Comparative study on air quality status in Indian and Chinese cities before and during the COVID-19 lockdown period

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Abstract
Amidst COVID-19 pandemic, extreme steps have been taken by countries globally. Lockdown enforcement has emerged as one of the mitigating measures to reduce the community spread of the virus. With a reduction in major anthropogenic activities, a visible improvement in air quality has been recorded in urban centres. Hazardous air quality in countries like India and China leads to high mortality rates from cardiovascular diseases. The present article deals with 6 megacities in India and 6 cities in Hubei province, China, where strict lockdown measures were imposed. The real-time concentration of PM2.5 and NO2 were recorded at different monitoring stations in the cities for 3 months, i.e. January, February, and March for China and February, March, and April for India. The concentration data is converted into AQI according to US EPA parameters and the monthly and weekly averages are calculated for all the cities. Cities in China and India after 1 week of lockdown recorded an average drop in AQI PM2.5 and AQI NO2 of 11.32% and 48.61% and 20.21% and 59.26%, respectively. The results indicate that the drop in AQI NO2 was instantaneous as compared with the gradual drop in AQI PM2.5. The lockdown in China and India led to a final drop in AQI PM2.5 of 45.25% and 64.65% and in AQI NO2 of 37.42% and 65.80%, respectively. This study will assist the policymakers in devising a pathway to curb down air pollutant concentration in various urban cities by utilising the benchmark levels of air pollution.

Keywords Air quality index · China · COVID-19 · India · NO2 · PM2.5

Introduction
In the present time, with the emergence of rapid globalisation and urbanisation, megacities in developing nations are facing severe health issues due to ambient air pollution. According to WHO (World Health Organization), seven million people die each year because of exposure to polluted air (UN Environment Programme 2018). Numerous epidemiological studies in the past two decades have highlighted outdoor air pollution as a cause of various respiratory diseases such as asthma, premature deaths and cardiovascular diseases. These have been identified as primary causes of mortality. In such cases, the population living in the vicinity of major roadways in metropolitan cities suffers the most (Park et al. 2020). In urban areas, 80% of people live in concentrations exceeding the WHO limits (Blaszczyk et al. 2017). Motor-vehicle emitted compounds in urban areas which include carbon monoxide (CO); nitrogen oxides (NOx); coarse (PM10), fine (PM2.5), and ultrafine (PM0.1) particle mass, black carbon, polycyclic aromatic hydrocarbons and benzene which are found in elevated concentrations as reported by Venkatram and Schulte (2018). Moreover, studies suggest that particulate matter and NO2 levels are higher in cities with greater transportation activity and urban backgrounds (Rodríguez et al. 2016). PM10 and PM2.5 are the two primary particulate matters monitored all over the world. However, PM2.5 possesses a higher health risk as compared with PM10 because of its high retention time and ability to penetrate deep into the lungs and enter the bloodstream (US EPA 2018). The WHO ambient air quality guidelines suggest an annual mean PM2.5 concentration limit of 10 μg/m³ and 25 μg/m³ for the 24-hourly mean. The NO2...
limit is 40 μg/m³, and 200 μg/m³ for the annual and 1-h mean, respectively (World Health Organization 2005).

At the dawn of twenty-first century, developing economies like India and China are undergoing rapid industrialisation and modernisation, which are leading to hazardous levels of air pollution similar to the Industrial Revolution in Europe. It is well-understood that megacities in both countries like Beijing, Shenyang, Taiyuan, New Delhi, Mumbai, and Chennai are the world’s most polluted cities (Zhu 2005). The primary sources of air pollution in India have been identified as vehicular emissions, industrial emissions, coal combustion, biomass burning, road dust, and refuse burning (Pant and Harrison 2012). Likewise, the poor air quality in China is a matter of global concern. The air pollution caused by transportation and industries is a serious environmental issue in urban settlements, and 50% of the PM in the urban air comes from traffic emissions (Li et al. 2017). Kumar and Joseph (2006) analysed ambient and kerb site air pollution correlation of PM_{10}, PM_{2.5}, and NO_{2} in Mumbai, India. The results indicated a strong correlation between PM_{2.5} and NO_{2} at the ambient site due to vehicular emission as a result of high traffic density. A 2016 report estimated that only 3% of the Chinese population and less than 1% of the Indian population have exposure to PM_{2.5} concentrations complying with WHO guidelines (IEA OECD 2016), although, an overall monotonic decrease in air pollutants was recorded in China from 2015 to 2018 (Fan et al. 2020). The existing levels of ambient PM_{2.5} and NO_{2} are above the safe limit. A 2017 report on global air pollution stated that China and India contribute to 52% of global PM_{2.5}—attributable deaths (1.525 million deaths) (Health Effects Institute 2019). In the past decades, both countries have been pro-active towards the efforts reducing air pollution. However, no long-term solution has been identified yet. Numerous academic studies have been conducted in both nations regarding the growing air pollution and its health effects. Kumar and Mishra (2018) conducted an assessment of major air pollutants at 36 transport corridors in Delhi, India, and the results of the study concluded that 31 corridors had “severe” and “very poor” AQI, and high traffic volume in most corridors is characterised by traffic-induced human health risks. It has been found that high levels of ambient PM_{2.5} and NO_{2} increase the risk of cardiovascular diseases and lung cancer in humans (Liu et al. 2018; Siddique et al. 2010).

In late December 2019, there was an outbreak of a highly contagious disease caused by the novel coronavirus, SARS-CoV-2. The first case emerged from Wuhan City, Hubei Province, China. The disease has been identified as Coronavirus disease (COVID-19). It’s an outbreak, recognised as a “Pandemic” by WHO, has been extensively worldwide and exponential with more than 200 countries and territories reporting 3,267,936 cases and 234,703 deaths (7.18%) as of April 30, 2020 (WHO 2020). Individuals with underlying health problems, weak immunity, and the elderly are most likely to become extreme cases (Chen et al. 2020a). The critical sources of infection are patients infected with the novel coronavirus and those with asymptomatic infection (Wang et al. 2020a). Studies indicate correlation between the long-term exposure to air pollutant and COVID-19 death rate. Cities with hazardous air quality face a serious threat from the pandemic (Wu et al. 2020b; Conticini et al. 2020). Therefore, in the absence of a vaccine or treatment available for COVID-19, there has been a coordinated global response of imposing “lockdown” measures on citizens. As of now, more than a third of the worldwide population is under restriction. India recorded 34,867 COVID-19 cases (as of 30-04-2020) and a nationwide lockdown was imposed in India on March 25, 2020 for 21 days (MoHFW 2020). The lockdown constrained people from stepping out of their homes. Transport services, road, air, and rail, were suspended along with institutions and industrial establishments except for essential goods and services (Jain and Sharma 2020) and has been extended up to May 3, 2020. In parallel, 82,862 cases (as of 30–04-20) were recorded in China and 82% of these cases were recorded in Hubei Province (National Health Commission of the People’s Republic of China 2020).

In Hubei province, Wuhan was regarded as the epicentre (Zhang et al. 2020) of the virus. On January 23, 2020, Hubei province, China, was kept under community quarantine with the shutdown of public transport, educational institutes, business centres, parks, and other social contacts to slow down the spread of COVID-19 (Wilder-Smith and Freedman 2020).

Further restrictions in Hubei province were lifted on March 23, 2020. With the implementation of lockdown and other federal restrictions in various countries around the globe, a visible reduction in air pollution is found in megacities. This study is aimed at quantifying and analysing the reduction in air pollution due to the lockdown imposed in two overpopulated and highly polluted countries of the world, viz. China and India, to determine the effect of lockdown on the air quality in an urban environment. The results of this study will help in gauging the ability of a full lockdown on reducing air pollution. Further, it will help in devising a response plan for unforeseen episodes of the high level of air pollution in urban environments.

Methodology of the study

Site selection

For the present study, 6 cities have been selected, each from India and Hubei Province, China. These locations are selected based on the availability of historical air pollution data, population density, monitoring station network, and the number of positive COVID-19 cases per million people. Selected cites
with their population, the number of monitoring stations taken into account, COVID-19 cases per million people, their geographical coordinates, and start and end date of lockdown are given in Table 1.

**Parameters for analysis**

For the analysis of the effect of the lockdown imposed by the governing authorities on the air quality, PM$_{2.5}$ and NO$_2$ are selected as parameters of the study. Both of these pollutants have a direct relationship with various anthropogenic activities that were restricted due to the lockdown (US EPA 2018; Ministry for the Environment New Zealand 2020). Hence, analysing these parameters assist in espying the effect of lockdown on the air quality of the selected locations.

**Data collection and interpretation**

During the data collection, 24-h average concentration (μg/m$^3$) data is taken for PM$_{2.5}$, and hourly average concentration data is taken for NO$_2$ (ppb) from respective EPAs of the locations selected. The data is collected in China for 13 weeks starting from January 1, 2020 except for Wuhan for which data was collected for 15 weeks since the lockdown was imposed till April 8, 2020. In India, data is collected for 13 weeks starting from February 1, 2020 to April 30, 2020. For the years 2016–2019, the data for Hubei Province, China has been collected from January 1 to March 31, and similarly, for India, the data has been collected from February 1 to April 30.

Weekly average data of PM$_{2.5}$ and NO$_2$ for the mentioned months has been calculated for the selected monitoring stations. The average value of the PM$_{2.5}$ and NO$_2$ concentration in a city is calculated by taking an average of all the monitoring stations selected, located at various distant locations throughout the city. The average value of the concentration of PM$_{2.5}$ and NO$_2$ is converted to individual AQI (AQI$_{PM_{2.5}}$ and AQI$_{NO2}$) by using the protocol suggested by US EPA for reporting the air quality data using the Air Quality Index (AQI) (Mintz 2012).

To analyse the changes in the AQI$_{PM_{2.5}}$ and AQI$_{NO2}$ levels, for each city, various drop percentages are calculated. The immediate drop percentage is calculated by the difference in average AQI$_{PM_{2.5}}$ and AQI$_{NO2}$ of the weeks before and after the lockdown was enforced. The final AQI$_{PM_{2.5}}$ and AQI$_{NO2}$ drop percentages are calculated by the difference in average AQI$_{PM_{2.5}}$ and AQI$_{NO2}$ of the week before lockdown and the last week when lockdown restrictions were lifted. Five-year and 1-year AQI$_{PM_{2.5}}$ drop percentages in the year 2020 are calculated for January, February, and March in China and February, March, and April in India. It has been calculated by the difference in average AQI$_{PM_{2.5}}$ of months of years 2016 and 2019 to the same months of 2020 for 5-year and 1-year drop percentages, respectively.

**Results and discussion**

With the parameters of immediate and final AQI$_{PM_{2.5}}$ and AQI$_{NO2}$ drop percentages, and 5 year and 1 year drop percentages of AQI$_{PM_{2.5}}$, analysis for the cities in China and India has been done followed by a comparative assessment between the two countries.

**Air quality analysis for the selected cities of China**

Due to a large number of reported cases, Wuhan and its neighbouring cities (Huanggang and Ezhou) implemented a lockdown on January 23, 2020 followed by several cities on

| Country | City     | Population (in million) | No. of stations monitored | COVID-19 cases per Million | Geographical coordinates |
|---------|----------|-------------------------|---------------------------|----------------------------|--------------------------|
| China   | Xiangyang| 5.89                    | 5                         | 199.22                     | 30° 48' 01" N 110° 23' 11" E |
|         | Jingzhou | 0.97                    | 3                         | 1624.77                    | 30° 13' 35" N 111° 47' 18" E |
|         | Huanggang| 6.628                   | 2                         | 438.55                     | 30° 24' 16" N 114° 42' 49" E |
|         | Xiaogan  | 5.17                    | 3                         | 679.26                     | 31° 03' 41" N 113° 25' 37" E |
|         | Wuhan    | 8.11                    | 5                         | 6204.90                    | 30° 42' 07" N 113° 46' 52" E |
|         | Yichang  | 4.37                    | 5                         | 213.18                     | 30° 41' 49" N 110° 48' 01" E |
| India   | Delhi    | 18.62                   | 5                         | 501.03                     | 29° 03' 55" N 76° 06' 09" E |
|         | Lucknow  | 3.12                    | 5                         | 88.30                      | 26° 52' 53" N 80° 41' 49" E |
|         | Kolkata  | 4.98                    | 5                         | 240.51                     | 23° 04' 44" N 87° 17' 22" E |
|         | Mumbai   | 13.80                   | 5                         | 1279.98                    | 19° 10' 38" N 72° 23' 50" E |
|         | Chennai  | 5.16                    | 5                         | 1153.44                    | 13° 07' 10" N 79° 44' 05" E |
|         | Jaipur   | 6.42                    | 4                         | 234.51                     | 27° 03' 33" N 75° 18' 19" E |
January 24, 2020 (Wu et al. 2020a). Wuhan, having the highest number of cases than any other city in China enforced lockdown with strict federal orders restraining anthropogenic activity to minimal level (Lu 2020), which entailed the highest immediate $\text{AQI}_{\text{NO}_2}$ (69.35%) and $\text{AQI}_{\text{PM2.5}}$ drop (15.95%) among the selected cities. In contrast, Xiangyang recorded the lowest immediate and final $\text{AQI}_{\text{NO}_2}$ drop of $-3.22\%$ and $-16.40\%$, respectively. This trend is observed since Xiangyang is one of the most industrialised cities in central China, and due to the high demand for PPE kits and testing equipment, industries were working at double shifts to meet the demand (Hubei Provincial People’s Government 2020).

The average immediate and final $\text{AQI}_{\text{NO}_2}$ drop recorded is 48.61% and 26.64%, respectively. It can be concluded that the final $\text{AQI}_{\text{NO}_2}$ drop percentage is lower than the immediate $\text{AQI}_{\text{NO}_2}$ drop percentage; as the lockdown progressed, citizens had to get out of their homes for necessary essential commodities. Every city experienced a drop in $\text{AQI}_{\text{PM2.5}}$ (Fig. 1a, b, c, d, e, and f); on an average, the immediate $\text{AQI}_{\text{PM2.5}}$ drop is 11.28%; subsequently, the average final $\text{AQI}_{\text{PM2.5}}$ drop is 26.37%. Before lockdown was implemented, every city had $\text{AQI}_{\text{PM2.5}}$ within unhealthy for sensitive groups (101–150) and unhealthy (151–200) range according to US EPA standards. Nevertheless, the $\text{AQI}_{\text{PM2.5}}$ level
reduced and reached the moderate category during the lockdown period. Furthermore, for January, February, and March 2020, the cities recorded the lowest AQI$_{PM2.5}$ levels in 5 years (Fig. 2a, b, c, d, e, and f). As the virus started to spread in Hubei province in January, the citizens avoided leaving their homes as a self-precautionary measure. As the lockdown was implemented from January 23, 2020 in various cities, a drastic drop has been recorded in AQI$_{PM2.5}$ levels.
from week 3 to week 4 (Fig. 1a, b, c, d, e, and f). The AQI_{PM2.5} level remained constant through 2016–2019, to a certain degree for January and February. The highest 5-year and 1-year AQI_{PM2.5} drop were recorded in Wuhan: 39.96% and 34.21%, respectively, while the lowest was found in Xiangyang: 8.53% and 26.55%, respectively. The average 5-year AQI_{PM2.5} drop for January, February, and March are 18.14%, 25.74%, and 29.18%, respectively. Subsequently, the average 1-year AQI_{PM2.5} drop for January, February, and March are 20.17%, 26.31%, and 9.97%, respectively. It can be recorded that the 5-year and 1-year AQI_{PM2.5} drop percentages are comparable in all months except March.

Additionally, meteorological conditions have an essential influence on the variations of PM_{2.5} and NO_{2} concentrations in the ambient environment (Agarwal et al. 2006). The cities Wuhan, Huanggang, and Xiaogan recorded a spike of AQI_{PM2.5} and AQI_{NO2} levels (Fig. 1a, b, and c) in week 5 which led to a gradual decline in the forthcoming weeks of AQI_{PM2.5} and AQI_{NO2}. The increase in the AQI levels was due to low precipitation recorded in week 5 in the three cities; total average precipitation for the three cities for week 4 and 5 were 42.6 mm and 0.34 mm, respectively. In the subsequent weeks, rainfall intensity increased, which led to the drop in AQI_{PM2.5} and AQI_{NO2} levels; the total average rainfall in weeks 6 and 7 for the three cities were 19.94 mm and 22.07 mm. In week 8, it has been observed from the Fig. 1a, b, c, d, e, and f that there is an increase in AQI_{PM2.5} and AQI_{NO2} levels. Wuhan experienced 4.2 mm precipitation in Week 8, as compared with 28.6 mm and 39.4 mm precipitation in Week 7 and Week 9, respectively. Hence, the abrupt increase in PM_{2.5} and NO_{2} in the cities is due to the low precipitation received in central China in Week 8 (19th–25th, February 2020). In the 13th week, a sharp decrease in AQI_{PM2.5} and AQI_{NO2} levels is recorded. The mean rainfall in six cities in the 12th week is 14.23 mm. In contrast, the 13th week recorded heavy precipitation in all cities with mean average rainfall of 66.36 mm.

**Air quality analysis for the selected cities of India**

India enforced a nationwide lockdown from March 24, 2020, to May 3, 2020, after successive extensions as a preventive measure against COVID-19 pandemic. As the lockdown was implemented from March 24, 2020, a drastic drop has been recorded in AQI_{PM2.5} levels of all selected cities from week 7 to week 8 (Fig. 3a, b, c, d, e, and f). Maharashtra, western peninsular state of India, has recorded the most cases of COVID-19 and deaths, 12,296 and 521, respectively (MoHFW 2020), and among the six megacities of India. Its capital, Mumbai, has shown the highest immediate drop of both AQI_{NO2} and AQI_{PM2.5}, i.e. 76.28% and 34.02%, respectively. Kolkata recorded the highest final AQI_{PM2.5} drop (76.67%), and Lucknow recorded the least immediate drop in AQI_{PM2.5} (6.47%) partly due to negligible precipitation in week 8. Chennai experienced the least immediate and final drops of AQI_{NO2}, which are 32.14% and 20.95%, respectively. It can be understood because of Chennai having an already low value of AQI_{NO2} (Fig. 3a) in week 7 and the weeks before the lockdown (Table 2).

The 6 cities experienced an average immediate AQI_{PM2.5} drop of 20.21%, and an average final AQI_{PM2.5} drop of 37.42%. Each one of the six Indian cities in the study recorded an immediate and final AQI_{NO2} drop with the average immediate AQI_{NO2} drop of 59.26% and an average final AQI_{NO2} drop of 65.80%. It has shown an overall drop in both AQI_{PM2.5} and AQI_{NO2}. The average 5-year AQI_{PM2.5} drop for the months of February, March, and April is recorded as 16.05%, 26.68%, and 37.51%, respectively; subsequently, average 1-year AQI_{PM2.5} drop for the months of February, March, and April is 3.48%, 17.98%, and 27.06%, respectively. Chennai recorded the highest 5-year drop and 1-year drop in AQI_{PM2.5} in April 2020 as 59.79% and 42.90%, respectively. All cities, except Mumbai in April 2020 and Chennai in March 2020, recorded the lowest AQI_{PM2.5} levels in March and April 2020 as compared with the past 5 years. Mumbai is the only Indian city in the study to have shown a 1-year rise (1.09%) in an average AQI_{PM2.5} in April 2020 (Fig. 4a, b, c, d, e, and f). A spike in AQI_{PM2.5} was recorded (Table 3) between weeks 9 and 10 in New Delhi. It is as a result of reported fireworks incidents recorded on April 5, 2020, the day-wise AQI_{PM2.5} levels of week 9 and 10 are given in Fig. 3b (The Indian Express 2020).

Furthermore, meteorological factors have an essential factor in the reduction and increase of PM_{2.5} and NO_{2} concentrations in the ambient environment. It can be recorded from Fig. 3c, in Kolkata, that AQI_{PM2.5} and AQI_{NO2} have decreased augmented by heavy precipitation in the weeks 11, 12, and 13 with 29.20 mm, 80.90 mm, and 60.20 mm, respectively. However, in the preceding weeks 9 and 10, there was no precipitation. On the other hand, New Delhi, Lucknow, and Jaipur recorded an increase in AQI_{PM2.5} in week 11 due to high surface winds in northern India due to dust storms from western India according to the Ministry of Environment and System of Air Quality and Weather Forecasting and Research (SAFAR) (Fig. 3b, e, and f) (ANI News 2020).

**Comparative analysis and discussion between China vs India**

An entire month lockdown was implemented in February 2020 in Hubei province, China; likewise in India, the month of lockdown was April 2020. The 1-year drop for February in China comes out to be 26.31%, whereas, for April in India, it is 26.06%. Hence, it can be deduced from the results that an entire month lockdown in urban centres results in a drop of around 26% in AQI_{PM2.5} if compared with previous year
Table 2  Chennai weekly AQI\textsubscript{NO\textsubscript{2}} averages (CPCB-CCR 2020; Mintz 2012)

| Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 | Week 8 | Week 9 | Week 10 | Week 11 | Week 12 | Week 13 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| AQI\textsubscript{NO\textsubscript{2}} | 4      | 5      | 4      | 4      | 4      | 3      | 3      | 2      | 3      | 4      | 3      | 3      | 2      |

Fig. 3  Weekly averages of AQI\textsubscript{PM\textsubscript{2.5}} and AQI\textsubscript{NO\textsubscript{2}} for cities of India
Several academic studies have been conducted to study the relationship between the local meteorological factors and concentration of various pollutants (viz. PM$_{2.5}$ and NO$_2$) (Guo et al. 2017). The prime factors which influence the concentration of PM$_{2.5}$ and NO$_2$ have been identified as precipitation, ambient temperature, wind speed, and relative humidity.

Fig. 4 Past 5 years’ averages of AQI$_{PM2.5}$ for cities of India
However, the 12 selected cities tend to show a tremendous reduction in the concentration of PM$_{2.5}$ and NO$_2$ due to lock-down enforcement. It reflects that cutting down on anthropogenic sources of various pollutants can be useful in reducing the AQI.

Huanggang, China, has a population of 6.62 million, and the AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$ of Huanggang before the lockdown were 147.1 and 12, respectively. After the first week of implementation of lockdown, there was found a decrease of 13.40% and 58.54% in AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$. Likewise, Jaipur, India, has a population of 6.42 million and the AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$ of Jaipur before the lockdown was implemented were 115.7 and 15, respectively. After the first week of the implementation of lockdown, a decrease of 27.50% and 60.37% in AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$ was recorded. Both cities have a comparable population and immediate AQI$_{NO_2}$ drop, but the immediate AQI$_{PM_{2.5}}$ drop differs by 14.1%. The lowest week average AQI$_{PM_{2.5}}$ recorded in Huanggang and Jaipur was recorded 68.7 and 73.4, respectively. After the first week of the implementation of lockdown, a decrease of 27.50% and 60.37% in AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$ was recorded. Both cities have a comparable population and immediate AQI$_{NO_2}$ drop, but the immediate AQI$_{PM_{2.5}}$ drop differs by 14.1%. The lowest week average AQI$_{PM_{2.5}}$ recorded in Huanggang and Jaipur was recorded 68.7 and 73.4, respectively. Both the cities’ AQI$_{PM_{2.5}}$ has dropped down from unhealthy for sensitive groups to moderate air quality. Within 4 weeks of implementation of lockdown, Huanggang experienced a drop of 53.30% and 65.85% in week average AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$. Furthermore, Jaipur saw a drop of 36.56% and 67.49% in week average AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$ in just 2 weeks.

For a holistic view, the cities selected in India recorded an average immediate AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$ drop of 20.21% and 59.26%, respectively. In contrast, on the other hand, the cities in China recorded an average drop of 11.32% and 48.61%, respectively. After 6 weeks of implementing the lockdown, cities in India recorded an average drop in AQI$_{PM_{2.5}}$ and AQI$_{NO_2}$ of 37.42% and 65.80%, respectively, while cities in China recorded a drop of 42.54% and 56.67% respectively. From these results, it can be inferred that the drop in PM$_{2.5}$ is rather gradual as compared with the sudden drop in NO$_2$ concentrations throughout the cities.

As shown in Fig. 5, the drop in AQI$_{PM_{2.5}}$ of coastal cities (viz. Chennai, Mumbai, and Kolkata) is relatively more significant than inland cities. The exceptional drop in AQI$_{PM_{2.5}}$ in the coastal cities is vastly due to the coastal winds which are very prominent in these cities. Previous studies conducted in these coastal cities show that coastal regions show a significant drop in PM$_{2.5}$ in the morning as compared with inland regions (Chen et al. 2020b; Gupta et al. 2004). The three coastal cities incorporated in the present study record an average immediate AQI$_{PM_{2.5}}$ drop of 24.96%, and the final average AQI$_{PM_{2.5}}$ drop was found as 54.90%. On the other hand,

| April 1, 2020 | April 2, 2020 | April 3, 2020 | April 4, 2020 | April 5, 2020 | April 6, 2020 | April 7, 2020 | April 8, 2020 | April 9, 2020 | April 10, 2020 | April 11, 2020 | April 12, 2020 | April 13, 2020 |
|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| AQI$_{NO_2}$  | 7             | 9             | 10.75         | 12.33         | 11            | 8             | 9.5           | 11            | 13            | 11.67         | 8.33           | 12            |
| AQI$_{PM_{2.5}}$ | 92.75         | 77.2          | 88.2          | 97.75         | 116           | 137           | 94.67         | 90.67         | 93.5          | 124.25        | 122.25        | 113           | 128.75

![Immediate and final Drop percentages of AQI$_{PM_{2.5}}$ for all cities](image-url)
the inland region cities recorded an average immediate AQI\textsubscript{PM2.5} drop of 12.70\% and the final average AQI\textsubscript{PM2.5} drop of 24.23\%. The drop in average immediate and final AQI\textsubscript{PM2.5} of cities in inland regions is moderate as compared with the drop in coastal regions.

Drop-in AQI\textsubscript{NO2} also shows similar trends as AQI\textsubscript{PM2.5} (Fig. 6). The coastal cities recorded a much higher percentage of drop in AQI\textsubscript{NO2} as compared with cities in inland regions. The coastal cities, except for Chennai, show an exceptionally high drop in AQI\textsubscript{NO2}. Mumbai and Kolkata recorded an immediate AQI\textsubscript{NO2} drop of 76.28\% and 55.70\%, respectively, whereas the final AQI\textsubscript{NO2} drop is 92.58\% and 76.67\%, respectively. However, Chennai is a coastal city that recorded a much lower percentage drop in AQI\textsubscript{NO2} as compared with the other two coastal cities, AQI\textsubscript{NO2} of Chennai was already at a record low values between 3 to 5 before even lockdown was implemented. Xiangyang recorded an increase in AQI\textsubscript{NO2} levels after the implementation of lockdown. Xiangyang, being a heavily industrialised city, had industries that were operating during the lockdown to produce essential medical equipment.

**Conclusion**

Both the nations followed different protocols for implementing lockdown in each country, although the lockdown in both of the nations was found effective in declining the rate of spread of COVID-19 cases (Wang et al. 2020b; Barkur et al. 2020), and it played a significant role in reducing the air pollution to record low values. The significant findings of the study are as follows:

- In China, the week before the lockdown was enforced, 4 out of 6 cities had an AQI\textsubscript{PM2.5} in the unhealthy category. Wuhan and Huanggang were found in unhealthy for sensitive group category. In the last week of lockdown, 5 out of 6 cities were found to be in unhealthy for sensitive group category except for Wuhan, which was found in the moderate category.
- In India, the week before the lockdown was enforced, 5 out of 6 cities had an AQI\textsubscript{PM2.5} that is unhealthy for sensitive group category except Chennai that was found under the moderate category. In the sixth week of lockdown, all cities were found in the good and moderate category except Delhi and Lucknow, which were found to be in unhealthy for sensitive group category.
- Meteorological factors are an essential factor in order to address pollutant concentration in ambient environment. Henceforth, meteorological should be taken into account before the execution of a response plan to mitigate pollution in urban cities around the world.
- For all 12 cities, a gradual decline has been recorded in AQI\textsubscript{PM2.5} levels in subsequent lockdown weeks. The mean immediate and final AQI\textsubscript{PM2.5} drops are 15.76\% and 31.89\%, respectively. However, in the case, AQI\textsubscript{NO2} levels, a sharp decline has been recorded in the first week of lockdown. The mean immediate and final AQI\textsubscript{NO2} drops are 53.93\% and 46.22\%, respectively.
- The coastal cities (viz. Chennai, Mumbai, and Kolkata) recorded a more significant decline in AQI\textsubscript{PM2.5} and AQI\textsubscript{NO2} as compared with the other inland region cities.

The lockdown implemented in various regions around the world provided us with a unique opportunity to identify the
benchmark levels of pollutants in various urban cities around the world. The findings of the study will assist the governing authorities and policymakers to calibrate a proper response plan to bring down the ever-increasing pollution levels in various developing urban regions across the globe, especially China and India.

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Availability of data and material The data used in the current study have been taken from respective EPA and is available in public domain.

Compliance with ethical standards

Competing interests The authors declare that they have no known competing financial interest or personal relationships that would have appeared to influence the work reported in this paper.

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