Strict lockdown measures reduced PM$_{2.5}$ concentrations during the COVID-19 pandemic in Kolkata, India

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Abstract
The COVID-19 situation is a critical state throughout the world that most countries have been forced to implement partial to total lockdown to control the COVID-19 disease outbreak. And displays the natural power to rejuvenate herself without the interference of human beings. So, the top-level emergency response including full quarantine actions are significant measures against the COVID-19 and resulted in a notable reduction in PM$_{2.5}$ in the atmosphere. India was severely attacked by COVID-19, and as a result, the Government of India has imposed a nationwide lockdown from 24th March (2020) to 30th May (2020) in different phases. The COVID-19 outbreak and lockdown had a significant negative impact on India’s socioeconomic structure but had a positive impact on environmental sustainability in terms of improved air quality due to the 68 days of the shutdown of India’s industrial, commercial, construction, and transportation systems. The current study looked at the spatio-temporal changes in PM$_{2.5}$ concentrations at different air quality monitoring stations (AQMS) in Kolkata during the COVID-19 period. The study revealed that the average concentration of PM$_{2.5}$ ($\mu g/m^3$) was slightly high (139.82) in the pre-lockdown period which was rapidly reduced to 37.77 (72.99% reduction) during the lockdown period and it was further increased (137.11) in post-lockdown period. The study also shows that the average concentration of PM$_{2.5}$ was 66.83 in 2018, which slightly increased to 70.43 (5.39%) in 2019 and dramatically decreased to 37.77 (46.37%) in the year 2020 due to the COVID-19 outbreak and lockdown. The study clearly shows that air quality improves during lockdown periods in Kolkata, but it is not a permanent solution rather than temporary. Therefore, it is necessary to make the proper policies and strategies by policymakers and government authorities, and environmental scientists to maintain such good air quality by controlling several measures of air pollutants.

Keywords Air pollutant · COVID-19 · Environmental sustainability · Lockdown · PM$_{2.5}$

Introduction
The deadly infectious disease COVID-19 was primarily reported in China in the last week of December 2019 and within a few days, it becomes the primary concern of the whole world (Sahoo et al. 2021). This fatal disease primarily originated from the seafood market of Wuhan city and spread rapidly rest of the world (Shehzad et al. 2020; Shen et al. 2021; Singh and Chauhan 2020) and has created the critical condition for the world’s population. By considering of global impact, the World Health Organization (WHO) declared the situation as a ‘Global pandemic’ on 12 march 2020 (Kumari and Toshniwal 2020a), and it became the largest pandemic after the Spanish flu, Asian flu, Hong Kong flu, and a flu pandemic which occurred in 1918, 1957, 1968, and 2009, respectively. Every sphere of modern human civilization has been influenced by this alarming issues (Wang et al. 2020). Therefore, according to Das et al. (2020), COVID-19 is a global threat to human survival. This was not only a health crisis but also a social, and economic crisis for the world (UNO). Globally, the impact on human health is very pathetic including 6,258,023 deaths recorded until 12 May 2022 due to the COVID-19 outbreak throughout the world (WHO 2022). Kumar et al. (2020) also showed a significant number of European countries were facing extremely worse
conditions than all the countries of the World. In a global scenario, India became a vulnerable place for her huge population and population density compared to other countries and the fatal aftermath of COVID-19 creates this unprecedented massacre worldwide (Bera et al. 2021a; Ruidas and Pal 2022). The rapid spreading nature of this fatal disease pushed the Indian government to take immediate necessary steps to prevent the deadly situation. As example, the Government of India (GOI) issued a ‘Janata Curfew,’ (People’s Curfew), on March 22, 2020, from 7 a.m. to 9 p.m., to break the cycle of Corona Virus (COVID-19) (Bera et al. 2021b; Das et al. 2021). After this COVID-19 pandemic crisis has reached such a severe level that scientists, physicians, and other health experts were worried about it and GOI finally declared an emergency countrywide lockdown from March 24th to April 14th (Phase I) (Datta et al. 2021; Pal et al. 2022a; Saha et al. 2021). The lockdown time has also been extended from the 15th of April to the 3rd of May (Phase II), from the 4th of May to the 17th of May (Phase III), and from the 18th of May to the 31st of May (Phase IV) to break the chain of the virus and stop its genetic mutation globally (Das et al. 2021; Srivastava et al. 2020). Globally accepted lockdown strategies with the social distancing become significant tools in weakening the terminal effect of COVID-19 (Huang et al. 2021).

The most devastating situation was coming in May 2021 at this point, India reached its peak after the curve it gradually declined till now a total of 524,157 deaths are recorded throughout the country (WHO 2022). So, the lockdown strategy of GOI along with several preventive measures including physical distancing, wearing a mask, cleaning, and sanitizing hands played a significant role in preventing the COVID-19 outbreak throughout the country which was taken by most of the countries in the world in the same time. During the total lockdown periods, international, national, state, and district-level transportation communication (with the exception of doctors, nurses, health workers, and government officials’ staff), industry, commercial and private sector, school, college, university, and religious places were all completely shut down. Daily marketing, bank service, electricity, water, sanitation, and grocery shops, among other things, were open, and it would be facilitated only if necessary precautions against the COVID-19 virus were taken, such as wearing masks, maintaining physical distance, and regularly washing hands with soap and water or using hand sanitizer on an as-needed basis. Das et al. (2021) established that these all have several impacts on all sectors of society can be economic and environmental. The 68-day nationwide lockdown, which lasted from March 24, 2020, to May 30, 2020, had a detrimental influence on all aspects of the Indian economy and human health, as well as mental health. Pal et al. (2021a, b) display how the poor strategy during the lockdown period affects all migrant workers in different parts of India. Hence, the restriction on all outdoor activities of human, and economic activities play an important role in the decrease of several toxic emission that brings the fundamental changes in environmental quality especially in environmental pollution more specifically air pollution in the Indian context (Sharma et al. 2020; Zhang et al. 2020). Therefore, according to (Son et al. 2020) the lower level of air pollution made indirect health benefits to the public health. However, it has had a positive impact on the environment, specifically on air quality, as a result of partial to total lockdown in various countries around the world (Kabiraj and Gavli 2020). The level of air pollution remarkably decreased during different lockdown phases in India (The Central Pollution Control Board, 2020). So, the lock-up stage of India helps the environment to heal in a natural way as well as in the improvement of air quality index throughout the world. In India, a metropolitan city experienced that the major pollutant like PM_{2.5} and PM_{10} were significantly decreased by 40–60% (Chowdhuri et al. 2022) along with the temperature also decreased (Chakrabortty et al. 2021; Pal et al. 2021a). The urban environment has been impacted by the air quality index of urban centres. Singh (2020) beautifully showed a positive relation between lockdown and a decrease in air pollution in the Delhi NCR region. Therefore, because of the nationwide transportation shutdown throughout the lockdown period, the environment has become less polluted and more stable in terms of air quality (Yadav et al. 2020). Agarwal et al. (2020) represent Kolkata as a metropolitan city and how improved its air quality. In this study, we have tried to find out these noteworthy changes in air quality with a special focus on PM_{2.5} concentrations in the metropolitan city of Kolkata in West Bengal.

Nowadays, particulate matter < 2.5 µg (PM_{2.5}) is the major air pollutant in many countries like India (Agarwal et al. 2020). Ambient (outdoor) air pollutant exposure such as PM_{2.5} was estimated to cause 4.2 million premature deaths all over the world. The maximum percentage of particulate matter (PM_{10} and PM_{2.5}) has been emitted from power plants, industries, and automobiles (Mandal et al. 2020). In terms of PM_{2.5} concentration, India has 14 out of 15 most polluted cities in the world. The intensity of respiratory and cardiovascular diseases such as asthma, lung cancer, bronchitis, COPD, heart attack, etc. has increased due to the long-time exposure to PM_{2.5} (Etchée et al. 2017; Rajak and Chattopadhyay 2020). The concentration of particulate matter is very high in the lockdown region than the open coastal region. Changes in the concentration of PM_{2.5} in the atmosphere have an enormous impact on human health as well as the environment (Chen et al. 2020). Several kinds of chronic health issues like pulmonary diseases, pneumonia, and bronchitis are caused by PM_{2.5} concentration in the
atmosphere (Singh 2018). The researchers (Ito et al. 2007; Nowak et al. 2013; Xing et al. 2016) have tried to establish how the PM$_{2.5}$ concentration adversely affects human health.

Kolkata is the second-worst megacity of India out of four in terms of the air quality index. The atmospheric condition of Kolkata city is severely attacked by construction, industrial, commercial, and vehicular gas emissions. PM$_{2.5}$ is the prominent air pollutant out of seven air pollutants (O$_3$, CO, SO$_2$, NO$_2$, NH$_3$, PM$_{10}$, and PM$_{2.5}$) referred by the Central Pollution Control Board (CPCB) of India (Saini and Sharma 2020). In Kolkata, construction works have generated maximum content of PM$_{2.5}$. The city of joy (Kolkata) transformed into the main containment zone of West Bengal due to severely attacked of COVID-19 and the similar preventive measure also adopted in Kolkata; due to this air quality of Kolkata was remarkably rejuvenated by improving air quality and reducing the emission of PM$_{2.5}$.

Few studies have been done by the previous researcher on air quality during lockdown period in Kolkata city, including (Bera et al. 2021b; Chowdhuri et al. 2020; Sahani et al. 2020). All the above-mentioned studies have been done on different air pollutants such as PM$_{10}$, PM$_{2.5}$, O$_3$, SO$_2$, NO$_2$, and CO. As a result, the current study focuses on improving air quality and the condition of the environment in terms of PM$_{2.5}$ concentration during the lockdown period by comparing the pre- and post-lockdown periods. This analysis also attempts to answer the issue of whether or not PM$_{2.5}$ concentrations improved in different air quality monitoring stations of Kolkata city during the lockdown period by comparing two prior year databases (2018 and 2019) of the same period.

**Study area**

Kolkata is the capital region of the Indian state of West Bengal and the third most populous city of India according to the 2011 census. Kolkata Municipal Corporation (KMC) and its adjacent area is the major urban agglomeration in West Bengal. It is extended from 22°30’N to 20°37’N latitude and from 88°17’E to 88°27’E longitude (Fig. 1). The total area of the study area is about 206.08 km$^2$ with a higher population density of 24,252 persons/km$^2$. Though this region is the educational, cultural, and economic hub of eastern India and it also facing significant problems due to poverty, overpopulation, traffic overcrowding situation (Das et al. 2015). Climatically this region is characterized by a tropical dry and wet climate with a 26.8 °C mean annual temperature. It is one of the biggest cities in India and the process of urbanization and road density is rapidly increasing day by day. On the other hand, the
data from different air quality monitoring stations in Kolkata city show the condition of air quality is very poor than other metropolitan cities of India except for Delhi metropolitan city. Exposure to PM$_{2.5}$ air pollutants is dominated in Kolkata city. There have several sources namely construction works, industrial, commercial, and transportation sectors increase the PM$_{2.5}$ concentration in the atmosphere of KMC. The total emissions of PM$_{2.5}$ from the different sectors were about 88,250 tons/year (48,350 tons from the industrial sector; 7700 tons from residential emissions; 6500 tons from the transportation sector; 6250 tons from open waste burning and 19,450 tons from other sectors) in the year of 2018 in Kolkata (Urban Emission Report, 2018).

Seven important industrial, commercial, and residential hubs with air quality monitoring stations (AQMS) of KMC namely Ballygunge (BAL), Bidhannagar (BID), Fort William (F.W), Jadavpur (JAD), Rabindra Bharati University (RBU), Rabindra Sarobar (R.S), and Victoria (VIC) have been considered here. As they are part of the Kolkata Municipal Corporation (KMC) and these AQMS have a great influence on air quality. In all the AQMS, the air quality is far more than the WHO (2021) referred permissible limit (25 µg/m$^3$ hourly).

Materials and methodology

Data

In 1984, the West Bengal Pollution Control Board (WBPCB) started to monitor the hourly basis ambient air quality database of various air pollutants under the guidance of the Central Pollution Control Board (CPCB) of India. All the daily average data of PM$_{2.5}$ is collected from the CPCB of India from 1st February to 30th December (https://app.cpcbcr.com/AQI_India/) to assess the spatial distribution of PM$_{2.5}$ concentrations. The collected dataset has divided into three categories such as Pre-Lockdown Period (1st February–15th March), Lockdown Period (30th March–30th May), and Post-Lockdown Period [15th June–30th July (Unlock 1.0 and 2.0) and 15th November–30th December (Unlock 6.0 and 7.0)] in the year of 2020 to get the meaningful spatio-temporal variation of ambient PM$_{2.5}$ exposure. Air quality data of PM$_{2.5}$ exposure in the year 2018 and 2019 have also been collected from the CPCB website for the same period of lockdown (March–May) to do a comparative study.

Methodology

Inverse distance weighted (IDW) spatial interpolation

There are several interpolation methods are available to perform the spatial distribution including kriging, IDW, spline, natural neighbor, moving average, polynomial regression, etc. But IDW is preferable for the small geographical area (Basu 2015) and is also used by several researchers in their work (Apak and Atay 2013; Pal et al. 2022b; Ruidas et al. 2021, 2022). According to (Zhang and Tripathi 2018), the IDW method is the most suitable tool for regional spatial distribution analysis. Therefore, the IDW interpolation method is used to analyze the spatial distribution of PM$_{2.5}$ concentration in different air quality monitoring stations in Kolkata city using ArcGIS Toolbox. The following equation helps to perform this technique:

$$Z_o = \frac{\sum_{i=1}^{S} \frac{Z_i}{d_i^s}}{\sum_{i=1}^{S} \frac{1}{d_i^s}}$$

where $Z_o$ represents the value of an unknown point, $Z_i$ represents the observed value at the I location, and the distance between i and o represent by $d_i$ and s is the number of known points (Guan and Wu 2008).

Statistical methods

Trend analysis To estimate the trend of PM$_{2.5}$ concentrations in different years (2018, 2019, and 2020) during the same period of lockdown (March–May 2020), a composite line graph has been prepared. An average line has been used to understand the fluctuation of PM$_{2.5}$ concentrations in the year 2020 (COVID-19 year) in comparison to the 2018 and 2019 normal years.

Box plot Box and whisker plots are also known as box plot which represent the variability of the dataset outside the upper and lower quartile (McGill et al. 1978). Box plot is used here to display the variation of PM$_{2.5}$ exposure at the time of lockdown in comparison to pre- and post-lockdown period.

Results

Spatio-temporal variation of PM$_{2.5}$ in pre-lockdown, lockdown, and post-lockdown period

In this study, PM$_{2.5}$ data of different air quality monitoring stations (AQMS) in Kolkata city has been used to analyze the spatio-temporal changes of PM$_{2.5}$ among different AQMS. The highest average concentration of PM$_{2.5}$ (µg/m$^3$) at Ballygunge (262), Bidhannagar (160), Fort William (199), Jadavpur (147), Rabindra Bharati University (234), Rabindra Sarobar (117), and Victoria (165), respectively. The lowest average concentration of PM$_{2.5}$ (µg/m$^3$) has been found at Ballygunge (120), Bidhannagar (77), Fort...
William (118), Jadavpur (123), Rabindra Bharati University (68), Rabindra Sarobar (109), and Victoria (82), respectively (Fig. 2).

The concentration of PM$_{2.5}$ among different AQMSs of Kolkata city has been rapidly declined after the implementation of the lockdown nationwide (Fig. 3). During the lockdown (30th March–30th May) period, the highest average concentration of PM$_{2.5}$ ($\mu$g/m$^3$) was recorded at Ballygunge (61), Bidhannagar (56), Fort William (86), Jadavpur (70), Rabindra Bharati University (70), Rabindra Sarobar (60), and Victoria (58), respectively. The lowest average concentration of PM$_{2.5}$ ($\mu$g/m$^3$) at Ballygunge (22), Bidhannagar (23), Fort William (23), Jadavpur (20), Rabindra Bharati University (25), Rabindra Sarobar (24), and Victoria (82), respectively.

The average concentration of PM$_{2.5}$ ($\mu$g/m$^3$) was recorded maximum at Ballygunge (39), Bidhannagar (31), Fort William (31), Jadavpur (27), Rabindra Bharati University (56), Rabindra Sarobar (26), and Victoria (37), respectively, and recorded minimum at Ballygunge (11), Bidhannagar (18), Fort William (22), Jadavpur (17), Rabindra Bharati University (19), Rabindra Sarobar (15), and Victoria (18), respectively, during unlocking 1.0 and 2.0 (1st June–30th July). After the full withdrawal of lockdown across the country during unlocking 6.0 and 7.0 (1st Nov–30th Dec), the average concentration of PM$_{2.5}$ has dramatically increased (Fig. 4). The highest level
Fig. 3  Spatial variation of PM$_{2.5}$ concentration during lockdown period
of average $\text{PM}_{2.5} (\mu g/m^3)$ concentration was recorded at Ballygunge (339), Bidhannagar (307), Fort William (335), Jadavpur (349), Rabindra Bharati University (343), Rabindra Sarobar (332), and Victoria (345), respectively, and lowest at Ballygunge (185), Bidhannagar (148), Fort William (184), Jadavpur (173), Rabindra Bharati University (278), Rabindra Sarobar (154), and Victoria (187), respectively. During the post-lockdown period (unlock 1.0 and 2.0–unlock 6.0 and 7.0), a maximum increase of $\text{PM}_{2.5} (\mu g/m^3)$ concentration was recorded at Ballygunge, which signified withdrawal of lockdown and partial to full relaxation of transport and industrial sector from unlocking 1.0–7.0 (Fig. 7).

**Changes in $\text{PM}_{2.5}$ concentration in pre-lockdown, lockdown, and post-lockdown period**

After the analysis of the $\text{PM}_{2.5}$ database, it was revealed from the study that the concentration of $\text{PM}_{2.5}$ has changed

![Spatial distribution of $\text{PM}_{2.5}$ concentration in post-lockdown period](image)
throughout the assessment period. The concentration of PM$_{2.5}$ was comparatively high in the pre-lockdown and post-lockdown period than in the lockdown period. The average concentration of PM$_{2.5}$ ($\mu$g/m$^3$) noticeably declined from 182.5 to 36.6 (Table 1) during the lockdown period which was reduced by about 79.95% (Table 2) in comparison to the pre-lockdown period at Ballygunge followed by Rabindra Bharati University (74.71%) and Victoria (73.94%). At Bidhannagar and Rabindra Sarobar the declination of PM$_{2.5}$ was recorded 66.07–67.37%, respectively, during the lockdown period.

The concentration of PM$_{2.5}$ decreased still partial withdrawal of lockdown (Unlock 1.0 and 2.0) at Kolkata. Maximum reduction of PM$_{2.5}$ was found at Ballygunge (47.4%) followed by Rabindra Sarobar (42.20%) and Fort William (38.08%) and minimum at Rabindra Bharati University (0%), Victoria (24.27%), and Bidhannagar (30.87%) during unlocking 1.0 and 2.0 in comparison to lockdown period.

The rapid increase of PM$_{2.5}$ was observed at different AQMSs of Kolkata city in unlocking 6.0 and 7.0 due to nationwide withdrawal of lockdown at different stages by withdrawal of different restrictions compare to unlock 1.0 and 2.0 (Tables 1 and 2). The average concentration of PM$_{2.5}$ ($\mu$g/m$^3$) was increased about 19.25 to 241 ($\mu$g/m$^3$) (1151.95%), 22.75 to 253 ($\mu$g/m$^3$) (1012.09%), 21.50 to 219.75 ($\mu$g/m$^3$) (922.09%), 26.75 to 250.5 ($\mu$g/m$^3$) (836.45%), 24.75 to 219.25 ($\mu$g/m$^3$) (785.86%), 28 to 247.75 ($\mu$g/m$^3$) (784.82%), and 38–307.25 ($\mu$g/m$^3$) (708.55%) at Ballygunge, Jadavpur, Rabindra Sarobar, Fort William, Bidhannagar, Victoria, and Rabindra Bharati University, respectively.

### Comparative analysis of PM$_{2.5}$ concentration in the year 2018, 2019, and 2020

To assess the status of air quality in terms of PM$_{2.5}$ concentration, data for 2018 and 2019 have been compared with the data of 2020 during the same period of lockdown (COVID-19 period). From Table 3 and Fig. 5, it is crystal clear that the concentration of PM$_{2.5}$ has decreased in the year 2020 due to the cause of the COVID-19 pandemic and lockdown across the country in comparison to the previous 2 years 2018 and 2019. The highest average concentration of PM$_{2.5}$ ($\mu$g/m$^3$) was recorded at 78.6, 71.8, and 69.8

#### Table 1 The average concentration of PM$_{2.5}$ in pre-lockdown, lockdown, and post-lockdown period

| Station | Pre-lockdown | Lockdown | Post-lockdown Unlock 1.0 and 2.0 | Unlock 6.0 and 7.0 |
|---------|--------------|----------|----------------------------------|-------------------|
| BAL     | 182.5        | 36.6     | 19.25                            | 241               |
| BID     | 105.5        | 35.8     | 24.75                            | 219.25            |
| F.W     | 150.25       | 43.2     | 26.75                            | 250.5             |
| JAD     | 133.5        | 36.4     | 22.75                            | 253               |
| RBU     | 150.25       | 38       | 38                               | 307.25            |
| R.S     | 114          | 37.2     | 21.5                             | 219.75            |
| VIC     | 142.75       | 37.2     | 28                               | 247.75            |

#### Table 2 Changes in per cent of PM$_{2.5}$ among pre-lockdown, lockdown, and post-lockdown period

| Station | Percentage of change Between pre-lockdown and lockdown | Between lockdown and unlock 1.0 and 2.0 | Between unlock 1.0 and 2.0 and unlock 6.0 and 7.0 |
|---------|--------------------------------------------------------|----------------------------------------|-----------------------------------------------|
| BAL     | − 79.95                                                | − 47.4                                 | 1151.95                                     |
| BID     | − 66.07                                                | − 30.87                                | 785.86                                     |
| F.W     | − 71.25                                                | − 38.08                                | 836.45                                     |
| JAD     | − 72.73                                                | − 37.5                                 | 1012.09                                    |
| RBU     | − 74.71                                                | 0                                     | 708.55                                     |
| R.S     | − 67.37                                                | − 42.2                                 | 922.09                                     |
| VIC     | − 73.94                                                | − 24.73                                | 784.82                                     |

#### Table 3 Average concentrations and changes in presentation of PM$_{2.5}$ in the year of 2018, 2019, and 2020

| Station | Average concentration of PM$_{2.5}$ 2018 and 2019, 2020 | Percentage of change Between 2018 and 2019 | Between 2019 and 2020 |
|---------|----------------------------------------------------------|---------------------------------------------|------------------------|
| BAL     | 78.6, 79, 36.6                                         | 0.51, − 53.67                              | − 53.67                |
| BID     | 67, 66.8, 35.8                                          | − 0.3, − 46.41                             | − 46.41                |
| F.W     | 67.6, 67.6, 43.2                                         | 0, − 36.09                                 | − 36.09                |
| JAD     | 64.6, 70.4, 36.4                                        | 8.98, − 48.3                               | − 48.3                 |
| RBU     | 71.8, 77.8, 38                                          | 8.36, − 51.16                              | − 51.16                |
| R.S     | 69.8, 78, 37.2                                          | 11.75, − 52.31                             | − 52.31                |
| VIC     | 48.4, 53.4, 37.2                                        | 10.33, − 30.34                             | − 30.34                |
Fig. 5 Spatial distribution of PM$_{2.5}$ concentration in the year 2018, 2019, and 2020 as the same period of lockdown.
at Ballygunge, Rabindra Bharati University, and Rabindra Sarobar, respectively, and the lowest at 48.4–64.6 at Victoria and Jadavpur, respectively, in the year of 2018 (Fig. 5). In the year 2019, PM$_{2.5}$ ($\mu$g/m$^3$) was spatially concentrated high at Ballygunge (79) followed by Rabindra Sarobar (78) and Rabindra Bharati University (77.8) and low at Victoria (53.4), followed by Bidhannagar (66.8) and Fort William (67.6). Among the different AQMSs of Kolkata city, Fort William has experienced the highest average concentration of PM$_{2.5}$ ($\mu$g/m$^3$) which is 43.20 which was followed by Rabindra Bharati University (38), Rabindra Sarobar (37.20), and Victoria (37.20) in the year of 2020. The lowest average concentration of PM$_{2.5}$ ($\mu$g/m$^3$) has experienced 35.80, 36.40, and 36.60 at Bidhannagar, Jadavpur, and Ballygunge, respectively (Table 3).

The average concentration of PM$_{2.5}$ has increased in the year 2019 in comparison to the year of 2018 and decreased in the year 2020 in comparison to the year 2018 and 2019 (Table 3). At Ballygunge, Jadavpur, Rabindra Bharati University, Rabindra Sarobar, and Victoria average concentration of PM$_{2.5}$ has increased by 0.51, 8.98, 8.36, 11.75, and 10.33 percent, respectively, in the year 2019. Study indicates that there was very little change in PM$_{2.5}$ concentration at Fort William and only Bidhannagar has recorded a declination of PM$_{2.5}$ concentration that was 0.30% in the year 2019 in comparison to the year 2018. Rapid declination of PM$_{2.5}$ level was noticed in the year 2020 due to the COVID-19 pandemic throughout India (Sahoo et.al 2020). In the year 2020, the most reduction of PM$_{2.5}$ has been recorded at Ballygunge (53.67%) followed by Rabindra Sarobar (52.31%) and Rabindra Bharati University (51.16%) and Victoria and Fort William recorded a comparatively minimum reduction of PM$_{2.5}$ that was 30.34–36.09%, respectively. Alongside, average concentration of PM$_{2.5}$ and trend analysis of PM$_{2.5}$ is presented in Figs. 6 and 7 accordingly to understand the nature of PM$_{2.5}$ concentration in the atmosphere in several condition. Figures 6 and 7 illustrate that the concentration of PM$_{2.5}$ increased in alarming rate in the COVID-19 pandemic period in 2020 than the same period of 2018 and 2019 due to the shutdown of industry, strictly stop of vehiciles and brick fields in Kolkata as well as through out India.

### Status of PM$_{2.5}$ in pre-lockdown, lockdown, and post-lockdown period

The PM$_{2.5}$ air quality status in terms of different air quality index categories—0–30 (Good), 31–60 (Satisfactory), 61–90 (Moderate), 91–150 (Poor), 150–250 (Very Poor), and > 250 (Severe) has shown the condition of air quality at various AQMSs of Kolkata city in pre-lockdown, lockdown, and post-lockdown period. In the pre-lockdown period, there was the absence of PM$_{2.5}$ in the good category and 14.29%, 57.14%, 25%, and 3.57% PM$_{2.5}$ concentrated in moderate, poor, very poor, and severe, respectively. The air quality was improved during the lockdown period and it experienced 45% good, 42.86% satisfactory, and 11.43% moderate status of PM$_{2.5}$ (Table 4). During the lockdown period, there was an absence of poor, very poor, and severe categories of air quality which signifies that the quality of air at that time was healthy than the pre-lockdown period. At the end of the lockdown period and beginning of the post-lockdown period, with partial relaxation of transport, industry, and other sectors, air quality of Kolkata city was gradually decreased and it reached its worst condition in December when unlock 7.0 was announced by Govt. of India. The status of PM$_{2.5}$ was 35% under good, 12.5% under satisfactory, 1.79% under moderate, 1.79% under poor, 25% under very poor, and 23.22% under severe category in post-lockdown period (Fig. 8).

### Discussion

The Indian cities are the most polluted cities in the world in terms of PM$_{2.5}$ concentration. In the last few decades, different air pollution controlling measures have been taken into consideration for maintaining the air quality but the target was not fulfilled completely. But the outbreak of COVID-19 and the consecutive strict lockdown has substantially improved the air quality and the sustainability of the environment. According to Banerji and Mitra (2021), the consecutive parameters had remarkable values in pre-lockdown stage but these significantly decrease in the lockdown stage and took place below the WHO prescribed standard limit. Sarmadi et al. (2021) also make research on several cities throughout the world and established that AQI significantly decline in India. PM$_{2.5}$ concentration has significantly reduced at different AQMS in Kolkata city and its surrounding in this lockdown period (24th March–30th May 2020) in comparison to the pre-lockdown and post-lockdown period. The concentration of PM$_{2.5}$ has declined significantly from 182.5 $\mu$g/m$^3$ to 36.6 $\mu$g/m$^3$ (79.95%) during the lockdown period in comparison to the pre-lockdown period at the Ballygunge air quality monitoring station. The highest reduction of PM$_{2.5}$ concentration has been observed at Ballygunge, i.e., 7–36.6 $\mu$g/m$^3$ in the year 2020 in comparison to the year 2019 (at the same period of lockdown, 2020).

During the time of lockdown, our present study as well as other related studies (Kumari and Toshniwal 2020; Menut et al. 2020; Schneider et al. 2022; Singh and Chauhan 2020; Yao et al. 2021) emphasize on the relation between air quality and restricted anthropogenic and all outdoor activities throughout the world. In India, the significant amount of PM$_{2.5}$ decreased during this lockdown phase (Ravindra et al. 2021) and several studies (Biswal et al. 2020; Naqvi et al. 2021; Rahaman et al. 2021) shows the change in air quality.
standard of pre during lockdown stage and results repre-
sent that there is significant improvement during lockdown
stage comparison to pre-lockdown stage. Though air qual-
ity of a region notable relies on anthropogenic activities,
emission sources of a region. Lockdown helps to reduce the
exposure of these major sources and make the meteorologi-
cal environment favorable for existing life forms on earth
rather the PM2.5 could be recorded as 33% higher than the
during lockdown stage (Sharma et al. 2020). The selected
study region is one of the most populated and polluted cit-
ties of India which has very much impacted air quality and
the environment. Therefore, as the several industrial sectors
were locked, Kolkata, Chennai, and Mumbai experienced
the highest level of reducing air pollutants (Ravindra et al.
2021). The major pollutant of Kolkata city is PM2.5 which
is primarily sourced from the vehicle, industrial sector, con-
struction sector, etc. The strict lockdown has improved the
air quality, environment, and PM2.5 concentration as well
due to the COVID-19 pandemic. Thus, the different AQMS
of Kolkata city has experienced a reduction of PM2.5 con-
centration in its air quality history.

All the aforementioned studies including our present
study highlight the air quality improvement and lockdown
strategy especially the reduction of all outdoor activities.
Therefore, where the air quality is very poor including the
PM2.5 concentration and becomes a major challenge to attain

![Fig. 6 Trend of PM2.5 concentration in pre-lockdown, lockdown, unlock 1.0 and 2.0, and unlock 6.0 and 7.0 in 2020](image-url)
the standard limit of air quality. Hence, it is very high and needs some significant strategies. (Kumar et al. 2017) states that the odd-even vehicle strategy does not so much measurable impact on air quality improvement. So, we have to adopt another strategy and a revised form of the existing

![Fig. 7 Average concentration of PM$_{2.5}$ in pre-lockdown, lockdown, unlock 1.0 and 2.0 and unlock 6.0 and 7.0 in 2020](image-url)

![Table 4 Status of PM$_{2.5}$ (%) in pre-lockdown, lockdown, and post-lockdown period](table-url)

| AQI category | Status of PM$_{2.5}$ (%) |
|--------------|-------------------------|
|              | Pre-lockdown | Lockdown | Post-lockdown |
| Good         | 0            | 45       | 35            |
| Satisfactory | 0            | 42.86    | 12.5          |
| Moderate     | 14.29        | 11.43    | 1.79          |
| Poor         | 57.14        | 0        | 1.79          |
| Very poor    | 25           | 0        | 25            |
| Severe       | 3.57         | 0        | 23.22         |

![Fig. 8 Status of PM$_{2.5}$ in pre-lockdown, lockdown, and post-lockdown period](image-url)
strategy in improving air quality standards. The sustainability of the environment could be maintained by taking the preventive measures. The air quality of selected study area as well as its surroundings could be managed and controlled from undesirable air quality pollutant such as PM$_{2.5}$ as the goals set in millennium development goals (MDGs) and sustainable development goals (SDGs).

So, the implication of the study signified that how the strict lockdown controls the air quality in terms of PM$_{2.5}$ concentrations and such short duration lockdown can improve the air quality in every part of the world; and it also helps to understand the small-time lockdown or reducing the excessive outdoor activities can improve the air quality as well. For the betterment of the environment, the government should take such measures as much as possible.

**Conclusion**

Lockdown was imposed in India to break the chain and limit the transmission of the coronavirus as much as possible. The objective was partially met in this respect, but another wonderful thing happened during the lockdown time, which was an increase in air quality and environmental sustainability. In this study, the declination of PM$_{2.5}$ concentrations in different most polluted AQMSs of Kolkata city was assessed during the lockdown period in comparison to the pre-lockdown and post-lockdown periods, as well as the reduction of PM$_{2.5}$ concentrations in the year 2020 (COVID-19 year) in comparison to the years 2018 and 2019 as the same lockdown period. According to the study, the average concentration of PM$_{2.5}$ decreased gradually (15.83%) from 1st February to 15th March (pre-lockdown period) and fast (73.70%) from 30th March to 30th May (lockdown period). During the lockdown period, partial to complete restrictions on transportation, construction, industrial, and other sectors dramatically decreased PM$_{2.5}$ emissions, which benefited air quality, the environment, and human health (in terms of airborne illnesses). The most polluting city, Kolkata, has seen a significant short-term reduction in PM$_{2.5}$ concentrations as a result of the implementation of lockdown in India and Kolkata. After the lockdown was lifted, the average concentration of PM$_{2.5}$ (µg/m$^3$) jumped from 37.33 to 137.11 (267.29%) from June to December 2020 (post-lockdown period). There was a modest increase (5.39%) in average PM$_{2.5}$ concentration between 2018 and 2019, and in 2020, the average PM$_{2.5}$ concentration fell considerably (46.37%) in comparison to the previous year. According to the study, the average concentration of PM$_{2.5}$ was decreased considerably throughout the lockdown time, and air quality improved noticeably. There was no question that the COVID-19 outbreak has improved air quality in terms of PM$_{2.5}$ at several AQMSs in Kolkata.

Our present study ensures, that it is very crucial to leave the environment as she wants to rejuvenate herself accordingly that is experienced by the whole world during the fatal COVID-19 disease; After removing all restrictions whole world gets its previous condition. It is not possible to leave nature, but some nature-oriented policies and strategies can help to fulfill this objective manually. Not only India but possibly most of the states adopted several strategies to reduce air pollution, especially particulate matter emission. Therefore, central agencies and all existing organizations have to be stricter on making and executing the policies mostly vulnerable regions to overcome the situation. The goals of MDGs and SDGs put in mind, the unwanted air quality pollutants should be minimized in such a way that the environment should not affected by the preventive measures. The current study assists planners, policymakers, and environmental scientists in improving air quality and implementing short-term restrictions on transportation, industry, and building projects, among other things.

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**Data availability** Data will be made available on request.

**Declarations**

**Conflict of interest** The authors declare that they have no conflict of interest.

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