Estimating the Inadvertent Decrement in Mortality due to Reduction in Ambient Fine Particulate Concentrations During COVID-19 Lockdown in India

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Abstract

The adverse health effects of long and short-term exposure to ambient air pollutants are well established in the epidemiological literature. Amongst all pollutants, fine particulate matter (PM_{2.5}), poses a significant mortality risk because of its toxicity and extensive human exposure. During COVID-19 lockdowns, numerous studies have reported a reduction in ambient PM_{2.5} concentrations due to decreased anthropogenic activities. Therefore, potential health benefits are plausible during this period. In this pursuit, the current study aims to estimate the potential deaths that might have been avoided due to the reductions in PM_{2.5} levels during COVID-19 lockdowns in India's 12 states. For the same, concentration–response functions are developed, and the changes in PM_{2.5} levels were calculated. Overall, PM_{2.5} levels in the analysed states decreased by an average of 19.61 µg/m³ (SD = 10.34 µg/m³) during the months of April–June 2020 compared to the previous year. The concentration–response coefficient (β) obtained for the Indian states is 0.02272 (0.01063–0.03481, 95% Confidence Interval). Upon using these values in the calculation, our analysis estimates that nearly 73,853–92,116 mortalities might have been avoided in the 12 analysed Indian states for the period of April–June 2020 due to the COVID-19 lockdown. Given the high levels of PM_{2.5} in India with its well-known associated health risks and the results of this study, it is likely that the number of lives potentially saved during the COVID-19 lockdown due to reduced concentrations of PM_{2.5} might surpass the COVID-19 deaths in the country.

Keywords COVID-19 · Concentration-response function · PM_{2.5} · Induced mortality

1 Introduction

Multiple pneumonia cases of unknown aetiology were reported in the Hubei province of China in December 2019 (WHO 2020a). A novel coronavirus from the SARS-CoV group, termed Novel Coronavirus Disease 2019 (COVID-19), was later identified as the cause of this unknown pneumonia (Eurosurveillance Editorial Team 2020). Since its outbreak, COVID-19 has reached almost 216 countries infecting more than 20 million people and claiming over

740 thousand lives globally, as on 14 August 2020 (WHO 2020b). The lack of pharmaceutical interventions further distresses the pandemic. Studies suggest that citywide closures are effective to control the spread of the epidemic (Liu et al. 2020). Consequently, several governments have been implementing nationwide lockdowns, restricting most non-essential activities to limit the virus's spread. While the cost of enforcing these restrictions is enormous, numerous studies reported a silver lining to COVID-19 lockdowns in terms of reduced ambient air pollution due to decreased anthropogenic activities (Chen et al. 2020; Karuppasamy et al. 2020; Singh and Chauhan 2020).

The adverse health effects of long and short-term exposure to ambient air pollutants are well established in the epidemiological literature (Zhang et al. 2019). World Health Organization (WHO) held air pollution responsible for approximately 4.2 million deaths worldwide in 2016 (WHO 2018). Amongst all pollutants, fine particulate matter (particles having an aerodynamic diameter less than 2.5 µm),

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poses a significant mortality risk because of its toxicity and extensive human exposure (Liu et al. 2019). Therefore, an indirect health benefit is plausible during the COVID-19 lockdown due to reduced atmospheric pollutants concentration. To scientifically evaluate this, the current study develops a concentration–response function for $\text{PM}_{2.5}$ associated mortality in India. Subsequently, it determines the potential reduction in mortality due to reduced $\text{PM}_{2.5}$ concentrations during three months of lockdown period in 12 Indian states. The methods adopted for the same are discussed in the following section.

2 Methodology

Firstly, the concentration–response function for $\text{PM}_{2.5}$ associated mortality was developed for India to assess mortality reduction due to a decrease in $\text{PM}_{2.5}$ concentration. Such functions typically take a log-linear form, as shown in (1) (Schwartz et al. 2002; Ren et al. 2017).

$$\log(y) = \beta \cdot \text{PM}_{2.5} + c \quad (1)$$

Here, y is the $\text{PM}_{2.5}$ associated mortality, and β is the concentration–response coefficient. The changes in $\text{PM}_{2.5}$ associated mortality due to changes in $\text{PM}_{2.5}$ concentration are derived from (1) and takes the form (2).

$$\Delta y = (e^{\beta \cdot \Delta \text{PM}_{2.5}} - 1)y_{\text{baseline}} \quad (2)$$

In (2), y_{baseline} is the baseline mortality incidence, relative to which the mortality change is calculated. In this analysis, the year 2019 is considered as the baseline scenario.

To develop the concentration–response function (as shown in (1)) for India, the annual $\text{PM}_{2.5}$ associated mortality for the years 2015–2017 was obtained from the Global Burden of Diseases (GBD) database (IHME 2020) for the 12 Indian states. The corresponding annual $\text{PM}_{2.5}$ concentrations for the selected states were downloaded from the online archive of the Central Pollution Control Board (CPCB) of India (CPCB 2020). The selection of these 12 states to develop the function was based on historical $\text{PM}_{2.5}$ data availability.

After developing the concentration–response function, the changes in $\text{PM}_{2.5}$ concentrations in the year 2020 relative to 2019 for April, May, and June months (COVID-19 lockdown period in India) were explored. $\text{PM}_{2.5}$ concentration data for 2019 and 2020 for the selected 12 Indian states were also downloaded from CPCB's online archive. The corresponding April, May, and June $\text{PM}_{2.5}$ differences were then determined.

One thing to note here is that the GBD dataset for $\text{PM}_{2.5}$ mortality is available from 1990 to 2017 (IHME 2020). However, in this analysis, the $\text{PM}_{2.5}$ mortality for the year

2019 is considered as the baseline mortality. To estimate the same, Autoregressive Integrated Moving Average (ARIMA) model was used. ARIMA is a time-series forecasting model that uses historical data's trends and seasonality to forecast future values. A detailed mathematical description of the development of ARIMA is discussed elsewhere (Ariyo et al. 2014). Therefore, in this analysis, ARIMA models were developed using the $\text{PM}_{2.5}$ mortality data from 1990 to 2017, and, using the developed ARIMA models, the $\text{PM}_{2.5}$ mortality for the year 2019 is forecasted. These ARIMA models were developed using the “auto.arima” function in R.

Finally, using the estimated baseline mortalities and the changes in $\text{PM}_{2.5}$ concentrations in Eq. (1), the potential reduction in mortality during the COVID-19 lockdown period in 12 Indian states were calculated. Each of these analyses was performed at a 95% confidence interval. A similar methodology has been previously used in studies to assess the mortality benefits of reduced pollutant concentrations for Korea, China, India, and other parts of the world (Bae and Park 2009; Lin et al. 2017; Liu et al. 2018; Upadhyay et al. 2018; Liang et al. 2020).

3 Results and Discussion

Figure 1 shows the developed $\text{PM}_{2.5}$ concentration–response function for India based on the available historical data. It is observed that the majority of the data points fall within the confidence interval (95%) of the function, indicating the significance of analysis and satisfactory results. The concentration–response coefficient (β) obtained from the developed function of India was found to be 0.02272. Laden et al. (Laden et al. 2006) developed similar log-linear functions for $\text{PM}_{2.5}$ mortality in 6 US cities and obtained a β value of 0.01484. Reports suggest that PM pollution in India is one of the highest globally (Balakrishnan et al. 2019). Moreover, it is well established in the epidemiological literature that prolonged exposure to PM toxins is detrimental to human health (Patra et al. 2021). In fact, India poses the highest burden of infant mortality due to air pollution (Nandi 2020). Therefore, as expected, due to the higher health risk of PM pollution in India, a higher β value was observed.

Once the concentration–response function was developed, the changes in $\text{PM}_{2.5}$ concentrations for April, May, and June 2020 relative to 2019 were calculated. The summary of $\text{PM}_{2.5}$ concentrations in 2019 and 2020 analysed for the 12 Indian states is shown in Fig. 2. From the figure, it is observed that the $\text{PM}_{2.5}$ concentrations have been reduced in all the analysed states due to the reductions in anthropogenic activities during the COVID-19 lockdown imposition by India's government. After estimating the changes in $\text{PM}_{2.5}$ concentrations during the COVID-19 lockdown period, the time-series forecasting to obtain the baseline mortality was

Fig. 1 Concentration–response function developed using analysed Indian states. The CI in the plot represents the confidence interval, which is 95% throughout the analysis, and the numbers indicated in the squared brackets are the CI for the estimated β value

performed. Figure 3 presents the mortality prediction in all the 12 states with a 95% confidence interval. The predicted values would represent the mortality if there were no COVID-19 lockdown scenario. However, due to episodic changes in $PM_{2.5}$ concentrations in India during COVID-19 lockdown (Karuppasamy et al. 2020; Singh and Chauhan 2020), a reduction in 2020 mortality values is expected. This potential reduction in mortality is calculated using the developed concentration–response function and obtained changes in $PM_{2.5}$ concentrations.

Table 1 summarizes the estimated reductions in $PM_{2.5}$ induced mortality in all the analysed Indian states for April, May, and June. Numbers shown in the brackets indicate the confidence interval of the number of mortalities avoided. The state-wise total number of mortalities avoided in the entire three months of COVID-19 lockdown is shown in Figure S1 in the supplement. Our analysis results suggest that nearly 73,853–92,116 deaths might have been avoided in 12 states of India for the period of April–June 2020 due to reductions in $PM_{2.5}$ concentrations. The highest reduction in mortality was observed for the state of Uttar Pradesh. According to the Global Burden of Diseases, India lost nearly 1.2 million lives to $PM_{2.5}$ pollution in 2017 (Balakrishnan et al. 2019). Given this, the projected mortality reduction numbers are highly likely, and it is also possible that the number of lives saved due to reduction in pollutant levels during COVID-19 might outnumber the deaths due to COVID-19.

However, the results of this analysis must be carefully interpreted. This analysis presents an estimate of potential mortality benefits during COVID-19 lockdown due to a

reduction in $PM_{2.5}$ concentrations using mathematical modelling and historical data. The current model did not include the possible changes in the chemical composition of $PM_{2.5}$ during the lockdown. Future models can be developed, incorporating the same to estimate the reduction in mortality. Besides, the reduction in mortality determined in the analysis is a mathematical estimate, which may vary from the actual numbers. However, the science within the estimation is logical and similar methodologies have been used by researchers to estimate the mortality reductions in China (Chen et al. 2020; Hualiang et al. 2017) and United States (Son et al. 2020; Donghai et al. 2020) during COVID-19.

4 Conclusions

The current study estimates the likely reductions in $PM_{2.5}$ induced mortalities in India's 12 states due to a decrease in $PM_{2.5}$ concentrations during COVID-19 lockdown. For calculating the same, a concentration–response function was developed using mortality data from the Global Burden of Diseases (GBD) and $PM_{2.5}$ data from the online archive of the Central Pollution Control Board (CPCB) of India. Furthermore, the mortality data from GBD was extrapolated using the ARIMA time-series model to determine the baseline mortality scenario, had there been no COVID-19 lockdowns. Using the baseline mortality, the changes in $PM_{2.5}$ concentrations, and the developed concentration–response function, our analysis estimated that nearly 73,853–92,116 deaths might have been avoided in 12 states of India for the period of April–June 2020. These mortality reductions

Fig. 2 Comparison of $PM_{2.5}$ concentration for 12 Indian states for the year 2019 and 2020

Fig. 3 Time-series forecasting of $PM_{2.5}$ mortality for 12 Indian states

Table 1 Estimated avoided deaths (95% confidence) during COVID-19 lockdown in India due to the reduction in $PM_{2.5}$ concentrations

State	April	May	June
Andhra Pradesh	327 (266–387)	901 (814–988)	580 (508–652)
Bihar	2322 (2140–2504)	3581 (3339–3822)	3392 (3159–3624)
Delhi	683 (654–712)	618 (591–645)	601 (575–627)
Gujarat	2410 (2214–2605)	1193 (1052–1333)	760 (638–881)
Karnataka	1599 (1307–1891)	2100 (1770–2431)	1935 (1617–2254)
Madhya Pradesh	1275 (1080–1471)	1322 (1125–1520)	1121 (933–1309)
Maharashtra	1945 (1515–2376)	1538 (1139–1938)	2569 (2092–3046)
Odisha	933 (775–1091)	708 (571–846)	1166 (987–1345)
Punjab	775 (690–860)	256 (202–310)	644 (567–721)
Rajasthan	4204 (3779–4628)	2969 (2618–3320)	2557 (2230–2883)
Uttar Pradesh	11,319 (10,467–12,171)	10,112 (9315–10,909)	7579 (6897–8261)
West Bengal	1899 (1668–2130)	2742 (2465–3019)	2350 (2094–2606)

are attributed to the decrease in $PM_{2.5}$ concentrations due to restrictions in non-essential activities during COVID-19 lockdowns. Considering the high mortality rates of $PM_{2.5}$ pollution in India and the results of the analysis, it is plausible that the number of lives saved due to reduction in pollutant levels during COVID-19 lockdown might outnumber the deaths due to COVID-19.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s41810-021-00097-3>.

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Availability of Data and Materials The datasets used and/or analysed during the current study are available with the corresponding author, and can be obtained upon reasonable request.

Code Availability Not applicable.

Declarations

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

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