Impact of Lockdown on Air Quality in Megacities of India During COVID-19 Pandemic

Pallavi Pradeep Khobragade and Ajay Vikram Ahirwar

Abstract In the month of March 2020, the World Health Organization (WHO) declared COVID-19 as a pandemic. Amid the COVID-19 pandemic, Government of India has also initiated preventive measures by imposing nationwide lockdown initially for three weeks from 24th March 2020 to 14th April 2020 and extended up to 3rd May 2020. The aim of this study is to assess the impacts on air quality ($PM_{2.5}$, PM_{10}, NO_2, NH_3, SO_2, CO and O_3) during different phases of lockdown in different cities (Delhi, Mumbai, Bengaluru and Nagpur) of India. As a result, significant reduction in aerosol concentrations were observed; 40%, 53%, 45% and 34% in $PM_{2.5}$ and 37%, 53%, 35% and 20% in PM_{10} at Delhi, Mumbai, Bengaluru and Nagpur respectively. Other air quality parameters such as NO_2, NH_3, SO_2 and CO showed declining trends whereas increasing trend for O_3 was observed. The present air quality data were also compared with previous year (2019) data and found significant reduction in the current year (2020). The overall results demonstrate that air quality is significantly improved due to nationwide lockdown. From this study, it can be observed that ambient clean air can be achieved by reducing people's mobility in urban areas. This could help in reducing concentrations of air pollutants in cities. This study helps to visualize the pollutants response due to reduction in anthropogenic emissions in megacities which can help in making atmospheric governance policies.

Keywords Corona virus · SARS-CoV-2 · COVID-19 · $PM_{2.5}$ · PM_{10} · Air pollution

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1 Introduction

COVID-19 is spread by the pathogen Severe Acute Respiratory Syndrome coronavirus 2 (SARS-CoV-2) and caused severe pneumonia outbreaks globally consecutively outspread over the entire world affecting 196 countries by March 25th 2020 raising extreme attention. (Ahmadi et al. 2020; Contini and Costabile 2020; Ficetola and Rubolini 2021). Covid-19 outbursts have become one of the most challenging problems for the Government (Ficetola and Rubolini 2021). Maximum countries in the world have declared some sort of lockdown to reduce human interaction by following social distancing ceasing the spread of this novel coronavirus thus reducing the effects of COVID-19 (He et al. 2020). The world is trying to fight with this novel coronavirus in every best possible way and control rapid spread of this SARS-CoV-2 in humans (Anjum 2020). The lockdown resulted positively by bringing unintentional social benefits in terms of air quality improvement in India by dropping the pollutant concentrations (Gautam 2020; He et al. 2020). The first affected person by SARS-CoV-2 in India is observed in Kerala in late January 2020 (Gautam 2020; Gautam and Hens 2020). Due to rapid spread of the virus, Kerala was the top most state reporting maximum number of novel corona virus affected positive cases. To get the situation of spreading this pandemic under control, the prime minister of India "Narendra Modi" declared complete lockdown sessions to decrease the effects and transmissions of the novel coronavirus and practice social distancing (Gautam 2020). It was decided that social distancing and home isolation measures will help to reduce the negative impacts of COVID-19 (Han et al. 2020). Aerosols are one of the ways for rapid spread of this virus and are recognized as one of the important pollutants by national and international agencies, associated with mortality and morbidity (Dutheil et al. 2020; Gautam 2020).

During lockdown phase, the main contributing sectors to air pollution were brought into halt. On March 22, 2020, the Lt. Governor of Delhi has notified the "Delhi Epidemic Diseases, COVID-19 regulations, 2020" ordering all the hospitals to have a flu corners testing all suspected cases, checking the travel history of the suspects and have a right to impose home or institution quarantine (Gautam and Hens 2020). During 2016, 4.2 million premature deaths were reported due to ambient air pollutants (WHO 2018). The air pollution index during the lockdown phase considerably prevents premature deaths due to improved air quality. The recent data over USA and Europe after the lockdown enforcement confirms the reduction in air quality benefiting environment and living beings (Suhaimi et al. 2020).

The associated viruses need specific environment for their growth and survival (Rios and Gianmoena 2020). Climatic variables were considered as the finest drivers of worldwide variation of confirmed Covid-19 cases growth rates (Ficetola and Rubolini 2021) and have diverse influences on epidemiology of various infectious diseases (Rios and Gianmoena 2020). COVID-19 may also spread through exhaled breath droplets known as microdroplets (Riediker and Morawska 2020). The air

Fig. 1 Geographical map of study locations

pollution weakens the immune system and makes humans susceptible to various respiratory virus infections (Han et al. 2020).

In this study, we carried out a severe analysis into the issue and estimate how lockdown affected air quality in terms of $PM_{2.5}$ and PM_{10} at various locations in Indian megacities including Delhi, Mumbai, and Nagpur (Fig. 1). The air quality data from different sites in the study areas are collected covering the entire region. Also, statistical analysis is executed to evaluate the relationship between temperature and humidity in the regions affecting transmissibility of COVID-19. The decrease in

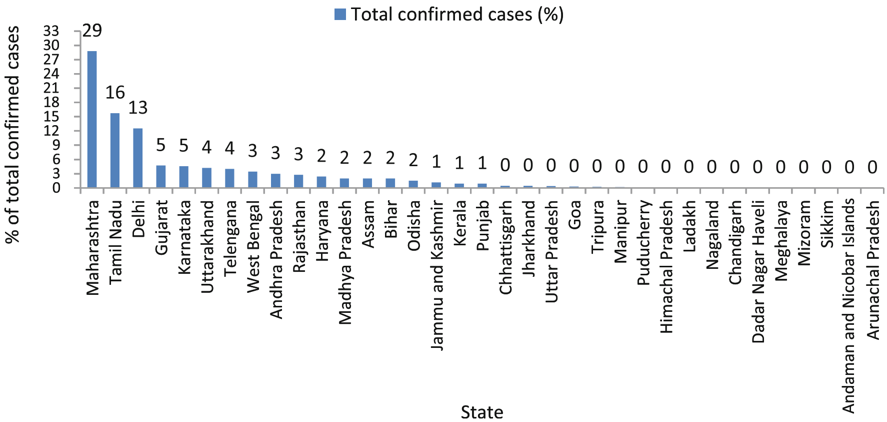

Fig. 2 Total active cases in India (%). Source: Ministry of Health and Family Welfare

particulate concentrations was observed immediately after a week due to reduced anthropogenic activities at all the locations.

Figure 2 shows that the highest number of cases has been reported in Maharashtra (29%), Tamil Nadu (16%), Delhi (13%) and Gujarat (5%) and it is increasing with time across the country. Few states in India including Arunachal Pradesh, Andaman and Nicobar Islands, Sikkim, Mizoram, Meghalaya, Dadar Nagar Haveli, etc. are still in a better position with minimum number of patients.

1.1 Site Description

Delhi, the national capital of India, is located between latitudes 28°24′17″ and 28°53′00″ N and longitudes 76°50′24″ and 77°20′37″E at 216 meters above the mean sea level (MSL). The city covers an area of approximately 1500 square kilometres. The sites selected for particulate samples data collection are spread over the entire city. Mumbai, the capital city of Maharashtra is located between latitudes 19°′4′33.924″N and 72°52′38.7336″E is the second most populous city after Delhi. Delhi and Mumbai are termed as epicentres for corona virus in India; also Maharashtra has maximum number of COVID-19 cases in which Mumbai holds first position in positive corona patients (Jain and Sharma 2020). In the south, is located at latitude 12° 58′ 20.7912′N and longitude 77° 34′ 50.3148″ E in Karnataka being another megacity is selected for analysis. Another city in Maharashtra state, Nagpur located at latitude 21° 8′ 47.8788′N and longitude 79° 5′ 19.8960″ E is selected to check the similarity in the increasing cases whether the number of positive cases in Mumbai and Nagpur are correlated. The details of the sampling stations are given in Table 1.

Table 1 Details of stations from selected cities

Sr. No	City	Number of stations considered	Name of stations
1	Delhi	10	Anand Vihar-DPCC, Ashok Vihar-DPCC, Bawana-DPC, Dwarka-Sector 8-DPCC, IGI Airport (T3)-IMD, Mundka-DPCC, North Campus, DTU-CPCB, Rohini DPCC, Sirifort-CPCB
2	Mumbai	8	Bandra, Borivali East, Chhatrapati Shivaji Int. Airport, Colaba, Kurla, Powai, Sion, Vile Parle west
3	Bengaluru	10	Bapuji Nagar, BTM Layout, BWSSB, City Railway Station, Hebbal, Hombegowda Nagar, Jayanagar 5th Block, Peenya, Sanegurava Hills, Silk Board Ballygunge
4	Nagpur	1	Opp GPO Civil Lines-MPCB

1.2 Methodology

Ambient particulate pollutant data ($PM_{2.5}$ and PM_{10}) is collected from Delhi, Mumbai, and Nagpur prior a month and during lockdown and compared it with same interval in 2019 to show fluctuations in air quality parameters. Air Quality Data i.e., 24 hours average concentrations were obtained from continuous ambient air quality monitoring 24 hours concentrations of $PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, NH_3 and O_3 was collected from Central Pollution Control Board, Ministry of Environment, Forests and Climate Change, New Delhi for the period of 24th February 2020 to 12th June 2020 and in 2019 for the same time frame. The stations having more than 75% data were considered for data collection from each station in every selected city. Spatiotemporal analysis is done to see the correlation between increasing number of corona cases and meteorological parameters at all the locations. Meteorological data on temperature and relative humidity for the study locations have been collected from worldweatheronline.com. Correlation between meteorological parameters and fluctuations of confirmed corona positive cases is analysed to understand the relationship between them.

2 Results and Discussions

2.1 Effect on Air Quality

The lockdown resulted in appreciable drop in particulate matter concentrations at all the major locations in the cities. A voluntary public curfew was observed on 22nd March 2020 in India few days after which noticeable downfall are observed in $PM_{2.5}$ and PM_{10} concentrations. All air quality control units positioned in the city were selected and used to collect data for 60 days (from February 24th 2020 to 12th June

2020). $PM_{2.5}$ and PM_{10} was found to be higher in all the selected study areas before the lockdown period as per the standards set by NAAQS and WHO. $PM_{2.5}$ and PM_{10} concentrations were within NAAQS limit immediately after the lockdown period due to low pollutant concentrations. The particulate pollutant concentration showed tremendous downfall after the public curfew immediately followed by lockdown due to stopping anthropogenic activities including industrial activities and vehicular movements. The data concerning assessment of sources of $PM_{2.5}$ and PM_{10} in the cities were obtained from local study report prepared by Automatic Research Association of India (ARAI) and The Energy and Resources Institute (TERI) (https://www.teriin.org/sites/default/files/2018-08/Report_SA_AQM-Delhi-NCR_0.pdf).

Although highly variable, in Delhi, the particulate concentration for $PM_{2.5}$ at Anand Vihar, Ashok Vihar, Dwarka and Sirifort after the lockdown period is found to be comparable (mean: 90.10–100.91 μg/m^3). IGI and North Campus showed minimum $PM_{2.5}$ concentrations (54.29–65.82 μg/m^3) indicating the influence of lower anthropogenic activities. Bawana, Mundka, DTU and Rohini have comparable $PM_{2.5}$ concentrations (110.91–132.43 μg/m^3) in the city. Particulate concentrations for PM_{10} at Bawana, Dwarka, Mundka, DTU and Rohini exhibit comparable concentrations (mean: 101.54–127.60 μg/m^3), AnandVihar, Ashok Vihar and Sirifort showed comparable PM_{10} concentrations (85.64–92.61 μg/m^3) and IGI and North Campus were found to have minimum PM_{10} concentrations (78.83–85.99 μg/m^3). Within few weeks, the AQI and particulate concentrations dropped down up to 25% after the lockdown (He et al. 2020). The city observed around 50% reduction in air pollution levels (Gautam and Hens 2020). In Mumbai, after the lockdown, Colaba, Kurla, Powai, Sion and Vile Parle had $PM_{2.5}$ concentration within the NAAQS limit (22.77–33.2 μg/m^3), Borivali and Chhatrapati Shivaji Terminal (CSTM) were found to have comparable $PM_{2.5}$ concentrations (42.68–43.68 μg/m^3) slightly crossing the NAAQS limit and Bandra (50 μg/m^3) station had highest $PM_{2.5}$ concentration in Mumbai. PM_{10} concentration at CSMT were found within the NAAQS standards (38.69 μg/m^3), Colaba, Powai and Vile Parle had comparable PM_{10} concentrations (40.08–59.37 μg/m^3), Bandra, Borivali and Sion had comparable concentration level (60.8–65.85 μg/m^3) and Kurla had maximum PM_{10} concentration (72.67 μg/m^3) in Mumbai. The $PM_{2.5}$ concentrations at Bapuji, BWSSB, Hebbal, Hombegowda, Jayanagar and Silk board were within NAAQS standards in. BTM exceeded the limit (54 μg/m^3) and Peenya (58.16 μg/m^3) had Maximum $PM_{2.5}$ concentration in. PM_{10} concentrations at maximum stations were within the set limits at Bapuji, BTM, Hebbal, Jayanagar and Silk board (26.25–46.82 μg/m^3), Sanegurava Halli crossed the limit (61.95 μg/m^3) with maximum concentration at City Railway station (82.38 μg/m^3). The $PM_{2.5}$ (37.5 μg/m^3) and PM_{10} (46.78 μg/m^3) concentration were within the NAAQS standards at Civil Lines in Nagpur city. The northern India has recorded 20 year low air pollution during the lockdown phase and the data shows 30% drop in air pollution over the Northeast U.S. (NASA 2020).

In Delhi, reductions in 2020 in comparison to 2019 by (60%) NO_2 concentration (110 ± 25–44 ± 23 μg/m^3), (31%) NH_3 concentration (11 ± 3–8 ± 3 μg/m^3), (36%)

SO_2 concentration (25 ± 10–16 ± 7 μg/m^3), (2%) CO concentration (80 ± 22–79 ± 25 μg/m^3) and an increase in (68%) O_3 concentration (23 ± 18–71 ± 62 μg/m^3) is observed.

Increment in concentrations of (63%) NO_2 (21 ± 9–34 ± 44 μg/m^3) and (51%) SO_2 concentration (22 ± 10–33 ± 20 μg/m^3) with decrease in (36%) CO concentration (89 ± 9–57 ± 25 μg/m^3) and (19%) O_3 concentration (29 ± 24–24 ± 20 μg/m^3) in Mumbai is observed from 2019 to 2020.

In, reductions in 2020 in comparison to 2019 by (70%) NO_2 concentration (70 ± 16–21 ± 15 μg/m^3), (31%) NH_3 concentration (4 ± 1–3 ± 1 μg/m^3) and (40%) O_3 concentration (60 ± 43–36 ± 12 μg/m^3) and increase in (31%) SO_2 concentration (9 ± 5–11 ± 3 μg/m^3) and (7%) CO concentration (26 ± 8–28 ± 10 μg/m^3) is noticed.

The COVID-19 lockdown in Nagpur resulted in reductions in 2020 in comparison to 2019 by (36%) NO_2 concentration (52 ± 16–33 ± 18 μg/m^3), (47%) NH_3 concentration (13 ± 7–7 ± 5 μg/m^3) and (63%) O_3 concentration (140 ± 46–52 ± 16 μg/m^3) although increase (79%) SO_2 concentration (20 ± 11–4 ± 4 μg/m^3), (32%) CO concentration (31 ± 11–21 ± 8 μg/m^3) is noticed which may be due to stationary source emissions like industrial sectors by fossil fuel burning (Broomandi et al. 2020).

Significant reduction in concentrations of $PM_{2.5}$, PM_{10} and NO_2 were observed at Delhi and Nagpur during 2020 lockdown except Mumbai. Delhi witnessed increased concentration of O_3 during the lockdown period in pandemic, whereas, Mumbai and Nagpur experienced lowered concentration as compared to year 2019. $PM_{2.5}$ and NO_2 increased up to 31% and 63% in Mumbai which may be due to emergency movement of vehicles. SO_2 increased at Mumbai and up to 41% and reduced up to 58% in Delhi and Nagpur. Average CO reduction was up to 16% at all the sites. The variation in NO_2 concentration is due to variation of city traffic (Wang et al. 2020a, b). The decrease in NO_2 also showed a reduction in $PM_{2.5}$ concentration indicating that vehicular emissions are an important contributor to $PM_{2.5}$ concentrations. Decrease in NO_2 and $PM_{2.5}$ is more in comparison to SO_2 and CO, this indicates that emissions from stationary sources didn't decrease as much as traffic. Industrial activities increased in Mumbai whereas reduced at Delhi and Nagpur (Chu et al. 2021).

2.2 Comparison Between Pre and Post COVID-19

The lockdown resulted in appreciable drop in $PM_{2.5}$ and PM_{10} concentrations at all the major locations in the city. The day after the "Janta Curfew", a significant drop down has been noticed at all the sites indicating that anthropogenic activities contribute majorly to the particulate sources. The counter COVID actions minimised the overall $PM_{2.5}$ concentrations during the study period up to 37% and PM_{10} concentrations up to 40%. The shutting down of redundant commercial activities reduces the particulate pollution with greater effects in cities with a larger economy,

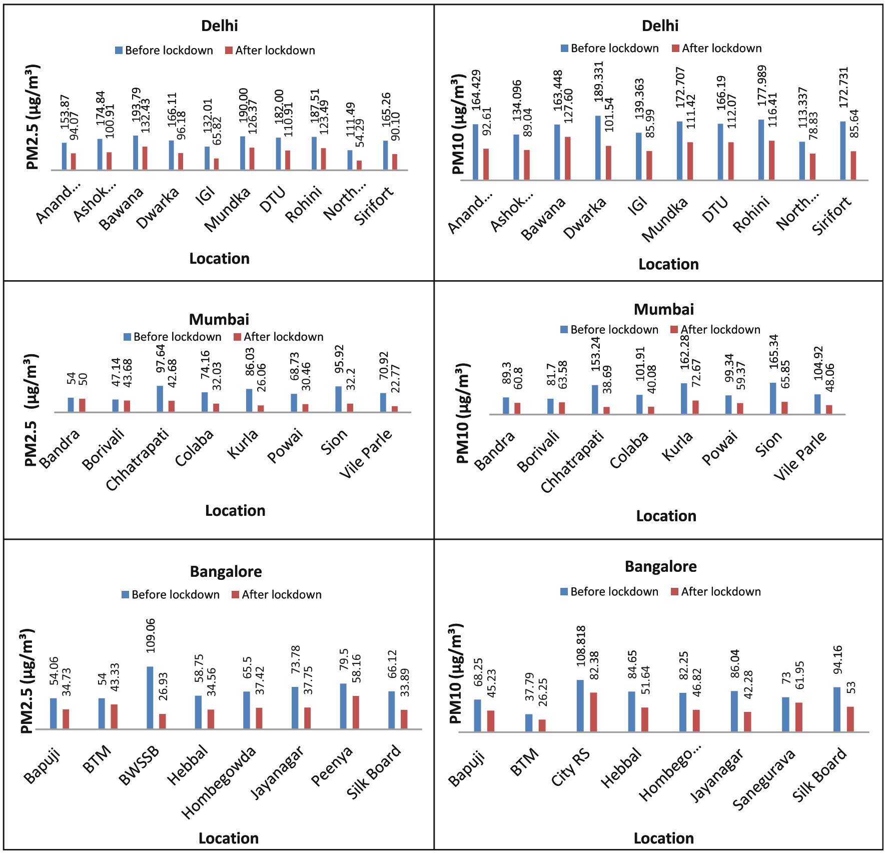

Fig. 3 Change in air pollutant concentrations at the study locations before and after lockdown

Table 2 Variation in average pollutant concentrations (µg/m^3) during 2019 and 2020

	Nagpur		Delhi				Mumbai	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
2020	41.96	51.34	117.94	121.15	46.95	59.37	22.08	35.44
2019	79.28	86.59	174.11	208.88	79.13	83.63	30.23	70.83
Percentage reduction in 2020	47	41	32	42	41	29	27	50

heavy vehicular pollution and higher industrial activities (He et al. 2020). The particulate matter level during the lockdown phase remained high, $PM_{2.5}$ concentrations was three times and two times higher than NAAQS standards respectively. People living in contaminated cities are at more risk from COVID-19 (Moftakhar et al. 2020).

Figure 3 shows the concentrations of $PM_{2.5}$ and PM_{10} at Delhi, Mumbai, and Nagpur before and after lockdown. The temporal investigation showed that there is a significant decrease in $PM_{2.5}$ and PM_{10} concentration at the study locations after the lockdown. The extent of decline in the pollutant concentration at the study locations is different. $PM_{2.5}$ showed an average change in concentration of 42%, 36%, 40% and 29% at Delhi, Mumbai, and Nagpur respectively whereas PM_{10} showed an average change in concentration of 37%, 57%, 36% and 30% at Delhi, Mumbai, and Nagpur respectively. Comparison was done in between the pollutant concentration data of 2019 and 2020 during the same time period. A significant decrease in the pollutant concentration data has been observed in 2020 as compared to 2019. Table 2 shows the decrease in the pollutant concentration during 2019 and 2020 during the same time period.

2.3 *Pre and Post-lockdown Variation in Gaseous Pollutants*

Delhi showed notable reductions from pre-lockdown period to post-lockdown in (53%) NO_2 (70 ± 17–33 ± 15 μg/m^3) and (24%) CO (93 ± 13–71 ± 26 μg/m^3) concentrations while increase in (13%) NH_3 (7 ± 2–8 ± 4 μg/m^3), (44%) SO_2 (10 ± 3–18 ± 7 μg/m^3) and (71%) O_3 (27 ± 17–93 ± 65 μg/m^3) concentrations. In Mumbai, decrease in (87%) NO_2 (85 ± 45–11 ± 10 μg/m^3), (53%) CO (93 ± 22–44 ± 9 μg/m^3) and (59%) O_3 (37 ± 24–15 ± 11 μg/m^3) concentrations is observed while increase in (47%) SO_2 (20 ± 3–38 ± 22 μg/m^3) concentration is noticed. Showed reductions in (41%) NO_2 (32 ± 3–19 ± 16 μg/m^3), (8%) SO_2 (12 ± 2–11 ± 3 μg/m^3) and (7%) CO (29 ± 10–27 ± 10 μg/m^3) and increase in (33%) NH_3 (2 ± 1–3 ± 1 μg/m^3) and (38%) O_3 (21 ± 11–34 ± 11 μg/m^3) concentrations. In Nagpur, decrease in (58%) NO_2 (65 ± 12–27 ± 11 μg/m^3), (70%) SO_2 (10 ± 8–3 ± 2 μg/m^3) and (20%) CO (25 ± 9–20 ± 8 μg/m^3) concentrations and increase in (14%) NH_3 (6 ± 2–7 ± 5 μg/m^3) and (9%) O_3 (48 ± 25–53 ± 13 μg/m^3) concentrations. Despite the decreases in particulate concentrations, increase in SO_2, NO_2, NH_3, CO and O_3 concentrations is observed which may be due to stationary sources, household cooking fuel and emergency movement of vehicles. In a similar study at Almati, non-traffic source contribution has found to be increased during the lockdown (Broomandi et al. 2020; Kerimray et al. 2020) which may be reason for enhanced concentrations of NH_3, SO_2 during the lockdown. Increased NH_3 concentrations in Delhi, and Nagpur may be due to agricultural activities and biomass burning (Bray et al. 2021), fossil fuel combustion (Wu et al. 2020). Increased SO_2 concentrations during the lockdown phase was observed at Delhi and Mumbai which again may be due to biomass burning and industrial emissions (Bari et al. 2020). However decrease in SO_2 concentrations is observed at and Nagpur during the lockdown period.

Figure 4 shows the air quality index (AQI) during 2019 and 2020 for $PM_{2.5}$ and PM_{10}. The AQI of $PM_{2.5}$ was moderate for 18% of the days, unhealthy for sensitive groups for 55% of the days, unhealthy for 26% of the days and very unhealthy

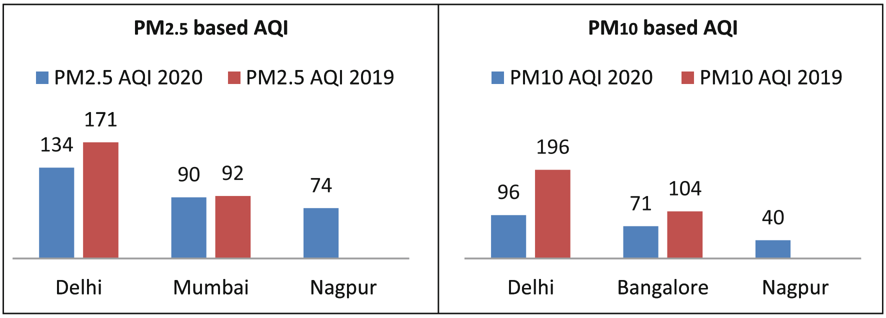

Fig. 4 Comparison between $PM_{2.5}$ based AQI and PM_{10} based AQI at study locations during 2020 and 2019

for 2% of the days and AQI for PM_{10} is good for about 6% of the days, moderate for 55% of the days, unhealthy for sensitive groups for 30% of the days, unhealthy for 8% of the days and very unhealthy for 2% of the days in Delhi during 2020. The AQI across Delhi is under "satisfactory" (AQI: 51–100) category after COVID-19 (http://safar.tropmet.res.in/). The lockdown measures in Delhi resulted in a dropdown in $PM_{2.5}$ up to 30% (Anjum 2020). The AQI for $PM_{2.5}$ in Mumbai was good for 7% of the days, moderate for 58% of the days, unhealthy for sensitive groups for 26% of the days and unhealthy for 8% of the days. The AQI across Mumbai is under "good" (AQI: 0–50) category after COVID-19 ((http://safar.tropmet.res.in/). The AQI for PM_{10} in was good for 10% of the days, moderate for 77% of the days, unhealthy for sensitive groups for 13% of the days during the study period in 2020. The AQI for $PM_{2.5}$ in Nagpur was good for 6% of the days, moderate for 87% of the days, unhealthy for sensitive groups for 8% of the days and AQI for PM_{10} was good for 89% of the days, moderate for 10% of the days and unhealthy for 1% of the days during the study period in 2020. The data for 2019 for Nagpur is not available. A significant positive association between $PM_{2.5}$, PM_{10} and confirmed corona cases has been observed indicating that the decrease in particulate concentration during the lockdown phase helped in keeping the number of positive patients low (Zhu et al. 2020). During 2020, $PM_{2.5}$ AQI is unhealthy for sensitive group at Delhi, moderate at Mumbai and Nagpur whereas during 2019, Delhi experienced unhealthy atmosphere and Mumbai had moderate pollution. PM_{10} AQI was moderate at Delhi and Mumbai and good in Nagpur during 2020 whereas it was unhealthy at Delhi and unhealthy for sensitive groups in during 2019.

2.4 Meteorological Data Collection and Processing

Meteorological factors including temperature (T) and relative humidity (RH) may enhance air pollution transmitting infection of diseases (Jiang et al. 2020). Ambient environmental factors including temperature and relative humidity show partial correlation with airborne pathogens (Suhaimi et al. 2020). Atmospheric temperature and relative humidity are found to have direct association with the spread of this pandemic (Wang et al. 2020a, b; Ahmadi et al. 2020). Virus transmission is affected by many factors including climatic variables like temperature, humidity and precipitation (Ahmadi et al. 2020; Méndez-Arriaga 2020; Menebo 2020). This makes it essential to understand relationship between climatic conditions in a geographical area and transmission of COVID-19 pandemic (Ahmadi et al. 2020). The data is collected from 24th February 2020 to 12th June 2020. The meteorological data was collected after every 3 hours in a day and daily average is calculated. An inconsistent lagged effect of temperature and humidity is observed on COVID-19 growth rate (Carleton et al. 2020). A strong relationship between local existing climate and COVID-19 increasing rates has been observed signifying the possibility of seasonal difference in the spatial design of outbreaks (Ficetola and Rubolini 2021). Ultraviolet radiation indicates a strong effect on COVID-19 growth rate with 1 kJ m^{-2} increase in hourly UV decreasing confirmed growth rate by 0.09 points causing a delay in the spread (Carleton et al. 2020).

Local temperature and humidity has found to influence directly transmitted diseases by affecting the survival and transmission of the virus outbreak (Ficetola and Rubolini 2021; Wang et al. 2020a, b). It is expected that the downfall in the air pollutant concentrations are not correlated with weather conditions (He et al. 2020). In Nagpur, no specific correlation between T, RH and number of corona cases is observed. In Mumbai and, T is found to be negatively associated with cases whereas RH is found to have positive correlation (0.6) with number of cases (Suhaimi et al. 2020). In Delhi, RH is negatively associated with number of cases whereas temperature is found to exhibit positive correlation (0.7) with number of cases. The duration of the epidemic is insufficient to study the impact of climatic factors on the transmission of SARS-Cov-2 virus (Wang et al. 2020a, b). It can be concluded that the total seasonal effects of climatic variables are indeterminate due to uncertainty in the effects of temperature and humidity.

3 Conclusion

Using a suitable and comprehensive dataset of the study areas, the positive effects of city lockdown on air quality has been analysed which partly offset the costs of the COVID-19 pandemic. The temporal investigation showed that there is a significant decrease in $PM_{2.5}$ and PM_{10} concentration at the study locations after the lockdown. The extent of decline in the pollutant concentration at the study locations is different. $PM_{2.5}$ showed an average reduction in concentration of 40%, 53%, 45% and 34% at Delhi, Mumbai and Nagpur respectively, whereas PM_{10} showed an average reduction in concentration of 37%, 53%, 35% and 30% at Delhi, Mumbai and Nagpur respectively. The result shows that the pollutants are significantly decreased, while the average level of O_3 has been increased in Delhi and slightly decreased at Mumbai and Nagpur during 2020 in comparison with 2019. Decrease in NO_2 and CO at Delhi and Mumbai (Vehicular activities) and increase in SO_2 (industrial, however in depth investigation needed) Meanwhile, around 39% and 43% was the average reduction of PM_{10} and $PM_{2.5}$ respectively, during lockdown compared with previous year owing to restricted vehicles movement, biomass burning events and construction activities. We find that the radical precautionary measures against the spread of the epidemic have a substantial impact on air quality. The remarkable enhancement in air quality might lead to considerable health benefits. The activities identified provoking the pollutants to cross the air quality standards must be controlled after the pandemic is over benefiting human health and society. Overall, the study exhibits the association between air pollution, meteorology and receptiveness to COVID-19 cases in study areas and finds that the lockdown indeed improved the air quality. The study shows that lockdown resulted in controlling pollutants for a time being, due to reduction in anthropogenic activities. This indicates that government should implement effective control policies after the lockdown to reduce pollutant concentrations in the cities.

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