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Factors affecting COVID-19 infection and deaths in the million-plus cities of India

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Abstract

Big cities are highly complex spatial units and have diverse subpopulations and neighborhoods with different sociocultural needs and vulnerable groups concerning public health emergencies, such as COVID-19. When these cities face an epidemic that spreads rapidly within the urban community, then human density and the urban setting have proven to be a tremendous liability and a matter of concern. The present study in this context is a preliminary attempt to understand the COVID-19 pandemic in the Indian context. The paper presents a city-level study of 46 million-plus cities in India to identify major determining factors (demographic, economic, environmental, infrastructural, and institutional interventions) of the COVID-19 infection and related deaths in different lockdown and unlock phases. Using the multiple regression model we found that the impact of these factors does significantly explains the variation in the COVID-19 infections and related deaths. However, the role of individual indicators does seem to have a differential impact across phases of the lockdown strategy. Indicators, such as GDP, hospital-doctor ratio, public transport usage, and administrative status of the city have been found to be the most significant factors influencing COVID-19 cases and deaths. On the other hand, co-morbidities do not appear as consistent significant factors, while the much-debated density parameter plays an insignificant role in the Indian big cities. We would like to emphasize that the results are at best indicative in nature, and for an in-depth understanding of each of these factors and spatial complexity, we require further detailed analysis at a more disaggregated level.

Keywords: *COVID-19, million-plus cities, India, lockdown, regression models*

Introduction

Big cities are highly complex spatial units and are not only dependent on each other (regionally and globally) but are also tied with the neighboring small towns and rural areas. Moreover, these urban areas have diverse subpopulations and neighborhoods with different socio-cultural needs and vulnerable groups concerning public health emergencies, such as COVID-19. When these cities face an epidemic that spreads rapidly within the urban community, then human density and the urban setting have proven to be a tremendous liability and a matter of concern. In developing countries like India with inherent diversity and stark disparity, a crisis such as COVID-19 highlights vulnerabilities of the cities which are intricately tied with the space-blind and uniform policies.

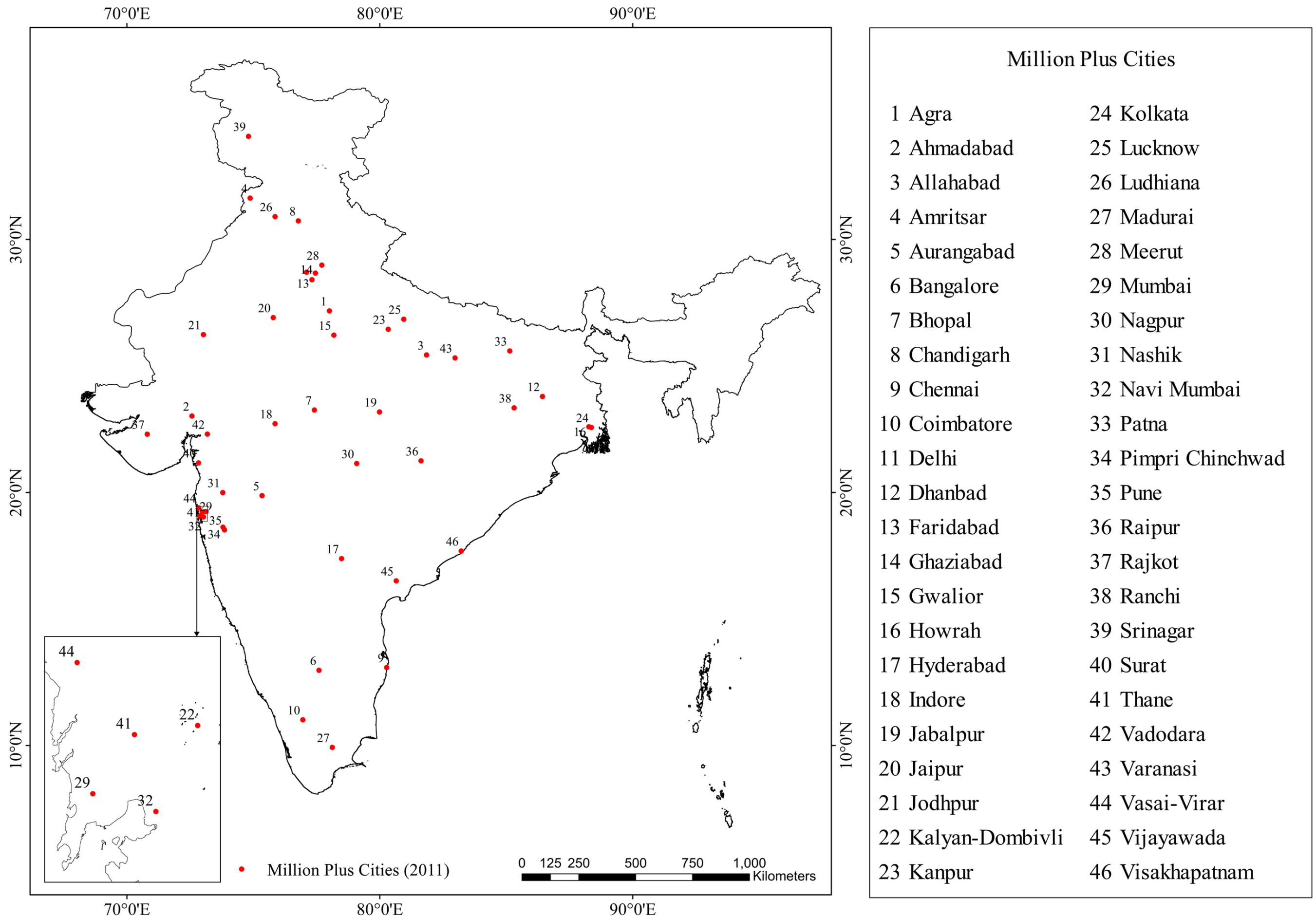
The urban risk from extreme events is affected by the location, density, scale, and connectivity. For example, location and scale (the positioning and city size) have linear effects, primarily affecting the population and the availability of resources. On the other hand, density and connectivity often have nonlinear impacts, both positive and negative. In addition, the urban risk is also affected by the feedback effects of interaction between the urbanization process and climate change (Siri et al., 2015). At this point, the vector and velocity of modern transport networks would play a key role in turning the epidemic into a pandemic. And in the case of COVID-19, it has been proven to be true. For example, a recent study by Yadav and Bhattacharjee (2020) has noted the impact of urbanization and connectivity on COVID-19 spread in India for the initial phases of the lockdown. The urban vulnerability may arise for many extreme events, and many times the factors that make cities attractive are also the ones that increase the risk. Cities are primarily high-density zones with heavy resource dependence and often resulting in their depletion. Land-use change is often witnessed in and around the cities. Hence, they are especially vulnerable to extreme events and often play major roles in aggravating the intensity of such events. Evidences suggest that civilizations (and, indeed, cities) that generate unsustainable demand are vulnerable to rapid collapse.

If we track the spatial trajectory of the ongoing pandemic, almost 90 percent of COVID-19 cases are found in urban areas and the consequent impact is most damaging in cities. In an urban setting where risks of transmission and its multidimensional impacts, such as social, physical, and economic are much higher (primarily due to a greater concentration of people and activities as well as better linkages with other regions), data and investigation are crucial for early outbreak detection and response (testing, diagnosis, isolation, contact tracing, and quarantine) to contain the transmission of the virus (UN, 2020). In this backdrop, it is important to understand the nuances of contagion from spatial-temporal perspectives. The current paper is a preliminary attempt in this direction to identify the factors affecting the transmission of this virus and the resultant deaths with regard to the million-plus cities in India.

Theoretical context and purpose

Multiple combinations of risk factors have been hypothesized to have an impact on COVID-19 cases and deaths. Yet not many studies have analyzed the potential confounding effects of these factors (Priyadarsini and Suresh, 2020). The present study with the help of multivariate analysis attempts to identify the factors affecting COVID-19 cases and death in the 46 million-plus cities of India (Figure 1) that have become the epicenters of the pandemic.

The choice of the variables hypothesized as significant factors in the spread of COVID-19 has been guided by studies that have tried to portray the relationship of certain variables with COVID-19 infection and related death rates. For example, several studies have focused on the impact of density on COVID-19 infection and mortality rates (Arif and Sengupta, 2020; Hamidi, et al., 2020; Henderson, 2020; Rocklöv and Sjödin, 2020; Shoichet and Jones, 2020). Hughes (2020) has noted that the metropolitan region with a higher number of counties linked with one another has become more vulnerable to the pandemic. This is further supported by Papandreou (2020) who pointed out that the connectivity factors have a direct effect on the transmission of the pandemic in a



Source: Prepared by Authors

Fig. 1: Million plus cities in India

local-global-local transportation pattern. Also, the role of public transport has been emphasized, drawing from a cluster case in Hunan (S. Chen, 2020; Meinsenzahi, 2020).

Certain economic aspects have also affected the infection and death rate. For instance, a significant positive association between GDP at the prefectural level and confirmed cases has been identified in selected provinces of China by Zhang et al. (2020). Moreover, a positive association between the poverty level and COVID-19 cases is also traceable in some studies (Finch & Finch, 2020). Apart from economic aspects, infrastructural aspects like rigorous testing for COVID-19 (advocated for pandemic control) have been found to possess a positive association with confirmed cases and consequently the recovery rate (Engelberg, 2020; Beaubian, 2020). However, it has also been noted that the testing rates vary significantly across space. For instance, according to Monnat and Cheng (2020), testing rates are lower in areas with more black and poor residents in the United States. This inevitably draws attention to certain social indicators. Low levels of literacy have been found to pose a substantial barrier in checking the spread of COVID-19 (Lopes and McKay, 2020; Frieden, 2020; Paakkari and Okan, 2020). Another important aspect pertains to health facilities, particularly the strength of the hospital staff. However, given the proliferating number of cases, health infrastructure has become burdened, and hence a distinct relationship between them is far from being acknowledged (Agarwal, 2020; Sebastian, 2020; Cavallo et al., 2020; Singh et al., 2020). Moreover, institutional factors such as government effectiveness and the extent to which ruling parties are well established have also explained variations in COVID-19 transmission rates (Maor & Howlett, 2020).

Studies have also focused on environmental factors mainly because of “flu” like symptoms and have revealed higher epidemic rates of COVID-19 with lower average temperature (Alvarez-Ramirez and Meraz, 2020; Ficetola and Rubolini, 2020; Pirouz et al., 2020). Moreover, a positive association between atmospheric pollution levels and a high level of COVID-19 lethality has been noted, since high pollutant levels render the population more vulnerable to respiratory diseases (Conticini, et al., 2020; Setti, et al., 2020). In fact, the discourse on incumbent respiratory disorders and COVID-19 necessarily brings into context an in-depth study of how vulnerable groups are affected by COVID-19. WHO (2020) has identified vulnerable groups in urban areas that include the elderly population and persons with underlying medical conditions and several studies have also reflected a positive association between underlying medical conditions like chronic kidney disease, obesity, cardiac issues, diabetes mellitus to the COVID-19 infection rate and deaths (BMJ, 2020; Centre for Disease Control and Prevention, 2020). In this backdrop, the present study provides a holistic viewpoint to capture the causality of the multiple set of factors to COVID-19 cases and deaths in Indian cities.

Database and Methodology

To better understand the causal factors, a multivariate regression model is used. To deal with heteroscedasticity, we have used robust standard errors (see Yadav, 2020 for details). At the initial stage of the study, 22 indicators were selected, but due to the multicollinearity, three indicators namely, the share of the elderly population, the share of obese/overweight population, and the presence of international airport have been dropped. Finally, 19 indicators have been used in the model as outlined in Figure 2, along with the data sources. The dependent variables namely, COVID-19 cumulative cases and deaths reported in the cities have been collated from the public data platform-howindialives.com.

Regression was run on the share of cumulative COVID-19 cases and deaths for the starting date of each of the four lockdowns and five phases. The government has announced nationwide lockdown phases and the same are mentioned below:

- Lockdown Phase I-25th March-14th April 2020
- Lockdown Phase II-15th April-3rd May 2020
- Lockdown Phase III-4th May-17th May 2020
- Lockdown Phase IV-18th May-30th May 2020

These are followed by five unlock phases as given below:

- Unlock phase I-1st June-30th June 2020
- Unlock phase II-1st July-31st July 2020
- Unlock phase III-1st August-31st August 2020
- Unlock phase IV-1st September-30th September 2020
- Unlock phase V-1st October-30th October 2020

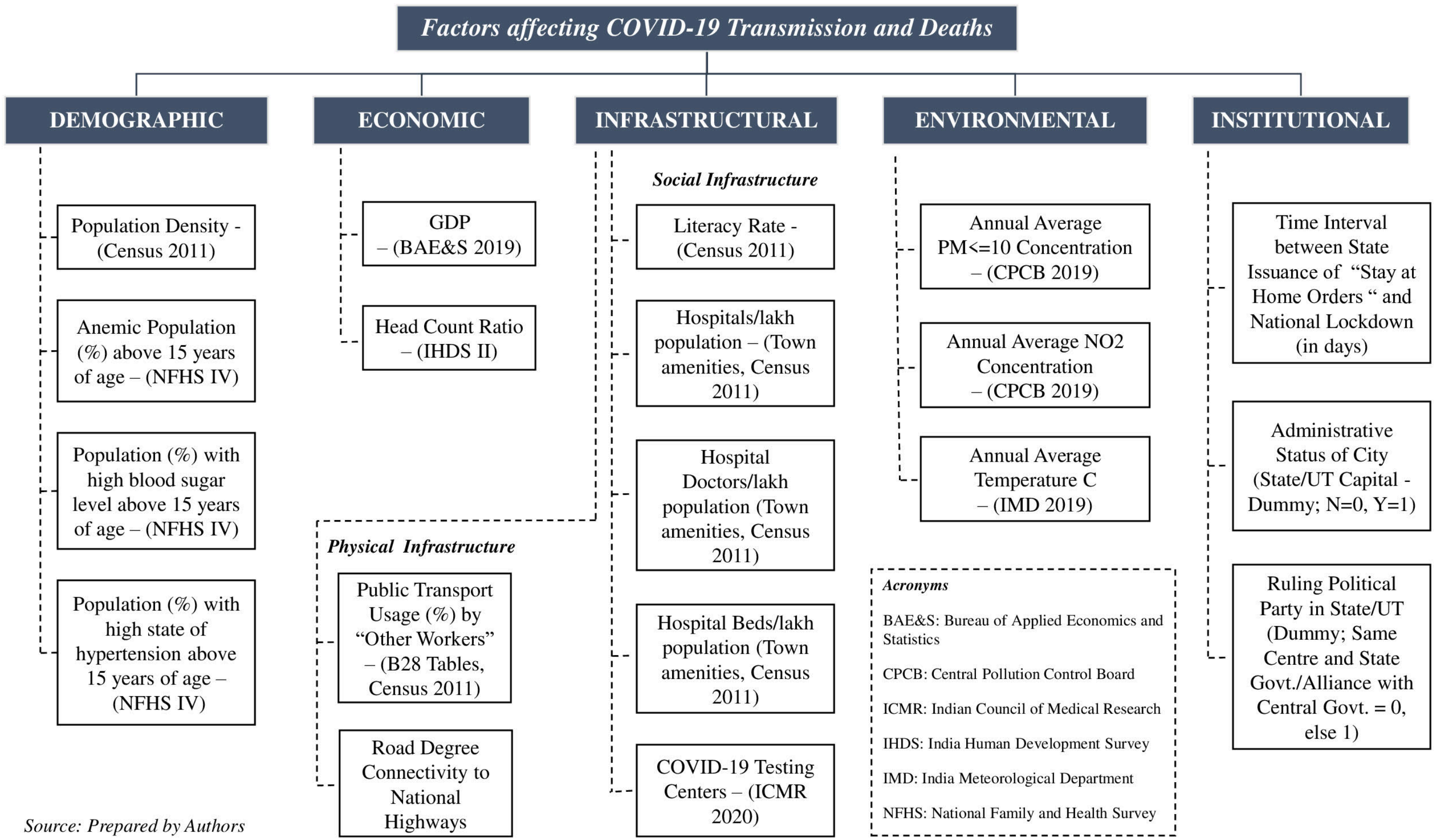
Analysis and Discussion

Results of the multivariate regression models (Tables 1 to 4) have reflected revealed that the set of multiple factors, such as demographic, economic, infrastructural, institutional, and environmental, explains about 75 percent to around 91 percent of the variation in COVID-19 cumulative cases reported in the 46 cities of India while it explains nearly 68 percent to 91 percent of the variation in the share of the reported cumulative deaths across the different lockdown and unlocks phases considered in the paper. The analysis is divided into sections-I and II presenting regression results of COVID-19 cases and related deaths respectively and is confined to the indicators that are statistically significant in explaining each of them. Population density, the share of the anemic population, road connectivity to National Highways, literacy rates, hospitals per lakh population, and ruling political party are the indicators that are statistically insignificant for explaining cases and deaths in different phases.

Section I: Factors affecting COVID-19 infection in million-plus cities in India:

The share of cases is significantly affected by the economic size of the city and is positively associated (Table 1 and 2). This is directly related to the fact that big cities act as economic giants with agglomeration effects and transport hubs that encourage higher flows and the associated risk of the virus spread. In line with a similar argument, we hypothesized that cities that are administrative capitals will report more infection. Results have lent support to this with a significant positive association for lockdown phase 1.0 and unlock phase 3.0, 4.0, and 5.0.

Social infrastructure indicators, such as hospital beds per lakh population have significantly affected the cases at the onset of lockdown 3.0 and 4.0. This could primarily be because the rapid increase in the number of cases resulted in immense pressure on the already skewed public health infrastructure resources. In fact, at the onset of lockdown 3.0 and unlock phase 3.0, 4.0,



Source: Prepared by Authors

Fig. 2: Factors affecting COVID-19 Transmission and Deaths

Table 1: Factors affecting COVID-19 transmission in Lockdown Phases - Multivariate Regression

Variables	25th March		15th April		4th May		19th May	
Share of Cases (Dependent Variable)	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Population Density in persons per sq. km	0.00	1.04	0.00	0.59	0.00	0.48	0.00	0.57
Share of anaemic population above 15 years	0.00	-0.01	-0.01	-0.19	0.03	0.42	0.03	0.58
Share of population above 15 years with high blood sugar level	-0.01	-0.11	0.12	0.74	0.19	0.84	-0.05	-0.27
Share of population above 15 years with high state of hypertension	0.22	0.45	1.43	1.86	1.38	1.7	1.42	1.86
GDP (Rs. Crore)	0.00	3.44*	0.00	4.35*	0.00	3.62*	0.00	4.16*
HC Ratio	-0.01	-1.08	0.02	0.79	0.00	-0.18	0.00	0.17
Literacy Rate	-0.02	-0.64	-0.03	-0.44	-0.01	-0.09	0.05	0.72
Hospitals per lakh population	0.02	0.19	-0.03	-0.24	0.14	0.91	0.17	1.5
Hospital Beds per lakh population	0.00	1.03	0.00	0.7	0.01	2.74*	0.00	2.6*
Hospital Doctors per lakh population	-0.02	-1.96	-0.01	-0.95	-0.04	-2.05*	-0.03	-1.75
Public Transport Usage by Other Worker (%)	0.01	0.51	0.03	0.69	0.03	0.67	0.08	2.21*
Road Connectivity to National Highways	0.35	1.48	0.10	0.3	0.18	0.47	-0.07	-0.2
Average Temperature (in C)	0.02	0.39	-0.17	-1.47	-0.24	-1.91	-0.16	-1.79
Annual average PM<= 10 conc.	0.00	-0.06	0.01	1.56	0.01	1.19	0.02	1.66
Annual average NO2 conc.	0.00	-0.19	-0.05	-1.43	-0.06	-1.16	-0.05	-1.37
Time interval (in days)	-0.07	-1.35	-0.11	-1.12	-0.22	-1.94	-0.18	-2.02*
Administrative Status of City	1.74	2.74*	2.01	1.98	2.72	1.81	2.02	1.71
Ruling Political Party in State	0.03	0.08	0.27	0.36	0.41	0.44	0.21	0.28
Number of Testing Centres	-0.65	-1.29	-1.14	-1.67	-1.53	-1.61	-0.85	-1.08
_cons	0.58	0.14	3.70	0.46	2.78	0.29	-3.39	-0.47
	R^2 = 0.74		**R^2 = 0.80**		**R^2 = 0.75**		**R^2 = 0.80**	

*statistically significant at 5 percent; Coef. = Coefficients — Source: Based on Authors' calculations

and 5.0, the association between hospital doctor ratio and the COVID-19 cases has emerged significantly with negative relation indicating that cases surged up tremendously owing to fewer resources in terms of health care professionals and the existing huge gap between the demand and supply of the medical staff.

If we look at the transport aspect and its role in the spread of the contagion, it is interesting to note that with the start of the lockdown phase 4.0 and unlock phase 1.0, 2.0, and 3.0, usage of public transport by "other" workers category[1] has emerged significantly with a positive association. The share of public transport usage is

1 Census of India (2011) provides data for the mode of travel to the top workplace by only "Other Workers" category i.e. other than cultivators, agricultural labourers and household industry workers. The defense forces and similar paramilitary personnel are not included. If the person was engaged in more than one economic activity during the last year, travel to the main economic activity is considered.

Table 2: Factors affecting COVID-19 transmission in Unlock Phases-Multivariate Regression Results

Variables	**1st June**		**1st July**		**1st August**		**1st September**		**1st October**	
Share of Cases (Dependent Variable)	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Population Density in persons per sq. km	0.00	0.63	0.00	1.23	0.00	1.69	0.00	1.58	0.00	1.38
Share of anaemic population above 15 years	0.05	0.69	0.00	0.05	-0.01	-0.25	0.00	0.03	0.00	0.15
Share of population above 15 years with high blood sugar level	-0.17	-0.68	-0.47	-2.19*	-0.33	-2.74*	-0.20	-2.38*	-0.15	-2.11*
Share of population above 15 years with high state of hypertension	1.38	1.51	1.63	1.66	0.42	0.80	0.06	0.16	-0.06	-0.19
GDP (Rs. Crore)	0.00	3.52*	0.00	8.97*	0.00	6.62*	0.00	4.92*	0.00	4.84*
HC Ratio	-0.01	-0.20	0.01	0.43	-0.02	-1.61	-0.02	-2.22*	-0.02	-2.12*
Literacy Rate	0.07	0.93	0.10	1.42	0.02	0.52	0.00	0.04	0.00	0.00
Hospitals per lakh population	0.25	1.91	0.14	1.77	0.09	1.53	0.05	0.82	0.05	0.83
Hospital Beds per lakh population	0.00	0.97	0.00	-0.66	0.00	-0.74	0.00	-0.86	0.00	-1.30
Hospital Doctors per lakh population	-0.03	-1.49	0.00	-0.02	-0.01	-2.31*	-0.02	-3.51*	-0.01	-3.61*
PublicTransport Usage by Other Worker(%)	0.13	2.70*	0.13	3.61*	0.06	2.64*	0.02	0.94	0.00	0.07
Road Connectivity to National Highways	-0.10	-0.23	-0.45	-1.16	0.00	-0.02	0.13	0.83	0.19	1.41
Average Temperature (in C)	-0.15	-1.50	-0.04	-0.61	-0.01	-0.37	-0.02	-0.66	-0.03	-1.13
Annual average PM<= 10 conc.	0.02	1.49	0.01	1.55	-0.01	-1.43	-0.01	-2.61*	-0.01	-2.93*
Annual average NO2 conc.	-0.06	-1.30	-0.03	-1.54	0.02	1.48	0.02	2.30*	0.02	2.56*
Time interval (in days)	-0.23	-2.15*	-0.07	-1.24	-0.08	-2.10*	-0.07	-2.24*	-0.06	-2.24*
Administrative Status of City	2.38	1.61	1.06	1.42	1.05	2.36*	0.83	2.84*	0.67	2.77*
Ruling Political Party in State	0.44	0.46	-0.19	-0.24	-0.10	-0.21	-0.04	-0.13	-0.01	-0.03
Number of Testing Centres	-0.82	-0.86	0.11	0.17	0.02	0.05	0.09	0.40	0.11	0.57
_cons	-5.87	-0.70	-8.56	-1.43	-0.30	-0.07	1.90	0.53	2.22	0.69
	R^2 = 0.79		**R^2 = 0.88**		**R^2 = 0.91**		**R^2 = 0.89**		**R^2 = 0.89**	

*statistically significant at 5 percent; Coef. = Coefficients

Source: Based on Authors' calculations

Table 3: Factors affecting COVID-19 deaths in Lockdown Phases - Multivariate Regression Results

Variables	**15th April**		**4th May**		**19th May**	
Share of Deaths (Dependent Variable)	Coef.	t stat	Coef.	t stat	Coef.	t stat
Population Density in persons per sq. km	0.00	0.15	0.00	-0.20	0.00	-0.26
Share of anaemic population above 15 years	0.12	0.55	0.05	0.54	0.07	0.81
Share of population above 15 years with high blood sugar level	0.83	1.26	0.52	1.73	0.60	2.18*
Share of population above 15 years with high state of hypertension	2.84	1.16	1.33	1.21	0.99	1.03
GDP (Rs. Crore)	0.00	2.86*	0.00	2.74*	0.00	2.71*
HC Ratio	-0.08	-1.11	-0.03	-0.75	-0.01	-0.36
Literacy Rate	-0.15	-0.72	-0.03	-0.30	0.01	0.10
Hospitals per lakh population	0.40	0.95	0.19	0.99	0.23	1.31
Hospital Beds per lakh population	0.02	3.39*	0.02	4.73*	0.01	4.96*
Hospital Doctors per lakh population	-0.17	-3.03*	-0.07	-2.99*	-0.06	-2.87*
Public Transport Usage by Other Workers(%)	-0.04	-0.29	0.01	0.15	0.03	0.69
Road Connectivity to National Highways	1.55	1.47	0.54	1.10	0.39	0.89
Average Temperature (in C)	-0.87	-2.29*	-0.37	-2.14*	-0.30	-1.99
Annual average PM <= 10 conc.	0.00	0.15	0.01	0.78	0.01	1.12
Annual average NO2 conc.	-0.10	-0.70	-0.04	-0.71	-0.04	-0.70
Time interval (in days)	-0.85	-2.53*	-0.37	-2.41*	-0.33	-2.43*
Administrative Status of City	9.31	2.13*	4.11	2.01*	3.21	1.79
Ruling Political Party in State	1.21	0.48	0.67	0.57	0.66	0.64
Number of Testing Centres	-6.75	-2.46*	-2.83	-2.19*	-1.97	-1.68
_cons	27.54	1.05	6.91	0.58	0.28	0.03
	R^2 = 0.68		**R^2 = 0.71**		**R^2 = 0.74**	

*statistically significant at 5 percent; Coef. = Coefficients

Source: Based on Authors' calculations

tremendously high for the metropolitan cities and the risk of COVID-19 infection has a direct connection to it, as triggered by inhaled aerosols, or tiny particles, breathed out by the infected passengers onboard (Chen, 2020). Also, the adherence of the passengers to the COVID-19 related protocols in public transport modes has remained a daunting task for the authorities to enforce. It is interesting that with the staggered easing of mobility restrictions since lockdown phase 4.0, there was a fear of the increase in the number of cases in these cities, and the same was supported by the regression results.

Furthermore, the time gap between implementation of the lockdown by respective states and that of the Central government has emerged significantly with the negative association since the onset of lockdown phase 4.0 because the states which imposed a total lockdown, days preceding the national lockdown were better able to check the spread of the pandemic. Last but

Table 4: Factors affecting COVID-19 deaths in Unlock Phases - Multivariate Regression Results

Variables	**1st June**		**1st July**		**1st August**		**1st September**		**1st October**	
Share of Deaths (Dependent Variable)	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat	Coef.	t stat
Population Density in persons per sq. km	0.00	-0.16	0.00	0.40	0.00	1.07	0.00	1.09	0.00	0.75
Share of anaemic population above 15 years	0.08	1.07	0.08	1.13	0.04	0.76	0.02	0.71	0.03	0.92
Share of population above 15 years with high blood sugar level	0.34	1.30	-0.01	-0.03	-0.23	-1.44	-0.16	-1.50	-0.13	-1.39
Share of population above 15 years with high state of hypertension	0.95	1.06	1.00	1.29	0.72	1.22	0.34	0.80	0.01	0.03
GDP (Rs. Crore)	0.00	3.23*	0.00	4.18*	0.00	4.88*	0.00	4.47*	0.00	4.29*
HC Ratio	-0.01	-0.24	0.01	0.34	-0.01	-0.80	-0.02	-1.73	-0.03	-2.38*
Literacy Rate	0.03	0.32	0.06	0.86	0.04	0.77	0.03	0.89	0.04	1.36
Hospitals per lakh population	0.29	1.88	0.21	1.61	0.14	1.39	0.12	1.39	0.18	2.63*
Hospital Beds per lakh population	0.01	4.58*	0.00	1.03	0.00	0.72	0.00	0.31	0.00	-0.83
Hospital Doctors per lakh population	-0.06	-2.70*	-0.03	-1.40	-0.03	-2.41*	-0.03	-3.21*	-0.02	-3.30*
PublicTransport Usage by Other Worker (%)	0.09	1.75	0.11	2.53*	0.11	3.69*	0.07	2.95*	0.04	2.30*
Road Connectivity to National Highways	0.32	0.73	-0.01	-0.02	0.17	0.65	0.24	1.27	0.21	1.25
Average Temperature (in C)	-0.26	-2.04*	-0.13	-1.31	-0.03	-0.42	-0.04	-0.78	-0.09	-2.18*
Annual average PM <= 10 conc.	0.02	1.29	0.02	1.77	0.01	0.78	0.00	-0.40	0.00	-1.22
Annual average NO2 conc.	-0.04	-0.83	-0.07	-1.35	-0.02	-0.78	0.00	0.17	0.01	0.65
Time interval (in days)	-0.33	-2.61*	-0.20	-1.84	-0.16	-2.45*	-0.14	-3.03*	-0.15	-3.66*
Administrative Status of City	3.04	1.80	2.18	1.51	2.55	2.67*	1.89	3.03*	0.89	2.00*
Ruling Political Party in State	0.78	0.79	0.65	0.74	0.58	0.97	0.54	1.27	0.47	1.28
Number of Testing Centres	-1.80	-1.62	-0.88	-0.95	-0.99	-1.58	-0.66	-1.61	-0.06	-0.22
_cons	-2.51	-0.26	-7.79	-0.96	-5.21	-0.93	-2.68	-0.63	-1.29	-0.35
	R^2 = 0.79		**R^2 = 0.83**		**R^2 = 0.89**		**R^2 = 0.90**		**R^2 = 0.91**	

*statistically significant at 5 percent; Coef. = Coefficients

Source: Based on Authors' calculations

not the least, environmental factors like PM 10 concentration have been found to have a significant (negative association) while NO_2 concentration has a significant positive association since the onset of unlocking phase 4.0 and 5.0. Although the reason behind the former is unclear, the latter is directly related to the incumbent risk of getting affected by respiratory diseases.

Section II: Factors affecting COVID-19 deaths in million-plus cities in India

Tables 3 and 4 relate to the factors affecting COVID-19 related deaths in the big cities of India. Economic size (positive association), hospital doctors ratio and time gap (negative association) have been found statistically significant in affecting the share of COVID-19 related deaths in different lockdown phases. At the onset of lockdown phase 4.0, a positive association between co-morbidity i.e. share of high blood pressure and death cases is evident. The same has been noted in research conducted by the Centre for Disease Control and Prevention (2020) where patients with high blood pressure were associated with an increased risk of COVID-19 deaths.

Similar to COVID-19 infection, the share of public transport usage by the "other" worker category has emerged to have significantly affected the COVID-19 related deaths since the onset of the unlock phase 2.0. This could mainly be because workplaces have gradually opened up, particularly for those activities where work from home option is not viable or are part of essential services; hence to meet the mobility demand public transport started operating in a staggered manner, which has increased the contagion risk and the consequent deaths. Furthermore, the environmental factor i.e. average temperature has emerged significantly with a negative association in lockdown phase 2.0, 3.0, and unlock phase 1.0 and 5.0; however, requires further detailed analysis for a better understanding of this. Other factors that have been found to yield a significant effect on COVID-19 deaths, are capital city status (positive association) at the onset of lockdown phase 2.0, 3.0 and unlock phase 3.0, 4.0, and 5.0, and the number of testing centers (negative association) in phase 2.0 and 3.0 of the lockdown phase.

Conclusions

In the Indian context, the impact of the set of multiple factors, such as, demographic, economic, infrastructural, environmental, and institutional does significantly explains the variation in the COVID-19 infections and related deaths. However, the role of individual indicators does seem to have a differential impact on the dependent variables in different phases of the lockdown strategy. Indicators, such as GDP, hospital-doctor ratio, public transport usage, and administrative status of the city have been found to be the most significant factors influencing COVID-19 cases and deaths. On the other hand, for example, co-morbidities do not appear as consistently significant factors, while the much-debated density parameter plays an insignificant role in the Indian big cities. Among others, these are few interesting empirical observations based on our preliminary understanding of the COVID-19 pandemic in India from the spatial-temporal perspective.

When we started working on this study, the COVID-19 situation was very new, and the availability of consistent comparable data across time did pose a major challenge, besides the lack of real-time comparable data on some of the parameters we have considered in the paper. Hence the study is limited in its scope but can be a useful contribution to the COVID-19 literature. The results are at best indicative in nature, and for an in-depth understanding of each of these factors and spatial complexity, we require further detailed analysis at a more disaggregated level. Since a pandemic may cause sudden, widespread morbidity and social, political, and economic disruption, studies reflecting on regional nuances are much useful though missing in contemporary research and in the policy framework.

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