Assessment of air pollution status during COVID-19 lockdown (March–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, 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 24 March to 12 May 2020. 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 Bangalore (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 , $\text{PM}_{2.5}$, O_3 , and SO_2) has been carried out for two periods: March–May 2020 (COVID-19 lockdown) and the corresponding period of 2019 during when there was no lockdown. 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 , $\text{PM}_{2.5}$, and O_3 between 01 March and 12 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 (01–23 March 2020) and lockdown (24 March–12 May 2020) periods has 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% ($\text{PM}_{2.5}$), 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.

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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 & Cao, 2020) became a global pandemic by March 2020 as declared by the World Health Organization (WHO) on 11 March 2020 (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 losses (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) in various parts of different countries. He et al. (2020) also found that highly industrialized and colder cities experienced a larger reduction in air pollution levels.

Nitrogen dioxide (NO_2), nitric oxide (NO), sulphur dioxide (SO_2), and particulate matter ($\text{PM}_{2.5}$ and PM_{10}) are some of the major ambient air pollutants in urban and industrial environments contributing to air pollution and deteriorating air quality. NO_2 is responsible for catalysing the ozone (O_3) 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 (Agrawal et al., 2006; Humbal et al., 2019; Le Tertre et al., 2002; Koken et al., 2003; Persinger et al., 2002; Arden Pope et al., 2004; Saeha et al., 2020). 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 (Singal & Prasad, 2005; Tayanc, 2000). 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 , NO_2 , SO_2 , PM_{10} , and $\text{PM}_{2.5}$ in lower atmosphere modifies the intensity of surface air temperature (Global Carbon Project, 2020). The two particulate pollutants PM_{10} 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 & Mehta, 2010).

During March–May 2020, India faced the COVID-19 crisis with the number of cases increasing exponentially (Gouda et al., 2020; Venkata 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 24 March 2020 and continued till 12 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; Gautam, 2020). Unlike other pollutants, SO_2 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 and Kolkata (Mitra et al., 2020; 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 the 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 & 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 (Gordon et al., 2018). Bangalore, the capital city of Karnataka is also witnessing very high levels of air pollution due to increased population and traffic. Bangalore

(12°0.40'N, 13°0.15'N, 77.20°E, 77.50°E), shown in Fig. 1, is located in the southern part of the state of Karnataka, covering an area of 741 km². The estimated population of the city is about 12.34 million which makes Bangalore the 24th most populous city in the world with a population density of about 4000/km². The city is located at an elevation of 900 m above mean sea level and enjoys a moderate climate thorough out the year with temperature ranging from 15 to 36 °C, and the average annual rainfall of around 1288 mm. 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, 2014). Earlier studies revealed that the air quality of the city is within acceptable limits set by CPCB, but there is an increasing trend in NO₂ and SPM over Bangalore (CPCB, 2010). The major sources of air pollution are; road dust re-suspension, open waste burning,

vehicular emission, and 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, COVID-19 also reached Bangalore, and the first positive case was reported on 8 March 2020, and 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}, NO_x, NO₂, NO, SO₂, and O₃ over the city of Bangalore for the period of 50 days between 24 March and 12 May 2020.

Fig. 1 Map of Bangalore showing the locations of air quality monitoring station by CPCB and KSPC

Materials 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 atmospheric pollutants, $\text{PM}_{2.5}$, NO_x , NO_2 , NO , SO_2 , and O_3 , over the city of Bangalore. The data (daily average) on air pollutant concentration ($\mu\text{g}/\text{m}^3$) was obtained from the CPCB and KSPCB for the period between March and May (for the years 2019 and 2020). The CPCB established the 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 $\text{PM}_{2.5}$. The detailed information like siting criteria, measurement techniques, and QA/QC procedures followed are reported in several earlier works (CPCB, 2003a, b; 2010). Ambient air pollutant measurements from 10 locations across the city of Bangalore are used in this analysis. These stations are listed in Table 1 as S1, S2, S3, ..., S10, and the exact locations are marked in Fig. 1. Table 1 also describes

the location category like commercial, industrial, and railway station. The daily meteorological measurements (temperature, rainfall, humidity, and wind speed) are being collected from the Indian Meteorological Department, Bangalore, and the daily variability is analysed during the lockdown period.

The phase-wise lockdown in India was imposed in 4 phases, i.e., lockdown 1 (24 March–14 April 2020), lockdown 2 (15 April–03 May 2020), lockdown 3 (4–17 May 2020), and lockdown 4 (18–31 May 2020). In 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; and 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 unchanged, but some relaxations were issued as per States/UTs/district administration. In lockdown 3, the

Table 1 Location of air quality monitoring stations

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 5th 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 Kadabesanahalli	Industrial	878	12.939 N 77.695 E

*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

movement of non-essential services (public transportation with restricted number of passengers, food delivery, etc.) were prohibited between 7 p.m. and 7 a.m. (night curfew), but allowed between 7 a.m. and 7 p.m.

Specific guidelines were also issued to different zones, red, orange, and green, depending on the number of COVID-19 cases of the zone. In Lockdown 4, different modes of transportation (except in containment zones), salons, liquor shops, markets, and inter-state travelling (with a permit from the state government) were allowed with restrictions. Night curfew was continued (Ministry of Health and Family Welfare, Government of India COVID-19 India dashboard, 2020). 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 a.m. and 7 p.m., and a complete lockdown was imposed on Sundays (State

Disaster Management Authority: Government of Karnataka, Karnataka COVID 19 Dashboard, 2020).

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 (24 March–12 May 2020) are compared with the corresponding pollutant concentration of the pre-lockdown period (01–23 March 2020).

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

$$CC(i) = \frac{Conc(i, 2020) - Conc(i, 2019)}{Conc(i, 2019)} \times 100 \quad (1)$$

where i is the day or month in each year.

Fig. 2 Daily time series of major meteorological parameters **a** temperature, **b** wind speed, **c** rainfall, and **d** relative humidity over Bangalore during 01 March to 31 May 2020

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

$$CCL(i) = \frac{Conc(lockdown) - Conc(prelockdown)}{Conc(prelockdown)} \times 100 \quad (2)$$

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

$CC(i)$ 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 the time series data.

Fig. 3 Daily time series of the concentration of 6 major air pollutants observed over Bangalore during 01 March to 12 May 2020

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 the India Meteorological Department. The analysis was carried out for the period of 3 months (01 March–31 May 2020) covering different stages of lockdown during COVID-19 and pre-COVID-19 as reference period (Fig. 2). The daily mean temperature varied between 23.4 and 30 °C, the range of relative humidity was from 33 to 84%, and the average observed wind speed varied between 0.2 and 1.9 m/s during the period of analysis over the city of Bangalore. It is also observed that during 01 March–23 March,

only 3 rainy days were observed, while it was 9 days during the lockdown 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-lockdown and lockdown period

seems to be the same at around 53%. During the lockdown period, the atmospheric condition was stable with moderate temperature and humidity, low wind speed (0.8–1 m/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.

Fig. 4 Relative change in pollutant concentration over Bangalore from 01 March to 12 May 2020. The changes are shown as percent of corresponding concentrations in 2019. The average relative change for the whole period is presented in the bracket

The daily average concentration of the six major air pollutants; $\text{PM}_{2.5}$, NO_x , NO_2 , NO , SO_2 , and O_3 over Bangalore for the period 01 March to 12 May 2020 is shown in Fig. 3. It is inferred from the time series analysis that most of the pollutants show a decreasing (liner) trend during the period of analysis with a maximum for $\text{PM}_{2.5}$ ($-0.34 \mu\text{g}/\text{gm}^3/\text{day}$); for NO_x and O_3 , it is about $-0.2 \mu\text{g}/\text{gm}^3/\text{day}$, and no trend for SO_2 , indicating the clear impact of lockdown on the daily concentration of the above atmospheric pollutants over Bangalore City.

The concentration of different pollutants is compared between two periods: 01 March to 12 May of 2019 and 2020. The daily relative percent change of pollutant concentration between the above two periods is computed using Eq. 1. The analysis presented in Fig. 4 shows a reduction in the concentration (73 days average) of all pollutants except SO_2 , coinciding with the implementation of lockdown. It is observed that NO , NO_2 , O_3 , and $\text{PM}_{2.5}$ 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 SO_2 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 , NO_2 , NO_x , and O_3 concentrations are lower for most of the time (50 days) during the lockdown period (24 March to 12 May 2020) when compared to the values in 2019 during the same period.

In the case of O_3 , SO_2 , and $\text{PM}_{2.5}$ levels, during the lockdown period, observed concentrations on 46, 12, and 47 days are lower when compared to the corresponding days of 2019. This observation is also valid for the comparison of pollutant concentrations over weekends and working days between the 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 atmospheric pollutants during the lockdown. As can be inferred from Fig. 5, except for SO_2 , all other pollutants show weekly reduction in the concentration relative to most of the corresponding weeks in 2019.

Fig. 5 Weekly relative percent change in pollutant concentration over Bangalore during 01 March–12 May 2020 with respect to same period of 2019

The $PM_{2.5}$ was increased only during the 1st and 2nd week during the lockdown as compared to the same weeks in 2019, pointing to the direct impact of lockdown on ambient concentration of atmospheric pollutants in the Bangalore City.

The analysis of the spatial distribution of pollutants concentration between the periods 2020–2019 also shows that, both in the months of March and April, the changes are negative, implying that there was a net reduction in the concentration in 2020 during the lockdown period when compared to the same period in 2019. It is true for the changes in relative percentage too. In the case of NO_2 , the change is as low as $-50 \mu g/m^3$, but for $PM_{2.5}$, the changes observed were as low as $-26 \mu g/m^3$ and $-57 \mu g/m^3$, respectively, for March and April 2020. In the case of relative percentage change, the range of NO_2 concentration is about -83 to 40% (during March) and -93 to 40% in April. For $PM_{2.5}$, 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 is presented as percent of pre-lockdown values in Fig. 6. During the whole phase of lockdown, i.e., 24 March to 12 May, there was a significant reduction in the concentration of NO , NO_2 , NO_x , SO_2 , $PM_{2.5}$, and O_3 with 47.3%, 49.0%, 49%, 10%, 37.4%, and 15.6%, respectively. All pollutants show significant reduction during the 1st lockdown except O_3 , which was only about -8% . The analysis of hourly ozone data for some locations indicate that the magnitude of O_3 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 & Bes, 2018) and decreased titration by NO (Sicard et al., 2020). The decrease in pollution levels may be attributed to the fact that the lockdown was very strictly implemented with no traffic or any other construction or industrial activities. The concentrations started increasing during lockdown

Fig. 6 Relative percent change in the pollutant concentration observed in whole Bangalore City during different phases of COVID-19 lockdown for the pre-lockdown period in the year 2020

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 (Fig. 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 was also carried out at each station to assess the region-wise impact

of COVID-19 lockdown on the ambient concentration of air pollutants and the results are presented in Fig. 7. It is observed that the concentration of NO, NO₂, and NO_x is very low at most stations during all phases of lockdown, but slightly increased in the station S5 and S8, which are located in the commercial area. Available PM_{2.5} 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

Fig. 7 Relative percent change in the pollutant concentration observed at 10 pollution monitoring stations in Bangalore during different phases of COVID-19 lockdown

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 O_3 concentration also decreased in all stations except for station S10 which is located in the industrial area. The average trend in all industrial stations (S4, S7, S9, and S10) shows greater reduction in the pollution concentrations 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 over the Bangalore City.

Conclusions

In this study, the variation in the ambient concentration of major air pollutants (NO , NO_2 , NO_X , $PM_{2.5}$, O_3 , and SO_2) across 10 monitoring stations over Bangalore City in India is compared at daily and monthly intervals for the period of March–May for the years 2019 and 2020. The main objective was to study the impact of COVID-19 pandemic-induced lockdown on ambient air quality (AAQ) at a city scale. 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%), NO_2 (−48%), NO_X (−48%), and O_3 (−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 (NO_2 , NO_X , 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% (NO_2), 49% (NO_X), 10% (SO_2), 37.7% ($PM_{2.5}$), and 15.6% (O_3) 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 City. 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.

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Data availability Data will be available on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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