could increase vulnerability and have detrimental effects on the prognosis of COVID-19 patients, it is important to estimate air pollution levels and their impact on the spread of infectious diseases (Cui et al 2003; Morales et al 2009). To prevent the rapid transmission of coronavirus, a countrywide lockdown was enforced in India on 24th March 2020 and continued till 31 May 2020. The lockdown led to a reduction in vehicular traffic and related emission of pollutants. In recent times, several studies have highlighted the impact of lockdown due to COVID-19 on atmospheric pollution over India (Bera et al 2020; Devara et al 2020; Mahato et al 2020; Sharma et al 2020;). Unlike other pollutants, SO₂ seems to have increased during the lockdown, and this could be due to no restriction on power plants (Sharma et al 2020). There was a reduction of particulate matter in the atmosphere during the lockdown in New Delhi (Mitra et al 2020) and Kolkata (Bera et al 2020). The present study is an attempt to assess the status of air pollution during the lockdown in the city of Bangalore using the ground-based observation obtained from central pollution control board (CPCB) and Karnataka State Pollution Control Board (KSPCB).
Many cities in India have witnessed a high level of air pollution (Garaga et al. 2018; Kota et al. 2018; Mukherjee and Agrawal 2018) in the past. The rapid growth in the industrial, power, and transportation sectors have contributed to the rapid increase in ambient air pollution (AAP) levels in India (Gordin et al. 2019). Bangalore, the capital city of Karnataka also witnessing a very high levels of air pollution due to increased population and traffic. Bangalore (12°.40'N, 13°.15'N, 77.20°E, 77.50°E) shown in figure 1 is located in the southern part of the state of Karnataka, covering an area of 741 km$^2$. The estimated population of the city is about 12.34 million. This makes Bangalore the 24th most populous city in the world with a population density of about 4000/ km$^2$. The city is located at an elevation of 900m above mean sea level and enjoys a moderate climate throughout the year with temperature ranging from 15 to 36°C, and the average annual rainfall of around 1288mm. There has been an increasing trend in air pollution over the years due to rapid urbanization, traffic, industry, and related economic and developmental activities (CPCB 2010). Earlier studies revealed that the air quality of the city is within acceptable limits set by CPCB but there is an increasing trend in NO$_2$ and SPM over Bangalore (CPCB 2010). The major sources of air pollution are; road dust re-suspension, open waste burning, vehicular emission, diesel generators used in industries (Guttikunda et al. 2019). People often spend more time in traffic and get exposed to air pollution which contributes to increased chronic diseases related to the Lungs and Heart. Like other parts of the globe, the COVID-19 also reached Bangalore, and the first positive case was reported on 8th March 2020, the number of cases rose to 200 in 2 months (https://www.mohfw.gov.in). During COVID-19 lockdown imposed by the Government of India and the State Government of Karnataka, roads were deserted with hardly any traffic except for essential and emergency services. All outdoor and commercial activities were closed down.

In this study, an attempt is made to assess the impact of COVID-19 lockdown on the ambient concentration of air pollutants like; PM$_{2.5}$, NOx, NO$_2$, NO, SO$_2$, and O$_3$ over the city of Bangalore for the period of 50 days between 24 March-12 May 2020.

2. Material And Method

In this study, we have considered the COVID-19 lockdown for the period 24 March-12 May 2020 (50 days) to assess the impact of lockdown on the ambient concentration of the pollutants; PM$_{2.5}$, NOx, NO$_2$, NO, SO$_2$, and O$_3$ over the city of Bangalore. The data (daily average) on air pollutant concentration ($\mu$g/m$^3$) was obtained from the Central Pollution Control Board (CPCB) and Karnataka State Pollution Control Board (KSPCB) for the period between March-May (2019 and 2020). The CPCB established national Ambient Air Quality Monitoring (AAQM) program in 1984 to monitor ambient air quality (Nasir et al. 2016). The monitoring of pollutants at CPCB stations is generally carried out daily with 4-hourly sampling for gaseous pollutants and 8-hourly sampling for PM$_{2.5}$. The detailed information like siting criteria, measurement techniques, and QA/QC procedures followed are reported in several earlier works (CPCB 2003; 2011). Ambient air pollutant measurements from 10 locations across the city of Bangalore are is
used in this analysis. These stations are listed in table 1 as S1, S2, S3,.., S10, and the exact locations are marked in figure 1. Table 1 also describes the location category like commercial, industrial, railway station. The daily meteorological measurements (temperature, rainfall, humidity, and wind speed) are being collected from the Indian Meteorological Department Bangalore, and analysed for daily variability.

The phase-wise lockdown in India was imposed in 4 phases i.e. Lockdown1 (March 24- April 14, 2020), Lockdown 2 (April 15-May 03 2020), Lockdown 3 (May 4 to May 17, 2020), and Lockdown 4 (May 18 to May 31, 2020). In the Lockdown 1, the guidelines issued by the government of India made it mandatory to close offices of private, public, and government sector; schools, colleges, transportation; hotels and recreation facilities; barred public meetings and private functions. However, there were exceptions for essential services, defence sector, post offices, disaster management, electricity, water, sanitation, hospitals, banks, print and electronic media, telecommunications, and some other emergency services (with a restriction on the number of employees in the workplace). In Lockdown 2, most of the restrictions remain changed, but some relaxations were issued as per States/UTs/district administration. In Lockdown 3, the movement of non-essential services (public transportation with restricted number of passengers, food delivery etc.) were prohibited between 7 pm to 7 am (night curfew), but allowed between 7 am and 7 pm.

Specific guidelines were also issued to different zones; Red, Orange, and Green, depending on the number of COVID-19 cases of the zone. In Lockdown4, different modes of transportation (except in containment zones), salons, liquor shops, markets, inter-state traveling (with a permit from the state government) were allowed with restrictions. Night curfew was continued (https://www.mohfw.gov.in). The division of zones was removed in Karnataka, and strict rules were implemented on containment zones. All the shops (except for shopping malls, cinema halls, and hotels) were allowed to function between 7 am to 7 pm and a complete lockdown was imposed on Sundays. (https://covid19.karnataka.gov.in).

In this work, to know the change in pollutant concentrations over 10 monitoring stations, we used two different methods of analysis. a).The change in pollutant concentration between two warm seasons of 2019 and 2020 for the period of 3 months (March to May). b).The changes in concentration between each phase of the lockdown and total lockdown period (March 24- May 12, 2020) are compared with the corresponding pollutant concentration of the pre-lockdown period (March 1- March 23, 2020)

The relative change in concentration (CC) in 2020 summer w.r.t. the year 2019 summer is computed as follows

\[
CC(i) = \frac{\text{Conc}(i,2020) - \text{Conc}(i,2019)}{\text{Conc}(i,2019)} \times 100
\]  

(1)
Where i is the day or month in each year.

Similarly, the relative change in concentration in lockdown (CCL) w.r.t. pre-lockdown is computed as

$$CCL(i) = \frac{\text{Conc(lockdown)} - \text{Conc(prelockdown)}}{\text{Conc(prelockdown)}} \times 100$$  \hspace{1cm} (2)

Where Conc (pre-lockdown) is the pollutant concentration averaged over the pre lockdown period (March 01 to 23, 2020), and Conc (lockdown) are the pollutant concentration averaged over the lockdown periods (lockdown-1, lockdown-2, etc.)

The CC (i) and CCL(i) are computed for all the stations. The pollutant concentration values for entire city of Bangalore are obtained by taking the mean over 10 stations. The trends are computed using linear regression over a time series data.

3. Results And Discussion

The daily variation in the major meteorological parameters such as temperature, wind speed, and rainfall are analyzed over the city of Bangalore using the observed data obtained from India Meteorological Department. The analysis was carried out for the period of three months (1st Mar- 31st May 2020); covering different stages of lockdown during COVID-19 and pre-COVID-19 as reference period (figure 2). The daily mean temperature varied between 23.4 to 30°C, the range of relative humidity was from 33 to 84%, and the average observed wind speed varied between 0.2 to 1.9 m/s during the period of analysis. It is also observed that during Mar 01- March 23, only 3 rainy days were observed, while it was 9 days during the lock down period (24 March to 12 May). Similarly, the average temperature during the lockdown period (April-May 2020, summer) was 28°C as against 27.6°C in the pre-lockdown period. The average humidity during both pre-lock down and lock down period seems to be the same at around 53%. During the lockdown period, the atmospheric condition was stable with moderate temperature & humidity, low wind speed (0.8 – 1m/s); and no intense rainfall. Thus, the prevailing atmospheric conditions over the city do not seem to be conducive for the quick dispersion of pollutants.

The daily average concentration of the six major air pollutants; PM$_{2.5}$, NO$_x$, NO$_2$, NO, SO$_2$, and O$_3$ over Bangalore for the period 01 March to 12 May 2020 is shown in figure 3. It is inferred from the time series plot that most of the pollutants show a decreasing (liner) trend during the period of analysis with a maximum for PM$_{2.5}$ (-0.34 µg/gm$^3$/day), for NO$_x$ and O$_3$ (-0.2 µg/gm$^3$/day), and no trend for SO$_2$, indicating the clear impact of lockdown on the daily concentration of the above pollutants over the city of Bangalore.

The concentration of different pollutants are compared between two periods; March 01 to May 12 of 2019 and 2020. The daily relative % change of pollutants concentration between the above two periods
is computed using equation 1 (figure 4). The figure shows a reduction in the concentration (73-days average) of all pollutants except SO₂, coinciding with the implementation of lockdown. It is observed that NO, NO₂, O₃ and PM₂.₅ concentrations are reduced by 63%, 48%, 48%, 23%, and 18% respectively in 2020 during the lockdown period as compared to the values during the same period in 2019. On the other hand, concentrations of SO₂ are found to be increased by 24% during the lockdown period in 2020 when compared to the values during the same period in 2019. It is also observed that NO, NO₂, NOₓ, and O₃ concentrations are lower for most of the time (50 days) during the lockdown period (March 24 to May 12, 2020) when compared to the values in 2019 during the same period.

In the case of O₃, SO₂, and PM₂.₅ levels, during the lockdown period, observed concentrations on 46, 12, and 47 days lower when compared to the corresponding days of 2019. This observation is also valid for the comparison of pollutant concentrations over weekend and working days between two periods. This shows that there is a reduction in the pollutant concentration in 2020 during the lockdown period when compared to the same day in the previous year. The same analysis was also carried out on a weekly scale to reduce the influence of meteorology on pollutants during the lockdown. As can be inferred from fig.5, except for SO₂, all other pollutants show weekly reduction in the concentration relative to most of the corresponding weeks in 2019. The PM₂.₅ was increased only during the 1st and 2nd week during the lockdown as compared to the same weeks in 2019, pointing to the impact of lockdown on ambient concentration of pollutants.

The analysis of the spatial distribution of pollutants concentration between the period 2020-2019 also shows that both in the month of March and April, the changes are negative implying that there was a reduction in the concentration in 2020 during lockdown period when compared to the same period in 2019, it’s true for the changes in relative percentage too. In the case of NO₂, the change is as low as -50µg/m³, but for PM₂.₅ the changes observed were as low as -26µg/m³ and -57µg/m³ respectively, for March and April 2020. In the case of relative percentage change, the range of NO₂ concentration is about -83% to 40% (March) and -93% to 40% in April. For PM₂.₅, the range of relative change is -48% to 10% and -84% to -30%, for March and April respectively.

To assess the real impact of different lockdown phases on air quality over the city as a whole, the relative change in the pollutant concentration (CCL) during the lockdown as compared to pre-lockdown, and is presented as % of pre-lockdown values in figure 6. During the whole phase of lockdown i.e., 24 March to 12 May, there was a significant reduction in the concentration of NO, NO₂, NOₓ, SO₂, PM₂.₅, and O₃ with 47.3%, 49.0%, 49%, 10%, 37.4% and 15.6% respectively. All pollutants show significant reduction during 1st lockdown except O₃ which was only about -8%. Analysis of hourly Ozone data for some locations indicate that the magnitude of O₃ levels is a bit higher during the lockdown period in day times compared to the pre-lockdown period. This may be because of the summer temperature (Warminski and Bes. 2018) and decreased titration by NO (Sicard et al 2020). The decrease in pollution levels may be
attributed to the fact that lockdown was very strictly implemented with no traffic or any other construction or industrial activities. The concentrations started increasing during lockdown 2 and lockdown 3 when compared to lockdown 1 due to easing of restriction and subsequent movement of vehicles. Nevertheless, concentrations were still low compared to the pre-lockdown period (Figure 6). Overall, the lockdown brought a reduction in the ambient air pollutants in the city during March-May 2020, this is in contrast with higher level pollution observed during the summer season. The same analysis (figure 7) was also carried out at each station to assess the region-wise impact of COVID-19 lockdown on the ambient concentration of air pollutants. It is observed that the concentration of NO, NO₂ and NOₓ is very low at most stations, during all phases of lockdown, but slightly increased in the station S5 and S8, which are located in commercial area. Available PM₂.₅ data over 8 stations show relatively low values, indicating the reduction of pollutants during most phases of lockdown. But, SO₂ was reduced only in 4 stations (S1, S3, S4, and S7), and the concentration is high in the other 6 stations, this may be attributed to domestic cooking and vehicle movements of essential services as mentioned earlier. Similarly, the trend of O₃ concentration also decreased in all stations except for station S10 which is located in industrial area. The average trend in all industrial stations (S4, S7, S9 and S10) shown greater reduction than the commercial stations (S1, S2, S5, S6, and S8) indicating the role of lockdown in reducing the ambient concentration of air pollutants and improved air quality.

4. Conclusions

In this study, the variation in the ambient concentration of major air pollutants (NO, NO₂, NOₓ, PM₂.₅, O₃, and SO₂) across 10 monitoring stations over Bengaluru are compared at daily and monthly intervals for the period of March–May for the year 2019 and 2020. The main objective was to study the impact of lockdown on Ambient Air Quality (AAQ). The impact of lockdown is shown to be remarkable in improving the air quality with a significant reduction in the ambient concentration of air pollutants; NO (-63%), NO₂ (-48%), NOₓ (-48%), and O₃ (-23%) during the lockdown period when compared to the same period in 2019. The spatial analysis also witnessed significant improvement in the air quality throughout the city during the lockdown. In Bangalore, to a large extent, the decline in road traffic resulted in a significant decrease (48% - 63%) in the levels Nitrogen Oxides (NO₂, NOx, and NO). Also, the comparison of concentrations during the lockdown and pre-lockdown period shows that the lockdown period (2020) witnessed a significant reduction by 47.3% (NO), 49% (NO₂), 49% (NOₓ), 10% (SO₂), 37.7% (PM₂.₅) and 15.6% (O₃) over Bangalore. These sharp reductions during April and May 2020 can be attributed to a reduction in industrial and traffic activities. The station-level analysis supported the widespread reduction of pollutants across the city. In a nutshell, the COVID-19 lockdown resulted in improved air quality over Bangalore. This type of observational studies can be integrated with model predictions to assess the impact of intervention strategies and help environmental monitoring and regulating agencies to achieve their objective of air quality compliance.

Declarations
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Conflict of interest:

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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**Table**

Table 1: Location of air quality monitoring stations. The * indicates the continuous ambient air quality monitoring stations (CAAQMS) where the measurements are carried out manually using instruments under national ambient air quality monitoring programme (NAMP) of Government of India.
| Station Code | Air quality monitoring Station Name     | Location Category | Elevation (m above MSL) | Latitude and Longitude |
|-------------|----------------------------------------|-------------------|-------------------------|------------------------|
| S1          | Bapuji Nagar,                          | Commercial        | 853                     | 12.956 N 77.539 E      |
| S2          | BTM Layout,                            | Commercial        | 908                     | 12.916 N 77.610 E      |
| S3          | CITY Railway Station*                  | Railway station   | 935                     | 12.764 N 76.571 E      |
| S4          | Hebbal*                                | Industrial        | 903                     | 13.035 N 77.597 E      |
| S5          | Hombegowda Nagar                       | Commercial        | 910                     | 12.937 N 77.594 E      |
| S6          | Jayanagar 5<sup>th</sup> Block*        | Commercial        | 919                     | 12.917 N 77.583 E      |
| S7          | Silk Board*                            | Industrial        | 887                     | 12.917 N 77.621 E      |
| S8          | Sanegurava Hali*                       | Commercial        | 893                     | 12.990 N 77.544 E      |
| S9          | Peenya                                 | Industrial        | 910                     | 13.028 N 77.519 E      |
| S10         | BWSSB Kadabesanalhalli                 | Industrial        | 878                     | 12.939 N 77.695 E      |