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COVID-19 Lockdown and Air Pollution Levels in India's Megacities

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Abstract

After the outbreak of COVID-19 in India, a nationwide lockdown was imposed from 25 March to 7 June 2020. Amid the uncertainty surrounding COVID-19, several studies report that the extended lockdown resulted in a reduction in air pollution levels across many Indian cities. In this context, the present study analyses the changes in air pollution levels in six megacities of India, namely Delhi, Mumbai, Kolkata, Chennai, Bengaluru, and Hyderabad, during the pre-lockdown period (1 January–24 March 2020), lockdown period (25 March–7 June 2020), unlock period (8 June–30 September 2020), and post-unlock period (1 October–31 December 2020). The air pollution data were obtained from the official website of the Central Pollution Control Board (CPCB), India. The analysis shows that all six megacities, which typically rank among the most polluted, experienced at least temporary relief during the lockdown and phased unlock periods.

Keywords: air pollution, COVID-19, lockdown, megacities, urban environment

INTRODUCTION

In December 2019, the first human case of the novel coronavirus was reported in Wuhan City, China. In January 2020, the World Health Organization (WHO) confirmed human-to-human transmission of COVID-19 through respiratory droplets. In January 2020, COVID-19 cases were also reported in countries such as the United States, Thailand, Japan, and the Republic of Korea. On 30 January 2020, the WHO declared COVID-19 a Public Health Emergency of International Concern. On the same day, the first confirmed COVID-19 case in India was reported in the Thrissur district of Kerala, where a student who had returned from Wuhan University in China tested positive for COVID-19.

In March 2020, the number of COVID-19 cases began to rise, leading to the closure of schools and colleges to limit its spread. Later, on 24 March 2020, the Prime Minister of India imposed a 21-day nationwide lockdown. The lockdown resulted in the closure of most economic and

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social activities in the country, except essential services. However, despite the lockdown, COVID-19 cases continued to increase, and the government extended the restrictions. On 8 June 2020, the nationwide lockdown was lifted in a phased manner.

As a result of the extended lockdown, industries were shut, offices were closed, and local markets ceased operations, confining people to their homes for an extended period. While the economic consequences of the lockdown have been widely debated, the sudden halt in economic and social activities for nearly three months had some positive impacts on the environment. Several studies report a substantial decline in air pollution in major cities of the country during the COVID-19 lockdown (Garg, Kumar, & Gupta, 2020; Shehzad, Sarfraz, & Shah, 2020; Singh & Chauhan, 2020). On 29 April 2020, Ramesh Pandey, an Indian Forest Service officer, shared images of the snow-capped peaks of the Himalayas visible from Saharanpur district, Uttar Pradesh, via his Twitter account, and the news soon went viral. The aerial distance between Saharanpur and the Himalayan peaks is approximately 200 km, and such visibility was observed after nearly 30 years. Similar reports emerged from other parts of India, including Jalandhar (Punjab) and Singhwahini village (Bihar). This improved visibility is attributed to a reduction in air pollution levels, particularly particulate matter, which plays a significant role in reducing atmospheric visibility (Zhao et al., 2013).

Amid the uncertainty surrounding COVID-19, the reported decline in air pollution provided a rare positive environmental outcome during the pandemic. Air pollution is highly detrimental to human health and is a major contributor to modern lifestyle-related diseases. According to the WHO, approximately 4.2 million deaths occur each year due to exposure to ambient (outdoor) air pollution. Globally, around 7 million deaths are attributed to air pollution annually, and 9 out of 10 people breathe air containing high levels of pollutants. In India, around 12.5% of total deaths in 2017 were linked to air pollution, with more than 51% occurring in individuals below the age of 70. Every year, air pollution is responsible for approximately 1.25 million deaths in India, contributing to 18.1% of global pollution-related mortality.

In this context, the present study analyses the changes in air pollution levels in six megacities of India, namely Delhi, Mumbai, Kolkata, Chennai, Bengaluru, and Hyderabad, during the pre-lockdown period (1 January 2020–24 March 2020), lockdown period (25 March–7 June 2020), unlock period (8 June–30 September 2020), and post-unlock period (1 October–31 December 2020). The objective of this study is to examine how the lockdown impacted air pollution levels in these major urban centres and to determine whether these changes were statistically significant.

AIR POLLUTION AND ITS CAUSES

Air pollution severely affects human health, and a majority of modern respiratory diseases are linked to it. The major sources of air pollution include vehicular emissions, industrial and factory emissions, dust from construction activities, thermal power plants, burning of waste, and the use of low-quality fuels (Bernard & Kazmin, 2018). The primary air pollutants include carbon monoxide (CO), lead (Pb), nitrogen oxides (NOx), ground-level ozone (O_3), particulate matter (PM), and sulphur oxides (SOx). Among these, PM2.5, PM10, sulphur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2) are commonly emitted from industries that rely on coal and other fossil fuels as primary energy sources. Vehicular emissions are a major source of particulate matter, hydrocarbons, carbon monoxide, and nitrogen dioxide. Elevated levels of these pollutants contribute to smog formation and lead to severe health and environmental issues.

Particulate Matter: Particulate matter (PM), also known as particle pollution, refers to a mixture of solid particles and liquid droplets present in the air. It includes PM2.5 (particles with a diameter of 2.5 micrometres or less) and PM10 (particles with a diameter of 10 micrometres or less). Due to their small size, these particles can penetrate deep into the respiratory system and even enter the bloodstream. Exposure to particulate matter can lead to respiratory problems such as coughing, asthma, and reduced lung function.

Carbon Monoxide: Carbon monoxide (CO) is a colourless, odourless, and toxic gas that can cause serious health issues (National Research Council, 2002). It is produced by incomplete combustion of fuels and is commonly emitted from vehicles, cigarette smoke, and burning of charcoal. Exposure to carbon monoxide can result in headaches, dizziness, nausea, and, in severe cases, cardiovascular complications.

Ozone: Ground-level ozone (O_3) is a colourless and highly reactive gas formed by chemical reactions between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. Exposure to ozone can cause breathing difficulties, coughing, throat irritation, and can aggravate respiratory diseases such as asthma and chronic bronchitis.

Nitrogen Oxides: Nitrogen oxides (NOx), primarily nitrogen dioxide (NO_2) and nitric oxide (NO), are produced during high-temperature combustion processes. These gases can irritate the respiratory system, cause inflammation of the airways, and increase the risk of asthma attacks. Long-term exposure to nitrogen oxides may lead to chronic lung diseases.

Sulphur Oxides: Sulphur dioxide (SO_2), a major component of sulphur oxides (SOx), is a colourless gas with a pungent smell. It is mainly produced by the combustion of sulphur-containing fossil fuels such as coal and petroleum. Exposure to sulphur dioxide can cause respiratory problems, including bronchitis, and can irritate the nose, throat, and lungs.

EFFECTS OF COVID-19 ON AIR POLLUTION IN INDIA

Shehzad et al. (2020) report that the level of nitrogen dioxide (NO_2) emissions reduced significantly during the period from 25 March to 20 April 2020, when a complete lockdown was imposed in India. The study highlights a substantial impact of the lockdown on air pollution levels based on Sentinel-5P satellite images obtained from the European Space Agency and the National Aeronautics and Space Administration (NASA). The reduction in pollution levels was more pronounced in several metropolitan cities as well as in parts of Gujarat. The shutdown of industries and reduced public mobility led to lower energy consumption during March and April 2020. Since power generation plants are among the major sources of NO_2 emissions in India, this contributed to the observed decline. Additionally, reduced maritime transport activity led to lower NO_2 levels over the Indian Ocean region. The study also notes that improvements in air quality were observed not only in India but also in neighbouring countries such as China, Pakistan, Iran, and Afghanistan.

Singh and Chauhan (2020) reported a reduction in PM2.5 concentrations across major metropolitan cities in India during the lockdown. The maximum reduction was observed in Kolkata (34.52%), while the least reduction was recorded in Hyderabad (3.99%) during the first phase of the lockdown. In Delhi, a declining trend in tropospheric NO_2 levels was observed immediately after the implementation of the lockdown. Similar trends were reported in Kolkata, Chennai, Mumbai, and Hyderabad, although the impact was less pronounced in Mumbai and Hyderabad.

Delhi, historically one of the most polluted cities in India, witnessed a considerable decline in pollutant concentrations within three weeks of the lockdown (Mahato, Pal, & Ghosh, 2020; Chimurkar, Patidar, & Phuleria, 2020). Mahato et al. (2020) report reductions of approximately 51.84% and 53.11% in PM10 and PM2.5 concentrations, respectively. At industrial monitoring stations, the reductions were even higher (around 62.61% and 59.74%). Other pollutants, such as NO_2 and CO, showed decreases of 52.68% and 30.35%, respectively. Similarly, Chimurkar et al. (2020) observed reductions in CO (30%), NO_2 (80%), PM2.5 (58%), and PM10 (71%) during the initial weeks of the lockdown. Prior to the lockdown, peak traffic hours (7:00–10:00 AM and 7:00–10:00 PM) contributed significantly to emissions; however, mobility restrictions during the lockdown led to a sharp decline in traffic-related pollution. Among the 17 cities analysed in their study, 13 cities recorded more than a 30% reduction in NO_2 levels, with Bengaluru showing the highest reduction (87%).

Jain and Sharma (2020) report that in Delhi, the average concentrations of PM2.5, PM10, NO_2, and CO declined by 41%, 52%, 50%, and 29%, respectively, while ozone (O_3) levels increased by 7%. Chennai also experienced reductions of 14%, 30%, and 25% in PM2.5, NO_2, and CO, respectively, along with a 3% increase in ozone levels during the first phase of the lockdown (25 March to 6 April 2020). The study further notes that ozone concentrations increased in Delhi, Mumbai, Chennai, and Kolkata, but decreased in Bengaluru.

Using three years of data (2018–2020), Garg et al. (2020) demonstrate a statistically significant reduction in the mean concentrations of PM2.5, PM10, and NO_2 at the 5% significance level in major COVID-19 hotspot cities, including Mumbai, Pune, Ahmedabad, Delhi, and Agra, during the period from 25 March to 25 April.

On the international front, Chauhan and Singh (2020) highlight a decline in PM2.5 concentrations in cities such as New York (32% in March and 20% in February) and Los Angeles (4% in March and 30% in February) compared to corresponding months in 2019. Other regions also reported improvements in air quality; for instance, Zaragoza (Spain) observed a decline of approximately 58% during March 2020 compared to February 2020, while Dubai recorded an 11% reduction in PM2.5 levels during March 2020 compared to March 2019. Similarly, Muhammad et al. (2020) report a reduction of up to 30% in NO_2 emissions across regions such as Wuhan (China), Spain, France, Italy, and the northeastern

United States, primarily due to reduced energy consumption, industrial shutdowns, and restricted mobility during the lockdown.

MATERIALS AND METHODS

The air pollution data used in this study were obtained from the official website of the Central Pollution Control Board (CPCB), under the Ministry of Environment, Forest and Climate Change, Government of India. The CPCB provides automatic monitoring data that record pollutant levels across multiple monitoring stations in various cities. The dataset consists of daily observations of five major pollutants—PM2.5, PM10, NO_2, SO_2, and O_3—for the period from 1 January 2020 to 31 December 2020.

The present study examines changes in the levels of these five pollutants across six major Indian megacities: Delhi, Mumbai, Kolkata, Chennai, Bengaluru, and Hyderabad. For analytical purposes, the data for the year 2020 were divided into four distinct time periods: (i) pre-lockdown period (1 January–24 March 2020), (ii) lockdown period (25 March–7 June 2020), (iii) unlock period (8 June–30 September 2020), and (iv) post-unlock period (1 October–31 December 2020). In the first stage of the analysis, average pollutant concentrations for each city were computed and presented graphically to identify trends and variations across the four time periods. These graphical representations provide an initial understanding of the temporal changes in pollution levels.

In the second stage, statistical analysis was conducted using Analysis of Variance (ANOVA) to examine whether the differences in pollutant levels across the four time periods are statistically significant. The null hypothesis (H_0) states that there is no significant difference in the mean pollutant levels across the four periods, while the alternative hypothesis (H_1) posits that at least one period differs significantly.

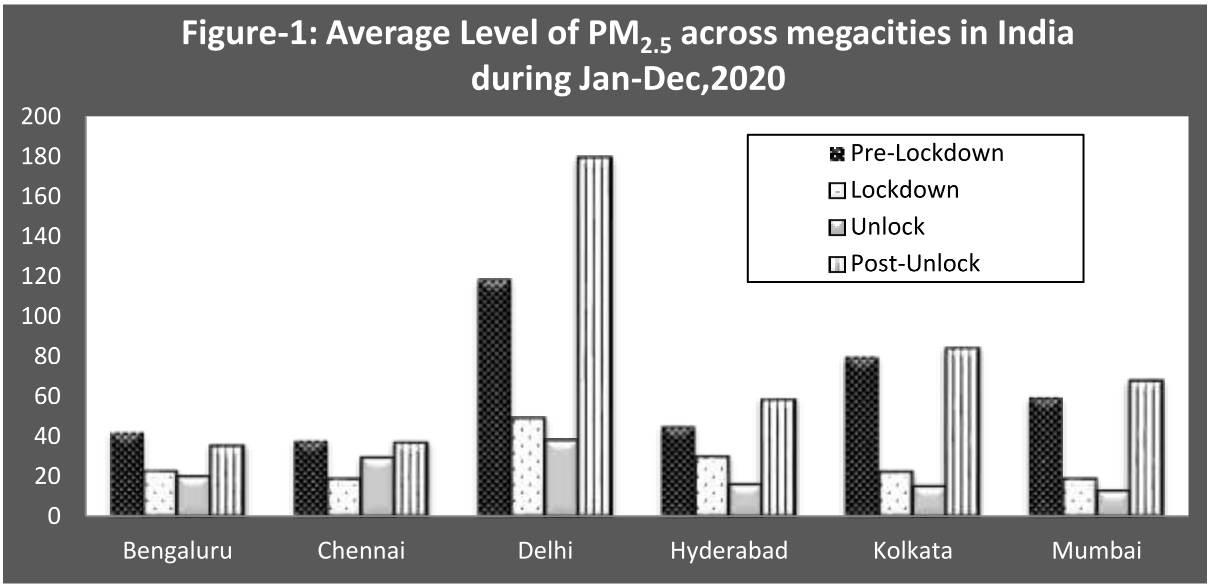
Following the ANOVA test, a post-hoc analysis was performed to identify the specific time periods between which statistically significant differences occur. This analysis helps to determine whether the observed changes in pollution levels are associated with the transition from pre-lockdown to lockdown, lockdown to unlock, and unlock to post-unlock phases.

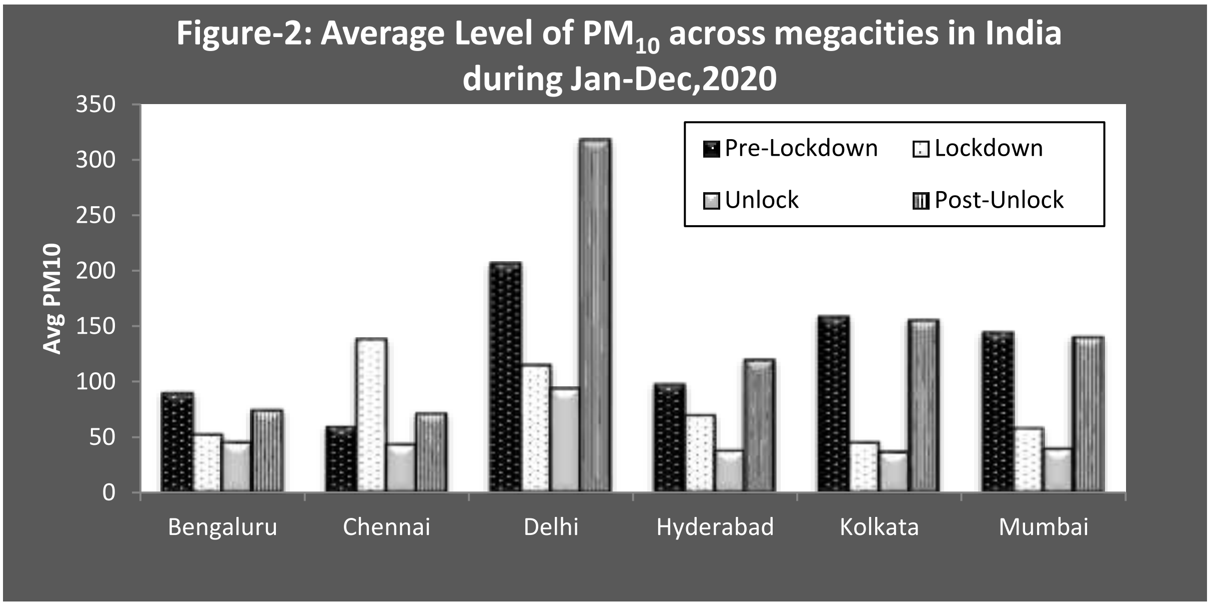
All statistical analyses were conducted using standard analytical tools, and results were interpreted at a 5% level of significance.

RESULTS

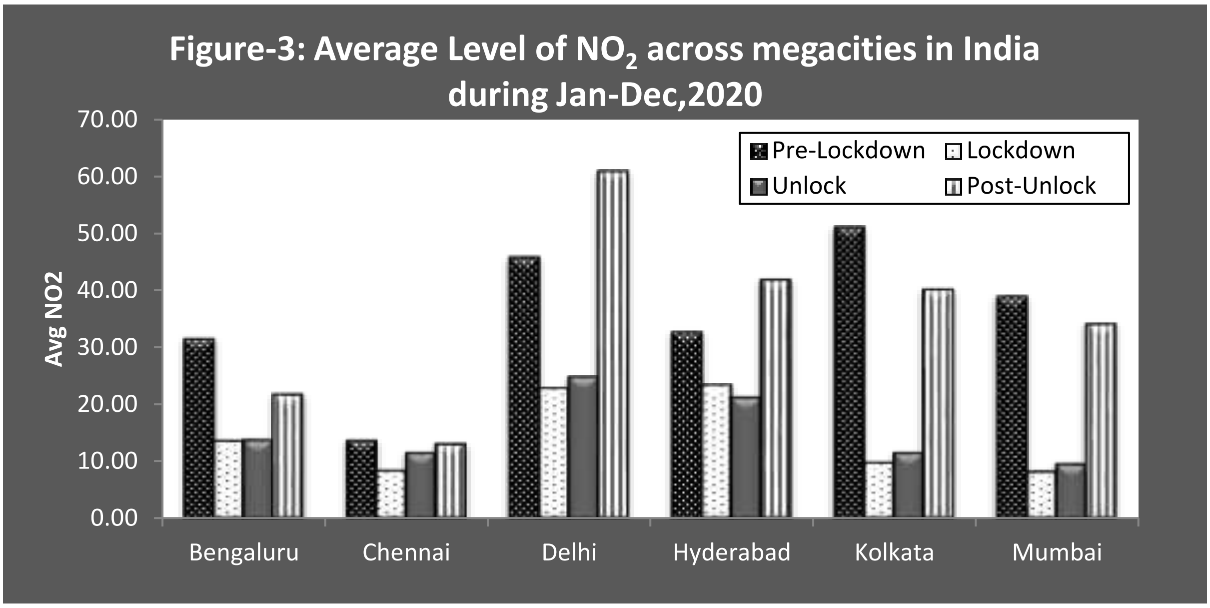
LEVELS OF VARIOUS POLLUTANTS DURING PRE-LOCKDOWN TO POST-UNLOCK PERIOD

It can be observed from Figure-1 that during the lockdown the average concentration of PM2.5 reduced significantly as compared to the pre-lockdown period for all megacities under study. A maximum decrease of about 72.3% was observed in Kolkata while only a 33.78% decrease is observed in Hyderabad during the lockdown period. Although the lockdown was lifted, people were still fearful of coronavirus and hence their mobility was highly restricted. A decreasing trend of PM2.5 during the unlock period indicates the same. But during the post-unlock period, the average concentration levels increased significantly in Delhi, Hyderabad, Kolkata, and Mumbai. During all four periods, Delhi was observed to have the highest concentration levels of PM2.5.

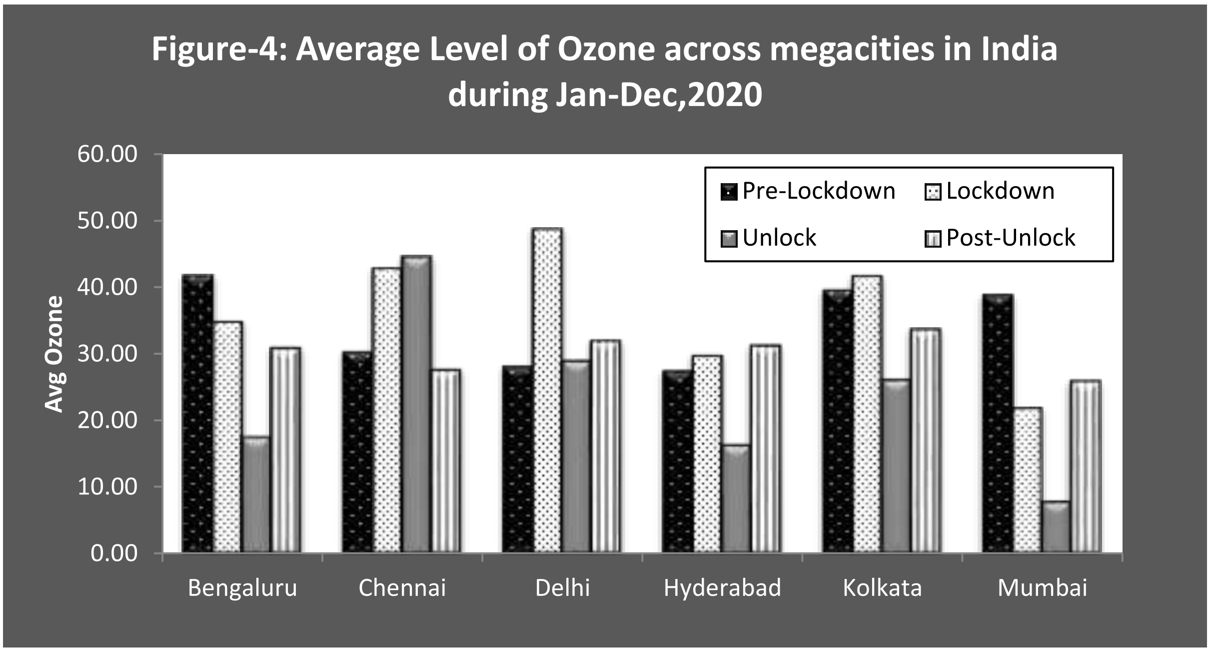




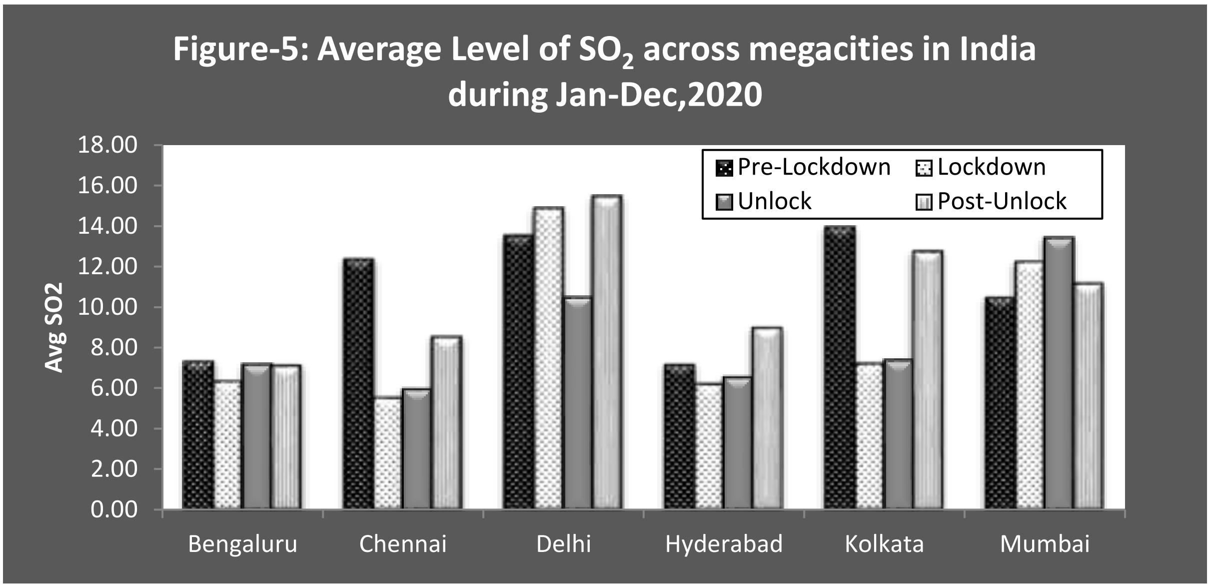
From pre-lockdown to lockdown phase, a decline in PM10 was observed in all other cities except Chennai. As shown in Figure-2 Chennai showed an increase of 135% in average concentration of PM10 as compared to the pre-lockdown period. From the lockdown to unlock period, all the megacities witnessed a decline in average concentrations of PM10. During the post-unlock period, Bengaluru and Chennai showed a moderate increase; Delhi, Hyderabad, Kolkata and Mumbai showed a surge in the level of PM10 of 239.88%, 218.66%, 328.29% and 257.79% respectively. The current level of PM10 in Delhi is the highest.



Like other pollutants, the level of NO_2 declined for all the cities during pre-lockdown to lockdown period. As shown in Figure-3, during the unlock period, the average concentration started increasing in Chennai by 37.1%, Kolkata by 17.31%, Mumbai by 16.51%, Delhi by 8.53% and Bengaluru by only 0.75% while in Hyderabad about 9.41% of decrease was observed. In the expected lines, the post-unlock period witnessed an upsurge in the NO_2 level across all the cities under study.



Unlike other pollutants, ozone level increased during the lockdown period in Chennai, Delhi, Hyderabad and Kolkata. Only Bengaluru and Mumbai observed a decline in average concentration of ozone during this period. From lockdown to unlock period, all cities except Chennai showed a decline in ozone level followed by an increase in the post-unlock period. In Chennai, the ozone level steadily increased from pre-lockdown till unlock period only to decrease during the post-unlock period. The observations can be validated from Figure-4.



As observed from Figure-5, the level of sulphur dioxide did not change much in Bengaluru throughout the study period and in Hyderabad till the unlock period. Delhi and Mumbai observed an increase in sulphur dioxide from pre-lockdown to lockdown period, while other cities observed a plunge during the same period. During the post-unlock period, when there was an increase in average concentration level of SO_2 in Chennai, Delhi, Hyderabad and Kolkata; Mumbai showed a decrease in the same of about 16.76%.

TESTING THE SIGNIFICANCE OF THE CHANGES OF THE POLLUTANTS

The previous section graphically illustrated that there is a drastic drop in the average level of a majority pollutants from the pre-lockdown period to the lockdown period for six megacities of the country. However, it is yet to ascertain whether the drop in the pollution level during the lockdown has been statistically significant or not. Changes in the levels of the pollutants were also observed from the lockdown to unlock phase and from unlock phase to post-unlock period. This section analyses and tests the statistical significance of these changes.

ANOVA is used to test whether there is any difference between the average levels of various pollutants during the pre-lockdown period to post-unlock period across all six megacities of the country. For this, the null hypothesis assumes that there is no such significant difference in the pollutant levels. The alternative hypothesis (the claim of this paper) states that the difference in the mean levels of the pollutants is statistically significant. Table-1 presents the ANOVA results.

For all those pollutants, whose average changes during the study period comes out to be significant for any city, a post-hoc analysis has been carried out to analyse exactly during which time period the changes have been statistically significant. The critical difference test post ANOVA has been applied for this and the results are presented in Table-2.

Table-1: ANOVA results for testing the significance of difference between average levels of pollutants through Pre to Post lockdown period, (January-December 2020)

H_0: There is no significant difference between the average levels of pollutants throughout the study period.

	Average level of pollutants				**Calculated F-value**	**Significance level (p-value)**
Delhi	**Pre-lockdown**	**Lockdown**	**Unlock**	**Post-Unlock**		
PM2.5	118.3430	48.8143	37.6883	179.3993	143.438	0.000*
PM10	206.4960	114.5793	93.6857	317.8216	177.802	0.000*
NO_2	45.6995	22.6521	24.7063	60.8868	306.430	0.000*
SO_2	13.5286	14.8419	10.4701	15.5036	70.328	0.000*
Ozone	27.9769	48.6864	28.8363	31.9350	105.643	0.000*
Mumbai						
PM2.5	59.6113	19.3119	12.4542	63.3161	236.949	0.000*
PM10	143.7732	58.5365	39.1418	132.4945	295.588	0.000*
NO_2	38.7962	7.9736	9.4046	32.2754	333.849	0.000*
SO_2	10.4425	12.3245	13.3532	11.1745	9.703	0.000*
Ozone	38.7699	21.3524	7.5927	23.9134	258.157	0.000*
Kolkata						
PM2.5	79.6844	21.9636	14.8454	84.5227	146.182	0.000*
PM10	158.0595	44.5380	36.0077	155.2541	167.097	0.000*
NO_2	51.1155	9.5673	11.2968	40.4718	218.420	0.000*
SO_2	13.9448	7.1335	7.3471	12.7641	79.922	0.000*
Ozone	39.4302	41.1681	26.0054	33.6578	41.684	0.000*
Chennai						
PM2.5	37.6374	18.6727	29.1934	36.0496	39.200	0.000*
PM10	58.6307	138.0615	42.8945	66.2081	40.565	0.000*
NO_2	13.6015	8.3007	11.3874	12.7201	34.534	0.000*
SO_2	12.3354	5.4975	5.9410	8.6067	69.897	0.000*
Ozone	30.0826	42.7788	44.4663	28.2268	73.373	0.000*
Bengaluru						
PM2.5	42.1096	22.4519	19.9000	35.1504	97.307	0.000*
PM10	89.3314	51.3885	44.6410	72.6426	116.381	0.000*
NO_2	31.4132	13.4161	13.5897	21.6183	257.530	0.000*
SO_2	7.2674	6.2997	7.1452	7.0992	17.979	0.000*
Ozone	41.6142	35.0659	17.4670	30.4392	178.347	0.000*

Hyderabad						
PM2.5	44.7585	29.7199	15.7147	57.9818	209.445	0.000*
PM10	96.8256	67.9669	37.0940	118.6313	181.897	0.000*
NO_2	32.4986	23.2971	21.1265	41.7320	162.320	0.000*
SO_2	7.1323	6.2200	6.5283	8.9697	17.459	0.000*
Ozone	27.4290	29.5928	16.1306	31.1597	132.291	0.000*
Note: 1.*significant at 5% level of significance i.e. H_0 is rejected at 5% level 2. Computed from pollution data obtained from https://cpcb.nic.in/ source.						

The ANOVA results (Table-1) show that for each of the six megacities, the average levels of all the pollutants are significantly different (at 5% level) throughout the four time periods under study. However, it is still not clear that in which time periods the mean differences in the level of pollutants are statistically significant. A post-hoc analysis is done to test the same. The results are delineated in Table-2.

Post-Hoc Analysis:

Table-2: Post-hoc Analysis to test in which time periods the mean difference in the level of pollutants is statistically significant, (January-December 2020)			
	Mean Difference between the levels of pollutants		
Delhi	**Pre-lockdown to Lockdown**	**Lockdown to Unlock**	**Unlock to post-unlock**
PM2.5	69.52871*(8.52293)	11.12601 (7.96265)	-141.71109* (7.50417)
PM10	91.91662*(11.88272)	20.89359(11.10158)	-224.13589*(10.46237)
NO_2	23.04739*(1.58187)	-2.05421(1.47788)	-36.18050*(1.39278)
SO_2	-1.31330*(.43059)	4.37178*(.40229)	-5.03350*(.37913)
Ozone	-20.70950*(1.34112)	19.85014*(1.25295)	-3.09874*(1.18081)
Mumbai			
PM2.5	40.29944*(2.66029)	6.85769*(2.48541)	-50.86191*(2.34231)
PM10	85.23668*(4.71342)	19.39471*(4.40358)	-93.35263*(4.15002)
NO_2	30.82259*(1.29308)	-1.43101(1.20808)	-22.87083*(1.13852)
SO_2	-1.88203*(.64711)	-1.02868(.60457)	2.17876*(.56976)
Ozone	17.41748*(1.24836)	13.75970*(1.16630)	-16.32067*(1.09914)
Kolkata			
PM2.5	57.72080*(4.70170)	7.11821(4.39262)	-69.67733*(4.13970)

PM10	113.52152*(7.96162)	8.53035(7.43824)	-119.24648*(7.00996)
NO_2	41.54814*(2.11951)	-1.72945(1.98018)	-29.17507*(1.86616)
SO_2	6.81130*(.60034)	-.21366(.56087)	-5.41700*(.52858)
Ozone	-1.73790(1.66199)	15.16274*(1.55273)	-7.65243*(1.46333)
Chennai			
PM2.5	18.96471*(1.95372)	-10.52072*(1.82529)	-6.85617*(1.72019)
PM10	-79.43075*(9.00263)	95.16701*(8.68400)	-23.31364*(5.72119)
NO_2	5.30088*(.55700)	-3.08672*(.52038)	-1.33272*(.49042)
SO_2	6.83789*(.55615)	-.44349(.51959)	-2.66578*(.48968)
Ozone	-12.69618*(1.51395)	-1.68755(1.41443)	16.23950*(1.33299)
Bengaluru			
PM2.5	19.65778*(1.62677)	2.55187(1.51983)	-15.25043*(1.43232)
PM10	37.94290*(2.89110)	6.74749*(2.70105)	-28.00157*(2.54552)
NO_2	17.99708*(.79027)	-.17361(.73832)	-8.02852*(.69580)
SO_2	.96765*(.14682)	-.84548*(.13716)	.04598(.12927)
Ozone	6.54830*(1.21570)	17.59891*(1.13578)	-12.97228*(1.07038)
Hyderabad			
PM2.5	15.03859*(2.01587)	14.00517*(1.88336)	-42.26715*(1.77492)
PM10	28.85866*(4.20095)	30.87293*(3.92479)	-81.53730*(3.69881)
NO_2	9.20150*(1.14876)	2.17054*(1.07325)	-20.60543*(1.01145)
SO_2	.91226*(.44572)	-.30835(.41642)	-2.44133*(.39244)
Ozone	-2.16375*(.96323)	13.46219*(.89991)	-15.02907*(.84810)

Note: 1.*Significant at 5% level of significance i.e. H_0 is rejected at 5% level

2. Positive differences imply that the levels of the pollutants declined in the later phase and vice-versa.
3. Figures in parenthesis show the standard error.
4. Computed from pollution data obtained from https://cpcb.nic.in/ source.

As can be seen from Table-2, the city of Delhi witnessed a substantial statistically significant decline in PM2.5, PM10, and NO_2 from pre-lockdown to the lockdown phase. However, SO_2 and ozone level significantly increased from pre-lockdown to lockdown period followed by a decrease during the unlock phase. The decline in the levels of PM2.5 and PM10 from lockdown to unlock period does not come out to be statistically significant. As the unlock phase progressed and the social and economic activities resumed, the city observed a statistically significant leap in the levels of PM2.5 and PM10 and a considerable increase in the levels of NO_2, SO_2 and ozone.

In Mumbai, except SO_2, all other pollutants declined significantly from pre-lockdown to lockdown phase. The decline in PM2.5, PM10 and ozone continued till the unlock phase. On the other hand, SO_2 seemed to decline slightly from unlock to post-unlock phase, when other pollutants significantly increased.

Kolkata witnessed statistically significant decline in the levels of PM2.5, PM10, NO_2, and SO_2 from the pre-lockdown to lockdown phase. However, further changes in the levels of these pollutants from lockdown to unlock phase do not come out to be significant. All these four pollutants are observed to shoot up significantly during the post-unlock phase. In case of ozone, there is a statistically significant decline during lockdown to unlock phase followed by an increase during the post-unlock phase.

The air pollution pattern in Chennai during the study period appears to be quite different as compared to other megacities. The city witnessed a substantial and statistically significant increase in PM10 from pre-lockdown to lockdown phase, while all other megacities witnessed a decline in the same during the same period. Ozone level also increased during this period, just like it increased in Delhi and Hyderabad. Rest of the pollutants viz. PM2.5, NO_2 and SO_2 declined (significant at 5% level) during pre-lockdown to lockdown phase, but then kept on increasing during unlock and post-unlock phase. PM10, which earlier increased during the lockdown, declined during the unlock phase and then again started increasing (significant at 5% level).

Bengaluru is one of the megacities where levels of all the five pollutants declined significantly during the lockdown phase. PM10 and ozone kept on decreasing significantly till the unlock phase, only to reverse its direction during the post-unlock phase.

In Hyderabad, except ozone, all other pollutants observed a declining pattern throughout lockdown and unlock period (SO_2's increase during the unlock period is not statistically significant). Ozone increased during the lockdown, then decreased during the unlock phase and then again increased during the post-unlock phase. All the pollutants show an increasing pattern during the post-unlock phase.

DISCUSSION AND CONCLUSIONS

The COVID-19 pandemic and the subsequent nationwide lockdown in India resulted in significant disruptions to economic and social activities, leading to substantial losses in employment and industrial output. However, this period also witnessed a notable improvement in air quality across major urban centers. The findings of the present study indicate that all six megacities—Delhi, Mumbai, Kolkata, Chennai, Bengaluru, and Hyderabad—experienced a

significant decline in the levels of major air pollutants during the lockdown and, to some extent, during the phased unlock period.
For instance, in Delhi, overall mobility reduced significantly during the lockdown, contributing to a marked decline in emissions from transportation and industrial activities. Similar trends were observed across other cities, highlighting the strong linkage between anthropogenic activities and air pollution levels. The statistical analysis using ANOVA confirms that the variations in pollutant concentrations across the different phases—pre-lockdown, lockdown, unlock, and post-unlock—are statistically significant.
However, the improvements in air quality were short-lived. As economic and social activities resumed during the unlock and post-unlock phases, pollution levels increased rapidly across all cities. This reversal underscores the persistent and structural nature of air pollution in urban India. Despite temporary improvements observed during 2020, India continues to rank among the most polluted countries globally, with a large number of cities consistently exceeding safe air quality limits.

These findings raise an important question: must extreme measures such as lockdowns be the only way to achieve cleaner air? While lockdowns are neither sustainable nor economically viable as long-term solutions, they provide valuable insights into the extent to which human activities contribute to environmental degradation. The temporary improvements observed during the lockdown demonstrate that targeted and well-planned interventions can lead to meaningful reductions in pollution levels.
Policy measures such as promoting remote work, enhancing public transportation systems, regulating vehicular emissions, adopting cleaner industrial technologies, and accelerating the transition to renewable energy sources can help sustain improved air quality without imposing severe economic costs. Additionally, urban planning strategies that reduce congestion and encourage sustainable practices can play a crucial role in long-term pollution control.
It is also important to acknowledge certain limitations of this study. The analysis is based on data for a single year (2020) and does not explicitly account for meteorological factors such as wind patterns, temperature, and humidity, which can influence pollution levels. Furthermore, the study focuses on observational trends and statistical associations rather than causal modelling.
In conclusion, the COVID-19 lockdown provided a unique natural experiment that highlighted the significant impact of human activities on air quality. While the improvements in pollution levels were temporary, they offer important lessons for policymakers and stakeholders. Sustainable and long-term strategies, rather than extreme restrictions, are essential to achieving cleaner air and improving public health outcomes in rapidly urbanizing economies such as India.

[1] https://www.hindustantimes.com/india-news/mobility-to-recreational-and-retail-places-drops-by-86/story-MuFjPEFBUGJrZdSNnUwYsJ.html accessed on 21st February 2021.
[1] https://www.iqair.com/us/world-most-polluted-cities

REFERENCES

Bernard, S., & Kazmin, A. (2018). *Dirty air: how India became the most polluted country on earth.* Financial Times.

Chauhan, A., & Singh, R. P. (2020). Decline in PM2.5 concentrations over major cities around the world associated with COVID-19. *Environmental Research*.

Chimurkar, N., Patidar, G., & Phuleria, H. C. (2020, June). Examining Effects of the COVID-19 National Lockdown on Ambient Air Quality across Urban India. *Aerosol and Air Quality Research*(20), 1759-1771.

Garg, A., Kumar, A., & Gupta, N. C. (2020). Impact of Lockdown on Ambient Air Quality in COVID-19 Affected Hotspot Cities of India: Need to Readdress Air Pollution Mitigation Policies. *Environmental Claims Journal*.

Jain, S., & Sharma, T. (2020). Social and Travel Lockdown Impact Considering Coronavirus Disease (COVID-19) on Air Quality in Megacities of India: Present Benefits, Future Challenges and Way Forward. *Aerosol and Air Quality Research*, 1222–1236.

Mahato, S., Pal, S., & Ghosh, K. G. (2020). Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. *Science of the Total Environment*.

Muhammad, S., Long, X., & Salman, M. (2020). COVID-19 pandemic and environmental pollution: A blessing in disguise? *Science of the Total Environment*.

National Research Council. (2002). *The Ongoing Challenge of Managing Carbon Monoxide Pollution in Fairbanks, Alaska: Interim Report.* Washington, DC: THE NATIONAL ACADEMIES PRESS.

Shehzad, K., Sarfraz, M., & Shah, S. G. (2020). The impact of COVID-19 as a necessary evil on air pollution in India. *Environmental Pollution*.

Singh, R. P., & Chauhan, A. (2020). Impact of lockdown on air quality in India during COVID-19 pandemic. *Air Quality, Atmosphere & Health*, 921-928.

Zhao, H., Che, H., Zhang, X., Ma, Y., Wang, Y., Wang, H., & Yaqiang Wang. (2013). Characteristics of visibility and particulate matter (PM) in an urban area of Northeast China. *Atmospheric Pollution Research*, 427-434.