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Exposure to Nitrogen Dioxide (NO_2) from Vehicular Emission Could Increase the COVID-19 Pandemic Fatality in India: A Perspective

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Abstract

The corona virus-2019 (COVID-19) is ravaging the whole world. Scientists have been trying to acquire more knowledge on different aspects of COVID-19. This study attempts to determine the effects of COVID-19, on a large population, which has already been persistently exposed to various atmospheric pollutants in different parts of India. Atmospheric pollutants and COVID-19 data, obtained from online resources, were used in this study. This study has shown strong positive correlation between the concentration of atmospheric nitrogen dioxide (NO_2) and both the absolute number of COVID-19 deaths ($r = 0.79$, $p < 0.05$) and case fatality rate ($r = 0.74$, $p < 0.05$) in India. Statistical analysis of the amount of annual fossil fuels consumption in transportation, and the annual average concentration of the atmospheric $PM_{2.5}$, PM_{10}, NO_2, in the different states of India, suggest that one of the main sources of atmospheric NO_2 is from fossil fuels combustion in transportation. It is suggested that homeless, poverty-stricken Indians, hawkers, roadside vendors, and many others who are regularly exposed to vehicular exhaust, may be at a higher risk in the COVID-19 pandemic.

Keywords Pollution and COVID-19 · COVID-19 pandemic in India · Atmospheric NO_2 · Emission from transportation

The threat of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), or COVID-19 is the toughest challenge thrown at the human race of the present world. The COVID-19 death toll is rapidly mounting worldwide (WHO 2019). The prevalence of the COVID-19 pandemic both in the tropical and temperate countries indicates that this virus is highly tolerant to wide variations in temperature and humidity. The effect of COVID-19 on human health is reported to be more severe in the presence of air pollutants (Conticini et al 2020; Ogen 2020). The aforementioned information is particularly important for developing countries which are already under the grip of COVID-19 pandemic, and where large sections of the population live in areas with poor ambient air quality. A recent study has shown that atmospheric particulate matter ($PM_{2.5}$) is a potential pollutant which could be responsible for increasing the risk of mortality from COVID-19 (Wu et al 2020; Science News by AGU 2020). However, adverse effects of COVID-19 on the health of individuals who have been exposed to different concentrations of air pollutants have not yet been completely elucidated.

In this study, India was selected because of its large population (the second largest population in the world), fast-growing economy, and poor environmental quality (fifth most-polluted country) (U.S. Census Bureau 2020; World Bank Report 2020). Twenty-one Indian cities are ranked among the first thirty most-polluted cities, in the world based on poor air quality (Khan and Hassan 2020; CNN 2020). Therefore, regular exposure to different atmospheric pollutants could put a part of the Indian population under severe threat during the COVID-19 pandemic. It is hypothesized that the number of deaths in a particular region by the COVID-19 epidemic could be related to the concentration

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of different atmospheric pollutants in that region. The aim of this study was to identify the atmospheric pollutants and their sources, whose long-term exposure could increase the severity of the COVID-19 pandemic.

It should be noted that our knowledge about the COVID-19 is very limited. The impact of COVID-19 on human health depends on many factors and the mechanism is extremely complex. In this investigation, an attempt was made to establish a link (if any) between, the number of COVID-19 deaths with the concentrations of different atmospheric pollutants in 18 states of India. It is assumed that the deceased subjects resided for the last year in the same state in which they died, and came in contact with the atmospheric pollutants prevalent in that state.

The data (used in this study) related to atmospheric pollutants and the COVID-19 pandemic were obtained from online resources (Central control room for air quality management- all India and https://www.covid19india.org/ respectively).

Materials and Methods

The details of the data processing and analysis methodologies are presented below.

The concentration of surface atmospheric pollutants from 207 stations of 128 cities distributed all over India (as shown in Fig. 1) were obtained from the website of Central Control Room for Air Quality Management (https://app.cpcbccr.com/ccr). The details of averaging of each pollutant are given below.

Let us assume that atmospheric data is monitored at "n" different stations in "x" different cities (A, B, and C…..X) of a state.

If the concentration of a pollutant at "n" different stations in city A are: A_1, A_2, A_3, A_4……A_n.

And, B_1, B_2, B_3……. B_n in city B and C_1, C_2, C_3……C_n in city C, and so on then,

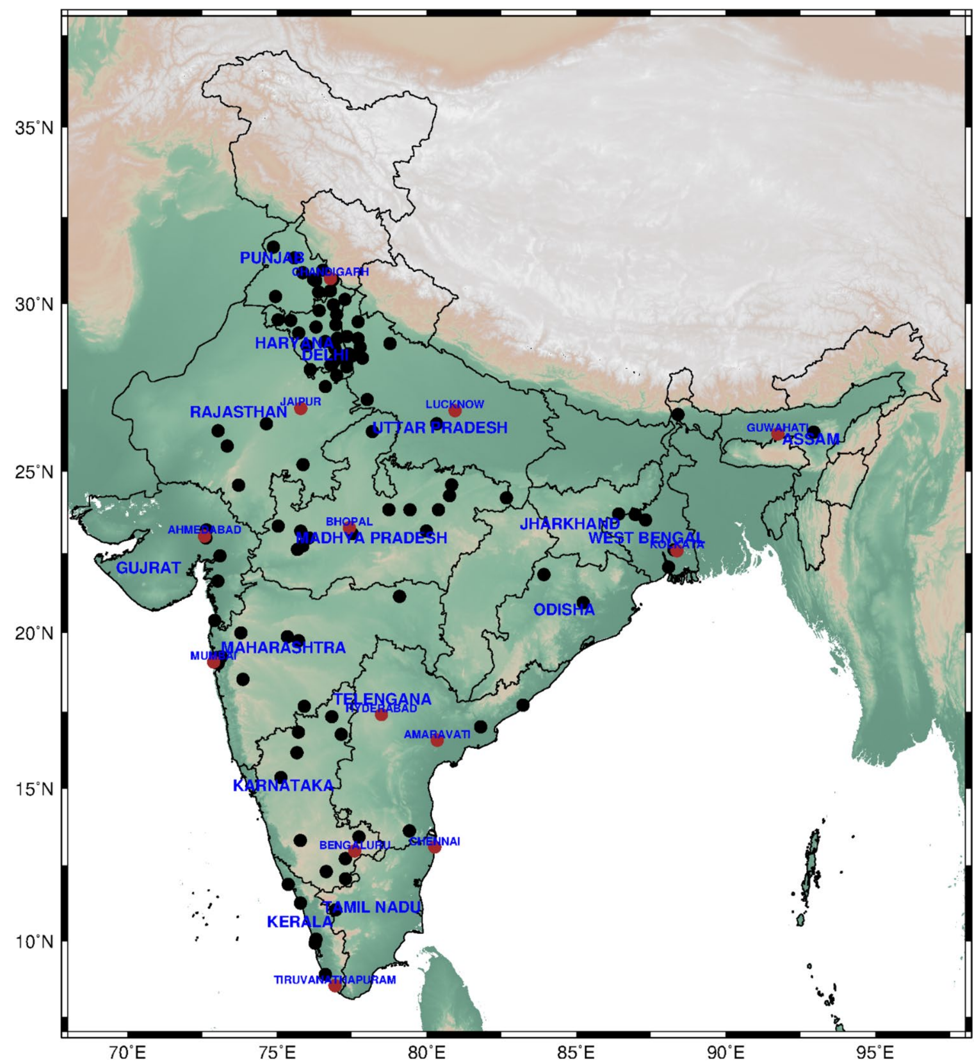

Fig. 1 Map of India showing 196 stations from 123 cities in 18 states from which atmospheric data were available

The average concentration of the pollutant in the City A will be $= \frac{A_1+A_2+A_3\ldots\ldots\cdots+A_n}{n} = A_{average}$

The average concentration of pollutant in the city B will be

$$= \frac{B_1 + B_2 + B_3 \ldots \ldots \cdots + B_n}{n} = B_{average}$$

The average concentration of pollutant in the city C will be

$$= \frac{C_1 + C_2 + C_3 \ldots \ldots \cdots + C_n}{n} = C_{average}$$

…

…

The average concentration of the pollutant in city the X will be

$$= \frac{X_1 + X_2 + X_3 \ldots \ldots \cdots + X_n}{n} = X_{average}$$

The average concentration of the pollutant in the state will be

$$= \frac{A_{average} + B_{average} + C_{average} + \ldots \ldots \ldots \ldots \ldots . + X_{average}}{\text{Number of cities}}$$

In this study, number of cities and n varied from one state to another (based upon the availability of the data). The detailed description of the stations (Fig. 1) and yearly average concentration of different atmospheric pollutants in different states of India are given in Tables SM 1–7.

The total number of COVID-19 cases on 8th June 2020 and 15th June 2020, and total number of deceased on 15th June 2020 in Indian states were obtained from https://www.covid19india.org/. The data were used to calculate the case fatality rate (CFR). The CFR describes the proportion of cases who have died from a disease over the course of a disease or pandemic once the pandemic is over.

However, during an ongoing pandemic like COVID-19, the above formula is not applicable. Therefore, the correct formula applicable for an ongoing pandemic is the one described by Ghani et al (2005):

$\text{CFR} = \frac{\text{deaths at day}\cdot x}{\text{cases at day}\cdot x-(\text{T})}$

where, T average time period from case confirmation to death.

In this case we assumed T = 7 days to calculate the CFR.

Total number of COVID-19 cases on 8th June 2020 and total number of deceased on 15th June 2020 were used to calculate the CFR. The CFR values in the Indian states are presented in Table SM 8.

All the data are presented with 95% confidence interval. The relationship between the concentration of atmospheric pollutants and the COVID-19 death and CFR in India were evaluated with Pearson's correlation coefficient and regression analysis.

Results and Discussion

Even though the concentrations of atmospheric pollutants (particulate matter with a diameter ≤ 2.5 µm ($PM_{2.5}$), particulate matter with a diameter ≤ 10.0 µm (PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2), nitrogen oxides (NO_X), ozone (O_3), sulphur dioxide (SO_2)) vary with the changing seasons (Fig. SM 1A–G), atmospheric levels of many of these pollutants remain higher than the recommended limits throughout the year in India (WHO 2018). This is likely a major reason that 21 of the top 30 cities of the world in terms of poor air quality are located in India (Khan, and Hassan 2020).

The yearly average concentration of many different atmospheric pollutants in the different states across India are presented as supporting material (Tables SM 1–7). $PM_{2.5}$ is one of the major atmospheric pollutants for many cities in India (Ministry of Environment, Forest and Climate Change, Government of India 2020; NACP 2019; Louisiana State University 2018). Statistical analysis show that there was a strong positive correlation between the concentration of $PM_{2.5}$ and PM_{10}, indicating that they were probably from same sources.

Even though there are reports on increasing severity of the COVID-19 pandemic with increasing $PM_{2.5}$ in the USA, this study however, couldn't find any relationships between $PM_{2.5}$ and the number of COVID-19 deaths or Case Fatality Rate (CFR) in India (Figs. SM 2 and SM 3). It is probably due to the fact that the COVID-19 pandemic in India is in stage 2 (clusters of cases) (WHO 2020). The atmospheric $PM_{2.5}$ probably plays an important role in spreading the virus when the epidemic is in stage 3 level (community transfer level) (Ma et al 2017). Therefore, $PM_{2.5}$ might play a crucial role in spreading the virus in the near future if the pandemic is not controlled soon.

The changing concentration of NO_X and SO_2, showed positive relationships with the number of COVID-19 deaths (Fig. SM 2). However, increasing concentration of atmospheric NO_2, showed a strong positive correlation with the number of COVID-19 deaths and the COVID-19 CFR in different states of India (Fig. 2a and b). This indicates that exposure to atmospheric NO_2 could exacerbate the morbidity associated with COVID-19.

Regression analysis suggests that increasing atmospheric NO_2 concentration by 1.0 µg m^{-3} $year^{-1}$, could increase the number of deaths in India by ~ 30. Increasing atmospheric NO_2 concentration by 10.0 µg m^{-3} $year^{-1}$, in India could increase the CFR by ~ 1.4%. The population living in the Indian cities that is regularly exposed to high levels of atmospheric NO_2 might be more vulnerable to infection by the COVID-19 virus than the population living in more rural areas. But it is important to remember that the epidemic is progressing rapidly. The death and mortality rate of COVID-19 are increasing and changing everywhere. Therefore, the estimated impact of NO_2 on the COVID-19 fatality rate (~ 1.4%) in India could be an underestimation. An increase in NO_2 concentration by 10 µg m^{-3} $year^{-1}$, could further increase the fatality rate in India in the future.

Human health effects are unlikely to be related to one single pollutant. Therefore, in epidemiological research the use of a single pollutant as a surrogates for a complex mixtures of pollutants from certain sources are not correct. Since $PM_{2.5}$ has been identified as a deadly atmospheric pollutant whose exposure can increase the severity of the COVID-19 epidemic (Wu et al. 2020; Yongjian et al. 2020) and this study also identified NO_2 as another atmospheric pollutant to affect the CFR of the pandemic, the CFR of COVID-19 in India might change with changes in concentrations of these two atmospheric pollutants. Therefore, $NO_2/PM_{2.5}$ ratio was used as an indicator to understand the contribution of atmospheric pollutants on specific health effects in a particular area in India. The $NO_2/PM_{2.5}$ ratio has already been used to assess the influence of atmospheric pollutants on human health (Hazenkamp-von Arx et al 2004).

This study showed that rise in $NO_2/PM_{2.5}$ ratio increased the COVID-19 CFR by ~ 7.2% (Fig. 2c) in India. Increasing atmospheric NO_2 levels or increasing ratio of $NO_2/PM_{2.5}$ (in the atmosphere) in a city could increase the severity of the COVID-19 pandemic in that city.

The concentrations of atmospheric NO_2 in Indian states were always positively correlated with the COVID-19 CFR (at three different times; on 4th May, 1st June and 15th June) (see Fig. 3a–c). This indicates that long-term exposure to high levels of atmospheric NO_2 could place a large fraction of the Indian population under a serious health threat during the COVID-19 pandemic.

Studies in the literature show that short-term NO_2 exposure (30 min to 24 h) can cause serious respiratory disorders resulting in increased number of hospital visits and even emergency medical treatment (Australian Government Department of Agriculture, water and the Environment 2005; USEPA 2017; Rangkuti and Musfirah 2019). Exposure to atmospheric NO_2 damages the lining of lungs, and weaken the immune system (Australian Government Department of Agriculture, Water and the Environment 2005). It has been reported that exposure to 50–100 ppm NO_2 for 30 min may lead to development of bronchiolitis, pulmonary edema and focal pneumonitis, all of which can increase the susceptibility of an individual to COVID-19 many-fold (National Research Council 1998). These symptoms however resolve spontaneously on cessation of exposure. However, persistent exposure to NO_2 can cause irreversible pathological changes in the lungs like alveolar hyperplasia and increased fibrin in the alveoli. These changes will probably not increase the rate of infection for COVID-19 but will play a major role in prognosis of the patient once infected. Furthermore, NO_2 induces accumulation of inflammatory cells in the alveoli of lungs. These cells may contribute to development of a ‘cytokine storm’, which in most cases is responsible for the death of a COVID19 patient (McGonagle et al 2020). Another indicator of bad prognosis of a COVID-19 patient is a decrease in O_2 saturation of blood. NO_2 may further aggravate the situation as it reacts with hemoglobin and converts it to methemoglobin or nitrosohemoglobin which reduces the oxygen carrying capacity of blood (Unnikrishnan and Rao 1995). These mechanisms combined together may explain the increased mortality of COVID-19 patients in regions with high atmospheric levels of NO_2. Therefore, the population exposed to atmospheric NO_2 could be under serious threat during the COVID-19

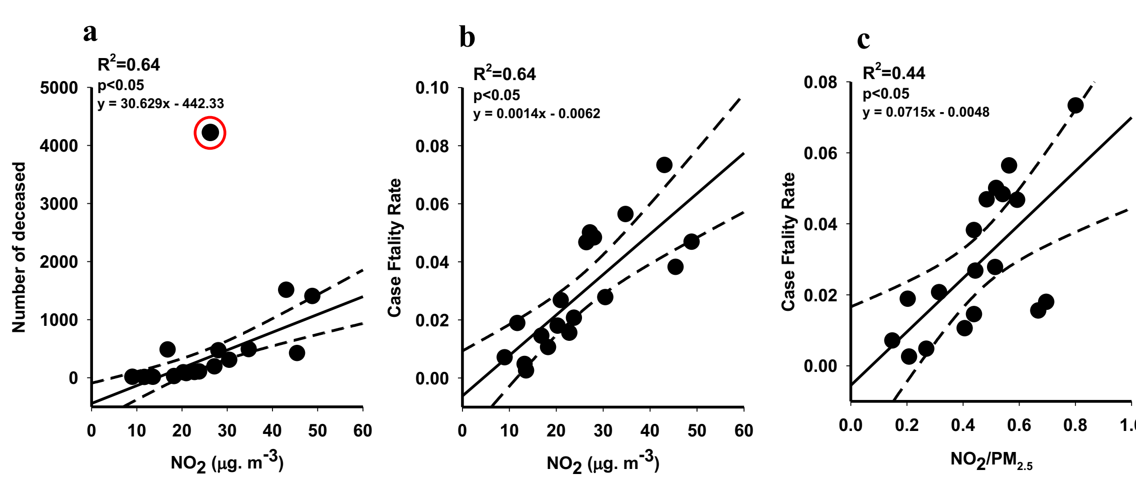

Fig. 2 Relationships between atmospheric NO_2 concentration and the total number of COVID-19 deaths (**a**) and case fatality rate (there is one outlier, marked in red) (**b**); and the relationship between the $NO_2/PM_{2.5}$ ratio and case fatality rate (**c**)

pandemic, which could lead to death. A large portion of NO_2 comes into the atmosphere due to combustion of fossil fuel from vehicles, power plants, and off-road equipment (USEPA 2011a, b). Although it is difficult to pinpoint the origin of atmospheric pollutants in the Indian cities, however, a rational analysis of concentrations of different atmospheric pollutants was carried out to identify the sources of atmospheric NO_2 in the different states of India.

This study found that the annual average concentration of $PM_{2.5}$ and PM_{10} were very highly correlated (r = 0.94, $p < 0.05$), indicating that $PM_{2.5}$ and PM_{10} originated from the same source (Fig. 4a). Chaloulakou et al (2003) also used the concentrations of $PM_{2.5}$ and PM_{10} to identify their sources. The $PM_{2.5}/PM_{10}$ ratios were very similar in the different states of India (as shown in Table SM 9). The aforementioned similar $PM_{2.5}/PM_{10}$ ratio indicates, that the source of the particulate matter (PM_{10} and $PM_{2.5}$) were the same in different states of India. Since the industries or dust storms or other factors cannot be the same in the different states (because India is a large country, and the geographical locations and growth of industrialization in the states are entirely different), it can be inferred that the source of the particulate matter from motor vehicle emissions, which are similar in different states.

This study also showed strong positive correlation (r = 0.72, $p < 0.05$), between atmospheric NO_2, and $PM_{2.5}$ levels (Fig. 4b). This indicates that fossil fuel combustion in transportation (which is the source of $PM_{2.5}$ or PM_{10}) is probably one of the major sources of atmospheric NO_2 in the Indian cities. Hazenkamp-von Arx et al (2004) have also showed a strong relationship between $PM_{2.5}$ and NO_2 in atmosphere, and concluded that both pollutants are from the same source (transportation). Numerous other articles also suggest that transportation is a regular source of NO_2 in Indian cities throughout the year (NACP 2019, Guttikunda et al 2014). Therefore, it was concluded that traffic emissions were probably the major contributors to the atmospheric concentration of NO_2 in the Indian cities.

The national clean air program was initiated in 2019 (NACP 2019). The target of the program is to curb air pollution. This is a wonderful initiative by the Government of India. The NACP aims to reduce $PM_{2.5}$ and PM_{10} air pollution in 102 cities by 20–30% by 2024 compared to 2017 levels. However, it is not correct to expect a huge improvement in the atmosphere in just 1 year of starting the program.

A strong positive correlation (r = 0.74, $p < 0.05$), between the annual fossil fuel consumption for transportation (state wise) (see, Table SM 10) and atmospheric NO_2 concentration (Fig. 4c) in the different states of India further reiterates the above mentioned point that a major part of the atmospheric NO_2 was derived from vehicle emissions. Sheel et al (2010) have shown that fossil fuel consumption in transportation could control atmospheric NO_2 concentration in Indian cities. Therefore, fossil fuel combustion (in transportation) was considered to be the major contributor of atmospheric NO_2 in the Indian cities of this study.

Many residents of urban India are regularly exposed to high concentrations of motor vehicle emissions, and consequently may be among the most vulnerable to suffer complications from COVID-19 coronavirus exposure.

Those who would likely be the most vulnerable are those who spend much of their time near polluted streets in a city. Overall, around 33 million people in India regularly get exposed to poor air (Li et al 2017). Homeless people, a

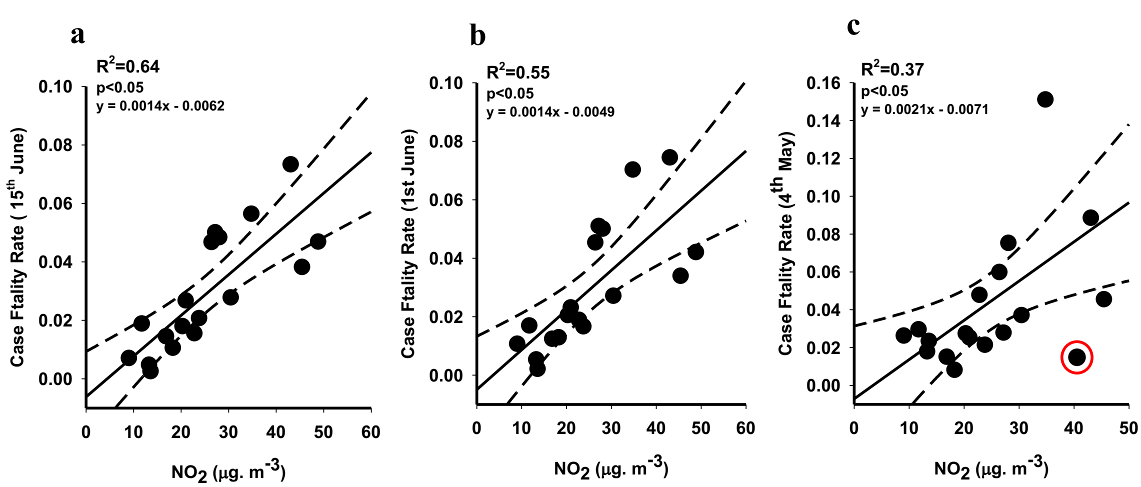

Fig. 3 The variation in CFR on **a** 15th June, **b** 1st June and **c** 4th May with respect to varying atmospheric NO_2 concentration (1 year average) in different 18 states of India (there is one outlier, marked in red). The annual average of this pollutant has been the average of the annual average obtained from all the stations in that state. Data has been collected from 196 stations of 123 cities in 18 states across India (obtained from the Central control room for air quality management- All India)

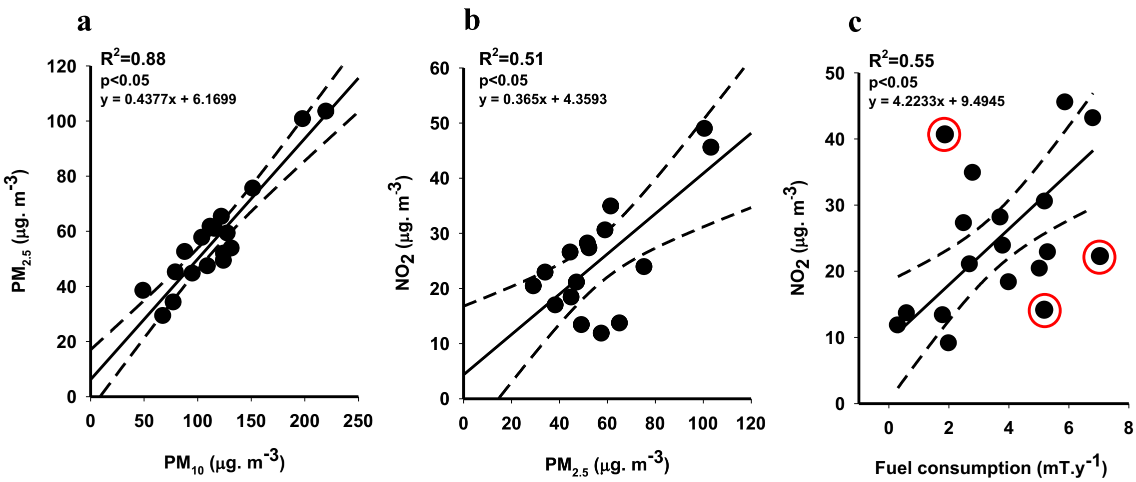

Fig. 4 The variation of average distributions of **a** atmospheric $PM_{2.5}$ with PM_{10}, **b** $PM_{2.5}$ with NO_2, **c** NO_2 with Fuel consumption in 18 states of India is shown (there are outliers, marked in red). The annual average of this pollutant has been the average of the annual average obtained from all the stations in that state. Data has been collected from 196 stations of 123 cities in 18 states across India (obtained from the central control room for air quality management- all India)

part of population living in densely populated slum areas, shanty towers, traffic police, street hawkers, auto-rickshaw drivers, bus drivers, roadside motor mechanics, daily passengers in public transport and, many others who regularly get exposed to vehicular emission could be under threat during this pandemic. Cross-sectional studies of chronic exposure to vehicular pollution to the population in many Indian cities has reported decreased lung function, increased blood pressure, suppressed immunity, and enhanced lung cancer risk (Ray and Lahiri 2010).

There are about 150 million homeless people around the world, and they are constantly exposed to various pollutants, which could also put them in grave danger during the COVID-19 epidemic. Homeless people can spread contagious disease much faster in society. Therefore, immediate necessary action needs to be taken to minimize the health risks of homeless people to control the spreading of COVID-19 pandemic.

This is the first report from this region that sought to understand relationships between the concentrations of different atmospheric pollutants and number of deaths and fatality rate in the COVID-19 pandemic. This study couldn't consider many other important covariates (such as confinement measures, clinical practice, number of conducted tests, the capacity of the healthcare system, population density, population demography (e.g. age structure, ethnicity, etc., and socioeconomic status) due to unavailability of online reliable data. Therefore, further extensive research is recommended to develop a more comprehensive understanding of the myriad factors involved with the COVID-19 pandemic.

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