Aggravation of CoVID-19 infections due to air pollutant concentrations in Indian cities

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1 **Aggravation of CoVID-19 infections due to air pollutant concentrations in Indian cities**

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Abstract:

In the beginning of March 2020, cases of CoVID-19 infections began rising worldwide, reacting to which the Government of India called for nationwide lockdown initially for March 25th to April 14th, 2020 and later extended it in phases till May 31st, 2020. Due to the forced restrictions pan-India on every level, the move led to drastic drop in pollution levels. The results demonstrated that during lockdown air quality is significantly improved and the pollution levels of PM_{2.5}, PM₁₀, SO₂ and NO₂ reduced drastically during the lockdown period than the preceding year for the same time frame. A direct relationship has been established between the high level of air pollutants (PM_{2.5}, PM₁₀, NO₂ and SO₂) and CoVID-19 infections being reported in these Indian cities. The correlation indicates that the air pollutants like PM_{2.5}, PM₁₀, NO₂ and SO₂ are aggravating the number of casualties due to the CoVID-19 infections. The high-level exposure of PM_{2.5} over a long period is found to be significantly correlated with the mortality per unit confirmed CoVID-19 cases as compared to other air pollutant parameters like PM₁₀, NO₂ and SO₂.

Keywords: Air quality, CoVID-19 infections, Environmental health, Linear Regression, SARS-CoV-2

1. Introduction

In the late December 2019, the emergence of coronavirus came into existence when several patients with viral pneumonia were found to be associated with the Wuhan seafood market (Lu et al., 2020). CoVID-19 has emerged as a severe health problem affecting people of all age groups throughout the globe (Chen et al., 2020) due to which the World Health Organization (WHO) has attributed it as a pandemic. Due to the pandemic spread, almost all nations called for country-wide lockdown. India too announced country-wide lockdown to safeguard the citizens on 25th March 2020 and then continued it further for almost 3 months in multiple phases. Due to multiple lockdown phases being implemented by the Government of India in an attempt to contain the spread of CoVID-19 infections, there has been significant drop in the pollution levels being reported in different parts of the country (Jain & Sharma, 2020; Mahato et al., 2020; Saadat et al., 2020). Table 1 shows the implementation of lockdowns that were carried out in 5 different phases, their durations and the restrictions imposed during those periods.

For the current study, tier-1 cities of India, namely Ahmedabad, Bengaluru, Chennai, Delhi, Hyderabad, Kolkata, Mumbai, Pune are been taken up. These tier-1 megacities are the single largest contributors to the urban population

and pollution. Severe air pollution poses a significant threat to the lives of the residents' health and also the environment. Urban air quality due to high levels of air pollution are being reported in Indian megacities and are one of the highest in the world due to industrial expansions, high population density and use of motor vehicles (Gurjar & Lelieveld, 2005). The effects of the uncontrolled population explosion have serious repercussion on the environment due to growth in industrialization and automation; and the most obvious result is worsening quality of ambient air (Gulia, Mittal, et al., 2018; Kanawade et al., 2020). According to multiple studies, it can be safely deduced that the air pollution is a risk factor for respiratory infection by carrying microorganisms and affecting body's immunity (Cai et al., 2007; Horne et al., 2018; Rastogi et al., 2020; Susanne Becker, Joleen M. Soukup, 1999; Xie et al., 2019; Xu et al., 2016; Zhu et al., 2020). Studies have shown that the CoVID-19 is a respiratory related disease and SARS-CoV-2 can remain active when they are bound in aerosols for a considerable amount of time (van Doremalen et al., 2020). Hence it is important to inspect the consequences of the pollutants like particulate matters and pollutant gases on the spread of the CoVID-19 infections. The report on the Environmental Performance Index published in the year 2018 by the Yale Center for Environmental Law & Policy in collaboration with the World Economic Forum, India ranked 177 out of the 180 countries globally (Wendling et al., 2018). Air Quality Index (AQI), which illustrates the probable effect of the air quality on the human health is primarily dependent on the concentration of key five pollutants like the particulate matters (PM_{2.5} and PM₁₀) along with pollutant gases like ground-level ozone (O₃), NO_x and SO₂. Several countries reported a steep decline in the air pollution levels due to the strict restrictions imposed on travel due to the alarming increase in CoVID-19 infections world-wide (Bao & Zhang, 2020; Saadat et al., 2020; Yao et al., 2021).

2. Site selection:

The cities in India are categorized in different groups based on the population and living cost. The living cost of a city depends on the number of people presiding over a place. Based on this criterion of classification, the cities are being divided in category X (tier-1), Y (tier-2) and Z (tier-3) cities (Shetty et al., 2020). In India, there are 8 tier-1 cities, 26 tier-2 cities, 33 tier-3 cities and over 5000 tier-4 cities, generally known as towns (Government of India, 2017). The 8 tier-1 cities that were taken into account for the current study are Bengaluru (Karnataka), Chennai (Tamil Nadu), Delhi, Mumbai (Maharashtra), Kolkata (West Bengal), Ahmedabad (Gujarat), Hyderabad (Telangana) and Pune (Maharashtra).

The CoVID-19 pandemic outbreak worldwide made the governments shutdown their respective countries completely to minimize the spread of the deadly virus to the citizens. Likewise, India too announced lockdown in

the entire country on 25th March 2020, which restricted factories to operate in lieu of the increasing number of CoVID-19 cases. Government of India also implied complete movement restrictions for the civilians. Police were deployed to check and monitor the movement of the citizens in different cities. Only few individuals were exempted from the travel restrictions like the medical practitioners, health-care workers and govt appointed vehicles to provide essential commodities to different parts of India. Tier-1 cities of India are selected for the present study as they are the hubs of huge job creation, which attracts people from different parts of India for good salaried jobs, high quality education and a good quality lifestyle and living standard due to which such cities often observe fastest growth rates in India (supplementary Table ST1) (Department of Economic and Social Affairs, U. N., 2018). Due to ever-increasing population and pollution of these cities, the spread of CoVID-19 infections saw a huge surge as the number of positive cases grew at an alarming rate as compared to the other cities of India (table 2).

3. Methodology:

This study attempts to find the differences between the pollution levels from different phases of lockdown in the selected tier-1 cities of India. The data of ambient air quality levels of each sampling site of tier-1 Indian cities are taken from the website of Central Pollution Control Board (<https://app.cpcbcr.com/ccr>) which reports continuous ambient air quality data throughout the country, which are being recorded using multiple monitoring stations operated by the CPCB (MoEFCC, Govt. of India, 2020), respective state pollution control boards (SPCB) and India meteorological department (IMD). The data which are being reported in this study are taken from a total number of 78 monitoring stations. Ambient air quality parameters like PM_{2.5}, PM₁₀, NO₂ and SO₂ listed in NAAQS are taken into account for the current study. Data of ambient air pollutants were taken (24-hour average) from the period of 1st January to 17th May for the current and preceding years.

3.1 Descriptive statistics

The statistical analysis was executed using the MS-EXCEL and MINITAB software. Experimental results for PM_{2.5}, PM₁₀, NO₂, SO₂ as well as CoVID-19 counts were stated as the mean $\pm$ SD (standard deviation). In this study the particulate matter concentration and the CoVID-19 data for the confirmed cases, active, recovered and deceased has been considered for the 8 tier-1 cities like Bengaluru, Chennai, Delhi, Mumbai, Pune, Ahmedabad, Hyderabad and Kolkata.

The study period for the CoVID-19 spread analysis was divided into 2 segments to demarcate the relaxation norms in the Indian sub-continent. The first segment (henceforth labelled as Phase-1) illustrated the duration from 26th April 2020 to 3rd May 2020 during which strict lockdown norms were being implemented with minimum public

interaction and restricted movement. The second segment (henceforth labelled as Phase-2) illustrated the time period from 4th May 2020 to 17th May 2020 during which strict lockdown norms were lifted and market places were opened for public. Table 3 presents daily average of air pollutant (PM_{2.5}, PM₁₀, NO₂, SO₂) concentrations recorded in the tier-1 cities of Bengaluru, Chennai, Delhi, Mumbai, Pune and Ahmedabad. Hyderabad and Kolkata were not included due to the non-availability of the data during the period 26th April – 17th May 2020. The data of the CoVID-19 infections in tier-1 cities were analyzed using analysis of variance, correlation and regression model.

3.2 Linear regression

In order to demonstrate the association between the response variable (mortality % per unit confirmed CoVID-19 cases) and the air pollution parameters (PM_{2.5}, PM₁₀, NO₂, SO₂), a linear regression analysis was used. The analysis was achieved with a single air pollution parameter at a time because these parameters were neither mutually exclusive nor independent. The linear regression model is characterized by a straight line as depicted by the equation 1 (Montgomery et al., 2012):

$$Y = mX + C + \varepsilon \quad (1)$$

where the response variable is termed as ‘Y’, which is the percentage mortality per total confirmed cases. The variable ‘m’ is the slope while the variable ‘X’ signifies the predictor variable, i.e., the air pollution parameter which is assumed to be normally distributed with equality of variance for every observation while C is the model constant. In our study the model X was calculated using the logarithmic alteration which reduces the skewness of the data set. ‘ε’ is the error which is uncorrelated and have zero mean. ANOVA (analysis of variance) on the regression model is executed to enumerate the strength of the relation of particle matter on the response variable which is depicted by the R² value. In order to analyze the influence of the predictor variable more closely on the response variable, multiple linear regression model has been done for the particle matter PM_{2.5} on the percentage mortality per confirmed CoVID-19 cases. The multiple linear regression model as a curve is depicted by the equation 2:

$$Y = a_0 + a_1x + a_2x^2 \quad (2)$$

where a_0, a_1, a_2 are parameters. In this model when the predictor variable increases from x to (x + 1), expected change in the response variable is $a_1 + a_2(2x + 1)$. For the small change in the predictor variable, the effect on the response is given by the total derivative with respect to x, i.e., $a_1 + 2a_2x$. The change in the response variable is what makes the relationship between the predictor and response variables non-linear even though the model is linear in parameters.

4. Results and discussion:

The data reported in the current study are particulate matters (PM₁₀ and PM_{2.5}) and pollutant gases like SO₂ and NO₂. The data from multiple monitoring stations are averaged for a single representative data for whole city. The data for the said air pollutants are reported for the 8 tier-1 cities of India for the year 2020 which were then compared with the data from the preceding year for the same time frame.

4.1 Particulate matters

Rapid urbanization and industrialization in India are one of the key factors for the increase of air pollution levels of India. The pollution levels being reported in India are one of the highest reported levels in the world. As per the findings of WHO, 14 out of 15 most polluted cities of the world are from India (Kumari et al., 2020). Balakrishnan et al., 2019 reported that the number of deaths due to the ambient particulate matter (PM₁₀ and PM_{2.5}) was 0.67 million in India with population weighted mean for PM_{2.5} was found to be 89.9 µgm⁻³. The PM_{2.5} and PM₁₀ were observed to drop during the lockdown implemented in 2020 as compared to the preceding year in all the tier-1 cities of India (supplementary Figure S1-S2). The highest drop in the PM₁₀ levels during the lockdown period were observed at Pune (63.2%) while the lowest was reported at Mumbai (20.9%). The national capital territory of Delhi too witnessed a drop of 58.3% in PM₁₀ levels during the lockdown period as compared to preceding year during the similar time frame. On the other hand, Ahmedabad witnessed the highest drop in PM_{2.5} levels (64.7%) in 2020 as compared to the year 2019 during the period of lockdown. On the contrary, Mumbai witnessed a rise of 3.7% in PM_{2.5} levels (supplementary Table ST2).

4.2 Pollutant gases

Ambient NO₂ pollutants in ambient air have significant health impacts and also deter plant growth. Photochemical smog and acid rain are also associated with increased concentration of tropospheric NO₂. An inventory given by Garg et al. (2001) reported that the emission of NO₂ is related to industrial processes (50%), vehicular emissions (32%) and biomass burning (10-20%). Ramachandran et al. (2013) marked Delhi, Mumbai & Kolkata region as hotspots of NO₂ emissions during the span of 8 years, i.e., 2003-2011 with annual average emissions greater than ~30 µgm⁻³. In the year 2019, India overtook Russia and China to be the world's highest emitter of ambient SO₂, and accounts for over 15% to total global anthropogenic SO₂ emissions (Myllyvirta, 2019). Almost all the SO₂ emissions from India is due to coal burning which is mainly used for power generation. Suneja et al. (2020) reported that the average concentration of SO₂ for 8 years (2011-2018) in Indian megacity of Delhi was 5.92 ±

1.26 μgm^{-3} with highest and lowest values of $6.44 \pm 1.78 \mu\text{gm}^{-3}$ and $4.89 \pm 0.94 \mu\text{gm}^{-3}$ for the years 2018 and 2013 respectively.

The NO_2 and SO_2 levels too were observed to drop during the lockdown implemented in 2020 as compared to the preceding year in all the tier-1 cities of India (supplementary Figure S3-S4). The highest drop in ambient NO_2 and SO_2 levels were observed at Ahmedabad with 69.2% and 49.8% respectively. On the contrary, Pune and Bengaluru witnessed an increase of 24.3% and 20.4% in NO_2 and SO_2 levels during the lockdown period (supplementary Table ST2). The increase in NO_2 levels in Pune might be due to elevated transportation activities in the vicinity of the sensor being installed. This is quite evident with sudden point spikes in NO_2 concentration (supplementary Figure S3). The data however might not be much reliable as Pune has single monitoring site collecting air pollution data. The SO_2 concentration levels recorded in Kolkata too showed a minor increase by 0.75%. Increase in SO_2 levels in Bengaluru during the lockdown period might be due to the elevated biomass burning incidents in industrial as well as domestic sectors. Kolkata has 2 thermal power plants in the 50 km radius which are the primary SO_2 pollution source for Kolkata and since they were operated throughout the lockdown period as the preceding year, the emissions were found to be quite similar for both the years. The SO_2 levels during the lockdown being reported in the rest of the tier-1 cities of India are found to be below the levels recorded in the previous year.

4.3 Impact of air pollutant parameters on CoVID-19 cases

The tier-1 cities of Bengaluru, Chennai, Delhi, Mumbai, Pune and Ahmedabad are well-known hotspots of the atmospheric pollution. The pollution parameters of $\text{PM}_{2.5}$, PM_{10} , NO_2 , and SO_2 concentration are often seen to exceed the safe levels prescribed by the WHO guidelines and Indian NAAQS permissible limits (Gulia, Nagendra, et al., 2018; Guttikunda et al., 2019; Guttikunda & Jawahar, 2012; Srivastava et al., 2020). The study found that during the investigated period 26th April – 3rd May 2020 (Phase-1) for each six tier-1 cities, the pollution levels ($\text{PM}_{2.5}$, PM_{10} , NO_2 , and SO_2) had reduced drastically and the air quality had significantly improved than the preceding year for the same time frame. The daily mean air surface concentrations of $\text{PM}_{2.5}$, PM_{10} , NO_2 , and SO_2 for the preceding year 2019 and current year are provided in supplementary Table ST2. During the Phase-2 (4th May -17th May 2020), the lockdown was eased allowing certain relaxations in public movement and re-opening of market, the air pollution began to increase (Table 3). The relaxations and re-opening of market places after ~40 days witnessed huge gathering especially in popular market areas where the people were generally seen flouting the social-distancing which resulted in huge upsurge in the CoVID-19 cases. The values of the air pollutants

exceeded the Indian NAAQS limits. For the regression analysis, data for the $PM_{2.5}$, PM_{10} , NO_2 , and SO_2 has been considered from 25th March 2020 – 17th May 2020 which covers both the phases i.e., period of complete lockdown followed by lockdown with relaxation. The data of the positive coronavirus infection cases has been considered from 26th April – 17th May 2020.

The mean of $PM_{2.5}$, PM_{10} , NO_2 , SO_2 for the year 2020 (during the lockdown period) in the tier-1 cities along with the percentage mortality per unit confirmed for CoVID-19 cases is calculated and given in the Table 4. Using the linear regression model, a relationship is established between the air pollution parameters and percentage mortality per unit confirmed cases of CoVID-19 (Table 5). The linear regression model on the response variable is fitted with respect to the particulate matters ($PM_{2.5}$ and PM_{10}) and pollutant gases (NO_2 and SO_2). Table 5 portrays the regression model coefficients and associated standard error (SE) for the regression coefficients. It has been observed that $PM_{2.5}$ has substantial impact on the ‘Y’ (response variable), i.e., the percentage mortality per confirmed CoVID-19 cases ($p < 0.05$ at confidence interval 95%). However, the air pollutants PM_{10} , NO_2 and SO_2 (with $p > 0.05$) does not show any substantial impact on the response.

The analysis of variance on the regression model is presented in Table 6(a) from which it can be inferred that the percentage mortality per confirmed CoVID-19 cases is correlated significantly with $PM_{2.5}$ ($R^2 = 86.98\%$) than with PM_{10} ($R^2 = 19.59\%$), NO_2 ($R^2 = 14.99\%$), but significantly with SO_2 ($R^2 = 57.16\%$). For predicting the mortality rate based on the developed regression model needs much bigger data set which is not possible in this case due to the non-availability of data. In Table 6(b), the analysis of variance on the multiple regression model for the $PM_{2.5}$ and can be inferred that percentage mortality per confirmed CoVID-19 cases is correlated significantly with $PM_{2.5}$.

Table 7 recapitulates the Pearson Coefficient descriptive statistics of CoVID-19 cases in the six tier-1 cities (total confirmed, active, recovered and deceased) and the 24-hour average air pollutant levels of $PM_{2.5}$, PM_{10} , NO_2 and SO_2 (as per the availability of data). Figure 1 represents the best fit line plot (for PM_{10} , NO_2 and SO_2) and the best fit curve plot (only for $PM_{2.5}$) for the parameters with 95% at confidence interval. The residuals are shown in Figure 2 through normal probability plot. The residuals are in close agreement with the normal distribution line, which confirms the fact stated in reference to Figure 1.

The contour plot for the percentage mortality per unit confirmed CoVID-19 cases is depicted in Figure 3(a)-(e). It can be observed that the highest values of the response variable are in the upper right corner of the plot which corresponds with the high values of both $PM_{2.5}$ and PM_{10} indicates the higher impact of these pollution parameters

on the mortality rate and as it is skewed more to the Y-axis indicates that the impact of $PM_{2.5}$ is more compared to PM_{10} . The impact of other air pollutants on the percentage mortality rate per unit confirmed CoVID-19 cases is also calculated. Fig 3(e) shows that the impact of NO_2 is more compared to PM_{10} on the percentage mortality rate per unit confirmed CoVID-19 cases. But the impact of SO_2 is also not less on the percentage mortality rate per unit confirmed cases. The correlation also supports that along with $PM_{2.5}$, SO_2 and NO_2 are also accelerating the number of CoVID-19 confirmed cases.

Conclusion:

CoVID-19 is likely to spread rapidly in humans with people coming in contact or in nearby vicinity to an infected person. Also, the transmission of the virus in the air is in the form of aerosols; and hence places which are highly polluted may see a proportionate rise in CoVID-19 cases due to the compromised immune system of the person living in that area. In this present work, a direct relationship has been established between the high level of air pollutants ($PM_{2.5}$, PM_{10} , NO_2 and SO_2) and CoVID-19. This correlation indicates that the air pollutants like $PM_{2.5}$, PM_{10} , NO_2 and SO_2 are aggravating the number of casualties due to the CoVID-19 infections. Further, it has been observed that high level exposure of $PM_{2.5}$ over a long period is found to be significantly correlated with the mortality per unit confirmed CoVID-19 cases as compared to other air pollutant parameters like PM_{10} , NO_2 and SO_2 . Concluding with the results, it is evident that the air pollution is in turn acting as a catalyst in the mortality rates due to the CoVID-19 infections. As the virus carrying aerosols are in the range of $1 - 5\mu m$, hence outside wearing of mask in tier-1 cities should be compulsory. In the light of increasing CoVID-19 infections worldwide, it is vital to identify the hotspots with very high concentrations of air pollution and implement strict rules on the movement of residents freely without following safety protocols. Usage of masks should be made compulsory and high amount of monetary fines to be implemented to those found without following safety norms.

Tier-1 cities, are by default, in high-risk zone and hence government authorities need to have pro-active steps to curb and control it, in terms of health care, patient tracking, restricted movement etc. Health of people should be the prime concern for a nation. Being a developing country, its challenging but it needs to be addressed by controlling the high amount of pollution and promoting healthier lifestyle. Viruses, one form or the other will be encountered in future also, but human immune system should be strong enough to deal with it, at its capacity.

250 **Declarations:**

251

252 **Ethics approval and consent to participate**

253 Not applicable.

254 **Consent for publication**

255 Not applicable.

256 **Declaration of Competing Interests**

257 The authors declare that they have no competing interests.

258 **Availability of data and materials**

259 All data generated or analyzed during this study are included in this published article and its supplementary
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269 **Author Contributions**

270 AM had collected the data, analyzed them and drafted the manuscript. AS carried out the statistical analysis part,
271 contributed in manuscript drafting and shaping the manuscript into the final format. SKS collected the data and
272 helped in manuscript writing. SM and AKM conceptualized the idea, provided overall guidance in planning and
273 had contributed in shaping manuscript into the final format.

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Figure 1: Quadratic Regression fitted line plot for PM_{2.5}; Linear Regression fitted line plot for PM₁₀, NO₂ and SO₂

Figure 2: Normal probability plot depicting the residual for (a) PM_{2.5}; (b) PM₁₀; (c) NO₂; (d) SO₂

Figure 3: Contour plot for the percentage of mortality per unit confirmed cases with respect to (a) $\text{PM}_{2.5}$ and PM_{10} ; (b) $\text{PM}_{2.5}$ and NO_2 ; (c) $\text{PM}_{2.5}$ and SO_2 ; (d) SO_2 and NO_2 ; (e) PM_{10} and NO_2

388 Table 1: Different lockdown phases implemented in India

Lockdown #	Duration	Additional details
Lockdown 0	22nd March 2020 (14 hours) [Janta curfew]	Partial lockdown
Lockdown 1.0	25th March 2020 to 14th April 2020	Complete lockdown
Lockdown 2.0	15th April 2020 to 03rd May 2020	Complete lockdown
Lockdown 3.0	04th May 2020 to 17th May 2020	Lockdown with some relaxations
Lockdown 4.0	18th May 2020 to 31st May 2020	Lockdown with some relaxations

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391 Table 2: Reported cases of CoVID-19 in tier-1 cities of India (as of 17th May 2020)

Tier-1 Cities	Confirmed	Active	Recovered	Deceased
Ahmedabad	8683	5287	2841	555
Bengaluru	240	111	122	7
Chennai	7125	5468	1600	57
Delhi	10054	5409	4485	160
Hyderabad	981	653	305	23
Kolkata	1372	706	501	165
Mumbai	20150	15918	3498	734
Pune	3821	2113	1511	197
Total (tier-1 cities)	52426	35665	14863	1898
Rest of India	45195	21041	22988	1160
Total (whole India)	97621	56706	37851	3058

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394 Table 3: Daily average PM_{2.5}, PM₁₀, NO₂ and SO₂ concentrations recorded in six tier-1 cities in India during the
 395 Phase-1 (complete lockdown) and Phase-2 (lock down with relaxation)

	26 th April – 3 rd May 2020	Range	4 th May – 17 th May 2020	Range
Bengaluru				
PM _{2.5} (µg/m ³)	19.9 ± 3.1	13.4 – 24.2	22.3 ± 4.6	15 – 29.3
PM ₁₀ (µg/m ³)	50.5 ± 7.2	38.7 – 59.3	62.3 ± 11.6	41.3 – 86.8
NO ₂ (µg/m ³)	13.5 ± 2.3	11.1 – 17.3	16 ± 2.2	12.9 – 19.3
SO ₂ (µg/m ³)	6.4 ± 1.8	5.4 – 10.6	6.8 ± 0.7	5.8 – 7.6
Chennai				
PM _{2.5} (µg/m ³)	11.1 ± 2.4	6.6 – 14.6	13.4 ± 6.5	7.2 – 28.5
PM ₁₀ (µg/m ³)	75.8 ± 10.15	61.5 – 90	77.1 ± 20.3	61.8 – 136.2
NO ₂ (µg/m ³)	6.9 ± 2.9	3.7 – 11.4	5.8 ± 1.8	3.5 – 10.4
SO ₂ (µg/m ³)	4.7 ± 0.8	4.1 – 6.6	4.4 ± 0.9	3.4 – 7.2
Delhi				
PM _{2.5} (µg/m ³)	43.7 ± 10.2	32.6 – 60.6	53.5 ± 12.5	30.9 – 80.6
PM ₁₀ (µg/m ³)	101.7 ± 25.4	59.0 – 140.5	120.0 ± 27.0	67.2 – 168.0
NO ₂ (µg/m ³)	17.0 ± 1.84	14.6 – 19.4	21.6 ± 3.2	17.3 – 26.6
SO ₂ (µg/m ³)	14.9 ± 1.88	11.6 – 17.2	13.9 ± 1.4	11.9 – 16.0
Mumbai				
PM _{2.5} (µg/m ³)	17.8 ± 3.15	12.9 – 21.4	17.3 ± 6.4	12.2 – 33
PM ₁₀ (µg/m ³)	46.5 ± 7.95	34.5 – 57.2	61.4 ± 23.8	36.2 – 119.2
NO ₂ (µg/m ³)	5.6 ± 0.81	4.8 – 7.0	6.0 ± 1.4	4.0 – 8.2
SO ₂ (µg/m ³)	13.4 ± 0.48	12.8 – 14.1	24.6 ± 8.6	12.3 – 36.9
Pune				
PM _{2.5} (µg/m ³)	26.6 ± 14.1	19.6 – 60.9	22.85 ± 11.45	11.5 – 58.41
PM ₁₀ (µg/m ³)	34.5 ± 3.96	31.3 – 43.3	31.74 ± 8.65	18.4 – 42.55
NO ₂ (µg/m ³)	10.1 ± 5.4	7.4 – 23.1	8.59 ± 4.5	4.37 – 22.2
SO ₂ (µg/m ³)	22.9 ± 2.6	20.7 – 28.7	21.03 ± 5.73	12.18 – 28.19
Ahmedabad				
PM _{2.5} (µg/m ³)	27.38 ± 3.5	22.2 – 32.32	25.68 ± 4.6	19.03 – 36.03
PM ₁₀ (µg/m ³)	76.0 ± 10.2	61.47 – 90.04	77.08 ± 20.34	61.76 – 136.23
NO ₂ (µg/m ³)	17.88 ± 4.24	13.38 – 24.84	18.18 ± 3.3	14.75 – 27.62
SO ₂ (µg/m ³)	28.9 ± 10.8	9.03 – 44.65	N/A	

399 Table 4: Data on air pollution level and CoVID-19 cases in 8 tier-1 Indian cities w.r.t. mortality rate

S. No.	City	Daily Mean Air pollution parameters (2020)				CoVID-19 cases (Till 17 th May 2020)		Percentage mortality per unit reported case
		PM _{2.5} (µgm ⁻³)	PM ₁₀ (µgm ⁻³)	NO ₂ (µgm ⁻³)	SO ₂ (µgm ⁻³)	Total reported cases	Total Reported Deaths	(death/case) x 100
1	Ahmedabad	29.3	79.6	22.1	26.2	8683	555	6.39
2	Bengaluru	24.6	52.1	13	6.3	240	7	2.91
3	Chennai	16.2	79.3	7.4	5.3	7125	57	0.8
4	Delhi	46.2	103.6	20.4	14.3	10054	160	1.59
5	Hyderabad	30.2	61.6	22	5.8	981	23	2.34
6	Kolkata	24.9	47.8	10.2	5.3	1372	165	12.02
7	Mumbai	21.4	63.8	7.4	12.9	20150	734	3.64
8	Pune	43.9	35.3	16.6	22.7	3821	197	5.15

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Table 5: Linear regression relationship between air pollution parameters and percentage mortality per confirmed CoVID-19 cases

Predictors	Coefficient	SE Coefficient	T-Value	P-Value
PM_{2.5}				
Constant	-67.7	15.9	-4.25	0.024
logPM _{2.5}	70.1	15.7	4.48	0.021
PM₁₀				
Constant	13.31	9.95	1.34	0.252
logPM ₁₀	-5.41	5.48	-0.99	0.379
NO₂				
Constant	-0.67	5.06	-0.13	0.902
logNO ₂	3.85	4.59	0.84	0.448
SO₂				
Constant	-2.61	2.72	-0.96	0.393
logSO ₂	5.61	2.43	2.31	0.082

406 Table 6(a): Analysis of Variance (ANOVA) for the linear regression model

Source	DF	Seq SS	Seq MS	F-Value	P-Value
PM_{2.5}					
Regression	2	18.8669	9.4334	10.02	0.047
logPM _{2.5}	1	18.8606	18.8606	20.03	0.021
Residual Error	3	2.8248	0.9416		
S=0.970366	R ² = 86.98%	R ² (adj) =78.30%			
PM₁₀					
Regression	1	4.250	4.2504	0.97	0.379
logPM ₁₀	1	4.250	4.2504	0.97	0.379
Residual Error	4	17.441	4.3603		
S=2.08814	R ² = 19.59%	R ² (adj) =0.00%			
NO₂					
Regression	1	3.251	3.251	0.71	0.448
logNO ₂	1	3.251	3.251	0.71	0.448
Residual Error	4	18.440	4.610		
S=2.14712	R ² = 14.99%	R ² (adj) =0.00%			
SO₂					
Regression	1	12.399	12.399	5.34	0.082
logSO ₂	1	12.399	12.399	5.34	0.082
Residual Error	4	9.292	2.323		
S=1.52417	R ² = 57.16%	R ² (adj) =46.45%			

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408 Table 6(b): Analysis of variance for the polynomial regression model for the PM_{2.5}

Source	DF	Seq SS	Seq MS	F-Value	P-Value
Regression	2	19.9212	9.96062	16.88	0.023
Error	3	1.7704	0.59015		
S=0.768210	R ² =91.84%	R ² (adj)= 86.40%			

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Table 7: Pearson's correlation coefficient between CoVID 19 cases in tier-1 cities and air pollutant concentrations- a comparison between the Phase 1 and 2 for each tier-1 cities of Bengaluru, Chennai, Delhi, Mumbai, Pune and Ahmedabad

CoVID-19 cases	Phase 1 (26th April-3rd May 2020)				Phase 2 (4th May-17th May 2020)			
Bengaluru	PM _{2.5}	PM ₁₀	NO ₂	SO ₂	PM _{2.5}	PM ₁₀	NO ₂	SO ₂
Confirmed total cases	0.52	0.7	0.93	0.51	-0.46	-0.46	-0.44	0.15
Total active cases	0.03	0.04	0.24	-0.41	-0.46	-0.52	-0.42	0.08
Total recovered	0.49	0.65	0.78	0.6	-0.43	-0.4	-0.42	0.2
Total deceased	0.21	0.28	0.79	0.72	-0.49	-0.45	-0.57	-0.2
Chennai								
Confirmed total cases	0.56	-0.56	-0.64	-0.43	0.33	-0.24	0.7	-0.17
Total active cases	0.56	-0.57	-0.63	-0.4	0.33	-0.26	0.72	0.39
Total recovered	0.46	0.34	0.68	0.66	0.3	-0.15	0.54	0.7
Total deceased	0.65	0.49	0.57	0.48	0.39	-0.17	-0.08	-0.07
Delhi								
Confirmed total cases	-0.18	0.05	-0.37	-0.45	0.6	0.29	0.67	0.25
Total active cases	0.26	0.02	0.4	-0.53	0.5	0.27	0.52	0.1
Total recovered	-0.003	0.18	-0.16	-0.26	0.62	0.3	0.74	0.35
Total deceased	-0.06	0.28	-0.35	-0.34	0.62	0.3	0.8	0.36
Mumbai								
Confirmed total cases	-0.7	-0.64	-0.66	0.95	0.78	0.78	0.63	-0.04
Total active cases	-0.74	-0.68	-0.65	0.94	0.78	0.79	0.61	-0.03
Total recovered	-0.52	-0.46	-0.65	0.98	0.76	0.76	0.69	-0.08
Total deceased	-0.57	-0.51	-0.65	0.98	0.79	0.79	0.66	-0.07
Pune								
Confirmed total cases	-0.62	-0.12	-0.62	-0.11	0.53	0.47	0.53	0.47
Total active cases	-0.68	-0.06	-0.68	-0.06	0.46	0.37	0.46	0.37
Total recovered	-0.48	-0.15	-0.48	-0.15	0.56	0.5	0.56	0.5
Total deceased	-0.54	-0.22	-0.54	-0.22	0.56	0.62	0.56	0.62
Ahmedabad								
Confirmed total cases	0.65	-0.5	0.39	0.01	0.02	0.18	-0.12	N/A
Total active cases	0.66	-0.5	0.39	-0.01	0.16	0.14	0.13	N/A
Total recovered	-0.62	0.5	0.37	0.01	0.14	0.19	0.1	N/A
Total deceased	0.67	-0.55	0.36	-0.04	0.16	0.26	0.16	N/A

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