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# Impact of air pollutants on COVID-19 transmission: a study over different metropolitan cities in India

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**Abstract**
India is affected strongly by the Coronavirus and within a short period, it becomes the second-highest country based on the infected case. Earlier, there was an indication of the impact of pollution on COVID-19 transmission from a few studies with early COVID-19 data. The study of the effect of pollution on COVID-19 in Indian metropolitan cities is ideal due to the high level of pollution and COVID-19 transmission in these cities. We study the impact of different air pollutants on the spread of coronavirus in different cities in India. A correlation is studied with daily confirmed COVID-19 cases with a daily mean of ozone, particle matter (PM) in size $\leq 10\ \mu$m, carbon monoxide, sulfur dioxide, and nitrogen dioxide of different cities. It is found that particulate matter concentration decreases during the nationwide lockdown period and the air quality index improves for different Indian regions. A correlation between the daily confirmed cases with particulate matter ($PM_{2.5}$ and $PM_{10}$ both) is observed. The air quality index also shows a positive correlation with the daily confirmed cases for most of the metropolitan Indian cities. The correlation study also indicates that different air pollutants may have a role in the spread of the virus.

**Keywords** Coronavirus · COVID-19 · Particulate matter ($PM_{2.5}$ and $PM_{10}$) · Meteorological parameters · Air pollutants · Air quality index (AQI)

## 1 Introduction

The extremely contagious Coronavirus Disease 2019 (COVID-19) was discovered in Wuhan, China in November 2019 (Ma, 2020). Within a short period, COVID-19 became a global health hazard and spread worldwide with different variants. The Coronavirus disease was classified as COVID-19 by the World Health Organization (WHO) in February 2020, and the virus was named as Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2) by the International Committee on Taxonomy of Viruses (ICTV). At the moment, four mutant Coronavirus variants are the most dominant: (a) Brazil variant [P.1 (P.1)] (MoHFW, 2021b), (b) Indian variant [B.1.617] (WHO et al., 2021), (c) South Africa

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variant [501Y.V2 (B.1.351)], and (d) UK Variant [VOC 202012/01 (B.1.1.7)] (MoHFW, 2021a).

The spread rate of the virus may depend on a large number of environmental parameters. Several studies focused on the impact of atmospheric parameters like temperature, humidity, wind speed, UV index, and pressure (Manik et al., 2022a; Arumugam et al., 2020; Chiyomaru & Takemoto, 2020; Pirouz et al., 2020; Notari, 2021; Sajadi et al., 2020; Wu et al., 2020b; Xie & Zhu, 2020; Manik et al., 2022c; Meyer et al., 2020; Bashir et al., 2020a; Adekunle et al., 2020; Tosepu et al., 2020; Lym & Kim, 2022). Social interaction is one of the important factors which may increase the spread of the virus rapidly (Manik et al., 2022d, b; Bontempi & Coccia, 2021; Bontempi et al., 2021; Calbi et al., 2021; Block et al., 2020; Oraby et al., 2021). India is one of the countries that was affected very strongly by the virus and went through several waves of COVID-19. The healthcare system is strongly affected by the virus. We have studied the variation of COVID-19 confirmed individuals for five main mega-metropolitan Indian cities (Bengaluru, Chennai, Delhi, Kolkata, and Mumbai) during the COVID-19 first wave (2020–04-26 to 2021–02-28).

The virus may be transmitted through the air, where $PM_{2.5}$ works as a carrier toward which virus droplets attach and stay for a while (Feng et al., 2016; Domingo et al., 2020; Fattorini & Regoli, 2020). Recently, several studies have found a linkage between COVID-19 transmission and $PM_{2.5}$ (Domingo et al., 2020; Fattorini & Regoli, 2020; Frontera et al., 2020; Wu et al., 2020a; Ogen, 2020). Earlier findings suggest that a person who spends decades in a place with $PM_{2.5}$ levels well above the permitted limit has a 15% higher chance of dying from COVID-19 than someone who lives in a region with one unit fewer $PM_{2.5}$ (Dutheil et al., 2020; Chen et al., 2013). A positive association between COVID-19 and atmospheric pollution was reported over Italy (Conticini et al., 2020). The study over Italy showed that the COVID-19 cases were higher in polluted places in Italy, so pollution may play an important role in the virus spreading.

The rapid spread of the virus raises a question about the medium of transmission, i.e., the airborne transmission of the virus, which may have a dangerous impact on a community worldwide. Throughout the globe, different studies are conducted to look for the correlation between the COVID-19 and air quality ($PM_{2.5}$, air pollutants impact). Most of the worldwide studies found that the air pollutant like $PM_{2.5}$, $PM_{10}$ and other pollutant gases may have an impact on to spread of the virus (Lym & Kim, 2022; Chauhan & Singh, 2020; Bashir et al., 2020b; Villanueva et al., 2021; Zoran et al., 2020; Ayoub et al., 2021; Sahu et al., 2021; Das et al., 2021). Lym and Kim (2022) investigated the impact of air pollutants (PM 2.5) and temperature on COVID-19 transmission and found a positive correlation between a 7-day lagged effect of PM 2.5 concentration and the number of confirmed COVID-19 cases for a region of South Korea. They have found that temperature has a negative correlation with the number of COVID-19 cases (Lym & Kim, 2022). Chauhan and Singh (2020) found that $PM_{2.5}$ concentration reduced for different major cities worldwide (New York, Los Angeles, Zaragoza, Rome, Dubai, Delhi, Mumbai, Beijing, and Shanghai) due to lockdown during COVID-19. Bashir et al. (2020b) investigated the impact of air pollution on COVID-19 over California and a significant correlation was found between different environmental pollutants ($PM_{10}$, $PM_{2.5}$, $SO_2$, $NO_2$, and CO) and the COVID-19 epidemic. Bashir et al. (2020b) studied the effect of surface levels of particulate matter ($PM_{2.5}$ and $PM_{10}$) on COVID-19 in Milan, Italy, and found that daily new cases of COVID-19 are positively correlated with particulate matter and Air Quality Index (AQI). This study indicates that airborne aerosols may be one of the possible ways of COVID-19 transmission. The study over Milan, Italy suggested that warm weather will not stop COVID-19 spreading (Bashir et al., 2020b). Another study in London, United Kingdom, suggested that different air pollutants ($PM_{2.5}$, CO, and $O_3$) have a positive correlation with daily cases and daily deaths of SARS-CoV-2.

We have conducted a detailed study on the impact of air pollution on COVID-19 transmission over different Indian mega metropolitan cities. It is well known that India's capital city, Delhi, is one of the most polluted megacities in the world (Gurjar et al., 2010). Delhi frequently violates the standard limits of the National Ambient Air Quality Standards (NAAQS) (Guttikunda & Goel, 2013). Earlier few studies have been investigated the correlation of air quality with different respiratory diseases (Agarwal et al., 2006; Balakrishnan et al., 2013; Dholakia et al., 2014; Chhabra et al., 2001; Rajarathnam et al., 2011; Kumar et al., 2010; Jayaraman, 2008). We have included Delhi in our study along with four different megacities in India.

In the present paper, we look at the impact of different air pollutants on COVID-19 transmission. We have studied the variation of different air pollutants and the air quality index for different Indian cities. The impact of different air pollutants on daily new COVID-19 cases is studied in detail for a large population of Indian metropolitan cities, which is very relevant to the practical scenario. We have studied the correlation between confirmed cases and particulate matter ($PM_{2.5}$, $PM_{10}$ both) for different Indian cities for a long time scale of nearly ten months. We also estimated different gaseous air pollutants like carbon monoxide (CO), nitrogen dioxide ($NO_2$), ozone ($O_3$), sulfur dioxide ($SO_2$) for different cities. The air quality index (AQI) is calculated using the values of all these air pollutants. The correlation between AQI and daily confirmed COVID-19 cases for different cities is being investigated to look for the impact of air pollution on COVID-19 cases.

The data analysis and methodology is discussed in Sect. 2, the results and discussion of our study are given in the Sect. 3. We summarized the important findings in Sect. 4.

## 2 Data analysis and methodology

We have used the COVID-19 data set from the COVID-19 India API to track reported cases across different metropolitan cities in India[1]. We have acquired air quality data as the hourly concentrations of $PM_{2.5}$ (diameter < $2.5\mu m$), $PM_{10}$ (diameter < $10\mu m$), $SO_2$, $NO_2$, CO, and $O_3$ from the OpenAQ database and estimated air quality index (AQI) from the pollutants data during the COVID-19 first wave (2020–04-01 to 2021–02-28) over the different Indian ground-based pollution monitoring stations (Kolkata, Delhi, Mumbai, Chennai, and Bengaluru). AQI is a dimensionless measure of air quality. The Indian National Air Quality Index considers eight pollutants ($PM_{10}$, $PM_{2.5}$, $NO_2$, $SO_2$, $NH_3$, CO, $O_3$ and Pb) with a 24-hour average period (Mamta & Bassin, 2010). They are divided into six categories: good (0–50), satisfactory (51–100), moderate (101–200), poor (201–300), very poor (301–400), and severe (401–500). As indicated in Eq. 1, Sub-indicators for individual contaminants at monitoring points are calculated using 24-hourly average concentrations (8-hourly in the case of CO and $O_3$) and health breakpoint concentration ranges. The AQI comes from the largest sub-AQI of all pollutants, as in Eq. 2. When the AQI is 50 or higher, the source of the maximum sub-index is identified as the main pollutant source for the day. We have used standard Python packages i.e., Numpy, Scipy, Pandas, Matplotlib, and Epitools (Manik et al., 2022b).

[1] https://data.covid19india.org/

$$\mathrm{IAQI}_P = \frac{I_{\mathrm{high}} - I_{\mathrm{low}}}{C_{\mathrm{high}} - C_{\mathrm{low}}}(C_{\mathrm{P}} - C_{\mathrm{low}}) + I_{\mathrm{low}} \tag{1}$$

$$\mathrm{AQI} = \max(I_1, I_2, ..., I_n) \tag{2}$$

$\mathrm{IAQI}_P$: the air quality sub index for air pollutant $p$;
$C_P$: the concentration of pollutant $p$;
$C_{\mathrm{low}}$: the concentration breakpoint that is $\leq C_P$;
$C_{\mathrm{high}}$: the concentration breakpoint that is $\geq C_P$;
$I_{\mathrm{low}}$: the index breakpoint corresponding to $C_{\mathrm{low}}$;
$I_{\mathrm{high}}$: the index breakpoint corresponding to $C_{\mathrm{high}}$.

We have studied the variation of daily confirmed cases for major metropolitan cities (Kolkata, Delhi, Mumbai, Chennai, and Bengaluru) in India. We have looked at the evolution of the particulate matter concentrations ($PM_{2.5}$ & $PM_{10}$) and estimated AQI for these cities during this time span. To minimize the effect of noise, we have used a 3-day rolling mean of both the daily confirmed cases and air quality data. Since the pollutants are not expected to have an immediate effect on COVID-19 transmission, we have used 7 days of lag in air quality data to the reported cases. Linear regression is carried out between the 7 days lagged pollutants data ($PM_{2.5}$, $PM_{10}$, AQI) and the confirmed cases of COVID-19 to understand the effect of air pollutants on COVID-19 transmission. The linear regression method (Freedman, 2009) is used to find the regression coefficient $R^2$ which represents the coefficient of determination for linear regression models. We have computed the $p$-value (Thiese et al., 2016) to determine the significance of the linear correlation. A $p$-value is a number between 0 and 1 that evaluates how well the data reject the null hypothesis that there is no relationship between the two variables being compared. Successful rejection of this hypothesis means that the results can be statistically significant. A correlation is considered statistically significant if the $p$-value is low (usually $\leq 0.05$), and a $p$-value greater than 0.05 indicates that the correlation is not statistically significant.

## 3 Results and discussion

In the present study, we have used the time series data for confirmed individuals of COVID-19 for different cities in India. We have studied the evolution of different air pollutants for different Indian megacities and looked for the effect of these parameters on the daily confirmed cases of COVID-19. In the first row of Fig. 1, we have shown the variation of the daily new cases of COVID-19 for different Indian metropolitan cities. The second row and third row of Fig. 1 have shown the variation of $PM_{2.5}$ and $PM_{10}$, respectively for five different cities. The bottom panel of Fig. 1 shows the variation of the air quality index (AQI) for different Indian cities during the study. The daily mean values of the respective particulate matter, nitrogen dioxide, sulfur dioxide, ozone, and carbon monoxide present in the air are used to estimate the air quality index.

### 3.1 Impact of particulate matter ($PM_{2.5}$, $PM_{10}$) on COVID-19 transmission

Particulate matter (PM) is one of the major contributors to air pollution. There are several natural sources (forest fire, volcano eruption, sea salt, wind and dust storms, reactions between gaseous emissions, and soil erosion) and man-made sources (fuel combustion,

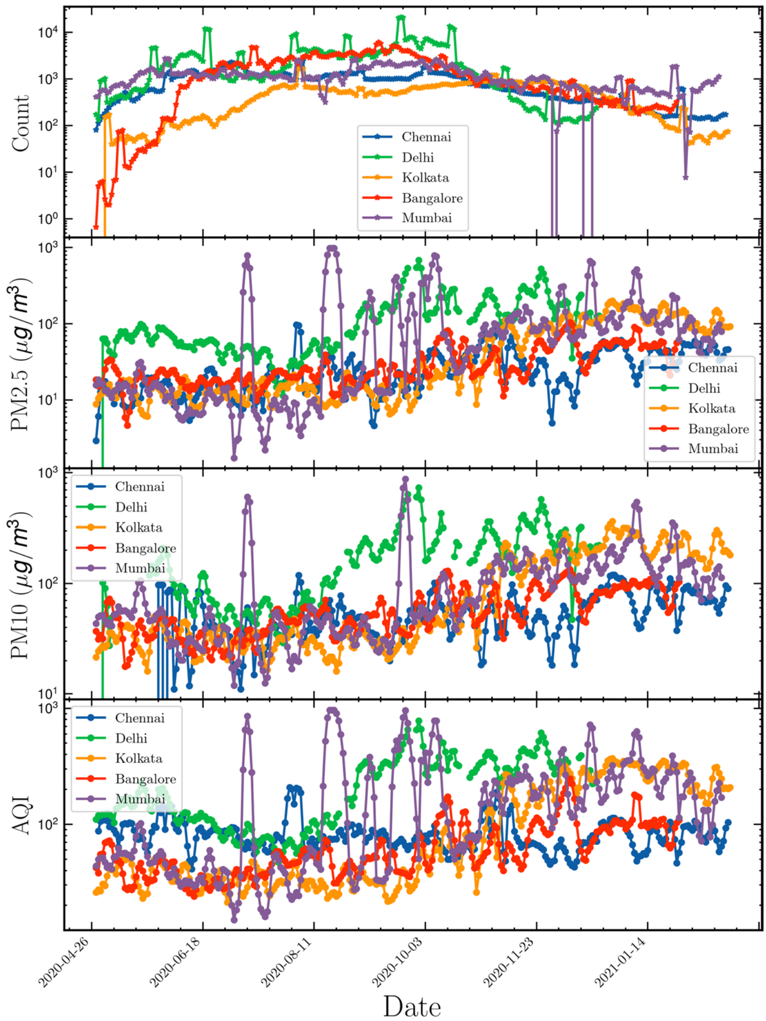


**Fig. 1** Variation of COVID-19 daily confirmed cases, particulate matter (both $PM_{2.5}$ and $PM_{10}$) and Air Quality Index (AQI) with 3 days rolling mean for five different metropolitan cities of India

power plants, burning of coal, industrial areas, mining, automobiles, fly-ash emissions, and agriculture) which can generate this type of pollutants. Particulate matter includes all solid and liquid particles suspended in the air. During the biomass burning release, PM was reported with a diameter of less than 2.5 $\mu$m.

Particulate matters are found in the form of different shape and sizes (the ultra-fine particles $PM_{0.1}$ with diameter < 0.1 $\mu$m; fine particles $PM_{2.5}$ with diameter ≤ 0.25 $\mu$m; coarse particles $PM_{10}$ with diameter > 0.25 $\mu$m and ≤10 $\mu$m (Zoran et al., 2019; Khan et al., 2019).

Earlier, a strong correlation between particulate matter and the outbreak of various diseases like asthma, respiratory infection, lung cancer, etc. was found (Adams et al., 2015; Raaschou-Nielsen et al., 2013; Beelen et al., 2013). These earlier studies established the concept of a strong correlation between air pollution and respiratory diseases. Most of the studies were performed in North America, Europe, and a few studies were conducted focusing on Asian cities (Maji et al., 2018a, b) with early data of COVID-19. In the context of Indian mega metropolitan cities, the relationship between different air pollutants and COVID-19 confirmed cases is limited and unexplored. We have used a long time series (ten months) of data to investigate the correlation between different air pollutants and COVID-19 for Indian cities.

We have studied the evolution of particulate matter ($PM_{2.5}$, $PM_{10}$ both) over ten months. In Fig. 1, we have shown the variation of $PM_{2.5}$, $PM_{10}$ for Bangalore, Chennai, Delhi, Kolkata, and Mumbai during the first wave (2020–04-26 to 2021–02-28). Delhi shows the maximum value of $PM_{2.5}$ and $PM_{10}$ both confirming that it is the most polluted Indian city. During the nationwide lockdown period (April–August 2020), the air quality in Delhi improved and the concentration of particulate matter ($PM_{2.5}$ and $PM_{10}$ both) decreased. Most metropolitan Indian cities also showed a reduction in air pollutants and an improvement in air quality during the lockdown phases.

The first and second columns of Fig. 2 show the correlation of $PM_{10}$ with confirmed cases and $PM_{2.5}$ with confirmed cases, respectively, for five Indian mega metropolitan cities which are strongly affected by the COVID-19. All cities show a positive correlation between confirmed cases with $PM_{10}$ and $PM_{2.5}$ which implies that the particulate matter has a significant correlation with COVID-19 and particulate matter associated with COVID transmission and an increase in $PM_{2.5}$ and $PM_{10}$ also increase the virus spread. The particulate matter may be playing a role in the spread of the virus faster. Table 1 summarizes the results of the correlation study. Bengaluru, Kolkata, and Delhi show a very strong correlation between the confirmed cases with particulate matter ($PM_{10}$) with a $R^2$ value of 43%, 71% and 38%, respectively. All these correlations are statistically highly significant ($p$-value << 0.05). For the cities of Mumbai and Chennai, a positive correlation between the confirmed cases and particulate matter ($PM_{10}$) is found with a regression coefficient of 12% and 16% which is statistically significant.

The correlation study of the $PM_{2.5}$, $PM_{10}$ with confirmed COVID-19 cases indicates a significant outcome. The city with a higher value of particulate matter concentration reported a higher number of confirmed cases of COVID-19. The concentration of particulate matter has an important impact on controlling the air pollution level of a city. From the results, it is conclusive that air quality and pollution levels have an important role in the spread of the virus (Table 1).

### 3.2 Impact of different air pollutants on COVID-19 transmission

Air pollution is a major burden and an urgent problem in developing countries like India. Air pollution was considered the world's most serious environmental health threat (Krewski et al., 2009; Pedersen et al., 2013; Pope Iii et al., 2002; Smith et al., 2014). Approximately 7 million people die each year as a result of air pollution (World Health Organization, 2014).

Delhi, the capital of India, is a well-known hotspot for air pollution with $PM_{2.5}$ and $PM_{10}$ concentrations and other gaseous air pollutants like CO, $NO_2$, $O_3$, $SO_2$, etc. The National Capital Territory of Delhi (NCTD) is the leading centre to the majority of Indian polluted cities, making it a global pollution hotspot (Tiwari et al., 2012; Pandey et al., 2016). Besides Delhi, we also study the air pollution levels in Chennai, Kolkata, Bangalore, and Mumbai. We have estimated the contribution of major air pollutants, and for each

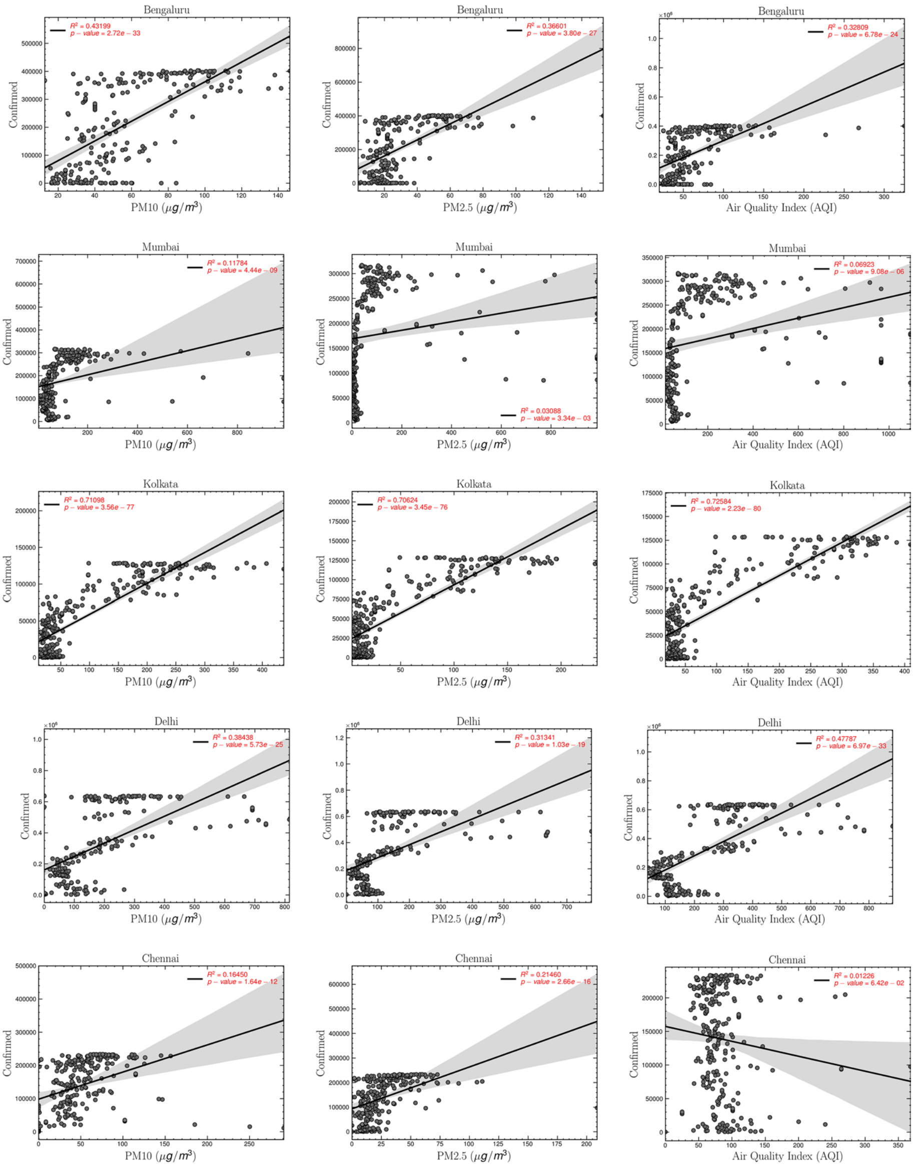


**Fig. 2** Variation of COVID-19 confirmed $C(t)$ cases with particulate matter (both $PM_{2.5}$ and $PM_{10}$) and air quality index (AQI) for five different metropolitan cities of India. The first column shows the correlation between confirmed cases and $PM_{10}$ for five different metropolitan cities and the second column represent the correlation between confirmed cases and $PM_{2.5}$. The third column shows the correlation between the AQI and confirmed cases of COVID-19

metropolitan city, we have calculated the air quality index (AQI). The variation of AQI can be a major determinant of the air pollution level of a region.

We have investigated the relationship of air pollutants with COVID-19 confirmed cases in different mega-cities of India for a long duration of 10 months. Air pollutants, especially

**Table 1** Value of regression coefficient $R^2$ and p-value in different Indian cities for correlation study between confirmed cases $C(t)$ vs $PM_{2.5}$, confirmed cases $C(t)$ vs $PM_{10}$, and confirmed cases $C(t)$ vs AQI plot.

| Metropolitan cities | $R_{PM\,2.5}^2$ (%) | p-value | $R_{PM\,10}^2$ (%) | p-value | $R_{AQI}^2$ (%) | p-value |
|---|---|---|---|---|---|---|
| Kolkata | 70.62 (+) | $3.45\times10^{-76}$ | 71.09 (+) | $3.56\times10^{-77}$ | 72.58 (+) | $2.23\times10^{-80}$ |
| Mumbai | 3.09 (+) | $3.34\times10^{-03}$ | 11.78 (+) | $4.44\times10^{-09}$ | 6.92 (+) | $9.08\times10^{-06}$ |
| Chennai | 21.46 (+) | $2.66\times10^{-16}$ | 16.45 (+) | $1.64\times10^{-12}$ | 1.22 (–) | $6.42\times10^{-02}$ |
| Delhi | 31.34 (+) | $1.03\times10^{-19}$ | 38.43 (+) | $5.73\times10^{-25}$ | 47.78 (+) | $6.97\times10^{-33}$ |
| Bangaluru | 36.60 (+) | $3.80\times10^{-27}$ | 43.20 (+) | $2.72\times10^{-33}$ | 32.80 (+) | $6.78\times10^{-24}$ |

The '+' sign implies positive correlation and '–' sign implies negative-correlation

particulate matter, can play a crucial role in COVID-19 transmissions and infection. We also estimate the air quality index to look for the air pollution level including all gaseous air pollutants (CO, $NO_2$, $O_3$, $PM_{2.5}$, $SO_2$). The bottom panel of Fig. 1 shows the variation of the air quality index for Chennai, Delhi, Kolkata, Bangalore, and Mumbai. The AQI for Delhi shows a higher value than other cities, which implies a higher air pollution level in Delhi during the period of 2020–04-26 to 2021–02-28. It is also found that during the nationwide lockdown period (April–August 2020) the air quality improves and the AQI reduces for most of the Indian megacities.

The third column of Fig. 2 shows the correlation between confirmed cases and the air quality index for five Indian metropolitan cities which are strongly affected by COVID-19. All the cities except Chennai show a positive correlation between confirmed cases and AQI, which implies that AQI may have a role in the spread of the virus. Table **1** summarizes the values of the regression coefficient with the significance (p-value). For the cities of Bangalore, Kolkata, and Delhi, the regression coefficient shows a higher value of 32.8%, 72.5%, and 47.7%, respectively, with high statistical significance, which implies that the confirmed cases highly correlate with AQI. Among these five cities, Kolkata shows the highest value of regression coefficient ($R^2$=72.5%). Mumbai also shows a positive correlation between the confirmed cases and AQI with a value of 7% and Chennai shows a weak negative correlation of $R^2$=1.2% which is statistically less significant (p-value>0.05). The improvement in the air quality index may reduce the COVID-19 cases and transmissible risk of the virus.

Earlier, the dependence of $PM_{10}$ and $PM_{2.5}$ on the death rate of COVID-19 is studied over China, which suggested that a higher concentration of particulate matter increases the number of deaths by COVID-19 (Yao et al., 2020). Another study found a significant impact of $PM_{2.5}$ on the daily death rate of COVID-19 and investigated that 15% increase in the COVID-19 death rate was associated with only 1 $\mu g/m^3$ in $PM_{2.5}$ (Wu et al., 2020a).

Environmental pollution and weather conditions may affect the transmissibility of SARS-CoV-2 infection, according to the previous studies (Meo et al., 2020, 2021a). A recent study revealed that wildfire-induced increases in $PM_{2.5}$, CO, and $O_3$ concentrations were linked to an increase in COVID-19 cases and deaths in different areas of California (Meo et al., 2020a, 2021b).

Previous researches have also found a link between high levels of ambient fine particles, or $PM_{2.5}$, and respiratory deceases (Horne et al., 2018; Zhu et al., 2020; Gandini et al., 2018). A correlation was found between air pollution (mainly ground ozone) and COVID-19 cases for different states of the US (Razzaq et al., 2020). Similarly, the present study results reveal a positive correlation between different environmental air pollutants and the number of SARS-CoV-2 cases. The present study findings show an increasing trend of COVID-19 cases with environmental pollution in India. Countries need to take more precautions to reduce air pollution levels as well as the transmission of viruses to reduce COVID-19 related deaths.

## 4 Conclusion

We have studied the evolution of different air pollutants (CO, $NO_2$, $SO_2$, $O_3$, $PM_{2.5}$, and $PM_{10}$) and their impacts on COVID-19 transmission. There is a link between daily confirmed cases and particulate matter (both $PM_{2.5}$ and $PM_{10}$). This suggests that particulate matter may play a crucial role in the propagation of the virus. All the metropolitan Indian cities (Kolkata, Mumbai, Chennai, Bangaluru, and Delhi) show a positive association of particulate matter with COVID-19. The air quality index also shows a positive association with COVID-19 confirmed cases. The correlation analysis indicates that different air pollutants may have an important role in virus transmission. It is found that the lockdown period has an important impact on air quality improvement. Most of the megacities of India show that there is a reduction in particulate matter concentration ($PM_{2.5}$ and $PM_{10}$ both) during the lockdown. The evaluation of pollutant concentrations such as $PM_{2.5}$, $NO_2$, CO, and $SO_2$ has become crucial, specifically for policy making in many countries to minimize environmental pollutants related to health hazards. Pollution levels influence the COVID-19 daily confirmed cases. Environmental pollution management authorities of countries should establish relevant regulations and assistance in planning to reduce pollution and the spread of COVID-19.

**Author Contributions** Mr. Manik made data analysis and visualization of results. Mr. Mandal contributed to the conceptualization and writing of the manuscript. Dr. Pal contributed to the conceptualization of the project and the manuscript writing.

**Funding** Not applicable.

**Data availability** We have used COVID-19 cases data from https://data.covid19india.org/

**Code availability** Not applicable.

## Declarations

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

**Ethical approval** Not applicable.

**Consent to participate** Not applicable.

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