Reduction in concentration of PM_{2.5} in India's top most polluted cities: with special reference to post-lockdown period

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Abstract

Lockdown in India begins from 25 March and continues until 31 May 2020 due to the COVID-19 pandemic situation. Due to such an extended period of lockdown for about more than 2 months resulted in 1.38 billion populations restricted themselves from mass activities that contribute to air pollution. Thus, through our quantitative approach and trend analysis, the study aims to evaluate the changes in the level of PM_{2.5} as a major pollutant for the top ten polluted cities in India, with a special emphasis on finding what happened to its concentration after the lockdown ended. Thus, to better understand the nature of variation in PM_{2.5}, we divide the entire 7 months into three periods for our analysis, i.e., before lockdown (1 January to 24 March), during lockdown (25 March to 31 May), and post-lockdown or unlock 1 and 2 (1 June to 31 July). Our investigation reveals that before lockdown, all the top polluted cities of India violating the national standard of PM_{2.5}, as the lockdown begins interestingly, all cities show a momentous reduction in PM_{2.5} concentration. Further, surprisingly we found that after the post-lockdown period, the concentration of PM_{2.5} was reduced to minimal, as the average concentration of PM_{2.5} for all the cities is below the National Ambient Air Quality Standard (NAAQS). The study reveals that the lockdown has a consequence in improving overall air quality for the top polluted cities in India and further lockdown in the future with proper planning should be considered an alternative approach to restrain excessive emissions.

Keywords Lockdown · COVID-19 · Air pollution · PM_{2.5} · India

Introduction

The present situation due to the COVID-19 pandemic has created a chaotic situation globally. In 11 March 2020, the World Health Organization (WHO) declared a pandemic due to SARS-COV-2 virus and named the contagious diseases as COVID-19 due to the thirteen-fold increases in the number of cases in China affecting 114 countries (WHO 2020). The first spread of COVID-19 from Wuhan, China, in December 2019, results in total cases above one million within the first 4 months (Sharma et al. 2020). India reports its first case of COVID-19 patient on 30 January 2020 with travel history from Wuhan (India Today 2020); after that, the number of

cases continued to spike in the country. Until then, the situation became more sensitive as the numbers of cases continue to rises and India finally initiates its first lockdown announced by the prime minister of India on 24 March 2020 and the lockdown will be effective from 25 March 2020 (Mahato et al. 2020). Since then, anthropogenic activities like mass vehicle movement, industrial activities, construction works, restaurants and malls, flight and cargo ships, and schools and colleges were restricted and it has a massive impact on the overall air quality. According to the latest report of 23 December 2020, India records about more than 10 million cases with more than 1.4 million deaths (<https://www.worldometers.info/coronavirus/>).

Few studies have shown that reduction in concentration PM_{2.5} (particulate matter size with 2.5-μ diameter) and overall air quality improves due to sudden lockdown globally. For example, Chauhan and Singh (2020) analyze the reduction in PM_{2.5} concentration due to lockdown in major global cities. They found that compared to the previous year, a momentous change in PM_{2.5} concentration was noticed. Also, Dhaka et al. (2020) assess the attenuation of PM_{2.5} and the reduction of haze events due to lockdown in Delhi. Further, Lian et al.

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(2020), Wuhan City of China, find that the reduction of NO_2 (53.3%) was more compared to $\text{PM}_{2.5}$ (36.9%), and also they discover lower air quality by 33.9% than before lockdown and 47.5% reduction compared to 2015–2019. Sharma et al. (2020) conducted their comprehensive research to find the level of emission over 22 Indian cities' during the lockdown period. They found $\text{PM}_{2.5}$ had shown maximum reduction followed by PM_{10} , CO, and NO_2 . Further, the study conducted by Mahato et al. (2020), in their study over Delhi, India, found about 40–52% reduction in the concentration of $\text{PM}_{2.5}$, PM_{10} , NO_2 , SO_2 , CO, and NH_3 compared to pre-lockdown periods.

The importance of lockdown to restore air quality is not yet clearly understood. Thus, through our study, we further try to fill the gap to better comprehend the actual scenario of the top polluted cities in India, especially after the lockdown ended. Does the unlocking again accumulate the surge of $\text{PM}_{2.5}$ concentration in the top polluted cities in India? To find this question, we conduct our study using a quantitative approach to find $\text{PM}_{2.5}$ concentration at different phases of lockdown with special reference to the post-lockdown period. Many studies show that due to excessive $\text{PM}_{2.5}$ exposure in India as it is one of the leading countries in terms of air pollution, consequence in a significant threat to human health as it causes major problems related to cardiovascular activity, respiratory illness, and increase in mortality rate (Ghude et al. 2016; Balakrishnan et al. 2018; Spears et al. 2019). Therefore, our scientific study attempted to understand the benefits of lockdown as an alternative approach to restrain the air quality. This paper aims (i) to find out the tendency and changes (%) in the concentration of $\text{PM}_{2.5}$ for the top polluted cities of India during the period of before, during, and after lockdown (Table 1); (ii) what is the nature of $\text{PM}_{2.5}$ for the top polluted cities after the lockdown ended? Hence, this study is very much feasible for the scientific community and the policymakers to better restrain the air qualities of the top most polluted cities in India and the world by considering lockdown as alternative measures with proper planning.

Material and methodology

Selection of study cities

We selected the top ten most polluted cities of India for our study which was ranked accordingly to the “World Air Quality Report” of 2019 published by IQAir visuals (2019) where $\text{PM}_{2.5}$ was the significant pollutants (Table 2). Based on this rank, we attempt to analyze the present scenario of $\text{PM}_{2.5}$ concentration in these top ten cities and its changes due to pandemic lockdown. However, the 6th and 10th cities' data are not available for a more extended period, hence excluded and the next alternative cities were selected for the study.

Data source

The entire study was based on secondary data and to interpret the changes in the concentration of $\text{PM}_{2.5}$ due to lockdown in different cities, daily (24 h) automatic data from 1 January to 31 July 2020 was collected. The data of $\text{PM}_{2.5}$ for Delhi was collected from online portal known as AirNow which was maintained by the US Environmental Protection Agency ([https://www.airnow.gov/international/us-embassies-and-consulates/#India\\$New_Delhi](https://www.airnow.gov/international/us-embassies-and-consulates/#India$New_Delhi)) and the rest of the data for nine cities were collected from the Central Pollution Control Board (CPCB) of India which was available online (<https://app.cpcbcr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data>). The data provided by the CPCB is very authentic and standardized as they follow a variety of rules and regulations for the collection and evaluation of data (Mahato et al. 2020). Furthermore, satellite images obtained from the Copernicus Tropospheric Monitoring Instrument (TROPOMI) were used to display the improvements in $\text{PM}_{2.5}$ concentration over the Indian atmosphere. This satellite, developed by the European Space Agency (ESA), is primarily used for the measurement of air quality, including the concentration of various particulate matters and also to track climate forecasting (Lokhandwala and Gautam 2020).

Data analysis

In order to assess the different scenarios of $\text{PM}_{2.5}$, we divide the data in terms of before lockdown (from 1 January to 24 March), during lockdown (25 March to 31 May), and post-lockdown period (from 1 June to 31 July) to comprehend better the nature and changes of $\text{PM}_{2.5}$ (Table 1). The mean concentration of $\text{PM}_{2.5}$ was calculated for each phase (i.e., before, during, and after lockdown) in order to compare the changes (%) and variation among pre-during and pre-post lockdown periods (Table 3). For cities like Ghaziabad, Gurugram, Noida, Greater Noida, and Lucknow, which have more than one automatic air monitoring stations, the data of $\text{PM}_{2.5}$ for these cities are calculated by aggregating the number of stations.

Both descriptive and inferential statistics were conducted, including mean, standard deviation (SD), paired t test, linear regression model, and coefficient of determination. A paired t test was included to understand the mean difference between dependent observations to determine whether there are considerable differences between the concentrations of $\text{PM}_{2.5}$ for the period of pre-during and pre-post lockdown. The t test is a statistical analysis technique constructed by William Sealy Gosset in 1908 to determine if two sets of data are significantly different

Table 1 Different phases of lockdown in India due to COVID-19 pandemic

Lockdown phases in India	Dates	Source
Pre-lockdown phase	1 January to 24 March (considered - for study)	
Lockdown phase	25 March to 31 May	https://en.wikipedia.org/wiki/COVID-19_pandemic_lockdown_in_India
Post-lockdown (unlock 1 and 2)	1 June to 31 July	https://timesofindia.indiatimes.com/topic/Unlock-1 . https://indianexpress.com/article/india/india-unlock-2-guidelines-rules-what-is-allowed-coronavirus-6482192/

from each other (Kim 2015). The paired *t* test with a 2-tailed method was performed at a 5% significance level. Also, the relationship between each independent and dependent variable is analyzed using the regression coefficient. Besides, the coefficient of determination was also assessed, which is also denoted by *R*-squared value; *R*² is the fraction of variation of one variable explained by other variables used to determine the strength of the relationship in the regression model (Kasuya 2018). Therefore, the higher *R*-squared value in this study indicates that the model fits the data well. Further trend analysis was carried out for each city separately by analyzing the daily average of PM_{2.5} for the entire 7 months, revealing the changing nature of its concentration due to lockdown and after the lockdown ended.

The Copernicus satellite images showing PM_{2.5} concentration over the atmosphere of India, acquired for the period of before lockdown (January to March), during lockdown (end of March to May), and also for post-lockdown (June and July), were shown in Fig. 3a–h. The dark red color shows a very high accumulation of PM_{2.5}, yellow color depicts moderate, and dark blue shows low concentration.

Result

According to the 2019 report from IQAir visual, out of thirty most polluted cities in the world, twenty-one belongs to India (The Indian Express 2019) and thus the study tries to reveal about the changes in the concentration of PM_{2.5} as major pollutants for the top most polluted cities during the different phases of lockdown. Our study found that the diurnal tendency of concentration for PM_{2.5} before the period of lockdown (i.e., from 1 January to 24 March 2020) shows violating the limit of the National Ambient Air Quality Standard (NAAQS) which is much higher than the safe limit (Figs. 1a, b, c, d, e, f, g, h, i, j and 2). However, the diurnal standard for PM_{2.5} in India was 60 µg m⁻³ set by the NAAQS for residential, industrial, and ecologically sensitive areas and breaching this limit consequence in bad air quality (CPCB report 2009). Based on our findings, the mean concentration of PM_{2.5} before the lockdown period was 133 µg m⁻³ for Ghaziabad followed by 122 µg m⁻³ for Noida, 120 µg m⁻³ for Greater Noida, 115 µg m⁻³ for Bulandshahr, 114 µg m⁻³ for Delhi, 105 µg m⁻³ for Faridabad, 104 µg m⁻³ for Lucknow, 89 µg m⁻³ for Muzaffarnagar, 88 µg m⁻³ for Gurugram, and 77 µg m⁻³ for

Table 2 Location of the top most polluted cities selected for the study and their rank accordingly

Sl. no.	Rank according to 2019*	City	Lat	Long	State/union territories
1	1	Ghaziabad	28° 40' 9" N	77° 27' 13" E	Uttar Pradesh
2	2	Delhi	28° 36' 0" N	77° 11' 24" E	Delhi
3	3	Noida	28° 32' 7.8" N	77° 23' 27.6" E	Uttar Pradesh
4	4	Gurugram	28° 27' 34.2" N	77° 1' 35.76" E	Haryana
5	5	Greater Noida	28° 28' 27.84" N	77° 30' 14.4" E	Uttar Pradesh
6	7	Lucknow	26° 50' 48.12" N	80° 56' 46.32" E	Uttar Pradesh
7	8	Bulandshahr	28° 24' 25.2" N	77° 50' 59.28" E	Uttar Pradesh
8	9	Muzaffarnagar	29° 28' 21.72" N	77° 42' 30.6" E	Uttar Pradesh
9	11	Jind	29° 19' 31.8" N	76° 17' 59.28" E	Haryana
10	12	Faridabad	28° 24' 32.04" N	77° 19' 4.08" E	Haryana

Data for rank 6th and 10th cities are not available for majority period; hence, the next alternate city was selected for the study

*Rank of the cities was based on the report published by IQAir visuals 2019

Table 3 Mean concentration of PM_{2.5} (μg m⁻³) for the top most pollutant cities of India during the period of before lockdown (1 January to 24 March), during lockdown (25 March to 31 May), and

after lockdown (1 June to 31 July 2020). The table also includes variation and changes (%) calculated for the period of before-during lockdown and before-after lockdown

City	Pre-lockdown (mean from 1 January to 24 March)	Lockdown (mean from 25 March to 31 May)	Post-lockdown/unlock 1.0 and 2.0 (mean from 1 June to 31 July)	Variation and changes			
				Before-during lockdown		Before-after lockdown	
				Net	%	Net	%
Ghaziabad	133	53	42	− 80	60.15	− 91	68.42
Delhi	114	44	36	− 70	61.40	− 78	68.42
Noida	122	45	43	− 77	63.11	− 79	64.75
Gurugram	88	43	41	− 45	51.14	− 47	53.41
Greater Noida	120	42	34	− 78	65.00	− 86	71.67
Lucknow	104	55	44	− 49	47.12	− 60	57.69
Bulandshahr	115	54	37	− 61	53.04	− 78	67.83
Muzaffarnagar	89	54	48	− 35	39.33	− 41	46.07
Jind	77	42	41	− 35	45.45	− 36	46.75
Faridabad	105	41	36	− 64	60.95	− 69	65.71

Jind (Table 3 and Fig. 2). Therefore, it reveals that the average concentration of PM_{2.5} emission before the lockdown period was much above the standard value than the limit set by the NAAQS, making these cities noxious to breathe.

The countrywide lockdown begins from 25 March 2020 due to the threatening situation of a pandemic. Since then, the mass industrial actions, constructional works, transportation movements, and many other anthropogenic activities were suspended, which consequences in dramatic impact over the concentration of PM_{2.5}. The primary sources of PM_{2.5} emissions are related to automobiles, transport and traffic activity, and industrial works including smelting, combustion, and manufacturing (Lee et al. 2003) and with the commence of lockdown in India, all these activities were discontinued. We interestingly found that with the beginning of the lockdown from 25 March, the concentration of PM_{2.5} for the top most polluted cities was drastically dropped below the NAAQS limit (Figs. 1a, b, c, d, e, f, g, h, i, j and 2). Also the mean concentration revealed that during the entire phase of lockdown up to 31 May 2020, all the cities showed a drastic reduction of PM_{2.5} concentration compared to pre-lockdown periods and for all the cities, the concentration was within the NAAQS standard (Fig. 2).

Table 3 shows the changes in concentration of PM_{2.5} for the period of before-during lockdown which reveals that Greater Noida shows the maximum reduction in PM_{2.5} concentration of about 65% (from 120 to 42 μg m⁻³), followed by Noida 63.11% (from 122 to 45 μg m⁻³), Delhi 61.40% (from 114 to 44 μg m⁻³), Faridabad 60.95% (from 105 to 41 μg m⁻³), and Ghaziabad 60.15% (from 133 to 53 μg m⁻³). All these five cities show a reduction in PM_{2.5} concentration by

more than 60% due to the lockdown. Besides the other five cities, they also show a significant decline in the PM_{2.5} concentration ranges between 39 and 53% due to the lockdown (Table 3). Thus, it is clear that restrict movement due to the lockdown in the country shows a definite reduction in PM_{2.5} concentration for the top polluted cities.

After the continued lockdown for more than 2 months (i.e., from 25 March to 31 May 2020), the unlocking procedure (unlock 1.0 and 2.0) and resumption of activities started from 1 June which continues until 31 July with specific constraints and limitations over the movement of people and goods (MHA 2020; Financial Express 2020). Surprisingly, the result shows that the unlocking of the city does not impact the concentration of PM_{2.5} as it shows further dwindle in its concentration during the post-lockdown period (Figs. 1a, b, c, d, e, f, g, h, i, j and 2). Also, Table 3 shows a comparison of PM_{2.5} for the period of before-after lockdown, and it depicts that majority of the cities show a decline in the concentration of PM_{2.5} by more than 60%. Greater Noida again shows maximum reduction in PM_{2.5} concentration during the post-lockdown which is about 71.67% (from 120 to 34 μg m⁻³), followed by Delhi and Ghaziabad 68.42% respectively for both, Bulandshahr 67.83% (from 115 to 37 μg m⁻³), Faridabad 65.71% (from 105 to 36 μg m⁻³), and Noida 64.75% (from 122 to 43 μg m⁻³). Besides, the remaining four cities also show that a significant reduction varies between 46 and 57%

Fig. 1 a–j Trend of PM_{2.5} concentration for the top most polluted cities in India for the time span of before lockdown (1 January to 24 March), during lockdown (25 March to 31 May), and post-lockdown (1 June to 31 July 2020)

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

(j)

Fig. 2 Location of the selected cities and mean concentration of $PM_{2.5}$ for each city for the period of before, during, and after lockdown

during the post-lockdown period (Table 3). Changes in the concentration of $PM_{2.5}$ depend on a variety of factors like seasonal variations, dust events, monthly flow of traffic, and other anthropogenic activities (Chauhan and Singh 2020). Thus, countrywide lockdown for the end of March to the end of May momentarily reduced $PM_{2.5}$, which was still effective after the lockdown ended as the mean of $PM_{2.5}$ for all the cities is minimal and below the NAAQS limit (Fig. 2).

The first three satellite images (Fig. 3a, b, and c) clearly show that the concentration of $PM_{2.5}$ was very high over the Indian atmosphere before the commencement of the lockdown, i.e., from January to March, especially over North India including the top most polluted cities. Subsequently, it is evident from the images (Fig. 3d, e, and f) the drastic reduction in $PM_{2.5}$ concentration during the time span of 2-month lockdown, i.e., from the end of March which continues until the end of May. Further, Fig. 3 g and h also reveal the scenario of post-lockdown and it is clear that the concentration of $PM_{2.5}$ was reduced to minimal.

Table 4 also reveals that since the calculated p value (0.0001) is less than the significance level at 0.05, this is

considered being statistically significant. Thus, it is evident that there is a massive change in the concentration of $PM_{2.5}$ from the top polluted cities of India due to the pandemic lockdown.

Discussion and conclusion

Our findings reveal that the implementation of lockdown due to COVID-19 pandemic results in a dramatic decrease in $PM_{2.5}$ concentration and an overall improvement in the air qualities for the top most polluted cities in India. Also, the p value (0.0001) shows a statistically significant reduction in the concentration of $PM_{2.5}$ due to the lockdown. About 39–65%

Fig. 3 a–c Copernicus satellite showing $PM_{2.5}$ concentration over India's atmosphere before the lockdown period (January–March). d–f Concentration during the lockdown period (end of March–May). g–h Concentration in the post-lockdown period (June–July). Retrieved from (<https://earth.nullschool.net/#current/particulates/surface/level/anim=off/overlay=pm2.5/orthographic>)

Table 4 Paired *t* test for the concentration of PM_{2.5} pollutant count for the period of pre-during and pre-post lockdown

Variables	Sample	Mean	Std. deviation	Std. error Mean				
Pre-lockdown	10	106.7	17.58	5.56				
During lockdown	10	47.3	5.89	1.86				
Post-lockdown	10	40.2	4.37	1.38				
Statistical <i>t</i> test result								
Variables	Mean	Std. deviation	Std. error mean	95% confidence interval of the difference	<i>t</i> value	Df	Sig. (2-tailed)	
				Upper	Lower			
Pre-during lockdown	59.4	64.9	5.5	47.0	71.8	10.8	9	0.0001
Pre-post lockdown	66.5	72.7	6.2	52.6	80.4	10.8	9	0.0001

reduction in PM_{2.5} was noticed during the lockdown period, and the range further increases to 48–68% after the lockdown ended. The study interestingly reveals that despite the unlocking and resumption of all activities during the post-lockdown periods, it does not result in a surge of PM_{2.5}. Further, the mean concentration of PM_{2.5} for all the top polluted cities was reduced to minimal after the lockdown ends. The present pandemic situation has threatened the society in every sphere of life, but its benefits to improve the overall environment were also remarkable and need to understand correctly for future benefits. So, to restrain the air quality of the major polluted cities in India and globally, well-designed short-term lockdown implementation should be required once or twice a month at regular intervals. Policymakers and the government must need to understand the positive impact of lockdown on curbing excessive emissions for future purposes and must adopt lockdown as an alternative strategy.

Indeed, the lockdown has brought critical economic loss nationwide, which is undeniable, but at the same time, short-term environmental refurbishment also has taken place. However, reasonable, cost-effective economic planning is necessary before initiating such a short-term lockdown either it will be an economic detriment.

The lockdown due to the pandemic has given us a short-term interlude when the concentrations of overall pollutants are reduced to a greater extent, mainly for the top polluted cities. However, the reduction in the PM_{2.5} concentration does not assure sustained clean air quality for a longer period. Once everything begins at a full pace from economic activity to buzzing traffic movement, the quality of air must inevitably be back to its previous worsen condition. However, this lockdown has allowed us to understand the positive benefits of isolation towards the environment and hence proper regulatory framework and technological intervention must be necessary to recover air quality in the later part. Huge repository of researches and data related to COVID-19 lockdown and its environmental benefit must be utilized and need to be reexamined.

Future research instructions

- The data of concentration of pollution need to be further correlated with population of the cities, to identify the sources of known pollution of these top most polluted cities and also comparison needs to be done with other regions.
- Also emphasis needs to be given over the spatial variations of regional meteorological factor, local geography, and air movements which have direct impact over the concentration of pollutants.

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Author's contribution Subham Roy—conceptualization, methodology, software, formal analysis, investigation, resources, writing—original draft, writing—review and editing, visualization, and supervision. Nimai Singha—formal analysis, investigation, data curation, resources, and writing—review and editing.

Data availability All the data used in the present study are freely available to all through proper request, if needed by anyone for further research.

Compliance with ethical standards

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

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