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Urban Indian Environment in the Context of a Pandemic

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ABSTRACT

The spread of the Coronavirus disease 2019 (COVID-19) has impacted human life severely since November 2019. The urban centers in the world, especially, were highly affected by the diseases. Several socioeconomic and environmental factors probably enhanced the spread of the pandemic and consequent mortality. Many studies examining environmental factors, such as air quality, in urban centers indicate the roles of those factors in the spread of diseases and consequent mortality. However, other socioeconomic factors that directly or indirectly elevate the mass death of people are seldom studied. The present study explores the socioeconomic factors and air quality influencing COVID-19 deaths in urban India. We randomly selected 19 Indian cities and collected each city's socioeconomic and air quality data from reliable and open sources. The data were analyzed using multivariate data analysis techniques using R statistics. The results showed significant positive relationships, population, and total area of the urban centers.

INTRODUCTION

The world has witnessed the intensity of the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-COV-2), also known as COVID-19, since November 2019. So far, the pandemic (declared by the World Health Organization on March 11, 2020) has led to the deaths of more than six million people around the globe (covid19.who.int). The virus is highly versatile and mutating (Balachandran et al. 2022). Its known transmission modes include contact, droplet, airborne, fomite, fecal-oral, bloodborne, mother-to-child, and animal-to-human transmission (www.who.int). The environmental setup is also a crucial factor in determining the spread. Since the Coronavirus attacks the respiratory tract, people exposed to highly polluted air and suffering from respiratory ailments (Subbarao et al. 2020) and people with other comorbidities, heart diseases, lung cancer, etc., are highly vulnerable to COVID-19 infection. People living in urban centers with considerably low air quality are also of prime concern (Conticini et al. 2020, Cao et al. 2020). For example, the highest cases of COVID-19 deaths reported in urban areas in China, South Korea, Iran, and northern Italy were exacerbated by poor air quality (Jiang et al. 2020, Gupta et al. 2021). The spread of the disease in a region is also linked to its geographical location, economy and public awareness. It is also associated with the region's health systems' capacity, readiness and ability to curtail the spread (Kejela 2020). At an individual level, community consciousness, age, and social (in fact, physical distancing) distancing are other significant factors influencing the spread of the disease (Raj & Azeez 2020, Lakshmi & Suresh 2020, Priya et al. 2021).

Regarding the Air Quality Index in 2020, the air quality in world cities, in general, is almost five times above the WHO exposure recommendations (WHO 2021). Six major pollutants, Carbon Monoxide, Lead, Nitrogen Oxide, Ozone, Particulate matter (PM), and Sulphur dioxide, are highly likely to affect a population's short and long-term health. Of the PMs (PM_{10} and $PM_{2.5}$), $PM_{2.5}$ is considered the most lethal; chronic exposure to $PM_{2.5}$ increases the risk of acute respiratory diseases among the older population (Benmarhnia 2020) since that can penetrate the bronchi deeper (www.who.int). As per a recent report by the European Environment Agency, around 0.30 million premature deaths in urban areas of 27 European countries were due to high $PM_{2.5}$. Vehicular emission (25%) followed by agriculture (22%), domestic fuel burning (20%), natural dust and salt (18%), and industrial activities (15%) significantly contribute to PMs (PM_{10}, $PM_{2.5}$, etc.) in cities (Karagulian et al. 2015).

Due to the poor air quality, approximately 1.24 million people lose their lives in India annually (Balakrishnan et al. 2019). It is reported that high pollution levels in the ambient air contribute to respiratory dysfunctions among urban dwellers (Balakrishnan et al. 2014, Venkataraman et al. 2018, Khilnani & Tiwari 2018). In 2019, air pollution accounted for 17.8 % of total mortality in India, of which 5% of deaths were attributed to PM pollution. However, the deaths due to household air pollution decreased from 74.2 million in 1990 to 0.61 million in 2019, around 64.2% of the total death cases (Pandey et al. 2021). In India, it is reported that the primary sector contributing significantly to ambient air quality is the transport sector, which substantially contributes (7-43%) to ambient air PM (Gurjar et al. 2016). Khilnani & Tiwari (2018) reported that the ambient air pollution in the major city centers of the country is showing an alarmingly rising trend.

From different studies carried out by the Central Pollution Control Board (CPCB), it has been found that 46 Indian cities are severely polluted (Nasir et al. 2016). It is widely known that most Indian metro cities are highly polluted, with 14 out of 20 Indian cities examined being shortlisted as among the world's most air-polluted cities (Sikarwar & Rani 2020). As a fast-developing country (fifth-largest economy in terms of nominal GDP), India has an active industrial sector and fossil fuel-based power plants. From 2010 to 2015, it was observed that the emission of CO_2 gas significantly increased in most parts of the country (Girdhar et al. 2021).

Air pollution is one of the significant outcomes of the current economic development model (Aditya et al. 2022). While the developed nations were historically massive emitters, the rapidly growing economies are increasingly contributing to air pollution since high emission level of air-polluting gasses like CO_2 is usual evils in the current economic development model. WHO and OECD reported that Europe's economic cost of premature death and disability from air pollution in 2015 was nearly USD 1.6 trillion (Manjula 2018). The adverse effects of air pollution are diverse, including social and psychological (Chen & Jin 2019, Heissel et al. 2022). Studies have also shown that a 10% rise in $PM_{2.5}$ caused a 2.4% fall in the price of houses in China during 2005-2013 (Sivarethinamohan et al. 2021). Present-day economic developmental models are committed to the financial growth calculated in terms of the Gross Domestic Productivity of a region and that, most times, fail to ensure the socioeconomic welfare of the people, except perhaps by the trickle-down effect. The major cities in developing countries like India are deprived of scientific urban planning and crucial amenities required for overall welfare, face urban chaos, and are highly vulnerable to natural and human-made disasters. Inadequacy of clean drinking water, clean air, green space, hygienic living conditions, hospitals, and other life-sustaining institutions in urban centers increases the vulnerability.

There is an inverse relationship between the quality of air and the COVID-19 mortality rate (Naqvi et al. 2021). For instance, it has been proven that PM can act as a carrier for SARS-COV-2 (Setti et al. 2020, Borisova & Komisarenko 2021, Pivato et al. 2021). The finer ones ($PM_{2.5}$) have a higher potential to spread the virus (Nor et al. 2021). However, such studies have not considered other possible socioeconomic factors influencing the COVID-19 death toll in urban centers. In that context, the present study examines the relationships between various socioeconomic factors and air quality that influenced the COVID-19 death in Indian cities.

MATERIALS AND METHODS

For the present study, we have selected 19 Indian cities based on the data available. These cities were Hyderabad, Visakhapatnam, Surat, Bangalore, Kochi, Bhopal, Indore, Jabalpur, Mumbai, Nagpur, Nashik, Pune, Jaipur, Chennai, Coimbatore, Kolkata, Delhi, Patna and Meerut (Fig. 1). These city centers in the corresponding districts are ascribed to be highly populous areas surrounded by less populated rural or sub-urban settlements. These city centers act as the centers of each district's economic, social, and administrative processes. In this study, the district-level COVID-19 death rate reported till 17 March 2022 was collected from the National Center for Disease Control under the Ministry of Health and Family Welfare, Government of India (https://www.ncdc.gov.in/Mortality/Home.html). We used the district-level data to represent the COVID-19 death cases of the cities since there were no reliable data available exclusively on the city-level COVID-19 death cases. Further, we assumed that the district-level data primarily represent the death cases reported from the urban centers; it is known that in India, rural COVID-19 death cases were not reported during the first wave and seldom reflected during the second wave (Jha et al. 2022).

The air quality data relating to SO_2, NO_2, and PM_{10} for ten years (2008-2019) corresponding to each of those cities was collected from the Indian Institute of Tropical Meteorology (IITM) (https://cpcb.nic.in/annual-report.php). Using the average values of SO_2, NO_2, and PM_{10}, the AQI for each city was calculated using the AQI matrix provided by the Central Pollution Control Board at https://app.cpcbccr.com/ccr_docs/AQI%20-Calculator.xls. The city's socioeconomic data, area, population, population density, per capita income, and the number of hospitals and hospital beds were collected from https://www.indiastat.com/, the annual death rates from https://crsorgi.gov.in/annual-report.html, and the GDP of the cities from https://ca.finance.yahoo.com/photos/the-top-15-indian-cities-by-gdp-1348807591slideshow.html.

Since there are no routine and exhaustive censuses conducted by the Census of India (Government of India) for 2021, we used the population data for the earlier 3 census periods, 1991, 2001, and 2011, and estimated the current population, making use of the growth trend and the well-known equation is given below:

$$PN = P_0(1 + \frac{r}{100})^t$$

Where *PN* is the projected population for the year *t*,

P_0 is the initial population

r is the population growth rate, and *t* is the years.

The growth rate was calculated using the equation

$$r = \{(P_n - P_0/P_0)100\}/N$$

Where *N* is the projected year.

Since there are no updated data on the number of hospitals and the total number of hospital beds available, we used the census data available for the years 2001 and 2011 procured from the office of the registrar general and census commissioner, India https://censusindia.gov.in/census.website/data/census-tables. While comparing the data between 2001 and 2011, we found that for some cities, there was a decrease in the number of hospitals and bed availability; hence, we used the latest census data (i.e. 2011) for the analysis.

Multiple correlation analysis was done to reveal the relationships among the variables. Multiple linear regression analysis was carried out to check the affinity of each variable to the COVID death rate since multiple regression analysis is a widely used simple model to predict an outcome variable (Y) from a group of predictor variables (X_n). In general, multiple regressions can be represented by the following equation:

$$\{Y = B_0 + B_1X_1 + B_2X_2 + \ldots B_nX_n + E\}$$

Where,

Y is the dependent predicted variable.

B_0 is the Y-intercept or value of Y when X values are 0.

B_1, B_2, and B_n are the regression coefficients for X_1, X_2, and X_n, respectively.

E is the residual standard deviation.

We used the R statistical package (Rstudio 2022.07.2) for all the analyses.

RESULTS AND DISCUSSIONS

The per capita income was highest in Surat, followed by Delhi and Mumbai, with the lowest per capita income in Jabalpur. The number of hospitals was highest in Mumbai, followed by Jabalpur, and the lowest number of hospitals in Jaipur. Mumbai has the highest number of hospital beds

Fig. 1: Map of India showing the location of the 19 selected cities for the study.

available, followed by Jabalpur and Kochi, and the lowest was in Meerut. Among the 19 cities, the projected population is highest in Bangalore, followed by Mumbai, Delhi, Surat, Hyderabad, Pune, Jaipur, Chennai, Kolkata, Nagpur, Indore, Nashik, Patna, Visakhapatnam, Bhopal, Meerut, Jabalpur, Coimbatore, and Kochi. According to the population projection, Bangalore surpasses all other cities, including Mumbai and Delhi, due to Bangalore's consistently higher population growth rate, escalated possibly by immigration. The decadal population growth between 1991 and 2011 in Bangalore is more than five million. The immigration of highly skilled workers due to employment opportunities in the ICT sector, in the city, growing at an incredible pace (Narayana 2011) the "livability" of the city, mainly infrastructure amenities, climate, etc., could be the other factors for the population growth in Bangalore. It is important to note that, as suggested by the projection, the tier-2 cities in India, like Surat, Pune, and Jaipur, surpass the tier-1 cities, such as Chennai and Kolkata, in population. Sikarwar (2020) studied the population trend in Kolkata city and found that after 1971, the city's population showed a trend that, after 2001, slanted toward negative growth.

Moreover, cities like Bangalore (Ramachandra 2018) and Hyderabad (Das 2015) showed significant spatial growth during the last decade after the census in 2011. Among the cities, the GDP of Mumbai is the highest, followed by Delhi, Kolkata, and Bangalore. Jabalpur has the lowest GDP level among the cities.

The correlation analysis shows that all variables except the number of hospital beds positively correlate to the COVID-19 death rate in cities. GDP, population, the average death rate of the cities, and the concentration of NO_2 levels in the air are significantly correlated with the death rates. Although the number of hospital beds negatively correlated with the death rate, it is insignificant; very rational in that higher bed availability, a capital stock (Ravaghi et al 2020), and reflected better access to inpatient health care. Similarly, the SO_2, PM_{10}, Air Quality Index, per capita income, number of hospitals, urban area, and population density are positively correlated with the COVID-19 death rate of the cities but do not show any significant trend (Table 1).

The multiple regression analysis results between the COVID-19 death rate in the city with the other variables, NO_2, SO_2, PM_{10}, GDP, population, and normal death, of the cities indicated a positive impact. In contrast, AQI, income per capita, number of hospitals, number of hospital beds, area of the city, and the population density of the city show a negative relationship with the death rate. Of this, notably, only the population and area of the city have a significant level of predictability on the COVID-19 death in the city. From the model, COVID-19 deaths in the city can be estimated by the formula:

COVID death = 5.8×103 + 0.0016 × Population − 21.9 × Area, and the model is significant (Adjusted R-squared: 0.7126: p-value of F-statistic: 0.03; Table 2).

There is a significant positive correlation between the COVID-19 death rate and the population (r= 0.68; p=0.0564). Among the selected cities, COVID-19 death was reported highest in Delhi, followed by Pune, Mumbai, and Bangalore, all densely populated megacities in India. The lowest number of personal losses due to COVID-19 was reported in Jabalpur. According to some studies, COVID-19 death cases were higher in cities with denser populations in Algeria (Kadi & Khelfaoui 2020). It has to be noted that in highly populated cities such as Kolkata, Chennai, Surat, and Hyderabad, the reported cases are fewer, which might be due to imprecise statistics or deliberate under-reporting by the authorities to reduce the instances (Jha et al. 2022, Anand et al. 2021, Lancet 2020). It is also reported that there is a lack of reporting the COVID-19 death cases in the older age group in India (Lewnard et al. 2022).

While checking for the significant correlation between the population and other variables, it is found that only two variables that relate to the city's economic status, the GDP and per capita income, are significantly and positively correlated with the population. In India, it is documented that the rural-to-urban mass migration for employment in the non-agriculture sector has increased many folds during the post-globalization of the Indian market economy (Siggel 2010). The city's urban centers offer many opportunities for people from the rural agricultural sector. Due to many factors, including higher input costs, insufficient returns, and an inadequate labor force, the rural agriculture sector has become unprofitable. The immigration of the poor rural labor eventually increased city centers' GDP and per capita income. Among the selected cities, the country's commercial capital, Mumbai, scores the highest GDP, followed by Delhi and Kolkata, and the GDP of Jabalpur is the lowest.

Similarly, the per capita income of Jabalpur is the lowest among the studied cities; Surat has the highest per capita income among these cities. It is reported that there is a direct connection between the availability of transportation networks with COVID-19 spread (Zhu & Guo 2021). The air transportation networks significantly increased epidemics' spread in general (Colizza et al. 2006). In the case of COVID, due to global and local air travel, cities with higher GDP have a chance of higher spread since it is there that global investment and consequent travelers would be high, as reflected by the initial spread in cities like Mumbai and Delhi.

Table 1: Correlation matrix of the variables (Pearson correlation coefficients - r).

	CD	NO	SO	PM	AQI	IC	GDP	NH	NB	P	ND	AR	DEN
CD	1.00												
NO	0.53*	1.00											
SO	0.26	0.22	1.00										
PM	0.26	0.57*	-0.20	1.00									
AQI	0.27	0.59*	-0.17	1.00	1.00								
IC	0.30	0.16	0.30	0.06	0.08	1.00							
GDP	0.78*	0.43	-0.05	0.35	0.35	0.35	1.00						
NH	0.28	0.01	-0.11	-0.01	0.02	0.14	0.60	1.00					
NB	-0.02	-0.25	-0.25	-0.23	-0.21	0.05	0.25	0.77*	1.00				
P	0.68*	0.30	0.02	0.34	0.36	0.63*	0.75*	0.46	0.19	1.00			
ND	0.83*	0.45	-0.01	0.37	0.36	0.39	0.88*	0.31	0.04	0.79*	1.00		
AR	0.45	0.20	-0.03	0.13	0.16	0.34	0.51	0.35	0.17	0.77*	0.59*	1.00	
DEN	0.33	0.25	0.17	0.38	0.39	0.62*	0.43	0.15	-0.04	0.57*	0.47	0.04	1.00

CD: COVID deaths, NO = NO_2, SO = SO_2, PM = PM_{10}, AQI = Air Quality Index, IC = Percapita income, GDP = GDP of the city, NH = Number of Hospitals, NB = Number of Hospital Beds, P = Total Population, ND = Annual death in number, AR = Urban area, and DEN = Population density.

The highly populated cities in India are the country's economic hubs and industrial centers. Emissions, vehicular, and power generation are also higher in megacities due to higher per capita vehicle availability and higher energy consumption by diverse sectors. Further, household carbon emission is also a crucial issue in India (Beig et al. 2021). All these activities are closely related to air quality, and exposure to highly polluted air is one of the primary reasons of chronic respiratory illness of people, which is a potential factor significantly hiking the chances of death in COVID-affected individuals (Schraufnagel et al. 2019).

Especially since people suffering from other respiratory diseases exposed to air pollution are considered highly vulnerable to COVID-19 death due to comorbidities (Naqvi et al. 2021). Metro cities such as Delhi, Kolkata, and Mumbai are considered the most polluted areas in the world regarding air pollutants (Guttikunda & Nishadh 2022, Guttikunda et al. 2014). As per the recent report by IQAir (https://www.iqair.com/), based on the average annual PM_{10} concentration, Delhi stands fourth most highly polluted city in the world, followed by Meerut, Patna, Kolkata, Jaipur, Mumbai, Indore, Visakhapatnam, Bhopal, Jabalpur, Pune, Nashik, Hyderabad, Bengaluru, Chennai, and Kochi. However, IQAir does not document the air quality for Surat, Coimbatore, and Nagpur.

A significant positive relationship between AQI and COVID-19 death has been reported by various researchers globally (Wu et al. 2020, Zhu et al. 2020, Conticini et al. 2020). A significant correlation is seen between industrial pollutants like $PM_{2.5}$ and COVID-19 deaths in metropolitan and industrial cities in India, as Travaglio et al. (2020) observed. While examining the disability-adjusted life years (DALYs) of the people living in Delhi and Mumbai in 2015, Maji et al. (2017b) found that for the low AQI, the mortality rate increased more than double the mortality observed during 1995 for both the cities. Kolluru et al. (2022) examined the significant relationship between air quality and the COVID spread during the second wave in Delhi. The present study also demonstrates a positive relationship between COVID-19 death and the AQI of cities, but it is not statistically significant. However, there is a significant correlation between the concentration of NO_2 in the urban air and COVID-19 death. The insignificance of AQI's relation with death might be due to the insignificance of the other variables, SO_2 and $PM_{10,}$ in determining the AQI of the city, possibly for the inaccuracy in the measurement of the parameters available in these official data sets.

Studies have already proved that prolonged exposure to high concentrations of NO_2 in the atmosphere can lead to other ailments (Ogen 2020), such as hypertension, diabetes (Shin et al. 2020), and other ischemic heart diseases (Qiu et al. 2013). A significant positive correlation between the average annual death rate and the COVID-19 death rate was observed in the present study. It is reported that 12.5% of India's average normal death rate is due to diseases associated with high exposure to poor air quality (Guttikunda & Goel 2013). Further, Maji et al. (2017a) concluded that poor air quality directly influences the annual mortality rate in Delhi alone. As mentioned earlier, it is reported that people exposed to poor AQI are highly vulnerable to mortality due to COVID-19 (Naqvi et al. 2021). Further, the present results indicate that the country still lacks monitoring infrastructure and high-resolution pollution concentration maps relating

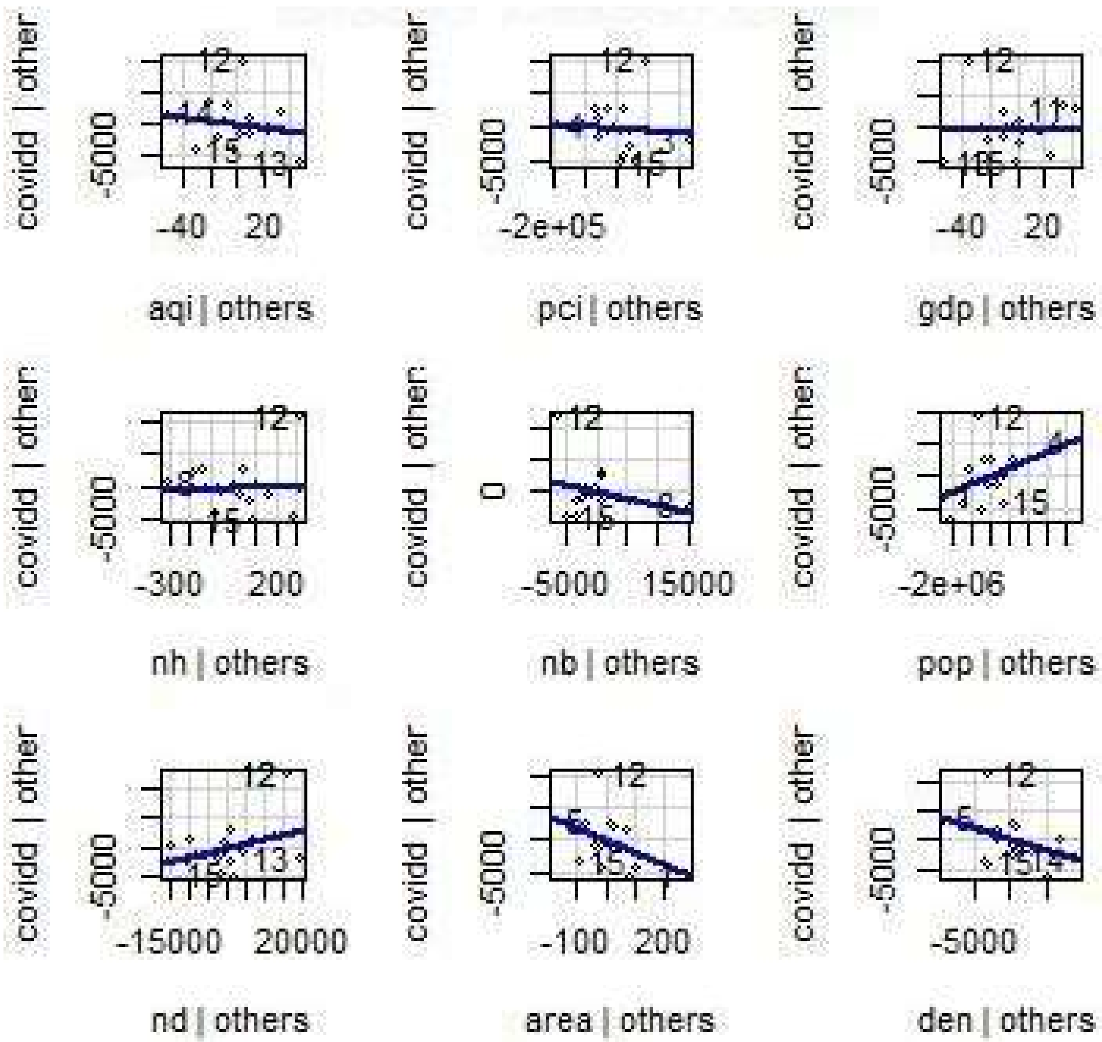

Fig. 2. Added variable plot for potential drivers for COVID death in urban India. AQI, per capita income, number of hospitals, number of hospital beds, the total area of the city, and population density showcase a negative relationship. Population and average annual death show a positive relationship, whereas per capita income, GDP, and the number of hospitals are almost neutral in association with COVID-19 deaths.

to urban India's real-time air quality assessment (Agrawal et al. 2021).

It must be noted that all megacities are at the top of the list while checking the number of hospitals and hospital beds in the cities. However, when it comes to the per capita availability of hospital facilities, cities including megacities, is very low. It has been found that the average death rate before the COVID-19 scenario shows no significant correlation between the per capita availability of hospital facilities and the annual death rate among the cities.

This again shows that the number of hospital facilities needs to be improved for the population. The number of hospital beds per the census data includes private and public hospitals; in India, it is clear that for most of the population, accessing private facilities is still a financial concern (Duggal 2007). Recent studies on the Indian healthcare system in the wake of the COVID-19 pandemic also reveal the fact that the privatization of medical facilities has become a financial, geographical, administrative, and logistic burden for the middle and low-income groups, the majority of the population in the country (Bhaduri 2020). The government's role has been highly restricted to financial aid for private parties (Chandwani 2021), while the government promotes the privatization of even such essential facilities.

It is worth noting that the present study does not testify to the inverse relationship between AQI and COVID-19 death, as reported by many others mentioned in the text. We presume this may be due to a shortage of data with adequate

Table 2: Multiple regression analysis results.

Parameter	Estimate	Std.Error	t value	Pr(>|t|)
(Intercept)	5.89E+03	1.04E+04	0.569	0.5902
NO_2	1.07E+02	1.00E+02	1.068	0.3264
SO_2	3.69E+02	2.13E+02	1.733	0.1338
PM_{10}	3.80E+01	2.99E+02	0.127	0.9028
AQI	-8.65E+01	4.09E+02	-0.211	0.8395
Income per capita	-1.24E-02	1.10E-02	-1.122	0.3049
GDP	6.18E+00	3.91E+01	0.158	0.8795
Hospital	-1.31E+00	5.32E+00	-0.247	0.8134
Hospital beds	-1.22E-02	2.22E-01	-0.055	0.9579
Population	1.59E-03	6.73E-04	2.359	*0.0564
Normal death	1.23E-01	1.06E-01	1.155	0.292
Area	-2.19E+01	9.85E+00	-2.222	*0.068
Density	-4.17E-01	2.20E-01	-1.899	0.1063

Significance codes: '*' 0.1
Multiple R-squared: 0.9042, Adjusted R-squared: 0.7126
F-statistic: 4.719 on 12 and 6 DF, p-value: 0.03406

precision and the sampling points not being statistically representative. The Added variable plot (Fig. 2) between drivers and COVID-19 deaths in urban India also indicates the absence of precise data. For example, as per Fig. 2, COVID-19 death is negatively influenced by the AQI of the respective cities, which is unreasonable according to the general understanding (Naqvi et al. 2021). Similarly, the negative relationship between the city's population density and COVID-19 deaths, as shown in the plot, is illogical since the disease spread is likely to be enhanced by physical closeness among the people (Kadi & Khelfaoui 2020). As mentioned earlier, data reliability is one of the major lacunae in countries like India, which is one of the major limitations of this type of study. It may be noted that the Death and Birth Registration Authority accepts the inadequacy of reliable data on mortality in India (Basu & Adair 2021).

CONCLUSION

Several studies from various parts of the globe documented the regional AQI in urban city centers and its influence in spreading the COVID-19 epidemic. However, we hypothesized that several more underlying socioeconomic factors influence the spread of COVID-19. The present study evaluates COVID-19 in urban India by examining the socioeconomic factors and the AQI of 19 randomly selected urban centers. Our results showcased that the COVID death positively correlates with AQI, population, population density, the average annual death rate in the city, the total area of the urban centers, income per capita, and GDP; and the correlation is significant for GDP, population and average annual death rate of the city. It is also found that among the factors determining the AQI, the concentration of NO_x is significantly correlated with COVID-19 death. COVID-19 death in cities is negatively correlated with the number of hospital beds in the city. The multiple regression analysis among the selected variables also showed significant positive relationships between COVID-19 death and the population and the total urban area in the city. The study also concluded that the lack of reliable data is a major lacuna while examining the crucial drivers of COVID-19 death in urban India.

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